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Comprehensive assessment of air quality dynamics in Delhi: a tri-phased analysis spanning pre, during, and post-lockdown periods

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Abstract: To mitigate the spread of the global COVID-19 pandemic, various regions, including India, implemented stringent measures such as nationwide lockdowns to curb the spread of the virus. The air quality dynamics during the COVID-19 lockdown period revealed diverse trends across various pollutants all over the world. This study explores the impact of these lockdowns on air quality in Delhi, one of India's megacities, across distinct phases: pre-lockdown, during lockdown, and post-lockdown periods. PM 10 was observed to show a substantial decline in concentration, particularly in April 2020, serving as a testament to the immediate effectiveness of implementing lockdown measures to control particulate matter concentrations. However, these levels returned to their previous peak in subsequent years post lockdown. PM 2.5 followed a similar pattern, experiencing an initial decline during the lockdown, but as industries and factories resumed their activities post June 2020, the levels shot up back to their original baseline, highlighting the transient nature of low PM concentrations. Other pollutants like Sulphur Dioxide (SO_2), Nitrogen Dioxide (NO_2), and Carbon Monoxide (CO) levels showed varying degrees of mild to steep decline during the lockdown, but they too returned to their original concentrations as few months after the lockdown was lifted. There was, contrary to expectations, an increase in ozone (O_3) concentrations after the implementation of lockdown, challenging our assumptions. Spatial mapping was done to observe the variation of concentration in different tehsils of Delhi.

1 Introduction

The extensive and rapid spread of the SARS-CoV-2 virus and the thousands of deaths that resulted from it led the World Health Organisation to declare it a pandemic on 12 March 2020[1]. Over 210 nations worldwide were affected, including India which saw upwards of 45 million positive cases and a death toll over 500,000. Due to COVID-19's impact on the majority of the global populace, there was a public health emergency of global concern, raising the alarm for medical and political organizations all over the world. COVID 19 is the first coronavirus following the Spanish Flu (1918–1919), to have had an impact this sizable on India's economy, psychology, and healthcare system[2, 3].

The initial cases of the COVID-19 viral disease were reported in the city of Wuhan, China, towards the end of 2019. As people traveled from China to other parts of the world, the virus rapidly spread across the globe. To protect citizens and limit the transmission of the disease through contact with infected individuals, governments worldwide implemented nationwide lockdowns and social distancing measures in their respective countries. India reported its first case of COVID-19 in Kerala, on January 30, 2020. Recognizing the potential for community spread, the Indian government imposed a nationwide lockdown on March 25, 2020, which was scheduled until April 14, 2020. This initial 21-day lockdown was followed by subsequent extensions, with Lockdown 2.0 spanning from April 15 to May 3, and Lockdown 3.0 from May 1 to May 17. After a 75-day period of complete lockdown, a phased reopening began on June 8, 2020[4]. The guidelines issued by the government during the nationwide lockdown in India mandated the suspension of all domestic and international air travel, train services, public transportation, individual vehicle movement, educational institutions, markets, construction activities, industrial and commercial operations, and other activities that required social interaction[5].

The nationwide social lockdown and the abrupt suspension of economic activities drastically altered the way citizens went about their daily lives. Although this proved to be a significant deterrent in the nation's economic growth[6], the opposite was true for the environment. There were significant improvements in the ecosystems of urban megacities, which had previously been the epicenters of noise, water and air pollution. India in particular, experienced an unprecedented improvement in air quality, showing substantial reductions in primary pollutants like fine particulate matter (42–60%), coarse particulate matter (24–62%), nitrogen dioxide (46–61%), ozone (22–56%) and Carbon Monoxide (16–46%)[7]. This sudden positive change was largely due to the cessation of operations of most large-scale factories as well as the lack of vehicular emissions contributing to the poor air quality.

Delhi, officially recognized as the National Capital Territory (NCT) of Delhi, constitutes both a city and a union territory within India, housing New Delhi, the nation's capital. Positioned at approximately 28.7°N and 77.1°E, the NCT spans an expanse of 1,484 square kilometers (573 sq mi). The 2011 census reported a population exceeding 11 million within the city limits and around 16.8 million in the NCT. Delhi experiences a dry winter humid subtropical climate intermingled with a hot semi-arid climate. To systematically monitor air quality, 40 Continuous Ambient Air Quality Monitoring Stations (CAAQMS) have been strategically established across Delhi.

