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Pollution Paradox: Addressing Air Quality in Indian Metropolitan Regions

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Abstract: There is a paradoxical situation where economic prosperity and declining air quality coexist in Indian metropolitan zones due to the fast urbanization and industrialization of these areas. This study investigates the intricate issues surrounding air pollution in urban areas of India, looking at the root causes, the effects on the environment and public health and the various approaches needed to reduce pollution levels. This review provides a thorough overview of the pollution paradox and makes recommendations for long-term solutions to enhance air quality in Indian metropolitan areas. In order to effectively handle this complicated situation, a multimodal strategy is needed that includes technical advancements, public awareness campaigns, regulatory interventions, and community participation efforts. In order to encourage cleaner fuels, enforce stricter emission limits, and reward sustainable transportation options, policy frameworks need to be enhanced.

Keywords: Air pollution, Air quality, Indian metropolitan regions, Climate change

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Introduction

Rapid urbanization has resulted in a deluge of socio-economic benefits and catastrophic environmental issues. In addition, one of the grave problems faced by the metro cities across India are air pollution (Singhal and Verma, 2023), which poses threats to public health (Kaur and Pandey, 2021) and the environment (Manisalidis *et al.*, 2020), and may even endanger social stability (Du *et al.*, 2018). The confluence of increasing urbanization and declining air quality pave the way for pollution dilemma across Indian cities. This conundrum depends on the cornerstone of national assessments because of its complexity, wide-ranging effects and significant implications for environmental sustainability, socioeconomic development and public health. Millions of people are moving from rural to urban areas in India at a rapid rate in quest of better living conditions and employment possibilities (Singh, 2016). The concentration of people and economic activity in metropolitan areas are the result of the trend toward urbanization and the growth of industry. Air pollution levels are greatly increased as a result of the rise in vehicle traffic, industrial

emissions, construction activity and garbage generation. The dense population of Indian urban areas contributes to a rise in emissions from a variety of sources, such as automobiles, industries, homes and businesses. Pollution exposure is worse by the proximity of residential areas to industrial zones and transportation corridors, especially for vulnerable people residing in low-income communities. Fossil fuels, including coal, oil and natural gas, are burned more frequently in urban areas due to the rising need for energy for transportation, industry and the production of electricity. Automobile emissions make up a sizeable amount of the overall pollution levels and the widespread use of motor vehicles in Indian metropolitan areas is a key contributor to air pollution. The situation is made worse by the usage of antiquated vehicles, poor maintenance procedures and insufficient emission control systems, which raise the levels of air pollutants. Thus, this review illustrates the effects of pollution, particularly on air quality across India's major cities.

Major factors and sources

As air pollution puts city dwellers' health at risk, it is a major concern in megacities where pollution levels frequently above allowable limits (Chattopadhyay *et al.*, 2010; Debone *et al.,* 2020). Air pollution exposes India's urban centres to unsanitary and harmful circumstances (Dutta *et al.*, 2021). Over the past few decades, urban air pollution in India's megacities has been alarmingly increasing (Faheem *et al.*, 2021) which is an imminent environmental problem. Primary or secondary air pollutants can be significant interior and outdoor air pollutants in metropolitan settings. Particulate matter, respirable particulate matter (RPM), suspended particulate matter (SPM), SO_2, NO_2, CO, ammonia and dust particles are among the primary air pollutants that are directly released into the atmosphere. Secondary air pollutants include smog, ozone and Peroxyacyl Nitrates (PANs), among others. The pollution dilemma is made worse by a number of interrelated issues that contribute to air pollution in Indian metropolitan areas. It is essential to comprehend these elements in order to create strategies that effectively address issues related to air quality. Figure 1 depicts Major sources of air pollution in Indian cities. Followings are some key contributors:

