Romanian Journal of Ecology & Environmental Chemistry, 8(1), 2026
https://doi.org/10.21698/rjeec.2026.102

Review

Smart air pollution management in Smart Indian Cities: a narrative review

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Received: *18.01.2026* *Accepted:* *17.06.2026* *Published:* *07.07.2026*

Abstract

Rapid urbanization, industrialization and motorization have intensified air pollution challenges in Indian cities, posing significant risks to public health and sustainable development. Conventional air quality management approaches, largely reactive and static, are insufficient to address the complex and dynamic nature of urban air pollution. This manuscript reviews the role of artificial intelligence (AI) and environmental technologies in advancing air pollution management within the framework of India's Smart Cities Mission and the National Clean Air Programme (NCAP). AI-driven techniques, including machine learning and deep learning, enable improved air quality forecasting, source apportionment, hotspot identification and decision-support systems through integration of multi-source data from sensors, satellite observations and meteorology. The study further examines environmental technologies targeting pollution reduction across transport, industrial, construction, indoor and outdoor environments, including electric mobility, advanced emission controls, carbon capture, dust mitigation, outdoor air purification and nature-based solutions. An integrated smart city framework is proposed linking data, AI analytics, interventions, monitoring and health-focused outcomes. The findings suggest that coordinated AI-enabled governance and targeted technologies can substantially reduce air pollutant levels, enhance regulatory efficiency and support healthier, climate-resilient urban environments in India.

Keywords: *allergy, air pollution, Delhi, India, Smart City*

INTRODUCTION

Air Pollution as a public health challenge in urban India

Air pollution indicates one of the prominent public health crises which the urban India face today. Industrial growth, motorisation, rapid urbanisation and unplanned city expansion have led to consistently elevated ambient air pollution across major cities in India. India is known for many of the world's most polluted cities with poor air quality which has become routine reality for millions of residents in cities of India [1,2].

It was found that approximately 1.67 million premature deaths have occurred in India due to air pollution which accounts for around 18% of total mortality nationwide [3]. The underlying reason for this burden is chronic exposure to fine particulate matter (PM2.5) that diffuses deep into systemic circulation and lungs, causing inflammation through oxidative stress pathways [4]. People in cities experience excess burden of this exposure due to intense traffic, construction activity and industrial clusters. Presently, India regulates air quality via the National Ambient Air Quality Standards (NAAQS) under the Central Pollution Control Board by the Air (Prevention and Control of Pollution) Act. The present standards, revised in 2009, denote the maximum permissible concentrations for major air pollutants in ambient air. For particulate matter, the annual permissible standards are 40 $\mu g/m^3$ for $PM_{2.5}$ and 60 $\mu g/m^3$ for PM_{10}, with corresponding 24-hour limits of 60 $\mu g/m^3$ and 100 $\mu g/m^3$ respectively. For gaseous air pollutants, the annual limits comprise of 40 $\mu g/m^3$ for NO_2 and 50 $\mu g/m^3$ for SO_2, while the 24-hour limits are 80 $\mu g/m^3$ for both air pollutants. Ozone levels are regulated at 100 $\mu g/m^3$ for an 8-hour average, and CO limits are regulated at 2 mg/m^3 for an 8-hour exposure period. These regulatory thresholds serve as the primary benchmarks for monitoring air quality and policy interventions in India.

Major cities in India often report annual average $PM_{2.5}$ concentrations more than 50 µg/m^3, that are significantly greater than typical levels documented in most European countries where concentrations usually remain below 15÷20 µg/m^3. Though China historically reported severe urban air pollution, strict regulatory interventions over the past decade resulted in notable improvements in most urban centres. Contrary to this, many cities in South Asia, including India, persist to report constantly elevated air pollution levels, emphasizing the requirement for more efficient and technology-mediated air quality management strategies.

Effects of urban air pollution on health

The effects of chronic air pollution in Indian cities affect multiple organ systems in life course. The most common outcome is respiratory diseases, with increasing prevalence of asthma among paediatric age group and chronic obstructive pulmonary disease (COPD) among adults in people living in cities [5]. Persistent exposure during the early period of life has been found to retard lung growth in children, causing decreased lung function which persists into adulthood and heightens the risk of respiratory infections [6]. Additionally, chronic air pollution significantly elevates the risk of cardiovascular diseases, including hypertension, myocardial infarction, arrhythmias and stroke [7]. Emerging research also shows side effects like cognitive and neurological effects, with correlations found between air pollution exposure and defective cognitive performance, high risk of neurodegenerative conditions and neurodevelopmental delays [8]. Pregnant women, adults, children and people with co-morbidities like cardiovascular disease and diabetes are particularly vulnerable. These health effects translate into decreased quality of life, heavy healthcare utilization and avoidable mortality.

Major sources of urban air pollution

Air pollution in urban part of India develops from various interacting sources. Vehicular emissions was a leading contributor and driving factor for air pollution, driven by traffic congestion, high vehicle density and laxer emission standards, though the conversion to Bharat Stage VI (BS-VI) fuel and newer vehicle norms denotes a notable policy advance [9]. Furthermore, industrial emissions including those from manufacturing units, power plants and small-scale industries, result in ambient particulate and gaseous pollutants. Road and construction dust are significant, yet often under-regulated sources of PM2.5 and PM10, particularly in rapidly growing Indian cities [10]. Additionally, biomass burning for the purpose of heating and cooking in household use, and burning of agricultural residue in peri-urban areas constantly worsens air quality seasonally [11].

The primary reason behind these is poor urban planning, reflected by urban sprawl, inadequate public transport, poor enforcement of environmental regulations and restricted green spaces.

Economic consequences

Air pollution causes significant economic burden in India. It was found that India lost approximately 1.3% of its GDP annually due to air pollution related healthcare expenditure, poor labour productivity and early mortality. These economic losses persist beyond macroeconomic indicators, impacting daily household incomes and augmenting cycles of poverty. This economic burden is particularly said to be unequally distributed. Marginalised and low-income communities tend to live in high-pollution areas near industrial areas with poor indoor air quality, augmenting prevailing health inequalities.

Ongoing challenges

In view of ongoing air pollution crisis, the Government of India implemented the National Clean Air Programme (NCAP), targeting to decrease PM2.5 and PM10 concentrations via city-specific action plans, improved monitoring and intersectoral coordination [12]. Supporting initiatives comprising expansion of renewable energy, promotion of electric vehicles and stricter emission and fuel standards.

In spite of these efforts, potential challenges exist and interventions are often reactive instead of preventive with inconsistent enforcement and uneven air quality monitoring networks. While existing tools like satellite-based monitoring and Air Quality Index (AQI) have supported surveillance, conversion of data into effective, timely action is still limited.

Need for smart and integrated solutions

In India, air pollution is not just an environmental issue, but a critical national public health emergency necessitating sustained and comprehensive solutions. Short term or isolated measures like personal protective behaviours and temporary restrictions are insufficient. Instead, there is an urgent requirement for integrated strategies that combine smart urban planning, technological innovation, health-focussed governance and behavioural change.

Intelligent and smart air pollution management frameworks which use real-time monitoring, artificial intelligence, environmental technologies and specific interventions might contribute to an opportunity to expand beyond passive measurement toward preventive protection of people's health from air pollution in India's rapidly growing smart cities.

CONCEPT OF SMART AIR POLLUTION MANAGEMENT

Smart air pollution management denotes an advanced shift in environmental governance which utilises digital technologies to extend beyond static, traditional regulatory protocols toward a data-driven, real time, dynamic and preventive approach to improve air quality and public health protection [13].

It integrates networks of centralized data platforms, Internet of Things (IoT) sensors and artificial intelligence (AI) to foster real-time, continuous monitoring critical air pollutants like CO, $PM_{2.5}$ and NO_2 at good spatial resolution, thereby overcoming existing limitations of using conventional monitoring stations [14]. By synthesizing air quality data from meteorological variables, traffic trends, industrial emission patterns and land-use information, smart air pollution allows evidence-based practical decision making and reiterates predictive analytics that are capable of forecasting air pollution episodes much before they occur. This provides opportunities for authorities to shift from reactive responses to preventive interventions, encompassing temporary emission regulation measures, dynamic traffic management, specific deployment of environmental air purification systems and prompt public health advisories.

