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AIR QUALITY ASSESSMENT AND MITIGATION STRATEGY IN REDUCING PARTICULATE MATTER IN BAREILLY CITY

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ABSTRACT

Bareilly, under the National Clean Air Program, has adopted an end-to-end pavement strategy to significantly reduce particulate matter (PM_{10} and $PM_{2.5}$) levels by 40% by 2024. This paper presents a technically detailed account of the city's efforts, including its emission inventory, road dust mitigation measures, funding strategies, and the tangible improvements in air quality. The success of these interventions provides a scalable model for other cities aiming to tackle air pollution. An ambient air quality study focusing on particulate matter based on the emission inventory was undertaken in Bareilly city, U.P., India during the financial year 2019 to 2024. The air quality data was obtained from 4 monitoring sites across the city. The annual average particulate matter (PM_{10}) concentrations were above 200 μg/m^3 levels during the 2019 which is above the National Ambient Air Quality Standards (NAAQS). The ambient air quality was correlated with the traffic density in the city. The pollution level was observed to be positively correlated with higher road dust and road congestions which is the major source of air pollution in the city. The ambient air quality at different monitoring sites was categorized into different pollution level based on WHO. Light to moderate air pollution conditions were present at different sites. Sampling site of Civil Lines (SVII) observe maximum AQI of 64.48 and 70.81 and falls under category of moderate pollution.

Keywords: Road Dust, Air Pollution, PM10, PM2.5, End-To-End Pavement, NCAP, Bareilly.

I. INTRODUCTION

In the year 2024, Air Pollution has become one of the biggest problems globally, especially in the urban areas of developing countries. While in Indian cities, particularly particulate matter (PM_{10} and $PM_{2.5}$), is a pressing environmental and public health concern. The city of Bareilly, located in Uttar Pradesh, faces significant air quality challenges, largely driven by road dust. As part of the National Clean Air Program, Bareilly embarked on an aggressive strategy to curb its particulate emissions, aiming for a 40% reduction by 2024. This research paper outlines the city's comprehensive strategy, focusing on road dust management through end-to-end pavement projects. The primary objective of this study is to analyze the role of Bareilly's end-to-end pavement strategy in reducing air pollution, specifically focusing on particulate matter (PM_{10} and $PM_{2.5}$) emissions. The study addresses the correlation between road dust re-suspension and air pollution and evaluates the implementation of infrastructure improvements aimed at reducing this source of pollution.

II. METHODOLOGY

The methodology used to study seasonal trend and modeling of air quality of Bareilly district from three air monitoring stations is done as per the guidelines of Central Pollution Control Board of India CPCB.

Three monitoring stations were selected based on traffic frequency.

2.1. Site Description

Bareilly is also known as "Nath Nagri" due to the 7 Shiva temples, situated on the left of Ramganga at an altitude of 252 meters above sea level and 28.343921, 79.411191 state of Uttar Pradesh near the foothills of Himalayan Kumaon Range and Pilibhit Forest Cover. It's the capital of Bareilly division and the geographical region of Rohilkhand. The current estimated population in 2024 of Bareilly is approximately 120000 (as per census 2011 population was 903668). This study was conducted from 2022 to 2024.

2.2. Climatic Condition

Bareilly experiences moderate climatic conditions with an average wind speed of 2.3 m/s and a maximum wind speed of 7 m/s. The ambient temperature averages around 24.5°C, fluctuating between 5.3°C in the cooler months to 40.4°C during the hotter periods. Relative humidity remains high, averaging 69.3%, with values ranging from 20% to 99.8%. Station pressure varies between 988 hPa and 969 hPa, averaging at 1004 hPa. Predominantly, the wind in Bareilly blows from the west-northwest (WNW), accounting for approximately 23.92% of all wind directions.

