



Air Quality Management Can Build Healthier Cities

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Air quality management (AQM) is an integrated approach that combines pollution monitoring, emission inventories, air-quality modelling, regulatory measures, technological interventions, and public participation to improve urban air quality. This article reviews the major components, emerging technologies, management strategies, governance challenges, and research gaps associated with AQM. Effective monitoring supported by standardized calibration, validation, and quality-assurance systems provides the foundation for reliable decision-making. Urban Air Quality Management Plans further integrate monitoring, modelling, emission inventories, control strategies, and stakeholder participation. Recent technological advances, including low-cost sensors, Internet of Things (IoT) systems, satellite remote sensing, and artificial intelligence (AI), are expanding the spatial and temporal capacity for pollution monitoring and forecasting. However, evidence regarding the effectiveness of several traffic-management and pollution-control strategies remains limited, highlighting the need for rigorous evaluation. Experiences from China, Mexico City, Africa, and Europe demonstrate that successful AQM depends not only on technological capacity but also on institutional coordination, public participation, regulatory implementation, and political commitment. Key research gaps include limited ex-post evaluation, insufficient spatial modelling, inadequate assessment of co-benefits and unintended consequences, and limited attention to emerging mobility challenges. Overall, cleaner urban air requires an integrated, evidence-based management framework linking reliable data, innovative technologies, effective policies, and coordinated governance.

Introduction

Every breath a city dweller takes carries an invisible mixture of gases and particles that shape long-term health. Yet knowing *how polluted* the air is turns out to be only the first step. Air quality management the science of monitoring, understanding, and acting on that information is what actually determines whether cities get cleaner over time (Gulia et al., 2015). It weaves together regulation, technology, data science, and public participation into a single system. Without governance and political will, even the best monitoring network changes little (Gulia et al., 2015; Molina et al., 2019). This article explores how cities are moving from simply measuring pollution to genuinely managing it and what still stands in the way.

What is Air Quality Management?

Air quality management is the coordinated effort to keep the air people breathe within acceptable limits. It brings together regulatory frameworks, monitoring networks, emission inventories, air-quality modelling, and pollution-control strategies, all designed to maintain acceptable ambient air quality (Gulia et al., 2015). Think of it as a feedback loop rather than a single fix: data flows in from monitoring stations, that data feeds models and inventories, which

in turn shape policy, which then requires more monitoring to check whether it worked. Successful implementation of this loop depends heavily on stakeholder participation, political will, and the integration of scientific evidence into policy (Gulia et al., 2015; Molina et al., 2019) a reminder that air quality management is as much a social and institutional challenge as a technical one. Interestingly, how far countries have progressed along this loop varies widely. Developed countries typically maintain full-fledged air quality management plans backed by regulatory frameworks, while many developing nations are still in the process of formulating effective approaches (Gulia et al., 2015). That gap matters, because it shapes who has access to reliable air-quality information and who doesn't.

Measuring Pollution to Managing it

Monitoring is the foundation on which everything else in air quality management rests but only if the data it produces can be trusted. That trust comes from quality management systems: standardized procedures, calibration, validation, and regular audits that ensure consistency and comparability of results across monitoring sites (Kozłowski et al., 2024). Without this scaffolding, two monitoring stations in the same city could report different pollution levels simply due to instrument drift or inconsistent methods undermining public confidence and policy decisions alike. When these quality-assurance systems are in place, they enable reliable reporting to governmental units, researchers, and communities, supporting transparent education and prevention measures (Kozłowski et al., 2024). In other words, good monitoring isn't just about having sensors it's about having sensors whose numbers everyone can trust.

An air quality Management Plan

Once reliable monitoring is in place, cities can begin building what's known as an Urban Air Quality Management Plan (UAQMP). The process typically starts with identifying air quality control regions based on ambient monitoring data, followed by initiating time-bound programs that involve all relevant stakeholders (Gulia et al., 2015).

