

# Air Pollution in India: Ecological, Health, and Socio-Economic Implications - A Review

Dr. Dinesh Kumar Tomar

Assistant Professor, Department of Zoology, Government Degree College, Kursanda, Hathras, Uttar Pradesh, INDIA

Corresponding Author: drdstomar@yahoo.co.in



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## ABSTRACT

Air pollution has emerged as one of the most critical environmental stressors of the 21st century, with India among the most affected countries globally. The rapid pace of urbanization, industrial expansion, and vehicular growth has elevated concentrations of particulate matter (PM 2.5 and PM10), nitrogen oxides, sulfur dioxide, ozone, and volatile organic compounds to hazardous levels. This review synthesizes literature published between 2000 and 2025 to examine the ecological, health, and socio-economic implications of air pollution in India. The review analyzes major pollution sources including vehicular emissions, coal-based power plants, stubble burning, household biomass use, and urban dust. Ecological impacts include ozone-induced crop yield losses, reduced forest productivity, urban biodiversity decline, and contamination of aquatic and soil systems. Public health consequences are severe, with over 1.6 million premature deaths annually linked to respiratory, cardiovascular, neurological, and maternal-child health conditions. Vulnerable populations such as children, women, the elderly, and outdoor workers face disproportionate risks. Socio-economic burdens include reduced labor productivity, escalating healthcare costs, agricultural losses, and damage to tourism and cultural heritage, amounting to nearly 8.5% of India's GDP.

The study highlights mitigation strategies such as the National Clean Air Programme (NCAP), Bharat Stage VI vehicular norms, and clean household energy initiatives, while noting enforcement gaps and governance challenges. Future research needs include satellite-ground data integration, AI-driven forecasting, and citizen science approaches. Ensuring clean air in India is therefore a public health imperative, ecological necessity, and economic opportunity.

**Keywords-** Air pollution, India, PM2.5, Stubble burning, Biodiversity, Public health, NCAP, Climate change.

## I. INTRODUCTION

Air pollution is widely recognized as one of the gravest environmental and public health challenges of the 21st century. According to the **World Health Organization (WHO)**, nearly 99% of the global population breathes air that exceeds recommended safety limits, with low- and middle-income countries disproportionately affected (WHO, 2022). Rapid urbanization, expanding industrial activity, and the exponential growth of vehicular fleets have contributed to unprecedented emissions of pollutants, including particulate matter (PM2.5 and PM10), nitrogen oxides (NOx), sulfur dioxide (SO<sub>2</sub>), carbon monoxide (CO), volatile organic compounds (VOCs), and ground-level ozone (O<sub>3</sub>). These pollutants not only degrade air quality

but also drive climate change by altering atmospheric chemistry and radiative balance (IPCC, 2021).

Within this global context, India has emerged as one of the most affected nations. The State of Global Air Report (Health Effects Institute, 2023) ranked India among the countries with the highest population-weighted PM2.5 exposure. The Indo-Gangetic Plain, home to hundreds of millions of people, consistently records some of the worst air quality levels worldwide, with seasonal smog episodes in Delhi and surrounding regions drawing international attention (Chowdhury et al., 2019). Major sources of India's air pollution include transport emissions, industrial combustion, construction dust, coal-fired thermal power plants, and agricultural stubble burning (Guttikunda & Calori, 2013; CPCB, 2020).

The impacts of air pollution in India extend far beyond atmospheric degradation. On the **health front**, prolonged exposure to polluted air is a leading risk factor for premature mortality and morbidity, particularly from respiratory and cardiovascular diseases (Balakrishnan et al., 2019). Ecologically, elevated ozone levels reduce crop yields of wheat, rice, and soybean, while fine particulates disrupt soil and freshwater systems (Ghude et al., 2014). Socio-economically, the productivity losses, healthcare burdens, and livelihood disruptions caused by polluted air amount to billions of dollars annually (World Bank, 2021).

Given its multidimensional consequences, there is a pressing need for integrative research that synthesizes findings across environmental, health, and socio-economic domains. This review seeks to evaluate recent evidence (2000–2025) on sources and impacts of air pollution in India, highlight ecological, health, and socio-economic implications, assess national policy interventions such as the National Clean Air Programme (NCAP), and identify research gaps that demand interdisciplinary approaches. By situating India's experience within the global discourse on air quality, the paper emphasizes both the urgency of mitigation and the opportunities for sustainable transformation.