Contrary to static control, based on infrequent compliance checks and fixed standards, smart management systems are continuously responsive, adaptive to changing city conditions and might be competent of identifying specific air pollution hotspots rather than relying solely on wider regional averages. Smart cities play a crucial role in facilitating smart air pollution management by offering the required digital infrastructure, governance mechanisms and intersectoral integration needed to connect air quality management with energy, intelligent transport and urban planning systems [15]. Through improved monitoring, transparent public communication and integrated mitigation approaches, smart air pollution could have significant potential to decrease air pollution associated morbidity and mortality, by promoting healthy environment and empower communities to enable making informed decisions which collectively lead to healthier and sustainable urban environments in India.

MONITORING AND SENSING TECHNOLOGIES FOR AIR POLLUTION

Monitoring and sensing technologies offer real-time data of air pollutant concentrations, helping accurate assessment, informed air quality management for smart cities and early warning (Figure 1).

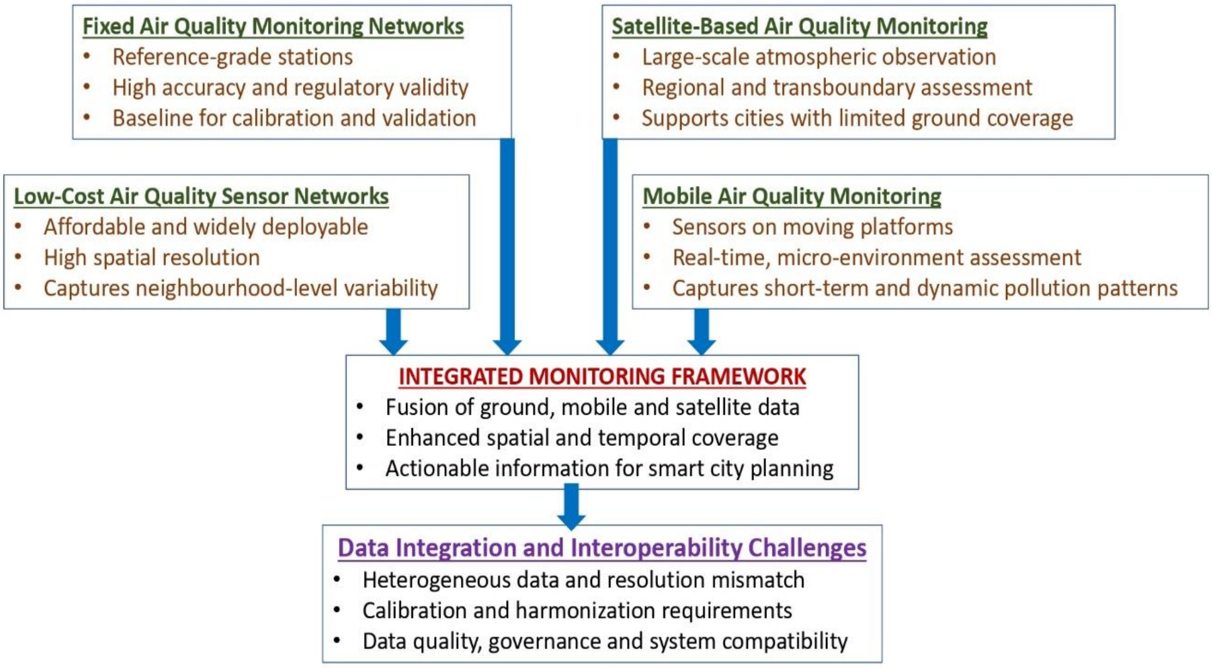

Fig. 1. Monitoring and sensing technologies for air pollution

1. Fixed air quality monitoring networks

Fixed air quality monitoring networks forms the basis of air pollution assessment in urban cities and are well appreciated as the gold standard for research and regulatory compliance. These networks comprise of a highly developed and costly analytical tools. Their main purpose is to generate accurate, precise and legally valid air quality data, that is needed for implementing national and international standards for air quality, determining policy effectiveness and assisting long-term epidemiological and environmental studies. Fixed stations periodically measure pollutants such as particulate matter, sulfur dioxide (SO_2), nitrogen oxides (NO_x), carbon monoxide (CO) and ozone (O_3), using advanced methods like chemiluminescence, beta-attenuation and non-dispersive infrared analysis. Because of standardized measurement protocols, rigorous calibration procedures and strict quality assurance practices, the data obtained are highly accurate and often provide as reference for standardizing upcoming monitoring technologies and assisting air quality forecasting and modelling efforts [16].
Despite their reliability and high accuracy, fixed air quality monitoring networks encounter potential limitations in spatial coverage due to high expense related to installation, operation and maintenance. Consequently, the number of stations deployed within a city is less, causing coarse spatial resolution which might not efficiently capture localized emission hotspots near industrial zones, roads or densely inhabited regions or neighbourhood-level pollution variability. Even though these fixed monitoring networks are good at offering regulatory-grade datasets and long-term temporal trends, they might miss short-range pollution dynamics which are highly important in smart cities. However, fixed monitoring stations are important and integral as a baseline and validation layer inside multi-layered monitoring frameworks. This helps in calibrating low-cost sensors and integration with satellite and mobile data. In countries such as United States, data obtained from these monitoring stations are shared publicly through platforms like AirNow, thereby improving public awareness, transparency and informed decision-making [17,18]. Therefore, fixed air quality monitoring networks continue to play a crucial role in air quality management in smart city, especially when incorporated with supporting sensing technologies and developed data analytics.

2. Low-cost air quality sensors

Low-cost air quality sensors had dramatically changed monitoring of air pollution in urban regions by enabling widespread deployment and enhancing community participation. These sensors are said to be affordable, compact and comparatively easy to install, and can be implemented as dense sensor networks in complicated urban setups. Hence, they might offer high spatial resolution data which could collect localized air pollution patterns and short-range air pollution dynamics that are often missed by conventional fixed air quality monitoring networks. Previous studies have reported that low-cost sensors are highly effective for tracking selected gaseous pollutants and particulate matter ($PM_{2.5}$ and PM_{10}), thereby helping applications like exposure assessment, neighbourhood-scale mapping and smart city planning [19].

In spite of these notable advantages, low-cost air quality sensors usually lack the accuracy, long-term stability and selectivity of reference-grade air quality instruments. The performance of low-cost sensors could be influenced potentially by various environmental factors like relative humidity, temperature, sensor aging or drift and cross-sensitivity to other gases, which might impart systematic biases if not properly resolved. Hence, calibration via field col-location with reference monitors, laboratory testing or machine learning-based correction techniques is needed to enhance reliability of data [20]. When accurately quality-regulated and standardized, low-cost sensors might contribute useful and actionable data which complement fixed air quality monitoring networks, especially for locating air pollution hotspots, depicting micro-scale variability and visualizing environmental exposure inequalities in urban regions.

Apart from the technical contributions of low-cost sensors, they play a pivotal role in community-based and public-engagement research initiatives. By facilitating local organizations, schools and residents to explicitly measure air quality in their neighbourhoods, these instruments drive public awareness, public engagement in air quality governance and environmental literacy [21]. This way of community monitoring programs was found to improve trust in environmental data, inform local air pollution reduction strategies and helps grassroots advocacy, especially in previously unmonitored or underserved areas. Networks like PurpleAir demonstrate this strategy, with sensor data been highly incorporated into public-facing platforms and might sometimes use alongside regulatory data to offer near-real-time information of air quality. Hence, low-cost networks might not work as replacements for fixed air quality monitoring networks, rather it works as supporting tools which expands spatial coverage, strengthen data-driven management of air quality and aids participatory monitoring, particularly where official monitoring infrastructure is limited in smart cities.

