



# From Seasonal Smog to Persistent Crisis: Climate Change and Uneven Air Pollution Realities in Delhi NCR

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## Abstract

Air pollution in Delhi NCR (National Capital Region) has evolved from seasonal environmental concern into a persistent urban crisis which increasingly intensified by ongoing climate change. This paper examines that how climate-induced alterations in wind dynamics, temperature and atmospheric stability are amplifying air pollution patterns in Delhi, Ghaziabad and Noida despite their close geographic proximity. Using a comparative micro-regional approach, industrial concentration, the study analyses variations in Air Quality Index (AQI) trends in relation to urban structure and climate sensitivity across these three cities. Rising winter temperatures have weakened the wind dispersal mechanisms, while expanding the urban heat islands have enhanced pollutant trapping, which leads to extended smog episodes and prolonged inversion periods. Changes in the rainfall patterns further reduces natural pollutant washout and intensifying pollution persistence across the region. The findings highlight distinct pollution realities within the NCR: Delhi's dense urban traffic saturation and fabric, Noida's planned yet rapidly industrializing landscape, and Ghaziabad's high industrial load and construction activity which collectively interacts with the climate variability to produces uneven pollution exposure. Beyond conventional health impacts, the study emphasizes, educational disruption due to poor visibility and school closures, heightened vulnerability of outdoor labour populations, educational disruption due to poor visibility and school closures and human consequences, including reduced productivity among students and workers. By conceptualizing the air pollution as a climate-amplified phenomenon rather than a purely emission-driven problem, this paper underscores the urgent need for climate-responsive and city-specific air governance strategies. This study positions the Delhi NCR as a critical case for understanding, how climate change is reshaping urban pollution dynamics in rapidly expanding megacities of the Global South.

**Keywords:** Climate change; Delhi National Capital Region (NCR); Air pollution; Atmospheric inversion; Air Quality Index (AQI)

## Introduction

The Indo-Gangetic Plain (IGP) has long been prone to winter smog. In the early 2010s, Delhi's pollution peaks were largely confined to post-monsoon and winter months, driven by crop-residue burning and cool, calm conditions. Today, persistent haze blurs seasonal boundaries. The 2025 National Clean Air Programmed report ranks Delhi as the most polluted city in India based on PM<sub>10</sub> (197 µg/m<sup>3</sup> annual average), with Ghaziabad (190 µg/m<sup>3</sup>) and Greater Noida (188 µg/m<sup>3</sup>) close behind. All NCR cities exceed national ambient standards for most of the year. The Centre for Research on Energy and Clean Air (CREA) notes that Delhi's annual PM<sub>2.5</sub> concentration reached 96 µg/m<sup>3</sup> in 2025, almost double the Indian standard of 40 µg/m<sup>3</sup> and twenty times the World Health Organization (WHO) guideline of 5 µg/m<sup>3</sup>. Ghaziabad (93 µg/m<sup>3</sup>) and Noida (around 90 µg/m<sup>3</sup>) also ranked among the top ten most polluted cities.

Understanding why pollution persists even outside the traditional smog season requires looking beyond emissions alone. Climate change is altering regional meteorology – reducing wind speeds, increasing the frequency of temperature inversions and changing rainfall patterns – that together trap pollutants near the surface. Furthermore, urbanization and industrialization differ across Delhi, Noida and Ghaziabad, producing uneven pollution realities. This paper follows a structured approach to investigate these factors.

Recent scientific evidence increasingly suggests that the air-pollution crisis in the Indo-Gangetic Plain cannot be explained by emission growth alone. Rising background temperatures, a shallowing of the winter boundary layer,

and more frequent stagnation events have reduced the atmosphere's natural capacity to disperse pollutants. Warmer winters delay the breakdown of temperature inversions, while irregular rainfall weakens the natural cleansing of particulate matter from the air. These climate-driven changes interact with rapidly evolving urban forms within the NCR, where dense traffic corridors, expanding industrial zones, and large-scale construction activity modify local airflow and heat retention. As a result, cities located within the same airshed experience markedly different pollution intensities and exposure durations. Despite growing recognition of climate–air quality linkages, limited attention has been paid to how these interactions operate at a micro-regional scale within megacity clusters such as Delhi NCR. Addressing this gap is essential for designing pollution control strategies that are responsive not only to emission sources but also to emerging climatic constraints.