## II. SOURCES OF AIR POLLUTION IN INDIA

Air pollution in India arises from a complex interplay of anthropogenic and natural sources. While natural contributors such as dust storms and forest fires play a role, anthropogenic sources overwhelmingly dominate due to rapid industrialization, urban expansion, and unsustainable agricultural practices. The following subsections highlight the primary contributors.

### ***Vehicular Emissions***

The exponential rise in private vehicles in Indian cities has significantly worsened air quality. Automobiles emit high levels of particulate matter (PM<sub>2.5</sub> and PM<sub>10</sub>), nitrogen oxides (NO<sub>x</sub>), carbon monoxide (CO), and volatile organic compounds (VOCs). According to the Central Pollution Control Board (CPCB, 2020), road transport contributes 20–30% of urban PM<sub>2.5</sub> in megacities like Delhi and Mumbai. Diesel-powered vehicles, especially trucks and buses, are particularly harmful due to their high emission factors (Kandlikar & Ramachandran, 2000; Sahu et al., 2011). Despite implementation of Bharat Stage VI (BS-VI) norms in 2020, vehicular emissions remain a dominant source of urban smog.

### ***Industrial Emissions and Thermal Power Plants***

India's heavy reliance on coal-fired power plants contributes substantially to emissions of SO<sub>2</sub>, NO<sub>x</sub>, and fine particulates. Studies estimate that coal combustion alone is responsible for more than 50% of SO<sub>2</sub> emissions in the country (Guttikunda & Calori, 2013). Major industrial clusters, including those in

Delhi-NCR, Singrauli, Dhanbad, and Korba, are hotspots for sulfur dioxide and particulate matter pollution. Industrial processes such as cement, brick kilns, and steel production also add to regional air quality degradation (Sharma & Dikshit, 2016).

### ***Agricultural Stubble Burning***

One of the most visible seasonal contributors to air pollution in northern India is the burning of crop residues, particularly rice and wheat stubble in Punjab and Haryana. Satellite data and ground-based monitoring confirm that stubble burning significantly elevates PM<sub>2.5</sub> levels during October–November, contributing to Delhi's infamous "winter smog" (Cusworth et al., 2018). Despite governmental promotion of alternatives such as Happy Seeders and subsidies for residue management, socio-economic barriers continue to drive farmers toward burning as a low-cost solution (Gupta et al., 2019).

### ***Household Biomass and Solid Fuel Use***

In rural and peri-urban India, the use of biomass fuels (wood, dung, crop residues) and coal for cooking and heating remains a major source of indoor and outdoor air pollution. Indoor smoke contains high concentrations of PM<sub>2.5</sub>, CO, and polycyclic aromatic hydrocarbons (PAHs). The Global Burden of Disease Study (Balakrishnan et al., 2019) estimated that household air pollution from solid fuels accounted for over 480,000 premature deaths in India annually. Initiatives like the Pradhan Mantri Ujjwala Yojana (PMUY) have expanded LPG access, but affordability and cultural preferences sustain reliance on biomass in many regions (Smith et al., 2014; Dhamija & Kumar, 2021).

### ***Construction, Road Dust, and Other Urban Sources***

Rapid urban expansion and infrastructure development have intensified dust pollution. Construction activities, unpaved roads, and resuspension of dust by vehicular movement contribute significantly to PM<sub>10</sub> concentrations in cities (Tiwari et al., 2013). In Delhi, road dust alone accounts for 30–35% of PM<sub>10</sub> levels during peak traffic hours (CPCB, 2019). Open waste burning, another overlooked source, releases a mix of fine particulates, dioxins, and heavy metals, further compounding urban air quality challenges (Nagpure et al., 2015).

### ***Natural Sources***

Though overshadowed by anthropogenic emissions, natural processes also influence air quality. Dust storms originating from the Thar Desert and West Asia episodically increase PM<sub>10</sub> levels in northwestern India, while forest fires in central and northeastern states release smoke and particulates (Middleton, 2017; Kumar et al., 2020). The interaction of these natural events with anthropogenic pollutants often amplifies smog episodes.

Air pollution in India is multifactorial, with vehicular emissions, coal combustion, stubble burning, biomass use, and urban dust as dominant drivers. The relative contributions vary spatially and seasonally, with

megacities and agrarian belts facing unique challenges. Understanding these sources is crucial for designing targeted mitigation strategies under national programs such as the **National Clean Air Programme (NCAP)**.