3. Satellite-based and mobile air quality monitoring

Smart cities progressively incorporate mobile and satellite-based air quality monitoring strategies to address spatial limitations of fixed air quality monitoring systems. Mobile air quality monitoring comprises of mounting sensors on moving platforms like taxis, drones, public transport vehicles, personal wearable devices and bicycles. This approach allows to collect real-time, highly resolved air quality data over widespread urban microenvironments, including residential neighbourhoods, roadways and pedestrian zones. By constantly sampling air quality along movement trajectories, mobile air quality monitoring offers granular spatial information which could not be attained by fixed monitoring stations alone and is especially effective for obtaining sharp pollution gradients within urban areas. Mobile systems are highly useful for detecting transient pollution events, determining individual air pollution exposure levels under rea-world conditions and mapping air pollution across traffic corridors [22]. However, they necessitate robust data processing and validation to adjust for sensor variability and movement-induced measurement noise.

These monitoring strategies provides a supporting, large-scale perspective with the help of Earth-observing instruments to identify atmospheric pollutants like CO, NO_2, O_3, SO_2 and aerosol optical depth (AOD), that serves as a proxy for particulate matter. Satellite observations are pivotal for monitoring regional air pollution patterns, biomass burning, long-range transport of pollutants and transboundary air pollution, especially in regions with restricted ground-based infrastructure like urban cities [23]. Recent developments in remote sensing have enhanced the temporal and spatial granularity of satellite products, that allows more detailed analysis of urban air quality dynamics and promoting near-real-time environmental surveillance.

Integrated frameworks which merge satellite data with mobile and ground sensor networks improve the accuracy and value of these observations. For instance, SAMIRA (Satellite monitoring for air quality) denotes a holistic approach which integrates satellite remote sensing, in situ assessments and advanced data assimilation to enhance near-surface air pollution estimation, complement exposure assessments and helps to make plan for urban air quality management [24]. By this means of integration, it helps to address limitations of individual systems including satellite sensitivity to atmospheric layers above ground level and mobile sensor discontinuities by generating integrated datasets which are precise, spatially continuous and actionable. Previous studies have shown that integrated paradigm reported a greater potential to derive surface-level pollutant concentrations like particulate matter, from columnar satellite data when appropriately calibrated with local ground observations and to cover monitoring gaps across urban and peri-urban regions where fixed air quality monitoring stations are limited.

Open data repositories and public platforms which offer access to satellite and fused datasets, comprising NASA's air quality portals, SAMIRA-based products and Sentinel-5P/TROPOMI mission outputs are progressively used in planning smart city, public health research and environmental policy. By integrating the wider spatial view of satellites with fine-scale resolution of fixed and mobile networks, these integrates strategies helps to map air pollution effectively, identify, potential sources and forecast air quality, thereby strengthening evidence-based planning of air pollution management in urban environment [25].

4. Data integration and interoperability challenges

A potential challenge that exists in managing air quality smart city is integration of heterogenous data streams produced by fixed air quality monitoring networks, low-cost sensor networks, mobile platforms and satellite-based air quality monitoring networks. These data sources differ considerably in temporal and spatial resolution, data formats, measurement precision and uncertainty characteristics, leading to technically complex harmonization and joint analysis [26]. Fixed air quality monitoring networks generate precise but spatially sparse data, while low-cost sensors produce dense spatial coverage at the expense of greater uncertainty. Furthermore, satellite data add regional-scale context, but assess columnar instead of surface-level concentrations. Combining these distinct datasets effectively needs advanced calibration approaches, hybrid physical-statistical strategies and machine learning, to create coherent and reliable information on air quality.

Interconnectivity across data infrastructures and monitoring platforms is crucial for understanding the full potential of smart city air quality systems. The lack of calibrated data models, communication protocols and metadata conventions often leads to fragmented data sources which restrict effective data sharing and coordinated analysis over technologies and agencies [27]. Previous studies have shown that necessity for interoperable architectures which aids open data standards, real-time data exchange and continuous integration with decision-support systems. Upcoming smart city frameworks highly rely on Internet of Things (IoT) architectures, application programming interfaces (APIs) and cloud-based platforms to enable scalability and interoperability. However, securing compatibility over legacy systems and newly employed sensors persists as a challenge.

Assurance of data quality and validation are existing concerns, especially for low-cost sensors which are highly susceptible to sensor drift, environmental interference and operational changes [28]. Additionally, large volume and velocity of data produced by dense sensor networks ad satellite observations create a challenge associated with computational processing, data storage, ethical data governance and cybersecurity. The fundamental objectives behind building a data-driven, trustworthy systems are ensuring secure data handling, privacy protection and transparent use of air quality information.

ROLE OF ARTIFICIAL INTELLIGENCE IN AIR POLLUTION MANAGEMENT

Artificial intelligence (AI) is set to enhance management of air pollution by extending beyond traditional monitoring and forecasting, towards adaptive, automated and intervention-related solutions (Figure 2). Modern applications integrate AI within control and regulatory frameworks, improving real-time emission mitigation, auto-controlling environmental systems, and smart purification mechanisms. These advancements are particularly important for handling the complicate, evolving air quality challenges prevalent in Indian smart cities under national initiatives like National Clean Air Programme (NCAP).

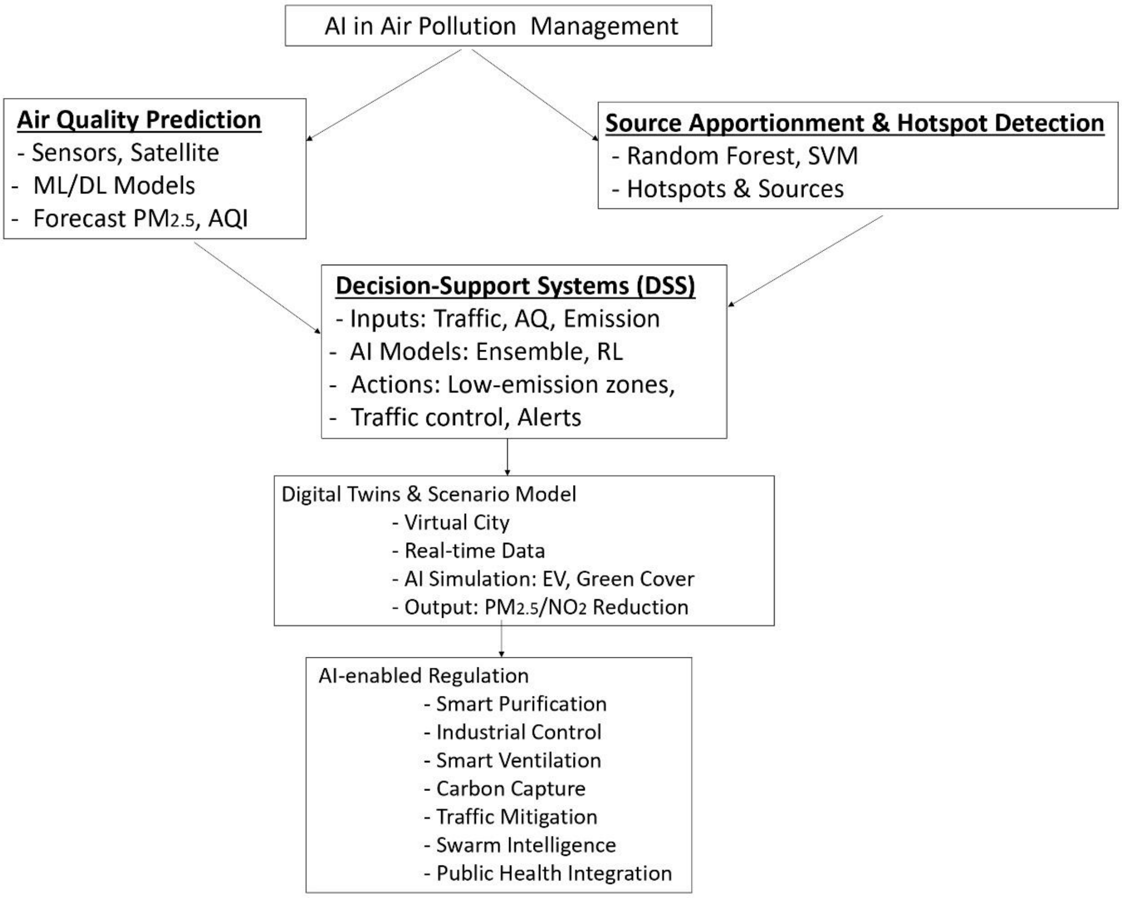

Fig. 2. Role of AI in air pollution management

1. AI-based air quality prediction and forecasting

AI has become a transformative strategy for predicting and forecasting air quality by helping analysis of large, complex, heterogenous datasets obtained from ground-based sensors, meteorological observations, IoT networks, historical pollution records and satellite imagery. Traditional deterministic and statistical models often fail to capture nonlinear, complex and spatiotemporal changes of atmospheric air pollution. On the other hand, deep learning (DL) and machine learning (ML) techniques can determine hidden relationships and patterns within multidimensional data, resulting in enhanced forecasting accuracy for critical air pollutants like NO_2, $PM_{2.5}$, PM_{10}, O_3 and composite air quality indices [29]. These AI-mediated predictive systems complement early warning mechanisms, smart urban planning decisions, public health alerts and air pollution emissions control approaches, thereby playing a pivotal role in environmental management of smart city and sustainable development.

