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Evaluating the Environmental and Public Health Inference of COVID-19 Lockdowns: A Longitudinal Study of Air Quality in Delhi and National Capital Region (NCR)

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Abstract:
The COVID-19 virus has had a huge impact on communities around the world, leading to lockdowns to reduce the spread of the virus. This research paper aims to provide a detailed comparison of the impact of the lockdown on air quality in Delhi's National Capital Region (NCR). It also aims to assess the short- and long-term effects of the lockdown on residents of the Delhi National Capital Territory by analyzing various air pollutants. The research will compare pre- and post-closure conditions and explore differences in the impact of different demographics and health groups. Findings from this study can inform policymakers, urban planners, and community health officials in developing effective strategies to prevent and improve health in similar situations in the future. This research paper explores changes in air pollution, specifically PM2.5, PM_{10}, NO_2, and ozone over the four years from 2019 to 2023. These pollutants show differences and changes in air quality over time.

Keywords- Delhi air pollution; PM_{10}; $PM_{2.5}$; COVID-19; Lockdown.

Introduction

The lockdown due to COVID-19 in India started on March 21, 2020, and the complete lockdown is from March 25, 2020, to May 31, 2020. These restrictions during this period caused significant changes in the environment, especially air pollution, and provided a unique opportunity to investigate the impact of human activities on the environment. In the early 2000s, emerging economies such as India and China became fast and modern economies, resulting in an alarming climate reminiscent of the European Industrial Revolution. In particular, megacities such as Beijing, Shenyang, Taiyuan, New Delhi, Mumbai, and Chennai have been identified as some of the most polluted cities in the world (Zhu 2005). In recent years, the National Capital Region (NCR) of Delhi, India has experienced serious air pollution problems due to rapid urbanization and industrial development. Bad breath poses a serious threat to public health and the environment. To deal with this growing problem, the outbreak of the COVID-19 pandemic in 2020 has led to unprecedented measures, including strict lockdowns.

Although pollution levels decreased during the closure, air quality did not improve as closure rules were eased. In urban areas, 80% of people live in environments that exceed the World Health Organization limit. (Błaszczyk et al. 2017). Urban vehicles emit more compounds such as carbon monoxide (CO), nitrogen oxides (NO_x), coarse (PM_{10}), fine ($PM_{2.5}$) and ultra-fine ($PM_{0.1}$), black carbon, polycyclic aromatic hydrocarbons (PAHs) and Benzene. (Venkatram and Schulte 2018).

Studies have shown that cities with more traffic and urban backgrounds have more particulate matter (PM) and nitrogen dioxide (Rodriguez et al., 2016). Among the smaller particles, $PM_{2.5}$ poses a greater health risk due to its ability to penetrate deep into the lungs and blood (US EPA 2018).

The WHO's ambient air guidelines recommend that the annual mean concentration limit of $PM_{2.5}$ is 10 µg/m3 and the 24-hour mean concentration limit is 25 µg/m3. The NO_2 limit is 40 µg/m3 annually and 200 µg/m3 per hour (World Health Organization, 2005). Ambient Current levels of $PM_{2.5}$ and NO_2 have exceeded safe limits.

The 2017 Global Air Pollution Index report states that China and India are responsible for 52% of global $PM_{2.5}$-related deaths (1,525 million deaths) (Institute of Health 2019). Both countries are working to reduce pollution, but long-term solutions have yet to be determined. Most research has focused on air pollution and its health effects in China and India. For example, evaluated air pollution levels in 36 transport corridors in Delhi, India, and found that the air quality index (AQI) of 31 corridors was "severe" and "very poor", indicating that transport-related pollution is a serious risk to humans. (Kumar and Mishra 2018) High levels of $PM_{2.5}$ and NO_2 in the environment are associated with an increased risk of heart disease and lung cancer in humans (Liu et al., 2018; Siddique et al., 2010).

As of 30 April 2020, there are thirty-four thousand eight hundred sixty-seven cases of COVID-19 in India, leading to a nationwide lockdown on 25 March 2020 (MoHFW 2020). This closure has led to the suspension of transport (rail, road, and air), institutions, and factories, except for essential goods and services (Jain and Sharma 2020). Studies will cover specific time periods, including before, during, and after the lockdown period. By comparing air quality data from these different phases, the study aims to identify significant improvements or changes due to closure restrictions. In addition, this study will explore the potential interaction between climate change and certain measures such as traffic restrictions, economic activity, etc

The findings of this study will provide policymakers, environmental organizations, and city planners with a better understanding of the effectiveness of mitigation measures in reducing bad weather. In addition, this study will contribute to improving knowledge on the impact of human activities on air quality and provide guidance for future strategies to improve the environment around the safety of the Delhi National Capital Territory and similar cities around the world.

Methodology

This research paper presents a comprehensive analysis of pollution data collected during the lockdown period of COVID-19 in Delhi's National Capital Territory and compares it to the corresponding period one year before and three years after closure. The selected period includes the closed period from March 25, 2020, to May 31, 2020, the relevant period in 2019 (March 25, 2019, to May 31, 2019), and 2021, 2022, and 2023 by month of the year, respectively. The purpose of this research report is to identify and compare the impact of the closure on various air pollutants including particulate matter ($PM_{2.5}$ and PM_{10}), nitrogen dioxide (NO_2), and ozone (O_3) in the National Capital Territory of Delhi. This study aims to understand how closure affects air quality in different parts of the region by making a comparative analysis.

1. Study Area and Collection of Data:

The study area for this study is the National Capital Territory (NCR) of Delhi, India. Current weather data is a closed period i.e. 25 March 2020 - 31 May 2020, year-equivalent period before COVID-19 (25 March 2019 - 31 May 2019) and relevant months of 2021, 2022, and 2023 from various air pollution monitoring in Delhi Stations in different parts of the National Capital Territory. Data. The key pollutants include particulate matter ($PM_{2.5}$ and PM10), nitrogen dioxide (NO2), and ozone (O3).

2. Selection of Pollution Monitoring Stations:

We choose six locations from Delhi NCR those are, Dwarka Sector 8, Anand Vihar, Ashok Vihar, ITO, Delhi, Sector 125 Noida, and Okhla Phase II (Dig 1). These locations are chosen on the base of higher pollution history.

A network of air pollution monitoring stations has been selected to have a comprehensive impact on climate change in Delhi's National Capital Territory. The selection of these areas includes multiple land use patterns, including commercial areas, urban transport, residential areas, and open spaces. This option aims to capture the spatial heterogeneity of the climate in the region.

3. Quality Control and Data Collection:
Air pollution data of $PM_{2.5}$, PM_{10}, NO_2, and O_3 at a given time are taken from various air pollution monitoring stations. The data collection process was carried out in accordance with standard procedures and quality control to ensure the accuracy and reliability of the data. Identify and resolve missing or faulty data through association or assignment procedures.