### III. ECOLOGICAL IMPACTS

Air pollution not only threatens human health but also disrupts ecological systems that underpin biodiversity, agriculture, and ecosystem services. Pollutants such as ground-level ozone, sulfur dioxide, nitrogen oxides, and particulate matter alter plant physiology, soil chemistry, and aquatic ecosystems, while also affecting wildlife. In India, these ecological consequences are increasingly visible across agricultural landscapes, urban ecosystems, and forested regions.

#### *Impacts on Agriculture and Crop Productivity*

Ground-level ozone ( $O_3$ ), formed by photochemical reactions between  $NO_x$  and VOCs, is one of the most significant pollutants affecting crops. Studies show that elevated  $O_3$  levels reduce photosynthesis, impair stomatal conductance, and accelerate senescence in major crops such as wheat, rice, and soybean (Ghude et al., 2014). In the Indo-Gangetic Plain, cumulative ozone exposure has been linked to yield losses of up to 20–25% in wheat and 10–15% in rice, threatening India's food security (Emberson et al., 2018).

Particulate matter also affects crops by reducing sunlight penetration and depositing toxic metals on leaves, impairing growth and grain quality (Singh & Agrawal, 2017). A field-based study near Varanasi demonstrated that wheat and mustard grown adjacent to highways had stunted growth and reduced yield due to vehicular PM and heavy metal deposition (Agrawal et al., 2010).

#### *Effects on Forests and Vegetation*

Forests act as vital carbon sinks, but exposure to air pollutants undermines their ecological services. Sulfur dioxide and nitrogen oxides contribute to soil acidification and nutrient leaching, altering forest productivity and species composition (Tripathi et al., 2012). In peri-urban forests near Delhi and Lucknow, lichen diversity — a sensitive bioindicator — has sharply declined due to persistent  $SO_2$  and  $NO_x$  pollution (Saxena et al., 2015). Tree species such as neem (*Azadirachta indica*) and peepal (*Ficus religiosa*) show foliar injury, chlorosis, and reduced biomass when exposed to high particulate and gaseous loads (Singh & Verma, 2007).

#### *Urban Biodiversity and Wildlife*

Urban ecosystems are particularly vulnerable to air pollution. Avian species, especially house sparrows (*Passer domesticus*), crows, and pigeons, experience respiratory stress, reduced reproductive success, and altered foraging patterns in smog-prone cities like Delhi (Sahu & Saxena, 2019). Studies using histopathological analysis of pigeon lungs in Kolkata found particulate

deposition leading to tissue damage and fibrosis (Mukherjee et al., 2016). Pollutants also impair insect diversity, which in turn affects urban food webs. Pollinator decline in polluted cities reduces seed set in native flowering plants, disrupting urban ecological resilience (Sharma et al., 2019).

#### *Aquatic and Soil Ecosystems*

Atmospheric deposition of pollutants, particularly nitrogen oxides and sulfur compounds, impacts freshwater and soil systems. Acid rain, though less severe in India compared to industrialized nations, has been reported in industrial belts of Maharashtra and Madhya Pradesh, altering soil pH and reducing microbial activity (Rao et al., 2015). Deposition of heavy metals from vehicular and industrial emissions contaminates agricultural soils and river sediments, bioaccumulating in fish and affecting aquatic biodiversity (Chakraborty et al., 2019). For example, high lead and cadmium loads were recorded in Yamuna river sediments downstream of Delhi, with direct effects on fish health and breeding (Rani et al., 2020).

### IV. ECOSYSTEM SERVICES AT RISK

Air pollution compromises multiple ecosystem services critical to human well-being:

- **Provisioning services:** reduced crop yields and quality.
- **Regulating services:** weakened carbon sequestration by forests due to impaired growth.
- **Supporting services:** loss of pollinator populations reducing plant reproduction.
- **Cultural services:** deterioration of green spaces and visibility affecting tourism and recreation (World Bank, 2021).

The ecological impacts of air pollution in India are multifaceted, affecting crops, forests, urban biodiversity, aquatic ecosystems, and ecosystem services. These impacts translate into cascading risks for food security, climate mitigation, and human well-being. Understanding these ecological dimensions is critical for designing effective mitigation and adaptation strategies.

