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Air pollution in India: Public health impacts and environmental challenges – A review

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Abstract
Air pollution remains a significant environmental health challenge globally, driven by rapid industrial growth, urbanization, and increased reliance on fossil fuels. This review synthesizes current research on the main sources of air pollution and then assesses its effects on public health and the environment. Particulate matter, including PM2.5 and PM10, along with nitrogen oxides and sulfur dioxide, are important pollutants that are strongly linked to negative health effects. These effects include respiratory problems, heart and blood vessel diseases, and early death. Air pollution, beyond its direct effects on human health, significantly contributes to environmental decline. This includes serious environmental problems like climate change, the creation of acid rain, and the loss of biodiversity. The analysis dives into existing strategies for mitigation and policy measures designed to regulate emissions and enhance air quality. The results indicate that, despite ongoing efforts, challenges remain. These challenges are due to insufficient enforcement of existing regulations and the increasing sources of pollution. These sources include industrial emissions and vehicle exhaust, which together hinder efforts to improve air quality. Consequently, it is crucial to implement thorough monitoring systems, enforce stricter regulatory frameworks, and embrace sustainable technologies and practices to effectively mitigate air pollution and protect public health as well as environmental integrity.

Keywords: Air pollution, public health, environmental impact, respiratory diseases, climate change, pollutants

Introduction
Air pollution represents a significant environmental issue that threatens human health and the integrity of ecological systems globally (Chen *et al*. 2024) [5]. The term encompasses the presence of harmful atmospheric constituents, including particulate matter ($PM_{2.5}$ and PM_{10}), nitrogen oxides (NO_x), sulfur dioxide (SO_2), carbon monoxide (CO), and ground-level ozone (O_3). These pollutants originate from a variety of sources, both anthropogenic and natural (Meo *et al*. 2024) [20], such as industrial discharges, vehicular emissions, agricultural practices, biomass burning, and wildfires. The accelerated rate of industrialization, urbanization, and escalating energy demands has significantly intensified the emission of these pollutants, particularly within developing nations. In recent decades, air pollution has become a prominent global health risk factor (Nakhjiri and Kakroodi 2024) [23]. The World Health Organization (WHO) estimates that polluted air is responsible for millions of early deaths annually, primarily due to respiratory and cardiovascular ailments. Fine particulate matter, particularly $PM_{2.5}$, poses significant health hazards (Thangavel, Park, and Lee 2022) [32]. This is largely because it can get deep into the lungs and then into the bloodstream, impacting a wide range of people. Vulnerable populations, including children, the elderly, and those with pre-existing health issues, are disproportionately affected. Moreover, the environment suffers significantly from air pollution (Hooper and Kaufman 2018) [14].
The emission of greenhouse gases and short-lived climate pollutants, such as black carbon, significantly contributes to climate change. Consequently, atmospheric contaminants facilitate the genesis of acid rain, which subsequently degrades soil composition, disrupts aquatic environments, and adversely affects plant life (Bolan *et al*. 2024) [3]. Increased concentrations of ozone could conceivably diminish agricultural productivity and jeopardize food availability; moreover, sustained pollution may precipitate biodiversity decline and ecological instability.
Air pollution is a significant global issue, impacting nations across the spectrum of development. Its effects, however, are especially pronounced in areas undergoing swift urbanization, where population increases, and economic growth outstrips the implementation of environmental safeguards and the expansion of necessary infrastructure. Urban centres frequently exhibit elevated levels of pollutants, a consequence of factors such as traffic congestion, industrial clustering, and ongoing construction activities (Wang 2018) [40]. Despite increasing awareness and policy efforts, significant obstacles to effectively managing air pollution remain. These include insufficient monitoring systems, lax enforcement of environmental regulations, and a continued reliance on fossil fuels. Considering the extensive and varied effects of air pollution, it is essential to achieve a thorough understanding and adopt integrated strategies for mitigation (Galimova, Ram, and Breyer 2022) [10]. This review paper seeks to examine the current literature regarding the origins and makeup of air pollution, its implications for public health, and its consequences for the environment. Furthermore, the objective is to evaluate current mitigation strategies and policy interventions, highlighting the imperative for enduring practices and more stringent regulatory structures to address this pressing global issue.

