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Mitigating Air Pollution and Protecting Public Health: Analyzing the Impact of National Clean Air Programme in Kota, Rajasthan

MONIKA SHARMA*, M. P. CHOUDHARY and ANIL K. MATHUR

Civil Engineering Department, Rajasthan Technical University, Kota, Rajasthan, India.

Abstract

The clean air plan in India involves a set of rules, policies, and initiatives targeted at improving the air quality and public health by way of decreasing emissions from various sources. The study aims to evaluate the impact of National Clean Air Program (NCAP) on lowering air pollution levels and improving public health outcomes in Kota city, Rajasthan, highlighting progress, challenges, and the need for sustained emission control efforts. Kota's selection for this study highlights its significance as an educational hub, attracting students from all over India. The rapid population growth and increased vehicle emissions in the city cause adverse impacts on air quality. Improving air quality will not only enhance the health of residents and students but also contribute to a more conducive learning environment. The action plan of NCAP involves enforcing the construction and demolition waste management rules 2016, implementing emission control measures like water sprinkling and covered transport for construction activities, and extensive campaigns against open burning of biomass and waste. It also includes regular checks on industrial emissions, proper waste collection and disposal, and mandatory green belt development in residential areas. It employs a mixed-method approach, combining air quality monitoring data collected from the Central and State Pollution Control Boards from 2014 to 2023. It also examines trends in key pollutants, including NO_2, SO_2, and PM_{10}, and analyzes the effect of regulatory measures such as emission controls and waste management rules. The study reveals a decreasing trend in NO_2 (nitrogen dioxide) levels in Kota city, Rajasthan from 35.35 µg/m³ to 29.90 µg/m³ during 2014 to 2023, showing a significant drop during the COVID-19 lockdown. Similarly, PM_{10} (particulate matter) levels peaked at 153.28 µg/m³

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CONTACT Monika Sharma ✉ msharma.phd18@rtu.ac.in Civil Engineering Department, Rajasthan Technical University, Kota, Rajasthan, India.

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in 2018 but saw a significant reduction to104.80 μg/m³ by 2020, indicating an improvement in air quality. However, SO_2 (sulfur dioxide) concentrations slightly increased in 2019-2023 compared to 2014-2018. The air quality index (AQI) improved modestly but frequently surpassed 100, indicating hazardous air quality for vulnerable populations. The study concludes that while the NCAP in India has significantly improved air quality, challenges remain, with NO_2 levels rebounding post-COVID-19 lockdown and persistent high particulate matter levels. It is recommended to ensure stricter enforcement of emission control measures, enhanced monitoring systems, and public awareness campaigns. Future work should focus on the long-term health impacts of particulate matter and strategies to achieve sustained air quality improvements in high-risk regions.

Introduction

The Government of India, through its Ministry of Environment, Forest, and Climate Change (MoEFCC), took a major step in January 2019 by launching the National Clean Air Program (NCAP) to reduce particulate matter (PM_{10} and $PM_{2.5}$) pollution levels by 20-30% by 2024, taking 2017 as the baseline. This initiative focuses on 122 cities across India and provides a structured framework of protocols, plans, and initiatives aimed at enhancing air quality and protecting community health.[1] The program prioritizes cost-effective strategies to address key pollution sources, emphasizing the need for sector-specific, economical emission reduction measures.[2] Health impact assessments underscore the urgency of such efforts, particularly in areas with high emissions.

Air pollution has a profound effect on health, with residential biomass combustion estimated to be responsible for approximately 268,000 deaths. Additionally, coal burning in power plants and industries contributes to around 169,000 fatalities, while anthropogenic dust is associated with about 100,000 deaths. Additionally, agricultural burning is associated with approximately 66,000 deaths, and over 65,000 deaths are attributed to emissions from road transportation, non-road diesel engines, and brick-making factories.[3-5]

To address these impacts, the Ministry of Health and Family Welfare, Govt. of India proposed a management approach centered on exposure reduction, aiming to integrate the negative impacts of air pollution on health with proper strategic planning.[6] In Uttar Pradesh (UP), which is India's most populous state and a major pollution hotspot, a target of 40% reduction in particulate matter has been set under the NCAP by year 2026. A recent study using the prophet forecasting model assessed NCAP's impact on 15 non-attainment cities, revealing persistently unhealthy air quality levels in most areas.

