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High-Resolution Dispersion Modeling and Validation of Urban Air Quality: An Integrated AERMOD and GIS Approach

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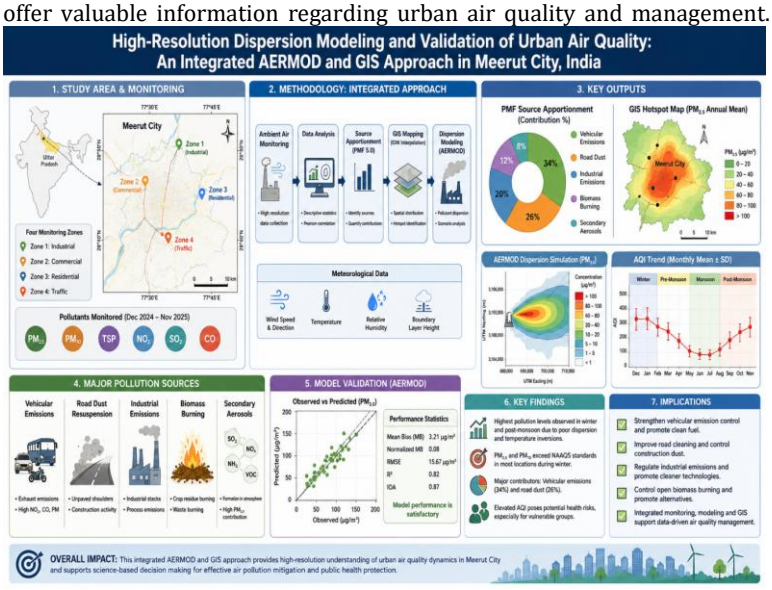
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ABSTRACT

Urban air pollution is a major concern both from environmental and public health perspectives, especially for fast-expanding cities situated on the Indo-Gangetic Plain region. The objective of this study is to examine the effect of particulate matter ($PM_{2.5}$, PM_{10} and TSP). This research work will address the spatial and temporal variability of particulate pollutants (TSP, $PM_{2.5}$ and PM_{10}) and gaseous air pollutants (NO_2, SO_2 and CO) in major industrial and trafficked areas in Meerut City, India. Air quality data will be acquired from four major zones in the city over one year (December 2024 to November 2025), which will include analysis of pollutant concentration; Pearson correlation analysis; source apportionment of air pollution by positive matrix factorization (PMF); Geographical Information System (GIS) analysis to identify seasonal pollutants and PMF components versus latitude/longitude; analysis of annual trends in Air Quality Index (AQI) and its month wise variations (mean ± SD); and air pollutant dispersion modeling by AERMOD. These high levels of pollutants are mainly caused by vehicle exhaust and road dust. The winter season and monsoon period are the two peak periods for pollutants owing to temperature inversions and poor atmospheric mixing. Validating the Model: The AERMOD model appears to be accurate based on the results of mean bias (MB) and root mean square error (RMSE). Conclusion: The interdisciplinary analysis will offer valuable information regarding urban air quality and management.



Keywords: Air Quality Index (AQI), $PM_{2.5}$, PM_{10}, Source Apportionment, AERMOD, GIS Mapping, Urban Pollution, Health Risk Assessment.

1. Introduction

Increasing air pollution caused by rapid urbanisation and industrial development of Indian cities has become one of the prime environmental issues affecting public health in both developing and developed economies. Over the last decades, energy demand and the build-up of transport infrastructure have drastically increased as a consequence of rapid urban growth, population rise and the development of economic activities that, in turn, have resulted in higher emissions from vehicles or other sources. Cities in the Indo-Gangetic Plain, especially those in Uttar Pradesh, are particularly vulnerable to poor air quality due to the combination of meteorological circumstances and anthropogenic pollutants. Carbon monoxide (CO), nitrogen dioxide (NO_2), sulphur dioxide (SO_2), coarse particles (PM_1), and small particulate matter (PM_2). The pollutants come from mobile sources by means of vehicle fuel combustion, industrial activities, Construction activity for foundations and buildings, re-suspension of road dust particulates, and open biomass burning. Numerous health effects, such as respiratory and cardiovascular illness, lung function impairment, and an elevated risk of early death, are linked to these pollutants. Prolonged exposure to $PM_{2.5}$ is associated with severe health impacts because these particles can penetrate deep into the lungs and enter the bloodstream *(Balakrishna et al., 2019; WHO 2023)*

Famed Meerut City has been blessed as a historically important urban locale of Uttar Pradesh, which has now become part of the major industrial and urban corridor of the National Capital Region (NCR). This is also one of the reasons that pollution levels are rising due to its proximity to Delhi and continuous industrial development. Pollution in Meerut is the result of local emissions and naturally dispersed pollutants/ contaminants carried over from surrounding regions. NO_2 and CO are mainly released from heavy vehicular traffic, especially in commercial and transport corridors, while many other contaminants can only be expected to come from the nearby industry. The PM_{10} levels are particularly high because of dust being raised by construction sites and badly maintained roads. It is worsened by seasonal conditions; in winter, temperature inversions and light winds hold and trap pollutants close to the surface, producing a thick layer of smog. Crop residue burning and biomass burning in surrounding areas also lead to periodic increases in particulate matter concentrations ***(****Guttikunda & Nishadh, 2023; Singh & Tiwari, 2025)*

