



## Editorial

### Addressing air pollution in India: Innovative strategies for sustainable solutions

Globally, air pollution poses significant challenges, with over seven million deaths attributed to it annually<sup>1</sup>. Its effects are particularly severe in low- and middle-income countries like India. Air quality in India, both ambient and household, is significantly influenced by geographical variability and seasonal weather patterns. Key pollutants such as particulate matter (PM), oxides of nitrogen (NO<sub>x</sub>), ammonia (NH<sub>3</sub>), sulphur dioxide (SO<sub>2</sub>), and non-methane volatile organic compounds (NMVOCs) are predominantly emitted from transport, industrial processes, farming, energy generation and domestic fuel use for cooking and heating<sup>2-4</sup>. Alarmingly, pollution levels in India are often much higher (overall annual geographic mean of PM<sub>2.5</sub> in India increased from 27 µg/m<sup>3</sup> in 1998 to 44 µg/m<sup>3</sup> in 2022)<sup>5</sup> than the World Health Organization's recommended levels<sup>6</sup>, particularly during the winter season in cities and harvesting periods in rural areas of the northern Indian States. Rapid industrialization, urbanization, climate change, crop burning, and population growth have further diversified and intensified pollution sources. This editorial will briefly explore the sources of air pollution in India, its effects on health and the environment, government efforts to address it, technological mitigation strategies, public awareness and engagement, challenges faced, successful intervention case studies, and the future outlook for tackling this critical issue.

#### Sources of air pollution in India

Air pollution sources in India vary widely across geographical regions, including natural (pollen grains, desert dust, mineral dust, *etc.*) and anthropogenic sources. Some of the primary anthropogenic sources are: (i) *Industrial emissions*: many factories and manufacturing units, such as cement factories and brick kiln industries, release harmful atmospheric pollutants, such as particulate matter (PM), sulphur dioxide (SO<sub>2</sub>), and oxides of nitrogen (NO<sub>x</sub>); (ii) *Vehicular emissions*: Vehicles in India increased from 128 million to 326 million from 2010 to 2020<sup>7</sup>, and significantly contribute

to air pollution by exhausting fumes containing NO<sub>x</sub>, CO and volatile organic compounds (VOCs); (iii) *Agricultural activities*: Crop residue burning, in particular, releases large amounts of toxic smoke into the air, leading to a phenomenon known as crop burning pollution along with small rural industries such as jaggery plants using unprocessed biomass for energy; (iv) *Domestic fuel*: About 60 per cent of Indian population use solid fuels for cooking and heating, and is a primary source of household air pollution (HAP), particularly in rural areas<sup>8</sup>. Burning biomass fuels such as wood, dung, and crop residues releases pollutants that not only impact HAP but also contribute to outdoor pollution when emitted into the atmosphere; (v) *Indoor sources*: Indoor Air Pollution (IAP) poses significant health risk to individuals of all ages, particularly young children, elderly and those with pre-existing health conditions. In urban areas, people spend over 70 per cent of their time indoors, with an additional 20-30 per cent spent in enclosed environments such as schools, workplaces, shops, and transport. IAP comprises a wide range of physical (*e.g.*, damp), biological (allergens, mould, and airborne respiratory pathogens), and chemical agents<sup>9</sup>. Their sources are varied and include water ingress, pets, building materials, furniture and furnishings, smoking, paints, varnishes, glues, cleaning products, air fresheners, deodorants, perfumes, pesticides, fungicides, burning mosquito coils, and candle or incense burning. The extent of IAP exposure largely depends on structural factors like a building's ventilation and insulation, proximity to important sources of ambient air pollution, such as busy roads or polluting industries, crowding, and personal behaviours, including smoking, pet ownership, and using various chemicals for cleaning.

#### Effects of air pollution

The Global Burden of Diseases study estimates that air pollution attributed to 1.67 million (0.98M from AAP and 0.6M from HAP) deaths in India in 2019, accounting for 17.8 per cent of total deaths

in the country<sup>10</sup>. While the deaths due to HAP decreased by 64 per cent from 2010 to 2020, deaths attributed to Ambient Air Pollution (AAP) increased by 115 per cent<sup>10</sup>. Although specific mechanisms of harm are not fully understood, substantial evidence indicates that even low-level exposure to air pollution adversely affects cardiovascular and respiratory health. Exposure during pregnancy and childhood is linked to an increased risk of asthma and impaired lung development, potentially leading to long-term respiratory issues and lower life expectancy<sup>10,11</sup>. Children, older people and individuals with pre-existing multi-morbidities such as cardiovascular or respiratory conditions are also particularly vulnerable to the effects of air pollution<sup>12</sup>. Daily exposure to PM has been associated with increased hospitalization and mortality due to acute exacerbations of heart disease, chronic obstructive pulmonary disease (COPD), and asthma. Furthermore, data from high-income countries shows that long-term exposure to air pollution increases the risks of developing lung cancer, heart disease, diabetes, stroke and dementia<sup>13</sup>.