AI-mediated forecasting of air quality consists of a structured pipeline comprising of collection of data, preprocessing, model training, prediction and deployment. Historical and real-time datasets are incorporate from satellite platforms, IoT-enabled sensors and meteorological records, succeeded by preliminary processing steps like data cleaning, normalization, feature engineering and decomposition of signal to improve model robustness [30]. ML algorithms like Extreme Learning Machines, CatBoost, Random Forest and DL architectures, especially Long Short-Term Memory (LSTM) networks are increasingly used due to their efficiency in obtaining temporal dependencies in air pollution time-series data. Emerging strategies also integrate computer vision techniques which analyse sky images to conclude visual air pollution cues like haze and atmospheric discolouration, contributing budget-friendly complements to environmental sensing. Forecast results are executed through mobile applications or dashboards for health agencies and policy makers. Even though these systems exhibit real-time applicability, superior accuracy and scalability, relative to conventional methods, limitations exist related to distinguishing air pollution from handling minute particulate changes, meteorological artifacts, securing access to large labelled datasets, and maintaining interpretability of model and computational efficiency for practical field implementation.

2. Source apportionment and hotspot identification

AI plays a critical role in apportionment of air pollution source and detection of hotspot by applying recent ML techniques to multi-source datasets, improving precise attribution of emissions and detection of specific pollution-intensive areas in urban set up [31]. Conventional receptor-based strategies, like positive matrix factorization, often has restrictions when targeting high-dimensional data and nonlinear relationships related to diverse sources including industrial processes, vehicular traffic, construction activities and biomass combustion. AI-mediated methods like Support Vector Machines, Random Forest and deep neutral networks incorporate complex datasets from satellite observations, ground sensors, IoT networks and meteorological parameters to determine fractional source contributions to ambient concentrations of SO_2, $PM_{2.5}$ and NO_2. For instance, convolutional neural networks used to satellite imagery enhance spatial resolution, improving the differentiation between local emissions and long-range air pollutant transport, especially across regions such as Indo-Gangetic plains.

In Indian cities like Punjab and Haryana, AI-enabled analyses have been central in determining seasonal air pollution events like agricultural residue burning [32]. Investigational studies in Delhi reveals approximately 20÷40% of levels of $PM_{2.5}$ in winter due to such events, though recent observational evidence shows minimal contributions of around 3-10% in certain years following alleviation efforts. Integrated ML-GIS frameworks improve the neighbourhood-scale air pollution mapping for hotspots, particularly near industrial zones and traffic corridors, repeatedly achieving predictive model R^2 values going beyond 0.7. These technologies help near-real-time detection via mobile sensing and widespread data analytics platforms, created by major research institutions like IIT Madras and IIT Kanpur. Existing challenges consisting of uneven data coverage, standardization needs against reference-grade monitors and considerable computational demands. Yet, AI-based source appointment improves implementation of NCAP by providing evidence-based knowledge which guide specific interventions and decrease health inequities among vulnerable populations.

3. Decision-support systems for air pollution control

AI-mediated decision-support systems (DSS) are strengthening air pollution control in urban regions by converting real-time data into actionable intelligence, which mediates anticipatory governance and emission control in smart cities of India. These platforms apply ML techniques comprising of ensemble learners like CatBoost and XGBoost, long with reinforcement learners, to incorporate inputs from air quality monitoring networks, meteorological forecasts, traffic surveillance systems and air pollution emission inventories. By creating interactions across these domains, DSS provide recommendations for active interventions like implementations of low-emission zones, adaptive traffic management and industrial emission control, particularly during episodes of air pollution, thereby transforming policy responses from reactive to proactive modes [33].

In country like India, where air pollution emission sources are numerous and enforcement capacity differs, DSS integrated with NCAP objectives help to focus on interventions at air pollution hotspots and correlate air quality metrics with public health indicators for populations at-risk. Collaborations consisting of institutions like IIT Kanpur have created AI-mediated DSS platforms for hyper-local identification of source and circumstance-based simulations, predicting potential $PM_{2.5}$ decrease by up to 20-25% via specific NCR-wide regulation strategies [34]. Models like SAFAR offer AI-based AQI visualization and public alerts via dashboards, indicating enhanced detection of severe air pollution scenarios in recent years. While benefits consist of improve resource allocation and better forecasting precision, limitations exist related to data interoperability, system transparency and scalability in zones with poor infrastructure. Ethical factors like the requirement to assure equitable access and prevent reinforcing prevailing social disparities, are also important. Together, AI-operated

DSS improve cross-sectoral coordination and assist the objectives of India's Smart Cities Mission by fostering healthier urban environments.

4. Digital twins and circumstance modelling for cities

AI-mediated digital twins provide virtual illustrations of urban systems, which enable advanced scenario modelling for management of air pollution in smart cities of India. These digital platforms incorporate real-time data from satellite observations, IoT sensors and AI algorithms like deep reinforcement learning, to recreate traffic flows, urban infrastructure and atmospheric mechanisms. By combining ML-based forecasts with physical dispersion models like WRF-Chem, digital twins examine the outcomes of policy interventions such as electric vehicle adoption or green cover on pollutant levels including NO_2 and $PM_{2.5}$ [35].

It was found that AI-powered digital twins helps predictive urban planning and climate-resilient approaches in areas like Delhi under NCAP with potential decrease in PM ranging from 10-30% via effective emission control measures. Early-stage systems, including cloud-based implementations, have attained moderate to strong predictive performance ($R^2 > 0.6$) for experimentation of policy and AQI forecasting consisting of biomass and industrial emission regulations. Main advantages consist of energy-efficient optimization and immersive 3D visualization of urban systems, while limitations comprise of data privacy concerns, integration with legacy infrastructure and high computational price [36]. Further advancements, especially through generative AI for circumstance synthesis, has potential role for broadening accessibility and enhancing sustainable, equitable and health-responsive urban planning and development.

5. Emerging AI-enabled air pollution regulation technologies

AI is widely incorporated within recent air pollution control and air purification systems employed over urban environments, including hybrid indoor-outdoor systems, roadside purification units and widespread installations. ML algorithms dynamically control filtration ability, airflow changes and operational schedules related to real-time air pollutant concentrations, population density patterns and meteorological conditions. These intelligent technologies focus air pollutants like NO_2 and $PM_{2.5}$ during peak air pollution exposure periods, improving removal efficacy while decreasing consumption of energy by around 20÷30% in prototype deployments [37]. Predictive AI processes improve proactive activation before regulatory thresholds are surpassed.

- *AI-based smart air purification systems*
  Modern roadside and hybrid purification systems uses ML-mediated optimization, with Indian traits, especially those related with IIT Kanpur, demonstrating superior energy efficiency and air pollutant-specific clearance performance [38].
- *Autonomous air pollution emission regulation in industrial systems*
  Reinforcement learning techniques improve chemical reactions, industrial combustion mechanisms and exhaust treatment systems like electrostatic precipitators and scrubbers, reducing emissions without affecting productivity and decreasing dependence on manual monitoring [39].
- *AI-mediated smart ventilation and creating air pollution control:*
  In smart building within cities, AI combines indoor and outdoor air quality data to equalize ventilation rates, air pollution removal efficacy and energy utilization, dynamically changing biofiltration systems and airflow during air pollution spikes [40].
- *AI in capturing air pollution and carbon-based technologies*
  ML models improve the ability of carbon capture, utilization and storage (CCUS) systems by improving sorbent materials, regeneration cycles and operational temperature, while simultaneously augmenting the discovery of specific catalysts for gaseous air pollutants and particulate matter [41].
- *AI-regulated smart traffic emission mitigation systems*
  Upcoming solutions aid adaptive implementation of low-emission regions, vehicle access regulations, dynamic road pricing and roadside barriers in reaction to real-time air quality

conditions, giving rise to responsive urban mobility ecosystems, including pilot trials in cities like Delhi [42].