- *Industrial Emissions*: In urban areas of India, industries are one of the main causes of air pollution. Particulate matter (PM), Sulfur dioxide, Nitrogen oxide and Volatile Organic Compounds (VOCs) are among the pollutants released by manufacturing operations, including those in the textile, chemical and construction industries. Many companies lack proper pollution control methods and still rely on antiquated technologies.
- *Vehicular Exhaust*: In urban areas, the number of cars, trucks, buses and two-wheelers are growing at a rapid rate, which greatly contributes to air pollution. Pollutants include carbon monoxide, nitrogen dioxide, hydrocarbons, and particulate matter is released by vehicles. Emissions levels are made worse by things like old car fleets, inadequate maintenance and traffic.
- *Biomass Burning*: The use of biomass for cooking and heating purposes, particularly in rural and peri-urban areas surrounding metropolitan regions, contributes to air pollution. Traditional cooking practices, such as burning wood, crop residues, and cow dung, release pollutants such as particulate matter (PM), carbon monoxide (CO), and volatile organic compounds (VOCs) into the atmosphere.
- *Construction and Demolition Activities*: Metropolitan regions experience a great deal of building and demolition activity as a result of rapid infrastructure development and urbanization. The earthmoving, building material, and excavation processes produce dust and particulate matter (PM). The amount of particulate matter in the air is increased at

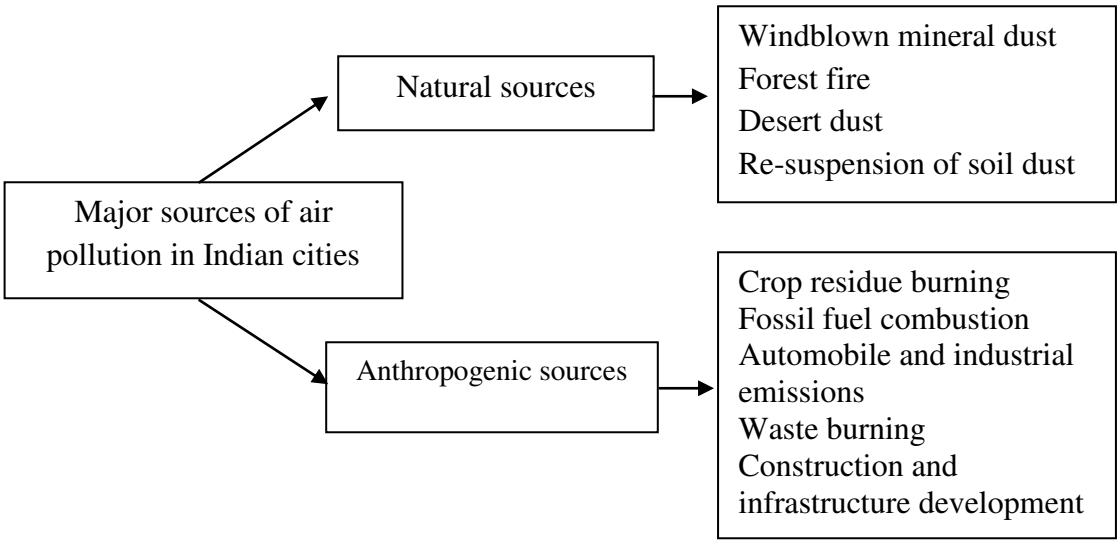

Fig 1: Major sources of air pollution in Indian cities.

building sites due to insufficient dust management techniques.

- *Power Generation*: Within Indian urban areas, one of the main causes of air pollution is the reliance on coal-fired power plants for the production of electricity. Pollutants including sulfur dioxide, nitrogen oxides, particulate matter (PM), and mercury are released into the atmosphere during the burning of coal. Reducing emissions from electricity generation requires a shift to greener energy sources, like natural gas and renewable energy.
- *Waste Burning and Landfills*: Inadequate landfill management and open burning of rubbish are two examples of improper waste management practices that lead to air pollution in urban areas. When municipal solid waste is burned, harmful substances, carbon monoxide (CO) and particulate matter (PM) are released into the atmosphere. Landfill methane emissions are a contributing factor to both climate change and air pollution.
- *Geographical and Meteorological Factors*: The topography and meteorological circumstances of a certain area affect air pollution levels in urban areas. Air quality issues are made worse by elements like temperature inversions, which trap pollutants near to the ground and stagnant atmospheric conditions. Pollution levels are also influenced by seasonal fluctuations, such as patterns of the monsoon and crop burning in the post-harvest period as in the case of Delhi metropolitan area (Saxena *et al.*, 2021).

