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# Linking Air Quality, Climate Change, and Health: A Review Focused on Indian Cities

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## Abstract:
Climate change (CC) and air pollution (AP) are critical concerns, especially in rapidly urbanizing Indian cities. This review highlights the severe health threats of extreme climate events like heatwaves, heavy rainfall, floods, and droughts, which get intensified by increasing temperatures (temp.s). Urbanization combined with excessive weather volatility like heavy rainfall, rising temp.s, flooding, and drought have raised health risks for city residents. Prolonged and intensified heatwaves related to CC have contributed to thermal distress and other heat-associated health issues. The review also emphasizes exacerbating air quality (AQ) in Indian metropolitan cities, where levels (lvl.s) of pollutants consistently surpass national standards. Particular emphasis is given to aerosols and particulate matter, which pose severe health threats on inhalation and absorption by the respiratory tract. The complex interaction between urbanization, CC, and AP is also discussed because air pollutants influence the Earth's climate. The current study tries to offer a point of reference for policymakers to locate hotspots and execute targeted mitigation and adaptation strategies to address both climate-associated health effects and AP in Indian urban cities.

***Keywords:*** *Air pollution, CC, pollutants, particulate matter, urbanization*

## INTRODUCTION
AP stands as a major global threat, contributing significantly to premature mortality and a wide range of diseases, making it the most critical environmental health risk worldwide. It not only impairs public health and diminishes life expectancy but also constrains economic productivity. Addressing AP is integral to attaining the Sustainable Development Goals (SDGs), which emphasize minimizing the health burden caused by environmental pollutants. Moreover, both CC and AP pose essential challenges to the world's rapidly growing urban regions. In progressing nations like India, where shift from a largely rural society to a rapidly urbanizing populace is in progress, these challenges become even more pronounced (Singh et al., 2021). Projections suggest that by 2050, India's urban populace would increase by about 416 million, and 53% of the national populace residing inside urban areas (Kaur and Panday, 2021).

This ongoing process of urbanization leads to transformations in land use along with land cover patterns, which change regional climate by modifying surface characteristics and boundary layer atmospheric conditions. Urban growth hence changes the climate by propagating anthropogenic emissions, causing intensified precipitation events that may create urban flooding, increased temp. and heatwaves, all bearing serious issues for human health. These regional climatic changes are usually glimpsed in terms of significant meteorological variables like temp. and precipitation. The factors increasing this local climatic change are the emission of GHGs and other anthropogenic emissions.

While CC situations arise from urbanization, increased urban populace and vehicular traffic are contributors to high atmospheric pollution and aerosol concentrations. Studies show the combined effect of populace increase, shift of populace from rural areas to urban ones, and rapid urban expansion as the principal cause of heavy aerosol loading over the Indian subcontinent (Kaur and Panday, 2021). AP and CC thus remain the two main health and well-being adversaries affecting urban life. Hence, the complementary interplay of AP and CC is elaborated further within this study.

## Air Pollution in Indian Cities

In India's major cities where pollutant concentrations exceed permissible limits most of the time, AP has become a critical concern, jeopardizing the health of urban populace (Debone et al., 2020). These cities mainly are prone to becoming unhealthy and dirty living sites for AP to increase (Dutta et al., 2021). Also, the continuous along with alarming increase in urban AP during recent decades has become the most pressing environmental concern in the Indian megacities.
Progressing countries like India, which are undergoing rapid urbanization, face increasing AP problems because of poor infrastructure provision, e.g., a highly inefficient transport management system, limited road network, and uncontrolled siting of industries (Rumana et al., 2014). Traffic congestion inside cities slows down vehicle movement, causing higher vehicular emissions and further contributing to deteriorating AQ. The integration of uncontrolled urban growth, industrial development, and rising populace is increasing the threat to public health through heightening the lvl.s of AP, leading to numerous health complications (Dutta et al., 2021).

