International Journal of Scientific Engineering and Research (IJSER)
ISSN (Online): 2347-3878
SJIF (2024): 6.623

Comparative Analysis of Aerosol-Driven Air Pollution Across Residential, Industrial, and Traffic Zones in Delhi: A Case Study of May 2025

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Abstract: ***This study presents a comparative analysis of air quality in three contrasting urban zones of Delhi-Anand Vihar (traffic-dense), Mundka (industrial), and Punjabi Bagh (residential)-using $PM_{2.5}$ and PM_{10} data collected during May 2025. The objective is to investigate spatial variations in particulate matter concentrations across different land-use types and understand the implications for public health. Data obtained from CPCB monitoring stations was analyzed to determine daily and monthly averages, identify pollution peaks, and observe trends. Initial findings reveal that Punjabi Bagh recorded the highest $PM_{2.5}$ levels, while Mundka exhibited extreme PM_{10} spikes due to industrial activity. The results highlight the need for targeted air pollution control strategies tailored to each area's environmental dynamics.***

Keywords: urban air quality, PM2.5 and PM10, land use variation, Delhi pollution, public health risk

1. Introduction

Air pollution remains one of the most pressing environmental challenges worldwide, contributing significantly to morbidity, mortality, and climate change. Among the various pollutants, particulate matter (PM), especially $PM_{2.5}$ and PM_{10}, has drawn major concern due to its ability to penetrate deep into the respiratory system and even enter the bloodstream. Prolonged exposure to PM can lead to a range of health complications such as asthma, bronchitis, reduced lung function, cardiovascular issues, and in severe cases, premature death. These pollutants also contribute to atmospheric visibility reduction, alter radiative forcing, and impact local and regional climate patterns.

Delhi, the capital of India, frequently ranks among the most polluted cities globally, with its Air Quality Index (AQI) often reaching hazardous levels. A combination of dense vehicular traffic, ongoing construction activities, industrial emissions, burning of crop residues in nearby states, and meteorological factors such as temperature inversions and low wind speeds contribute to the city's deteriorating air quality [1–3]. The annual mean $PM_{2.5}$ and PM_{10} concentrations in Delhi often exceed the limits prescribed by the World Health Organization (WHO) and India's National Ambient Air Quality Standards (NAAQS), posing a critical threat to the health and well-being of its over 30 million residents.

While many studies have focused on overall pollution levels and seasonal variations in Delhi, there is limited research that specifically dissects the spatial distribution of particulate matter across different urban functional zones. Industrial regions like Mundka are likely to contribute high PM levels due to emissions from manufacturing units and unregulated combustion. Traffic-heavy zones such as Anand Vihar experience pollution spikes during peak hours due to vehicular exhaust, road dust, and idling emissions. Meanwhile, residential areas like Punjabi Bagh may experience relatively lower emissions but remain vulnerable due to atmospheric dispersion and proximity to polluted zones.

Studying aerosol concentrations through a zone-wise lens is crucial because population density, exposure time, and pollution sources differ significantly across residential, industrial, and traffic-centric regions. Additionally, urban zones respond differently to meteorological conditions, which influence pollution retention and dispersion.

This paper attempts a comparative analysis of $PM_{2.5}$ and PM_{10} levels across three representative zones in Delhi-Punjabi Bagh (residential), Mundka (industrial), and Anand Vihar (traffic-dense)-using hourly air quality data sourced from OpenAQ for the month of May 2025. May is chosen due to its typical pre-monsoon meteorological profile, characterized by high temperatures and low humidity, which significantly affect particulate dispersion. The study aims to evaluate daily and monthly pollutant trends, identify pollution peaks, and interpret zone-specific aerosol behavior. The findings are intended to inform targeted air quality management and mitigation strategies tailored to the environmental dynamics of each zone.

2. Literature Review

Air pollution, particularly from fine particulate matter such as $PM_{2.5}$ and PM_{10}, has been extensively studied due to its adverse effects on human health and the environment. Numerous epidemiological and atmospheric studies have linked long-term exposure to elevated PM levels with respiratory and cardiovascular diseases, premature mortality, and reduced life expectancy [4, 5]. The World Health Organization (WHO) has consistently emphasized the need for countries to monitor and control particulate pollution to reduce its health burden [6].

