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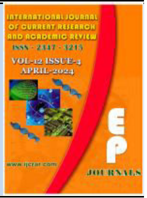

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Air Pollution Impact on Vegetation in Vishwakarma Industrial Area Jaipur, India

Aakriti Chauhan*, Shashwat Arya, Yashvi Garg, Kanishk, Bhavana, Tanu Sharma and Rameshwar

Department of Agriculture Vivekananda Global University Sector 36, NRI Colony Rd, VI T Campus, Jagatpura, Jaipur, Rajasthan – 303012, India

**Corresponding author*

Abstract

Air pollution refers to the presence of harmful substances in the Earth's atmosphere, resulting from human activities and natural processes. These pollutants can include particulate matter, ground-level ozone, carbon monoxide, sulfur dioxide, nitrogen dioxide, and volatile organic compounds (2016). The Air Quality Index (AQI) is a numerical scale that quantifies the level of air pollution in a specific area, providing an indication of the potential health effects. The AQI considers several parameters, such as concentration levels of different pollutants, and categorizes them into different index levels ranging from "Good" to "Hazardous." Each level corresponds to a different level of health concern, helping authorities and the public assess the air quality and take appropriate measures. Studying air pollution is crucial due to its detrimental impact on human health, ecosystems, and the environment. Exposure to polluted air can lead to respiratory and cardiovascular diseases, exacerbate existing health conditions, and even cause premature death. Additionally, air pollution contributes to climate change, damages crops, and harms aquatic ecosystems. Understanding and addressing air pollution is essential for developing effective policies, technologies, and lifestyle changes to mitigate its adverse effects on both human health and the planet (2021).

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Keywords

Air pollution, gases, particulate matter, biological molecules, Air Quality Index (AQI).

Introduction

Air pollution is a pressing environmental (2021) issue that significantly impacts the quality of the air we breathe. It refers to the presence of harmful substances in the Earth's atmosphere, resulting from both natural processes and human activities. These pollutants can take various forms, including gases, particulate matter, and biological molecules, each with its own set of detrimental effects on human health and the environment. The Air Quality Index (AQI) serves as a crucial metric to quantify and communicate the level of air pollution in a specific area. The AQI takes into account various pollutants, such as ground-level ozone, particulate matter (PM10 and PM2.5), carbon monoxide, sulfur dioxide, and nitrogen dioxide. Each of these pollutants has distinct sources, ranging from vehicular emissions and industrial activities to natural sources like wildfires and dust storms.

Particulate matter, one of the key parameters measured in the AQI, consists of tiny particles suspended in the air. PM10 includes particles with a diameter of 10 micrometers or smaller while PM2.5 refers to even finer particles with a diameter of 2.5 micrometers or smaller. These particles can penetrate deep into the respiratory system, causing various health problems such as respiratory and cardiovascular diseases. Ground-level ozone, (2022) another significant contributor to the AQI, forms when pollutants emitted by vehicles, power plants, and other sources react in the presence of sunlight. Ozone can cause respiratory issues and aggravate existing health conditions. Carbon monoxide, sulfur dioxide, and nitrogen dioxide are gases produced by the combustion of fossil fuels and industrial processes. These gases can have direct and indirect effects on human health, affecting the respiratory and cardiovascular systems.

Understanding and monitoring air (2023) pollution through the AQI are essential for several reasons. Firstly, it serves as a vital tool for public awareness, allowing individuals to make informed decisions about outdoor activities based on current air quality levels. High AQI values indicate poor air quality, prompting people to take precautions, especially those with respiratory conditions or vulnerable populations such as children and the elderly. Secondly, studying air pollution is crucial for assessing the environmental impact of human activities. Industries, transportation, and energy production significantly contribute to air pollution, and monitoring AQI levels helps identify sources and implement regulations to mitigate pollution. This, in turn, contributes to the development of sustainable practices and policies to safeguard air quality.

Thirdly, air quality is intricately linked to climate change. Some air pollutants, known as greenhouse gases, contribute to global (2020) warming and climate change. By addressing air pollution, we can simultaneously tackle climate-related challenges, emphasizing the interconnectedness of environmental issues.