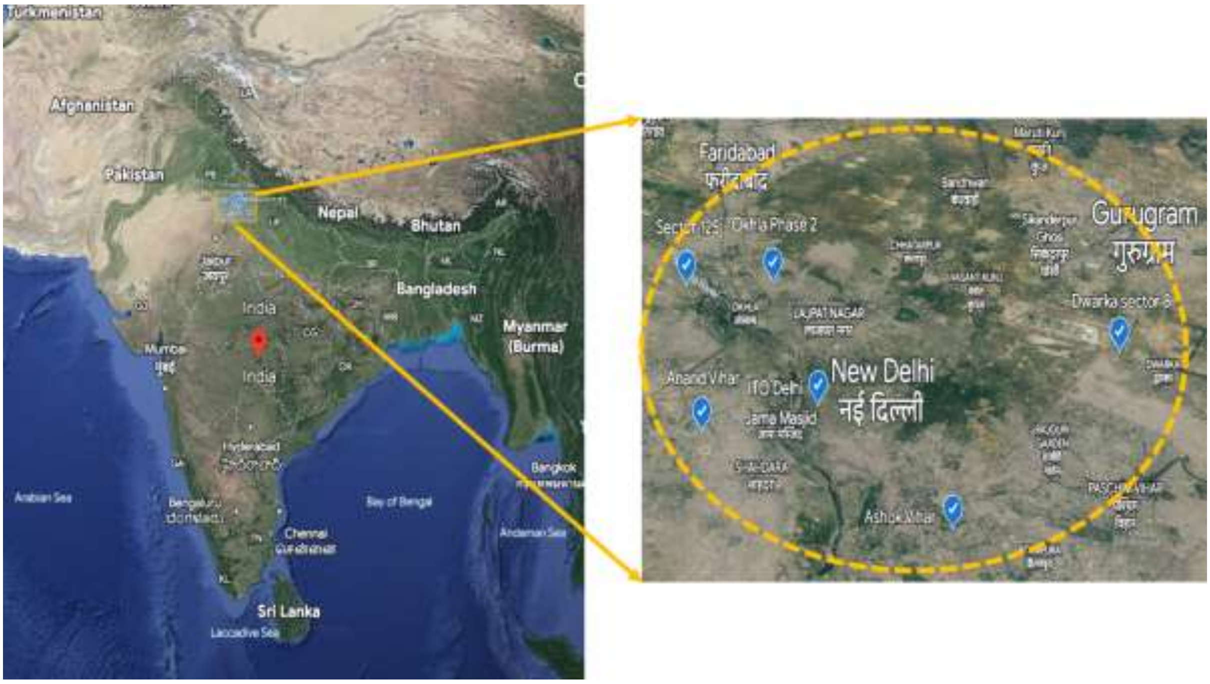

Fig-1: Depicting the geographical extent of the study area within the Delhi National Capital Region (NCR).

4. Statistical Techniques:

a. Descriptive statistics:

Descriptive statistics techniques are used to collect atmospheric data on each pollutant over a period of time. Means, medians, standard deviations, and percentages will be calculated to understand the mean and standard deviation of the data.

b. Time Series Analysis:

Time series analysis will be used to examine the pattern of air pollution over the study period. Good tests will help identify significant changes in air pollution.

c. Comparative Analysis:

A comparative analysis was conducted comparing air pollution at the time of the COVID-19 lockdown to the relevant period in the year before and three years after the lockdown. This study will use a variety of statistical methods to compare weather data in the National Capital Territory of Delhi(Fig.1) over time, focusing on the closed period during COVID-19 and the previous year and after the outbreak. These findings will provide valuable information on the impact of air quality closures and inform policy-making and urban planning to address regional air quality issues.

Result and Discussion

Anand Vihar

$PM_{2.5}$ concentrations decreased (-70%) from 2019 to 2020, then increased from 2020 to 2021 (+148%). Further increase (+43%) in 2021-2022, then decreased in 2022-2023 (-54%). PM_{10}concentrations fell from 2019 to 2020 (-79%), followed by an increase (+198%) from 2020 to 2021. An increase (+71%) from 2021 to 2022, then a lower (-54%) decrease from 2022 to 2023
Nitrogen dioxide concentrations dropped significantly (-84%) from 2019 to 2020. Significant growth (+402%) between 2020 and 2021. NO_2 levels increase slightly from 2021 to 2022

(+44%) and then decrease from 2022 to 2023 (-50%). Ozone concentrations decrease (-66%) from 2019 to 2022 in 2020 and then from 2020 to 2021 (+138%). Ozone concentration increased from 2021 to 2022 (+38%), then slightly increased from 2022 to 2023 (+8%) (Table 1).

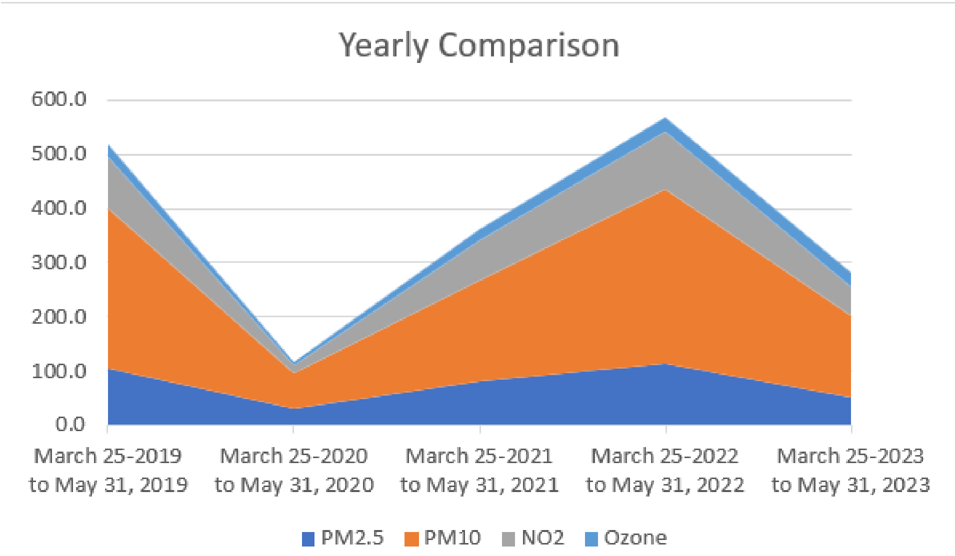

Fig 2. Graphical representation of the lockdown effect (before and after) on $PM_{2.5}$, PM_{10}, NO_2, and O_3 levels at Anand Vihar