Several studies have analyzed the temporal trends and seasonal variability of air pollutants in Delhi. Guttikunda and Gurjar (2012) examined the city's emission sources and found that transport, industry, and open waste burning were the major contributors to ambient PM levels [7]. Similarly, Sharma and Dikshit (2016) investigated the seasonal variation of PM concentrations and identified post-monsoon and winter as the most polluted periods due to temperature inversion and stagnant atmospheric conditions [8]. However, fewer studies have focused specifically on the pre-monsoon summer months, such as May, where high temperatures and wind patterns also influence pollutant dispersion.

Research by Tiwari et al. (2015) emphasized the significance of spatial variability in PM concentrations across Delhi, highlighting the need to disaggregate pollution data by land use and population exposure [9]. Their work suggested that traffic intersections and industrial belts are consistent pollution hotspots. Moreover, Srivastava et al. (2018) performed a source apportionment study and confirmed that resuspended road dust and vehicular emissions dominate PM_{10} in traffic-dense areas, while industrial combustion activities largely contribute to $PM_{2.5}$ in industrial zones [10].

Despite these insights, the majority of existing literature treats Delhi as a homogenous pollution zone, overlooking the stark differences in pollutant concentrations across distinct urban regions. This approach limits the development of targeted interventions. More recent studies have begun to explore the utility of low-cost sensor networks and open-source data platforms such as OpenAQ and AQICN for localized air quality monitoring [11]. These tools provide high-resolution temporal and spatial data, facilitating a more granular analysis of pollution dynamics.

In light of the above, the present study contributes to the literature by using open-source data to conduct a zone-wise comparative analysis of $PM_{2.5}$ and PM_{10} concentrations in Delhi. By focusing on three functionally distinct regions-Punjabi Bagh (residential), Mundka (industrial), and Anand Vihar (traffic-centric)-during the pre-monsoon month of May 2025, this research aims to uncover spatial differences in aerosol behavior and identify patterns that can guide localized pollution control policies.

3. Methodology

3.1 Study Area

The study focuses on three urban zones in Delhi selected based on their dominant land-use characteristics:

- **Punjabi Bagh (Residential Zone):** A densely populated with residential houses and commercial establishments. more ever, this site has heavy vehicular traffic, fueled by gasoline, diesel and compressed natural gas (CNG) and relatively low industrial interference. It serves as a representative of daily human exposure to ambient urban pollution in residential settings.
- **Mundka (Industrial Zone):** This site is an industrial-cum-residential area. Most of the industries in Delhi, mainly ready-made and leather garment factories, pharmaceutical manufacturing units, plastic and packing industries, printing presses, machinery manufacturers and others are located in this area.
- **Anand Vihar (Traffic-Dense Zone):** A major bus terminal and transit hub that experiences high vehicular emissions throughout the day. This zone represents pollution caused by transportation and traffic congestion.

3.2 Data Source

Air quality data was retrieved from the OpenAQ platform, which consolidates open-source, real-time pollution data from Central Pollution Control Board (CPCB) monitoring stations. The parameters used in this study are:

- $PM_{2.5}$ (Particulate Matter ≤ 2.5 microns)
- PM_{10} (Particulate Matter ≤ 10 microns)

The data spans the entire month of May 2025, a period marked by dry, dusty summer conditions typical of Delhi, which can significantly influence particulate matter levels.

3.3 Data Collection and Preprocessing

The raw data consisted of timestamped records for $PM_{2.5}$ and PM_{10} concentrations recorded every 15 minutes. The data was downloaded in CSV format for each location separately. Preprocessing included:

- Filtering relevant columns (pollutant, date-time, and values).
- Identifying and removing missing, duplicate, or erroneous entries.
- Averaging 15-minute values into hourly means (if needed) using Excel formulas.
- Aggregating hourly values into daily and monthly averages.

3.4 Data Analysis

Following data preprocessing, statistical and comparative analyses were performed. The steps included:

- Calculating daily average concentrations of $PM_{2.5}$ and PM_{10} for each site.
- Computing monthly averages and identifying peak pollution days.
- Comparing pollutant trends across zones using tables and graphs.
- Analyzing potential correlations with land-use types and local human activities.

3.5 Additional Parameters Considered

In addition to particulate matter ($PM_{2.5}$ and PM_{10}), the study also takes into account basic meteorological parameters-namely **temperature** and **relative humidity**-which were available from the OpenAQ datasets and CPCB sources for the same monitoring stations.