Jhansi recorded a moderate AQI of 72.73 in 2023, while Gorakhpur exhibited high values up to 249.31 during 2019. Cities like Noida, Ghaziabad and Moradabad situated in western UP are also grappling with serious environmental issues. However, significant PM_{10} reductions are forecasted for cities like Bareilly (70%), Raebareli (58%), and Moradabad (55%), with Gorakhpur and Prayagraj expected to see increases of 50% and 32%, respectively.[7]

Further analysis of air quality management in Uttar Pradesh highlighted that action plans prioritize road dust and construction activities (24% weightage). Urban local bodies play a key role, implementing about 50% of initiatives, with around 56% requiring collaboration across agencies.[8] Additionally, a study emphasized the importance of enhancing ambient air monitoring by designing representative air shed areas and establishing optimal sampling methods.[9] Central Pollution Control Board (CPCB) data indicates a reduction in NO_2 and $PM_{2.5}$ levels at several locations, and satellite data for Visakhapatnam and Tirupati from 2019 to 2022.[10] A study in Kota city from January to March 2020 measured respirable suspended particulate matter, revealing that SO_2 and NO_2 levels remained within AQI limits (80 μg/m³), though PM_{10} concentrations exceeded the safe limit of 100 μg/m³, underscoring the need for continued regulatory action and monitoring.[11]

The selection of Kota city for this study underscores its importance as a major educational hub, drawing students from across India. The city's rapid population growth and rising vehicle emissions have significantly impacted its air quality, leading to health concerns for both residents and the large student population. Addressing air quality issues in Kota city is therefore crucial not only for public health but also for fostering a healthier and more supportive learning environment, benefiting students and the broader community alike.

Table 1 provides a detailed progression of regulatory measures and strategic planning frameworks implemented in India to control air pollution. It highlights key policies, rules, and initiatives introduced over time, showcasing the evolution of India's approach toward mitigating air pollution and improving public health. The table outlines milestones in legislative advancements, targets set under programs like the NCAP and sector-specific strategies aimed at reducing emissions from major pollution sources. These coordinated efforts reflect India's growing commitment to addressing air quality challenges comprehensively and systematically.

Table 1: Chronological Strategy of Regulatory Measures to Control Air Pollution[12]

Time Period	Milestone Activity
1974	**CPCB:** Establishment of the Central Pollution Control Board under the Water Act, 1974
1981	Air Quality Mandate: CPCB is entrusted with powers under the Air Act, expanding its role in pollution control.
1986	**Environmental Safeguards:** Introduction of provisions from the Environment (Protection) Act, 1986 enhancing CPCB's authority.
1994	**NAAQS Introduction:** National Ambient Air Quality Standards were introduced to monitor and regulate air quality.
1997	**Delhi's Strategy:** A strategic plan was developed by the Ministry of Environment, Forest and Climate Change (MoEFCC) to combat pollution specifically in Delhi.
1998	**EPCA Formation:** The Supreme Court of India ordered the establishment of the Environment Pollution (Prevention & Control) Authority (EPCA) in 1998 to address Delhi's severe air pollution, implementing measures like CNG adoption for public transport and stricter mission norms.
1998	**NAAQS Revision:** First major revision of the National Ambient Air Quality Standards.
2003	**Supreme Court Directive:** Mandate for cities to create clean air plans, targeting RSPM reduction.
2009	**Pollution Index Launch:** CPCB introduces the Comprehensive Environmental Pollution Index for industrial assessment.
2009	**$PM_{2.5}$ Inclusion:** NAAQS revised to incorporate $PM_{2.5}$ standards, recognizing its health impacts.
2014	**AQI Methodology Established:** Standardized Air Quality Index methodology is adopted nationally.
2015	**42 Action Points:** CPCB issues directives for pollution control measures in major cities under the Air Act.
2016	**$PM_{2.5}$ Monitoring:** Manual stations are required to monitor $PM_{2.5}$ as part of the National Air Monitoring Program.
2016	**GRAP Launch:** The Graded Response Action Plan (GRAP) was introduced to manage air quality emergencies in Delhi's National Capital Region (NCR).
2018	**NCAP Draft Circulation:** The MoEFCC issues a draft idea for NCAP, outlining time-bound techniques.
2018	**Non-Attainment Cities Identified:** 102 cities designated as non-attainment under the NCAP framework.
2018	**NGT Directive:** National Green Tribunal (NGT) orders states with non-attainment cities to prepare actionable plans for air quality improvement.