Sources of Air Pollution
Air pollution arises from a multifaceted interplay between anthropogenic actions and natural phenomena, both of which contribute to the accumulation of deleterious pollutants within the atmosphere. Comprehending these sources is crucial for formulating effective strategies to mitigate pollution and establish suitable regulatory frameworks (Li *et al*. 2025) [18].

Anthropogenic Sources

Anthropogenic sources are a major contributor to air pollution, especially in cities and industrial areas. The combination of economic growth, a growing population, and increased energy use has significantly increased emissions in many sectors. Industrial activities contribute significantly to the presence of air pollutants. Industrial operations, including factories, thermal power plants, and refineries, emit significant amounts of sulfur dioxide (SO_2), nitrogen oxides (NO_x), particulate matter, and volatile organic compounds (VOCs). Coal-fired power plants continue to be a significant energy source in many countries, which is linked to increased emissions of particles and sulfur (Sadykanova, Kumarbekuly, and Yessimbekova 2025) [28].

The transportation sector significantly contributes to environmental harm. Emissions from various vehicles, including cars, commercial trucks, public buses, and motorcycles, release pollutants into the atmosphere. These pollutants include carbon monoxide (CO), nitrogen oxides, hydrocarbons, and fine particulate matter. The rapid increase in vehicle numbers, especially in cities, has worsened the decline in air quality. Furthermore, the combustion of fossil fuels, including coal, oil, and natural gas, for both energy production and domestic use, significantly exacerbates atmospheric pollution (Zhang and Batterman 2013) [43].

In many developing regions, the reliance on biomass fuels, such as wood, agricultural residues, and animal dung, for cooking and heating purposes, results in the emission of substantial quantities of both indoor and outdoor air pollutants. Agricultural practices significantly impact air quality, particularly through activities like crop residue burning, which releases substantial quantities of particulate matter and greenhouse gases (Yadav *et al*. 2024) [42]. Furthermore, the use of fertilizers and pesticides releases ammonia (NH_3) and other chemicals into the air. The chemicals that are released can then interact, which leads to the formation of secondary pollutants. Construction and mining operations also produce a significant amount of dust and particulate matter (Dziubak and Ślęzak 2025) [7]. Activities like excavation, moving materials, and demolition release coarse particles (PM_{10}), which can stay in the air and affect nearby communities.

Natural Sources

In addition to human actions, natural processes also significantly contribute to air pollution. These sources, though often episodic or seasonal, can exert considerable localized and regional impacts. Volcanic eruptions, for instance, release large amounts of ash, sulfur dioxide, and other gases into the atmosphere, which can potentially affect air quality over large areas. Similarly, forest fires, whether caused by natural events or human actions, release smoke, carbon monoxide, and particulate matter, which greatly reduces air quality (Almeida, Neves, and Duarte 2026) [2].

Dust storms are a notable natural occurrence, particularly in regions characterized by arid and semi-arid climates. These processes contribute to the movement of large amounts of mineral dust over long distances, which then increases the concentration of particles in the atmosphere. Sea salt aerosols, which arise from the interaction of ocean waves and wind, constitute a significant source of atmospheric aerosols, particularly in coastal regions (Filonchyk and Peterson 2022) [9]. While generally less harmful than pollutants from human activities, these emissions still affect atmospheric chemistry and the characteristics of particulate matter. Moreover, human actions often worsen the effects of natural sources, which contribute to air pollution. Human-caused emissions increase the total amount of pollutants and interact with natural processes, which worsen and prolong air quality problems. Therefore, managing human-caused sources is a crucial part of tackling air pollution, both locally and globally (Ofremu *et al*. 2025) [24].

Impact of Air Pollution on Public Health

Air pollution is a major global health problem, significantly contributing to illness and death in many populations. Inhalation of elevated levels of airborne contaminants has been clearly associated with a wide array of adverse health outcomes, affecting multiple organ systems. The severity of these effects depends on several factors, including the level of pollution, how long someone is exposed, and the person's individual vulnerability (Manisalidis *et al*. 2020) [19].