In conclusion, air pollution, as measured by the AQI, is a multifaceted problem with far- reaching consequences for both human health and the environment. Monitoring and understanding the parameters of air pollution are critical for creating awareness, implementing effective regulations, and developing sustainable practices to ensure clean and healthy air for present and future generations. As we strive for a more sustainable and resilient future, the study of air pollution remains an indispensable component of environmental stewardship.

Review of literature

Air pollution has emerged as a significant challenge worldwide, affecting both developed and developing nations. Various emission sources continuously release particulates and gaseous pollutants into the environment. This issue significantly impacts urban communities, particularly in open-road settings, as well as street canyon environments.

In addition to primary pollutants such (2022) as soot particles, carbon monoxide (CO), sulphur oxides (SOx), and nitrogen dioxide (NO2), air emissions also consist of various other harmful substances. These include photochemical secondary pollutants like ozone (O3) and smaller quantities of toxic chemical gases, heavy metals, organic compounds, and radioactive isotopes.

Studies have shown that air pollutants contribute to substantial vegetation damage and result in significant losses in crop yields. Additionally, it has been reported that the economic impact of air pollutant removal on plant and tree health is particularly pronounced for ozone and particulate matter with aerodynamic diameter.

Studies have indicated (2019) that among various gaseous air pollutants, sulphur dioxide (SO2), nitrogen oxides (NOx), and ozone (O3) exert the most substantial impact on plants. Sulphur dioxide induces a decline in biomass growth by imposing abiotic stress (NOE *et al.,* 2011; Bell, 1982). On the other hand, NO2 undergoes atmospheric chemical reactions, converting into nitrous and nitric acids, leading to detrimental effects on cell membranes and chlorophyll degradation upon exposure (Sheng and Zhu, 2019; Hu *et al.,* 2021).

Moreover, research has demonstrated that NO2 exposure significantly affects leaf chlorophyll content and causes oxidative damage to plants. Antioxidants play a crucial role in mitigating this damage (Sheng and Zhu, 2019). The exposure of plants to pollutants results in the production of reactive oxygen species (ROS). An intricate antioxidative system (AOS) in plants operates to counteract these harmful reactive species, predominantly ROS, maintaining cellular homeostasis (Dumanovi´c *et al.,* 2021). When the levels of antioxidants fall below the plant's 'ROS-neutralizing capacity,' oxidation of biomolecules occurs, leading to protein damage, apoptosis activation, lipid peroxidation, enzyme release inhibition, and nucleotide oxidation (Bikis, 2023).

Ozone, due to its oxidative nature, affects plants differently compared to other pollutants. Its interaction with plants occurs in three stages: firstly, O3 penetrates the leaf boundary layer, then it gets absorbed by plant tissues through stomata, and finally, it undergoes chemical interactions within the plant tissue (Zhang *et al.,* 2012). Being highly reactive, O3 directly damages organic molecules and induces inflammation. This exposure leads to visible symptoms on plant leaves, such as white spots that progress into brown necrotic spots, wilting, accelerated senescence, and various unconventional color patterns on leaves (Sokhi *et al.,* 2022).

Studies have showcased a range of visible foliar symptoms on plant species exposed to elevated ozone levels, including pale yellow patches, dark brown/black spotting, stippled patches turning necrotic, chlorosis, browning on interveinal areas, and extensive white patches between leaf veins. Older leaves and leaflets near the base of compound leaves are often most affected. Plant structures like cell walls, leaf density, and intercellular spaces offer some protection against ozone damage (Peng Wang *et al.,* 2023).

