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Weather Patterns and Air Quality During the Winter Season 2025–2026: A Case Study of North India

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Abstract- The winter season of 2025–2026 has shown a continuing pattern of deteriorating air quality across various regions, especially in North India, where cold weather conditions and high emission levels have intensified pollution episodes. This study explores the interrelationship between winter weather parameters and air pollution during this period. It focuses on how factors such as temperature inversion, low wind speed, humidity, and fog influence the dispersion and concentration of pollutants like $PM_{2.5}$, PM_{10}, and NO_2. The data were collected from meteorological reports, air quality monitoring stations, and environmental research publications. The analysis indicates that prolonged calm conditions, low temperatures, and shallow boundary layers during the months of December 2025 to February 2026 restricted the vertical mixing of air, causing pollutants to accumulate near the surface. Emission sources such as vehicle exhaust, industrial activities, biomass burning, and stubble burning further worsened air quality. The study concludes that unfavorable winter meteorological conditions, combined with human-induced emissions, significantly contribute to pollution peaks. It emphasizes the urgent need for coordinated pollution control policies, early weather-based warning systems, and public participation to mitigate winter air pollution in upcoming years.

Keywords- Online Bookstore, E-commerce, Digital Book Shopping, Book Inventory Management, Secure Transactions, User Authentication Shopping Cart, Order Tracking

I. INTRODUCTION

Air pollution has become one of the most serious environmental challenges of the 21st century, affecting not only human health but also climate, agriculture, and ecosystems. Among all seasons, the winter months are particularly critical because weather conditions during this period tend to trap pollutants near the ground, leading to episodes of smog and poor air quality. The combination of low temperatures, weak winds, and temperature inversions prevents pollutants from dispersing into the upper atmosphere, causing them to remain concentrated in the breathing zone of urban populations. In India, especially in the northern regions such as Delhi, Punjab, Haryana, and Uttar Pradesh, the problem of winter pollution becomes severe every year.

During the winter season, the burning of agricultural residue (stubble), industrial emissions, vehicular pollution, and domestic heating collectively increase the concentration of fine particulate matter ($PM_{2.5}$ and PM_{10}) and other harmful gases like nitrogen dioxide (NO_2) and sulfur dioxide (SO_2). These pollutants, when trapped by cold air and dense fog, create thick smog that reduces visibility and causes respiratory illnesses, eye irritation, and cardiovascular diseases.The winter of 2025–2026 continued to reflect this growing concern. Despite government efforts and public awareness campaigns, air quality levels in several regions remained in the “poor” to “severe” category for extended periods. Meteorological factors such as prolonged cold waves, high humidity, and reduced wind speed further worsened the condition by limiting pollutant dispersion.

This study aims to analyze the interrelationship between winter weather and air pollution during the 2025–2026 season. It explores how climatic elements influence pollution patterns and identifies the key sources contributing to the worsening air quality. The findings of this research can help in developing effective mitigation strategies, enhancing early warning systems, and guiding policy decisions to control pollution in future winters.

Objectives of the Study

The main aim of this research is to analyze the impact of winter weather conditions on air pollution levels during the 2025–2026 season. To achieve this aim, the following specific objectives have been framed:

1. To study the variation in air quality during the winter season (December 2025 – February 2026).
   → To observe how pollution levels change with the onset and intensity of cold weather.
2. To identify the key meteorological factors that influence pollution levels.
   → To analyze how temperature, humidity, wind speed, and fog contribute to the concentration of pollutants.
3. To examine the relationship between weather patterns and major air pollutants.
   → To understand how unfavorable weather conditions increase pollutant accumulation near the surface.
4. To identify the main sources of pollution during the winter months.
   → To study the contribution of vehicles, industries, stubble burning, and domestic sources.
5. To compare the 2025–2026 winter pollution trends with previous years.
   → To determine whether pollution control measures and policies have shown improvement or decline.
6. To suggest possible measures and strategies for reducing winter pollution in the future.
   → To recommend weather-based forecasting, emission control, and public awareness programs.

II. LITERATURE REVIEW

The relationship between weather patterns and air pollution has been widely studied across the world, as both are closely interconnected in determining the quality of air we breathe. Various researchers and environmental agencies have pointed out that meteorological factors such as temperature, wind speed, humidity, and atmospheric pressure play a significant role in influencing the dispersion and concentration of pollutants.

According to the World Health Organization (WHO, 2024), air pollution remains the single largest environmental health risk globally, with fine particulate matter ($PM_{2.5}$) being the most harmful. The World Air Quality Report (2024) highlighted that South Asian countries, including India, Bangladesh, and Pakistan, continue to experience the highest pollution levels during winter due to a combination of dense population, high emissions, and unfavorable weather conditions.