2019	**NCAP Official Launch:** National-level strategy to combat air pollution initiated, with oversight by a central committee.
2019	**Expanded Non-Attainment List:** 20 additional cities identified for intervention post-NGT's review.
2024	**Pollution Reduction Target:** The goal is to decrease $PM_{2.5}$ levels by 20-30% in 122 non-attainment cities relative to 2017 levels.

This study examines the efficiency of the much anticipated National Clean Air Program specifically in the city of Kota. It evaluates both the progress in local air quality improvements and the persistent challenges faced. By addressing this gap, the study provides insights into how well the NCAP initiatives have been implemented at the city level, highlighting the areas of success as well as those requiring further attention for sustainable air quality management.

Materials and Methods

The CPCB has identified 122 cities across 21 states and 2 union territories (Delhi and Chandigarh) as failing to meet air quality standards, based on data from its extensive monitoring network established under the NCAP. Among these cities, Delhi's deteriorating air quality receives extensive media coverage and remains one of the most researched topics on pollution in India.[13-17] In Rajasthan, five cities namely Alwar, Jaipur, Jodhpur, Kota and Udaipur have been flagged for not meeting the required air quality standards.[4]

The NCAP has introduced key strategies for cities nationwide, including improvements to public transportation, measures to control dust from roads and construction, a ban on open burning of waste, support for cleaner cooking methods, strict enforcement of industrial emission limits, expansion of air quality monitoring networks, and efforts to raise public awareness about air pollution issues.

Kota's air quality is tracked by an automated Continuous Ambient Air Quality Monitoring Station (CAAQMS) and six other manually operated and maintained stations under the National Air Quality Monitoring Program (NAQMP), which measure particulate matter, gaseous pollutants, and meteorological parameters. For this study, air quality data were obtained from CPCB/RSPCB websites, covering above seven monitoring stations in Kota. Monthly data for these pollutants and the AQI were compiled and averaged into annual mean values for two periods: before NCAP implementation (2014-2019) and after NCAP implementation (2019-2023). This allows for a comparative assessment of air quality improvements resulting from NCAP initiatives.

Figure 1 shows the flowchart of methodology adopted for analysis of air quality data in Kota city.

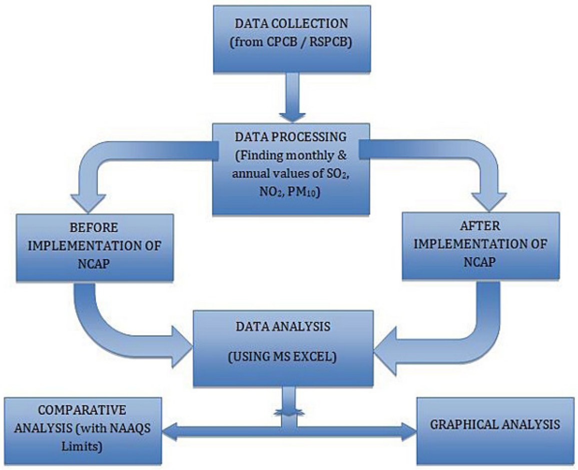

Fig. 1: Methodology Flowchart

Air quality profoundly affects human health, the livability of urban and rural areas, and the broader ecosystem. Predominantly driven by human activities, air pollution can cause various health issues, particularly affecting the cardiovascular and respiratory systems, and may even lead to cancer. Health risks can arise even from short-term exposure to polluted air. Groups like children, the older adults, and others having existing diseases related to heart and lung are particularly vulnerable to the harmful effects of air pollution.[18-20]

