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Explainer

Reading the Air: A Practical Guide to Air Quality Data and Its Uses

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SIM-air Working Papers

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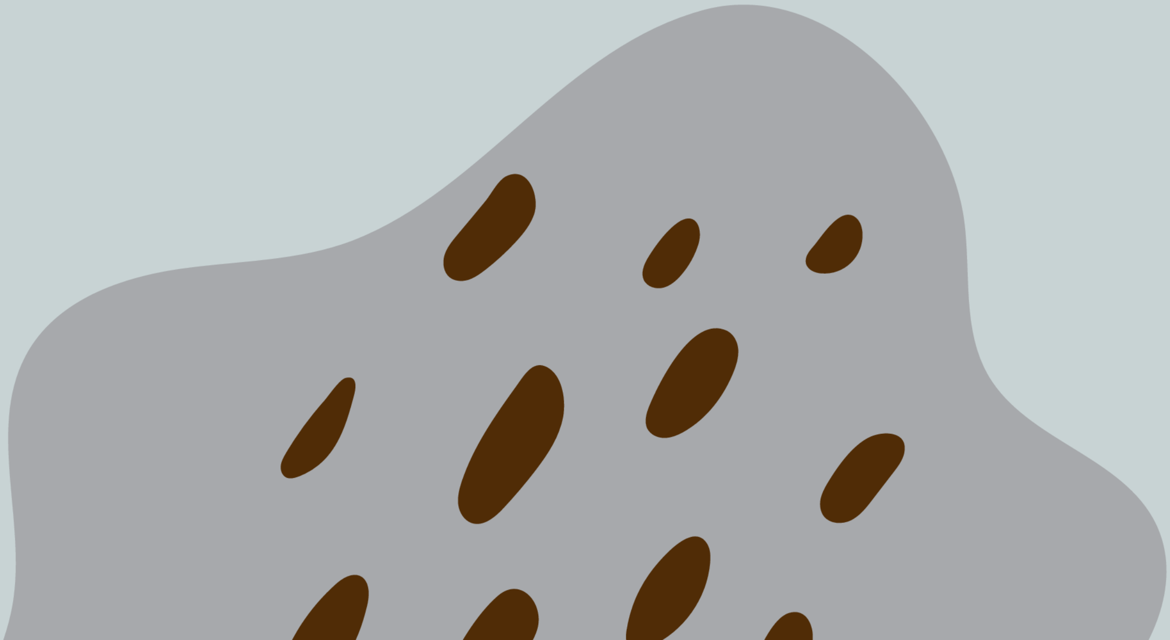


About UrbanEmissions.Info

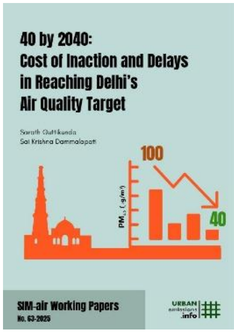
UrbanEmissions.info (UEinfo) was founded in 2007 with the vision to be a repository of information, research, and analysis related to air pollution and focusing on four key objectives:

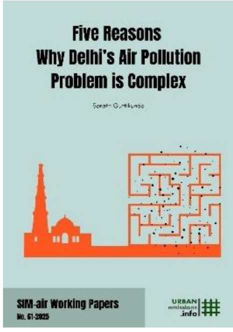
- Sharing knowledge on air pollution
- Providing science-based air quality analysis
- Promoting advocacy and raising awareness on air quality management
- Building partnerships among local, national, and international airheads

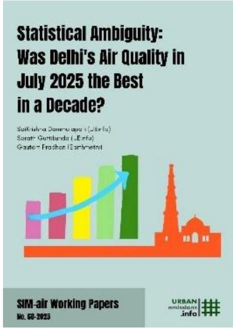
About SIM-air Working Papers

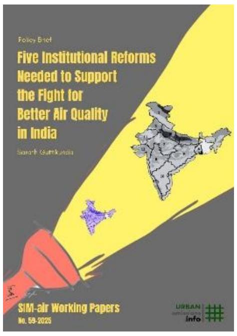
The working-papers describe case studies where we applied the SIM-air family of tools, document general notes on emissions and pollution modeling, and present our reviews on topics related to air pollution analysis @ https://urbanemissions.info/publications

Last 5 working papers









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0. Introduction: Reading the Air

[1]Different stakeholders engage with air quality data in ways shaped by their specific needs. Policymakers to evaluate interventions and set standards; urban planners to guide infrastructure and land-use decisions; health researchers to quantify disease burden and exposure risks; citizens to make day-to-day choices about outdoor activity, and students to build an understanding of environmental systems. Each group looks at the same underlying information, but interpreted, visualized, and communicated in the form that is most meaningful to them.