2.3. Sampling Sites

Air quality data in Bareilly was collected over five years from two Continuous Ambient Air Quality Monitoring Stations (CAAQMS) located at GIC College, Civil Lines, and the UPPCB Office, Rajendra Nagar, along with two manual monitoring stations situated at IVARI, Izzat Nagar, and Prabha Talkies, Civil Lines. Sampling sites across various sectors were selected based on population density and presumed pollution levels, covering industrial, residential, commercial, and roadside areas, as well as background locations. Residential sampling included areas with arterial roads and traffic counts to assess vehicular emissions. Additional data was gathered on PNG and LPG connections from the Supply Office to evaluate fuel usage in residential areas, including slums and connected villages where wood or coal is still used for cooking. Newer colonies with modern houses and ongoing construction reflect Bareilly's urban expansion under the Development Authority, while older colonies are characterized by parks, gardens, and green spaces.

III. EMISSION INVENTORY METHODOLOGY

3.1. Categorization of Sources: Air pollution sources were categorized into area (domestic and fugitive), industrial (point and area), and vehicular (line) sources. Each category's contribution to air quality was evaluated based on emissions.

3.2. Data Collection: Primary data were gathered via domestic surveys, traffic counts, and on-ground observations. Secondary data were obtained from UPPCB, Census of India, CPCB, and other official websites.

3.3. Emission Factor Calculation: The emissions were calculated using the general equation:

$$E = A \times E_f \times \left(1 - \frac{E_r}{100}\right)$$

Where:

- E = Emission rate,
- A = Activity rate,
- Ef = Emission factor,
- Er = Emission reduction efficiency (%).

3.4. Domestic Sector: Emissions were estimated based on fuel consumption patterns and population distribution across 70 wards in Bareilly. Emission density was calculated using the formula:

$$\text{Emission Density } (\text{kg/d/m}^2) = \frac{\text{Emission of Ward (kg/d)}}{\text{Ward Area } (\text{m}^2)}$$

Grid emissions were calculated by determining the fraction of each ward in the grid.

$$\text{Grid Emissions} = \sum_{i=1}^{N} (\text{ area of fraction ward i in grid } \times \text{emission density of ward, i})$$

Where, N = no. of wards in the grid; i = i^{th} ward in the grid

3.5. Brick Kilns: Emissions from eight brick kilns inside Bareilly's city boundary were calculated using CPCB emission factors. Fuels included wood and coal.

3.6. Construction and Demolition: Data from surveys and GIS-based analysis identified construction and demolition sites. Emissions were calculated based on materials used and debris handling.

3.7. Hotels, Restaurants, Guest Houses, and Banquet Halls: Fuel consumption surveys estimated emissions from 365 establishments using LPG and coal. Emissions for pollutants such as PM10, PM2.5, SO2, NOx, and CO were calculated and mapped.

3.8. Municipal Solid Waste Burning: Emission factors from CPCB were used to estimate MSW burning emissions, based on collected data on solid waste generation and burning frequency in different income areas.

3.9. Hospitals: Emissions were estimated from approximately 192 hospitals based on DG set operations and fuel use. The average DG set capacity was 70 KVA, running two hours daily.

3.10. Industries: Emissions were calculated from 88 industrial units using CPCB and USEPA emission factors. These industries were divided into area sources (stack height <15 m) and point sources (stack height >15 m).

3.11. Industrial Diesel Generator Sets (DG Sets): Approximately 400 DG sets in industries were included in the inventory, and emissions were estimated based on operational hours and capacity.

3.12. Parking Lot Survey: Surveys at six locations assessed vehicle technology and fuel use to estimate vehicular emissions using ARAI and CPCB factors.

3.13. Vehicular Line Sources: Traffic data from six locations were used to calculate vehicular emissions across road grids. Road lengths were calculated using ArcGIS.

3.14. Traffic Congestion: Traffic data were analyzed for congestion hotspots, identifying bottleneck points in the city. Congestion levels were color-coded based on traffic flow.