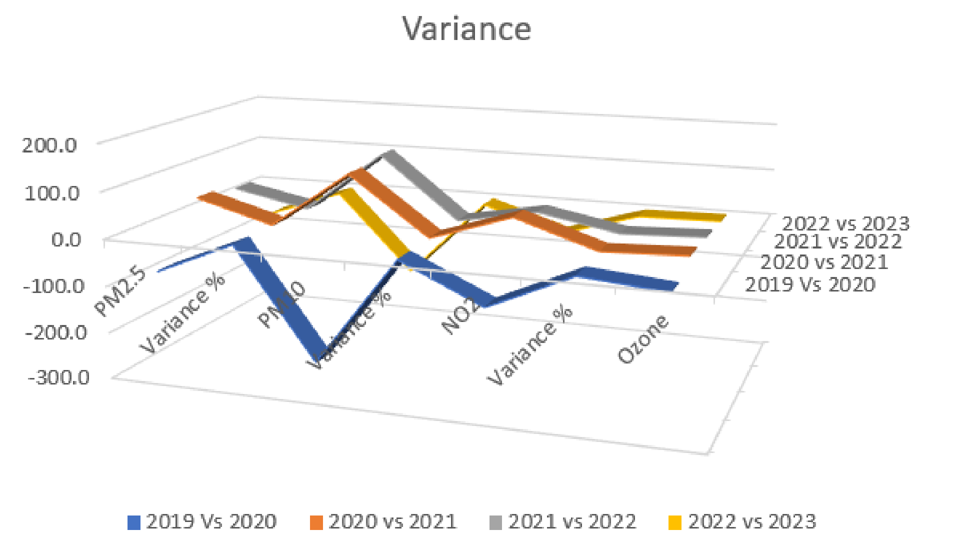

Fig 3 Graphical representation of the lockdown effect (in the form of variation percentage) (before and after) on PM2.5, PM_{10}, NO2, and O_3 levels at Anand Vihar .

Year Comparison	$PM_{2.5}$	Variance %	PM_{10}	Variance %	NO_2	Variance %	Ozone	Variance %
2019 Vs 2020	-73.6	-70%	-231.2	-79%	-79.8	-84%	-15.2	-66%
2020 vs 2021	47.7	148%	124.5	198%	59.7	402%	11.0	138%
2021 vs 2022	34.2	43%	133.4	71%	32.7	44%	7.1	38%
2022 vs 2023	-61.6	-54%	-172.3	-54%	-54.0	-50%	2.1	8%

Table-1 Shows the comparison of variation percentages in $PM_{2.5}$, PM_{10}, NO_2, and O_3 levels across different years in Anand Vihar, Delhi.

Ashok Vihar

$PM_{2.5}$ concentrations fell from 2019 to 2020 (-48%), then increased from 2020 to 2021 (+40%) . It increased (+25%) in 2021-2022, then decreased (-33%) in 2022-2023. PM_{10} concentrations fell from 2019 to 2020 (-56%), then increased from 2020 to 2021 (+92%). Further increase from 2021 to 2022 (+46%), and then a reduction from 2022 to 2023 (-29%) was reported.

Nitrogen dioxide concentrations dropped significantly (-67%) from 2019 to 2020. Significant growth (+128%) between 2020 and 2021. NO_2 levels increased slightly (+5%) from 2021 to 2022 and then fell from 2022 to 2023 (-44%). Ozone concentrations slightly increased from 2019 (+2%) to 2020 and then from 2020 to 2021 (+43%). Ozone concentrations fell from 2021 to 2022 (-36%) and then further from 2022 to 2023 (-60%) (Table 2).

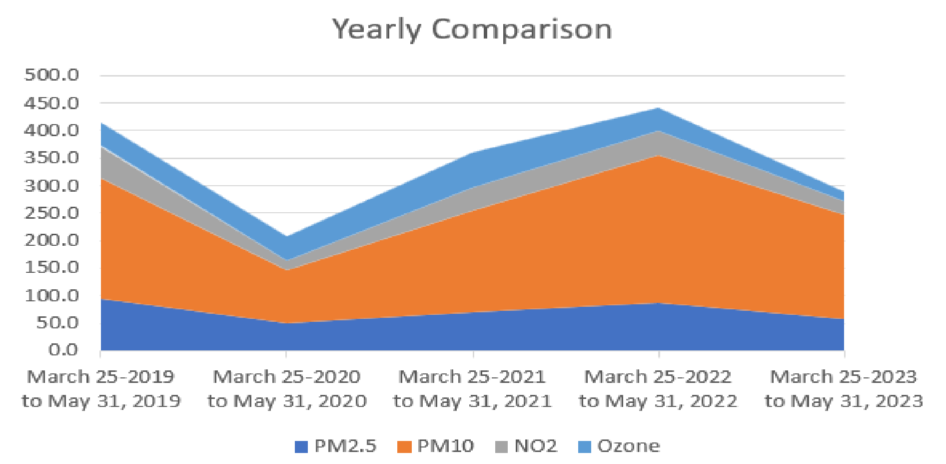

Fig.4 Graphical representation of the lockdown effect (before and after) on PM2.5, PM_{10}, NO2, and O_3 levels at Ashok Vihar.

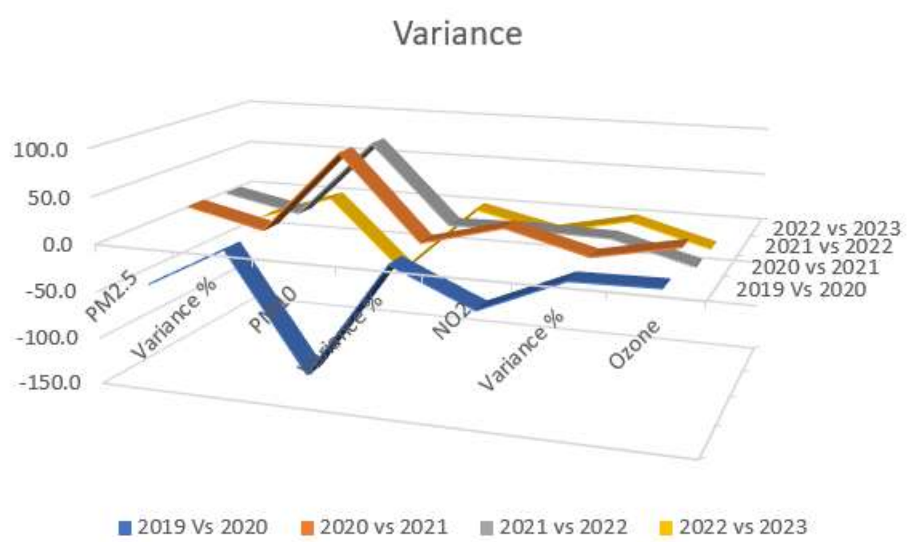

Fig.5 Graphical representation of the lockdown effect (in the form of variation percentage) (before and after) on PM2.5, PM10, NO2, and O3 levels at Ashok Vihar .