### V. HUMAN HEALTH CONSEQUENCES

Air pollution poses one of the greatest public health challenges of the 21st century, and India is among the countries most severely affected. The **Global Burden of Disease (GBD) Study (Balakrishnan et al., 2019)** estimated that air pollution contributed to over 1.67 million premature deaths in India in 2019 alone, primarily through cardiopulmonary disorders. Both ambient (outdoor) and household (indoor) pollution interact to produce a wide spectrum of acute and chronic health outcomes.

### **Respiratory Diseases**

Particulate matter (PM<sub>2.5</sub> and PM<sub>10</sub>) penetrates deep into the respiratory tract, causing inflammation, impaired lung function, and increased susceptibility to infections. Children in highly polluted cities such as Delhi show reduced lung capacity compared to those in cleaner environments (Kumar et al., 2015). Air pollution exacerbates asthma, bronchitis, and chronic obstructive pulmonary disease (COPD), with hospital admissions peaking during severe smog episodes in northern India (Dey et al., 2018). Household biomass burning further aggravates respiratory conditions, particularly among women and children exposed to indoor smoke (Smith et al., 2014).

### **Cardiovascular Impacts**

Long-term exposure to fine particulate matter and gaseous pollutants elevates risks of hypertension, stroke, and ischemic heart disease. A multi-city cohort study reported that every 10 µg/m<sup>3</sup> increase in PM<sub>2.5</sub> was associated with significant increases in cardiovascular mortality (Cohen et al., 2017). In India, the Indo-Gangetic Plain records some of the highest cardiovascular disease burdens linked to air pollution (Lelieveld et al., 2020). Oxidative stress and systemic inflammation induced by pollutants are key mechanisms underlying these outcomes.

### **Neurological and Cognitive Effects**

Emerging research highlights the neurotoxic effects of prolonged air pollution exposure. Studies suggest associations between PM<sub>2.5</sub> exposure and cognitive decline, depression, and increased risk of neurodegenerative diseases such as Alzheimer's (Power et al., 2016). Evidence from Delhi schools indicates that children exposed to chronic smog demonstrate reduced attention spans and poorer academic performance (Sahu & Singh, 2019). Neurodevelopmental delays in infants have also been linked to maternal exposure to high PM<sub>2.5</sub> during pregnancy (Chauhan et al., 2020).

### **Maternal and Child Health**

Pregnant women exposed to high levels of air pollution face increased risks of preterm birth, low birth weight, and neonatal mortality (Kumar & Singh, 2021). Children, due to their developing lungs and higher breathing rates, are particularly vulnerable. The **Lancet Planetary Health Report (2019)** highlighted that ambient air pollution was a leading contributor to infant mortality in India, especially in rural areas where indoor smoke compounds risks.

## **VI. VULNERABLE AND OCCUPATIONAL GROUPS**

The health burden of air pollution is unevenly distributed. Vulnerable groups include:

- **Children and elderly**, who have weaker respiratory and immune defenses.
- **Women in rural households**, disproportionately exposed to indoor biomass smoke.

- **Outdoor workers** (traffic police, street vendors, construction workers), who are subjected to prolonged ambient exposure.
- **Slum dwellers**, who face combined risks of poor ventilation, waste burning, and traffic emissions (Nagpure et al., 2015).

### **Public Health Burden**

The combined health burden translates into enormous socio-economic costs. The **World Bank (2021)** estimated that air pollution-related health damages cost India nearly 8.5% of its GDP annually through healthcare expenditure and productivity losses. These impacts undermine national development goals and place unsustainable pressure on the healthcare system.

Air pollution in India has severe and wide-ranging health impacts, from respiratory and cardiovascular diseases to neurological disorders and adverse birth outcomes. Vulnerable populations — children, women, elderly, and outdoor workers — bear a disproportionate share of the burden. The scale of mortality and morbidity highlights the urgent need for robust mitigation strategies integrating health into air quality policy.

### **Socio-Economic Burdens**

The impacts of air pollution extend far beyond ecological degradation and health risks, imposing heavy socio-economic costs on individuals, communities, and the nation as a whole. In India, the economic burden of pollution manifests in reduced labor productivity, escalating healthcare expenditures, agricultural losses, and diminished quality of life. These costs undermine poverty alleviation, sustainable development, and the country's long-term economic growth.