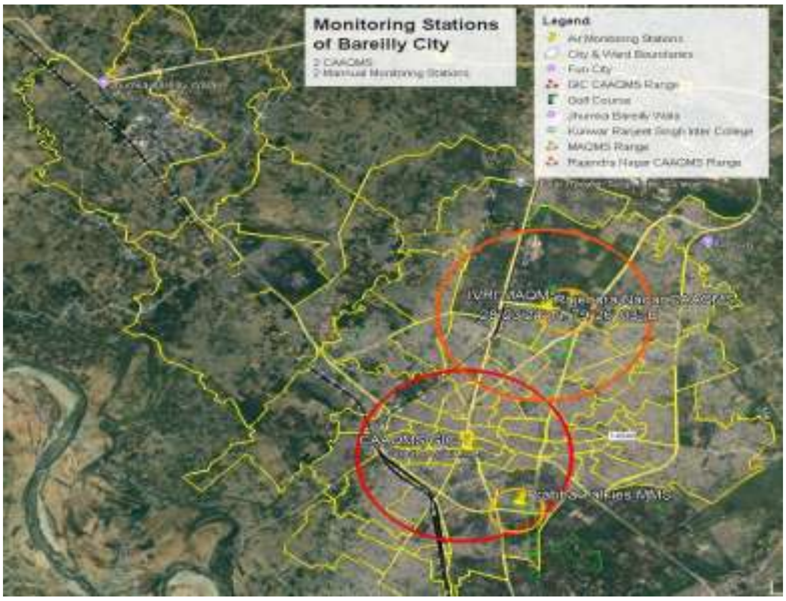
3.15. Paved and Unpaved Road Dust: Road dust emissions were estimated using the formula:

$$E = \frac{\left[k\left(\frac{sL}{2}\right)^{0.65} \times \left(\frac{W}{3}\right)^{1.5} \times VKT\right]}{1000}$$

Where:

- E = Emission from road dust (kg/d),
- VKT = Vehicle kilometer travel,
- sL = Road surface silt loading (g/m^2),
- W = Average vehicle weight (tons),
- k = Constant for particle size.

Silt loading and vehicle weights were measured at seven locations to estimate road dust emissions.



IV. RESULT & DISCUSSION

4.1. Comparison with NCAP Base Year and Yearly PM10 Reduction Targets:

The NCAP identified 2019-20 as the baseline year for air quality assessment, where PM10 levels in Bareilly stood at 185 µg/m^3. The target was set to bring this down to 80.08 µg/m^3 by 2023-24—a reduction of 61%. However, following an initial increase in PM10 levels to 193 µg/m^3 in 2020-21, sustained efforts in subsequent years led to a steady decline, demonstrating the city's commitment to reaching NCAP targets.

4.2. Emission Inventory & Source Apportionment

The emission inventory and source apportionment study conducted by IIT Kanpur played a pivotal role in understanding the sources of air pollution in Bareilly. The study revealed that over 76% of PM_{10} emissions were attributable to road dust. This provided the city with clear evidence to prioritize infrastructure interventions, specifically the paving of unpaved and broken roads.