This information brief outlines the principal dimensions of air quality information: the sources of data, the scales at which analysts examine it, and the analytical forms that translate raw information into actionable insights for different stakeholders.

Air quality data primarily has two pathways: monitoring and modelling.

'So when your monitoring data evaluates and calibrates my models, and my models extend the reach and interpretive depth of your data, we can figure out how much, when, where, and what sources are responsible for this pollution, right?'

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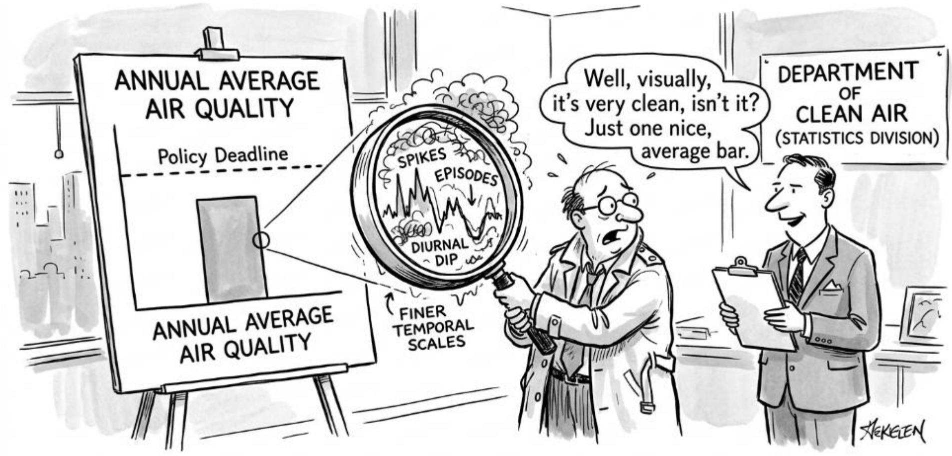
[1] All the images in this document are artificially generated

Monitoring involves placing physical instruments at ground level to directly measure pollutant concentrations in the ambient air. These monitoring networks represent the gold standard for ground-truthing, as they capture real conditions at specific locations and provide the most direct evidence of what individuals (and communities) are breathing. However, monitoring is resource-intensive, and networks are rarely dense enough to cover all areas of interest.

On the other side, modelling takes a bottom-up approach. Atmospheric chemical transport (dispersion) models accept emission inventories (with details broken down by source type, location, and time) and 3-dimentional meteorological data as inputs and simulate how pollutants are dispersed and chemically transformed through the atmosphere. Models can generate spatially continuous fields of pollutant concentrations across an entire region, filling gaps that a monitoring network cannot. They become the essential tools for scenario analysis, such as estimating the effect of a proposed policy like a change in fuel mix of the vehicle fleet.

1. Annual Averages

Annual averages represent the most widely used metric for policy and regulatory purposes.



'The annual average sure makes the air quality look manageable, dear.'

Because emission management and urban planning operate over long timeframes, annual averages smooth out short-term fluctuations and provide a stable baseline for comparison across years, cities, and countries. Most national and international air quality standards, including the WHO guidelines, are expressed as annual mean concentrations, making this metric central to regulatory compliance assessments.

In health impact assessments, annual averages are the preferred exposure metric for evaluating chronic health effects. Long-term exposure to elevated pollutant concentrations is associated with a range of adverse outcomes including cardiovascular and respiratory disease, lung cancer, and premature mortality. Epidemiological studies link population-level annual average concentrations to the prevalence of these conditions, allowing analysts to estimate the disease burden attributable to air pollution across a given population.

2. Seasonal and Monthly Averages

Seasonal and monthly averages reveal the cyclical nature of air pollution and are closely tied to the meteorology and geography of a region.