- *Swarm intelligence and distributed air pollution regulation*
  Networks of Ai-mediated mobile units like sensor-purifier hybrids, collaboratively detect and targets air pollution hotspots, dynamically changing to conditions in construction zones, high-density zones and during huge public events [43].
- *Incorporation with public health protection systems*
  AI integrates air pollution mitigation strategies with data from health surveillance, including wearable sensors, hospital admissions and mobility patterns to emphasize protective actions for high-risk populations and improve health-adaptive air pollution regulation strategies [44].

ENVIRONMENTAL TECHNOLOGIES FOR DECREASING AIR POLLUTION

Technologies which target to reduce air pollution includes engineered solutions ranging from large-scale industrial systems like scrubbers, electrostatic precipitators (ESP), carbon capture and selective catalytic reduction, to urban-level advancements like vehicle-mounted filters, roadside purifiers, nature-inspired filtration and electric vehicles (Figure 3). These technologies use chemical, physical and nanomaterial-based techniques to obtain, neutralize or inhibit the emission of pollutants like SO_2, PM, VOCs, etc. These technologies align with NCAP that aims to decrease 20-40% of PM_{10} in non-attainment cities via stricter emission standards, city-specific plans and encouraging cleaner technologies. Furthermore, incorporating IoT and AI improves real-time enhancement, helping health-centric smart city objectives [45].

1. Transport and traffic-related interventions:

In cities like Delhi, up to 40% of PM2.5 is contributed by transportation, driven by congestion, road dust and tailpipe emissions. Interventions target low- or zero- emission mobility, supporting infrastructure and advanced after-treatment technologies to decrease air pollutants, while enabling sustainable city planning under Smart Cities Mission and NCAP [46].

(i) Hybrid and electric vehicle technologies:

Hybrid models and electric vehicles (EVs) are pivotal to decrease transport-based air pollution, eliminating or minimizing tailpipe emissions of air pollutants that potentially leads to urban smog and subsequent respiratory illnesses. Presently, adoption of EV has augmented through initiatives like NCAP and FAME-II, with estimated 56 lakhs EVs registered by initial period of 2025, mostly in two- and three- wheelers appropriate for short commutes and dense urban traffic. It was found in TERI studies that EVs could potentially prevent millions of tonnes of CO_2 per year and reduce urban NO_x by around 20÷70% in compliant fleets [47].

Hybrid vehicles integrate electric propulsion with internal combustion engines, thereby attaining 30-50% reduced emissions in practice, while EVs run on battery technologies such as lithium-ion and emerging solid-state batteries, contributing ranges up to 500 km and DC fast charging within 30 minutes.

Potential challenges comprise of establishing robust charging facilities and managing grid dependency, that might indirectly increase emissions if driven by coal. This can be mitigated by renewable integration like solar-powered stations in Pune. Hence, these environmental technologies might decrease air pollution, lower fuel price, offer health benefits like decreasing incidence of asthma in children and are critical for India’s net-zero goals by 2070 [48].

(ii) Advanced emission control systems:

Advanced emission control systems comprising of diesel particulate filters (DPFs), catalytic converters and selective catalytic reduction (SCR) are important retrofits and regulatory requirements for internal combustion vehicles to achieve strict standards like Bharat Stage IV (BS-IV), relative to Euro VI, targeting to reduce vehicular air pollution in India’s cities. Three-way catalytic converters chemically convert toxic exhaust gases like hydrocarbons to water & CO_2, CO to CO_2 and NO_x to nitrogen thereby attaining up to 90% efficacy in gasoline engines, as found by CPCB data depicting CO reduction post-BS-VI rollout in the year 2020 [49].

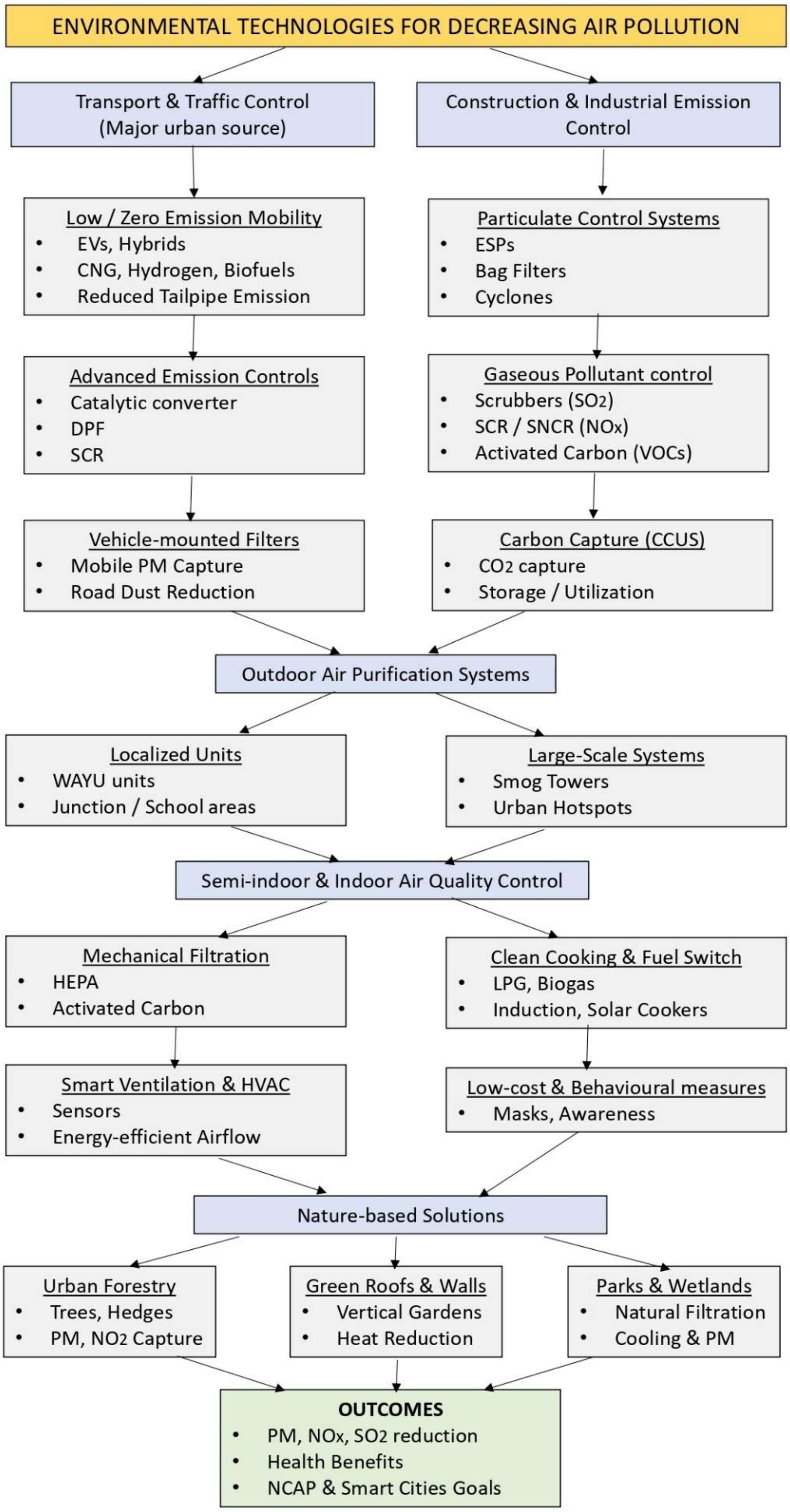

Fig. 3 Environmental technologies for air pollution management

DPFs capture soot and PM from diesel engines with about 89% efficacy, regenerating passively or actively to prevent clogging. SCR systems inject urea to decrease NO_x by about 70÷90% in heavy vehicles such as trucks that hugely contribute to roadside air pollution around cities like Delhi-NCR. Effective performance needs high-quality low-sulphur fuels with <10 ppm sulphur and BS-VI compliant. Real-world testing found variability in performance because of poor maintenance or tampering, but onboard diagnostics (OBD) helps to assure compliance. Potential health benefits include lowering cardiovascular risk, though possible challenges like higher initial costs and urea supply exist, mandating subsidies and awareness campaigns [50].

