

Impact of Ambient Air Pollution on Respiratory Health Morbidity and Mortality in the Delhi National Capital Region (NCR)

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Abstract—This paper synthesizes epidemiological and environmental data to quantify the chronic and acute respiratory health burden attributable to ambient air pollution in the Delhi National Capital Region (NCR). The region consistently operates under conditions ranging from 'Very Poor' to 'Severe' air quality, driven predominantly by fine particulate matter (PM_{2.5}), with annual average concentrations dramatically exceeding global health benchmarks. Environmental monitoring confirms that the annual mean PM_{2.5} concentration in the region is often twenty times the World Health Organization (WHO) guideline of 5 µg/m³. Recent air quality data demonstrates that the NCR is functioning as a unified airshed, with hotspots such as Greater Noida recording a 'Severe' Air Quality Index (AQI) of 454. The study establishes a statistically significant correlation between these elevated pollutant levels and severe respiratory morbidity across pediatric and adult populations. Findings indicate a high prevalence of respiratory symptoms in Delhi children (32.1%) compared to 18.2% in rural controls, alongside a massive surge in Acute Respiratory Illness (ARI) emergency room visits in central hospitals, logging over 200,000 cases between 2022 and 2024. Physiological studies confirm that chronic exposure progressively impairs lung function, evidenced by reduced Forced Expiratory Volume in 1 second/Forced Vital Capacity (FEV₁/FVC) ratios, and exacerbates conditions like Chronic Obstructive Pulmonary Disease (COPD) via sustained oxidative stress and inflammation. While reactive policy tools, such as the Graded Response Action Plan (GRAP), offer temporary respite, the sustained increasing trends in Respirable Suspended Particulate Matter (RSPM) and nitrogen dioxide (NO₂) highlight the

failure of preventative measures. This necessitates a strategic shift toward long-term, preventative, and multi-sectoral reforms that address regional emission sources and implement sustained engineering controls.

Index Terms—Air Pollution, Delhi NCR, PM_{2.5}, Respiratory Health, COPD, Asthma, FEV₁/FVC, Epidemiology, GRAP.

I. INTRODUCTION

1.1 Global and National Context of Air Pollution Burden

Ambient air pollution represents the single largest environmental health risk worldwide, contributing to an estimated 4.2 million premature deaths globally in 2019. In the context of India, and specifically the Delhi National Capital Region (NCR), this threat is magnified by environmental conditions that routinely exceed both national safety standards and international health thresholds. The crisis is defined by pervasive, chronic exposure to fine particulate matter (PM_{2.5}), which, due to its microscopic size (less than 2.5 micrometers), is capable of penetrating the body's natural defenses to lodge deep within the pulmonary system and potentially enter the bloodstream.

The long-term epidemiological consequences of this toxic environment are stark. Chronic Obstructive Pulmonary Disease (COPD), historically viewed as a pathology linked primarily to tobacco consumption, has ascended dramatically to become the second-leading cause of death in India, surpassed only by

ischaemic heart disease. This shift underscores the growing role of environmental etiology. The evidence now firmly points toward outdoor and indoor air pollution, biomass fuel exposure, and occupational dust as major drivers of COPD prevalence, displacing smoking and age as the dominant risk factors. By 2019, India accounted for 17.8% of the global COPD burden, signifying a public health emergency that requires rigorous scientific investigation to inform comprehensive policy responses.

1.2 Rationale and Problem Statement

Despite governmental and judicial interventions over the last two decades, including the mandatory conversion of public transport to Compressed Natural Gas (CNG), air quality in Delhi NCR remains a chronic, year-round respiratory hazard. Analysis of air quality trends reveals persistent danger: the annual mean PM_{2.5} concentration in the region consistently measures at levels dramatically higher than global safety recommendations, reaching $100 \mu\text{g}/\text{m}^3$ in 2021–2022, which is twenty times the WHO guideline. Such chronic exposure leads to progressive, often irreversible, pulmonary damage.

The fundamental challenge in the current mitigation strategy is the reactive, episodic focus on managing acute pollution spikes during the winter smog season (reaction), rather than establishing a sustained, comprehensive prevention policy to address year-round chronic exposure. Current policies are often undermined by their geographical restriction, failing to control regional emissions that contribute substantially to the pollution load, allowing air quality to rebound quickly once temporary operational bans are lifted. This study provides a necessary integrative review, synthesizing environmental monitoring, epidemiological data, and clinical physiology to rigorously establish the exposure-morbidity link, thereby necessitating a scientific basis for structural and engineering policy solutions.