## Study Area and Methodology

### Study area

Delhi, India's national capital, is a dense metropolis of over 20 million people. Its urban fabric includes residential, commercial and industrial zones interwoven with congested road networks. Noida and Greater Noida, located southeast of Delhi, are planned satellite cities built in the 1970s but have rapidly industrialized, attracting electronics, automobile and construction industries. Ghaziabad, situated east of Delhi, is an older industrial city known for steel, ceramics and foundries. Despite geographical proximity, the three cities exhibit distinct land-use patterns and emission sources.

### Data sources

This study integrates multiple data streams:

**Air-quality data:** Annual and daily  $PM_{2.5}$  and  $PM_{10}$  concentrations were obtained from reports by the Central Pollution Control Board (CPCB) and CREA, which rely on Continuous Ambient Air Quality Monitoring Stations (CAAQMS) and manual samplers. The 2026 NCAP progress report provided city-level averages and compliance statistics.

**Meteorological data:** Information on temperature, wind speed, humidity and rainfall was drawn from the India Meteorological Department (IMD) and peer-reviewed studies. The India-specific Atmospheric Stagnation Index quantified stagnation days and future projections.

**Literature and news reports:** Scientific articles, government plans and credible news sources were reviewed to identify emission sources, health impacts and policy measures. The Delhi Heat Action Plan and Down-to-Earth articles provided details on UHI and rainfall patterns. Health impact studies on outdoor workers offered epidemiological insights.

**Qualitative assessments:** Reports and articles documenting illegal industrial activities (e.g., ready-mix concrete plants in Noida) and local action plans (e.g., Ghaziabad's plan to monitor industrial emissions) were used to contextualize governance challenges. The synthesis of these sources allowed comparison of climate-induced meteorological changes, emission profiles and socio-economic impacts across the three cities.

## Climate-Induced Atmospheric Dynamics

### Atmospheric stagnation and weakened winds

Air-pollution episodes in the NCR often coincide with periods of low wind and strong temperature inversions. Researchers developed an India-specific Atmospheric Stagnation Index that links high  $PM_{2.5}$  concentrations with low precipitation, calm winds and strong inversions. Stagnation days lead to 34% higher  $PM_{2.5}$  levels. Under high-emission scenarios, winter stagnation days in northern India are projected to increase by about seven days by 2100, raising winter  $PM_{2.5}$  by  $\sim 7 \mu g/m^3$ . Observational data for December 2025–February 2026 show average wind speeds in Delhi NCR of 2–4 km/h and temperatures of 5–10 °C, conditions conducive to strong inversions.

### Reduced rainfall and pollutant wash-out

Precipitation cleanses the atmosphere by scavenging particulate matter. Yet climate change has disrupted rainfall patterns. Between 1 October and 19 November 2024, Delhi NCR recorded almost no rainfall. Without rain,

particulate matter from vehicles, industry and construction accumulated. On 23 January 2026, light rain only briefly lowered PM<sub>2.5</sub> concentrations; air quality remained four times above the national standard because stagnant conditions prevented dispersal. These events highlight that rainfall alone cannot compensate for persistent emissions when winds are weak.

### Urban heat islands and aerosol feedback

Urban heat islands result from impervious surfaces, high building densities and anthropogenic heat. They modify local circulation and can intensify pollution. A review of UHI-pollution interactions found that aerosols warm the atmosphere, stabilizing the boundary layer and reducing energy dissipation. Delhi exhibits nighttime heat islands 4–7 °C warmer than rural surroundings; these differences diminish after rainfall due to aerosol wash-out. Under low winds (<2 m/s), UHI induces centripetal winds that converge pollutants over the city centre, increasing nocturnal smog. Climate change exacerbates UHI intensity by increasing baseline temperatures.

## Emission Sources and Urban Structure

### Local versus regional contributions

Emission inventories reveal that local sources contribute significantly to NCR pollution, but regional transport also plays a major role. A 2025 source-apportionment study estimates that transport accounts for 46 % of Delhi's local PM<sub>2.5</sub>, followed by industry (22 %) and households (11 %). Construction and road dust, power generation and waste burning account for the remainder. However, only about 35 % of Delhi's PM<sub>2.5</sub> originates within the city; the remaining 65 % comes from surrounding districts and states. During October and November, smoke from agricultural residue burning in Punjab and Haryana adds to background pollution, though its relative contribution has declined (to ~7 % on average in November 2025) due to improved farm-fire management.