(iii) Alternative clean fuels:

Alternative clean fuels such as hydrogen, compressed natural gas (CNG) and biofuels offer road to decarbonize vehicles and decrease air pollutants by replacing with lower-emission fuels, in India's public and commercial fleets dominated by diesel. It was found that auto-rickshaws and buses in Delhi widely use CNG since the order from supreme court, which emits 20÷30% less NO_x and PM than diesel, but needs accurate engine tuning to avoid methane leakage. Hydrogen fuel cells, piloted in projects such as NTPC's green hydrogen buses in Leh, produce electricity through electrochemical reactions with nil tailpipe emissions, possible removing NO_x, though green production is critical to prevent upstream emissions. By year 2030, India's National Hydrogen Mission aims 5 million tonnes [51]. Biofuels, encompassing biodiesels from ethanol blends or jatropha, decrease SO_2 and PM by about 10÷50% while using agricultural waste, though limitations include engine compatibility and land use.

These fuels enhance energy security, aid rural economies and decrease health risks like COPD, but necessitates policy incentives and infrastructure development for large-scale deployment.

(iv) Vehicle-mounted ambient air filters:

Vehicle-mounted ambient air filters are active or passive systems integrated on mobile vehicles to capture surrounding air pollutants, transforming transportation into part of alleviation strategy, particularly in dense-traffic regions with consistent PM and dust. Pariyayantra system of IIT Bombay piloted on 30 buses in Delhi, utilizes rooftop biodegradable filters driven by vehicle motion to capture up to 98% of PM which is equal to 6-8 room air purifiers per unit. It was found that 1.5 kg of dust was collected over 10 days, decreasing local $PM_{2.5}$ by about 20÷30% across routes. Electrostatic filters on trains and vehicles capture particles without adding drag. These low-cost, scalable units are effective and maintainable in urban areas, in which road dust accounts for 25÷35% of PM. Health benefits consist of decreased exposure for pedestrians and commuters, though challenges like low-speed efficiency and filter saturation needs periodic replacement and IoT-mediated monitoring [52].

(v) Policy and infrastructure enablers:

Infrastructure and regulatory measures such as congestion pricing and low-emission zones (LEZs) drive cleaner transport behaviours by limiting high-polluting vehicles and enhancing traffic flow in dense Indian cities. LEZs, employed in regions of Delhi-NCR and planned for parts in Mumbai, charge or ban old diesel vehicles (pre-BS-IV), attaining 10÷25% PM reductions. Congestion pricing planned for Bengaluru, utilizes dynamic tolls to decrease peak-hour traffic by about 20÷30%, reducing CO and NO_x from idling engines, with revenues funding infrastructure of EV. Supportive measures comprise of charging networks of around 1 million public chargers by the year 2030, dedicated EV lanes, separate EV lanes and subsidies of up to Rupees 1.5 lakhs for cars. These motives enhance equity by improving public transport access but has potential challenges like enforcement gaps and public resilience, ultimately bolstering healthier urban environments with less air pollution-related hospitalizations [53].

2. Construction and industrial emission control technologies

Construction and industrial activities produce 20÷40% of $PM_{2.5}$ in urban parts of India, from manufacturing, combustion and dust. CPCB suggests advanced regulations, targeting on end-of-pipe solutions and tracking to attain NCAP targets.

(i) Particulate matter regulation systems:

Technologies controlling particulate capture soot, dust and aerosols from industrial emissions, alleviating subsequent health risk such as lung inflammation. ESPs are extensively used in coal-fired plants, which ionize and capture particles with up to 99% efficacy. However, adaptations for high-ash Indian coal needs hybrid designs. Fabric or baghouse filters trap particles in porous bags which are cleaned by pulses, attaining removal of 99.9% $PM_{2.5}$ in steel and cement plants. It was found from

CPCB audits that they show over 80% compliance in large units. Furthermore, cyclone separators are cost-effective and simpler for particles >10 microns, which use centrifugal force in multi-stage systems. Together, these technologies could decrease ambient PM by around 50-90%, though periodic maintenance is crucial and 2025 norms emphasize real-time monitoring in non-attainment areas [54].

(ii) Gaseous pollutant regulation technologies:

Technologies by using chemical reactions and adsorption targets VOCs, SO_2 and NO_2 to trap or neutralize emissions. Dry or wet scrubbers impart alkaline solutions to clean SO_2 by up to 95%, with retrofits planned for about 50% of capacity by the year 2025. SCR or SNCR systems inject urea or ammonia to decrease NO_x by about 70÷90%, important in chemical and fertilizer plants. Activated carbon adsorption traps VOCs in paint and pharmaceutical industries. These techniques need energy of about 5÷10% plant output and produce byproducts such as gypsum, but NCAP incentives helps adoption for health benefits, especially in industrial zones like Gujarat [55].

(iii) Carbon capture, utilization and storage (CCUS):

CCUS traps CO_2 from industrial flue gases for storage, conversion or reuse, targeting emissions in hard-to-abate sectors such as steel and cement that account for 8÷10% of India's CO_2. It was reported that amine absorption or membrane separation captures about 85÷95% CO_2, with use in improved oil recovery or chemicals and storage in geological formations. Furthermore, CCUS policy of India in the year 2025 with R&D fund of around Rupees 1-lakh-crore support pilots, including Vindhyachal plant, targeting for about 500 million tonnes yearly by the year 2050. Potential difficulties include high cost and need for infrastructure, but co-benefits such as SO_2 co-capture enhance air quality that might support net-zero goals [56].

(iv) Construction dust alleviation strategies:

Construction dust mitigation measures decrease fugitive PM from construction sites, which is a major contributor in urban air pollution by up to 30%. Additionally, anti-smog guns atomize water, reducing $PM_{2.5}$ by about 45÷70% for duration of 3 hours, which are mandatory as per NGT orders for sites >20,000 m^2. Covered transport, dust nets, mechanized street sweeping and wet suppression in Delhi-NCR decrease road dust by about 50%. Additionally, precast concrete reduces on-site emissions. These cost-effective, low-tech techniques decrease exposure-associated health issues such as silicosis [57].

(v) Compliance and monitoring systems:

Compliance and monitoring technologies assure adherence through real-time data and market processes. Continuous emission monitoring systems (CEMS), implemented since the year 2014 in over 11,000 units, monitor SO_2, PM and NO_x, supporting CPCB oversight and enforcement. Emission trading schemes (ETS) in places like Gujarat capture PM and aid allowance trading, attaining about 29% reductions cost-effectively. AI validation could reduce data tampering risks [58].

3. Outdoor air purification systems

Outdoor sir purification systems work as supplementary interventions to source-control strategies, especially in urban air pollution hotspots where emissions from industry, traffic and construction sited generate constant air pollution pockets. These techniques are designed to actively trap and remove gaseous pollutants and PM from ambient air, supporting to decrease exposure in high-risk regions like school areas, traffic intersections and public gathering spots. They support policies such as Smart Cities Mission and NCAP by contributing targeted correction of air quality where infrastructure or behaviour-mediated controls might take longer time to attain good results [59].

(i) Localized purification units:

Localized air purification units like Wind Augmentation and PurifYing Unit (WAYU) created by CSIR-NEERI, are designed to actively purify ambient air at particular locations, specifically high-traffic junctions. These units actively deploy high-efficiency fans, activated carbon for VOC absorption, HEPA filtration and UV sterilization to capture both microbial contaminants and PM. Each unit could encompass approximately area of about 500 m^2, utilizing low energy of 0.5 kWh/day, documenting them as an energy-efficient solutions for urban micro-environments [60].