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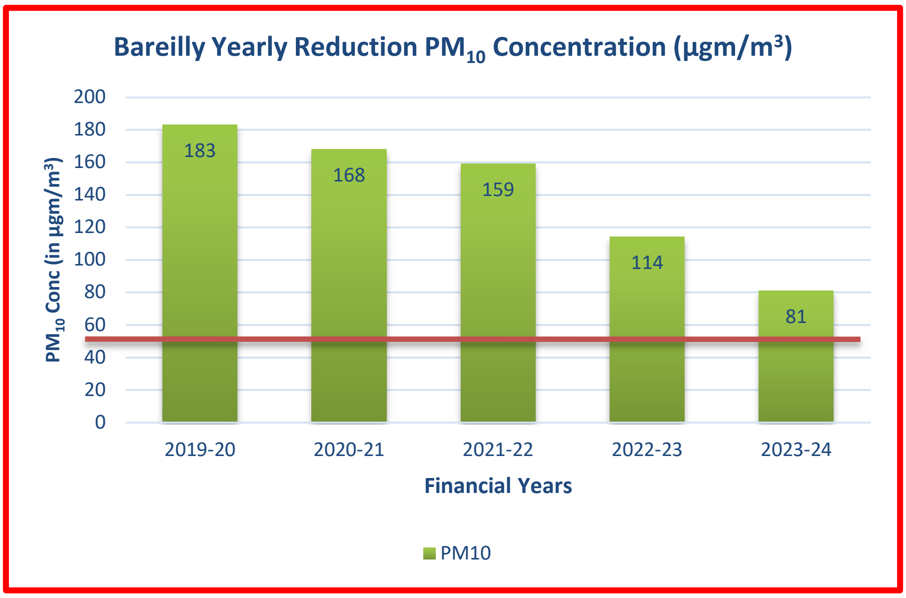