A well-formed UAQMP generally includes:

- **Goals and objectives:** clear targets for pollution reduction
- **Monitoring networks:** the sensing infrastructure that tracks progress
- **Emission inventories:** systematic accounting of pollution sources
- **Air-quality modelling:** tools to simulate how pollutants move and accumulate
- **Control strategies:** the actual interventions, from traffic rules to industrial limits
- **Public participation:** engaging citizens as both data sources and stakeholders

These components are not optional add-ons; they are described as the key components of such plans (Gulia et al., 2015). The plan works best as an integrated system rather than a checklist modelling without monitoring produces guesswork, and control strategies without public buy-in tend to stall.

Which Strategies Actually Help?

This is where the evidence gets nuanced and where honesty about what we don't know matters as much as celebrating what works. A review of traffic management strategies found that of the many approaches studied, only some produced demonstrated air quality effects, and the overall evidence base for such strategies remains weak, with insufficient evidence for most strategies and poorly studied population exposure and health impacts (Bigazzi & Rouleau, 2017). Among 22 strategies studied, area road pricing was shown to improve air quality, while low emission zones were one of only two traffic management strategies with demonstrated effects both falling into a "limited evidence" category rather than a proven one (Bigazzi & Rouleau, 2017). A separate rapid review found a different pattern: active travel infrastructure cycling and walking networks — showed consistent benefits across the high-air-quality cities studied, making it one of the more promising interventions (Quarmby et al., 2019). In contrast, pollution-removal technologies (physical devices meant to filter or capture pollutants directly from the air) remain largely unproven at meaningful scale (Quarmby et al., 2019). Two broader lessons emerge from this evidence base. First, most air quality strategies focus on discouraging private car use through regulation, legislation, and investment in alternative transport, and

policies work best as a mutually reinforcing suite of measures rather than in isolation (Quarmby et al., 2019). Second, aggressive area-based strategies such as low emission zones appear necessary to generate substantial benefits, but traffic-management measures must be implemented carefully to avoid unintended detrimental or rebound effects for instance, traffic simply shifting to nearby streets (Bigazzi & Rouleau, 2017).

Technology Revolution in Air Quality Monitoring

Traditional air-quality monitoring relied on a small number of expensive, high-precision stations. That's changing fast, as several complementary technologies expand what's possible. **Low-cost wireless sensors** are increasingly deployed alongside conventional stations. Coupling low-cost wireless sensor stations with a limited number of conventional real-time monitoring stations creates cost-effective yet robust networks (Gulia et al., 2020) extending coverage into neighbourhoods that could never have afforded dense networks of research-grade instruments. These low-cost sensors are also proving useful for more than just measuring levels they can help trace pollution back to its source. When combined with statistical techniques such as Positive Matrix Factorization and k-means clustering, low-cost sensors successfully pinpointed and quantified pollution sources at construction, quarry, and roadside sites (Bousiotis et al., 2023).

IoT-based systems (Internet of Things networks of connected sensors and devices) are extending monitoring indoors. Such systems enable real-time indoor air-quality monitoring and forecasting of carbon dioxide, PM2.5, and total volatile organic compounds in educational and institutional settings (Rosa-Bilbao et al., 2025) a reminder that air quality management isn't only about outdoor smog, but also the air inside schools and offices.

Artificial intelligence and machine learning, discussed further below, are being layered on top of this expanded sensor data to forecast pollution levels rather than simply report them after the fact.

Satellites: Watching Pollution from Above

Ground-based sensors, however dense, can only see so far. Satellite remote sensing fills in the gaps at a regional and even continental scale. Satellite-based remote sensing, when calibrated with ground-level measurements, can capture transboundary pollution transport at regional scales (Gulia et al., 2020) useful for tracking pollution that drifts across national or state borders, where ground monitoring networks simply stop. More recent satellite systems have pushed this further: geostationary satellites now provide hourly or sub-hourly data, supporting health-risk assessments, emissions-inventory constraints, and regulatory trend tracking (Holloway et al., 2025). This doesn't replace ground monitoring the two work best together, with satellites providing broad regional context and ground stations providing street-level precision.

Can Artificial Intelligence Help Us Breathe Better?

