Urban Air Quality Responses to Reduced Anthropogenic Activities during Lockdown Periods in Lucknow, India

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ABSTRACT

Air pollution remains a major environmental and public health concern in rapidly urbanising Indian cities. Lucknow, the capital of Uttar Pradesh, has experienced persistently poor air quality due to increasing population, vehicular density and urban activities. This study examines air quality levels **before, during and after lockdown periods**, focusing on changes associated with reduced anthropogenic activities rather than the COVID-19 pandemic itself. Secondary data on PM_{10}, $PM_{2.5}$, NO_2, SO_2 and Air Quality Index (AQI) were obtained from the Uttar Pradesh Pollution Control Board for the period 2019–2025.

Results show that during the lockdown period, mean PM_{10} and $PM_{2.5}$ concentrations declined from approximately **190–260 µg/m³ to 135 µg/m³** and **60–80 µg/m³ to 45 µg/m³**, respectively, though values still exceeded the **WHO Air Quality Guidelines (2021)**. Post-lockdown periods recorded sharp increases, particularly in NO_2, reflecting renewed traffic and urban activity. The findings indicate that observed air-quality improvements were temporary and closely linked to reduced human activities, highlighting the need for sustained emission-control strategies.

Keywords: Air quality; anthropogenic activities; particulate matter; lockdown period; Lucknow

INTRODUCTION

Environmental pollution has gradually emerged as one of the most pressing challenges of modern civilisation. As human societies have advanced technologically and economically, a parallel and often unintended outcome has been the progressive deterioration of environmental quality. Pollution may be broadly defined as the introduction of harmful substances or forms of energy into the environment at levels that disrupt ecological balance and adversely affect living organisms (Miller & Spoolman, 2016). What makes pollution particularly concerning in the contemporary context is not merely its existence, but its magnitude, persistence and close association with everyday human activities.

Pollution manifests in various forms, including air, water, soil, noise, thermal and radioactive pollution. Although all these forms pose serious environmental risks, air pollution has received increasing global attention due to its widespread distribution and direct implications for human health. Unlike water or soil pollution, air pollution does not remain confined to specific locations; it can spread rapidly across regions, affect large populations simultaneously and often remains unnoticed until its health impacts become severe.

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Consequently, air pollution is now widely recognised as both an environmental and a public health concern (World Health Organization [WHO], 2021).

Air pollution occurs when harmful substances are released into the atmosphere in quantities that exceed the natural assimilative capacity of the environment. These substances originate from both natural and anthropogenic sources. While natural sources such as dust storms, wildfires and volcanic eruptions contribute intermittently, human-induced sources dominate in urban and semi-urban areas (Seinfeld & Pandis, 2016). Vehicular emissions, industrial activities, fossil fuel combustion, construction work and open biomass burning are among the most significant contributors to urban air pollution. These activities release a complex mixture of pollutants, including particulate matter (PM_{10} and $PM_{2.5}$), nitrogen oxides, sulphur dioxide, carbon monoxide and ground-level ozone. Among these pollutants, fine particulate matter ($PM_{2.5}$) is considered particularly harmful due to its ability to penetrate deep into the respiratory system and enter the bloodstream, thereby affecting multiple organ systems (Pope & Dockery, 2006).

At the global scale, air pollution has reached alarming levels. The WHO estimates that exposure to ambient air pollution is responsible for approximately seven million premature deaths annually, largely due to cardiovascular diseases, respiratory illnesses and lung cancer (WHO, 2021). The burden of air pollution is unevenly distributed, with low- and middle-income countries experiencing higher exposure levels as a result of rapid urbanisation, limited regulatory enforcement and continued reliance on polluting energy sources (Health Effects Institute, 2020). Urban centres across the world have become pollution hotspots because they concentrate population, transport networks, industrial activities and energy consumption within limited geographical spaces. In many developing countries, urban growth has occurred more rapidly than the development of sustainable infrastructure, resulting in persistent deterioration of air quality (UN-Habitat, 2020).

