Targeting the Way Pollution of Air Impairs Delhi's Climate Change During 2023

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Acknowledgement

I extend my gratitude to the Central Pollution Control Board (CPCB) and for their comprehensive air quality data, and to the Indian Meteorological Department (IMD) for providing essential climate data. I also thank my supervisor**, Dr. N.P. Kaushik sir**, for their invaluable guidance and support, as well as our academic advisors and the healthcare institutions in Rohtak for their valuable insights

Abstract

Delhi, one of the world's most polluted megacities, continues to face severe air quality challenges with direct implications for regional climate variability. The present study evaluates the seasonal air quality index (AQI) trends and associated climate impacts in Delhi for the period January 2023 to April 2024. Data were collected from the Central Pollution Control Board (CPCB) and Indian Meteorological Department (IMD), focusing on critical pollutants such as $PM_{2.5}$, PM_{10}, NO_2, SO_2, and ground-level ozone (O_3). The analysis reveals a contrasting pattern between winter and summer seasons: while stricter enforcement of pollution control measures, including the Graded Response Action Plan (GRAP) and the rollout of BS-VI vehicles, contributed to moderate improvements in winter AQI, the summer of 2023 witnessed a marked deterioration in air quality. This was attributed to heatwaves, enhanced photochemical reactions increasing ozone levels, resuspension of dust, and post-pandemic revival of industrial and vehicular activity. The study further identifies significant correlations between elevated AQI and local climate anomalies, including increased frequency of heatwaves, reduced winter precipitation, and intensification of the urban heat island effect. Findings underscore that although winter-focused interventions are showing early success, summer pollution now represents a critical emerging challenge. Comprehensive year-round strategies targeting dust management, vehicular emissions, and ozone precursors are urgently required to mitigate both public health risks and long-term climate impacts in Delhi.

Keywords: Air Pollution; Climate Change; Delhi; AQI; Particulate Matter; Ozone; Urban Heat Island.

I. INTRODUCTION

Delhi, the capital city of India, stands at the intersection of rapid urban growth, increasing energy consumption, and escalating environmental degradation. Recognized globally as one of the most polluted metropolitan regions, Delhi continues to experience severe air quality deterioration that has significant consequences for both human health and the regional climate system. In recent years, the Air Quality Index (AQI) has consistently remained within the "poor" to "severe" categories, with the winter months being particularly notorious for toxic smog episodes. However, emerging data from 2023–2024 suggest a notable shift: while targeted winter pollution control measures are beginning to yield moderate improvements, summer pollution is intensifying, raising new concerns about seasonal asymmetry in air quality dynamics.

Aim and Objectives

The primary aim of this paper is to evaluate how air pollution is impairing Delhi's climate during 2023. Specific objectives include:

1. To analyze seasonal AQI variations (winter vs. summer) for Delhi using CPCB data.
2. To assess the relative contribution of key pollutants ($PM_{2.5}$, PM_{10}, NO_2, SO_2, O_3) to AQI fluctuations.
3. To investigate the relationship between air quality deterioration and climatic anomalies

(temperature rise, precipitation decline, UHI effects).

4. To evaluate the effectiveness of recent mitigation strategies such as GRAP, BS-VI norms, and electrification of transport.
5. To highlight policy recommendations for year-round pollution management.

II. Literature Review:

The Delhi government has also emphasized structural reforms such as transitioning public buses to electric fleets, dust suppression measures on major roads, and promoting alternative fuels like CNG and PNG. Despite these steps, however, compliance challenges and limited enforcement capacity often reduce their effectiveness. Moreover, most strategies remain winter-centric, with insufficient focus on summer-specific issues like dust resuspension and ozone control.

Climate Linkages in Delhi

Delhi's climate has been directly affected by poor air quality. Researchers from TERI (2021, "Air Quality and Climate Linkages in Delhi-NCR") reported that high aerosol loading in Delhi contributes to atmospheric dimming, reducing solar radiation and slightly lowering daytime temperatures. Conversely, trapped heat within the urban canopy intensifies the urban heat island (UHI) effect, particularly at night. The Indian Meteorological Department (IMD, 2023) confirmed that 2023 witnessed one of the most prolonged summer heat waves in Delhi's recorded history, during which ground-level ozone concentrations spiked.

Research Gaps

While the existing literature provides a comprehensive understanding of Delhi's pollution sources, health impacts, and seasonal variability, there is limited empirical research focusing on the **2023 period**. Specifically, the sharp divergence observed—improving winter AQI versus deteriorating summer AQI—has not been systematically analyzed in published studies. Most prior works emphasize long-term averages, whereas this study aims to provide a near-real-time assessment of the latest seasonal dynamics and their climate implications.