Respiratory Diseases

Breathing problems are a common and well-studied result of air pollution. When airborne pollutants, such as particulate matter ($PM_{2.5}$ and PM_{10}), ozone (O_3), and nitrogen oxides (NO_x), are inhaled, they can enter the lungs. This can cause inflammation and oxidative damage. Prolonged exposure to these environmental pollutants can lead to the development and worsening of respiratory diseases, including asthma, Chronic Obstructive Pulmonary Disease (COPD), and lung cancer (Hamanaka and Mutlu 2025) [12].

Fine particulate matter is especially detrimental, given its propensity to access the alveolar region and subsequently compromise pulmonary functionality. Children, the elderly, and those with pre-existing respiratory ailments constitute vulnerable populations that are disproportionately impacted. Specifically, in children, exposure to polluted air can impede lung development and elevate the likelihood of respiratory infections; conversely, older adults may experience exacerbated symptoms and diminished pulmonary function (Dondi *et al*. 2023) [6].

Cardiovascular Diseases

Cardiovascular diseases are also significantly affected by air pollution. Fine particulate matter can enter the bloodstream through the lungs, which then triggers inflammation and oxidative stress throughout the body. As a result, this process contributes to the development of atherosclerosis and other cardiovascular problems. Epidemiological studies have consistently shown a connection between prolonged exposure to air pollution and a higher risk of cardiovascular problems, including heart attacks, strokes, and high blood pressure (Hamanaka and Mutlu 2018) [11]. Moreover, short-term exposure to heightened pollution concentrations can precipitate acute cardiovascular events, particularly in individuals with pre-existing cardiac conditions. As a result, air pollution is recognized as a significant risk factor for cardiovascular-related illness and death worldwide (Miller 2022) [21].

Other Health Effects

Beyond its detrimental effects on the respiratory and cardiovascular systems, air pollution is linked to a range of additional health consequences. Individuals residing in areas with high pollution levels frequently report irritation of the

eyes, nose, and throat, potentially resulting in physical distress and a diminished quality of life (Nakaishi *et al*. 2024) [22]. Furthermore, extended exposure to air pollutants may exacerbate skin conditions, potentially leading to inflammation and accelerated skin aging. Studies have demonstrated that air pollution, including microplastics, can negatively impact lung function, and this effect isn't limited to those with pre-existing health issues (Verma 2025b) [34]. New research suggests possible links between air pollution and neurological and metabolic diseases, although more study is needed in these areas.

Air pollution, a significant environmental concern, presents considerable threats to the health of mothers and their children. Maternal exposure to environmental pollutants during pregnancy has been linked to negative outcomes, including low birth weight, premature birth, and developmental issues (Verma 2025d) [36]. These effects go beyond immediate health problems, potentially impacting a child's development throughout their life.

Environmental Impacts of Air Pollution

Air pollution significantly affects the environment, impacting ecosystems, natural resources, and global climate systems. In addition to its known effects on human health, the accumulation of atmospheric pollutants causes complex ecological disruptions, which can have lasting and often irreversible consequences (Shetty *et al*. 2023) [29].

Climate Change

Air pollution significantly worsens climate change, representing a major environmental problem. Greenhouse gases, including carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), contribute to the greenhouse effect by trapping heat within the Earth's atmosphere, thereby fostering global warming and climate instability. Furthermore, short-lived climate pollutants, such as black carbon and tropospheric ozone, substantially influence atmospheric temperature patterns. Consequently, these alterations can disrupt weather systems, increase the frequency of extreme events like heatwaves and floods, and jeopardize global water and food security. The interplay between air pollution and climate change establishes a feedback loop, thereby intensifying environmental degradation (Cassia *et al*. 2018) [4].