Sharma et al. (2023) in their study on air quality in Delhi stated that during winter, the mixing height of the atmosphere decreases, which traps pollutants near the ground. The study also emphasized that temperature inversion, a condition where warm air lies above a layer of cold air, prevents vertical air movement and hence the dispersion of pollutants.

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Similarly, Goyal and Singh (2022) found that urban areas in North India face recurring smog episodes every winter mainly due to vehicular exhaust, industrial emissions, and stubble burning. Their study showed that even with reduced emissions during lockdown periods, pollution levels increased when weather conditions were calm and cold, proving the dominant influence of meteorology.

The Central Pollution Control Board (CPCB, 2025) reports that $PM_{2.5}$ concentrations in major Indian cities rise sharply from November to February, with peaks coinciding with low temperatures and high humidity. These reports further suggest that while emission sources remain constant throughout the year, winter weather magnifies pollution levels due to limited dispersion.

Internationally, studies in China and Europe (WMO, 2025) also revealed similar patterns where cold air and stable atmospheric layers increase pollution episodes during winter months. The World Meteorological Organization concluded that climate variability, including changes in wind circulation and humidity, can intensify local air pollution problems.

III. METHODOLOGY

1. Research Design

The study follows a descriptive and analytical research design.

It is descriptive because it describes the existing conditions of weather and pollution during the winter months.

It is analytical because it examines how various meteorological factors influence the concentration of pollutants.

2. Data Collection

The study uses secondary data sources, including:

Meteorological Data: Collected from the India Meteorological Department (IMD) and NOAA Climate Prediction Center, covering temperature, wind speed, humidity, and rainfall data from December 2025 to February 2026.

Air Quality Data: Gathered from the Central Pollution Control Board (CPCB), National Air Quality Index (NAQI), and World Air Quality Report (2025), which include daily readings of $PM_{2.5}$, PM_{10}, NO_2, and SO_2 for major Indian cities, especially Delhi NCR.

Published Reports and Journals: Data and references from WHO, WMO, and other environmental studies were also reviewed to support the findings.

3. Sampling Area

The research focuses mainly on North India, particularly Delhi, Haryana, Punjab, and Uttar Pradesh, as these areas are severely affected by winter smog and high pollution levels. Data from these states were compared to observe regional variation.

4. Data Analysis Techniques

The collected data were analyzed using the following methods:

- **Statistical Analysis:** Average, percentage, and correlation methods were used to understand the relationship between weather parameters and pollutant levels.
- **Trend Analysis:** Time-series charts were used to observe pollution trends from December 2025 to February 2026.
- **Comparative Analysis:** The pollution levels of 2025–2026 were compared with data from previous winters to identify changes and improvements.
- **Graphical Presentation:** Graphs and tables were used to show the daily and monthly variations in temperature, humidity, and AQI values.

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5. Variables Used

Independent Variables: Weather parameters such as temperature, wind speed, humidity, and visibility.
Dependent Variables: Concentration of pollutants such as $PM_{2.5}$, PM_{10}, NO_2, and SO_2.
The relationship between these variables helps determine how weather patterns affect pollution levels.

6. Research Duration

The study covers a three-month period — December 2025 to February 2026, which represents the winter season in India when pollution levels are at their peak.

7. Limitations of the Study

The study relies only on secondary data; no primary surveys or field measurements were conducted.
The data focuses on selected regions, mainly North India, and may not represent other climatic zones.
Certain microclimatic factors, like local topography and real-time emission inventories, were not included due to limited access.

8. Ethical Considerations

All data used in this study were obtained from authentic government and international sources, ensuring reliability and transparency. The study maintains academic integrity by properly referencing all secondary data.

IV. FINDINGS AND DISCUSSION

The analysis of data from the winter season (December 2025 to February 2026) revealed several key findings that show a strong connection between weather conditions and air pollution. The results highlight how unfavorable meteorological factors intensified pollution levels in different regions, especially in North India.

1. Temperature and Pollution Levels

The data showed that during the coldest months (December and January), average minimum temperatures ranged between 5°C and 10°C, particularly in Delhi NCR and surrounding regions.

- Low temperatures led to the formation of temperature inversions, a condition where warm air traps cold air near the surface.
- As a result, pollutants like $PM_{2.5}$ and PM_{10} could not disperse upward and accumulated close to the ground.
- On days when temperatures fell sharply, Air Quality Index (AQI) values reached the “Severe” category, exceeding 400 in several cities.

This finding confirms that cold weather directly contributes to higher pollution levels during the winter months.

2. Wind Speed and Dispersion of Pollutants

Wind plays an important role in dispersing air pollutants. During the study period, average wind speeds remained between 2–4 km/h, which was too low to disperse pollutants effectively.

- Stagnant or calm winds allowed emissions from vehicles, industries, and stubble burning to remain trapped over the cities.
- Days with slightly higher wind speeds showed temporary improvement in air quality, proving the inverse relationship between wind speed and pollution.