Due to the highly heterogeneous and multi-source nature of urban air pollution in cities like Meerut, an integrated approach along with some theoretical framework for assessing standardized Air quality becomes paramount. This study investigates the spatial and temporal variation of three important air pollutants, identifies matching pollution sources, and finally assesses health risks associated with them. A mix of Analytical techniques is used. Field monitoring gives us high-resolution pollutant concentration data at various locations, while statistical correlation analysis develops relationships among pollutants and possible common sources. We use positive matrix factorisation (PMF) to perform source apportionment based on contributions from vehicular emissions, industrial activities and biomass burning. GIS tools for mapping pollution hotspots and visualising spatial distribution patterns. About the MB TAC — AVERAGE Daily Value of Surrounding. Every day, the Air Quality Index (AQI) framework offers a simple way to measure general air quality through an index that translates … it is based on various definitions, and you can use this… Furthermore, an AERMOD dispersion

model is provided to predict the transportation and dispersion of pollutants under different meteorological conditions. Together, these approaches elucidate air pollution dynamics in Meerut, which will help design better mitigation strategies for air quality improvement and public health *(Central Pollution Control Board, 2024)*

2. Materials and Methods

2.1 Study Area and Monitoring Sites

Four representative sites were selected:

Location	Type	Characteristics
Delhi Road	Traffic	High vehicular congestion
Begum Bridge	Commercial	Mixed commercial activities
Partapur	Industrial	Industrial emissions
Shastri Nagar	Residential	Low emission intensity

2.2 Pollutants and Data Collection

The following pollutants were monitored:

- $PM_{2.5}$ and PM_{10}
- NO_2 and SO_2
- CO

Meteorological parameters (temperature, wind speed, humidity) were also recorded.

2.3 Methods for Measurement of AQI

Conventional pollutant concentration data of Meerut City were collected, and the Air Quality Index (AQI) for each land-use category and the overall city was estimated based on these data as per the respective Central Pollution Control Board guidelines. Four major land-use category pollutant concentrations were calculated from air pollution monitoring stations located at traffic, commercial, industrial, and residential zones of this area. Each of these zones has very different emission properties from emission sources in other regions that affect local air quality differently. Places with heavy traffic, for example, highways and significant intersections, will in general have significantly more nitrogen dioxide (NO_2), carbon monoxide (CO) and particulate matter as a result of the enormous upheaval of vehicles and fuel burning. Past studies have viewed vehicular emissions as one of the major sources of NO_2 and PM_2. Pollution in India: Major pollutants PM_{10} $PM_{2.5}$ urban environments *(Kumar et al., 2024; Pant & Harrison, 2013)* Along with small businesses and local transport, in commercial places where too many humans are active moderately pollutions is happened due to vehicle emissions from the vehicles as well as diesel generators and burning some wastes on time. Most of the nitrogen dioxide and particulate matter pollution comes as a result of fuel burning and industrial activities. We pollute our environment with toxic substances during

production. Industrial activities significantly contribute to urban air pollution through emissions of particulate matter and gaseous pollutants *(Sharma & Dikshit, 2023)*

Pollution in housing areas is caused mostly by automobiles, combustion of fuels at home, construction work, among others. Pollution in residential areas is quite low compared to that in urban centres. The levels of pollution in such areas depend on weather conditions and season. Meteorological conditions and seasonal variations strongly influence pollution levels in residential areas *(Singh & Tiwari, 2025; World Health Organisation, 2023).* Air Quality Index (AQI) involves assessing pollution in all regions. AQI offers an excellent assessment tool for determining the quality of air in residential areas and identifying the most polluted regions.

2.3.1 Pollutant Sampling and Measurement Techniques

(A) Sampling Methodology

Sampling of air pollutants has been done using the method prescribed by the Central Pollution Control Board (CPCB).

1. Particulate Matter ($PM_{2.5}$ and PM_{10})

The particulate matter samples have been collected through RDS (Respirable Dust Sampler) for PM_{10} and Fine Particulate Sampler for $PM_{2.5}$.

- **Sampling Tool:** Respirable Dust Sampler (RDS) with Size Selective Inlet
- **Sampling Duration:** 24 hours continuous sampling
- **Number of Samples:** Twice weekly at all sample sites
- **Air Flow Rate:** 1.0 to 1.2m^3/minute (for PM_{10}), according to recommendation of CPCB
- Filter Papers:
- GF/A Filter Paper from Whatman for PM_{10}
- PTFE Filter Paper for $PM_{2.5}$
- **Principle:** Air samples are passed through a previously weighed filter to collect particulate matter. Mass concentration is measured gravimetrically using the change in weight of the filter before and after sampling.

2. Gaseous Pollutants (NO_2, SO_2, CO)

The gases were tested using continuous ambient air quality monitoring systems.

- **Periodicity of Sampling:** Continuous, hourly average
- **Sampling Methodology:** Active, by inlets of analysers
- **Resolution of Data:** Conversion of hourly data to daily averages

B. Pollutant Measurement Techniques

Pollutant	Method Used	Principle
$PM_{2.5}$ / PM_{10}	Gravimetric / Beta Attenuation	Mass concentration based on filter weight difference
NO_2	Chemiluminescence	Light emission from reaction with ozone
SO_2	UV Fluorescence	Fluorescence under UV radiation
CO	Non-Dispersive Infrared (NDIR)	Infrared absorption by CO molecules

2.3.2 AQI Calculation

The AQI sub-index for each pollutant was computed using:

$$I_p = \frac{(I_{HI} - I_{LO})}{(BP_{HI} - BP_{LO})} \times (C_p - BP_{LO}) + I_{LO}$$

The overall AQI is determined as:

$$AQI = \max(I_1, I_2, I_3, ..., I_n)$$

2.4 Source Apportionment (PMF)

To determine the main sources of pollution, Positive Matrix Factorisation (PMF 5.0) was employed:

Vehicular Emissions

Vehicle emissions pose a threat to urban areas experiencing rapid growth. Approx 16.9% of India's total energy consumption, or 36.5 million tons of oil, comes from the transportation sector *(Ramachandra & Shwetmala, 2009).* Using gasoline and diesel in our vehicles results in the formation of pollutants such as NO_2, CO, hydrocarbons and PM_2 in the atmosphere. This deteriorates the air quality. It poses serious health concerns. Prolonged exposure to vehicular emissions can lead to the risk of respiratory diseases and cardiovascular diseases such as shortness of breath, coughing and pain during inhalation *(Dockery & Pope, 1994)* The older vehicles, maintenance problems, limited road space and unplanned traffic restricts normal vehicular movement thus, congestion increase the problem further *(Wijetilleke & Karunaratne, 1995)* As urban areas experience more usage of private vehicles, this issue is exacerbated. As congestion increases in the area, this is due to the poor air being trapped there since it remains stagnant, especially during periods when the wind is not blowing.