## Types and Sources of Air Pollution

In Indian cities, air pollutants have both natural alonog with anthropogenic sources. Also, natural sources of AP are the transport of desert dust over extended distances, mostly in summer and pre-monsoon months, which is blown into the region from arid regions like the Thar Desert inside Rajasthan, the Middle East, and parts of Africa. Alternatively, most pollutants are due to anthropogenic activities. This section accounts for a detailed description of several air pollutants leading to AP, with their sources. These consist of human activities like industrial discharge, motor vehicle emissions, and agricultural activities, in addition to natural sources like wildfires and volcanic emissions (Figure 1).

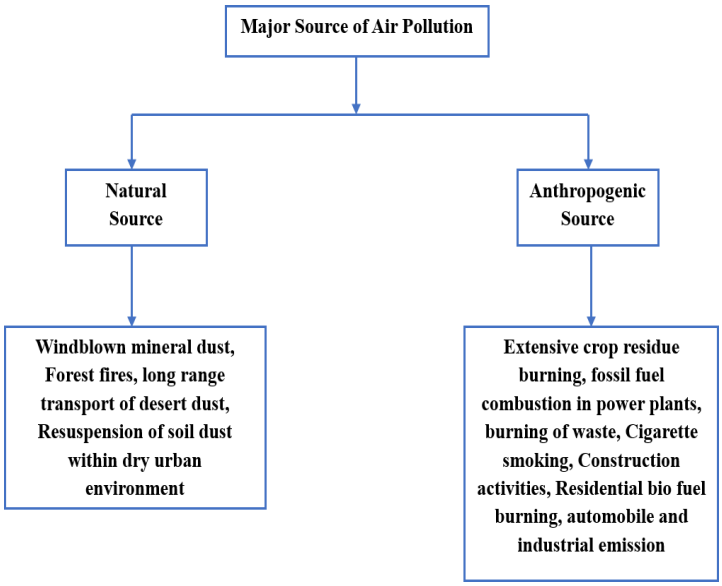


**Figure 1. Major AP sources inside Indian cities.**

## Key pollutants and their impacts

**Nitrogen Dioxide (NO2)** along with **Sulphur Dioxide (SO2):** These gases are harmful gases contributing to respiratory problems, smog formation, acid rain, and psychological stress, particularly among children. Vehicle emissions are the main source. SO2 concentrations in Delhi are within the safe limit (<10 μg/m3), but pollution by NO2 is a hazard (Gul & Das, 2023).

**Ozone (O3):** Ozone at the surface is generated by photochemical reactions between nitrogen oxides (NOx) along with volatile organic compounds (VOCs), chiefly discharged by power plants, industries, and automobiles in urban areas like Delhi. VOCs also account for the formation of PM1, which is severe in its health implications (Zhou et al., 2023).

**Ammonia (NH3):** The Delhi atmospheric haze formation is caused by ammonium chloride through the increase in aerosol liquid water content (Chen et al., 2022).

**Particulate Matter (PM2.5 and PM10):** Fine particulate matter is one of the most dangerous pollutants, having adverse effects on the respiratory system, cancer, and mental health. Exposure to PM2.5 during pregnancy elevates low birth weight by 18% (Lee et al., 2022). In Delhi, transport (45%) is the main source of PM2.5, whereas PM10 mainly derives from the residential sector (34.5%). In 2022, the PM2.5 lvl. in Delhi was 84.17 μg/m3, more than 17 times greater than WHO's safe limit (Chaudhary et al., 2023).

Lead (Pb): Sources are vehicle exhaust, paints, smelting, and coal or wood burning. An episode of poor AQ in Delhi in November 2016 recorded a spike in PM2.5 from 142 to 563 μg/m3 with stagnant air and burning of biomass (Gul & Das, 2023).

**Carbon Monoxide (CO):** Even low lvl.s of CO are toxic since it binds extremely tightly to haemoglobin, preventing oxygen transport throughout the body. Traffic congestion increases the exposure to CO, with resultant symptoms of headache, drowsiness, and impaired vision.

**Carbon Dioxide (CO2):** While naturally occurring, CO2 is a very strong greenhouse gas that triggers global warming and CC (EIA, 2019).