1.3 Research Objectives

The objectives of this research are designed to provide a comprehensive, expert-level analysis of the air pollution crisis and its health consequences in Delhi NCR:

1. To characterize the exposure levels, geographic variability, and long-term trends of key respiratory pollutants in Delhi NCR.
2. To quantify both the acute and chronic respiratory morbidity burden using established

epidemiological metrics, including symptom prevalence, hospitalization rates, and measures of functional impairment.

3. To analyze the molecular and physiological mechanisms underpinning pollution-induced lung injury, with specific attention to chronic conditions and vulnerable populations.
4. To critically assess the efficacy, limitations, and unintended socio-economic consequences of current policy responses, particularly the Graded Response Action Plan (GRAP), and to propose sustainable interdisciplinary recommendations.

II. AIR QUALITY DYNAMICS IN DELHI NCR: EXPOSURE CHARACTERIZATION

2.1 Particulate Matter Concentrations: Chronic and Acute Status

The air quality crisis is underpinned by dangerously high pollutant concentrations. Long-term studies indicate that the mean PM_{2.5} concentration over a 15-year period averaged $125 \pm 86 \mu\text{g}/\text{m}^3$, which is three times the Indian NAAQS. This level of chronic exposure provides the background for the high incidence of non-communicable respiratory diseases. During peak pollution events, the situation rapidly escalates to hazardous levels. These acute spikes, exacerbated by seasonal factors like lower temperatures, lack of wind, and crop residue burning in neighboring states, can push hourly PM_{2.5} concentrations up to $750 \mu\text{g}/\text{m}^3$. Data from January 1, 2025, confirmed Delhi's air quality averaged 328 AQI (Very Poor), with PM₁₀ and PM_{2.5} being the dominant pollutants.

2.2 Geographic Heterogeneity and Hotspots

Air quality monitoring confirms that the entire NCR functions as a contiguous airshed, meaning that the dispersion and concentration of pollutants are regional, not confined to the administrative boundaries of Delhi. Pollution levels across the adjacent satellite cities frequently reach or exceed those recorded in the core NCT. This is critically demonstrated by the CPCB update from November 2025, which reported Greater Noida achieving the highest pollution levels among assessed cities, with an AQI of 454, categorized as 'Severe,' and PM₁₀ being the prominent pollutant. Other key areas also registered extreme risk: Noida (Sector 62) recorded 330 (Very Poor), and Ghaziabad (Indirapuram) recorded 309 (Very Poor).

The observation that peripheral NCR cities consistently rank high in pollution charts strongly confirms that control strategies restricted primarily to Delhi will inherently fail to deliver sustained clean air. Pollution arriving from regional sources, including construction activity, industrial belts, and residential heating outside Delhi's strict purview, significantly

contributes to the overall risk. The integrated nature of this airshed necessitates mandated, uniform enforcement of emission standards across all contiguous states.

The comparative severity across key NCR monitoring stations is provided below (Table 1).

Table 1: Comparative Air Quality Status (AQI) in Key Delhi NCR Stations (Recent Data)

City (Monitoring Station)	Reported AQI Value	Air Quality Category	Prominent Pollutant	Source
Delhi (Nehru Nagar)	404	Severe	PM2.5	
Greater Noida (CPCB Update)	454	Severe	PM10	
Noida (Sector 62)	330	Very Poor	PM2.5	
Ghaziabad (Indirapuram)	309	Very Poor	PM2.5	

2.3 Pollutant Profiles and Emission Source Analysis
Analysis of pollutant trends between 2003 and 2019 reveals critical shifts in the effectiveness of source control policies. A positive trend was noted for sulfur dioxide (SO₂), which showed an annual average reduction ranging from 1.49% to 4.09%, reflecting successful measures to introduce cleaner fuels. However, the analysis of particulate and nitrogen oxides reveals increasing pressures. Respirable Suspended Particulate Matter (RSPM) showed an increasing trend, with an annual average increment in the range of 0.98% to 3.19%, particularly pronounced at industrial and construction sites. This RSPM growth highlights the challenges in controlling fugitive dust and emissions from decentralized sources. The most significant finding is the sustained increase in nitrogen

dioxide (NO₂), an indicator primarily associated with vehicular combustion, which increased with an annual average ranging from 5.21% to 6.07%.