Road Dust

Road dust is one of the major sources of coarse particulate matter (PM_{10}) pollution in cities. According to a report by the Central Pollution Control Board (CPCB), road dust accounts for the majority of PM_{10} emissions in Indian cities, accounting for 45% of total emissions *(Khan et al., 2023),* which is released from the roads through resuspension of dust. A study based on source apportionment receptor modelling conducted in India using filter sampling data found that road dust and vehicle emissions are the major contributors towards PM_{10} and $PM_{2.5}$, respectively *(Wang et al., 2024).* Other sources

include construction dust, dusty soils, and poor street cleansing services. In the absence of rain, winds and vehicular movements help in distributing these dust particles and cause high levels of pollution. Road dust is an important but often neglected source of air pollution in cities *(Guttikunda & Jawahar, 2012)*

Industrial Emissions

Different types of air pollutants are released from industrial operations, depending upon the process involved. In Indian context, industrial emissions significantly contribute to the atmospheric concentrations of sulfur dioxide, nitrogen oxides, and particulate matter *(Behera et al., 2011)* Moreover, Small-scale decentralized commercial activities and peri-urban industrial clusters including brick kilns, metal industries, and chemical industries often comprise a poorly measured but highly consequential source of atmospheric criteria pollutants *(Mohan et al., 2007)* The air quality in the Ganga Basin, which includes metropolitan cities like Meerut, is significantly impacted by Industrialisation and anthropogenic activities *(Sahu et al., 2011)* In addition to this, the employment of sub-standard fuels and absence of appropriate technologies for reducing pollutants lead to increased levels of pollution. It is noteworthy that Industrial complexes located near residential areas have adversely affected ambient air quality *(Paatero & Tapper, 1994)*

Biomass Burning

Biomass burning contributes significantly to particulate pollution and associated health risks *(Guttikunda & Jawahar, 2012; World Health Organisation, 2023).* The process involves the emission of considerable amounts of $PM_{2.5}$, PM_{10}, carbon monoxide (CO), and other harmful pollutants in the atmosphere. Regional biomass burning is the main cause of particulate pollution *(Awasthi et al., 2024).* There is a marked increase in pollution levels during agricultural burning that occurs seasonally in winter. Apart from affecting visibility, it adversely affects human health, causing respiratory and heart-related ailments.

Secondary Aerosols

Secondary aerosols are produced in the atmosphere through chemical interactions between primary aerosols like SO_2, NO_x, and NH_3. Such chemical interactions lead to the production of fine particles, accounting for a significant mass of $PM_{2.5}$ (about 50%) *(Behera & Sharma, 2010)*, capable of travelling for considerable distances. Secondary aerosols are formed through atmospheric chemical reactions involving precursor gases and contribute substantially to $PM_{2.5}$ concentrations *(Pant & Harrison, 2013; Seinfeld & Pandis, 2016)* moreover, the contribution of secondary pollutants indicates that, without a thorough understanding of the connections between emissions and the formation of secondary pollutants, shutting industries or reducing vehicle emissions may not be sufficient to attain clean air in the long run *(Tripathi et al., 2023)*

2.5 GIS Mapping

The spatial distribution of air pollution in Meerut was done through GIS-based methodology. Spatial mapping and interpolation were conducted through ArcGIS 10.8 software. The Inverse Distance Weighting method was used to derive a smooth spatial surface for air pollutants using the discrete monitoring data. This technique assumes that pollution levels at neighbouring locations are more

similar compared to locations farther away from each other. Consequently, accurate spatial mapping of pollution can be achieved through such a method. The IDW interpolation technique is commonly used for predicting air pollution levels in GIS-based studies *(Burrough & McDonnell, 1998; Kumar et al., 2024).* All spatial data were georeferenced in the WGS 84 coordinate system. The coordinates of all monitoring stations were obtained via GPS devices and input into a GIS analysis tool. The IDW interpolation was done by setting a power value of two and varying search radii for optimal pollutant distribution mapping.

Regarding particulate matter (PM_{10}), the IDW mapping suggests that high concentrations are confined to locations dominated by roads and industrial activity. Road intersections, transport links, and industrial locations become important pollution centres because of emissions from vehicles, re-suspended road dust, and construction. Such centres are usually characterised by higher values in the mapping, whereas low values prevail in residential and outer locations. Such variations clearly reflect the considerable effect of local anthropogenic activities and land use on the distribution of PM_{10} concentration. This has been noted in many research studies carried out for urban centres of the Indo-Gangetic Plain, wherein road dust and industrial pollutants constitute the main sources of particulate pollution *(Burrough & McDonnell, 1998)*

In this context, NO_2, a common air pollutant, shows a very distinct distribution pattern, which is highly dependent on motor vehicle pollution. The presence of high amounts of NO_2 is observed in areas near main roads and commercial areas where there is heavy traffic density. In proportion to the increased distance from such high-density traffic locations, the amount of pollutants decreases significantly. The contribution of industrial areas to NO_2 is less compared to motor vehicles. This scenario is consistent with earlier research findings that indicate that the level of NO_2 and traffic density have a significant relationship *(Pant & Harrison, 2013; Singh & Tiwari, 2025)*