Year Comparison	$PM_{2.5}$	Variance %	PM_{10}	Variance %	NO_2	Variance %	Ozone	Variance %
2019 Vs 2020	-45.1	-48%	-123.2	-56%	-38.1	-67%	0.7	2%
2020 vs 2021	19.6	40%	89.0	92%	23.6	128%	18.8	43%
2021 vs 2022	17.3	25%	84.4	46%	2.3	5%	-22.7	-36%
2022 vs 2023	-29.0	-33%	-79.3	-29%	-19.4	-44%	-24.0	-60%

Table-2 Shows the comparison of variation percentages in $PM_{2.5}$, PM_{10}, NO_2, and O_3 levels across different years in Ashok Vihar, Delhi

Sector 125 Noida

$PM_{2.5}$ concentrations decreased from 2019 to 2020 (-54%), then increased from 2020 to 2021 (+78%). In the year 2021 to 2022, It increased (+32%), and then there was a fall of -20%. PM_{10} concentrations fell from 2019 to 2020 (-54%), then increased from 2020 to 2021 (+99%). Another increase (+48%) in 2021-2022, then decrease (-26%) in 2022-2023. Nitrogen dioxide concentrations dropped significantly (-78%) from 2019 to 2020. It was followed by a slight decrease (-19%) from 2020 to 2021, followed by an increase (+601%) from 2021 to 2022. Nitrogen dioxide levels increased from 2022 to 2023 (+123%). Ozone concentrations increased (+40%) from 2019 to 2020, then slightly increased (+31%) from 2020 to 2021. Ozone concentrations increased from 2021 to 2022 (+139%) and then from 2022 to 2023 it was a decrease of +42%.(Table 3)

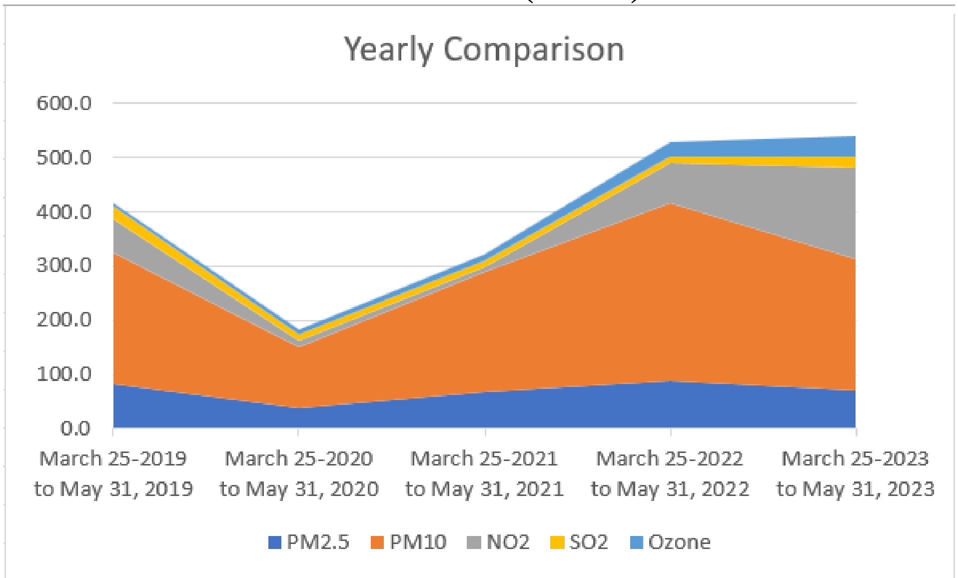

Fig.6 Graphical representation of the lockdown effect (before and after) on $PM_{2.5}$, PM_{10}, NO_2, and O_3 levels at Sector 125 Noida

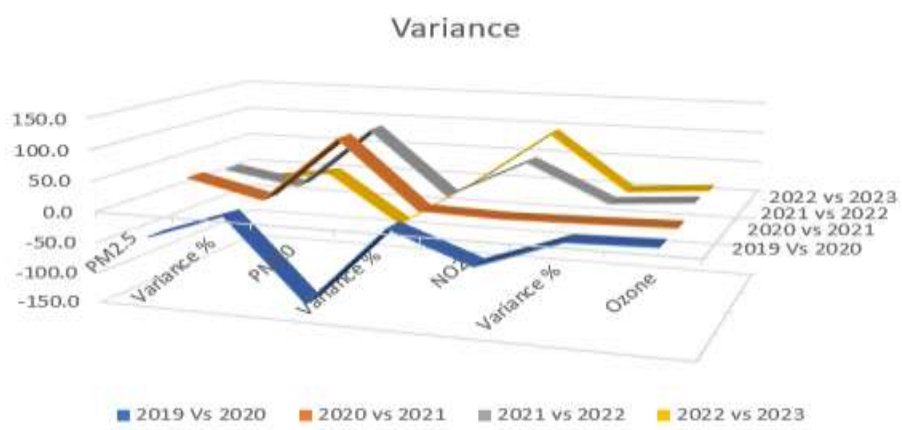

Fig.7 Graphical representation of the lockdown effect (in the form of variation percentage) (before and after) on PM2.5, PM10, NO2, and O3 levels at Noida sector 125 .

Year Comparison	$PM_{2.5}$	Variance %	PM_{10}	Variance %	NO_2	Variance %	Ozone	Variance %
2019 vs 2020	-44.6	-54%	-131.8	-54%	- 48.7	-78%	2.5	40%
2020 vs 2021	29.7	78%	109.7	99%	-2.6	-19%	2.8	31%
2021 vs 2022	21.7	32%	105.0	48%	65.3	601%	16.3	139%
2022 vs 2023	-18.2	-20%	-84.9	-26%	93.5	123%	11.9	42%

Table-3 Shows the comparison of variation percentages in $PM_{2.5}$, PM_{10}, NO_2, and O_3 levels across different years in sector 125 Noida.

Okhla Phase 2

$PM_{2.5}$ concentrations fell from 2019 to 2020 (-42%) and then increased from 2020 to 2021 (+34%). Further increase (+38%) in 2021-2022 and decrease (-24%) in 2022-2023. PM_{10} concentration decreased from 2019 to 2020 (-44%), but increased from 2020 to 2021 (+66%). PM_{10} levels increased from 2021 to 2022 before falling lower (-30%) from 2022 (+55%) to 2023

NO_2 levels decreased (-59%) from 2019 to 2020, then increased (+126%) from 2020 to 2021. Nitrogen dioxide levels increased (+67%) in 2021-2022, then decreased (-27%) 2022 in 2023. Ozone levels fell from 2019 to 2020 (-40%). However, from 2020 to 2021, ozone concentrations increased significantly (+122%). Ozone concentrations will increase insignificantly (+1%) from 2021 to 2022 and decrease (-19%) from 2022 to 2023.(Table 4)

Fig.8 Graphical representation of the lockdown effect (before and after) on PM2.5, PM_{10}, NO2, and O_3 levels at Okhla Phase II.