## Health Impacts of Air Pollution in India

Over the past few decades, AQ in most Indian cities has significantly deteriorated, with many urban centres, including Kolkata and Delhi, experiencing severe AP problems. In these cities, air pollutant concentrations always remain higher than safety limits recommended by both the Central Pollution Control Board (CPCB) and the World Health Organization (WHO). Studies inferred that daily and annual average concentrations of different gaseous pollutants were significantly high inside most Indian cities (Dandotiya et al., 2020).

Research identifies that the Indo-Gangetic Plain, specifically, has a high burden of ambient AP, which is a major source of AP-related disease burden inside India (Prabhakaran et al., 2020). Previously, Rajput et al., (2016) studied the temporal variability and sources of PM1 and determined the occurrence of trace metals, and five major elements, along with four water-soluble inorganic species (WSIS) inside the Indo-Gangetic Plains. WSIS contributed about 26% to the overall PM1 mass. In addition, secondary aerosols dominated by stationary combustion sources were responsible for nearly 60% PM1 concentrations. The occurrence of atmospheric fog in winter seasons also makes the AQ of the region more complex through the strengthening of chemical interactions in the IGP air-shed, intensifying pollution.

Outdoor AP was the fifth highest fatality cause inside India in 2012, preceded by heightened blood pressure (BP), indoor AP, poor nutrition, along with smoking and responsible for approx. 0.62 million premature deaths (NYT, 2014). Short-run exposure to AP can lead to eye, throat, and nasal passage irritation, and the development of respiratory illnesses like bronchitis and pneumonia. Long-run exposure leads to long-run respiratory illnesses, cardiovascular disease, lung cancer, along with brain, liver, kidney, and nervous system damage (Faheem et al., 2021). Both short- and also long-run exposure are known to increase the likelihood of high BP along with hypertension (Prabhakaran et al., 2020).

Air pollution exerts significant health impacts, especially on vulnerable groups like children, older people, pregnant women, and individuals having underlying cardiovascular or respiratory conditions. Children are the most vulnerable due to their immature pulmonary structures (Smith, 2013). The scale of health impacts is reliant on pollutant concentration along with exposure duration (Faheem et al., 2021). Studies have attributed AP to respiratory diseases, decreased lung function, asthma, cardiovascular illness, and premature death (Prabhakaran et al., 2020). The fine particulate matter (PM) is the primary agent responsible for these conditions, followed by the hazards of gaseous pollutants including NO2 and SO2. More than 50% of the populace in India are exposed to more than national standards of PM (Ramya et al., 2021).

The Central Pollution Control Board (CPCB) is accountable for AQ monitoring under National Air Monitoring Programme (NAMP) and National Ambient Air Quality Standards (NAAQS). Globally, 91% of the populace reside in areas with more than tolerable pollution, causing approx. 3.8 million yearly deaths (Mostafavi et al., 2021). In India, pollution of the air resulted in 1.24 million fatalities in 2017, with 0.67 million ascribed to ambient AP and 0.48 million due to domestic pollution. In the year 2019, this figure increased to 1.67 million fatalities, constituting 17.8% of mortality (GBD, 2015).

Cities like Kolkata also show extreme effects, where 70% of their populace suffer from respiratory disease and have very high premature deaths and lung disease, particularly seen in children. Cancer hazards due to toxic particulate matter also increase in areas that are highly polluted like the IGP (Rajeev et al., 2018). The economic burden of AP in India was found to be USD 80 billion inside 2010, approx. 5.7% of the GDP of the country (Maji et al., 2016).

## Worldwide Impact of Air Pollution

According to WHO (2018), the present AP epidemic is now rated as serious as the earlier tobacco epidemic, causing millions of premature deaths, deteriorating quality of life, and carrying significant healthcare and economic costs globally. The most affected are progressing nations with greater pollution lvl.s and weak environmental regulations. Countering this problem calls for collaboration between governments, environmental groups, and healthcare industries to make people aware, educate them, and have in place successful emission control measures directed at industries, transport, and power plants.
Global climate agreements have played a pivotal role in addressing environmental pollution. The 1997 Kyoto Protocol paved the way by having countries commit to curbing greenhouse gas emissions by 5% by 2012. There have been follow-up conferences since, like Copenhagen in 2009 and Durban in 2011, that reaffirmed international commitments, with China emerging as a critical player due to its burgeoning industry. The 2015 Paris Agreement was a milestone development, calling nations to implement sustainable development strategies, reduce emissions, and enhance public outreach and capacity-building for addressing climate and pollution issues.