The sustained and rapid increase in NO₂ concentrations suggests that the growth rate and emission intensity of the vehicular fleet have overwhelmed earlier mitigation strategies. Nitrogen dioxide is a potent respiratory irritant, and its continued upward trend directly correlates with an increased risk of chronic respiratory morbidity. This finding establishes the urgent need for structural changes in the transportation sector, mirroring successful international urban electrification and vehicle norm tightening efforts, to manage this rapidly growing combustion-related risk.

III. EPIDEMIOLOGY AND RESPIRATORY MORBIDITY

3.1 Pediatric Health Burden and Developmental Risks
The impact of air pollution on children is particularly severe because their developing lungs are highly susceptible to permanent damage. Chronic exposure to toxic particulate matter interferes with the natural process of lung growth, potentially leading to smaller, weakened lungs and a significantly heightened lifetime risk for asthma, bronchitis, and other chronic disorders.

Epidemiological evidence from Delhi reveals a substantial and statistically significant difference in respiratory health outcomes compared to control areas. Studies found that 32.1% of children in Delhi suffered from respiratory problems, contrasting sharply with 18.2% of children in cleaner rural areas. The association was particularly strong between PM10 levels and the prevalence of lower respiratory tract symptoms. Upper respiratory symptoms (URS) were also dramatically higher in the exposed group (23.1% prevalence vs. 14.6%), with a confirmed Odds Ratio (OR) of 1.24 (95% CI: 1.02–1.47).

The long-term implication of these findings is that continuous exposure during formative years establishes a foundation for respiratory vulnerability throughout adulthood, contributing directly to the observed high prevalence of obstructive lung diseases in the adult population.

3.2 Acute Morbidity and Hospitalization Rates

Air pollution crises place an enormous, predictable burden on Delhi's healthcare infrastructure. Data from six central Delhi hospitals spanning 2022 to 2024 revealed that more than 2 lakh patients with Acute Respiratory Illnesses (ARI) reported to emergency departments, resulting in over 30,000 hospitalizations. The sheer volume of these cases represents a catastrophic failure to protect public health during peak pollution events, resulting in massive, avoidable costs to the healthcare system and diversion of critical resources.

The correlation between acute pollutant increases and hospital visits is highly sensitive. Emergency room visits for conditions such as Chronic Obstructive Airway Disease (COAD) are reported to increase by 24.90% during periods when ambient pollutant levels exceed acceptable thresholds.

Further analysis isolating the impact of sulfur dioxide (SO₂) demonstrates its acute pathogenic role. While SO₂ averages have decreased annually, localized, short-burst exposures are extremely dangerous. A 10 µg/m³ increase in the cumulative concentration of SO₂ over a six-day period was associated with an 83.33% rise in hospital visits (Relative Risk, RR: 1.83, 95% CI: 1.35–2.49). This disproportionately high risk indicates that effective policy must focus not just on lowering annual averages, but on rigorous, real-time control of localized high-emission industrial breaches that trigger immediate, severe acute respiratory crises.

Table 2: Epidemiological Association between Air Pollution and Respiratory Morbidity in Delhi

Health Outcome Category	Observed Prevalence/Effect Magnitude	Associated Pollutant	Significance (Odds Ratio/Change)	Source
Pediatric Respiratory Symptoms	32.1% prevalence (vs. 18.2% in controls)	PM10 (Long-term)	Strong, statistically significant association	
Acute COAD ER Visits	24.90% increase	High Ambient Pollutant Levels	Correlation with non-acceptable levels	
Hospital Visits (Acute)	83.33% rise (cumulative lag 0-6)	10 µg/m ³ increase in SO ₂	RR: 1.83 (95% CI: 1.35, 2.49)	
Chronic Obstructed Airflow	> 20% of Delhi adults show early signs	PM2.5 (Long-term)	Risk of COPD increased by 25-30%	

3.3 Chronic Disease Burden: COPD and Non-Smokers

The long-term impact of chronic PM_{2.5} exposure is most strikingly evident in the prevalence of Chronic Obstructive Pulmonary Disease (COPD). Long-term inhalation of fine particulate matter is confirmed as a significant risk factor, increasing the probability of COPD development by 25–30%. This finding solidifies the link between environmental exposure and the dramatic surge of COPD to the second-leading cause of death in India.