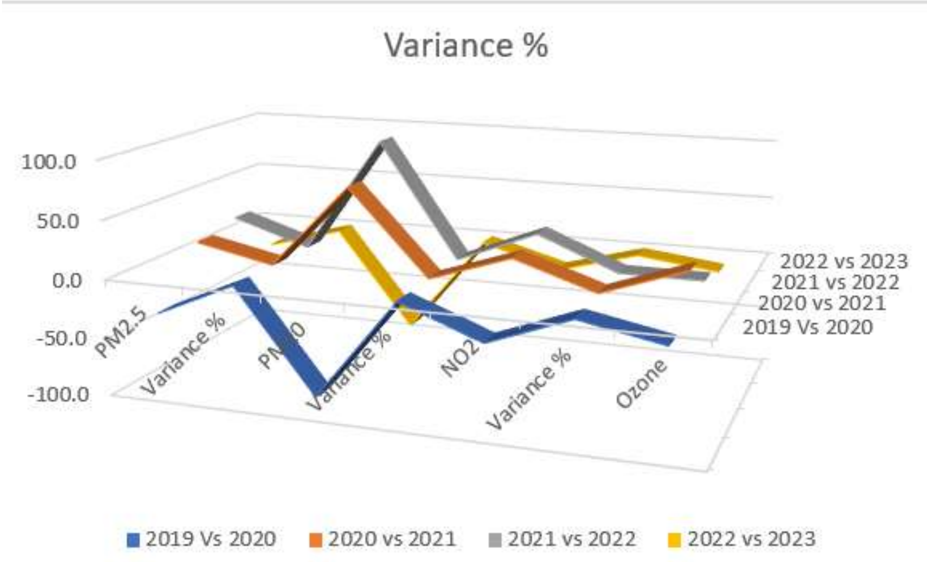

Fig.9 Graphical representation of the lockdown effect (in the form of variation percentage) (before and after) on $PM_{2.5}$, PM_{10}, NO2, and O_3 levels at Okhla Phase II .

Year Comparison	$PM_{2.5}$	Variance %	PM_{10}	Variance %	NO_2	Variance %	Ozone	Variance %
2019 Vs 2020	-30.9	-42%	-87.5	-44%	-26.9	-59%	-14.2	-40%
2020 vs 2021	14.5	34%	72.6	66%	24.0	126%	26.1	122%
2021 vs 2022	21.9	38%	99.7	55%	28.8	67%	0.4	1%
2022 vs 2023	-19.1	-24%	-85.3	-30%	-19.4	-27%	-8.9	-19%

Table-4 Shows the comparison of variation percentages in $PM_{2.5}$, PM_{10}, NO_2, and O_3 levels across different years in Okhla Phase II, Delhi.

ITO

$PM_{2.5}$ concentrations fell from 2019 to 2020 (-13%) and then again from 2020 to 2021 (-19%). However, $PM_{2.5}$ levels will increase (+60%) and decrease from 2021 to 2022 (- 51%) from 2022 to 2023. PM_{10} concentrations are lower (-47%) compared to 2019-2020, but 2020-2021 is higher (+20%) compared to PM_{10} levels rise from 2021 to 2022 (+80%) and then fall from 2022 to 2023 (-60%). NO_2 levels decrease from 2019 to 2020 (-57%), then slightly increase from 2020 (-30%) Nitrogen dioxide levels increase in 2021-2022 (+95%), then increase in 2022-2023 (+98%). Ozone levels increased from 2019 to 2020 (+222%). However, from 2020 to 2021, ozone concentrations decreased (-59%). Ozone concentration slightly increases from 2021 to 2022 (+38%) and decreases from 2022 to 2023 (-35%).(Table 5)

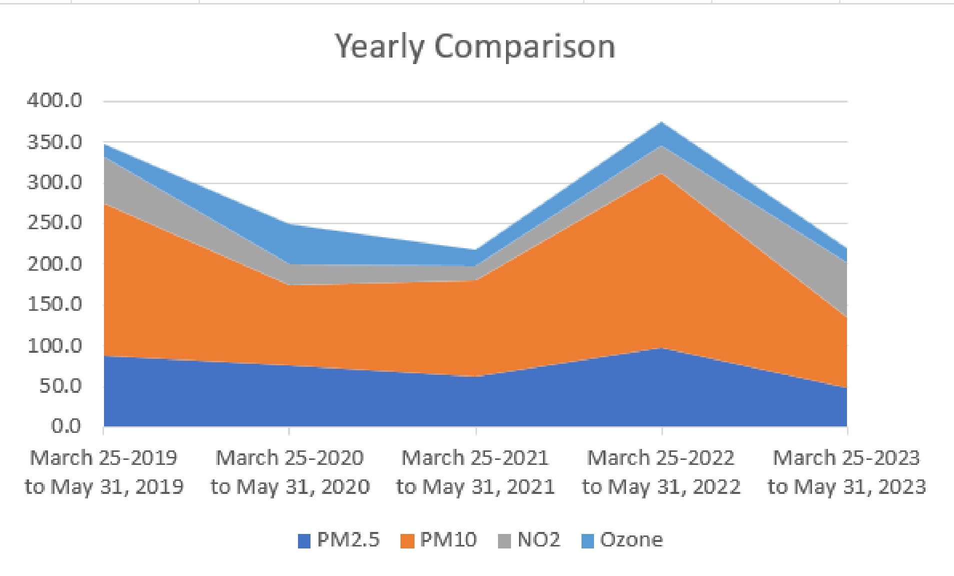

Fig10.Graphical representation of the lockdown effect (before and after) on PM2.5, PM_{10}, NO2, and O_3 levels at ITO Delhi.