In general, the GIS-based analysis of the spatial distribution indicates unique patterns of particulate matter and gas emissions, allowing the detection of vital areas of pollution. Spatial analysis is crucial for urban planning and policymakers who can devise appropriate plans for controlling the air pollution problem *(Cimorelli et al., 2005; Jain & Sharma, 2024)*

2.6 AERMOD Dispersion Modeling

This model was used in the current study for the purpose of predicting the dispersion of air pollutants in Meerut city. This model, referred to as the AERMOD dispersion model, is a steady-state Gaussian model designed by the United States Environmental Protection Agency. In India, AERMOD has recently been added to the list of recommended models for regulatory applications *(Mohan et al., 2011)*. The model takes into consideration emission data, meteorological data, and terrain data in order to predict the dispersion of pollutants at the receptors. This model utilises boundary layer theory to take into account the variables that influence dispersion, such as atmospheric stability, mixing height, wind speed, and turbulence *(Cimorelli et al., 2005; United States Environmental Protection Agency, 2023)*

In this study, AERMOD modeling was performed by taking into account an extensive emission inventory consisting of sources that generate pollutants such as motor vehicle emissions, industrial

emissions, construction activity emissions, and biomass burning. Different emission rates were considered depending on the severity and type of the respective source to make the simulation more realistic. Wind velocity, wind direction, temperature, and atmospheric stability classes were considered as meteorological parameters to account for any changes due to time and seasonality in the dispersion characteristics. While Meerut is characterised by flat terrain, some variations in terrain were considered in the model to increase accuracy, since topography affects the movement and deposition of pollutants. For an enhanced understanding of pollution dynamics, several simulations were performed. One was the simulation for high emissions, where traffic emissions and emissions from industries reached their peak. This was associated with higher levels of pollutants found in central urban locations and in road networks. Another simulation was that of winter conditions, which were associated with lower wind speed and temperature inversion, leading to poor dispersion, with higher pollutant build-up, reflecting poor air quality. The third was the monsoon season or high wind conditions, leading to efficient dispersion and lower pollutant concentrations. AERMOD (Dispersion modeling) efficiently captures extreme seasonal fluctuations in megacities, revealing how cold temperatures and low wind speeds significantly raise ground-level particulate matter concentrations *(Dey et al., 2017)*. The accuracy of model prediction was tested by comparing predicted concentration values against actual observations through various statistics, including MB and RMSE values. The smaller the value of the above-mentioned statistics, the better the agreement between observations and the results, indicating that the boundary layer mechanism that influences the dispersion of contaminants is better displayed in the AERMOD model *(Kumar & Mishra, 2021)*. On the whole, it can be said that the AERMOD model is a sound approach to pollutant dispersion studies.

3. Results and Discussion

3.1 Pollutant Concentrations and Correlation Analysis

Table 1: Annual Mean Pollutant Concentrations (Dec 2024–Nov 2025)

Location	$PM_{2.5}$	PM_{10}	NO_2	SO_2	CO
Delhi Road	85	173	43	13	1.64
Begum Bridge	79	162	39	11	1.50
Partapur	93	188	47	17	1.78
Shastri Nagar	69	148	32	9	1.18

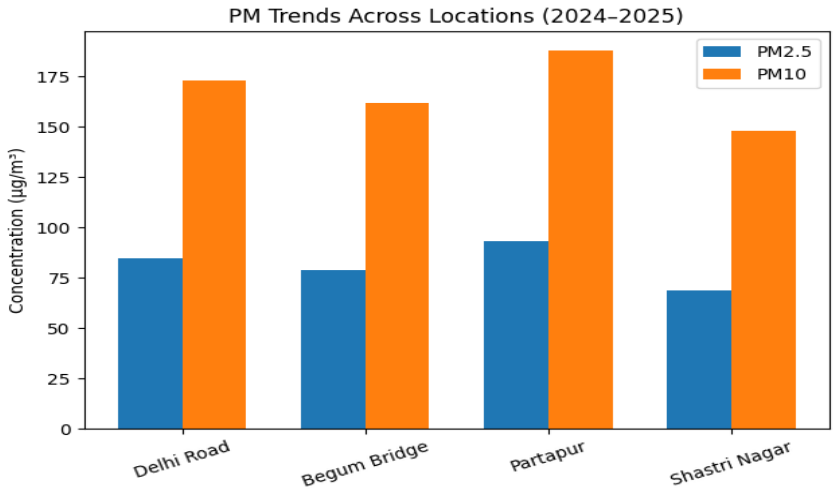


Figure-1: Spatial Variation of $PM_{2.5}$ and PM_{10} Concentrations Across Selected Monitoring Sites in Meerut (2024–2025).

Based on the annual average pollutant values shown in Table 1 and Figure 1 below, there is notable spatial variability in air quality across Meerut. As observed in the table above, Partapur (industrial zone) records high values for all pollutants, including $PM_{2.5}$ (93 µg/m³), PM_{10} (188 µg/m³), NO_2 (47 µg/m³), SO_2 (17 µg/m³), and CO (1.78 mg/m³). Delhi Road (highly trafficked zone) is the second most polluted in terms of particulate matter and NO_2, due to significant traffic pollution. Begum Bridge (commercial zone) is moderately polluted owing to mixed pollution sources, including traffic pollution. On the other hand, Shastri Nagar (residential zone) is the least polluted of all zones in terms of pollutant concentrations. It is worth noting that values of $PM_{2.5}$ and PM_{10} values are higher than the permissible limits at all locations; the ($PM_{2.5}$/PM_{10}) ratio is important for determining the origin of particulate matter. A greater ($PM_{2.5}$/PM_{10}) ratio indicates that fine particles are mostly released by human activities *(Fatima et al., 2022),* thus posing a significant environmental problem. Also, concentrations of NO_2 are relatively high in highly trafficked and industrial zones.