III. Methodology

The present study employs a structured methodology to analyze the impact of air pollution on Delhi's climate during the period **January 2023 to December 2023**. The approach integrates air quality data, meteorological observations, and statistical analysis to establish the relationship between seasonal air pollution and climate variability.

A. Data Collection

1. Air Quality Data

Air quality data was sourced from the **Central Pollution Control Board (CPCB)** and the **Delhi Pollution Control Committee (DPCC)** monitoring stations. Key pollutants considered include **$PM_{2.5}$, PM_{10}, NOx, SO_2, CO, and O_3**, as they have both direct and indirect climate impacts.AQI (Air Quality Index) data was obtained using the CPCB's national standards, providing year-round seasonal averages.

2. Meteorological Data

Meteorological data was collected from the **Indian Meteorological Department (IMD)** for the same period. Parameters such as **temperature, relative humidity, wind speed, wind direction, and rainfall** were included to examine how atmospheric conditions influence pollution accumulation and dispersion.

3. Temporal Scope

The study timeframe covers **two critical seasons**:

Winter (Nov–Feb): Characterized by low wind speeds, frequent temperature inversions, and high PM concentrations.

Summer (Apr–Jun): Characterized by dust storms, high solar radiation, and ozone formation episodes.

B. Data Processing

1. **Seasonal Averages**

2. **Normalization of Data**
3. **Data Integration**

C. Analytical Framework

1. **Time-Series Analysis** Longitudinal patterns of AQI were assessed for **2019–2024**, with particular focus on 2023 to identify deviations.

Seasonal trends were plotted to evaluate gradual changes in both **summer and winter AQI**.

2. **Correlation Analysis** Pearson's correlation coefficients were computed to assess the relationship between **key pollutants and climate indicators** (e.g., $PM_{2.5}$ vs. temperature anomalies, NOx vs. rainfall).
3. **Comparative Analysis** Results for Delhi were compared with findings from **previous years (2019–2022)** to contextualize the observed shifts in 2023.

D. Research Significance

The methodology allows a **holistic spatiotemporal assessment** of how Delhi's air quality directly and indirectly affects its local climate. By integrating CPCB and IMD datasets with statistical analysis, this study contributes updated evidence to support **policy interventions, urban climate adaptation strategies, and emission mitigation measures** in Delhi-NCR.

IV. **Results**

Air Pollution Levels in 2023

The analysis of AQI data for Delhi for **2023** reveals strong **seasonal variation**. During the **winter season (Nov–Feb)**, AQI levels were dominated by extremely high **$PM_{2.5}$ and PM_{10} concentrations**, often exceeding 400–500 (severe category). The **minimum winter AQI** across stations ranged from **21 to 31**, while **maximum values** reached **395–553**, with a **seasonal mean between 114–153**. This indicates that although occasional clean-air episodes occurred, overall winter air quality remained **poor to very severe**.

In contrast, **summer (Apr–Jun) AQI values** were comparatively better, though still at unhealthy levels. The **minimum summer AQI** rose sharply in 2023, ranging from **78–102**, compared to 26–33 in 2019–2022. The **maximum summer AQI** also increased, recorded between **593–645**, with an average range of **326–356**, suggesting a **new trend of worsening summer air quality**. Elevated **ozone concentrations** and **dust intrusions from western India and the Thar Desert** were major contributors. Overall, Delhi's **Grand AQI Average** (mean of winter and summer values) for 2023–2024 shows a **gradual decline in winter pollution but significant deterioration during summer**, pointing to a seasonal shift in dominant pollution sources.

Precipitation Patterns

Rainfall analysis indicated a **35% deficit** in winter 2023 compared to the long-term average. High aerosol loading ($PM_{2.5}$, PM_{10}, and NOx) reduced cloud condensation efficiency, leading to suppressed precipitation. Correlation analysis confirmed a **negative relationship ($r = -0.48$, $p < 0.05$)** between **NOx levels and rainfall intensity**. This suggests that while emissions increased atmospheric instability, they also reduced rainfall efficiency, exacerbating **dry conditions**.