To tackle air pollution in urban areas of India, all-encompassing approaches that focus on various sources and factors of pollution are necessary. To reduce emissions and enhance urban inhabitants' access to clean air, these efforts ought to include technical advancements, public awareness campaigns, community involvement programs and regulatory measures.

Health Impacts

Recent decades have seen a significant increase in air pollution, which poses a considerable

toxicological risk to both the environment and human health. Given the connections between air pollution and a number of harmful health consequences, such as respiratory illnesses, cardiovascular conditions and early mortality, the pollution paradox has significant ramifications for public health (Ghorani-Azam *et al.*, 2016). The health effects of air pollution can exacerbate disparities in health outcomes for vulnerable populations, including children, the elderly and those with pre-existing medical illnesses. In addition to having a negative influence on human health, air pollution harms ecosystems, reduces biodiversity and accelerates climate change. Emissions of pollutants into the atmosphere aggravate ecological imbalances and environmental degradation by causing smog, acid rain and ozone depletion which all negatively affects human health (Mabahwi *et al.*, 2014). The major health implications are given below:

- *Respiratory Diseases*: Respiratory conditions such as asthma, bronchitis, chronic obstructive pulmonary disease (COPD), and respiratory infections are linked to exposure to air pollutants such as particulate matter (PM), nitrogen dioxide, sulfur dioxide, and ozone. Elevated PM levels have the ability to deeply enter the lungs, resulting in inflammation and aggravating respiratory ailments (Ünver *et al.*, 2019).
- Cardiovascular Disorders: Heart attacks, strokes, hypertension, and arrhythmias are among the cardiovascular conditions for which air pollution is associated with a higher risk. The circulation can be contaminated by fine particulate matter (PM2.5) and other pollutants, which can lead to endothelial dysfunction, oxidative stress, and systemic inflammation - all of which worsen cardiovascular health (Rajagopalan *et al.*, 2028).
- *Premature Mortality*: Research has shown that prolonged exposure to air pollution increases the risk of dying young from cardiovascular and respiratory diseases, making it a major risk factor for early mortality. According to estimates from the World Health Organization (WHO), air pollution causes millions of premature deaths worldwide each year, with urban dwellers in developing nations like India bearing a disproportionate share of the blame (Silva *et al.*, 2013*)*.
- *Neurological Effects*: There is growing evidence that air pollution may negatively impact neurological health and cognitive function. Children's neurodevelopmental diseases, such as attention deficit hyperactivity disorder (ADHD), autism spectrum disorders, and poor cognitive function, have been linked to prenatal exposure to air pollution (Costa *et al.*, 2020).
- *Vulnerable Populations*: The health effects of air pollution are more dangerous for several demographic groups, such as children, the elderly, pregnant women, and people with pre-existing medical disorders. The growing respiratory and immune systems of children make them particularly vulnerable, and those with underlying medical disorders and the elderly are more likely to have an exacerbation of pre-existing ailments (Maharjan *et al.*, 2022). Table 1 portrays Different health consequences with the most prevalent pollutants.

In short, air pollution in metropolitan regions poses significant health and environmental risks, with adverse effects on respiratory health, cardiovascular function, neurological development, ecosystems, and climate stability. Addressing these impacts requires concerted efforts to reduce emissions, improve air quality monitoring and management, and promote sustainable development practices that prioritize human health and environmental protection.