India presents a striking example of the challenges associated with air pollution in rapidly developing economies. Over the past decade, several Indian cities have consistently featured among the most polluted cities globally (IQAir, 2023). According to the Central Pollution Control Board, major sources of air pollution in India include vehicular emissions, coal-based power generation, industrial discharges, construction dust and agricultural residue burning (CPCB, 2022). The health implications are substantial, with air pollution contributing to over one million premature deaths annually, in addition to widespread morbidity and reduced life expectancy (Balakrishnan et al., 2019). The Indo-Gangetic Plain is particularly vulnerable due to its dense population, intensive economic activities and meteorological conditions that favour pollutant accumulation, especially during winter months (Ghude et al., 2016).

Lucknow, the capital city of Uttar Pradesh, reflects many of these broader national challenges. In recent years, the city has experienced rapid urban expansion accompanied by population growth, increasing vehicle ownership and large-scale infrastructure development. These changes have significantly altered the city's emission profile, with transport and construction activities emerging as dominant sources of air pollution (Uttar Pradesh Pollution Control Board [UPPCB], 2023). Air quality monitoring data indicate that concentrations of PM_{10} and $PM_{2.5}$ in Lucknow frequently exceed national air quality standards, particularly during the winter season. Traffic congestion, ageing vehicle fleets, resuspended road dust and unregulated construction activities contribute substantially to the city's deteriorating air quality (Sharma et al., 2021). Seasonal meteorological conditions, such as low wind speeds and temperature inversion, further aggravate pollution levels by limiting atmospheric dispersion.

Population growth plays a critical role in intensifying air pollution in urban environments. As population increases, so does the demand for transport, housing, energy and consumer goods, all of which contribute to increased emissions and waste generation (Ehrlich & Holdren, 1971). In cities such as Lucknow, population growth has often outpaced infrastructure development, resulting in traffic congestion, inefficient public transport systems and greater dependence on fossil fuels. The relationship between population growth and air pollution is particularly evident in the transport sector, where rising vehicle numbers and limited adoption of cleaner technologies have significantly increased emission levels (Guttikunda & Goel, 2013).

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The nationwide lockdowns implemented in India in 2020 led to a substantial reduction in industrial activity, vehicular movement and construction work. This period provided an unintended opportunity to observe how changes in the intensity of human activities influence urban air quality. Several studies reported temporary declines in concentrations of major air pollutants across Indian cities during lockdown periods (Mahato et al., 2020; Sharma et al., 2020). However, these improvements were not sustained, with pollution levels increasing again as economic and transport activities resumed (Navinya et al., 2021). Importantly, such changes were associated with reduced anthropogenic activities rather than the pandemic itself.

Against this background, examining air quality levels in Lucknow across periods of normal activity, reduced activity and subsequent recovery offers valuable insights into the dynamics of urban air pollution. Understanding these patterns is essential for evaluating the effectiveness of emission-control measures and for informing long-term strategies aimed at improving air quality and protecting public health in rapidly growing cities.

METHODOLOGY

The present study adopts a **quantitative, descriptive and comparative analytical approach** to examine variations in urban air quality in Lucknow under different levels of human activity. The analysis focuses on changes in air pollution levels before, during and after lockdown periods, which were characterised by varying degrees of restriction on transport, industrial operations and construction activities. This approach enables a systematic assessment of air quality trends under conditions of normal activity, reduced anthropogenic activity and subsequent recovery.

The study area is **Lucknow (26.85°N, 80.95°E)**, the capital city of Uttar Pradesh, India. Lucknow is a rapidly expanding urban centre marked by increasing population density, growth in vehicular ownership and extensive infrastructure development. The city experiences a subtropical climate with distinct summer, monsoon and winter seasons, which play an important role in influencing pollutant dispersion and accumulation.

Secondary air quality data were obtained from officially published records of the **Uttar Pradesh Pollution Control Board (UPPCB)** for the period **2019–2025**. The data were collected from continuous ambient air quality monitoring stations located at major urban locations across the city. The pollutants analysed in the study include **particulate matter (PM_{10} and $PM_{2.5}$)**, **nitrogen dioxide (NO_2)**, **sulphur dioxide (SO_2)** and the **Air Quality Index (AQI)**, selected due to their relevance to urban air pollution and established public health significance.

To facilitate comparison, the study period was categorised into three phases: **pre-lockdown (January 2019 to February 2020)**, representing normal urban activity; **lockdown period (March 2020 to December 2020)**, characterised by restricted mobility and reduced industrial and construction activities; and **post-lockdown period (January 2021 to December 2025)**, representing the gradual resumption and intensification of urban activities.