This study focuses on assessing the effectiveness of NCAP in Kota, Rajasthan, particularly in minimizing the air pollution and its associated health impacts. It aims to analyze trends in key pollutants, including PM_{10}, NO_2 and SO_2 and to evaluate the success of NCAP's mitigation measures on public health and air quality in Kota. The primary contributors to air pollution in Kota are roadside dust, vehicle emissions, construction debris, and industrial emissions. The Rajasthan State Pollution Control Board (RSPCB) monitors polluting industries regularly, enforcing necessary controls to limit industrial emissions.[21]

A limitation of this study is that its relatively short duration may not capture the full, long-term effectiveness of NCAP measures. Additionally, external factors, including the COVID-19 pandemic, could introduce variability by impacting pollution levels and health outcomes. The lack of primary data collection further restricts insights into public awareness and compliance with air quality regulations, leaving some gaps in understanding NCAP's effectiveness at a community level.

Results and Discussion

The following table 2 displays the annual average concentrations of NO_2, PM_{10}, SO_2 and the Air Quality Index (AQI) in Kota city, Rajasthan, for the period from 2014 to 2023. This data provides a clear view of air quality trends over time, offering insights into the effectiveness of the National Clean Air Program's pollution mitigation strategies, especially before and after the NCAP implementation.

Table 2: Concentration of Various Air Quality Parameters during 2014-2023

S. No.	Year	Concentration (µg/m³)			AQI
		NO_2	PM_{10}	SO_2	
Pre-NCAP					
1	2014	35.35	126.42	6.67	114.26
2	2015	34.18	134.00	6.45	119.79
3	2016	34.34	127.97	6.86	114.31
4	2017	27.44	129.49	8.64	116.58
5	2018	27.49	153.28	7.17	135.15
Post-NCAP					
6	2019	24.01	119.26	6.76	108.83
7	2020	23.91	104.80	6.28	99.99
8	2021	27.28	122.89	7.14	112.72
9	2022	30.88	129.99	9.75	117.92
10	2023	29.90	124.26	8.23	113.56

Variation in NO_2 Concentration

From 2014 to 2018, NO_2 levels in Kota showed a gradual decline. Starting at 35.35 in 2014, there was a slight decrease to 34.18 in 2015, remaining relatively stable at 34.34 in 2016. In 2017, a significant drop was observed, with levels reaching 27.44, followed by a marginal increase to 27.49 in 2018.

In the subsequent period from 2019 to 2023, following the implementation of the NCAP, NO_2 levels began at 24.01 in 2019 and continued to decrease slightly to 23.91 in 2020. However, an upward trend was noted thereafter, with concentrations rising to 27.28 in 2021, peaking at 30.88 in 2022, and then slightly decreasing to 29.90 in 2023.

These data highlight initial improvements in NO_2 levels following the NCAP implementation, though resurgence in concentrations from 2021 suggests that additional or sustained mitigation efforts may be required to achieve long-term reductions.

Figure 2 presents a graphical representation of NO_2 concentrations in Kota city for the periods 2014-2018 and 2019-2023, highlighting the changes before and after the implementation of the NCAP.

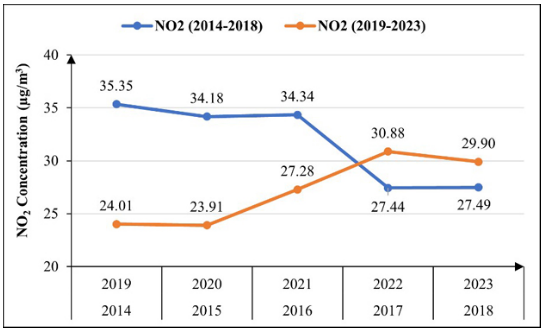

Fig. 2: Variation of NO_2 concentration

Overall, the data indicates a general decline in NO_2 levels from 2014 to 2020, followed by an increase from 2021 to 2023. The peak concentration was recorded in 2014 at 35.35, while the lowest level occurred in 2020 at 23.91.

NO_2 levels typically fluctuate throughout the year due to various factors, including weather changes, temperature variations, sunlight exposure, and human activities.[22] For instance, NO_2 concentrations may be elevated in winter due to increased heating usage and lower wind speeds, whereas summer can see lower levels attributed to higher sunlight and increased wind speeds.[23]

Variation in PM_{10} Concentration

From 2014 to 2018, PM_{10} concentration levels varied between 126.42 and 153.28. The peak concentration during this period was recorded in 2018 at 153.28, while the lowest level was observed in 2014 at 126.42. For the years 2019 to 2023, PM_{10} concentrations ranged from 104.80 to 129.99. The highest concentration in this timeframe occurred in 2021 at 129.99, while the lowest was noted in 2020 at 104.80.