## Climate Change: Impacts and Trends

CC is significantly influencing global temp., rain patterns, and amount of solar radiation. The IPCC (2007) states the Earth's mean surface temp. has increased by about 0.65˚C over the last 50 years, with expected future increases at between 1.1°C and 6.4°C. This warming has also led to a constant sea lvl. rise. For instance, the coast of Mumbai is experiencing a rise in sea lvl.s at the rate of approximately 2.5 to 3 mm per year (Pramanik, 2017). Additionally, NASA (2015) reports that the Mumbai region has experienced a 2.4˚C rise in average temp. between 1881 and 2015. Alongside temp. rise, the frequency of extreme rainfall events has increased, raising the risk of urban flooding. Mumbai, in particular, is highly vulnerable, with its large coastal populace facing the greatest threat from sea-lvl. rise and flooding (IPCC-SREX, 2012). According to UN-HABITAT (2010), Mumbai is recognized as an extremely climate-vulnerable cities globally (Mehta et al., 2019).
Rainfall pattern changes during the past century (1901-2019) have also been noted in India. Kuttippurath et al., (2021) examined rainfall data (119 years) and detected a substantial change in rainfall patterns after 1973 with a yearly reduction of around 0.42 ± 0.024 mm per decade. Interestingly, the record for the wettest location on Earth has transferred from Cherrapunji to Mawsynram in recent decades as a consequence of these pattern shifts.
Furthermore, rising temp.s are accelerating glacier melt. Kumar et al. (2021) discussed that the Nanda Devi area of the Central Himalaya lost approximately 26 km2 (10%) of glacier cover during the period from 1980 to 2017. CC is also strengthening extreme weather events like floods, storms, heavy rain, and drought, which cause widespread human hardship, leading to thousands of deaths and affecting millions (Majra and Gur, 2009).

## Health Consequences of Climate Change

The increasing corpus of scientific evidence points to the serious and mounting effects of CC on human health. Several studies project that such health hazards will progressively get aggravated as global temp.s continue to rise (Bell et al., 2018; Filippelli et al., 2020). CC causes numerous health risks by enhancing the frequency and severity of severe weather conditions like heatwaves, intense rainfalls, floods, and droughts, storms, and landslides (Orimoloye et al., 2019). Temp. and precipitation pattern alterations lead to health issues like heat-related diseases, waterborne and airborne diseases, vector-borne diseases, malnourishment, and increased incidence of diarrheal diseases (Dutta and Chorsiya, 2013).
Vulnerable populace like children, older adults, and the urban poor experience increased health hazards from these climate-related disasters (Haines et al., 2006; Filippelli et al., 2020). An estimated 150,000 deaths along with approx. 5 million illnesses occur every year all over the world due to the direct and indirect impacts of CC (Dutta and Chorsiya, 2013). Increased temp.s, particularly in cities, result in many heat-related illnesses, like skin cancer, heatstroke, cardiovascular conditions, and gastrointestinal system diseases like diarrhea (Orimoloye et al., 2019). Heat stress similarly results in dehydration, cramps, fatigue, eye and skin infections, and in extreme cases, organ failure (Dutta and Chorsiya, 2013).