This research wishes to answer the following questions:

1. How did the concentration levels of PM 2.5, PM 10, SO_2, NO_2, CO, and O_3 change during the pre-lockdown, lockdown, and post-lockdown periods in Delhi?
2. Which pollutants exhibited the most pronounced changes in concentration levels during the lockdown period?
3. What were the potential factors contributing to the observed changes in air pollution levels during the lockdown?
4. How did the spatial distribution of pollutant concentrations vary across different tehsils (administrative subdivisions) of Delhi?

By analyzing the variation in levels of air pollution during the COVID-19 lockdown, this study aims to provide valuable insights into the effectiveness of lockdown measures in reducing air pollution and inform policy decisions to mitigate air pollution in Delhi and other similarly affected cities. The findings of this study will also contribute to a better understanding of the direct and indirect correlation between human activities, air pollution, and public health, ultimately informing strategies to improve air quality and protect human health in the face of future pandemics or environmental crises.

2 Analysis

The ten reviewed papers collectively investigate the impact of COVID-19 lockdowns on air quality across various regions, focusing on key pollutants such as PM 2.5, PM 10, NO_2, SO_2, CO, and O_3. The findings consistently highlight significant reductions in particulate matter and nitrogen dioxide during lockdown periods, indicating the positive influence of restricted anthropogenic activities on air quality. Noteworthy improvements are observed in major polluted cities, emphasizing the potential of strategic lockdowns at pollution hotspots. The global scope of some studies enhances the understanding of the pandemic's impact on air quality worldwide.

However, a common limitation is the temporary nature of improvements, with pollutant levels rebounding post-lockdown. Additionally, there's a tendency to overlook the role of meteorological conditions and the complex interplay of atmospheric chemistry in pollutant variations. Future studies should delve deeper into the long-term effects of lockdowns, considering secondary pollutants, regional disparities, and the persistence of cleaner air beyond immediate lockdown periods. Comprehensive research incorporating meteorological factors, secondary pollutants, and sustained policy measures is crucial for effective long-term air quality management.

3 Data sources and methodology

3.1 Study area, period of study and data sources

This research is aimed at undertaking a detailed assessment on the evolution of air quality in Delhi over five years, from 1st January 2018 to 31st December 2023. The study mainly involves an analysis of daily mean concentration data for six primary criteria pollutants viz. PM 10, PM 2.5, NO_2, O_3, SO_2 and CO within NCT of Delhi.

The study obtained daily average concentrations for these parameters from Continuous Ambient Air Quality Monitoring Stations (CAAQMS) in Delhi. This data was accessed through the Central Control Room portal CCR on the CAAQMS section platform on this website. The CCR portal managed by Central Pollution Control Board (CPCB) acts as a one-stop-shop for ambient air quality data from CAAQMS installations across the country.

Delhi has a network of forty CAAQMS that are purposefully installed in different locations under the supervision of various bodies including CPCB, DPCC, IMD and IITM.

Unlike previous studies that occasionally excluded stations due to data irregularities, our approach is characterized by an inclusive strategy, maximizing data points wherever feasible to enhance precision and reliability. The longer time horizon facilitates a more nuanced and detailed exploration of the long-term fluctuations in air quality trends, including baseline conditions, the immediate repercussions of the lockdown implementation, and the resulting trajectory over the post-lockdown periods.

3.2 Methodology

This research conducts an in-depth study of the ambient air quality levels of the NCT of Delhi, over a five year period, from 2018 to 2023, emphasizing on six key criteria of air pollutants, namely: PM 10, PM 2.5, Sulphur Dioxide (SO_2), Nitrogen Dioxide (NO_2), Carbon

Monoxide (CO) and Ozone. The data set used for this analysis consists of the daily average concentration records taken from the official website of the Central Pollution Control Board (CPCB). This data is recorded by the extensive network of 40 monitoring stations dispersed strategically across the city to ensure comprehensiveness and representativeness in the collected data.

The process of data collection and processing involved a thorough five-year data extraction process conducted in a methodical way, leading to a detailed and extensive account of the atmospheric conditions of Delhi during the period of study.

The daily average concentrations were then systematically compiled into monthly averages through comprehensive measures involving extensive data processing. This methodological refinement was performed with the intent to reduce inherent local perturbations in day-by-day observations and well as to increase analytical relevance by utilizing long-term trends.