The results of a study accomplished in Uttar Pradesh and the current study show differing trends in PM_{10} concentrations over time. Significant fluctuations have been reported in PM_{10} levels among various cities in Uttar Pradesh, with Gorakhpur peaking at 286.45 µg/m³ in 2019 and Jhansi reaching a low of 92.38 µg/m³ during the COVID-19 lockdown and cities like Bareilly showing over 70% reductions.[7] In contrast, the current study recorded PM_{10} levels between 126.42 and 153.28 µg/m³ from 2014 to 2018, peaking in 2018, and 104.80 to 129.99 µg/m³ from 2019 to 2023, with the highest in 2022. This indicates more stable PM_{10} levels in the current study, suggesting localized pollution sources and the need for targeted air quality management to address PM_{10} pollution effectively.

Figure 3 illustrates the PM_{10} concentration levels in Kota city for two distinct periods: 2014-2018 (before the implementation of the NCAP) and 2019-2023 (after its implementation). This graphical representation allows for a visual comparison of how PM_{10} levels have changed over time, highlighting the consequences of the NCAP on city's air quality.

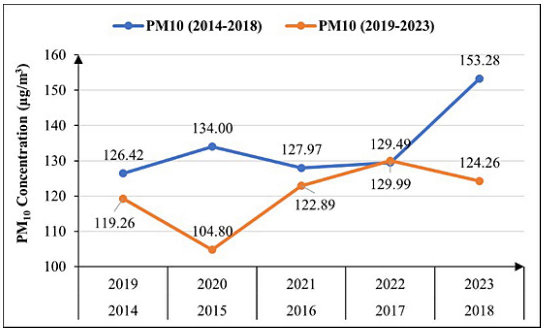

Fig. 3: Variation of PM_{10} Concentration

The above Fig. 3 shows that there has been a slight decrease in PM_{10} concentration levels in the latter period (2019-2023) compared to the earlier period (2014-2018). However, it is noteworthy to mention that such levels are still quite high and could potentially have health implications for the residents of Kota city. It is always recommended to take necessary precautions when air pollution levels are high.

Variation in SO_2 Concentration

SO_2 is a gas released from burning fossil fuels and other industrial processes and is a significant contributor to air pollution.[24] The analysis of sulfur dioxide (SO_2) concentrations shows a slight increase from 2019 to 2023 compared to 2014-2018, with maximum levels rising from 8.64 µg/m³ in 2017 to 9.75 µg/m³ in 2021 and minimum levels marginally increasing from 6.45 µg/m³ in 2015 to 6.28 µg/m³ in 2020. This rise suggests intensified emissions from industrial activities and fuel combustion, possibly due to increased activity, regulatory gaps, or natural factors like meteorological conditions.

The health and environmental implications of elevated SO_2 levels are significant, as the gas is a known respiratory irritant that can exacerbate health issues such as asthma and bronchitis, particularly in vulnerable populations. Additionally, higher SO_2 levels contribute to acid rain formation, threatening ecosystems and infrastructure. To address these challenges, recommendations include tightening SO_2 emission regulations, expanding air quality monitoring, raising public awareness about pollution risks, and encouraging a shift toward renewable energy sources to lessen dependence on fossil fuels. Figure 4 shows the graphical representation of SO_2 concentration during 2014-2018 and 2019-2023 i.e. before and after the implementation of NCAP in Kota city.