Comparative analysis was carried out to examine variations in pollutant concentrations across these periods, assess the magnitude of change during the lockdown phase and evaluate the extent of pollution rebound in the post-lockdown period. AQI values were interpreted using standard classification categories (Good, Satisfactory, Moderate, Poor and Very Poor) and compared with the **World Health Organization Global Air Quality Guidelines (2021)** to assess compliance and potential health implications. Descriptive statistics and graphical trend analysis were employed to present and interpret the results.

RESULTS AND DISCUSSION

The present section summarizes the observed variations in air pollution levels in Lucknow across different phases of the COVID19 pandemic, namely pre COVID, during COVID, and post COVID periods. The analysis is based on averaged concentrations of major air pollutants and Air Quality Index (AQI) values derived from official monitoring data.

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Variation in PM_{10} Concentration

Table 1: Average Air Pollution Levels in Lucknow Across COVID Phases

Study period	PM_{10} (µg/m³)	$PM_{2.5}$ (µg/m³)	NO_2 (µg/m³)	SO_2 (µg/m³)	AQI range	AQI category	WHO guideline (2021)
Pre-lockdown (2019–early 2020)	190	60	35	12	150–250	Moderate–Poor	PM_{10}: 45 (24-h); $PM_{2.5}$: 15 (24-h); NO_2: 25 (24-h); SO_2: 40 (24-h)
Lockdown period (mid–late 2020)	135	45	22	10	90–175	Satisfactory–Moderate	PM_{10}: 45; $PM_{2.5}$: 15; NO_2: 25; SO_2: 40
Post-lockdown Phase I (2021–22)	220	65	40	14	140–260	Moderate–Poor	PM_{10}: 45; $PM_{2.5}$: 15; NO_2: 25; SO_2: 40
Post-lockdown Phase II (2023–24)	260	80	50	16	160–300	Poor–Very Poor	PM_{10}: 45; $PM_{2.5}$: 15; NO_2: 25; SO_2: 40
Post-lockdown Phase III (2025)	230	70	45	45	140–260	Moderate–Poor	PM_{10}: 45; $PM_{2.5}$: 15; NO_2: 25; SO_2: 40

Source: Uttar Pradesh Pollution Control Board (UPPCB)

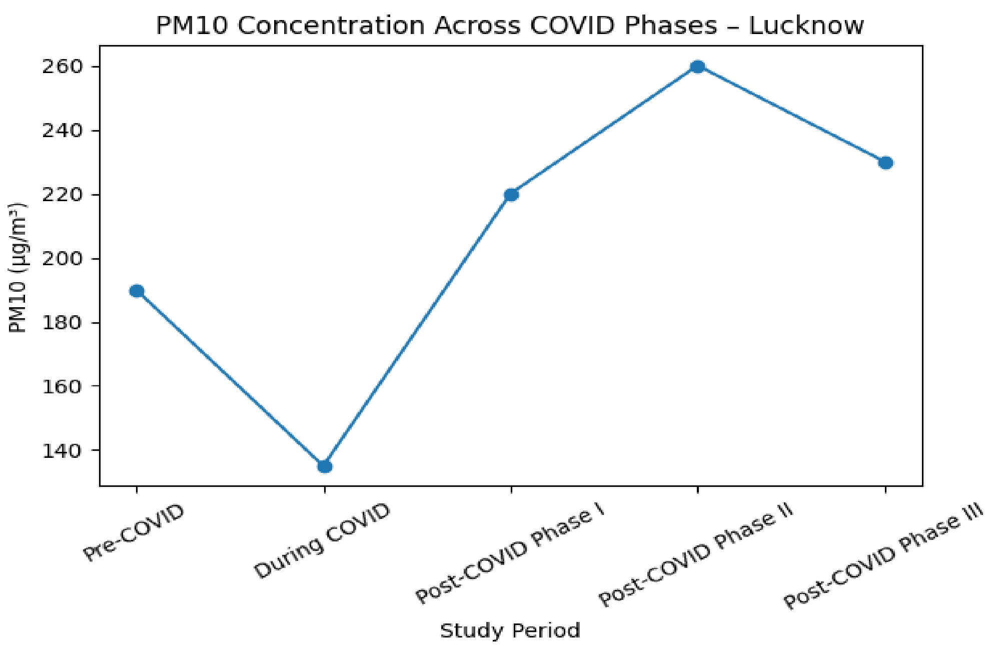

Figure 1: PM_{10} concentration across pre COVID, during COVID, and post COVID phases in Lucknow.