Beyond its health impacts, air pollution has significant environmental consequences and economic implications, particularly in countries like India. With over 45 per cent of the population in 2022 engaged in agriculture<sup>14</sup>, the detrimental effects on agricultural productivity are enormous. Air-borne pollutants can cause acid rain and smog formation, damaging ecosystems, including forests, water bodies and wildlife habitats.

The economic costs associated with air pollution are substantial, including healthcare expenses, lost productivity due to illness and damage to infrastructure and crops. Poor air quality can discourage foreign investment and reduce tourism, hindering a country's overall economic development.

### Challenges in addressing air pollution

Combating air pollution is a complex task requiring many stakeholders' sincere and coordinated efforts. Some challenges that hinder air pollution control in India<sup>15</sup> are: (i) *Lack of enforcement*: Inadequate enforcement of environmental regulations, leading to non-compliance by industries, vehicle owners, and other polluting entities. India lacks stringent air pollution standards, relying on country-specific guidelines, which are way higher than WHO-recommended guidelines; (ii) *Rapid urbanization*: urbanization in India has resulted in increased

pollution levels due to higher energy consumption, vehicular traffic, and industrial activities concentrated in urban centres, posing a significant challenge to air quality management; (iii) *Socio-economic factors*: poverty, lack of access to clean energy sources, and inadequate infrastructure in rural areas contribute to the persistence of HAP and AAP in India, exacerbating the air pollution problem<sup>15</sup>.

### Government initiatives to combat air pollution

The scale of air pollution in many countries, including India, is huge, requiring a collaborative effort from the government, industries, civil societies, and the general public. The Indian government has initiated several measures to combat and reduce HAP and has developed some policies and regulations that are likely beneficial if implemented.

The Indian government launched the National Clean Air Program (NCAP) in 2019 to combat air pollution comprehensively. The programme aimed to formulate a plan to reduce PM concentrations by 20-30 per cent by 2024 through source apportionment studies in 102 cities nationwide<sup>16</sup>. The Government of India has formulated various policies and regulations to control air pollution, including emission standards for industries and vehicles, restrictions on crop burning, and measures to promote cleaner fuels and renewable energy sources. Transitioning to renewable energy sources such as solar, wind, and hydropower can help reduce reliance on fossil fuels and lower greenhouse gas emissions, mitigating air pollution and combating climate change. India has an ambitious target of getting 500 GW of energy from renewable sources by 2030. As of March 2024, it has already achieved 190 GW, with targets likely to be met ahead of schedule<sup>15,17</sup>.

In 2015, India launched the Air Quality Index (AQI) tool (<https://cpcb.nic.in>) to communicate air quality levels to the public in an easily understandable format. AQI monitoring and reporting is currently established in 34 of 36 States and Union Territories<sup>18</sup>. The primary aim is to raise awareness about air pollution and its health impacts, encouraging individuals to take preventive actions. Educating the public about the causes and consequences of air pollution and advocating for policy changes and sustainable solutions are essential in raising awareness and fostering a collective effort to combat this environmental challenge.

Several technological advancements have enabled citizens and industries to find solutions to minimize air-

borne pollutants released into the atmosphere or protect vulnerable individuals. In the short term, when AAP or HAP cannot be lowered, susceptible individuals are advised to use air purifiers equipped with HEPA (high efficiency particulate air) filters and activated carbon to improve indoor air. Individuals can play a crucial role in reducing air pollution by adopting sustainable practices such as avoiding burning domestic waste in their gardens, carpooling, using public transportation, conserving energy, and supporting clean air initiatives in their communities. Similarly, adopting electric vehicles (EVs) and hydrogen fuel as alternatives to traditional gasoline two-stroke and diesel vehicles can significantly reduce vehicular emissions in urban areas. However, infrastructure upgrades are necessary to meet the demand of the large population.