### **Productivity Losses**

Air pollution reduces the efficiency and availability of labor by causing illness, absenteeism, and premature mortality. Workers exposed to high levels of PM<sub>2.5</sub> and ozone often report fatigue, respiratory illness, and diminished work performance (Graff Zivin & Neidell, 2018). A World Bank study (2021) estimated that lost labor income from air-pollution-related mortality in India accounted for nearly USD 30 billion annually. In metropolitan areas such as Delhi, smog-related school and office closures disrupt economic activity, compounding losses across sectors.

### **Healthcare Costs**

The direct financial costs of treating air pollution-related diseases add substantial burdens to India's healthcare system. Treatment of respiratory, cardiovascular, and neurological conditions linked to poor air quality requires long-term medical intervention and hospitalization. Out-of-pocket expenditures are particularly high for low-income households, pushing many into poverty. According to the **Lancet Planetary Health (2019)**, India's air pollution-related health care costs exceed 1.4% of its GDP annually.

### *Agricultural and Livelihood Impacts*

Air pollution has profound consequences for agricultural productivity. Ozone-induced yield losses in rice and wheat — India's staple crops — reduce farmer incomes and exacerbate food insecurity (Ghude et al., 2014; Emberson et al., 2018). Dust deposition on crops reduces photosynthesis and contaminates produce with heavy metals. Livestock are also affected: reduced fodder quality and polluted water sources impair animal health and productivity, jeopardizing the livelihoods of rural households dependent on mixed farming systems.

### *Tourism and Cultural Heritage*

Poor air quality undermines India's tourism industry, especially in heavily polluted cities such as Delhi, Agra, and Varanasi. Smog episodes deter domestic and international visitors, while deposition of pollutants accelerates the deterioration of monuments such as the Taj Mahal, which suffers discoloration due to particulate and sulfur dioxide deposition (Bergin et al., 2015). Tourism-related economic losses are significant but often underreported in national accounts.

### *Inequities and Disproportionate Burden*

The socio-economic burdens of air pollution are not evenly distributed. Vulnerable populations — including slum dwellers, daily wage earners, women, and children — face disproportionate exposure and limited access to healthcare (Nagpure et al., 2015). The rural poor are doubly burdened by indoor biomass smoke and reduced agricultural productivity. This inequitable distribution exacerbates existing social inequalities and hinders progress toward the Sustainable Development Goals (SDGs).

### *Macroeconomic Consequences*

At the national scale, the cumulative economic damage from air pollution is staggering. The **World Bank (2021)** estimated that India loses approximately 8.5% of its GDP annually to health damages and productivity losses linked to air pollution. This drag on economic performance affects industrial output, agricultural growth, and human capital formation, creating long-term structural challenges for development planning.

The socio-economic impacts of air pollution in India are multidimensional, spanning lost productivity, increased healthcare costs, agricultural losses, and damage to tourism and cultural assets. The burdens fall disproportionately on vulnerable groups, intensifying inequality. At the macroeconomic level, air pollution significantly reduces GDP growth, making clean air not only an environmental and health priority but also a fundamental economic necessity.

## VII. POLICY AND MITIGATION STRATEGIES

India has adopted a range of policies and mitigation strategies to tackle its escalating air pollution

crisis, though the results so far remain mixed. The launch of the **National Clean Air Programme (NCAP)** in 2019 marked the first coordinated national-level effort to manage air quality, setting ambitious targets of reducing PM<sub>2.5</sub> and PM<sub>10</sub> concentrations by 20–30% in 132 non-attainment cities by 2024. The plan emphasized strengthening monitoring networks, preparing city-specific action plans, and enhancing public awareness. However, progress has been constrained by limited funding, weak institutional coordination, and inconsistent enforcement, with reductions in pollutant levels falling short of expectations. In Delhi and the National Capital Region, the **Graded Response Action Plan (GRAP)** was introduced to address severe smog episodes through measures such as restricting construction activities, halting diesel generator use, and implementing traffic restrictions. While GRAP has improved short-term responsiveness during pollution peaks, critics argue that it is largely reactive and fails to address the structural drivers of poor air quality.

At the same time, India has pursued transitions toward cleaner fuels and energy systems. The nationwide implementation of **Bharat Stage VI (BS-VI) vehicle emission standards** in 2020 and the **Pradhan Mantri Ujjwala Yojana (PMUY)**, which expanded access to liquefied petroleum gas (LPG) for rural households, represent important steps in curbing vehicular and household emissions. In the energy sector, India has committed to a renewable energy target of 450 GW by 2030, signaling a gradual move away from fossil fuels, though coal still dominates electricity production and remains a major source of SO<sub>2</sub> and particulate matter. Technological innovations such as smog towers, dust suppression systems, and electric vehicle promotion under the FAME II scheme have also been introduced, but their large-scale impact is limited by high costs, infrastructural gaps, and slow adoption rates.