### Industrial profiles and urban morphology

**Delhi:** As the capital, Delhi contains a mix of residential neighborhoods, commercial districts and scattered industrial clusters. Its dense road network and high vehicle ownership lead to chronic congestion. The built-up environment creates large UHI that restrict wind flow. Thermal power stations on the city's periphery emit Sulphur oxides and particulate matter.

**Noida and Greater Noida:** Initially planned as industrial townships with wide roads and sectors, these cities have rapidly diversified. Major electronics, automobile and textile factories operate alongside residential complexes. A Down-to-Earth investigation revealed that illegal ready-mix concrete plants and batching units along the Yamuna floodplains run 24/7, generating dust and emissions while trucks banned under the Graded Response Action Plan (GRAP) continue to haul materials. The presence of such unregulated units undermines planning efforts.

**Ghaziabad:** Known as the "Gateway of Uttar Pradesh," Ghaziabad is an old industrial hub hosting steel, ceramics, glass and foundries. Its population exceeds 2 million. Major sources of pollution include vehicles, industrial emissions, construction dust and unpaved roads. The city's action plan aims to convert industrial plants to cleaner technologies and monitor emissions, but enforcement remains weak.

### Construction and road dust

Rapid urbanization has increased construction activity across the NCR. Dust from excavation, cement mixing and unpaved roads significantly contributes to coarse particulate (PM<sub>10</sub>). In Ghaziabad, construction waste and unpaved roads were identified as major sources of pollution. In Noida, illegal concrete plants along the Yamuna belt create continuous dust plumes. Road dust resuspension accounts for a large share of PM<sub>10</sub> and is exacerbated by traffic and poor street sweeping.

## Comparative Air Quality Trends

### Dominant Pollutants and Their Behaviour in Delhi NCR

Particulate matter, specifically PM<sub>2.5</sub> and PM<sub>10</sub>, emerges as the most critical pollutant shaping air-quality conditions across the Delhi National Capital Region. PM<sub>2.5</sub>, owing to its fine size, poses a heightened health risk as it can penetrate deep into pulmonary tissues and enter systemic circulation, thereby increasing the likelihood of cardiovascular and respiratory disorders. PM<sub>10</sub>, although coarser, remains a major driver of pollution episodes, particularly during periods of intensified dust resuspension and construction activity. Observational data from severe pollution episodes indicate that concentrations of both PM<sub>2.5</sub> and PM<sub>10</sub> frequently rise well beyond safe thresholds, pushing air-quality levels into the 'severe' category and creating conditions hazardous for the general population. Urban traffic emissions constitute the dominant local source, while industrial activity and seasonal biomass burning in surrounding states further compound particulate loading. Crucially, these elevated concentrations are amplified by unfavourable meteorological conditions, including low wind speeds and weak atmospheric dispersion, which restrict pollutant dilution and prolong exposure duration.

Air-quality data reveal both similarities and differences across the three cities:

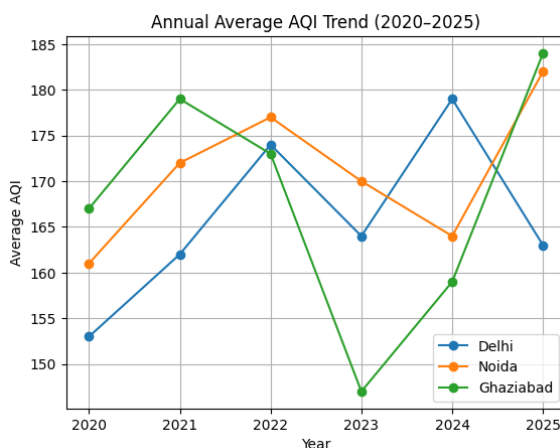
- **Delhi** recorded an annual PM<sub>2.5</sub> of about 96 µg/m<sup>3</sup> in 2025. Daily concentrations frequently exceeded 200 µg/m<sup>3</sup> during winter. PM<sub>10</sub> averaged 197 µg/m<sup>3</sup>, with 31 % of days in the "severe" category (PM<sub>2.5</sub> > 250 µg/m<sup>3</sup>). Diurnal cycles show morning and late-evening peaks due to traffic and cooking emissions.