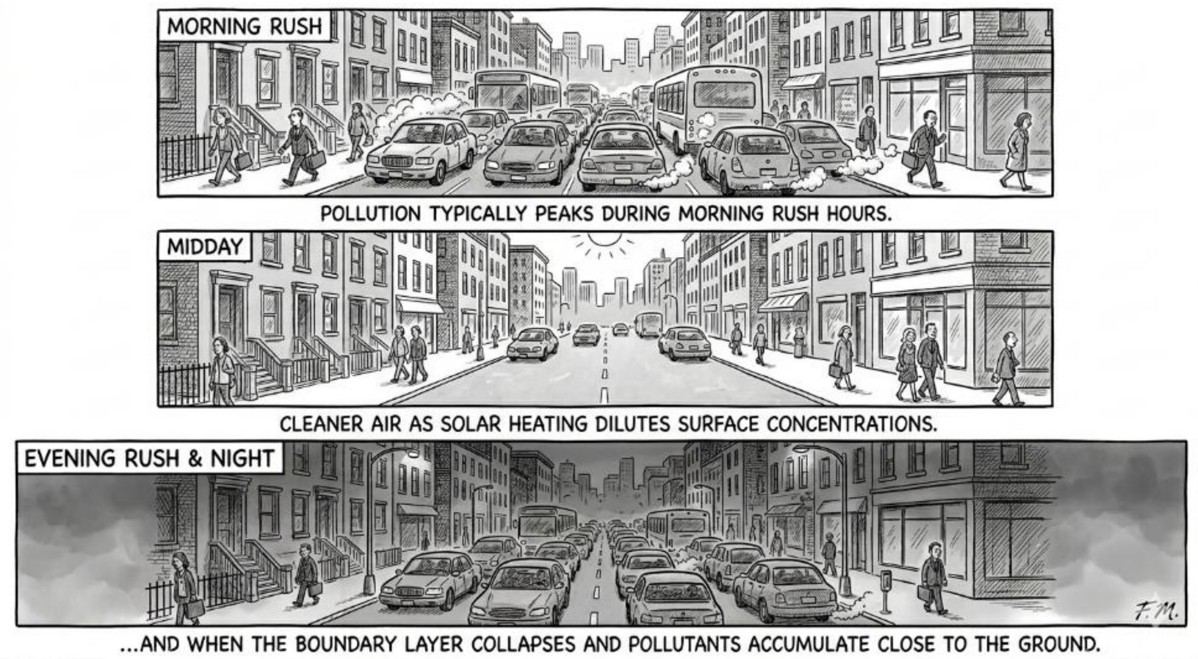
Pollution is strongly seasonal across much of the world. In northern latitudes, winter months see elevated $PM_{2.5}$ as residential heating with solid fuels combined with reduced atmospheric mixing, while summer months drive elevated ozone through photochemical reactions, and the monsoons show low concentrations due to wet scavenging of most of the pollutants. Recognizing these patterns is critical for interpreting annual averages, identifying dominant emission sources, and guiding targeted interventions. For example, transitioning households from biomass to cleaner fuels ahead of the winter heating season.

Seasonal averages also have practical implications for exposure management and public health communication. If pollution is known to peak in a particular season, health advisories, school schedules, and outdoor activity guidelines can be adjusted accordingly.

Monthly averages often serve as a useful complement to seasonal averages, providing finer temporal resolution to identify precisely when within a season pollution peak begins and starts to decline.

3. Daily and Diurnal Averages

Daily averages and diurnal (hour-by-hour) cycles capture the within-day rhythm of air pollution. Most urban environments experience predictable diurnal patterns driven by traffic, industrial activity, and atmospheric boundary layer dynamics.