Figure 1 illustrates the variation in PM_{10} concentration across different study periods. During the pre COVID phase, the average PM_{10} concentration was recorded at approximately 190 µg/m³. A substantial decline was observed during the COVID19 lockdown period, with PM_{10} levels reducing to about 135 µg/m³. In the post COVID phase, PM_{10} concentrations increased sharply, reaching a peak of 260 µg/m³ during 2023–24, followed by a slight reduction to 230 µg/m³ in 2025.

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Variation in $PM_{2.5}$ Concentration

The trend in $PM_{2.5}$ concentration shows a pattern similar to PM_{10}, as presented in Figure 2. The pre COVID average $PM_{2.5}$ concentration was approximately 60 µg/m³, which declined to 45 µg/m³ during the lockdown period. Post COVID Phase II recorded the highest $PM_{2.5}$ concentration at around 80 µg/m³, indicating a pronounced rebound effect. In 2025, $PM_{2.5}$ levels showed a marginal decrease but remained significantly higher than during the lockdown phase.

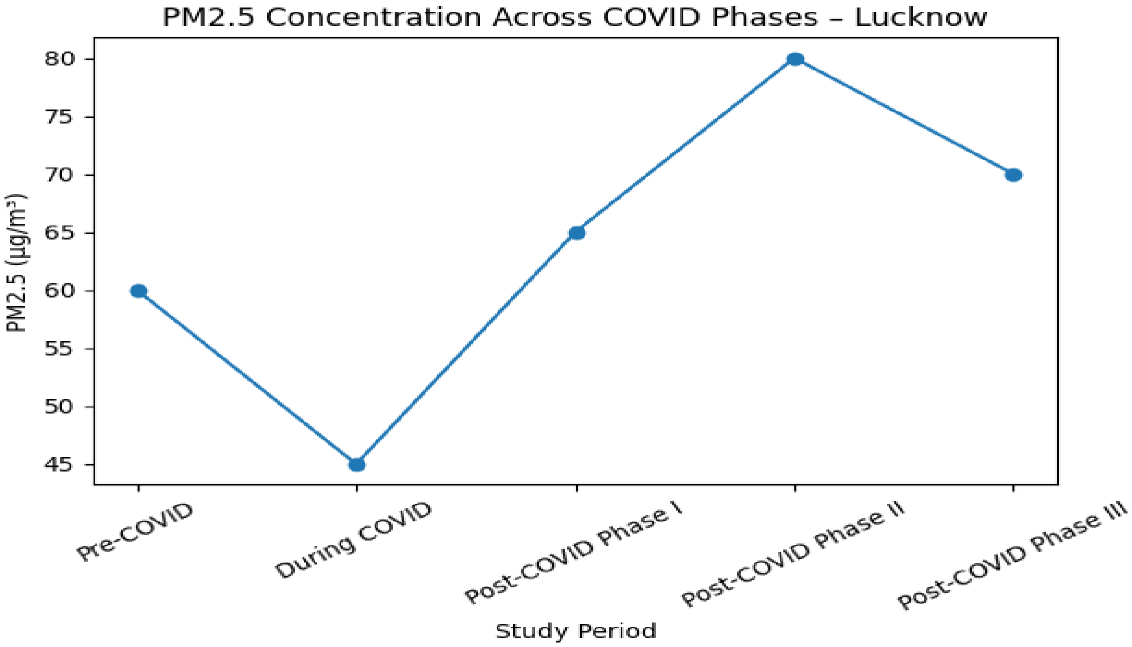

Figure 2: $PM_{2.5}$ concentration across pre COVID, during COVID, and post COVID phases in Lucknow.

Variation in Nitrogen Dioxide (NO_2) Concentration

Nitrogen dioxide (NO_2) levels exhibited notable variation across the study periods (Figure 3). During the pre COVID phase, NO_2 concentration averaged 35 µg/m³. A marked reduction was observed during the COVID19 lockdown, with concentrations declining to 22 µg/m³. Post COVID phases showed a steady increase, with the highest average concentration (50 µg/m³) recorded during 2023–24, followed by a slight decline in 2025.