4 Data analysis, comparison and results

4.1 Graphical observations

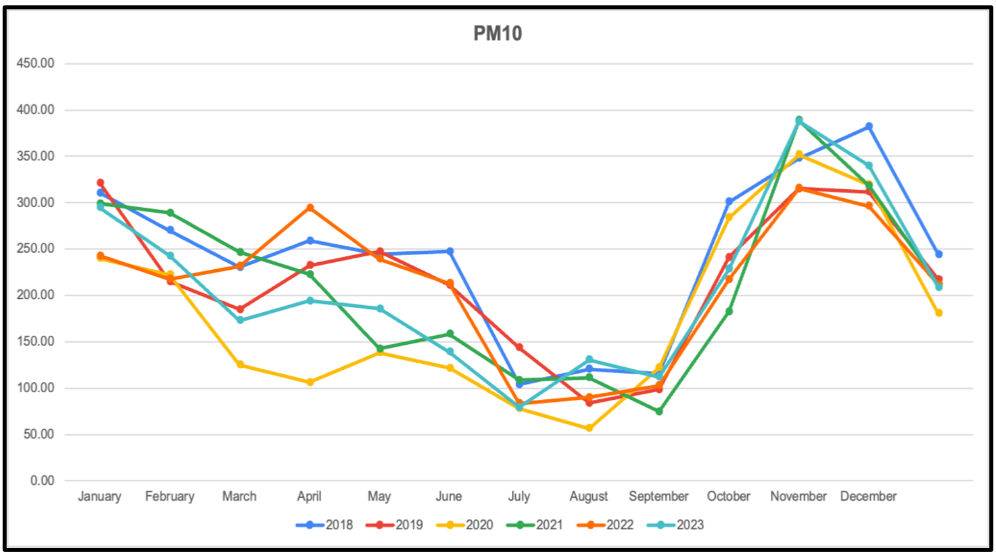

Fig 1. Graph Representing variation of PM 10 concentration with time

The PM 10 graph (Fig 4.1) displayed a significant drop during the lockdown in 2020, indicating an improvement in air quality compared to previous years. PM 10 levels dropped dramatically from 232 to 106 µg/m³ in April 2020, indicating a significant drop during the lockdown. This significant drop highlights how well the policies put in place to reduce particulate matter levels in the atmosphere are working.

Even following the lifting of the lockdown, a sustained relief in PM 10 concentrations persisted for an additional three months. This protracted improvement suggests a lasting impact on air quality beyond the specific lockdown period, emphasizing the enduring benefits of reduced anthropogenic activities on particulate matter levels. Within the same year (2020), PM 10 levels rebounded to typical winter norms despite the earlier reduction during the lockdown period. This seasonal fluctuation underscores the complex interplay of meteorological conditions and human activities on particulate matter concentrations.

However, in 2021 and 2022, PM 10 levels reverted to pre-lockdown norms, indicating a lack of sustained pollution reduction compared to the distinctive improvements observed during the lockdown period. This suggests that the temporary relief witnessed in the immediate aftermath of the lockdown was not a lasting trend, emphasizing the need for continued efforts in pollution control to maintain air quality improvements. 2023, however, saw a decline in PM 10 levels.