Government initiatives

The National Clean Air Programme (NCAP) was initiated by the Indian government as a nationwide initiative to lower air pollution levels. In the Budget of FY 2020–21, ₹ 4400 crores have

Table 1: Different health consequences that the most prevalent pollutants at higher levels experience [Modified from Botkin and Keller (2007); Mabahwi *et al.* (2014)]

Pollutant	Description	Health effects
Ozone	Colourless gas with slightly sweet odor	These gases irritate the airways of the lungs, increasing the symptoms of those suffering from lung diseases, strong irritant, aggravates asthma, causes injury to cells in the respiratory system, coughing, chest discomfort, eye irritation
Particulate matter	Very small particles	Fine particles can be carried deep into the lungs where they can cause inflammation and a worsening of heart and lung diseases
Carbon monoxide	Colourless, odourless gas	This gas prevents the uptake of oxygen by the blood. This can lead to a significant reduction in the supply of oxygen to the heart, particularly in people suffering from heart disease. Causes headache, fatigue, nausea
Nitrogen oxide	Most are colourless and odourless, NO_2 with particles is reddish-brown	Non-irritating gas may aggravate respiratory infections and symptoms (sore throat, cough, nasal congestion, and fever), increase the risk of chest cold, bronchitis, and pneumonia in children.
Sulphur dioxide	Colourless, odourless gas	Increase in chronic respiratory disease, shortness of breath, narrowing of airways for people with asthma
Lead	Heavy metal	Children most at risk; brain damage, behaviour problems, nerve disorders, digestive problems

been allocated to address the issue of air pollution for 42 cities and urban agglomerations with a population of one million or more, in accordance with the recommendations of the Fifteenth Finance Commission. For the 132 non-attainment cities that have been identified, as well as for the million+ cities that include metropolises, city-specific action plans have been created and are now being implemented in these cities. These action plans concentrate on short-, medium-, and long-term strategies tailored to each city to reduce air pollution from sources like construction, industrial emissions, burning of biomass and municipal solid waste, road dust, and vehicle emissions. In addition, hot spots have been identified and a Graded Response Action Plan and Public Grievance Redressal System have been devised. To track the development of the city action plan at the ground level, committees for the implementation of city level policies and Air Quality Management Cells (AQMC) at the level of Urban Local Bodies have also been established (MoEFCC, 2021).

The Way Ahead

The interplay of air pollution and climate change with urban climate and human health in cities of developing country such as India is under intense pressure. The environment has a significant impact on the temporal and spatial distribution of air pollution. A major contributor to climate change is stratospheric ozone depletion and greenhouse gas warming. The concentration of air pollutants and the creation of secondary pollutants can both be impacted by climate change. In addition to atmospheric characteristics,

geography and urban settlements, the climate also affects how pollutants disperse, accumulate and change in the atmosphere. According to D'Amato *et al.* (2002), the spread of these air pollutants may result in respiratory conditions such asthma, emphysema, allergies, and chronic bronchitis. Thus, concerted policy structures and stringent implementation are the need of the hour. The following are some of the key steps to be implemented for a better future:

- *Enhancing Policy Frameworks*: Stricter emission limits must be enforced, and current air quality laws and regulations must be strengthened. Adopting thorough air quality management strategies that cover pollution sources from all industries, including waste management, transportation, energy, and industry, should be a top priority for policymakers.
- *Promoting Clean Energy Transition*: It is imperative to expedite the shift towards clean and renewable energy sources, like hydroelectric, solar and wind power, in order to curtail greenhouse gas emissions and alleviate air pollution. This shift can be aided by providing incentives for the use of clean technology and gradually eliminating subsidies for fossil fuels.
- *Investing in Sustainable Transportation*: Reliance on personal automobiles can be decreased and cleaner forms of transportation can be encouraged by making investments in sustainable transportation infrastructure, such as bike lanes, public transportation networks, and pedestrian-friendly metropolitan areas. Other important tactics for lowering car emissions include promoting the use of electric vehicles and raising fuel quality regulations.
- *Strengthening Monitoring and Enforcement*: By implementing cutting-edge monitoring technologies and improving air quality monitoring networks, real-time data on pollution levels and sources may be obtained, allowing for focused interventions and enforcement measures. Imposing fines for non-compliance and fortifying regulatory enforcement systems are crucial for discouraging polluters and guaranteeing accountability.
- *Fostering Green Urban Planning*: Urban planning procedures can reduce pollutant exposure and encourage sustainable development by incorporating air quality issues. Urban infrastructure projects can improve livability and lessen pollution hotspots by incorporating green spaces, encouraging mixed land use, and putting pollution control systems in place.
- *Promoting Public Awareness and Education*: It is imperative to empower communities to take action and to educate the public about the harmful effects of air pollution on health. Campaigns for public awareness, educational activities, and citizen science projects can encourage behavior changes, increase support for pollution control measures, and increase knowledge of air quality issues.
- *Encouraging Collaborative Governance*: Coordinated action on air quality management can be facilitated by enhancing cooperative governance frameworks and developing alliances between government agencies, business stakeholders, civil society organizations, and communities. Key tenets of good governance include involving stakeholders in decision-making procedures and encouraging accountability and openness.
- *Investing in Research and Innovation*: The development of affordable pollution control technology, monitoring systems, and sustainable development plans all depend on research and innovation spending. Knowledge and solutions to solve air quality concerns can be generated by sponsoring research programs focused on pollution modelling, mitigation strategies, and air quality monitoring, as well as by supporting

multidisciplinary research collaborations.

- *Addressing Socio-economic Disparities*: An essential component of efficient air quality management is addressing socioeconomic inequalities and advancing social justice. Specific actions to enhance the quality of the air in underprivileged and marginalized neighborhoods can lower health disparities and encourage inclusive growth.
- *Strengthening International Cooperation*: For the purpose of managing air quality, strengthening international collaboration and partnerships can help with technology transfer, capacity building, and knowledge sharing. Enhancing transboundary air pollution and regional haze by cooperation with adjacent nations can improve the efficacy of air quality control initiatives.

To summarise, tackling the issues related to air quality in Indian metropolitan areas necessitates a multifaceted strategy that integrates technical advancements, governmental interventions, public participation and collaborative governance. Indian metropolitan areas can accomplish sustainable development objectives and raise the standard of living for all citizens by putting these suggestions into practice and giving the environment and public health top priority.

Conclusion

The paradox of pollution in Indian cities is a complex problem that needs quick attention and collaboration. Comprehensive strategies, such as technology developments, public awareness campaigns, policy interventions, and community participation initiatives, are required to address this conundrum. These will safeguard the environment, public health, and socioeconomic development while lowering pollution levels. Every day, in India's vast metropolitan areas, a perverse situation comes to pass: the dangerous effects of declining air quality combined with unparalleled urban growth. The challenge of striking a balance between economic growth and environmental sustainability embodies this contradiction, as rising pollution levels are a result of population growth, industrialization, vehicle emissions and unrestrained urbanization. The urgent need to address and mitigate air pollution, which seriously jeopardizes human health, environmental integrity, and general quality of life, is at the core of this contradiction. Indian metropolitan areas suffer from some of the highest levels of air pollution in the world, which is typified by high amounts of particulate matter, nitrogen dioxide, sulfur dioxide, ozone, and volatile organic compounds, while being hubs of innovation and economic activity. Robust monitoring and data-driven decision-making processes are equally vital for tracking pollution levels, locating pollution sources, and evaluating the effectiveness of mitigation strategies. In the end, resolving the pollution conundrum in Indian cities calls for a coordinated effort to advance social justice, environmental conservation and sustainable development which lead the path to more sustainable, healthier and clean urban environments for all by valuing innovation, encouraging teamwork and putting the welfare of present and future generations first.

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