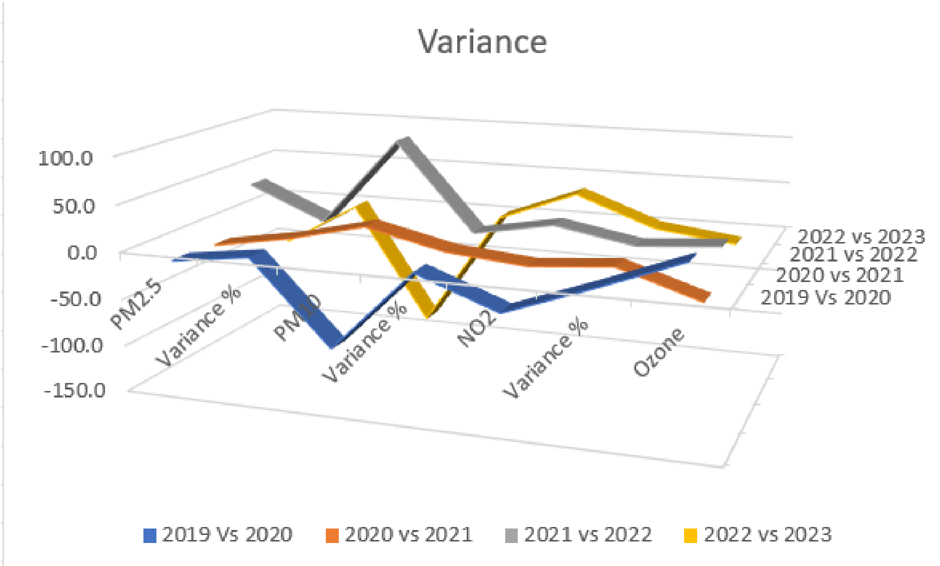

Fig.11 Graphical representation of the lockdown effect (in the form of variation percentage) (before and after) on PM2.5, PM10, NO2, and O3 levels at ITO Delhi .

Year Comparison	$PM_{2.5}$	Variance %	PM_{10}	Variance %	NO_2	Variance %	Ozone	Variance %
2019 Vs 2020	-11.2	-13%	-87.5	-47%	-32.7	-57%	33.4	222%
2020 vs 2021	-14.5	-19%	19.8	20%	-7.6	-30%	-28.3	-59%
2021 vs 2022	36.6	60%	95.9	80%	16.4	95%	7.7	38%
2022 vs 2023	-49.5	-51%	-128.5	-60%	33.0	98%	-9.7	-35%

Table-5 Shows the comparison of variation percentages in $PM_{2.5}$, PM_{10}, NO_2, and O_3 levels across different years in ITO Delhi

Dwarka Sector 8

$PM_{2.5}$ concentration decreased from 2019 to 2020 (-43%), but increased from 2020 to 2021 (+49%). $PM_{2.5}$ level increased (+20%) in 2021-2022, then fell lower (-21%) in 2022-2023. PM_{10} concentrations showed a decline (-54%) from 2019 to 2020, followed by a large increase (+78%) from 2020 to 2021. However, PM_{10} levels fall from 2021 to 2022 (-32%). NO_2 levels fluctuate over the years. NO_2 concentrations fell from 2019 to 2020 (-59%), but remained stable (-3%) from 2020 to 2021. 2022-2023. Ozone levels change every year. It was followed by a significant increase (+12%) in ozone concentrations from 2019 to 2020, followed by a decrease (-54%) from 2020 to 2021. Ozone concentration remained stable (2%) from 2021 to 2022 and slightly lower (-9%) from 2022 to 2023(Table 6).

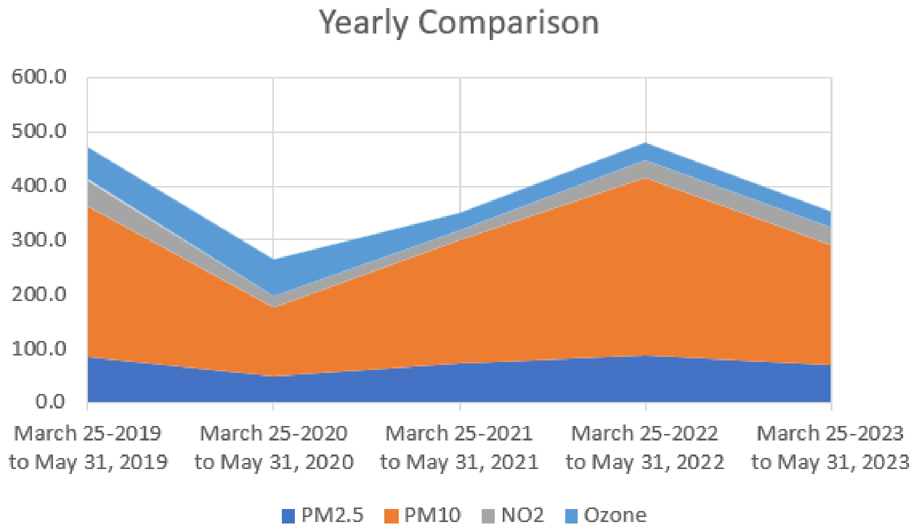

Fig 12.Graphical representation of the lockdown effect (before and after) on PM2.5, PM_{10}, NO2, and O_3 levels at Dwarka Sector 8.

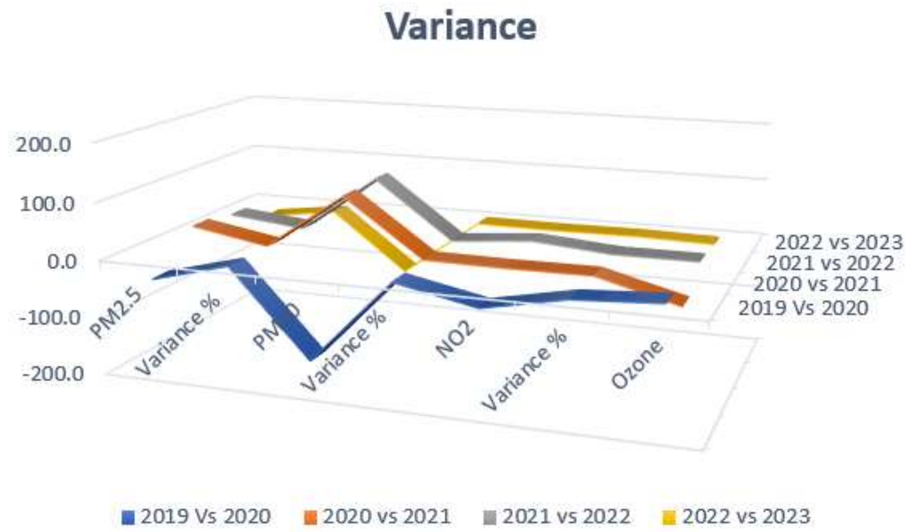

Fig.13 Graphical representation of the lockdown effect (in the form of variation percentage) (before and after) on PM2.5, PM_{10}, NO2, and O_3 levels at Dwarka Sector 8 .

Year Comparison	$PM_{2.5}$	Variance %	PM_{10}	Variance %	NO_2	Variance %	Ozone	Variance %
2019 Vs 2020	-36.5	-0.4	-148.6	-0.5	-29.0	-0.6	7.5	0.1
2020 vs 2021	24.1	0.5	99.4	0.8	-0.7	0.0	-37.0	-0.5
2021 vs 2022	14.2	0.2	101.9	0.5	12.1	0.6	0.7	0.0
2022 vs 2023	-18.5	-0.2	-104.8	-0.3	-1.3	0.0	-2.8	-0.1

Table- 6 Shows the comparison of variation percentages in $PM_{2.5}$, PM_{10}, NO_2, and O_3 levels across different years in Dwarka Sector 8.