Consequently, O3 exposure diminishes assimilation, slows plant growth (Ainsworth *et al.,* 2012), reduces seed production, and alters the plant's resistance to pests (Cotrozzi *et al.,* 2021). Notably, certain plant genotypes exposed to O3 show varying sensitivity levels, affecting insect feeding preferences and potentially inducing early senescence (Heath *et al.,* 2009; Mahmood *et al.,* 2020; John H. Ludwvig *et al.,* 1965)

Air pollutants adversely affect plants' normal functions, disrupting their metabolism and hampering their ability to enhance production. Among air pollutants, ozone (O3) stands out as the most conspicuous and damaging to plants, with particulate matter (PM) ranked as the second most impactful pollutant (Han *et al.,* 2022; Hill, 1971). Ozone's impacts encompass visible injuries, foliar chlorotic mottles, necrotic lesions, chlorophyll degradation, changes in crop quality, induced stomatal closure affecting gas exchange, altered carbon allocation, membrane lipid peroxidation, yield losses, inhibited photosynthesis, accelerated senescence, increased susceptibility to stresses, genetic alterations, metabolic disorders, weakened defense against pests and diseases, and induction of oxidative stress (Kurinji *et al.,* 2022).

The damage inflicted on plants due to pollutants translates into economic losses through reduced biomass production and diminished yields. For instance, the total ozone-induced yield loss in China, Japan, and Korea amounts to an estimated 63 billion USD, with the highest relative yield losses in China for wheat, rice, and maize at 33%, 23%, and 9%, respectively. Similarly, in India, ozone exposure led to crop yield losses estimated at approximately 5 billion USD for wheat and 1.5 billion USD for rice during the 2014–15 period (Assessment of industrial air pollution in Jaipur district, 2020).

Regarding research on air pollution in India, an analysis from the pre-internet era to the present has been conducted. The evolution of air quality research in India alongside legislative measures has been discussed. A project focusing on compiling Indian researchers' studies on air pollution has resulted in the creation of a virtual platform called the Indian Air Quality Studies Interactive Repository (IndAIR).

This repository, which encompasses data from 1950 to February 2020, includes approximately 1670 research papers, 30 reports and case studies, 66 court trials, and over 7 statutes. Notably, the National Capital Territory, Delhi, Maharashtra, and Uttar Pradesh have been more extensively researched, with the most studies concentrated in major cities having high pollution sources. Conversely, regions like Dadra, Daman, and Nagaland have seen fewer studies (Kumar and Verma, 2020).

The study highlights the geographical disparity in research on air quality, primarily focused on major cities experiencing episodic air pollution events. Majorly studied domains include particulate matter, health impacts, and outdoor air quality, whereas socioeconomic impacts and indoor air quality have been comparatively less explored in India (Maharajan *et al.,* 2010). A finer analysis of Maharashtra, Uttar Pradesh, and Tamil Nadu reveals that Mumbai, Pune, Agra, Kanpur, and Lucknow were among the most extensively studied cities in these states, emphasizing the impact of air pollution on various aspects within these regions (Jain and Mandowara, 2021).

Delhi consistently grapples with year-round air pollution, attributed to various sources such as vehicle exhaust, road and construction dust, cooking and heating emissions, open waste burning, light and heavy industries, diesel generator sets, as well as seasonal contributors like agricultural burning and dust storms. Additionally, pollution sources beyond Delhi's administrative boundary contribute significantly to the city's air quality issues (Sunil Guliaa *et al.,* 2022; Sokhi *et al.,* 2022; Peng Wang *et al.,* 2023; Paliwal, 2023; Fuller *et al.,* 2023). Despite being a subject of extensive national and international studies and discussions, there's limited consensus regarding the sources and their respective contributions to Delhi's air pollution. Studies conducted between 1990 and 2022 employed diverse methods, including filter sampling with chemical analysis, multi-pollutant emission inventories, chemical transport modeling, and real-time instrument utilization (Peng Wang *et al.,* 2023, Paliwal, 2023, Singh and Nagar, 2019, Chouhan *et al.,* 2018, Chandani and Sethi, 2022). Over time, continuous ambient air quality monitoring in Delhi has evolved from predominantly manual monitoring in the 1990s to the presence of more than 40 real-time monitoring stations by 2022.