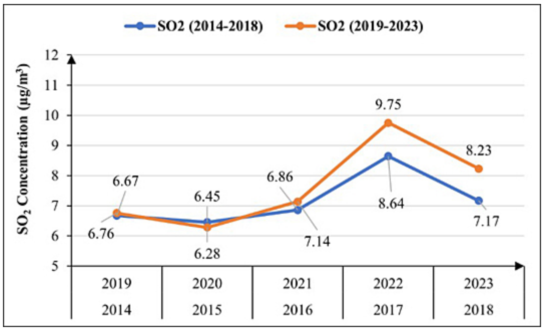

Fig. 4: Variation of SO_2 Concentration

Variation in AQI

The AQI is an important metric that informs the public about current air pollution levels and forecasts future pollution trends. It acts as an important resource for assessing and communicating the overall status of air quality in the area.[25-27] Figure 5 shows the graphical representation of AQI levels during 2014-2018 and 2019-2023 i.e. before and after the implementation of NCAP in Kota city.

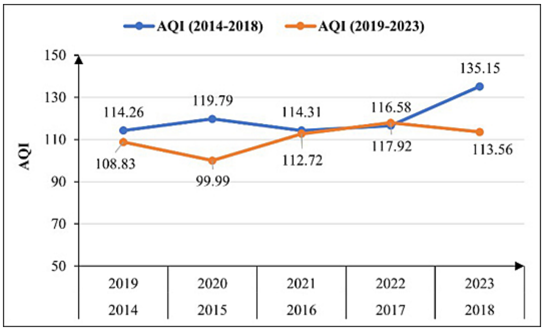

Fig. 5: Variation of AQI

In Kota city, the AQI ranged from 114.26 to 135.15 during pre-NCAP and from 99.99 to 117.92 during post-NCAP. This suggests a trend of relatively stable air quality, with a maximum AQI of 135.15 in 2018 and a minimum of 99.99 in 2020.

The results of a study conducted in Uttar Pradesh and the current investigation highlight notable differences in AQI trends across various timeframes and locations. The study reported significant annual average variations in AQI levels among non-attainment cities in Uttar Pradesh during 2017 to 2023, with values consistently categorized as 'moderate' to 'poor.' In particular, Gorakhpur exhibited a peak AQI of 249.31 in 2019, contrasting sharply with 72.73 as the minimum value of AQI in Jhansi in 2023. Additionally, gradual improvements in AQI, especially post-COVID-19 lockdown were noted.[7] In comparison; the present study reveals a narrower range of AQI levels from the years 2014 to 2023 in Kota city.

While both studies indicate fluctuations in AQI over time, the findings of the Uttar Pradesh study suggest a more pronounced deterioration and subsequent improvement in air quality across specific non-attainment cities, whereas the current study reflects a more stable but consistently elevated level of air pollution within its assessed timeframe. This comparison underscores the necessity of contextualizing AQI data within geographic and temporal frameworks to better understand air quality dynamics.

The above Fig. 5 represents that there has been a slight decrease in AQI levels in the latter period (2019-2023) compared to the earlier period (2014-2018). However, it is important to note that an AQI value over 100 is considered unhealthy for sensitive groups, and values above 150 are unhealthy for everyone. Therefore, continuous efforts are needed to improve the air quality in Kota city.

As compared to the pre-NCAP period (2014-2019), levels of NO_2, PM_{10}, SO_2 and the overall AQI either decreased or remained stable during 2020-2021 but began to rise again afterward. The air quality improvement during 2020-2021 can be attributed primarily to the COVID-19 lockdowns, which took effect across the country and around the world, reducing pollution sources temporarily. However, as lockdowns were lifted, air quality declined again with the resumption of large-scale commercial activities. For Kota specifically, the major factors like construction and demolition dust, vehicular emissions and fly ash from Kota Thermal Power Station (KTPS) are significant contributors to pollution. The NCAP indeed faces challenges in cities like Kota with ongoing industrial and construction activities. Addressing these sources may involve enhanced emission controls, implementing stricter emissions regulations for vehicles and encouraging electric vehicle adoption can reduce vehicular pollution. Increasing public awareness and stricter enforcement of pollution control norms for these sectors could support Kota's NCAP goals, ultimately aiming for sustained improvements in air quality.