Artificial intelligence is often oversold as a magic fix for complex environmental problems. The evidence here is more measured AI is a forecasting and decision-support tool, not a solution to pollution itself. Machine-learning models, particularly a type called LSTM (Long Short-Term Memory, a neural network architecture well-suited to time-series data), have achieved high prediction accuracy for pollutants such as PM2.5 and PM10 across urban monitoring stations (Neo et al., 2023). In practice, this means AI-assisted systems can help forecast tomorrow's pollution levels, alerting residents and authorities before a smog episode peaks, rather than only reporting what already happened. What AI does *not* do, based on the available evidence, is reduce emissions on its own. It supports monitoring, forecasting, and decision-making the actual reduction still depends on the policies and control strategies discussed earlier.

Governance: The Missing Piece

Even the best sensors and models are of little use if the institutions responsible for acting on the data are fragmented or under-resourced. This is where much of the real-world struggle in air quality management plays out. Policy resistance often undermines air quality management

when stakeholder goals are misaligned, driven by three reinforcing problems: insufficient monitoring data, fragmented jurisdictional authority, and weak local compliance (Gujral et al., 2025). These loops tend to feed each other poor data weakens enforcement, weak enforcement discourages further investment in data, and so on. One proposed way out is reorienting systems around public-health goals, such as reducing premature mortality, which can help align stakeholder incentives and reduce resistance (Gujral et al., 2025). Specific leverage points identified include integrated air-and-health data platforms, airshed-based governance that operates across jurisdictional boundaries rather than within them, and citizen-science oversight, where residents themselves contribute to monitoring and accountability (Gujral et al., 2025).

Lessons from Different Regions

Air quality management doesn't follow a single template different regions have taken markedly different paths, each with its own strengths and gaps.

- **China** adopted a comprehensive, multi-pollutant control policy, requiring emission reductions of 60%, 40%, 50%, and 40% for SO₂, NO_x, PM₁₀, and VOCs respectively, measured against 2005 levels (Wang & Hao, 2012) an example of a top-down, target-driven approach spanning multiple pollutants simultaneously.
- **Mexico City's** successive PROAIRE programs, running from 1990 onward, illustrate a different lesson: political will to translate scientific knowledge into action, backed by strong social support, was identified as the most important factor behind their progress (Molina et al., 2019).
- **Africa's** experience highlights a different imbalance. A scoping review found that 75% of identified air-quality strategies were technology-based, only 20% policy-based, and just 5% education-focused, with 83% targeting household air pollution rather than the rising outdoor emissions associated with urbanization (Okello et al., 2022) suggesting a mismatch between where investment goes and where new risks are emerging.
- **Europe's** approach leans heavily on modelling. European air quality plans commonly use modelling tools to assess emission-abatement scenarios, though health and environmental impacts are rarely quantified alongside them (Miranda et al., 2015). Some cities have gone further: Integrated Assessment Methodologies applied in cities such as Antwerp and London evaluate how emission reductions improve air quality, reduce exposure, and protect health in a more connected way (Miranda et al., 2015).

Where the Gaps Remain

For all this progress, the research base itself has notable blind spots.

- **Spatial analysis and air-pollution modelling** remain underexplored topics within air quality management research (Santoso et al., 2024).
- **Ex-post evaluations** assessing how implemented strategies actually performed after the fact are lacking, which limits evidence-based transportation planning (Bigazzi & Rouleau, 2017).
- **Mobility strategies** make up only about 6% of African air-quality research, despite the continent's rapid motorization (Okello et al., 2022).
- **Co-benefits and unintended consequences** of greenhouse-gas policies on air quality require more comprehensive assessment than they currently receive (Neo et al., 2023).

Conclusion

Cleaner air will not arrive through a single sensor network, a single policy, or a single algorithm. The evidence gathered here points instead to an integrated management approach one that pairs rigorous, quality-assured monitoring with honest evaluation of which strategies actually work, layers emerging technologies like satellites and AI onto that foundation, and grounds the whole system in governance capable of crossing jurisdictional lines. Where that integration has been attempted, as in Mexico City's sustained programs, progress has followed political will as much as scientific insight (Molina et al., 2019). Where it hasn't, fragmented authority and thin evidence continue to hold back even well-intentioned efforts (Gujral et al., 2025; Bigazzi & Rouleau, 2017). The path to smarter, healthier cities runs through that integration not around it.

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