Table 2: Winter Season Pearson Correlation Matrix (Partial)

Variable	$PM_{2.5}$	PM_{10}	NO_2	CO
$PM_{2.5}$	1.00	0.86	0.79	0.75
PM_{10}	0.86	1.00	0.72	0.69
NO_2	0.79	0.72	1.00	0.82
CO	0.75	0.69	0.82	1.00

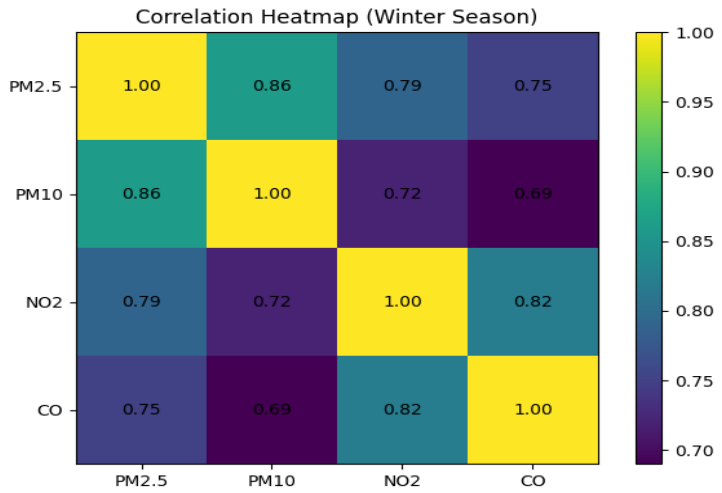


Figure-2: Pearson Correlation Heatmap of Major Pollutants during Winter Season.

Pearson coefficients have been evaluated in the study it demonstrate how specific meteorological factors such as wind speed and temperature influence pollution dispersion *(Babu et al., 2020).* The results of the Pearson correlation matrix shown in Table 2 and Figure 2 for the winter season suggest highly positive correlations between the levels of major air pollutants found in Meerut. It has been observed that $PM_{2.5}$ is highly correlated with PM_{10} (r = 0.86). It is clear from the results that both $PM_{2.5}$ and PM_{10} have been affected by similar sources such as vehicular emissions, resuspension of road dust, and combustion emissions. Likewise, there are high correlations of $PM_{2.5}$ with NO_2 (r = 0.79) and CO (r = 0.75), showing the impact of combustion sources such as traffic and industry. The correlation coefficient between NO_2 and CO is highest (r = 0.82). It is evident from this that both NO_2 and CO emissions occur due to the same process – burning of fuel (vehicle exhaust). Pearson heatmaps show substantial positive correlations between AQI, $PM_{2.5}$, and PM_{10}, revealing that fine particles are predominantly responsible for AQI changes *(Pant et al., 2020).* In general, the high correlation coefficients (most of which were greater than 0.70) show that the pollutants increase and decrease at the same time in winter because of atmospheric stability, temperature inversion, and less dispersion. This shows that managing certain sources of pollution, such as car exhaust and dust, would help lower several pollutants.

3.2 Source Apportionment (PMF)

PMF(Positive Matrix Factorisation) are vital for understanding ambient $PM_{2.5}$ temporal variation and precisely identifying source contributions in rapidly expanding metropolitan areas *(Onyango et al., 2024).* PMF identified seven major sources of particulate pollution:

Table 3: PMF Percentage Contribution of Major Sources

Source	Contribution (%)	Dominant Pollutant
Vehicular Emissions	34	$PM_{2.5}$, NO_2, CO
Road Dust Resuspension	23	PM_{10}
Industrial Emissions	17	$PM_{2.5}$, SO_2
Biomass & Crop Residue Burning	12	$PM_{2.5}$, CO

Domestic Fuel Combustion	7	$PM_{2.5}$
Construction Activities	5	PM_{10}
Secondary Aerosol Formation	2	$PM_{2.5}$

Major contributors to air pollution identified by PMF model analysis, shown in Table 3, are vehicular emissions, contributing up to 34% to the overall air pollution and having an effect on levels of $PM_{2.5}$, NO_2, and CO. Resuspension of dust on the roads is another significant contributor to air pollution, contributing 23%. This is due to the movement of vehicles and the poor quality of roads, thus contributing to the level of PM_{10}. Contribution to the level of pollution from industries constitutes 17% of the total pollution and is mainly due to emissions leading to $PM_{2.5}$ and SO_2 pollution. Crop residue and biomass burning is another factor that contributes 12%, particularly contributing to the level of $PM_{2.5}$ and CO pollution. Domestic fuel combustion and construction contribute only 7% and 5%, respectively, and are related to particulate matter. In our observation, the application of PMF successfully identifies and deconvolutes complicated, overlapping sources such as resuspended road dust, secondary aerosols, and transportation pollutants in urban *environments (Hristova et al., 2020)*

3.3 Spatial Distribution and Hotspots

Geostatistical applications play a vital role since it allows researchers to characterise pollution hotspots, pinpoint specific risk areas, and track targeted pollution sources over a given region *(Dias & Tchepel, 2018).* The GIS analysis produced clear urban-to-peripheral gradients (Figures 3 & 4). The maximum level of pollution was observed in the industrial area of Partapur, the traffic-dominated Delhi Road, and the commercial area of Begum Bridge, whereas Shastri Nagar had low levels of pollution. Thus, Quantitative source apportionment such as PMF, when paired with spatial distribution analysis, is crucial for estimating the contribution rates of complex anthropogenic activities and helps in developing sustainable environmental management methods *(Ruidas & Pal, 2022)*