This environmental damage is not limited to those with existing conditions; it is endemic in the exposed population. More than 20% of Delhi's adult population already exhibits early signs of obstructed airflow. This indicates a widespread progressive lung injury characterized by reduced lung elasticity, increased

mucus production, and chronic respiratory impairment. The environment itself has become a major etiological agent, shifting COPD from a primarily lifestyle-linked illness to a disease driven by the failure of public health and environmental protection policies.

IV. CLINICAL AND PHYSIOLOGICAL IMPACTS: MECHANISMS OF LUNG INJURY

4.1 Pathophysiology of Particulate Matter Exposure

The molecular pathology of air pollution exposure begins with the deposition of fine particles deep within the alveoli. Particulate matter is highly pro-inflammatory, inducing significant oxidative stress in the lung cells. This biological mechanism triggers an

acute neutrophilic inflammatory response, resulting in symptoms such as cough, wheeze, bronchial hyperreactivity, and acute phase reactions. This inflammatory activity exacerbates pre-existing airway conditions, particularly asthma, where individuals with allergic asthma face heightened risks during high-exposure periods.

On a chronic level, air pollution causes structural damage by promoting a cycle of injury and dysregulated repair. Pollution damages the airway lining and can alter lung cell phenotype, promoting a state of persistent inflammation and damage. Studies suggest that this dysregulation, potentially mediated by signaling molecules such as Interleukin-6 (IL-6), contributes to the development of lung fibrosis and chronic loss of pulmonary function. Furthermore, particulate exposure affects the pulmonary immune system, modifying T cell differentiation and potentially reducing the proportion of TH1 effectors, thereby heightening vulnerability to severe respiratory infections.

4.2 Quantification of Reduced Pulmonary Function (FEV1 and FVC)

Objective spirometric measurements confirm the severity of functional impairment caused by chronic exposure. The degree of physiological damage is directly correlated with the cumulative time spent in the polluted environment. Study participants who had resided in Delhi for 18 years or more demonstrated significantly lower FEV1/FVC ratios and Peak Expiratory Flow (PEF) compared to those residing for five years or less. This established dose-response relationship provides clear evidence that the damage is progressive and cumulative.

Moreover, the mode of daily transport constitutes a major difference in exposure dose and resulting health status. Individuals who utilized open transport methods for commuting (e.g., non-A/C buses or scooters) displayed significantly lower values of FVC and FEV1 compared to those who used closed, filtered environments such as the metro, car, or air-conditioned buses. This difference in lung function is not merely correlational; it provides a direct, measurable real-world validation that the choice and availability of protected transport systems are critical public health determinants. This evidence strongly justifies aggressive investment in expanding closed public transit infrastructure as a necessary, quantifiable intervention to mitigate the daily pollution

dose for the working population. Similarly, residing near localized sources, such as smoke-producing factories, also significantly decreased FVC and FEV1, underscoring the critical importance of localized industrial regulation.

V. POLICY INTERVENTIONS AND CHALLENGES

5.1 Analysis of Reactive Policy: The Graded Response Action Plan (GRAP)

The Graded Response Action Plan (GRAP) provides a structured, four-stage framework designed to enable rapid intervention when the AQI crosses specific thresholds. Stage III (Severe, AQI 401–500) and Stage IV (Severe+, AQI > 500) implement stringent measures, including construction bans, intensified traffic regulation, and industrial shutdowns.

While GRAP is effective in achieving rapid, temporary reduction of particulate emissions during acute crisis periods, offering short-term relief to vulnerable groups, it suffers from critical systemic and socio-economic limitations.

GRAP is fundamentally reactive; it is triggered only after the pollution has become hazardous, failing to prevent the chronic exposure that drives long-term morbidity. Furthermore, relying heavily on bans and restrictions, such as construction halts, imposes severe, adverse socio-economic consequences. The Supreme Court has acknowledged that perennial enforcement of GRAP is impractical because its restrictions disproportionately harm daily-wage earners and migrant labourers, necessitating court orders for providing subsistence allowances to those who lose employment. This policy constraint means that sustained, structural improvements—such as massive, consistent investment in source elimination technology—must take precedence over economically disruptive operational bans.

5.2 Assessment of Long-Term Source Control Efforts
Long-term source control necessitates comprehensive engineering and policy execution. Interventions spearheaded by the Civil Engineering sector focus heavily on mitigating fugitive dust, RSPM, and PM10. These include surveys and repairs of roads, greening and paving of road shoulders, enhancing Construction and Demolition (C&D) waste processing capacity, and mandating the use of recycled C&D products in government projects.