These monitoring stations track various pollutants, including aerosols like particulate matter (PM2.5 and PM10), gases such as sulphur dioxide (SO2), nitrogen oxides (NO and NO2), carbon monoxide (CO), ammonia (NH3), and ozone (Gope *et al.,* 2022; Rajak and Chattopadhyay, 2019). This paper's discussion focuses mainly on PM2.5, a critical pollutant frequently surpassing Indian air quality standards and contributing significantly to health issues related to the respiratory, cardiovascular, and neurological systems (Kapoor and Bhardwaj, 2016).

The judiciary, including the Supreme Court and the National Green Tribunal, has played a pivotal role in addressing Delhi's air pollution problem. In several instances, these institutions have mandated technical, economic, and institutional solutions, often ahead of national and state departments. Despite these efforts, Delhi's air quality in 2022 ranked as the worst among the world's capital cities (Fuller *et al.,* 2023).

Air quality forecasting was introduced in Delhi during the 2010 Commonwealth Games and later proposed for all non-attainment cities under the National Clean Air Programme (NCAP) in 2019. These forecasting systems predict future air pollution levels for both long-term planning and short-term pollution alerts. They utilize meteorological and emissions data to forecast pollutant concentrations, deposition levels, and chemical transformations. The primary aim is to empower people with air quality information to safeguard their health (Singh and Nagar, 2019).

Several institutes offer short-term (3 to 5-day) air quality forecasts using urban, regional, and global models. Notably, the Copernicus Atmosphere Monitoring Service (CAMS) forecasting system, provided by the European Union, uses mathematical models and satellite data to offer air quality forecasts globally and regionally. The system ensures reliable forecasts for Europe, with visualizations available through ESA's geostationary satellite data and on platforms like windy.com (accessed links and dates) (Chouhan *et al.,* 2018).

Several robust air quality forecasting systems operate for Delhi and other regions, employing various models and methods to predict air quality. The Early Warning System (EWS) by IITM (Indian Institute of Tropical Meteorology) utilizes the WRF-Chem regional model along with global modeling systems like GEOS and WACCM. This system provides national, regional, and city-level hourly maps, time series, and comparisons with CPCB's monitoring data. Additionally, it forecasts fog onset and visibility for Delhi while summarizing air quality forecasts for other cities (Chandani and Sethi, 2022).

Another system, NASA-GEOS, functions through the Global Modeling and Assimilation Office (GMAO) and offers a 10-day air quality forecast specifically for Delhi using the GEOS- 5 model. The GEOS system includes a data assimilation system (GEOS-DAS) with reanalysis archives dating back to 1990 (Saini *et al.,* 2021).

SAFAR (System of Air Quality Weather Forecasting and Research) relies on ground measurements, emission inventories, and mathematical models to predict air quality for up to three days. Initially developed for Delhi, SAFAR has expanded its coverage to include Mumbai, Pune, and Ahmedabad (Li *et al.,* 2021).

SILAM (System for Integrated modeLing of Atmospheric composition), managed by the Finnish Meteorological Institute (FMI), is a global chemical transport model. Under an agreement with the Indian Meteorological Department (IMD), FMI offers customized air quality forecasts specifically for the NCR Delhi region, accessible via the EWS portal (Gope *et al.,* 2022).

The Urban Emissions program employs the WRF-CAMx modeling system for the Indian Subcontinent and Delhi's airshed. It shares city-level results, source apportionment information, and real-time comparisons with CPCB's monitoring network (Rajak and Chattopadhyay, 2019).

Lastly, ensemble forecasting amalgamates results from various models to enhance prediction accuracy. This approach leverages each model's strengths while mitigating individual weaknesses, ultimately contributing to more comprehensive and accurate air quality forecasts (Jain and Mandowara, 2021).

Additionally, machine learning techniques like Artificial Neural Networks (ANN) are employed for predicting pollutants like PM10 due to their ability to handle complex relationships between variables. In a study focused on Guwahati, Multilayer Perceptron (MLP), a type of ANN, was utilized to create predictive models using inputs such as meteorological parameters, PM10, PM2.5, and gaseous pollutants to forecast the next day's PM10 concentrations. The MLP employed a network of interconnected neurons, demonstrating superiority over other techniques like Multiple Linear Regression (MLR) due to its capacity to predict the dependent variable more accurately.