Health Impacts of Air Pollution

The correlation between pollution levels and health outcomes is well-known, with various air contaminants like PM_{10}, $PM_{2.5}$, NO_2, SO_2 and ground-level ozone significantly impacting public health. These pollutants are responsible for various negative health outcomes, leading to respiratory disorders like asthma and COPD (chronic obstructive pulmonary disease), cardiovascular issues including heart attacks and hypertension, and even cancers linked to long-term exposure. Recently, a significant decrease was noticed in certain lung function parameters in students attending schools in motor vehicle-polluted areas compared to those in cleaner environments.[28] A strong association between $PM_{2.5}$ exposure and increased premature mortality, particularly among older adults has been highlighted.[29] A prolonged exposure to air pollution from traffic can adversely affect children's respiratory health, potentially leading to diminished lung development and increased vulnerability to respiratory diseases.[30]

These findings underscore the importance of regulatory measures, public health policies like the National Clean Air Program, and community awareness initiatives aimed at reducing pollution levels and safeguarding health, especially in low-income and heavily polluted urban areas. Continued research into the health impacts of air pollution is essential for creating valuable interferences and improving air quality to protect population health.

Potential confounding factors such as weather variations, seasonal changes, and socioeconomic conditions could significantly influence air quality measurements and health outcomes. For instance, fluctuations in temperature, humidity, and wind speed may affect pollutant dispersion and concentration levels. Additionally, socioeconomic factors, including population density and economic activities, could impact pollution sources and the vulnerability of certain populations to adverse health effects. Although these factors have not directly been analyzed in this study, recognizing their potential influence is crucial for interpreting the results accurately. Future investigations ought to integrate these confounding factors to enhance the overall understanding of the connections among air quality, public health, and the success of the NCAP.

Kota city in Rajasthan, situated within an arid and semi-arid agro-climatic zone, experiences substantial dust levels due to its dry climate and frequent hot air movement. These conditions contribute to high concentrations of particulate matter, particularly during summer and winter when thermal inversion traps pollutants closer to the ground. In response, the Rajasthan State Pollution Control Board (RSPCB) has devised and is implementing a comprehensive air quality management plan. This plan adopts a multi-sector approach targeting emissions from industries, vehicles, transportation systems, power plants, waste management practices, and domestic solid fuel use.[31] Integrating land use and land cover (LULC) strategies with emission control technologies could further enhance the effectiveness of these efforts in reducing air pollution and improving overall air quality.[32]

Conclusion

The study on the effectiveness of NCAP in Kota highlights significant progress in air quality improvement, while also acknowledging ongoing challenges. In Kota, NO_2 levels decreased from 35.35 μg/m³ in 2014 to 27.49 μg/m³ in 2018 and further to 24.01 μg/m³ in 2019, demonstrating the effectiveness of implemented strategies. The COVID-19 lockdown in 2020 led to a notable drop in NO_2 levels, reflecting the influence of anthropogenic activities on air quality. However, the levels rebounded to 29.90 μg/m³ by 2023. SO_2 concentrations slightly increased from 2019 to 2023 compared to the previous period, indicating a need for ongoing monitoring and control. Although AQI data shows modest improvement, levels often exceeded 100, suggesting harmful conditions for vulnerable populations.

While the NCAP's multi-sectoral interventions have had positive outcomes, high particulate matter levels remain a significant concern, surpassing environmental standards. The study calls for advanced policies, technologies, and greater public awareness to achieve sustained air quality improvements. The Rajasthan government has taken various measures to mitigate air pollution, with the Rajasthan State Pollution Control Board (RSPCB) implementing exclusive regional approaches to enhance air quality. Despite these efforts, particulate matter concentrations in Kota remain high and exceed the permissible limits set by the CPCB. The study emphasizes the importance of novel methods and technologies to control pollution sources and urges individuals to adopt eco-friendly practices, such as reducing vehicle use, proper waste disposal, and utilizing energy-efficient appliances, to collectively enhance air quality.

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Conflict of Interest

The author(s) do not have any conflict of interest.

Data Availability Statement

The data has been taken from the CPCB and RSPCB portals and are available with the corresponding author.

Ethics Statement

This research did not involve human participants, animal subjects, or any material that requires ethical approval.

Informed Consent Statement

This study did not involve human participants, and therefore, informed consent was not required.

Author Contributions

- **Ms. Monika Sharma:** concept, design, data collection, manuscript writing
- **Dr. M. P. Choudhary:** reviewed and revised the manuscript, supervision
- **Prof. Anil K. Mathur:** overall supervision

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