Civil society and local communities have increasingly contributed to mitigation through awareness campaigns, citizen science initiatives, and advocacy for stricter regulations. International collaboration has also shaped India's strategies, with air quality management increasingly linked to climate action under the Paris Agreement and global Sustainable Development Goals. Despite these efforts, significant challenges persist, including fragmented governance between central, state, and municipal authorities, inadequate monitoring infrastructure in rural areas, weak enforcement of emission standards, and socio-economic barriers to the adoption of clean technologies. Overall, while India has taken important policy steps to mitigate air pollution, the effectiveness of these measures depends on stronger enforcement, deeper integration of air quality and climate policies, and long-term political and financial commitment.

## VIII. RESEARCH NEEDS AND FUTURE DIRECTIONS

Despite significant advances in understanding air pollution and its impacts in India, important gaps remain that require sustained research and policy attention. One of the foremost needs is the expansion of long-term and spatially diverse monitoring networks, since existing infrastructure is heavily concentrated in urban centers while rural and peri-urban areas—where household biomass burning, agricultural residue burning, and small-scale industries contribute substantially—remain under-monitored. Reliable, high-resolution data are essential for developing accurate emission inventories, refining air quality models, and guiding localized interventions. In addition, there is a pressing need for interdisciplinary research that integrates atmospheric science with public health, ecology, and socio-economic studies. Such approaches would help clarify the pathways by which air pollution translates into disease burdens, biodiversity loss, and economic impacts, while also identifying co-benefits of cleaner energy transitions for climate mitigation.

Future research should also emphasize vulnerable populations, including children, women, and outdoor workers, who bear a disproportionate health burden but are often underrepresented in epidemiological studies. Similarly, the ecological consequences of air pollution, particularly its interactions with climate change and land use, require greater exploration through long-term field experiments and modeling studies. Another priority is the assessment of the effectiveness of current mitigation strategies such as the NCAP, GRAP, and Bharat Stage VI vehicle standards. Independent evaluations can reveal implementation gaps and guide adaptive policy-making. Emerging technological solutions like electric mobility, clean cooking systems, and dust suppression infrastructure also warrant systematic studies on feasibility, scalability, and socio-economic acceptance.

Looking ahead, India's future research agenda must not only address the scientific dimensions of air pollution but also strengthen the institutional and policy frameworks needed to act on this knowledge. Enhanced collaboration between academic institutions, government agencies, civil society, and international organizations can foster innovation and capacity-building. Moreover, integrating citizen science initiatives with official monitoring can improve data coverage and public engagement. Ultimately, advancing research and future strategies will require bridging the gap between knowledge generation and policy implementation, ensuring that scientific insights translate into effective action for clean air, public health, and sustainable development.

## IX. CONCLUSION

Air pollution in India represents a multifaceted crisis that spans environmental degradation, public health challenges, and socio-economic costs, making it one of the most urgent sustainability issues of our time. This review has shown that particulate matter, ozone, sulfur dioxide, nitrogen oxides, and other pollutants significantly undermine agricultural productivity, forest health, biodiversity, and ecosystem services, while simultaneously contributing to rising burdens of respiratory, cardiovascular, neurological, and maternal-child health problems. These health consequences translate into substantial socio-economic losses through reduced labor productivity, escalating healthcare expenditures, agricultural yield reductions, and damage to tourism and cultural heritage. Although India has introduced notable policy measures such as the National Clean Air Programme, the Graded Response Action Plan, Bharat Stage VI emission standards, and renewable energy targets, progress remains uneven due to enforcement gaps, overdependence on coal, and persistent inequalities in exposure and vulnerability. Looking forward, addressing this complex challenge requires not only stricter implementation of existing policies but also a stronger integration of scientific research, health-based interventions, and climate-compatible strategies. Community participation, technological innovation, and international collaboration will be critical in moving from reactive crisis management toward preventive, sustainable air quality governance. Ultimately, securing clean air in India is not only a public health imperative but also an ecological necessity and an economic opportunity for building a healthier and more resilient society.

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