- **Noida/Greater Noida** experienced similar or higher peaks. During November 2025, AQI values ranged from 213 to 636, categorised as “very poor” to “hazardous”. After the stubble-burning season ended, December 2025 saw PM<sub>2.5</sub> rise by 38 %, indicating the dominance of local sources. The presence of illegal concrete plants along the Yamuna floodplains exacerbated local dust emissions.
- **Ghaziabad** topped the pollution charts in November 2025 with an average PM<sub>2.5</sub> of 224 µg/m<sup>3</sup>, remaining above the national standard on all 30 days. The city recorded the highest number of “very poor” and “severe” days in India. Despite a decline in stubble-burning contribution (~7 %), PM<sub>2.5</sub> levels increased by 28 % in December, underscoring the role of urban emissions and stagnant meteorology.

These trends illustrate how climate-induced stagnation and urban emissions combine to make pollution persistent. The differences reflect varying emission sources: Delhi’s congestion and UHI, Noida’s industrialisation and

Year	Delhi – Avg AQI	Noida – Avg AQI	Ghaziabad – Avg AQI	Data Status
2020	~153	~161	~167	Final
2021	~162	~172	~179	Final
2022	~174	~177	~173	Final
2023	~164	~170	~147	Final
2024	~179	~164	~159	Final
2025	~139-187*	~182	~184	Delhi final (CAQM); Noida & Ghaziabad not yet published

unregulated construction.



## Health and Socio-Economic Impacts

### Health risks and vulnerable populations

Fine particulate matter (PM<sub>2.5</sub>) penetrates deep into the lungs and bloodstream, increasing the risk of asthma, bronchitis, lung cancer, stroke and heart disease. The WHO’s safe 24-hour limit for PM<sub>2.5</sub> is 25 µg/m<sup>3</sup>; Ghaziabad’s November 2025 average of 224 µg/m<sup>3</sup> is nearly nine times this limit. Outdoor workers face heightened exposure. A health impact assessment of Delhi’s auto-rickshaw drivers, street vendors and sweepers reported high prevalence of respiratory and ophthalmic symptoms: eye redness (44 %), eye irritation (36 %), breathlessness (28 %) and skin rashes (22 %) among auto drivers; headaches (43 %), eye redness (40 %) and joint pain (39 %) among vendors; and musculoskeletal problems and respiratory symptoms among street sweepers. Heat stress compounds risks; outdoor workers experience heat exhaustion, cramps and reduced productivity during extreme heat event. Children are also vulnerable. The Graded Response Action Plan (GRAP) allows closure of schools when air quality reaches severe levels. In January 2026, Delhi authorities contemplated hybrid learning due to poor air quality and cold wave conditions. Repeated closures disrupt education and outdoor play, affecting physical and cognitive development.

### Productivity losses and economic costs

Air pollution reduces labor productivity and increases health expenditures. An article in Mongabay-India reported that during November 2025, commuters experienced burning eyes and fatigue within minutes of exposure. A 2021 study estimated that employee productivity falls by 8–10 % on high pollution days and that about 1.3 billion working days are lost annually due to absenteeism. Presenteeism—being at work but not fully productive—costs Indian businesses an estimated \$30–41 billion per year. Employers in NCR report difficulty attracting and retaining skilled workers, as potential employees avoid relocating to polluted cities.

### Educational and social consequences

Poor visibility and health concerns lead to school closures and shifts to online classes. Students lacking digital access or quiet study environments face learning setbacks. Outdoor sports and social activities are curtailed. Road, rail and

air transport disruptions due to smog and fog further impede economic activity and daily life. For daily wage earners, lost workdays translate directly into lost income, deepening socio-economic inequality.

## Policy Responses and Governance Challenges

### National Clean Air Programme (NCAP)

Launched in 2019, the NCAP aims to reduce PM<sub>10</sub> levels by up to 40 % by 2026. However, the 2026 progress report reveals that only 74 % of allocated funds have been utilized. Spending is heavily skewed toward road-dust management (68 %), while critical sectors like industry, domestic fuel and public outreach receive less than 1 %. Only 90 of 130 non-attainment cities have completed source-apportionment studies, leaving many cities uncertain about dominant pollution sources. The underinvestment in industrial emission controls is particularly problematic given the heavy industrial presence in Ghaziabad and Noida.