Comparative analysis among different models—MLR, ANN (MLP), and CART—was performed using performance indicators such as Normalized Absolute Error (NAE), Mean Absolute Error (MAE), Mean Squared Error (MSE), Root Mean Squared Error (RMSE), Index of Agreement (IA), and R2 (coefficient of determination).

These indicators helped evaluate prediction performance efficiency, considering factors like prediction errors, average magnitude of errors, and prediction accuracy. R2 was considered the most crucial measure in assessing prediction accuracy, providing specific insights into the predictive model's performance (Paliwal, 2023). Text discusses various facets of air pollution, its historical occurrences, impacts on health, and the evolution of measures to address this environmental challenge. Here's a correlated summary:

Air pollution is characterized (2021) by the release of harmful substances into the environment, significantly impacting both human health and the quality of the environment itself. Factors such as rapid urbanization and increased transport usage, driven by population growth and economic activities, have contributed to deteriorating air quality in many urban areas globally. Various sources like industry, older vehicles, dust, and wood burning for cooking have been identified as key contributors to air pollution, causing health issues among individuals (Rajak and Chattopadhyay, 2019).

Historical events, such as the "Great London Smog" in 1952, attributed to burning low-grade coal for heating, resulted in severe air pollution episodes and a significant number of fatalities. While air pollution sources historically stemmed from industrial activities and heating, the focus has shifted to road traffic, becoming a global threat to health (Gope *et al.,* 2022).

Disparities in air quality concentrations (2021) across different regions persist, with areas in Asia, Africa, and Latin America experiencing some of the highest concentrations of pollutants like PM2.5. Recognizing the severe health impacts of air pollution has led to the development of transport and dispersion models, evolving from historical events like World War I's use of chemical weapons and advancements made thereafter by fluid dynamicists like Lewis Fry Richardson and George Keith Batchelor (Li *et al.,* 2021).

Models like CMAQ and WRF, incorporating detailed mechanisms for aerosol formation and meteorological inputs, are employed to simulate air quality patterns. These models utilize emissions data from inventories like MEIC and EDGAR, estimating vehicle emissions based on road emission ratios.

Historical air pollution episodes, (2022) like the ones in the Meuse Valley, Belgium, and Donora, Pennsylvania, raised awareness about the serious health implications of air pollution from industrial emissions during stagnant atmospheric conditions. Subsequent legislation such as the Clean Air Act in the 1970s aimed to control industrial emissions, with computer-based models solving equations to predict air quality and assist in monitoring nuclear power plant emissions.

Efforts to refine emission (2021) inventories and identify specific sources affecting urban air quality have become crucial to reducing uncertainties in air quality predictions. Collaborative efforts involving stakeholders and the use of dedicated tools for environmental assessment play a vital role in quantifying the impacts of emission control scenarios and formulating effective policies.

Analysis of India's energy (2023) and climate policies suggests that although current measures could improve air quality, they might fall short of the World Health Organization's recommended levels. An integrated policy response, considering synergies between air pollution and climate policy objectives, could lead to significant reductions in pollutants like SO2, NOX, and PM2.5 by 2040, offering substantial benefits to national health and the environment and contributing to the global fight against climate change (Paliwal, 2023).

This comprehensive approach to understanding the historical context, modeling, emission control, and policy integration underscores the complex and multifaceted nature of addressing air pollution, mainly in the

Maharashtra region of India, focusing on pollutants such as sulfur dioxide (SO2), nitrogen oxides (NOx), respirable suspended particulate matter (RSPM), ozone (O3), and benzene. Here's a correlated summary:

In most areas, SO2 concentrations (2019) remained below the annual limit, with exceptions noted in Kalyan RO, where slight increases were observed but levels stayed within the range of 21-34 µg/m³, primarily associated with MIDC complexes and industrial activities. Conversely, Mumbai RO exhibited significantly lower SO2 levels, well below the annual limit, indicating comparatively cleaner air quality. Other cities such as Amaravati, Aurangabad, Chandrapur, Nagpur, Nashik, and Raigad also maintained SO2 concentrations below 25 µg/m³ (Fuller *et al.,* 2023).