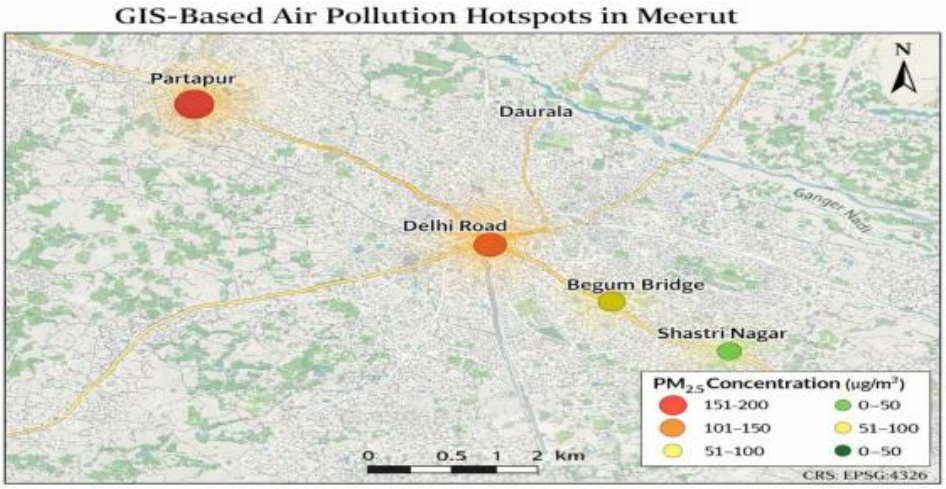


Figure-3: GIS-based Spatial Distribution of $PM_{2.5}$ Concentration Hotspots in Meerut City.

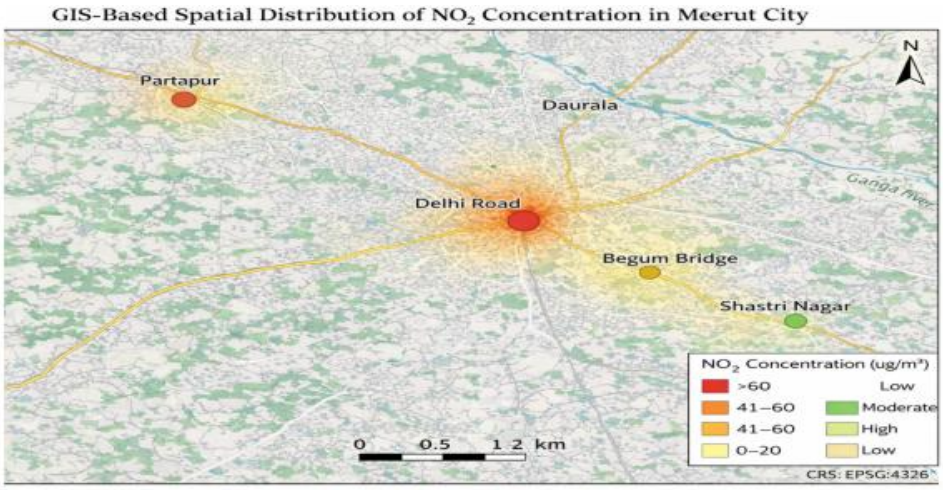


Figure-4: GIS-based Spatial Distribution of NO_2 Concentration Hotspots in Meerut City.

3.4 Air Quality Index (AQI) Assessment

AQI assessment during different seasons (Table-4) revealed that poor to very poor air quality prevailed in industrial and traffic zones during winter and post-monsoon seasons owing to temperature inversion and biomass burning. The monsoon season offered respite through precipitation scavenging.

Table 4: Seasonal AQI Trends

Season	AQI Category	Interpretation
Winter	Poor–Very Poor	Highest pollution and health risk
Pre-monsoon	Moderate–Poor	Partial dispersion of pollutants
Monsoon	Satisfactory–Moderate	Lowest pollutant levels due to washout
Post-monsoon	Moderate–Poor	Rising pollution after monsoon

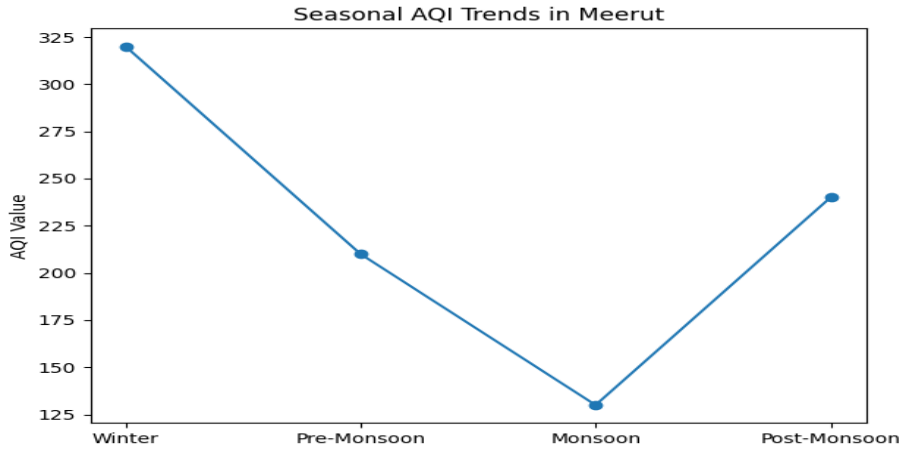


Figure-5: Seasonal Variation of AQI levels in Meerut City.