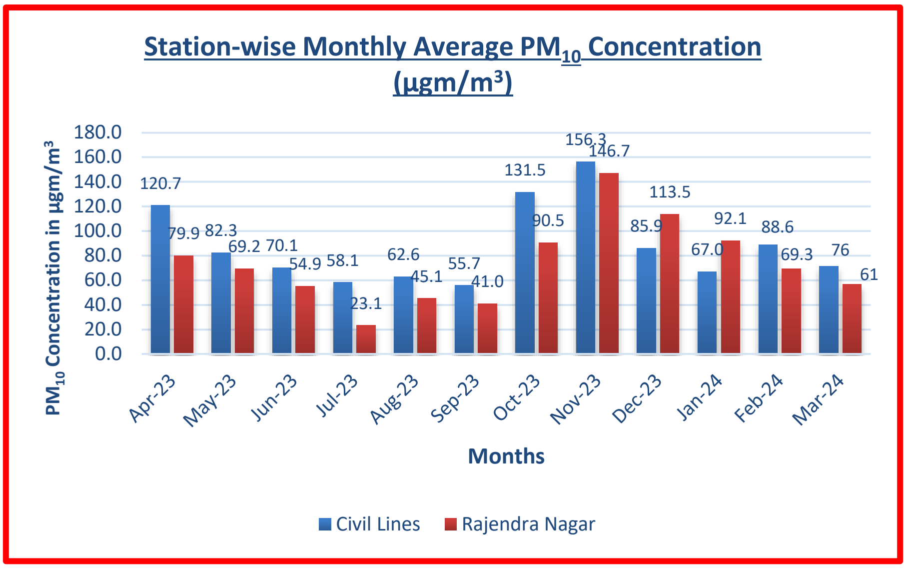

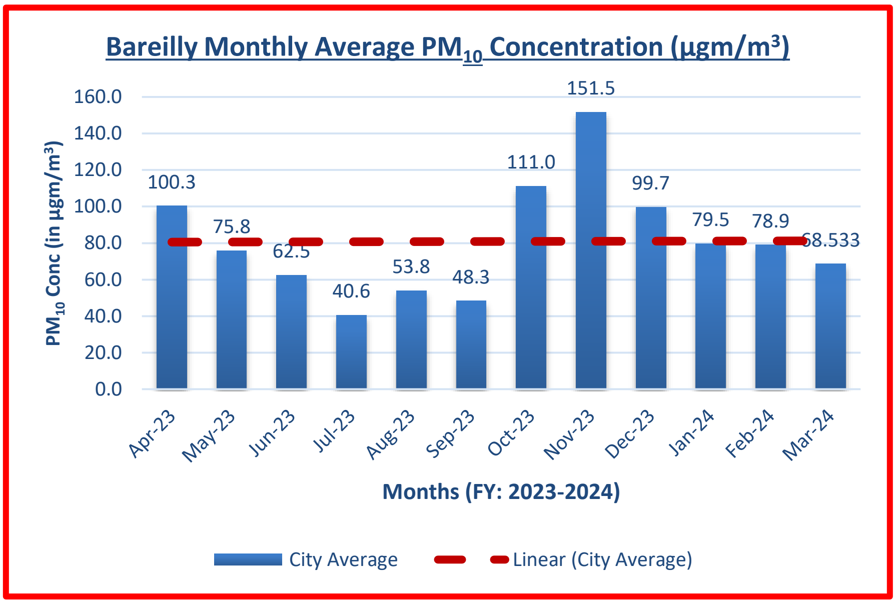

4.3. Spatial Mapping of Major Roads and Congestion Points

Figures depicting the spatial distribution of PM_{10} and $PM_{2.5}$ emissions from road dust revealed that the highest pollution concentrations were along major traffic arteries and congestion points. Key hotspots included:

- Chaupla Chauraha
- Bareilly Jhumka Point
- Izzat Nagar Railway Station
- Pilibhit Bypass
- Bisalpur Chauraha
- Stadium Road near City Hospital

These areas, characterized by high traffic volumes and poorly maintained roads, became the focus of Bareilly's end-to-end pavement strategy.

4.4. Implementation of the End-to-End Pavement Strategy

The core of Bareilly's strategy was the comprehensive paving of roads across the city. Unpaved and damaged roads were repaired and paved, significantly reducing the re-suspension of road dust. In addition, footpaths were created to promote pedestrian movement and non-motorized transport, further curbing dust emissions. The strategy also included the deployment of mechanical road sweepers for regular cleaning of paved roads.

4.5. Utilization of funds for the mitigation

A unique aspect of Bareilly's approach was the effective convergence of funding from various sources, ensuring the efficient use of financial resources. The following table shows the allocation of funds:

Activity	Unit (km)	NCAP (₹Cr.)	XVFC (₹Cr.)	SCM (₹Cr.)
End-to-end paving of roads	65.0	19.8	30.1	57.7
Road repair and maintenance	40.0	-	45.3	-
Creation of footpaths	10.5	-	-	-
Mechanical road sweeping per day	49.0	3.4	-	-
Total	19.8	75.4	57.7	

This allocation allowed for the completion of 65 kilometers of end-to-end paving, 40 kilometers of road repair, and the deployment of mechanical road sweepers, ensuring a comprehensive approach to road dust mitigation.

4.6. Impact on Air Quality

The implementation of the end-to-end pavement strategy resulted in significant improvements in Bareilly's air quality. The PM10 levels dropped from 185 $\mu g/m^3$ in 2019-20 to 80.08 $\mu g/m^3$ in 2023-24. This reduction not only aligned with the NCAP targets but also improved the city's overall Air Quality Index (AQI).

4.7. Secondary Benefits

In addition to improving air quality, the strategy enhanced urban infrastructure and safety. The creation of footpaths provided safe walking spaces for pedestrians and cyclists, promoting non-motorized transport. Moreover, the mechanical sweeping of roads improved the cleanliness and aesthetics of the city, contributing to an improved urban experience.

V. WAY FORWARD

Building on this success, Bareilly plans to expand the pavement coverage to other unpaved roads, continue mechanical road sweeping, and monitor air quality. Future initiatives include a proposed health impact study to assess the long-term health benefits of reduced particulate matter exposure. Furthermore, public engagement and awareness campaigns will play a key role in ensuring the sustainability of these efforts.

Road dust in the city is due to the unpaved roadsides, broken roads, and the construction dust which may be driven by windstorms and the vehicular movements. The city experience high traffic during the evening and morning hours, by both heavy and light motor vehicles.

VI. CONCLUSION

Bareilly's end-to-end pavement strategy provides a successful model for reducing air pollution caused by road dust. By prioritizing infrastructure upgrades and integrating multiple funding sources, the city effectively reduced PM10 levels, improved public health outcomes, and enhanced urban mobility.

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