Elevated NOx levels were (2022) recorded due to high vehicular movement, surpassing the annual average limit of 40 µg/m³ in several regions, including Aurangabad, Kalyan, Kolhapur, Mumbai, Navi Mumbai, Nagpur, Pune, Raigad, and Thane. Efforts aimed at transitioning from BS-IV to BS-VI emission norms seek to substantially reduce NOx emissions (Chouhan *et al.,* 2018).

Regarding RSPM concentrations, most AAQMS adhered to the standard limit (60 µg/m³), except in Chandrapur and Thane, where specific stations reported levels exceeding the standard due to coal mining, thermal power plants, and construction activities (Singh and Nagar, 2019).

Concerning ozone (O3) concentrations, elevated levels were detected in various regions, notably from January to April. Some CAAQMS in cities like Chandrapur, Kalyan, Mahape, Mulund, and Nagpur reported levels higher than the standard limit of 100 µg/m³. Furthermore, certain areas, particularly Dombivali and Mahape, registered benzene concentrations above the 5 µg/m³ limit (Peng Wang *et al.,* 2023).

Air quality monitoring in Maharashtra is conducted extensively by the Central Pollution Control Board (CPCB) through the National Ambient Air Quality Standards (NAAQS) and the National Air Quality Monitoring Programme (NAMP). The state hosts 84 monitoring stations that provide comprehensive air quality data (John H. Ludwvig *et al.,* 1965).

Research methodologies employed in studying air pollution effects encompass laboratory experiments involving various biological systems, spanning microorganisms to humans, as well as field studies focusing on epidemiology. Epidemiological studies aim to establish correlations between mortality, morbidity, health indicators, and vegetation damage with air pollution levels. Present research predominantly emphasizes subtle functional changes arising from long-term, low-concentration air pollution exposures, particularly targeting respiratory illnesses and chronic diseases (Dutta and Jinsart, 2021).

The detailed information highlights the worsening air quality in Delhi during the winter of 2020, despite proactive measures taken by the State Government. These measures included initiatives like the 'Yuddh Pradushan Ke Virudh' campaign and a seven-point action plan to combat air pollution, aiming to address the association between high air pollution and COVID mortality (Bikis, 2023).

Despite these efforts, PM2.5 levels remained significantly high, nearly three times above the National Ambient Air Quality Standards (NAAQS) between October 2020 and January 2021, surpassing levels observed in the previous year's winter. The data analysis delves into various factors contributing to this trend, analyzing meteorological parameters, source activities, and contributions to identify primary drivers of pollution during different phases of the winter season (Guttikunda *et al.,* 2023).

The updates and initiatives concerning source control measures encompass various key aspects:

Challenges persist in the implementation of more stringent emission standards for coal-fired thermal power plants. It is estimated that a majority of operational power plants in India will likely miss the 2022 emission deadline, which could result in prolonged periods of higher emissions (Sunil Guliaa *et al.,* 2022).

To address vehicular emissions, the government is actively promoting the adoption of Bharat Stage (BS) VI emission standards across different vehicle categories. Additionally, there are initiatives incentivizing the phasing out of older vehicles. National and state-level programs are focused on encouraging the adoption of electric vehicles as a means to curtail air pollution levels (Anand *et al.,* 2022). Cities are undertaking comprehensive emission inventories and source apportionment studies to pinpoint specific pollution sources. The introduction of guidelines and support from technical and research institutions is aimed at enhancing these studies for more effective air quality management (Guttikunda *et al.,* 2023).

Efforts are underway to expand the national network of ambient air quality monitoring stations. This includes plans to increase the number of real-time monitoring stations and the adoption of a hybrid approach that integrates data from satellite-based estimates and low-cost sensors, aiming to provide a more comprehensive and accurate assessment of air quality (Bikis, 2023).