These parameters were included to provide contextual understanding of pollution variation, as both temperature and humidity influence the concentration, dispersion, and settling of aerosols in the atmosphere. For example:

- High temperatures can promote photochemical reactions and resuspension of dust particles.
- Increased humidity can cause hygroscopic growth of fine particulates, impacting their mass concentration and respiratory effects.

Although these parameters were not subjected to detailed statistical modeling, their daily averages were observed and qualitatively correlated with fluctuations in PM concentrations to enhance interpretation of trends.

3.6 Tools Used

All data analysis and visualization was carried out using Microsoft Excel. Charts such as line graphs and bar graphs were used to represent temporal and spatial trends in pollutant concentrations. LaTeX was used for writing and formatting this research paper.

3.7 Limitations

- The study is based on a single month of data, which may not represent long-term seasonal variations.
- Only two pollutant parameters (PM2.5 and PM10) were considered due to the scope of the project.
- The analysis was conducted manually in Excel, limiting the complexity and automation of statistical computations.
- Although temperature and humidity were included in a qualitative manner, detailed modeling of their effects was not conducted due to data and scope limitations

Despite these limitations, the methodology provides a reliable snapshot of aerosol pollution differences across Delhi's diverse land-use zones.

4. Results and Discussion

4.1 Spatio-Temporal Variation of $PM_{2.5}$ and PM_{10}

The analysis of $PM_{2.5}$ and PM_{10} concentrations for May 2025 revealed distinct spatio-temporal patterns across the three selected zones-Anand Vihar (traffic-centric), Punjabi Bagh (residential), and Mundka (industrial).

All three locations experienced elevated pollution levels during the period of May 13–16, indicating a city-wide pollution episode likely driven by stagnant meteorological conditions.

Punjabi Bagh, despite its residential nature, recorded significant spikes in $PM_{2.5}$, suggesting possible transboundary pollution or localized emissions such as construction or garbage burning.

Mundka, characterized by industrial activity, exhibited elevated and sustained levels of PM_{10}, reflecting consistent emissions from manufacturing activities, dust resuspension, and a lack of pollution control infrastructure. $PM_{2.5}$ levels in this zone were also consistently high.

Anand Vihar, a high-traffic region, showed pronounced levels of both $PM_{2.5}$ and PM_{10}, especially during periods of peak vehicular movement. These values corresponded closely with traffic density and likely reflect a mix of exhaust emissions and road dust.

These observations indicate that pollution dynamics are not solely dependent on land-use categorization. For instance, the unusually high $PM_{2.5}$ spikes in a residential area like Punjabi Bagh point toward atmospheric stagnation or cross-zone transport of pollutants.

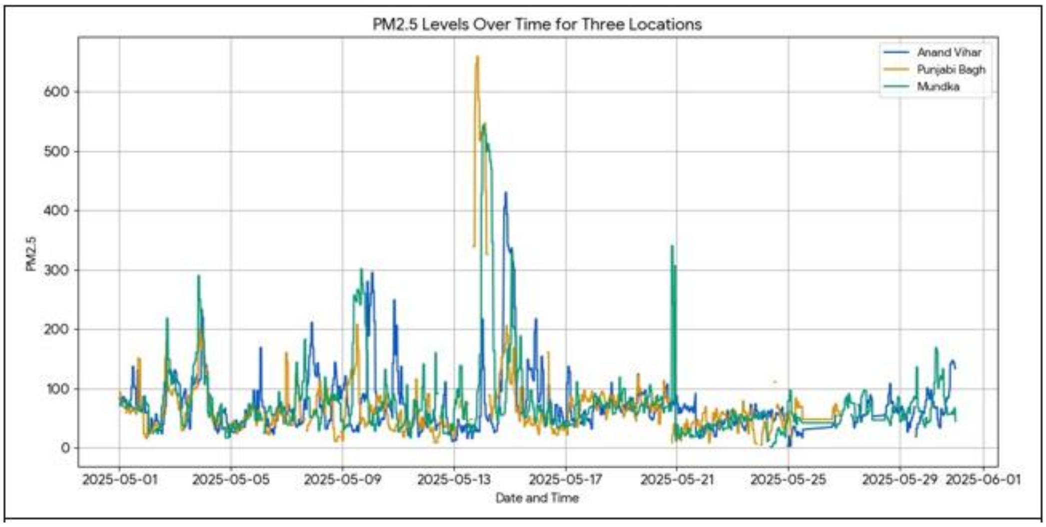

Figure 1: Temporal variation of $PM_{2.5}$ across Anand Vihar, Punjabi Bagh, and Mundka