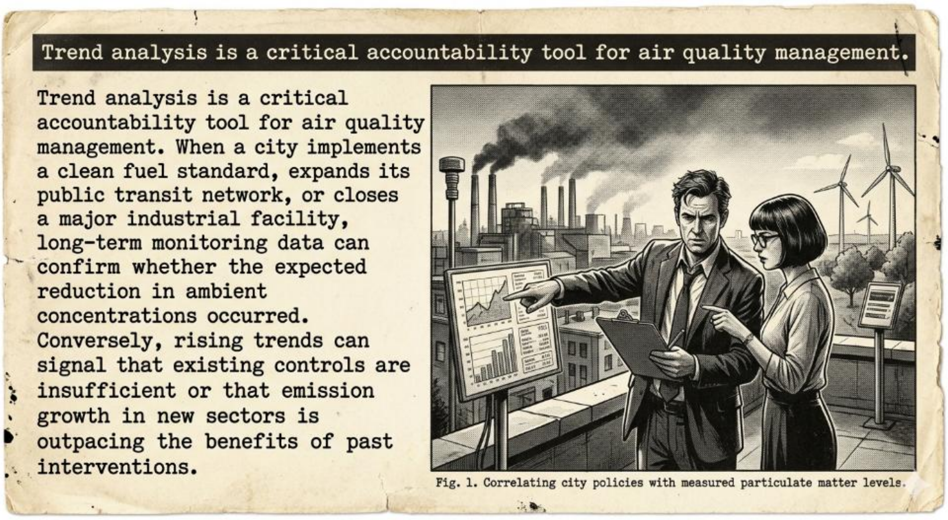
The most visible application of daily averages is the Air Quality Index (AQI). It distills the complex science of pollutant composition, health-based exposure thresholds, ambient standards, and measurement protocols into simple color-coded categories that anyone can interpret logically. This makes AQI actionable, a single color can be enough for individuals to decide what the quality of air is – green is good, red is bad, and yellow is moderate.

For individuals, diurnal cycle data is even more actionable. Commuters, outdoor workers, and people with respiratory conditions can use real-time or forecasted hourly data to plan their activities during lower-pollution windows and effectively reduce personal exposure. This is particularly valuable for vulnerable populations like children, the elderly, and those with pre-existing health conditions, who can benefit effectively from modest reductions in peak exposure.

From a regulatory standpoint, daily averages also feed into short-term air quality standards. Many countries (and WHO) maintain 24-hour and day-time peak standards/guidelines for most critical pollutants, to protect against acute health effects during high-pollution episodes. Monitoring these daily values, authorities can trigger emergency measures.

4. Temporal Trends and Variations

Beyond the routine cycles of seasons and days, long-term temporal analysis reveals whether air quality is improving or deteriorating over time.



Trend analysis is a critical accountability tool for air quality management.

Trend analysis is a critical accountability tool for air quality management. When a city implements a clean fuel standard, expands its public transit network, or closes a major industrial facility, long-term monitoring data can confirm whether the expected reduction in ambient concentrations occurred. Conversely, rising trends can signal that existing controls are insufficient or that emission growth in new sectors is outpacing the benefits of past interventions.

Fig. 1. Correlating city policies with measured particulate matter levels.

Time series data from monitoring networks and models, spanning at least five to ten years (and more), is needed to reliably detect trends, separate them from natural variability, and attribute changes to policy interventions. Shorter datasets are prone to year-to-year meteorological variability to support robust conclusions.

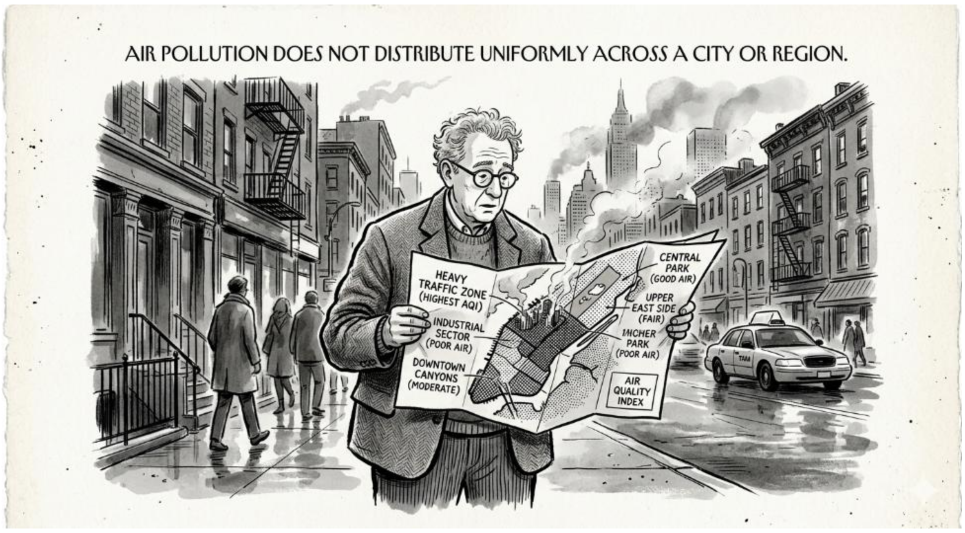
Linking pollution trends to changes in energy systems provides further analytical depth. By overlaying air quality trends with data on fuel consumption, power generation mix, and vehicle fleet composition, analysts can identify which sectors are driving improvements or deterioration. This trend analysis also allows decision-makers to prioritize the interventions with the greatest potential for pollution reduction.