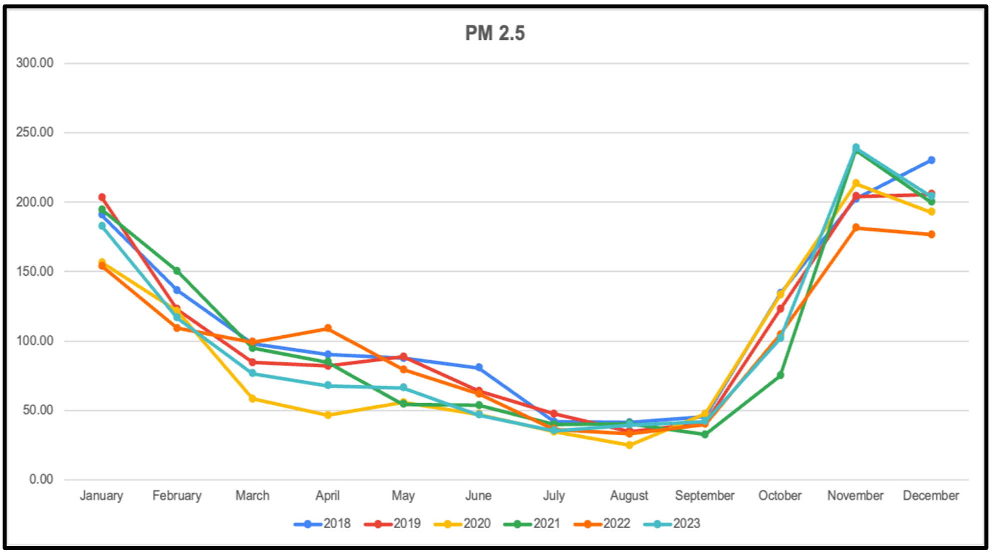

Fig .2 Graph Representing variation of PM 2.5 concentration with time

The PM 2.5 graph (Fig 4.2) exhibited a notable 43.44% decrease immediately upon the imposition of the lockdown (from 81.9 µg/m³ in April 2019 to 46.32 µg/m³ in April 2020), indicating a prompt response to reduced anthropogenic activities. However, unlike PM 10, no sustained relief in PM 2.5 concentrations was observed beyond the lockdown period. Even after the lifting of restrictions, PM 2.5 levels returned to pre-lockdown levels, underscoring the transient nature of the air quality improvements seen during the lockdown for this fine particulate matter.

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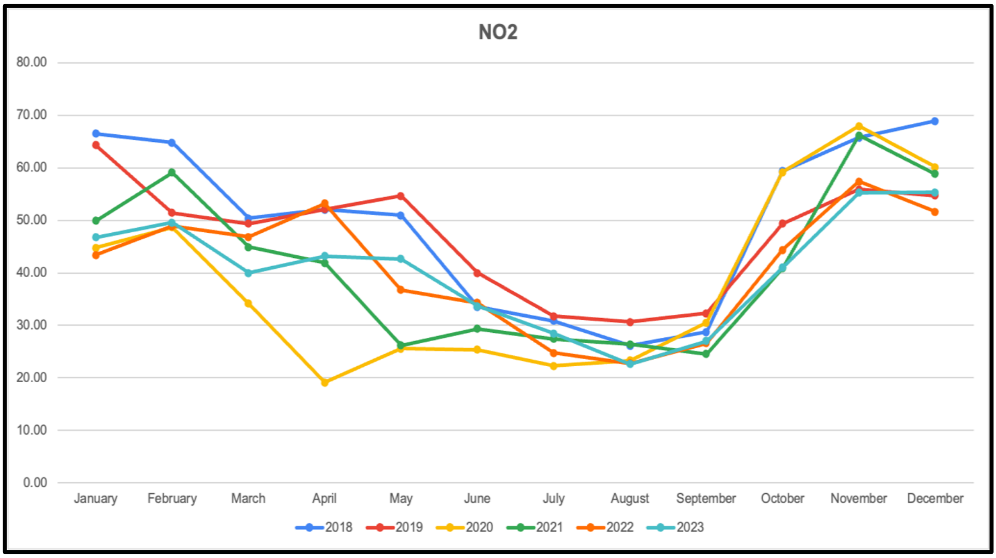

Fig 3. Graph Representing variation of NO_2 concentration with time

The NO_2 (Nitrogen Dioxide) graph (Fig 4.3) exhibited a substantial reduction following the initiation of the lockdown, indicative of the immediate impact of decreased anthropogenic activities.

However, post-lockdown, NO_2 levels gradually returned to their original concentrations, illustrating a resilience to sustained improvements after the easing of restrictions. This temporal pattern underscores the dynamic relationship between human activities and NO_2 emissions, emphasizing the transient nature of air quality enhancements during the lockdown period.

Subsequent to the lockdown period, the NO_2 trend persisted unaltered in the subsequent years, maintaining typical concentration levels. This steadfastness in the atmospheric levels of NO_2 underscores the resilience of pollutant concentrations to sustained changes in human activities, highlighting the need for continuous efforts in mitigating emissions to effect lasting improvements in air quality.

There was a minor decrease observed in NO_2 levels for 2021, 2022, and 2023, especially in May. Barring this slight decline, the general trend remained consistent with previous patterns, highlighting the consistency of nitrogen dioxide concentrations throughout this time period. This subtle dip implies that the overall trajectory of NO_2 concentrations seems to be consistent throughout time, despite possible small oscillations.