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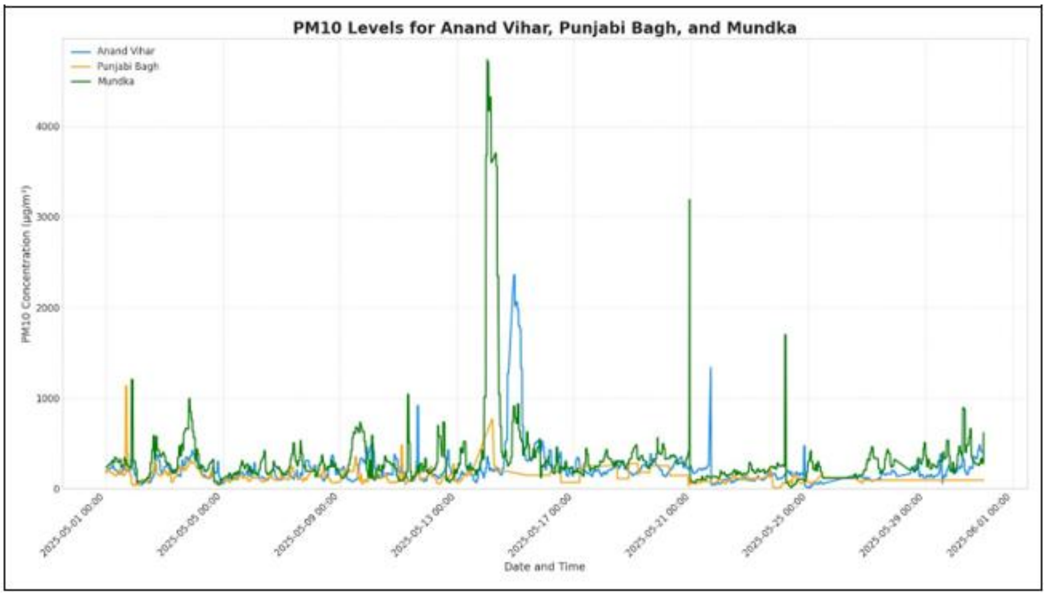

Figure 2: Temporal variation of PM_{10} across Anand Vihar, Punjabi Bagh, and Mundka

4.2 Temperature and Relative Humidity Influence

Meteorological conditions such as ambient temperature and relative humidity significantly influenced the aerosol behavior during the study period. The temperature exhibited a steady rise up to mid-May, coinciding with pollution peaks. Relative humidity showed moderate to low values, especially during the most polluted days.