### Other initiatives

Several cities in India have successfully implemented initiatives to reduce air pollution, such as introducing cleaner fuel standards, promoting public transportation, and establishing air quality monitoring systems to track pollution levels and inform policy decisions. Learning from other countries that have effectively tackled air pollution through a combination of stringent regulations, technological innovations, public awareness campaigns, and international collaborations to address transboundary pollution issues, India can adopt a similar multi-faceted approach. To address air pollution effectively, India must adopt comprehensive strategies, including stricter enforcement of environmental regulations, investment in clean technologies, promoting sustainable urban planning, and public participation in pollution control efforts. The long-term strategy should focus on transitioning to cleaner energy sources, improving public transportation infrastructure, enhancing green spaces in urban areas, and fostering a culture of environmental stewardship in the population.

### Unconventional approaches to combat air pollution

The air pollution problem is too big for any single sector or government to address alone. It requires a concerted effort from all stakeholders to utilize innovative SMART (Specific, Measurable, Achievable, Relevant, and Time-Bound) solutions. Out-of-the-box thinking to prioritize novel ideas might lead to impactful and sustainable interventions to address air pollution, improve public health, and drive positive

change. Given India's vastness and diversity, one-size-fits-all solutions might be impractical; local solutions with active community participation are essential.

Some unconventional approaches could be: (i) *Community-led air quality monitoring*: Empowering local communities to monitor air quality in their neighbourhoods using low-cost sensors and mobile apps, which can then be used to advocate for policy changes and implement interventions; (ii) *Green infrastructure initiatives*: Vertical gardens, green roofs, and urban forests to help absorb pollutants and improve air quality in urban areas; (iii) *Art and awareness campaigns*: Collaborating with local artists and influencers to create engaging campaigns that raise awareness about health impacts of air pollution and the importance of taking action; (iv) *Mobile health clinics*: Setting up mobile health clinics in highly polluted areas to provide healthcare services and screenings for various health outcomes such as respiratory illnesses, as well as education on prevention and management; (v) *Innovative clean cooking solutions*: Solar cookers, biogas stoves, and efficient biomass pellet-based cookstoves, to reduce indoor air pollution and improve health outcomes; (vi) *Policy advocacy through data visualization*: Presenting air quality data in a compelling and easy-to-understand way, advocating for stronger environmental regulations and enforcement; (vii) *School-based education programmes*: Developing interactive educational programmes for schools that teach students about the sources and effects of air pollution, as well as practical steps they can take to reduce their exposure; and (viii) *Corporate partnerships for clean air initiatives*: Collaborating with businesses to implement projects that improve air quality in exchange for recognition and branding opportunities, fostering a sense of corporate social responsibility.

In conclusion, air pollution is a complex and pervasive problem in India that demands urgent and coordinated efforts from the government, industry, civil society, and individuals to mitigate its adverse effects on public health and the environment. By implementing effective policies, embracing clean technologies, raising public awareness, and fostering a culture of sustainability, India can work towards a cleaner and healthier future for its citizens. All stakeholders must take responsibility, actively reducing air pollution, and ensure that the air we breathe is safe for us as well as for future generations. Active participation, innovative thinking, and sustained stakeholder commitment are crucial for achieving this goal.

**Financial support & sponsorship:** None.

**Conflicts of Interest:** None.

**Use of Artificial Intelligence (AI)-Assisted Technology for manuscript preparation:** The authors confirm that there was no use of AI-assisted technology for assisting in the writing of the manuscript and no images were manipulated using AI.

**Om P. Kurmi<sup>1,2</sup>, Tara Ballav Adhikari<sup>3,4,6</sup>,  
Sudhir K. Tyagi<sup>7</sup>, Per Kallestrup<sup>3</sup> &  
Torben Sigsgaard<sup>4,5\*</sup>**

<sup>1</sup>Research Centre for Healthcare and Communities, Coventry University, Coventry, United Kingdom,

<sup>2</sup>Department of Medicine, McMaster University, Hamilton, Canada, <sup>3</sup>Research Unit for Global

Health, <sup>4</sup>Danish Big Data Centre for Environment and Health (BERTHA), &

<sup>5</sup>Department of Public Health, Aarhus University, Denmark, <sup>6</sup>Nepal Health Frontiers, Kathmandu,

Nepal, & <sup>7</sup>Department of Energy Science and Engineering, Indian Institute of