Anand Vihar

The decline in $PM_{2.5}$ and PM_{10} concentrations from 2019 to 2020 can be attributed to the region's air quality measures and pollution control. Changes in the industrial sector and vehicle emissions will affect the increase in $PM_{2.5}$ and PM_{10} levels from 2020 to 2021 and 2021 to 2022. While the reduction in NO_2 emissions from 2019 to 2020 will be due to the

reduction in traffic and industrial emissions due to the closure, there could be a post-change in the size of NO_2 emissions from 2020 to 2021 and a change in NO_2 concentrations from 2021 to 2023. Relating to industrial activities and transportation.
Changes in ozone concentrations can be affected by changes in weather patterns and the presence of precursor pollutants. A large drop in ozone levels between 2019 and 2020 could be attributed to the lockdown. The change in ozone from 2020 to 2023 will be affected in advance by changes in meteorology and precursor pollutants.

Ashok Vihar

The decline in $PM_{2.5}$ and PM_{10} concentrations from 2019 to 2020 can be the result of the reduction of human interference in the environment due to the lockdown. Changes in the industrial sector and vehicle emissions will affect the increase in $PM_{2.5}$ and PM_{10} levels from 2020 to 2021 and 2021 to 2022.
The decrease in nitrogen dioxide concentrations from 2019 to 2020 could be due to reductions in automobile and industrial emissions. However, the increase from 2020 to 2021 and then the change in NO_2 levels from 2021 to 2023 may be related to changes in industrial and traffic patterns.
Changes in ozone concentrations can be affected by changes in weather patterns and the presence of precursor pollutants. The increase in ozone levels from 2019 to 2021 may be related to meteorological conditions supporting ozone production. The subsequent decline in ozone from 2021 to 2023 could be affected by earlier changes in meteorology and precursor pollutants.

Okhla phase 2

The decrease in $PM_{2.5}$ concentrations in 2019 and 2020 can be attributed to air quality measures and pollution control efforts. The increase in $PM_{2.5}$ levels from 2020 to 2021 and 2021 to 2022 will be affected by changes in traffic and industry. $PM_{2.5}$ reduced. The decrease in $PM_{2.5}$ concentrations from 2022 to 2023 may be due to improvements in pollution control.
The variation in PM10 concentration may be related to the variation in construction, road dust, and industrial emissions in this area. The decline in 2019 and the increase in 2020 may be related to changes in construction and business. The increase in 2021 and 2022 may be related to the increase in construction and dust activity, while the decrease from 2022 to 2023 may be due to better dust protection.
Changes in nitrogen dioxide concentrations may be related to changes in vehicle models and industry emissions.
The decline in 2019 and the increase in 2020 may be due to vehicle emission standards and control measures. The increase in 2021 and 2022 may be related to the increase in the market.
Ozone concentration fluctuations will be affected by atmospheric conditions and precursor pollutants. The decline in 2019 and the increase in 2020 may be related to the pre-existence of climate change and pollution. Subsequent changes from 2021 to 2023 may be affected by changes in meteorological conditions.

Sector 125 Noida

The decline in $PM_{2.5}$ and PM10 concentrations from 2019 to 2020 can be the effect of the lockdown where human interference was very low. Changes in the industrial sector and vehicle emissions will affect the increase in $PM_{2.5}$ and PM10 levels from 2020 to 2021 and 2021 to 2022.

The reduction in nitrogen dioxide from 2019 to 2020 will result from reductions in automobile and industrial emissions due to the lockdown. However, subsequent changes in NO_2 levels from 2020 to 2023 may be related to changes in industry and traffic patterns.
Changes in ozone concentrations can be affected by changes in weather patterns and the presence of pre-existing pollutants. The increase in ozone concentration from 2019 to 2020 may be related to weather conditions that favor ozone production. Changes in ozone levels from 2020 to 2023 will be affected by changes in meteorology and precursor pollutants**.**

Dwarka Sector 8

The decline in $PM_{2.5}$ concentrations in 2019 can be attributed to air quality measures and pollution control efforts. Future growth in 2020 was likely be affected by changes in the automotive and business sectors. The increase in 2021 and the decrease after 2022 and 2023 were related to climate change and extreme weather events.

Changes in PM_{10} levels can be attributed to changes in construction, dust activity, and industrial emissions in the area. The large increase in 2021 can be attributed to the increase in construction and road dust, while the decrease in 2022 can be attributed to better dust measurement.

Changes in nitrogen dioxide levels can be attributed to changes in vehicle models and emissions. While the decline in 2019 and 2022 may be due to better vehicle emission standards and control measures, the increase in 2021 will be related to the increase in industrial activities.

Changes in ozone levels can be attributed to changes in meteorological conditions and the presence of air pollutants. While the big increase in 2020 was affected by good weather for ozone production, the decrease in 2021 was related to climate change.

ITO Delhi

The decrease in $PM_{2.5}$ concentrations in 2019 and 2020 can be attributed to air quality measures and pollution control efforts. Future growth in 2021 will be affected by changes in traffic and industrial activities. A large increase in 2022 and a decrease in 2023 may be related to climate change and atmospheric conditions..

Changes in PM_{10} levels can be attributed to changes in construction, dust activity and industrial emissions in the area. The decline in 2019 and the increase in 2020 may be related to changes in construction and industrial activities. The big increase in 2021 could be related to the increase in construction and road dust, while the decrease from 2022 to 2023 could be related to the improvement of dust management.

Changes in nitrogen dioxide levels can be attributed to changes in vehicular traffic patterns and industrial emissions. The decline in 2019 and 2020 may be due to better car models and management, while the increase in 2021 and 2022 may be related to increased industrial activities. The extent of ozone concentrations in 2020 may be affected by atmospheric conditions suitable for ozone formation. Reductions after 2021 may be related to climate change and earlier pollution.

Nitrogen dioxide (NO_2) levels have dropped in many parts of the world during the COVID-19 lockdown. (Lee et al. 2020) reported a decrease of 42% in the UK, Shi and Brasseur (2020) found a decrease of around 60% in China, and Baldasano (2020) recorded a decrease of 56% in Spain.