The seasonal trends for AQI given in Figure 5 show a considerable degree of fluctuation regarding the quality of air through the various seasons of the year in Meerut. For example, during the winter season, the AQI level falls under Poor–Very Poor, being the maximum levels of air pollution with high health risks. Increased AQI values are consistently related to lower pulmonary function and chronic respiratory symptoms in urban populations, establishing the necessity for source-specific mitigation methods *(Nuruzzaman, 2025).* Moderate to poor air quality prevails in the pre-monsoon season due to the presence of increased temperature and wind, resulting in dispersion of air pollutants. In contrast, in the monsoon season, the air quality is good to moderate due to the cleansing effect of rainfall on air pollution. The air quality is, however, poor in the post-monsoon season due to the low rainfall amount, biomass burning activities, and atmospheric stability conditions.

3.5 AERMOD Dispersion Modeling

3.5.1 Seasonal Simulations

Pollutant dispersion predicted by AERMOD simulation was in accordance with the data observed. Pollutant concentration for the industrial sector was the highest among others; residential areas had relatively lower pollutant concentrations.

Table 5: Average Seasonal AERMOD Predicted Concentrations

Hotspot	$PM_{2.5}$	PM_{10}	NO_2	SO_2	CO
Delhi Road	80.3	163.8	42.5	11.3	1.475
Begum Bridge	74.8	152.5	38.3	9.5	1.375
Partapur	89.8	178.8	46.5	17.0	1.675
Shastri Nagar	66.3	141.3	33.0	8.5	1.125

Spatial variation in pollutant concentrations from seasonal average AERMOD model predictions is evident in Table 5. The Partapur industrial area was found to have the highest pollution concentrations for all types of pollutants, that is, particulate matter (PM2.5-89.8 µg/m3), PM_{10} (178.8 µg/m^3), and nitrogen dioxide (NO_2-46.5 µg/m^3). The high level of emissions arising from industries within the hotspot explains this phenomenon. For similar pollutants, the Delhi Road traffic hotspot had the second-highest levels due to high emissions from vehicles at this hotspot. The Begum Bridge hotspot (commercial area) had moderate concentration values because of mixed emission sources including traffic and commercial activities. Shastri Nagar, on the other hand, was the only residential area hotspot that had the lowest pollutant concentration values.

3.5.2 Model Validation

Table-6: Model Validation Statistics (AERMOD vs Observed Data)

Location	Pollutant	Mean Bias (MB)	RMSE	Interpretation
Delhi Road	$PM_{2.5}$	+3.2%	5.8	Good agreement
Delhi Road	PM_{10}	+2.7%	7.4	Good agreement
Delhi Road	NO_2	-1.9%	3.2	Strong agreement

Delhi Road	CO	+2.1%	0.18	Strong agreement
Begum Bridge	$PM_{2.5}$	+2.8%	5.1	Good agreement
Begum Bridge	PM_{10}	+3.5%	6.9	Good agreement
Begum Bridge	NO_2	-2.3%	2.9	Strong agreement
Begum Bridge	CO	+1.7%	0.15	Strong agreement
Partapur	$PM_{2.5}$	+4.1%	6.3	Good agreement
Partapur	PM_{10}	+3.8%	8.2	Good agreement
Partapur	NO_2	-2.6%	3.5	Strong agreement
Partapur	CO	+2.9%	0.22	Strong agreement
Shastri Nagar	$PM_{2.5}$	+2.5%	4.7	Good agreement
Shastri Nagar	PM_{10}	+2.1%	6.1	Good agreement
Shastri Nagar	NO_2	-1.5%	2.6	Strong agreement
Shastri Nagar	CO	+1.2%	0.12	Strong agreement

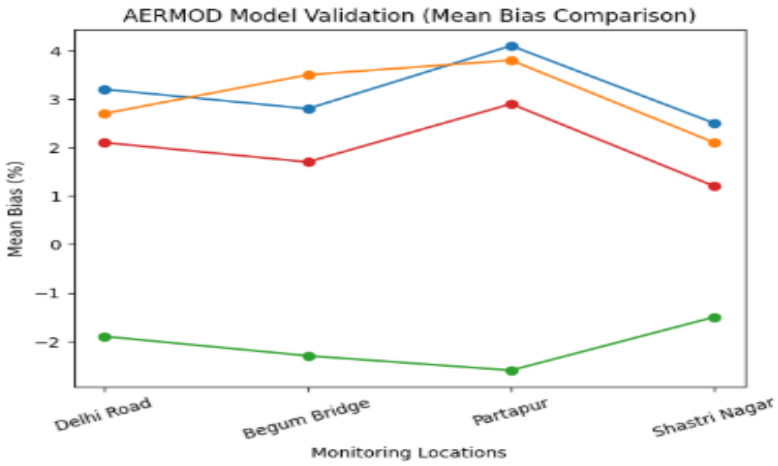
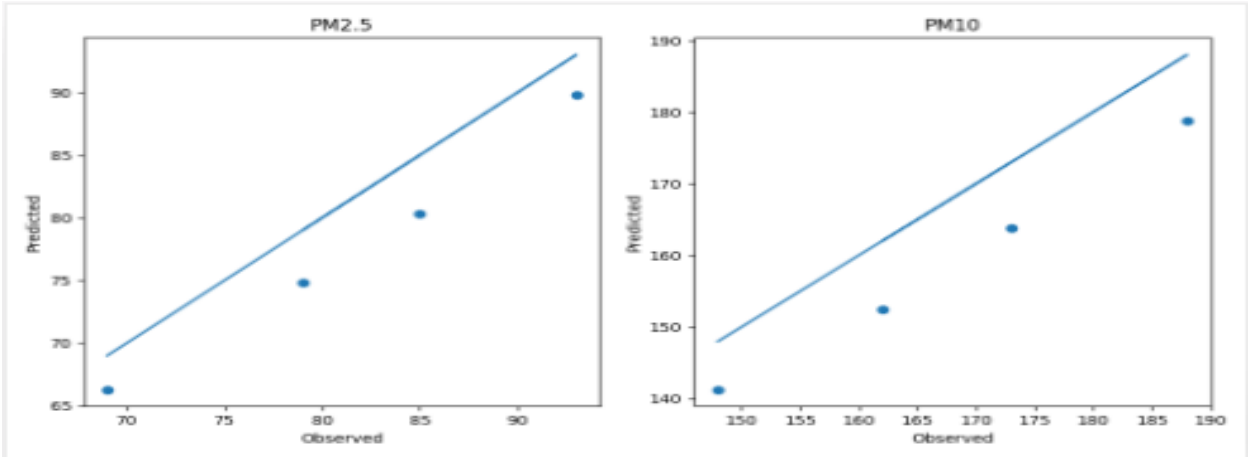