5. Spatial Heterogeneity

Spatial variability in air pollution is shaped by the proximity of emission sources, local topography, wind patterns, and land use.

Areas near highways, industrial zones, or densely trafficked intersections may experience pollutant concentrations several times higher than background levels just a few hundred meters away. Understanding this spatial heterogeneity is essential for identifying pollution hotspots and ensuring that health risk assessments reflect the actual exposure of different communities.

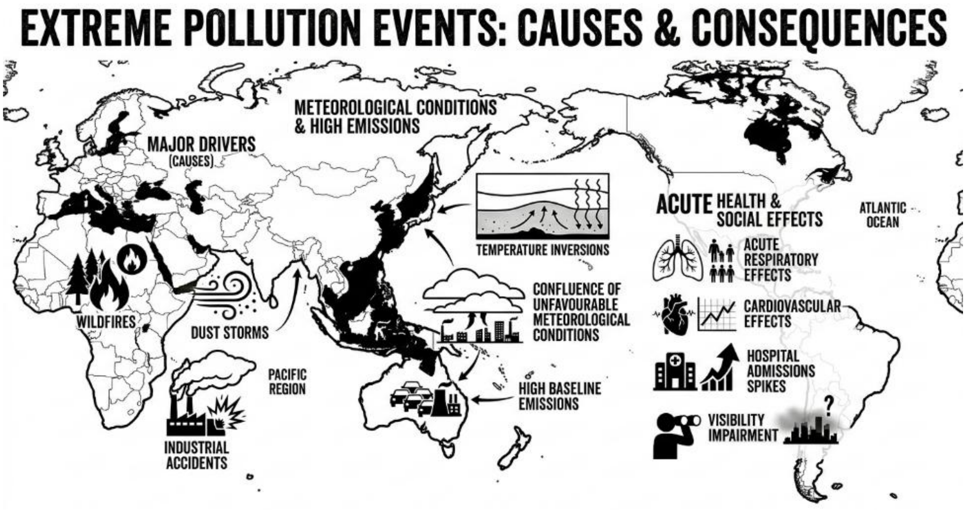
Monitoring networks provide spatially discrete measurements, but sparse networks miss significant hotspots in dense urban environments. Mobile monitoring campaigns, low-cost sensor networks, modelling exercises coupled with meteorology and emission inventories, and satellite-derived data increasingly fill these spatial gaps, building a more complete picture of the pollution landscape.



Spatial analysis also carries a strong equity dimension. Lower-income and marginalized communities tend to live closer to major emission sources and bear higher exposures. Mapping pollution alongside socioeconomic data helps policymakers identify environmental justice concerns and direct interventions where they are needed most.