It was found from field trials in Delhi that these units demonstrated 34÷49% PM_{10} reductions and 19÷25% $PM_{2.5}$ reductions, with the units capturing significant dust loads over short duration of about 1.5-2 kg in 10÷12 days. Solar-operated variants have been piloted to improve sustainability and decrease dependency on the grid. These units are specifically useful for hospitals, schools and crowded marketplaces, providing localized developments where widespread interventions might be impractical. However, they need repeated filter replacement, placement optimization and proper maintenance to improve efficacy. Closely related technologies like electrostatic filters on trams and vehicles that capture ultrafine particles without raising drag and rooftop air purifiers in large buildings, that enhance vertical pollution mitigation [61,62].

(ii) Large-scale urban cleaning systems:

Large-scale urban air purification systems like smog towers which are installed in places like Delhi, utilizes electrostatic filtration integrated with high-capacity fans to clean millions of cubic meters of ambient air quality. These smog towers might decrease $PM_{2.5}$ by about 15÷40% within 1÷10 km radii depending on tower height, wind and concentration of pollutant. Developed designs incorporate biofiltration units to clear VOCs and gaseous pollutants along with PM, providing multi-pollution control [63].

Other large-scale application in cities such as Milan and Beijing have reported significant benefits in improving localized air quality, public awareness and visibility enhancement. However, they need continuous structural maintenance and energy input. Combining multiple towers with predictive AI activation and sensor networks could improve efficiency and decrease operational costs, supporting these installations to complement wider technological and regulatory interventions.

(iii) Efficacy, limitations and implementation strategies:

The efficacy of outdoor air cleaning systems differs prominently with location, wind patterns, weather conditions and air pollutant density. They are highly efficient in semi-enclosed or enclosed urban micro-environments like congested intersections or narrow streets, and less efficient in wide open regions due to quick dispersion of air pollutant. Additionally, limitations comprise of electricity consumptions, high capital price of about ₹1-5 crore per large-scale system, limited scalability and maintenance needs for large-scale air quality improvements.

Implementation strategies under NCAP emphasize high-air pollution hotspots, incorporating IoT-mediated sensors for automated activation, real-time tracking and optimization of performance. Also, combining large-scale towers with localized units and smart urban planning generates a multi-layered defence, decreasing public exposure while regulation of long-term emission take effect [64].

4. Semi-indoor and indoor air quality interventions

Semi-indoor and indoor air quality strategies targets air pollutants from heating, cooking and outdoor infiltration, that affect about 60÷80% of households in India, especially in high-density and low-income areas. These interventions target to decrease CO, VOCs, PM and other indoor toxins, supporting cardiovascular and respiratory health while improving quality of life.

(i) Mechanical filtration systems:

Mechanical air filtration systems like HEPA filters capture about 99.97% of particles that are as small as 0.3 microns, while activated carbon layers remove odours and gases. Portable air purifiers decrease indoor PM by about 60÷80% and are extensively employed in hospitals, schools, semi-indoor spaces and offices. Advanced systems consist of UV sterilization, multi-stage filtration with pre-filters and negative-ion generation to capture microbial contaminants and ultrafine particles. Emerging filtration units incorporate mobile app connectivity with real-time air quality sensors for alerting users and tracking of changing air pollution levels [65].

(ii) Fuel transitions and clean cooking technologies:

Transformation from solid fuels to biogas, LPG and induction stoves potentially decreases household air pollution, thereby cutting emissions by about 35÷92%. It was stated that India's Pradhan Mantri Ujjwala Yojana has contributed over 100 million LPG connections, reducing black carbon emissions and consequently decreasing indoor levels of $PM_{2.5}$. Advanced clean cooking choices consist of improved biomass stoves with solar cookers, chimneys and electric induction systems which incorporate rooftop solar installations or microgrid, improving both energy efficiency and air quality [66].

(iii) Ventilation and HVAC solutions:

Smart HVAC systems consist of activated carbon units, HEPA filters and airflow sensors that improve indoor ventilation, reducing outdoor air pollutant infiltration by about 50÷70%. Contemporary solutions comprise of demand-regulated ventilation, energy recovery ventilators and air quality-based fan speed modulation, that preserve healthy indoor conditions while simultaneously conserving energy. Combining building management systems (BMS) helps predictive maintenance, decreasing filter fouling and maintaining consistent indoor air quality [67].

(iv) Low-cost solutions and behavioural interventions:

Affordable measures and behavioural approaches like low-cost air masks, public air pollution awareness campaigns, education on ventilation practices and portable monitors could decrease exposure by about 27÷91% in low-economic areas. Furthermore, initiatives comprise of adoption of window seals, community air quality monitoring, increasing use of indoor plants for pollutant deposition and training for household on ventilation practices and clean cooking, thereby adopting sustained behaviour change along with technological interventions [68].

5. Nature-based solutions:

Nature-based solutions and green infrastructure improve natural systems and vegetation for passive mode of air purification, ecosystem services and cooling. These nature-based solutions simultaneously enhance biodiversity, urban aesthetics and microclimate while trapping air pollutants like NO_2, PM and VOCs.

(i) Urban forestry:

Urban forests, roadside hedges and tree-lined avenues could decrease concentration of PM by about 10÷23%, thereby playing as windbreaks and natural filters. Native species such as banyan, neem and peepal are highly efficient in Indian cities due to pollutant tolerance and dense foliage. Proper urban planning assures multi-layered vegetation barriers, combining hedges, shrubs and tall trees to increase deposition of aerosols and dust [69].

(ii) Green walls, green roofs and vertical gardens:

Green walls and green roofs absorb gaseous pollutants such as NO_2 by about 15% and offer thermal insulation, decreasing demand of building energy. It was reported that vertical gardens in urban areas like Mumbai have shown cooling benefits of 2÷5°C, decreased heat island effects and improved urban aesthetics, while simultaneously causing capture of PM and reduction of VOC. Furthermore, incorporation with rainwater harvesting and irrigation systems enhances sustainability [70].

(iii) Wetlands, parks and urban green spaces:

Waterbodies, wetlands and urban parks play important role as natural air filters, decreasing PM by about 9÷36% while simultaneously absorbing excess heat and controlling humidity. Wetlands use microbial and plant systems to filter waterborne and airborne pollutants. Co-benefits comprise of mental health enhancement, recreation and biodiversity improvement, complementing overall urban resilience [71].

INTEGRATED FRAMEWORK FOR SMART CITY AIR POLLUTION MANAGEMENT

An integrated framework for smart city air pollution management is based on the combination of real-time monitoring systems, emerging environmental technologies and AI to help adaptive and continuous regulation of urban air quality (Figure 4). This integrated framework acts as a closed-loop system in which data from fixed air quality monitoring stations, low-cost networks of sensors, traffic monitoring systems, satellite data and meteorological data is continuously incorporated and processed via AI-enabled platforms. These analytical systems could contribute near-real-time air pollution visualizations, source identification outputs and exposure predictors, that generate targeted interventions over sectors like industry, transportation, public spaces and buildings.

Within this integrated framework, AI-mediated decision-making engines dynamically control or start air pollution mitigation works, comprising of emission regulation technologies, traffic management measures, indoor & outdoor air cleaning systems, and smart HVAC operations, in response to temporal and spatial changes in air pollution levels. Furthermore, data produced following implementation of intervention are constantly incorporated back into the system to analyze performance and refine responses accordingly, thereby enabling adaptive improvement while decreasing operational demands and energy use. Additionally, integration over sectors warrants that air quality management is integrated within wider smart city functions, encompassing energy systems, mobility planning, public health monitoring and construction oversight. This strategy converts air pollution governance from reactive and intermittent interventions to a health-focussed, predictive model, offering a base for resilient and scalable development of smart city.