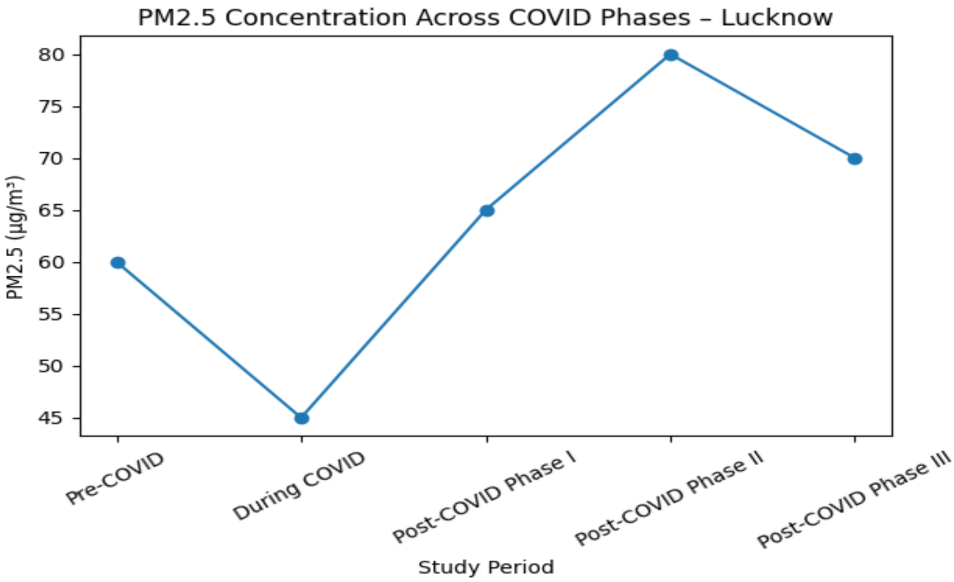

Figure 3: NO_2 concentration across pre COVID, during COVID, and post COVID phases in Lucknow.

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Changes in Air Quality Index (AQI)

AQI values reflect the combined effect of multiple pollutants and provide an integrated assessment of air quality. During the pre COVID phase, AQI values predominantly fell within the Moderate to Poor category. A noticeable improvement was recorded during the lockdown period, with AQI values shifting towards the Satisfactory to Moderate range. However, post COVID periods showed a deterioration in air quality, with AQI values frequently reaching the Poor to Very Poor category, particularly during 2023–24.

Percentage Change Analysis of Air Pollutants

To quantify the magnitude of change in air pollution levels across different phases of the COVID19 pandemic, a percentage change analysis was carried out for key pollutants. The analysis focuses on two critical transitions: Pre COVID to During COVID and During COVID to Post COVID peak period (2023–24).

Table 2: Percentage Change in Major Air Pollutants in Lucknow

Pollutant	Pre COVID → During COVID (%)	During COVID → Post COVID Peak (%)
PM_{10}	−28.95%	+92.59%
$PM_{2.5}$	−25.00%	+77.78%
NO_2	−37.14%	+127.27%

Source: Uttar Pradesh Pollution Control Board (UPPCB)

Reduction in Pollution During COVID19 Lockdown

The transition from the pre COVID phase to the COVID19 lockdown period shows a substantial reduction in all major pollutants. PM_{10} concentration declined by approximately 28.95%, while $PM_{2.5}$ levels decreased by 25%. The most pronounced reduction was observed in NO_2, which dropped by 37.14% during the lockdown period. This sharp decline reflects the immediate impact of reduced vehicular movement, industrial shutdowns, and restricted construction activities during the lockdown phase.

Post COVID Rebound in Pollution Levels

A contrasting trend is observed during the transition from the lockdown period to the post COVID peak phase (2023–24). PM_{10} concentration increased by 92.59%, while $PM_{2.5}$ levels rose by 77.78%, indicating a strong rebound effect. Notably, NO_2 exhibited the highest increase, rising by 127.27%, suggesting a rapid resurgence of traffic related emissions following the relaxation of restrictions. The magnitude of this increase highlights the temporary nature of air quality improvements during the lockdown and underscores the dominant role of anthropogenic activities in urban air pollution.