Acid Rain

Acid rain, a significant environmental problem, arises from the chemical changes of sulfur dioxide (SO_2) and nitrogen oxides (NO_x) in the atmosphere. When these pollutants mix with water vapor, they create sulfuric and nitric acids. These acids then fall to the ground as precipitation. The effects of acid rain can be quite harmful, impacting forests, soil, and freshwater ecosystems. It leaches vital nutrients from the soil, thereby diminishing its fertility, and releases toxic metals, including aluminium, which can be harmful to plant roots and aquatic organisms. Furthermore, in lakes and rivers, heightened acidity can disrupt aquatic life, consequently leading to reduced biodiversity and alterations in ecosystem functionality (Prakash, Agrawal, and Agrawal 2023) [25].

Damage to Vegetation

Airborne contaminants exert both direct and indirect influences on the vitality and productivity of plants. Ground-level ozone (O_3) is especially detrimental, capable of inflicting damage upon leaf tissues, diminishing photosynthetic efficiency, and stunting plant development. Exposure to these pollutants can manifest as visible harm, including chlorosis (leaf yellowing), necrosis (tissue death), and premature leaf abscission. Consequently, these effects ultimately diminish agricultural outputs and jeopardize food security. Forest ecosystems are also vulnerable. When trees are repeatedly exposed to pollutants, their health suffers. This makes them more susceptible to pests, diseases, and the effects of climate change (Agathokleous *et al*. 2020) [1].

Biodiversity Loss

Air pollution, which alters habitats and disrupts ecological balance, is a significant factor in the decline of biodiversity. Changes in the atmosphere and climate can affect where species live, how they reproduce, and their chances of survival. Species that are sensitive to environmental changes are at risk of population declines or even extinction, whereas those with greater adaptability may experience population increases, which could subsequently diminish ecosystem diversity. Furthermore, the synergistic impacts of acid deposition, climate change, and habitat degradation pose significant threats to wildlife populations and can destabilize ecosystems. Such disruptions not only affect individual species but also impair essential ecosystem services, including pollination, nutrient cycling, and carbon sequestration (Weiskopf *et al*. 2020) [41].

Air Pollution in Developing Countries

Air pollution constitutes a substantial environmental and public health concern within developing countries, a circumstance intensified by rapid urbanization, industrial expansion, population growth, and escalating energy demands. Urban areas across significant portions of Asia and Africa frequently experience perilous levels of particulate matter ($PM_{2.5}$ and PM_{10}), often exceeding globally recognized air quality benchmarks (Tavares *et al*. 2025) [31]. This issue is further compounded by the widespread use of fossil fuels and reliance on biomass for cooking and heating, coupled with inadequately controlled industrial emissions. Moreover, the ongoing problem of high pollution levels is significantly worsened by inadequate infrastructure, the lack of thorough air quality monitoring systems, and the ineffective implementation of environmental regulations. Informal economic activities, such as open waste burning and unregulated transportation systems, significantly increase the release of pollutants. The impact of these factors is particularly severe on low-income populations, who frequently encounter elevated pollution levels and face significant barriers to accessing healthcare resources (Joshi *et al*. 2025) [16]. The United Nations Environment Programme emphasizes the critical need for improved environmental governance, stronger regulatory frameworks, and the implementation of sustainable development strategies. To effectively address air pollution in developing countries, while also protecting human health and the environment, a combination of strategies is essential. The transition to clean energy, along with sustainable urban planning and increased public awareness, are all important part of the solution (Feng *et al*. 2025) [8].

Mitigation and Control Strategies

A comprehensive approach is essential for effectively reducing and managing air pollution. This approach should

include changes to policies, the use of new technologies, and the adoption of sustainable practices. Because air pollution is such a complex problem, we need to work together at local, national, and international levels (Rautela and Goyal 2024) [26].

Government Policies

To reduce air pollution, government action is crucial, primarily through the creation and enforcement of environmental regulations. To reduce the release of harmful pollutants into the atmosphere, it's crucial to implement strict emission standards for industries, power plants, and vehicles. Moreover, consistent air quality monitoring, facilitated by robust surveillance systems, allows governmental bodies to evaluate pollution levels and implement prompt remedial actions (Ross, Chmiel, and Ferkol 2012) [27]. In addition, encouraging the shift towards renewable energy sources, including solar, wind, and hydroelectric power, can substantially diminish reliance on fossil fuels, consequently reducing emissions. Policy initiatives, such as subsidies for the adoption of clean energy technologies, carbon pricing mechanisms, and urban planning reforms, also contribute to the advancement of sustainable development (Sohaib *et al*. 2025) [30].