### Local action and enforcement

Delhi's Graded Response Action Plan (GRAP) triggers measures such as halting construction, banning diesel generators and implementing odd-even vehicle schemes during severe pollution episodes. While these measures reduce peaks, their impact is limited when transboundary inflow and climate-induced stagnation persist. Noida authorities ordered industries to install continuous emission monitoring systems and temporarily shifted schools to hybrid mode during severe pollution. However, illegal ready-mix concrete plants along the Yamuna floodplains continue to operate 24/7 without permits. In Ghaziabad, the municipal action plan aims to convert industrial plants to cleaner technologies and curb waste burning, but enforcement remains weak.

### Towards climate-responsive governance

Most current policies treat air pollution as a local emission problem, but climate change is altering baseline conditions. Rising temperatures and weakened winds mean that the same emission levels now generate higher pollutant concentrations. A climate-responsive approach requires integrating air-quality management with climate adaptation strategies. Key elements include:

**Regional airshed management:** The fact that 65 % of Delhi's PM<sub>2.5</sub> originates outside the city highlights the need for cross-jurisdictional coordination. Creating a regional airshed authority can harmonise emission standards and facilitate joint actions among Delhi, Haryana and Uttar Pradesh.

**Sector-specific emission reductions:** Accelerate electrification of transport and expand public transit; enforce stricter emission standards for industries; subsidise cleaner cooking fuels; and regulate construction dust. Source-apportionment studies should guide targeted investments.

**Climate-informed forecasting:** Incorporate atmospheric stagnation indices and heat-wave forecasts into early-warning systems. Align air-quality alerts with heat-action plans to protect outdoor workers and vulnerable populations.

**Urban design and green infrastructure:** Expand green spaces and ventilation corridors to mitigate UHI effects. Promote green facades and pollution-absorbing materials. Retrofits should prioritise low-income neighbourhoods that lack tree cover.

**Social protection and awareness:** Provide personal protective equipment and cooling shelters for outdoor workers. Integrate air-quality considerations into school calendars and support digital learning infrastructure. Conduct awareness campaigns to encourage behavioural changes, such as avoiding open waste burning.

## Discussion

This study highlights how climate change, urbanization and policy gaps interact to shape air-quality outcomes in Delhi, Noida and Ghaziabad. Rising temperatures and weakened winds, along with reduced rainfall, create meteorological conditions that trap pollutants. Urban heat islands further stabilize the boundary layer. Emission sources vary by city: Delhi's high vehicle density and power generation, Noida's industrialization and unregulated construction, and Ghaziabad's heavy manufacturing base. Nonetheless, all three cities share a reliance on fossil fuels and face similar climate-induced stagnation. The findings underscore that emission reductions alone may not achieve air-quality targets if climate change is ignored. Without adaptive measures, even ambitious control policies could be undermined by more frequent stagnation days. Moreover, the health and economic impacts of persistent pollution threaten the NCR's productivity and human capital. The disproportionate burden on outdoor workers and children raises questions of environmental justice. Climate-responsive governance must therefore address both emissions and vulnerability. Comparing NCR with other megacities (e.g., Beijing or Los Angeles) reveals common themes: topographical constraints, industrialisation and motorisation drive high pollution, but aggressive regional coordination and investments in public transit and clean energy have yielded improvements. Delhi NCR could learn from these experiences while tailoring solutions to its unique climate and socio-economic context.

## Conclusion and Recommendations

Delhi NCR's evolution from seasonal smog to persistent air-pollution crisis illustrates the complex interplay between climate change, urban growth and policy. Rising temperatures, reduced winds and altered rainfall increase atmospheric stagnation, while urban heat islands and aerosols enhance pollutant trapping. Delhi, Noida and

Ghaziabad experience distinct pollution realities because of differences in urban structure and industrial composition. Health impacts on outdoor workers, productivity losses and educational disruptions reveal the human cost of inaction. National and local policies have reduced some emissions but remain insufficient; funds are under-utilized and industrial pollution is under-addressed. To move from crisis to resilience, the NCR must adopt climate-responsive and city-specific strategies. Regional airshed management, sector-targeted emission cuts, climate-informed forecasting, green urban design and social protection are key pillars. Engaging communities and industries in participatory planning can build public support. Ultimately, addressing air pollution in Delhi NCR requires recognising that climate change and local emissions are inseparable pieces of the same puzzle.

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## Author Contributions

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