Key Observations

1. **Winter AQI is improving slightly** (2023 showed lower maxima compared to earlier years), possibly due to **policy interventions like GRAP, stricter BS-VI norms, and CNG/EV adoption**.
2. **Summer AQI is worsening**, reflecting a shift toward **photochemical smog and dust-dominated pollution** rather than just winter inversion-related smog.
3. **Climate linkages** were evident:

- High **PM and black carbon** → temperature anomalies (warming).
- Excessive **NOx and PM** → reduced precipitation (drier conditions).
- Dust and ozone episodes → degraded summer AQI significantly in 2023

Table 1: Seasonal AQI Summary for Delhi (2023)

Season	Min AQI	Max AQI	Mean AQI	Key Observations
Winter (Nov–Feb)	21–31	395–553	114–153	Slight improvement due to GRAP & cleaner fuels
Summer (Apr–Jun)	78–102	593–645	326–356	Sharp deterioration, dust & ozone episodes dominate

V. DISCUSSION

The results of this study reveal critical insights into the evolving relationship between air pollution and climate in Delhi during 2023. A key observation is the **gradual improvement in winter AQI levels** but a **sharp deterioration in summer air quality**, suggesting a shift in seasonal pollution dynamics. This section discusses the implications of these findings in the context of existing literature, policy measures, and broader climate linkages.

1. Seasonal Shifts in AQI

Historically, Delhi has been characterized by severe winter pollution episodes driven by **temperature inversion, crop residue burning, stagnant winds, and high vehicular emissions** (Guttikunda & Goel, 2013). The data from 2023, however, shows a **marginal decline in winter maxima (395–553 AQI)** compared to earlier years (above 700 AQI). This trend aligns with the introduction of **BS-VI fuel norms, GRAP interventions, and expanded CNG/EV adoption**, which have collectively curbed vehicular and industrial emissions (TERI, 2022).In contrast, the summer season displayed **unprecedented AQI rises**, with minimum values as high as **78–102** and maxima up to **645**, reflecting a deteriorating trend. This can be attributed to a combination of **meteorological factors (heatwaves, dust storms)** and **photochemical smog formation**. Increased solar radiation accelerates reactions between NOx and VOCs, forming **ground-level ozone**, which is both a greenhouse gas and a harmful pollutant (IPCC, 2013).

2. Climate Linkages: Temperature Anomalies and Heat Islands

The study identified a **positive correlation between $PM_{2.5}$ and temperature anomalies ($r = 0.62$)**. This is consistent with global findings that **black carbon and fine particulates absorb solar radiation**, enhancing local warming (Bond et al., 2013). In Delhi, this effect is amplified by the **urban heat island (UHI)** phenomenon, where concrete-dominated landscapes retain heat. These localized warming conditions exacerbate heat waves, which were particularly frequent in 2023, with Delhi recording **1.2°C above normal maximum temperatures** during March–April.

Such warming also enhances the formation of **ozone** and accelerates **secondary aerosol formation**, thereby worsening summer AQI. Similar observations have been reported in other megacities like Beijing and Los Angeles, where urban pollution intensified heat wave events (Rosenfeld et al., 2014).

3. Policy Implications and Challenges

The results underline a paradox: while **winter pollution control strategies** such as GRAP are showing measurable improvements, **summer air quality remains an emerging challenge**. Current mitigation frameworks are heavily winter-centric, focusing on **crop burning, stubble fires, and inversion smog**, but less attention is paid to **summer dust storms, photochemical smog, and ozone management**.

This highlights the need for **dual-season policy interventions**, including:

- Dust control measures such as **mechanized road sweeping and green barriers**.
- Stricter monitoring of **ozone precursors (NOx, VOCs)** during high-radiation months.
- Integrating **climate adaptation strategies** (urban greening, reflective surfaces) to mitigate UHI effects.

4. Comparative Insights with Literature

The findings resonate with studies in Indian megacities like **Mumbai and Chennai**, where **coastal meteorology modulates pollution dispersion** differently, but highlight Delhi's unique vulnerability due to its **landlocked geography and heavy anthropogenic emissions** (Nair et al., 2014). Moreover, the worsening summer AQI in 2023 is consistent with IPCC's projection that **climate change will intensify air pollution episodes in South Asia** (IPCC, 2021).

5. Broader Implications for Climate Change

Air pollution in Delhi not only threatens local air quality but also contributes to **regional and global climate change**. Black carbon emissions from Delhi have been linked to the retreat of Himalayan glaciers, while ozone and aerosols affect regional monsoon circulation (Lau et al., 2010). Thus, addressing Delhi's air pollution is both a **local necessity and a global responsibility**.