Technological Solutions

Technological advancements are crucial for reducing air pollution. By using cleaner production technologies in industry, we can reduce emissions at the source. This not only increases efficiency but also lessens the negative impact on the environment. The transition to electric vehicles and the development of sustainable transportation systems, including public transit and non-motorized transport, can substantially decrease vehicular emissions, which are a major contributor to urban air pollution (Jain 2024) [15]. Consequently, enhanced waste management protocols, encompassing waste segregation, recycling initiatives, and scientifically sound disposal techniques, contribute to the mitigation of open burning practices and the subsequent reduction of toxic pollutant emissions. Moreover, sophisticated technologies, including air filtration systems, carbon capture and storage mechanisms, and real time emission monitoring, present viable strategies for pollution reduction (Hassan *et al*. 2025) [13].

Public Awareness

Raising public awareness is crucial for tackling air pollution. Environmental quality is significantly affected by both individual actions and community practices. When communities are informed about the sources, effects, and ways to reduce air pollution, it encourages responsibility and promotes the use of sustainable practices (Verma 2025a) [33]. Awareness initiatives can enable individuals to make well-informed choices, including decreasing energy usage, minimizing reliance on personal vehicles, and embracing more sustainable practices in both household and agricultural contexts (Verma 2026) [37]. Environmental education, incorporated into school programs and community engagement activities, is essential for fostering enduring changes in behaviour (Verma 2025c) [35]. Using mass media, social media, and local groups, public awareness campaigns can effectively share information about the health risks of air pollution and the benefits of adopting cleaner practices. These initiatives contribute to fostering civic engagement, motivating communities to get involved in environmental conservation efforts and policy advocacy. Moreover, increasing awareness among different groups, such as industries, farmers, and city residents, can encourage more responsible actions (Verma, 2025) [39]. Reducing emissions, stopping open burning, and promoting sustainable waste management are all important parts of the solution. In developing countries, community involvement is especially important, particularly when the rule of law isn't always followed (Kibria *et al*. 2023) [17].

Moreover, collaborations among government agencies, nonprofit organizations, and academic institutions can significantly improve the scope and impact of awareness initiatives. Public awareness campaigns that promote environmental responsibility can significantly reduce pollution, leading to improvements in both environmental quality and public health (Verma and Choudhary 2025) [39].

Conclusion

Air pollution is a major global issue, affecting the environment and public health, and causing serious problems for both people and the environment. The connection between exposure to pollutants, such as particulate matter, nitrogen oxides, sulfur dioxide, and ozone, and the occurrence of respiratory and cardiovascular diseases, negative pregnancy outcomes, and increased mortality is well-established. Furthermore, air pollution significantly contributes to environmental degradation, including climate change, acid rain, reduced agricultural yields, and the decline of biodiversity. Tackling this intricate problem necessitates collaborative and cross-sectoral initiatives. Governments need to adopt and rigorously apply strict air quality standards, advocate for renewable energy sources, and enhance monitoring frameworks. Industries should adopt cleaner production technologies and sustainable practices, while communities must adopt environmentally responsible behaviours. Technological advancements, such as electric vehicles, sophisticated emission control technologies, and improved waste management strategies, possess the potential to fortify regulatory frameworks. These innovations provide novel methodologies for emission reduction and enhance compliance with air quality standards. Ultimately, effectively managing air pollution requires a combination of policy changes, technological progress, and increased public understanding. Combining these strategies can reduce pollution, protect ecosystems, and improve public health. This will help create a more sustainable and healthier future.

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Conflict of Interest

The authors have no conflicts of interest to declare that are relevant to the content of this article.

Data Availability Statement

The data that support the findings of this study are available on request from the corresponding author.

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The AI tool has been used only for drafting the body of this review work.

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