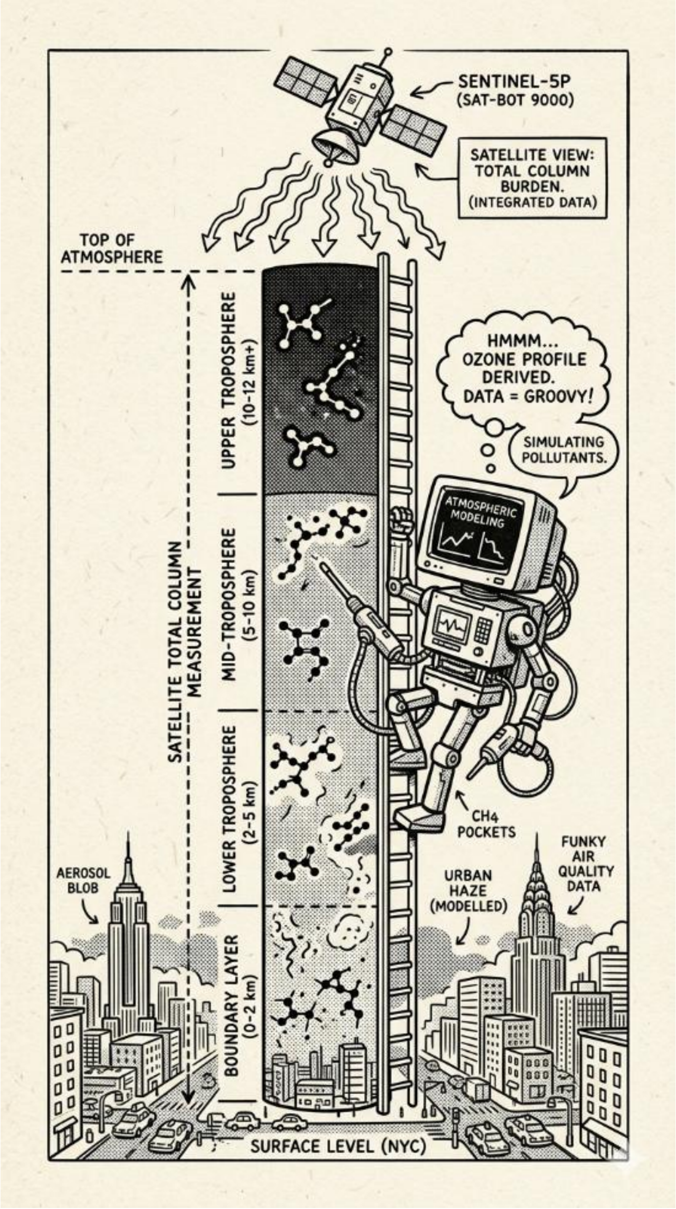
6. Extreme Values and Pollution Episodes

Extreme pollution episodes like wildfires, dust storms, severe temperature inversions, naturally draw public and media attention, but they do not necessarily dominate the overall pollution picture.



Effective air quality management requires both: the capacity to respond to acute episodes and the sustained commitment to addressing the everyday pollution that most people breathe most of the time. The danger lies in disproportionate coverage: when episodic events overshadow persistent background pollution in public communications, they distort the narrative. Chronic exposure to moderate but sustained pollution levels is responsible for most air quality related health burdens, and it demands equal, if not greater, attention from policymakers and communicators.

Monitoring and modelling systems designed to capture extreme events require high temporal resolution (ideally hourly or sub-hourly data) and must be capable of flagging exceedances in near real time. Early warning systems that detect the onset of a pollution episode can trigger public health advisories, activate emergency response protocols (like GRAP in India), and prompt authorities to implement short-term emission controls such as vehicle movement restrictions or industrial energy consumption cuts.



Statistical analysis of extreme values, such as the frequency, duration, and severity of exceedance events, complements average-based metrics by capturing the tail of the pollution distribution. In many regions, a small number of extreme episodes can contribute disproportionately to the annual average, meaning that reducing the frequency or magnitude of these events is as important as reducing baseline emissions.

7. Vertical Profiles

Most air quality monitoring and reporting focuses on ground-level concentrations, but the vertical distribution of pollution in the atmosphere also matters significantly.

Pollutants at higher altitudes are subject to stronger wind speeds and can travel greater distances, affecting air quality in regions far from the original emission point. In an airshed management setting, understanding vertical profiles is therefore important to address the transboundary nature of air pollution.

Traditionally, vertical profiles are derived from atmospheric chemical transport models and monitoring equipment like radio sondes, ozone sondes, aerosol sondes, and gaseous sondes.

Satellite-based models provide a complementary perspective, measuring the total column burden of certain pollutants. These products have become valuable tools for monitoring air quality in regions with sparse ground-based networks.