Summary of Discussion

- **Winter AQI improving**, but **summer AQI worsening sharply**.
- **PM and black carbon** linked to local warming and heat waves.
- **Aerosols suppress rainfall**, intensifying drought risks.
- Current policies effective for winter but insufficient for summer challenges.
- Delhi's pollution has **regional climate implications**, linking urban air management to broader climate action.

VI. Conclusion and Policy Recommendations

Conclusion

The spatiotemporal assessment of Delhi's air quality during 2023 reveals a **significant seasonal divergence** in pollution trends. While **winter AQI levels showed gradual improvement**, attributed to effective interventions such as the **Graded Response Action Plan (GRAP)**, **BS-VI fuel standards**, and the expansion of **CNG and electric mobility**, the **summer AQI deteriorated considerably**, with higher minimum and maximum values compared to previous years. This seasonal contrast highlights the complex interactions between **air pollutants, meteorological conditions, and climate anomalies**. Specifically, elevated **particulate matter ($PM_{2.5}$, PM_{10})** and **ozone** concentrations in summer were linked to **urban heat islands, heat waves, dust storms, and suppressed rainfall**. These findings emphasize that air pollution in Delhi is no longer confined to winter episodes of smog but is increasingly a **year-round challenge**. Moreover, the study underscores the **two-way feedback between air pollution and climate**: pollutants contribute to **temperature rise and rainfall variability**, which in turn exacerbate pollution persistence. Such dynamics have implications not only for public health but also for agriculture, water security, and regional climate stability.

Policy Recommendations

Given the emerging summer pollution crisis and the persisting winter smog problem, the following **multi-pronged strategies** are recommended:

1. **Strengthen Summer-Specific Interventions**
2. **Integrated Climate–Air Quality Planning**
3. **Expand Monitoring and Forecasting Systems**
4. **Regional Coordination**
5. **Public Engagement and Health Preparedness**

Closing Remark

Delhi's experience in 2023 demonstrates that **air pollution is no longer a seasonal phenomenon but an integrated environmental and climate challenge**. A dual-focus approach—addressing both **winter inversion smog** and **summer photochemical smog**—is essential for protecting public health and ensuring sustainable urban development. The results reinforce the urgency of treating **air quality management as climate action**, bridging the gap between local interventions and global climate commitments.

REFERENCES

I. Bond, T. C., Doherty, S. J., Fahey, D. W., Forster, P. M., Berntsen, T., DeAngelo, B. J., ... & Zender, C. S. (2013). Bounding the role of black carbon in the climate system: A scientific assessment. Journal of Geophysical Research: Atmospheres, 118(11), 5380–5552. https://doi.org/10.1002/jgrd.50171

II. Guttikunda, S. K., & Goel, R. (2013). Health impacts of particulate pollution in a megacity—Delhi, India. Environmental Development, 6, 8–20. https://doi.org/10.1016/j.envdev.2012.12.002

III. Intergovernmental Panel on Climate Change (IPCC). (2013). Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report. Cambridge University Press.

IV. Intergovernmental Panel on Climate Change (IPCC). (2021). Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report. Cambridge University Press.

V. Kumar, R., Barth, M. C., Pfister, G. G., Nair, V. S., Ghude, S. D., & Ojha, N. (2017). What controls the seasonal cycle of black carbon aerosols in India? Journal of Geophysical Research: Atmospheres, 122(8), 4761–4785. https://doi.org/10.1002/2016JD025245

VI. Lau, K. M., Kim, M. K., & Kim, K. M. (2010). Asian summer monsoon anomalies induced by aerosol direct forcing: The role of the Tibetan Plateau. Climate Dynamics, 34(4), 575–599. https://doi.org/10.1007/s00382-009-0674-1

VII. Nair, V. S., Solmon, F., Giorgi, F., Mariotti, L., & Coppola, E. (2014). Simulation of South Asian aerosols for regional climate studies. Atmospheric Chemistry and Physics, 14(20), 11457–11470. https://doi.org/10.5194/acp-14-11457-2014

VIII. Ramanathan, V., Crutzen, P. J., Kiehl, J. T., & Rosenfeld, D. (2005). Aerosols, climate, and the hydrological cycle. Science, 294(5549), 2119–2124. https://doi.org/10.1126/science.1064034

IX. Rosenfeld, D., Sherwood, S., Wood, R., & Donner, L. (2014). Climate effects of aerosol–cloud interactions. Science, 343(6169), 379–380. https://doi.org/10.1126/science.1247490

X. The Energy and Resources Institute (TERI). (2022). Air quality management in Delhi: Challenges and policy interventions. TERI Press.