However, the efficacy of these measures is challenged by environmental data, which shows a continued upward trend in RSPM (up to 3.19% annual increment) and a high increase in NO₂ (up to 6.07%) between 2003 and 2019. This discrepancy suggests that while source control measures are initiated, they are either insufficiently scaled, inadequately enforced, or are being overwhelmed by the rapid pace of urban development and vehicular growth. For dust management to effectively curb the rising RSPM, the adoption of cleaner construction practices and infrastructure repairs must become mandatory and consistent across the entire airshed.

5.3 Regional Cooperation and International Best Practices

Air quality is a regional governance challenge. Emissions from surrounding states—originating from sources such as stubble burning, upwind residential energy use, and neighboring industrial belts—cannot be resolved through Delhi-centric restrictions. Cleaning up regional emissions is a necessary condition for Delhi to achieve sustained relief.

India's reactive, seasonal strategy contrasts sharply with successful, systemic international efforts. China's response to its severe pollution crisis involved large-scale, sustained investment in pollution control equipment, stringent tightening of vehicle emission norms, and aggressive expansion of electric public transit. The critical lesson derived from such models is that long-term success requires a sustained political and financial commitment to preventative infrastructure transformation and rigorous, year-round enforcement across all contributing states, not just temporary bans activated during crises.

VI. CONCLUSION

The Delhi National Capital Region is trapped in a public health emergency where sustained exposure to hazardous ambient air pollution is inextricably linked to severe respiratory morbidity. The environment acts as a primary pathogen, permanently damaging developing lungs, inducing chronic loss of pulmonary function (FEV₁/FVC), and acting as a primary driver for the high prevalence of Chronic Obstructive Pulmonary Disease and surges in Acute Respiratory Illness hospitalizations. The data confirms the following key outcomes:

1. **Chronic Environmental Risk:** Annual PM_{2.5} averages in the NCR are hazardous, and the entire airshed, including rapidly developing satellite cities, faces 'Severe' air quality. The alarming increase in NO₂ signifies the growing, unmanaged combustion-related threat from the vehicular sector.
2. **Quantifiable Morbidity:** The exposure translates directly to quantifiable disease: 32.1% respiratory symptom prevalence in children, significant COPD risk for non-smokers, and massive, avoidable acute hospitalizations associated with pollutant spikes, particularly SO₂.
3. **Policy Insufficiency:** Current reactive policy tools, while necessary for temporary crisis mitigation, are structurally incapable of delivering long-term clean air. The socio-economic costs of these reactive measures highlight the fundamental need to redirect resources toward sustained, preventative, source-centric solutions.

The path toward sustainable respiratory health requires a decisive and multi-sectoral shift: implementing rigorous, technology-driven engineering controls to manage RSPM and aggressive infrastructural transformation in the transport sector to control NO₂. This must be executed through a robust, legally binding framework for regional cooperation that transcends state boundaries.

VII. RECOMMENDATIONS

To address the profound impact of air pollution on respiratory health in Delhi NCR, the following expert recommendations, focusing on interdisciplinary solutions, are presented:

1. **Enforceable Regional Airshed Governance:** Establish a permanent, legally empowered body responsible for air quality management across all NCR states. This body must enforce simultaneous, uniform emission control standards for industry and construction across the entire region, ensuring that localized gains in Delhi are not negated by uncontrolled pollution transport from neighboring jurisdictions.
2. **Mandatory Preventative Civil Engineering Protocols:** Utilize civil engineering expertise to rigorously control fugitive dust. This must include mandatory, 100% compliance for paving unpaved roads, implementing large-scale vacuum

sweeping, and strictly enforcing the use of wet processing and recycling for all Construction and Demolition (C&D) waste materials to immediately curb the rising trend in RSPM.

3. Aggressive Electrification and Closed Transit Expansion: To reverse the escalating NO₂ trend, a rapid phase-out policy for high-emission commercial and private vehicles is required. Simultaneously, government investment must prioritize the large-scale expansion of closed, filtered public transit systems (metro and A/C bus fleets) to offer protected commuting environments, thereby directly mitigating the quantifiable health risk observed among users of open transport methods.
4. Integrated Environmental Epidemiology Surveillance: Implement universal, mandatory lung function screening (FEV₁/FVC) for high-exposure populations, including school-aged children and occupational workers near major emission sources. This surveillance will provide crucial, granular epidemiological data to objectively measure policy effectiveness and pinpoint priority areas for health intervention.

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