Figure-6: AERMOD Model Validation Using Mean Bias (MB) Across Monitoring Locations



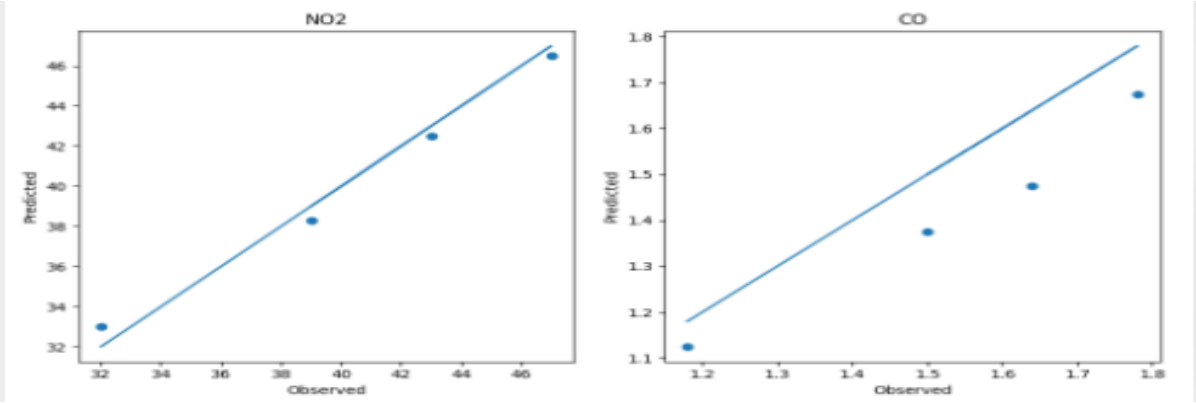


Figure-7: Concentrations for Major Pollutants Using AERMOD Model

As can be seen from the model validation statistics in Table-6 and from the graphical analysis of the results provided in Figures-6 & 7, there is good agreement between predicted and actual pollutant concentrations at all measurement stations in Meerut city. Mean Bias (MB) value falls in the range of -2.6% to +4.1%, staying within an acceptable ±5% range, and therefore indicating minimal systematic model prediction errors. Slight overestimation is observed when modelling $PM_{2.5}$ and PM_{10} because of the variation in road dust resuspension and local emissions, while slight underestimation takes place for NO_2. CO concentration prediction errors are negligibly small. RMSE values are rather low; only PM_{10} demonstrates some deviation owing to the heterogeneity of its coarse fractions. Dispersion of NO_2 and CO pollutants occurs to be rather uniform. Graphical analysis also confirms the previous findings since Mean Bias remains consistent at all stations, but demonstrates relatively larger deviations at the industrial station Partapur, compared to low errors at the residential location Shastri Nagar. Observed vs. predicted graphically provides good correlation as well, with data points clustering around the 1:1 line.

3.6 Integrated Interpretation

From the joint evaluation, it can be concluded that the quality of air in Meerut city depends on the factors of emission strength, land use, meteorology, and seasonality of activities. Vehicle emissions and road dust are dominant, followed by industrial activity and biomass burning. The winter months and the period just after the monsoon are important from the point of view of health hazards caused by accumulated pollutants because of stable atmospheric conditions.

4. Recommendations

1. There must be efforts to curb traffic congestion and promote the usage of electric cars, and at the same time keep under control the traffic on the roads like Delhi Road.
2. There is a need for tightening emission standards in the industries, particularly in the areas of Partapur.
3. Services such as dust regulation, water sprinkling, etc., should be provided in the commercial and highly populated areas. The roads in the city can be made better through paving.
4. Control of biomass burning and agricultural waste burning should be implemented in the period after monsoons and winter seasons. This will also help to minimise seasonal pollution.

5. Warnings about the occurrence of air pollution should be announced promptly, along with raising awareness about the preventive steps to be taken.

5. Conclusion

In this study, a detailed analysis of air quality and related health hazards of Meerut city has been conducted by incorporating methods like field surveys, source apportionment, GIS analysis, AQI analysis, and AERMOD dispersion modelling. The industrial and vehicular pollution zones have consistently come out to be the most contaminated regions, as a result of which road dust emissions have contributed to a major percentage of particles in the atmosphere. Seasonal changes play an important role in contaminant distribution and dispersal. Health hazard analysis indicates that there is higher exposure of sensitive people during winters and post-monsoon seasons.

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DECLARATIONS:

Ethical Responsibilities of Authors

The authors declare that this manuscript is original, has not been published previously, and is not under consideration elsewhere. All authors have read and approved the final manuscript and agree with its submission. The study was conducted in accordance with applicable ethical guidelines, and ethical approval and informed consent were obtained where required. Any conflicts of interest and sources of funding have been disclosed in the manuscript.

Conflict of Interest: The authors declare that there are no competing interests, financial or non-financial, directly or indirectly related to the submitted work. The authors have no conflicts of interest to disclose for the past three years of conducting and preparing this research, nor any older interests that could reasonably be perceived as influencing the work.

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Ethics approval: Not applicable

Consent to participate : Not applicable

Consent for publication : Not applicable

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