Key Observations from Percentage Change Analysis

- The COVID19 lockdown period resulted in significant short-term reductions in all major air pollutants.
- NO_2 showed the highest sensitivity to changes in human activity, reflecting its strong association with vehicular emissions.
- Post COVID pollution levels not only rebounded but, in some cases, exceeded pre COVID levels, particularly for particulate matter.
- The findings confirm that behavioral and policy driven reductions in emissions can yield rapid improvements, but such gains are difficult to sustain without long-term structural changes.

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The present study provides clear evidence of the strong influence of anthropogenic activities on urban air quality in Lucknow. The comparative analysis of pre COVID, during COVID, and post COVID periods reveals distinct shifts in pollution levels corresponding to variations in human mobility, economic activity, and urban functioning. The findings support the hypothesis that air pollution in rapidly growing cities is closely tied to patterns of human activity rather than being solely driven by natural or meteorological factors.

Impact of COVID19 Lockdown on Air Quality

One of the most striking observations of the study is the substantial reduction in air pollution levels during the COVID19 lockdown period. The percentage change analysis shows a decline of nearly 29% in PM_{10}, 25% in $PM_{2.5}$, and over 37% in NO_2 concentrations compared to pre COVID levels. Such reductions are consistent with reports from several Indian and global cities, where lockdown measures led to immediate improvements in air quality (Mahato et al., 2020; Sharma et al., 2020; Sicard et al., 2020).

The sharp decline in NO_2 concentrations during the lockdown is particularly noteworthy, as NO_2 is widely recognized as a traffic related pollutant. The restriction of vehicular movement, closure of offices, and suspension of public transport during the lockdown likely played a central role in reducing NO_2 emissions in Lucknow. Similar patterns have been reported in metropolitan cities such as Delhi, Mumbai, and Kolkata, reinforcing the view that road transport is a dominant contributor to urban nitrogen oxide emissions (Guttikunda & Goel, 2013; CPCB, 2021).

Temporary Nature of Pollution Reduction

Despite the marked improvement in air quality during the lockdown, the study reveals that these gains were short lived. Following the easing of restrictions, pollution levels rebounded sharply in the post COVID period. PM_{10} concentrations increased by more than 90%, while $PM_{2.5}$ levels rose by approximately 78% during the post COVID peak phase. The most dramatic increase was observed in NO_2, which surged by over 127%, indicating a rapid resurgence of traffic related emissions. This rebound effect highlights a critical insight: the improvement in air quality during the lockdown was not the result of structural changes in urban systems but rather a consequence of temporary restrictions on human activity. As economic activities resumed, vehicular traffic intensified, construction projects restarted, and energy consumption increased, leading to a rapid deterioration in air quality. Similar post lockdown rebounds have been documented in other Indian cities, suggesting a nationwide trend rather than a city specific phenomenon (Navinya et al., 2021).

Implications for Urban Air Quality Management

The findings of this study underscore the need for long-term, sustainable approaches to air pollution management rather than short-term emergency measures. While the COVID19 lockdown demonstrated that rapid improvements in air quality are possible, it also revealed the fragility of such gains in the absence of systemic changes. Effective strategies may include strengthening public transport infrastructure, promoting nonmotorized transport, regulating construction activities, enforcing vehicle emission standards, and expanding green spaces. Integrating air quality considerations into urban planning and population management policies is essential for achieving sustained improvements in cities like Lucknow.

Synthesis of Key Insights

Overall, the discussion highlights that air pollution in Lucknow is primarily driven by anthropogenic activities linked to urban growth and population pressure. The COVID19 lockdown served as a natural experiment, temporarily reducing emissions and improving air quality. However, the rapid post-lockdown rebound emphasizes the need for structural interventions to ensure long-term environmental and public health benefits.

CONCLUSION

This study demonstrates that variations in air quality in Lucknow were primarily driven by changes in human and industrial activities rather than the COVID-19 pandemic itself. Temporary reductions in PM_{10}, $PM_{2.5}$ and

NO_2 concentrations were observed during lockdown periods due to restricted traffic and industrial operations; however, pollutant levels remained above WHO global air quality guidelines (2021) values and increased sharply after restrictions were lifted. The post-lockdown rebound highlights the unsustainable nature of short-term air-quality improvements and underscores the need for long-term urban planning, transport management and emission-control policies to achieve lasting air-quality benefits

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