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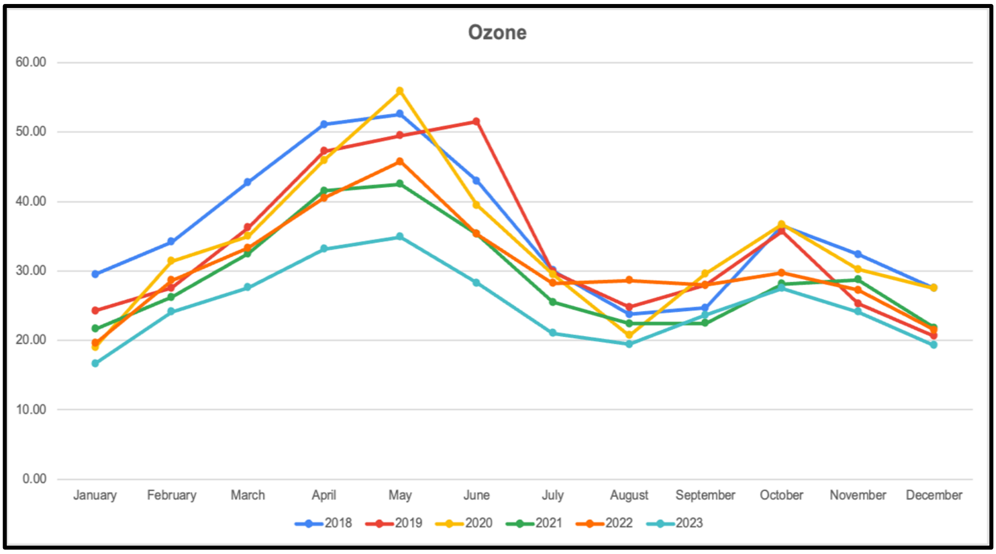

Fig 4. Graph Representing variation of ozone concentration with time

Contrary to expectations, the ozone graph (Fig 4.4) did not exhibit a decrease during the lockdown period; instead, it showed an unexpected increase in levels. This counterintuitive finding challenges our conventional assumptions about reduced human activities leading to lower ozone levels in the atmosphere. The observed rise in ozone levels throughout the lockout period highlights the necessity for a comprehensive research in interpreting the dynamics of air quality and the intricate interactions between precursor emissions and atmospheric chemistry.

The increase in ozone (O_3) during the COVID-19 lockdown, despite reduced pollutant emissions, can be attributed to a complex interplay of factors. The study conducted in Changzhou, China[8], found that the significant decrease in human activities during the lockdown led to lesser emissions of nitrogen oxides (NOx) and volatile organic compounds (VOCs), key ozone precursors. Surprisingly, this reduction led to a drop in VOC concentrations, especially aromatics, while NOx reduction was inappropriate. The imbalance in NOx and VOC reductions shifted O_3 formation from a VOC-sensitive regime to a VOC- and NOx-limited regime, resulting in an increase in O_3 during the lockdown. This counterintuitive finding underscores the need to carefully manage the reduction ratio of anthropogenic VOCs and NOx to mitigate ozone pollution effectively.

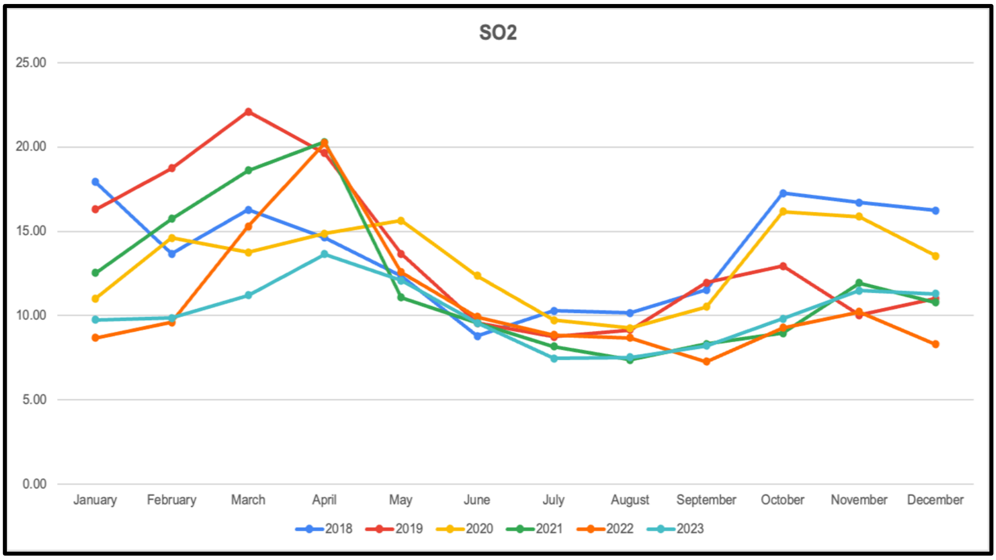

Fig 5. Graph Representing variation of SO_2 concentration with time

The SO_2 (Sulphur Dioxide) graph (Fig 4.5) revealed lower values during March and April, coinciding with the initial period of the lockdown. However, in the subsequent months, no prominent changes were observed, indicating a relative stability in SO_2 concentrations. This suggests that while short-term reductions occurred during the lockdown, the levels rebounded to baseline, highlighting the need for ongoing strategies to address sulfur dioxide emissions and maintain sustained air quality improvements.