Technology, Delhi, India

\*For correspondence:

ts@ph.au.dk

Received June 3, 2024

## References

1. State of Global Air. *How does air pollution affect life expectancy around the world?* Available from: <https://www.stateofglobalair.org/resources/report/how-does-air-pollution-affect-life-expectancy-around-world#:~:text=The%20major%20global%20health%20effects,as%20much%20as%201.8%20years>, accessed on May 25, 2024.
2. Kurmi OP, Lam KB, Ayres JG. Indoor air pollution and the lung in low- and medium-income countries. *Eur Respir J* 2012; 40 : 239-54.
3. Newell K, Kartsonaki C, Lam KBH, Kurmi O. Cardiorespiratory health effects of gaseous ambient air pollution exposure in low- and middle- income countries: a systematic review and meta-analysis. *Environ Health* 2018; 17 : 41.
4. Newell K, Kartsonaki C, Lam KBH, Kurmi OP. Cardiorespiratory health effects of particulate ambient air pollution exposure in low- and middle- income countries: a systematic review and meta-analysis. *Lancet Planet Health* 2017; 1 : e368-e80.
5. Van Donkelaar A, Martin RV, Li C, Burnett RT. Regional estimates of chemical composition of fine particulate matter using a combined geoscience-statistical method with information from satellites, models, and monitors. *Environ Sci Technol* 2019; 53 : 2595-611.
6. World Health Organization. *Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide. Global update 2005: Summary of risk assessment.* Available from: [https://www.who.int/publications/m/item/who-ambient-air-quality-database-\(update-2023\)](https://www.who.int/publications/m/item/who-ambient-air-quality-database-(update-2023)), accessed on May 25, 2024.
7. Statista. *Number of vehicles in operation across India from financial year 1951 to 2020 (in millions).* Available from: <https://www.statista.com/statistics/664729/total-number-of-vehicles-india/>, accessed on May 25, 2024.
8. Health Effects Institute. *State of Global Air 2024. Explore the data. Data source: Global burden of disease study 2021.* Available from: <https://www.stateofglobalair.org/data/#/air/plot?country=IND&pollutant=hap&measure=death&deathMetric=number&geography=country&region=country&subregions=&outcome=exposure&regionToggle=0&globals=false&hideCountry=false>, accessed on September 1, 2024.
9. Schweizer C, Edwards RD, Bayer-Oglesby L, Gauderman WJ, Ilacqua V, Jantunen MJ, *et al.* Indoor time-microenvironment-activity patterns in seven regions of Europe. *J Expo Sci Environ Epidemiol* 2007; 17 : 170-81.
10. Fuller R, Landrigan PJ, Balakrishnan K, Bathan G, Bose-O'Reilly S, Brauer M, *et al.* Pollution and health: a progress update. *Lancet Planet Health* 2022; 6 : e535-e47.
11. Kurmi OP, Devereux GS, Smith WC, Semple S, Steiner MF, Simkhada P, *et al.* Reduced lung function due to biomass smoke exposure in young adults in rural Nepal. *Eur Respir J* 2013; 41 : 25-30.
12. Hystad P, Duong M, Brauer M. Health effects of household solid fuel use: Findings from 11 countries within the prospective urban and rural epidemiology study. *Environ Health Perspect* 2019; 127 : 57003.
13. Sharma R, Kurmi OP, Hariprasad P, Tyagi SK. Health implications due to exposure to fine and ultra-fine particulate matters: a short review. *Int J Ambient Energy* 2024; 45 : 2314256.
14. International Labour Organization. Institute for Human Development. *India Employment Report 2024. Youth employment, education and skills.* Available from: <https://www.ihdindia.org/pdf/India-Employment-web-22-April.pdf>, accessed on September 1, 2024.
15. Energy Transition Commission. *Roadmap to India's 2030 decarbonization target.* Available from: <https://www.teriin.org/sites/default/files/files/Roadmap-to-India-2030-Decarbonization-Target.pdf>, accessed on May 28, 2024.
16. Council on Energy, Environment and Water (CEEW) and Urban Emissions. *How robust are urban India's clean*

- air plans? An assessment of 102 cities*. Available from: <https://www.ceew.in/sites/default/files/CEEW-How-Robust-are-Urban-Indias-Clean-Air-Plans-16Jun20.pdf>, accessed on September 1, 2024.
17. The Energy and Research Institute. *Air pollution in India: Major issues and challenges*. Available from: <https://www.teriin.org/article/air-pollution-india-major-issues-and-challenges>, accessed on September 1, 2024.
18. Central Pollution Control Board, Ministry of Environment, Forest and Climate Change, Government of India. *National Air quality index (AQI)*. Available from: <https://cpcb.nic.in/National-Air-Quality-Index/>, accessed on September 5, 2024.