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The updates and initiatives pertaining to source control measures encompass various crucial aspects: Challenges persist in implementing stricter emission standards for coal-fired thermal power plants, with most operational plants in India expected to miss the 2022 emission deadline, potentially resulting in prolonged periods of higher emissions (Rajak and Chattopadhyay, 2019).

In addressing vehicular emissions, the government is actively promoting the adoption of Bharat Stage (BS) VI emission standards across different vehicle categories while incentivizing the scrapping of older vehicles. National and state-level programs are actively encouraging the transition to electric vehicles as a means to mitigate air pollution levels (Gope *et al.,* 2022).

Cities are actively conducting emission inventories and source apportionment studies aimed at identifying specific sources of pollution. These studies are being supported by guidelines and assistance from technical and research institutions, aiming to enhance air quality management strategies (Li *et al.,* 2021).

There are ongoing efforts to expand the national network of ambient air quality monitoring stations. This initiative involves increasing the number of real-time monitoring stations and adopting a hybrid approach that integrates data from satellite-based estimates and low-cost sensors to provide a more comprehensive and accurate assessment of air quality (Fuller *et al.,* 2023).

Moreover, this project signifies an opportunity to conduct scientific research in an area that faces challenges within India. Despite the abundance of global evidence on the health impacts of air pollution, there are notable gaps in evidence within the Indian context. Specifically, more studies investigating the effects of both short and long-term exposures to PM2.5 are necessary. Ongoing cohort studies are examining the influence of household and ambient PM2.5 on chronic diseases. However, the available evidence base remains limited, particularly concerning the impact of air pollution on health, primarily due to the poor quality and lack of availability of PM2.5 and civil registration data (births and deaths) in the public domain (Paliwal, 2023).

The situation creates a paradox wherein the evidence primarily comes from modelled studies, such as the Global Burden of Diseases study. However, these models are based on assumptions and lack contextual data specific to India. Consequently, policymakers often question the validity of such evidence. While researchers argue that air pollution's health effects are consistent worldwide, generating contextual evidence can enhance not only scientific knowledge but also public perception (Guttikunda *et al.,* 2023).

Regarding the sources of air pollutants, they can enter the atmosphere through various natural and man-made activities such as dust storms, volcanic eruptions, industrial pollution, and more. These pollutants exist in solid, liquid, and gas forms. They are classified based on their mode of generation into natural (forest fires, volcanic eruptions, etc.) and man-made sources (domestic and industrial pollution).

Furthermore, based on how pollutants enter the atmosphere, sources are classified into point, line, and area volume sources. They can also be categorized as primary pollutants (directly emitted) and secondary pollutants (formed by chemical reactions). Additionally, pollutants are classified based on their chemical composition as organic (e.g., PAN, hydrocarbons) and inorganic (e.g., CO2, SO2, NO3) (Dutta and Jinsart, 2021).

Delhi confronts severe air pollution issues, especially during the winter season when pollutants like PM2.5 and PM10 exceed prescribed standards for Ambient Air Quality. Despite experiencing good air quality in October 2021, November 2021 witnesses severe air quality due to a combination of factors, including stubble burning, vehicular emissions, waste burning, and dust pollution. The average AQI for October 2021 was 173, whereas in November 2021, it drastically increased to 388 (till 12th November, 2021), reaching peaks of 462 and 471 on the 5th and 12th November, respectively.

Unfavorable meteorological conditions, such as slow winds during the day and calm winds at night, exacerbate the situation by hindering the dispersion of pollutants. The forecast predicts continued severe air quality due to ongoing agricultural residue burning and prevailing unfavorable meteorological conditions (Bikis, 2023).

Conclusion

This comprehensive literature review synthesizes the current state of knowledge on air pollution, emphasizing its multidimensional nature and far-reaching impacts. By amalgamating findings from diverse research domains, this review sets the stage for informed discussions on future research directions and effective strategies to address the complex challenges posed by air pollution.

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