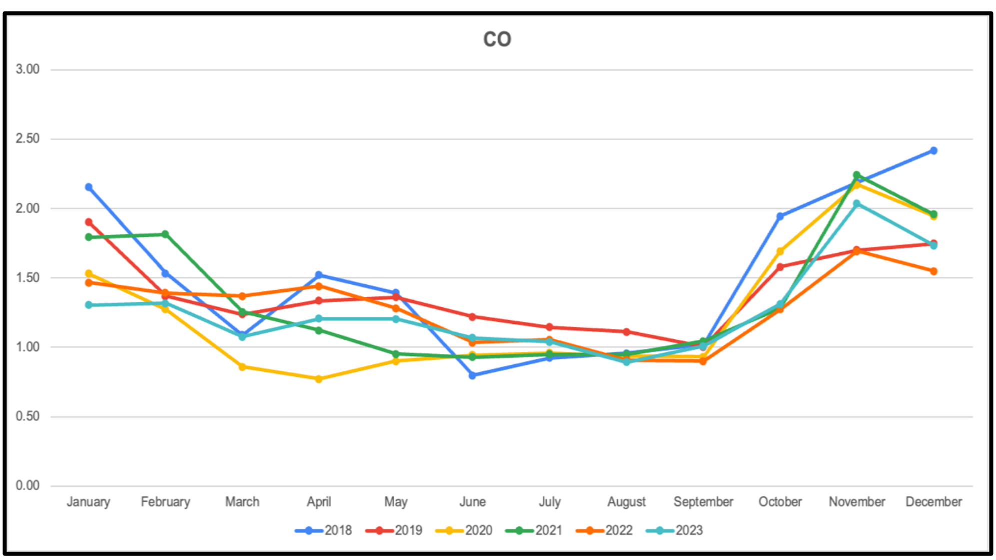

Fig 6. Graph Representing variation of CO concentration with time

Consistently, in both 2021 and 2022, SO_2 levels exhibited a similar pattern, remaining relatively stable and comparable to the baseline levels observed in the pre-lockdown period.

This sustained consistency underscores the persistent nature of sulfur dioxide concentrations, emphasizing the ongoing challenge of effectively managing and mitigating SO_2 emissions for lasting air quality improvements.

The CO graph (Fig 4.6) exhibited a substantial decline initially during the lockdown period, reflecting the immediate impact of reduced human activities. While a residual effect persisted post-lockdown, particularly noticeable, CO concentrations reverted to baseline levels by the winter months. This temporal pattern underscores the transient nature of the reductions, emphasizing the dynamic relationship between human activities and carbon monoxide emissions, with the return to typical levels indicating a resumption of regular sources of CO in the atmosphere.

In the subsequent years, 2021 and 2022, the CO graph showed no deviation from the established pattern, maintaining a consistent trend with no notable fluctuations. This stability in carbon monoxide concentrations suggests a resilience to sustained changes in human activities during these years.

4.2 Spatial mapping

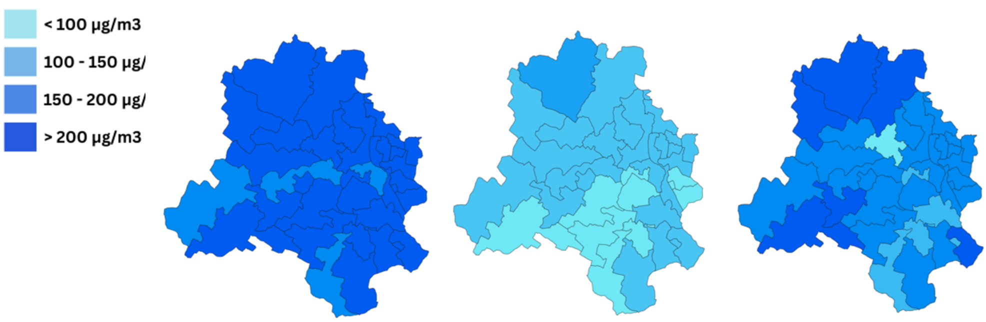

Fig 7. Maps representing spatial variation of PM 10 concentration across Delhi during pre (left), during (middle) and post (right) lockdown periods