Urban heat island (UHI) effect, which leads to increased temp.s in urban areas in relation to the surrounding areas, is a major issue in India. UHI has been observed in several Indian cities, leading to thermal discomfort and respiratory issues through AQ degradation by pollutants and cooling agents (Kaur and Pandey, 2020).
India has witnessed many extreme weather conditions in the past decades, immensely impacting public health and livelihoods. Eminent instances are the 1998 and 2004 heatwaves in Odisha, the super cyclone in Odisha in 1999, the heatwaves inside Andhra Pradesh within 2003, and the cold wave inside Uttar Pradesh along with Uttaranchal within 2004. Other occurrences are the 2004 tsunami in coastal states, the disastrous Mumbai floods in 2005, the cyclones in Andhra

Pradesh, and the heavy floods inside Gujarat, Madhya Pradesh, and Uttarakhand in 2013 (WHO, 2005; Majra and Gur, 2009).

These natural calamities have caused an enhanced dissemination of infectious diseases, like vector-borne diseases like malaria, dengue, chikungunya, filariasis, Japanese encephalitis, and plague. Odisha, West Bengal, Jharkhand, Chhattisgarh, Madhya Pradesh, and the north-eastern states are predominantly affected. Coastal areas are still at risk for cyclones and tsunamis (Dutta and Chorsiya, 2013).

Water-borne illnesses also increase extensively during such incidents, like amoebiasis, cryptosporidiosis, giardiasis, typhoid, cholera, and other diseases. WHO and UNICEF state that approximately 900,000 Indians lose their lives every year from consuming contaminated water along with breathing polluted air (by WHO and UNICEF, 2000). Moreover, India's Ministry of Health estimates 1.5 million childhood deaths annually under the age of five years, with 0.6 to 0.7 million due to diarrhoea alone.

### Interlinkages Between Climate Change, Air Pollution, and Human Health

The dynamic interaction between urban climate, AP, and human health is a critical issue, especially in rapidly urbanizing countries like India. Urban environments suffer from mounting pressure from the rise in pollution and CC, while research on their combined effects is still scant (Agarwal et al., 2006). Climate is crucial in distributing, concentrating, and dispersing air pollutants. These include greenhouse gas emissions, stratospheric ozone depletion, and increased temp.s that lead to the formation of secondary pollutants and modification of pollutant behavior. This results in numerous respiratory disorders like asthma, bronchitis, and allergies (D'Amato et al., 2002).

The WHO puts the estimated deaths caused by the last three decades' climate-related changes, like increased temp.s and changed precipitation, at approximately 150,000 per year. Air pollutants, particularly aerosols, not only worsen AQ but also affect the climate through altering monsoon systems, enhancing sea-land temp. gradients, affecting cloud formation, and altering the distribution of rainfall (Gautam et al., 2010). Urbanization enhances these problems by way of greater energy usage, burning of fossil fuels, and automotive emissions. Commercial and trafficked areas have higher pollutant lvl.s than more ecological ones, and pollutant concentrations vary with seasonal and atmospheric factors (Dandotiya et al., 2020). Urban structures worldwide account for an estimated 20% of greenhouse gas emissions, with transport forming 13% (IPCC). Urbanization enhances the urban heat island (UHI) impact by transforming natural environments into urban infrastructure, thereby heating up the environment and increasing energy requirements. Greater utilisation of cooling appliances like air conditioners leads to more greenhouse gas emissions, which aggravate CC and AP. Also, transformed wind patterns within cities enhance the circulation and deposition of contaminants, which boosts health risks including cardiovascular and respiratory diseases.

## CONCLUSION

This review highlights the alarming intensities of AP in Indian megacities, where pollutant lvl.s persistently surpass acceptable limits. The continuous emissions of both anthropogenic and natural origins, particularly elevated particulate matter, pose serious health threats and highlight the necessity for continuous monitoring through ground measurements and satellite remote sensing technologies. The findings can help in the formulation of city-lvl. mitigation strategies by pointing out vulnerable areas, enabling AQ modelling, and improving preparedness for AP control. Apart from this, CC has promoted health susceptibilities in Indian cities in terms of high-impact weather events like heatwaves, floods, and droughts. Increasing surveillance of health for climate-sensitive diseases and considering the high rate of urbanization and industrialization are key actions towards reducing health vulnerabilities. The integration of cutting-edge technologies, geospatial technologies, and green urban planning into smart cities is critical for counteracting the combined risks of AP and CC, upholding healthier cities.

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