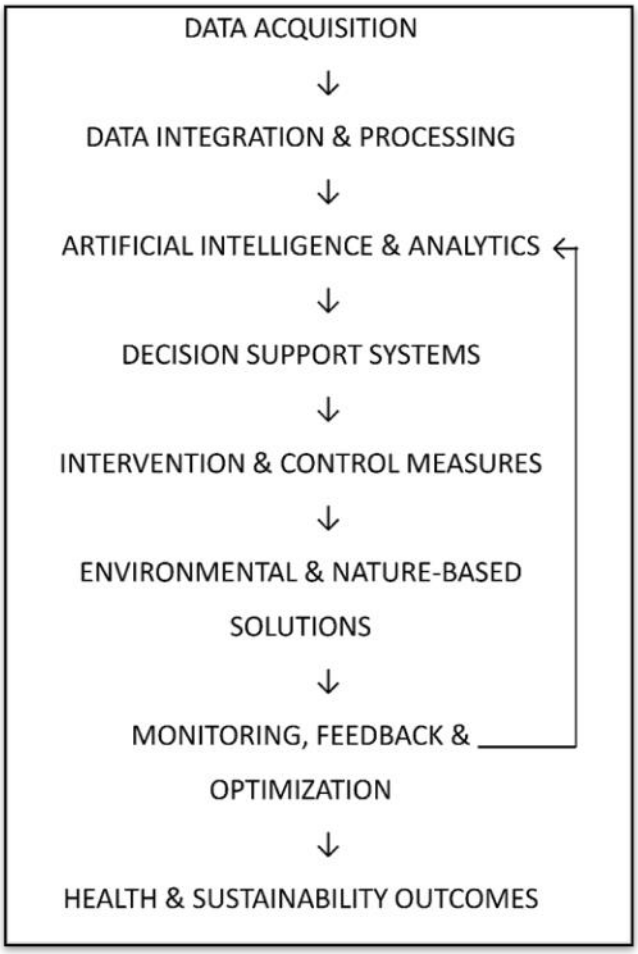

Fig. 4 Integrated framework for smart air pollution management

PUBLIC HEALTH IMPLICATIONS OF SMART MANAGEMENT OF AIR POLLUTION

Adopting smart approaches for management of air pollution have quantifiable and clear benefits for public health by reducing exposure to harmful air pollutants in both indoor and outdoor settings of smart cities. It was found that air quality improvements for shorter period are highly associated with drastic reduction in symptoms of acute respiratory illnesses, asthma flare-ups, hospital admissions and emergency department visits that are related to air pollution, especially during season of high exposure. Adaptive response measures and real-time warning systems could further protect high-risk populations by enhancing institutional actions and timely behavioural alterations [72].

Over extended duration, constant decrease in indoor and ambient air pollution lead to reduced incidence and prevent progression of chronic cardiovascular and respiratory conditions. Furthermore, minimal cumulative exposure to nitrogen oxides and fine PM are related with healthier lung development in children, reduced risks of stroke and ischemic heart disease, and lowering age-related reduction in lung function among adults. Growing evidence further suggests that long-term improvements in air quality might lower metabolic disturbances and chronic systemic inflammation, thereby decrease risk of diabetes and its associated cardiovascular complications. Overall, these major health improvements cause decreased healthcare use, reduced treatment expenditures, improved productivity and potential economic benefits, which further reinforces air pollution regulation as an essential part of public health rather than just an environmental concern [73].

ETHICS, EQUITY AND IMPLEMENTATION CHALLENGES

In spite of promising outcomes, smart air pollution management systems often present with potential ethical and equity challenges. Air purification systems, advanced air quality monitoring technologies and building-level interventions are routinely planned in commercial zones, affluent neighbourhoods and private establishments, while communities that face the greatest challenge of air pollution might have restricted access to those protections. In this context, smart city initiatives might risk augmenting prevailing health disparities related with housing conditions, socioeconomic status and occupational exposure [74].

The widespread implementation of mobile monitoring tools, sensor networks and AI-mediated analytics also increase concerns associated with surveillance, data privacy and governance. Hence, anonymization measures, clear data governance strategies and regulatory safeguards are critical to warrant responsible data use and to maintain public trust. Also, implementation challenges like limited technical capacity, high costs, concerns related to long-term sustainability and maintenance requirements, exist in resource-limited urban regions across India. Overcoming these challenges requires strengthened institutional capacity, scalable system designs, financing strategies and community participation that expand beyond short-term pilot projects [75].

GOVERNANCE AND POLICY CONSIDERATIONS IN INDIA

Successful adoption and implementation of smart air pollution management depend on supportive policy environments and coordinated governance processes. Additionally, alignment with national programmes like NCAP and Smart Cities Mission is crucial to incorporate air quality and health priorities within wider urban development strategies. Furthermore, efficient intersectoral collaboration across agencies responsible for health, environment, energy, transport, urban governance and housing is crucial to transform air quality intelligence into timely and practical interventions [76].

Public health professionals and clinicians have a prominent role in interpreting environmental data, correlating air pollution exposure to possible health outcomes and thereby making evidence-based policy decisions. The incorporation and illustration of health indicators like possible respiratory disease, cardiovascular evets and hospitalizations, in smart city dashboards informs policymakers to directly analyse the health effects of air quality interventions and bolsters accountability for public health outcomes. Such governance models reiterate the incorporation of health considerations into smart urban planning and facilitate a health-in-all-policies approach.

FUTURE DIRECTIONS

Smart air pollution management in smart cities will depend on the establishment of standardized health outcome measures which help constant analysis of intervention efficiency over various populations and cities. Employment of AI-mediated personalized exposure analysis, complemented by wearable sensors and mobile technologies, employs opportunities to decrease individual-level exposure while supporting wider population-based strategies.

As climate change aggravates air pollution via increasing temperatures, altered atmospheric mechanisms and wildfire events, smart city technologies should adapt to support climate-resilient management of air quality. There is also a raising requirement for interdisciplinary and clinician-led studies to bolster casual relations between smart air pollution interventions and health outcomes, analyse equity changes and inform adaptive policy advancements over diverse urban contexts.

CONCLUSIONS

Smart management of air pollution denotes a crucial transition from conventional reactive approaches toward data-driven, predictive, and health-focussed urban environmental governance. The present review emphasizes how integration of advanced monitoring systems, encompassing low-cost sensor networks, fixed stations, mobile sensing platforms, and satellite observations, could offer high-resolution air quality data needed for efficient decision-making. Additionally, AI strengthens these systems by facilitating accurate air quality forecasting, source apportionment, hotspot identification, adaptive decision-support systems which enables authorities to proactively respond to emerging air pollution events.

Furthermore, a wide range of environmental technologies comprising of emission control systems, electric mobility, indoor and outdoor air purification approaches, emission control systems, and nature-based solutions play a crucial role in decreasing air pollutant emissions and population exposure. When executed within an integrated smart city framework, these smart interventions could improve urban air quality while strengthening broader public health goals by decreasing cardiovascular events, respiratory diseases, and other pollution-associated health burdens.

However, successful execution needs addressing various operational and ethical challenges. Data interoperability over heterogeneous monitoring platforms, financial sustainability, long-term sensor networks maintenance, and equitable technological interventions distribution remain important concerns, especially in resource-restricted urban environments. It is essential to ensure that vulnerable populations would benefit equally from smart air pollution interventions to avoid widening environmental health disparities.

In future, smart air pollution management in India will rely on stronger interdisciplinary collaboration among clinicians, environmental scientists, policymakers, and engineers. Integrating health indicators into air quality management systems, broadening AI-mediated exposure assessment, and tightening policy alignment with national initiatives like the Smart Cities Mission and the National Clean Air Programme would be essential. Such health-oriented and integrated strategies could help Indian cities shift toward cleaner air, better public health, and more sustainable urban development.

ACKNOWLEDGEMENTS

The author sincerely acknowledges the academic and institutional environment that supported the development of this manuscript. No external assistance was received for data collection or analysis. The author also acknowledges the researchers, institutions and public agencies whose published work and datasets contributed to the conceptual understanding presented in this study.

AI Use Statement

The author used an artificial intelligence–assisted language tool solely for grammatical editing and improving clarity of expression. All scientific content, interpretations and conclusions are the sole responsibility of the author.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial or not-for-profit sectors.

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Citation: Dharani, B, Smart air pollution management in Smart Indian Cities: a narrative review, *Rom. J. Ecol. Environ. Chem.*, **2026**, 8, no.1, pp. 18÷39, https://doi.org/10.21698/rjeec.2026.102.