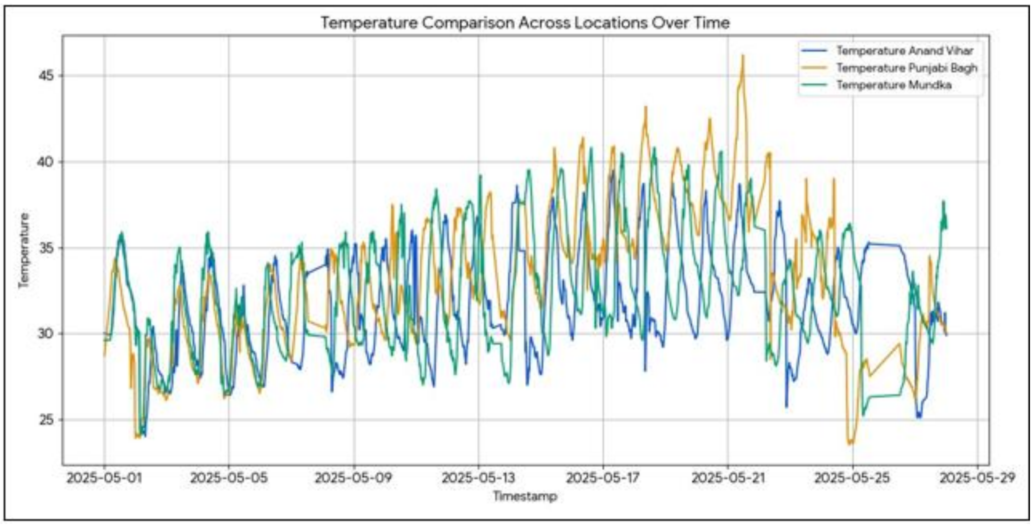

Figure 3: Temperature variation across Anand Vihar, Punjabi Bagh, and Mundka

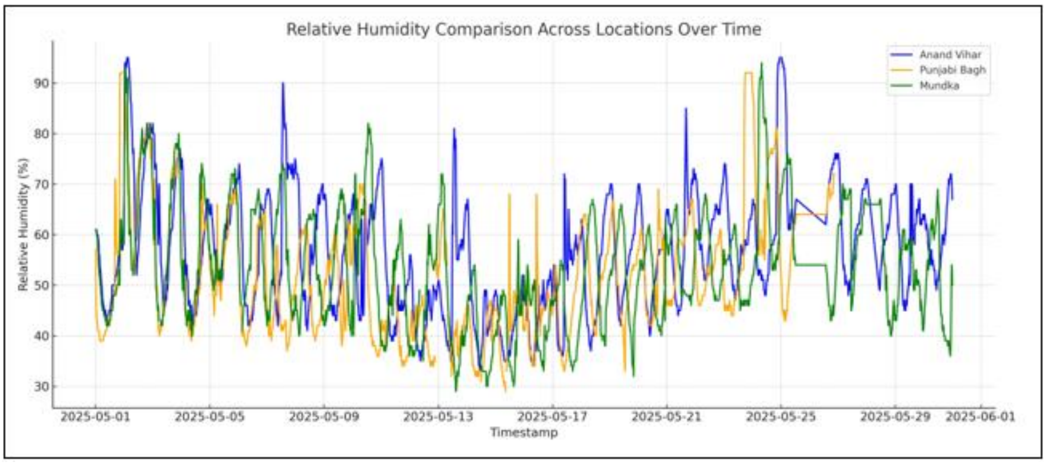

Figure 4: Relative humidity variation across Anand Vihar, Punjabi Bagh, and Mundka

These conditions likely contributed to pollutant build-up and atmospheric stagnation. Notably, lower humidity limited particulate deposition, allowing pollutants to remain suspended for longer durations.

5. Conclusion

This study examined aerosol-driven air pollution across three distinct zones of Delhi-Anand Vihar (traffic-dense), Mundka (industrial), and Punjabi Bagh (residential)-during the month of May 2025. Using $PM_{2.5}$ and PM_{10} data from open-source monitoring platforms, the research aimed to understand spatial differences in pollutant concentrations and their relationship to land-use patterns and meteorological conditions.

Among all three locations, **Punjabi Bagh** recorded the highest $PM_{2.5}$ concentration, reaching a peak of **659 µg/m^3**. This unusually high value in a residential zone highlights the possible impact of transboundary pollution, stagnant air conditions, or localized emissions such as construction and waste burning.

Mundka, representing the industrial zone, showed the highest PM_{10} levels, with a peak concentration of **4733 µg/m^3**, consistent with ongoing emissions from industrial activities, dust resuspension, and poor environmental regulation.

Anand Vihar, known for intense vehicular movement, showed substantial pollution levels as well, peaking at **430 µg/m^3** for $PM_{2.5}$ and **2356 µg/m^3** for PM_{10}, highlighting the compounded effects of traffic congestion and road dust.

These pollution spikes occurred during a period of high temperature and low relative humidity, particularly between May 13–16, indicating that meteorological conditions played a crucial role in exacerbating pollutant concentration and retention.

The findings emphasize the necessity for:
- Targeted emission control strategies in industrial zones like Mundka,
- Traffic decongestion and dust suppression in corridors like Anand Vihar,
- Air quality monitoring and early warnings in residential zones such as Punjabi Bagh,
- Integration of meteorological data into pollution forecasting and response planning.

In conclusion, effective air quality management in Delhi must consider not only the type of land use but also meteorological variables that govern aerosol dispersion and accumulation across different urban landscapes.

Acknowledgements
I sincerely thank my HOD, **Prof. Ravi Kant Chaubey**, for their constant guidance and support throughout this research. Their insights and encouragement were instrumental in completing this work.

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