Kang et al. (2020) studied $PM_{2.5}$ concentrations during lockdown in China and South Korea. They saw a decrease of about 16% in China and 10% in South Korea. However, it is worth noting that this reduction is not supported due to the ease of shutdown measures and the recovery of transport, energy, and trade.
The increase in air pollution is influenced by many climate factors, including decreased air distribution and increased humidity. Similarly, ambient emissions of $PM_{2.5}$, CO, NO_2, and SO2 in Hong Kong, China were reduced by 7%, 7%, 8%, and 14%, respectively, compared to the first days of closing average data. 2019 (Huang et al. 2020).
Between 2015 and April 2019, nitrogen oxide concentrations in urban streets in São Paulo, Brazil, fell by 65% relative to each other (Nakada and Urban 2020). A short study in Morocco before and after the block showed approximately 49% reduction in SO2 concentrations, 96% reduction in NO_2 concentrations, and 2% reduction in temperature (Otmani et al., 2020). Liu et al. (2020) conducted a global analysis showing a specific contribution to CO2 emissions, with ground transportation at 40%, power generation at 22%, miscellaneous industries at 17%, aviation at 13%, transportation at 6%, and commercial buildings and real estate around 3%.
Sanap (2021) examined a satellite-derived aerosol optical depth (AOD) dataset and found a decrease in AOD values across China from January, which may be related to the COVID-19 outbreak. During the closure months, aerosol levels increased due to man-made attacks in some areas, primarily fires, but also in some regions, including the Amazon Basin, parts of South America, Mexico, West and Central Africa, and Southeast Asia. However, from mid-March/April 2020, aerosol reductions were observed in most aerosol hotspots, with the lowest percentage reduction in May.
Research groups in India have reported similar patterns. Vadrevu et al. (2020) found reductions in nitrogen dioxide levels (43-62%) in 41 major cities. Mahato et al. (2020) found a negative change in NO2 (52.68%) and CO (30.35%) levels during the shutdown period in the National Capital Territory (NCT) of Delhi.
During the first phase of the shutdown, ozone levels increased by 7% in Delhi and 39% in Chandigarh due to reduced emissions of nitrogen oxides that contribute to ozone production (Jain and Sharma, 2020; Mor et al., 2021). Other research groups have also reported reductions in environmental pollution in Indian cities before and after closures (Kotnala et al., 2020 and Srivastava et al., 2020).
Garg et al. (2021) reported that air pollution and air quality (AQI) levels in five cities in India's National Capital Territory (NCR) decreased at the start of the lockdown compared to three weeks before the lockdown. NO has the highest reduction (60-78%), Ghaziabad has the highest AQI reduction at 67.63%, followed by Delhi (61.34%).
Creeley et al. (2021) evaluated the average changes in various air pollutants over three years in Delhi and Hyderabad and compared the results with a meteorological-based prediction model.
Many epidemiological studies over the years have emphasized the role of outside air pollution in respiratory diseases, premature death, and heart disease. People living in the city near highways are particularly vulnerable to these adverse effects (Park et al., 2020).
The study said that air pollution caused by $PM_{2.5}$ fine particles caused 54,000 deaths in Delhi in 2020 ($PM_{2.5}$ pollution claimed 54,000 deaths in the 2020 Indian capital). In the study, which draws attention to the fact that air pollution in Delhi is still about six times the World Health Organization's annual average limit of 10 g / m3, it is stated that the estimated

economic loss caused by air pollution is 8.1 billion dollars. (Rs 58,895 crore), equivalent to 13% of Delhi's annual GDP(India, P. T. of. 2021).

Conclusion

This research paper examines changes in $PM_{2.5}$, PM_{10}, NO_2, SO2, and ozone levels over the four years from 2019 to 2023. The analysis of pollutant variances and variance percentages provided valuable insights into the changing trends of air pollution and its implications for human health and the environment.

The study shows that air quality improved between 2019 and 2020, with reductions in $PM_{2.5}$, PM_{10} and NO_2 concentrations.

These reductions can be attributed to the lockdown which reduced human activities like vehicular pollution and industrial activities. The positive trends observed conclude that nature is very less contributor to Delhi's air pollution and is continuously repairing itself too so we just need to create policies that reduce human-related contribution in air pollution.

The following years were mixed with changes and increases in some pollutants. Changes in air pollution reflect the complexity of air pollution and the influence of many factors, such as emissions, weather patterns, and regional characteristics. More research is needed to underpin these changes and develop targeted strategies to address them.

Ozone concentration analysis showed little change over the study period. Ozone is a complex pollutant that is affected by photochemical reactions and weather conditions and requires constant monitoring and evaluation.

Heavy air pollution, especially fine particles ($PM_{2.5}$ and PM_{10}) and pollutants such as nitrogen dioxide (NO_2) and sulfur dioxide (SO_2) can cause many respiratory diseases such as asthma, pneumonia, chronic obstructive pulmonary disease (COPD). and exacerbates the symptoms of those who already have it. These particles can penetrate deep into the lungs, causing inflammation and reducing lung function. Prolonged exposure to air pollution increases the risk of cardiovascular diseases such as heart attack, stroke and high blood pressure. Air pollution can cause inflammation, oxidative stress, and narrowing of the arteries, which can lead to serious health problems.

Prolonged exposure to air can slow lung growth and lead to lung failure, especially in children. This can have long-term effects on overall health and quality of life. Studies have shown a direct link between high levels of air pollution and premature death. People exposed to high levels of air pollution are at risk of premature death from a variety of health problems. New research suggests that air pollution may affect the central nervous system and cognitive function.

There is evidence of a link between air pollution and neurodegenerative diseases such as Alzheimer's and Parkinson's. Pregnant women exposed to air pollution are at risk of experiencing problems such as premature birth, low birth weight and growth problems in their children. Air pollution can affect fetal development and affect long-term health.

Concentration of contaminants can cause eye and skin irritation, especially for children and people with sensitive skin. People with pre-existing medical conditions such as allergies and diabetes may experience more severe symptoms from exposure to air pollution. Prolonged exposure to pollution can weaken the body, making the person sick and ill. Bad weather reduces outdoor activities, affects mental health, and creates discomfort and discomfort that affects overall quality of life.

Reducing these health impacts requires concerted effort, including tighter emissions controls, more green space, better waste management and more options, clean transportation and public relations.

Long-term solutions are essential to address the root causes of pollution and protect the health and well-being of the people of Delhi NCR.
The findings show that continued efforts are needed to control ozone levels and ensure compliance with air quality standards.
The findings of this study provide valuable information for policy makers, environmental organizations and healthcare providers. Monitoring patterns and changes in air pollution can inform the development and use of evidence-based policies and interventions to address air pollution. Continuous monitoring of air quality and regular measurements are important to assess the effectiveness of pollution control and identify emerging trends.
This research work contributes to our understanding of air pollution and the impact of measuring air pollution over the study period. These findings highlight the importance of continued efforts to reduce air pollution, improve air quality and protect public health. By following these strategies and policies, we can work to create a clean, healthy environment for present and future generations.

Data availability

The authors ensure that all materials and data are available to support their published claims.

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Competing interests declaration

There are no conflicts of interest with the contents of this manuscript.

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