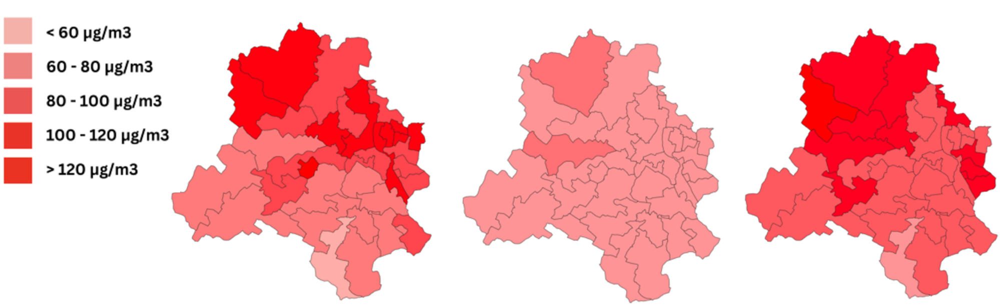

Fig 8. Maps representing spatial variation of PM 2.5 concentration across Delhi during pre (left), during (middle) and post (right) lockdown periods

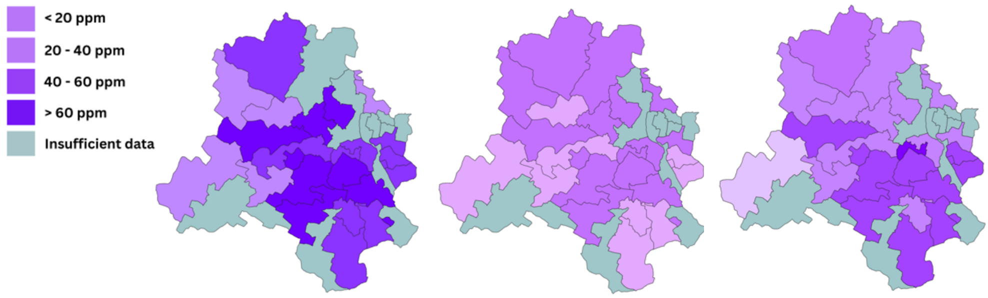

Fig 9 Maps representing spatial variation of NO_2 concentration across Delhi during pre (left), during (middle) and post (right) lockdown periods

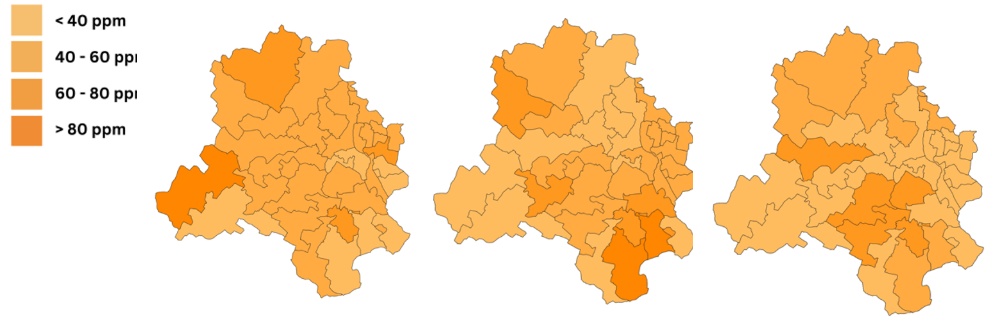

Fig 10. Maps representing spatial variation of O_3 concentration across Delhi during pre (left), during (middle) and post (right) lockdown periods

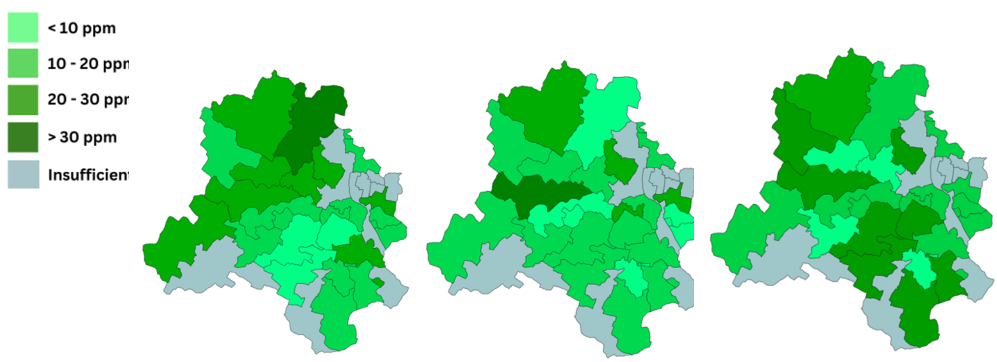

Fig 11. Maps representing spatial variation of SO_2 concentration across Delhi during pre (left), during (middle) and post (right) lockdown periods