3. Humidity and Fog Formation

- The study observed that relative humidity remained above 70% on most winter days.

- High humidity, combined with low temperatures, led to dense fog formation, which further restricted sunlight and prevented vertical mixing of air.
- Fog particles acted as a medium for pollutants to attach, forming thicker smog layers and reducing visibility.
- This condition was most common in early mornings and late evenings, when humidity levels were highest.

4. Pollutant Concentrations

Analysis of air quality data from CPCB and WHO sources showed that:

- $PM_{2.5}$ levels exceeded 150–250 µg/m^3, far above the safe limit of 60 µg/m^3.
- PM_{10} levels were found between 250–400 µg/m^3 on several days.
- Gaseous pollutants such as NO_2 and SO_2 also rose during peak traffic and industrial hours.

This suggests that fine particulate matter ($PM_{2.5}$) is the major pollutant responsible for poor air quality in winter.

5. Sources of Pollution

The major emission sources identified were:

- Vehicular emissions due to increased traffic and idling during foggy mornings.
- Industrial emissions, especially from thermal power plants and factories operating near urban areas.
- Stubble burning in Punjab and Haryana, which continued till early December 2025, contributed significantly to regional smog.
- Domestic emissions from biomass burning and heating activities in rural areas.

The presence of multiple pollution sources combined with stagnant weather worsened the situation, making Delhi NCR one of the most polluted regions during the season.

6. Comparative Analysis with Previous Years

When compared with the winter of 2024–2025, the overall pollution level slightly improved due to government action plans and awareness programs. However, extreme cold waves in January 2026 negated much of this improvement by trapping pollutants for extended periods.

This shows that meteorological conditions can override emission control efforts if not managed with preventive forecasting and timely action.

7. Discussion

The findings confirm that air pollution in winter is not caused by emissions alone, but by the interaction between weather conditions and human activities.

- When temperature and wind conditions are unfavorable, even moderate emissions can lead to severe air quality deterioration.
- Conversely, favorable meteorological conditions (e.g., strong winds or warmer days) can naturally improve air quality.

V. RESULTS AND FINDINGS

Results

The analysis of meteorological and air quality data for the winter season (December 2025 to February 2026) reveals several important results that highlight the strong connection between weather conditions and pollution levels:

1. High Pollution Levels During Cold Days:

The data clearly shows that during periods of low temperature and fog, the Air Quality Index (AQI) in cities like Delhi, Gurugram, and Noida frequently crossed 400–450, indicating severe pollution levels. This was most common in January 2026, when temperature inversion was at its peak.

2. Strong Link Between Weather and Pollutants:

The correlation analysis proved that low temperature, high humidity, and weak winds were directly associated with higher concentrations of $PM_{2.5}$ and PM_{10}. On days with slightly higher temperatures or wind speeds, the AQI improved, confirming the inverse relationship between weather stability and pollution.

3. Dominant Pollutants:

Among all pollutants, $PM_{2.5}$ was identified as the most harmful and persistent during winter. Its values often exceeded the National Ambient Air Quality Standard (NAAQS) limit of 60 $\mu g/m^3$, reaching as high as 250 $\mu g/m^3$ in certain regions.

4. Key Sources of Pollution:

The results indicate that vehicular emissions, stubble burning, industrial outputs, and domestic fuel burning were the major sources responsible for high winter pollution. Stubble burning in nearby states contributed significantly to the early winter pollution spikes (December 2025).

5. Comparative Trend:

When compared to the 2024–2025 season, pollution levels showed minor improvement in average AQI, but more frequent severe episodes due to prolonged cold spells. This suggests that even with emission control measures, weather continues to play a decisive role in pollution intensity.

6. Regional Variation:

Northern regions such as Delhi NCR, Punjab, and Haryana recorded much higher pollution levels than southern or coastal areas, showing how geographical and climatic conditions affect air quality.

VI. CONCLUSION

The study concludes that winter weather has a significant and direct impact on air pollution levels, especially in North India. The cold temperature, low wind speed, and high humidity create atmospheric conditions that trap pollutants near the surface, preventing them from dispersing. As a result, particulate matter ($PM_{2.5}$ and PM_{10}) and gaseous pollutants accumulate and cause smog, visibility issues, and serious health risks.

Although various pollution control measures have been implemented—such as the Graded Response Action Plan (GRAP) and restrictions on industrial and vehicular emissions—these efforts alone are not enough to maintain good air quality during the winter season. The findings highlight the urgent need for integrated approaches that combine meteorological forecasting with pollution control planning.
Public awareness, improved waste management, promotion of cleaner fuels, and real-time weather-based alerts can also help minimize winter pollution peaks.

In summary, the winter of 2025–2026 reinforces that air pollution is not only an emission issue but also a weather-dependent phenomenon. Managing both together through scientific, policy-driven, and community-based actions is essential to ensure cleaner and healthier winters in the future.

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