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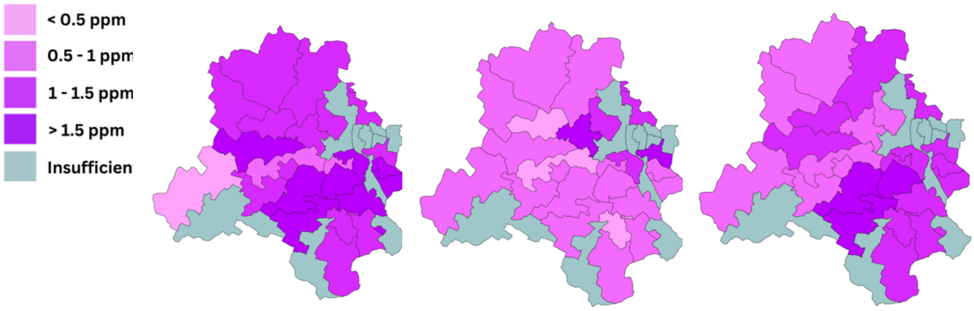

Fig 12. Maps representing spatial variation of CO concentration across Delhi during pre (left), during (middle) and post (right) lockdown periods

The spatial mapping shows how pollution levels changed in Delhi's various tehsils over the course of three separate time periods: before the lockdown, during the lockdown, and after the lockdown. A discernible pattern is revealed by contrasting the concentration levels shown on the maps.

In the pre-Lockdown period, the maps reveal comparatively high levels of pollution in the majority of Delhi's tehsils prior to the implementation of lockdown restrictions. This is to be expected, given regular levels of human activity—such as driving, manufacturing, and construction—contribute significantly to air pollution. In the lockdown period, the maps show a discernible decrease in pollution concentrations in all tehsils during the lockdown periods, when severe limitations on travel and business operations were in effect. This decline is explained by the significant drop in sources of emissions during the lockdowns, including factories, cars, and construction activity. Post the lockdown period, pollutant concentrations on the maps show a minor increase in comparison to the lockdown period, however overall levels remained lower than pre-lockdown conditions as lockdown restrictions were progressively lifted and economic activity restarted.

According to this rebound effect, although the lockdowns gave a little reprieve, once individuals went back to their regular schedules and businesses resumed operations, the fundamental causes of pollution soon reappeared.

5 Conclusion

Different pollutants exhibited different trends in air quality dynamics during COVID-19 lockdown period. PM 10 significantly reduced, particularly in April 2020, indicating the immediate effectiveness of locking down to mitigate levels of particulate matter. Nevertheless, this improvement was short lived and the levels reverted back to the baseline in subsequent years. Similarly, PM 2.5 also declined at the beginning of lockdown; however, it was evident that there were no lasting reductions past this time period for fine particulate matter.

Nitrogen Dioxide (NO_2) levels decreased significantly throughout the lockdown but eventually made a gradual recovery towards original concentrations, showing us its durability against long-term improvements. This pattern persisted in subsequent years thereby underlining that measures aimed at abating emissions must be continuous if lasting improvement on air quality is to be achieved Ozone levels actually increased during the lockdown, contrary to conventional expectations. Such surges were associated with disproportionately large cutbacks in nitrogen oxides (NOx) and volatile organic compounds

(VOCs), thereby transforming ozone formation paradigms, as per the study conducted in Changzhou, China[8].

6 Future Scope

The inferences extracted from this research lead to promising areas for further research on the air quality dynamics in urban settlements and the correlation of fluctuations in pollutant levels with anthropogenic activities. First and foremost, it is possible to carry out comprehensive apportionment studies to find out the sources of pollutants, thereby identifying whether regional or local factors are responsible for worsening air quality situations. The findings from these works will be useful in designing more targeted and efficient emission mitigation measures. On top of that, a deeper analysis of public health effects caused by air pollution is essential where correlation between pollutant levels and health outcomes is researched in Delhi. By doing so, comprehensive health impact assessment would be an effective tool for guiding policy makers to put measures which are not only meant to improve air quality but also safeguard public health. All together these future research activities could lead to development of policies based on evidence which will promote sustainable lifestyle and reduce air pollution related problems.

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