When calibrated against ground-based measurements and modeling databases, satellite data can substantially expand air quality information coverage. Interpreting this correctly requires accounting for the fact that satellites measure the full atmospheric column rather than surface concentration alone, making validation and post-processing essential steps before applying the data for regulatory or health assessment purposes.

8. Source Apportionment (Contributions)

Knowing how much pollution exists and where/when it occurs is only part of the air quality story. Source apportionment answers the equally important question: where is the pollution coming from?

“Source apportionment” is an analytical technique which quantifies the contributions of different emission sources, such as road transport, industry, residential burning, agriculture, and natural sources, to observed (or modelled) ambient pollutant concentrations at a specific location or across a region. These techniques use a combination of chemical fingerprints specific to various sources (top-down) and emission intensities (bottom-up).

Source apportionment results are directly actionable for policy. If, for example, residential biomass burning is found to contribute 40% of wintertime $PM_{2.5}$ concentrations in a city, policymakers can prioritize clean cooking and heating programs over traffic management measures. In the developing world, $PM_{2.5}$ source apportionment is particularly important given the diversity of emission sources that all compete for policy attention. In more developed contexts such as the US and the EU, apportionment studies frequently highlight the dominant role of NO_2 and Ozone from road transport.

Source apportionment is not a single concept, as it takes several distinct forms, each serving a different purpose in policy dialogue.

Pollution apportionment is the most used in public and policy discussions. It represents the pollution already present in the air and how much of that can be attributed to each source. By the time emissions reach this stage, they are well-mixed, both vertically and across the region, chemically transformed, and interacting with other pollutants. This is the air people breathe, and it is the most direct basis for health-linked and source-linked policy decisions.

Emissions apportionment, commonly known as an emissions inventory. Rather than measuring what is in the air, it quantifies the rate at which pollutants are released at the source -- how much an industry emits, collectively what is the vehicle exhaust amount, or the emission intensity of different cooking practices across a region. Emissions inventories are essential planning tools, but they do not account for atmospheric dispersion, chemical transformation, or mixing -- all of which occur after emission and before a pollutant reaches a receptor point (for example, a monitor or a nose).

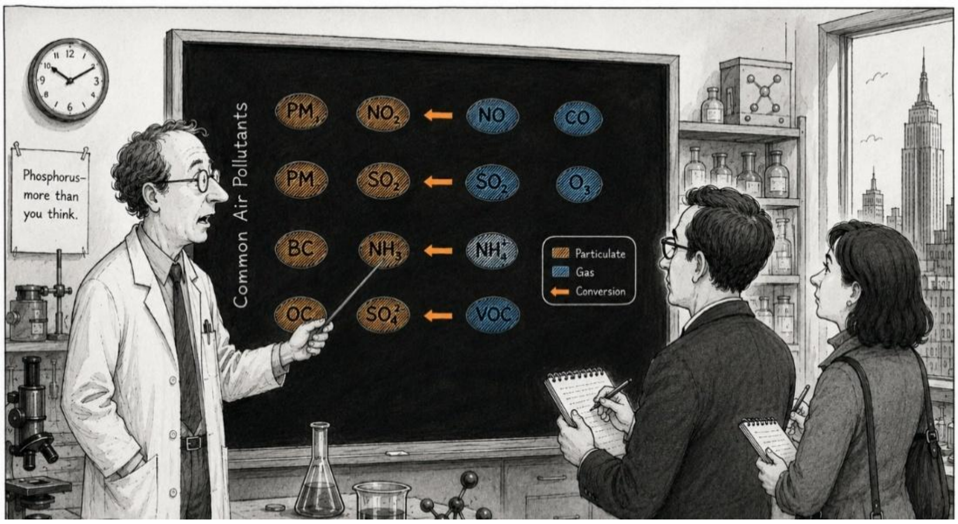
Health apportionment introduces a third dimension through the concept of intake fraction -- the proportion of emissions from a given source that is inhaled by the exposed population. A source may contribute heavily (like a power plant) to overall emissions yet have a low intake fraction if its pollutants disperse over a wide area before reaching people. Conversely, low-level sources such as vehicle exhaust, waste burning or roadside dust have very high intake fractions because emissions occur close to where people live and breathe, with little opportunity for dilution.

Perceived apportionment is the fourth and often overlooked dimension. Derived from public surveys and community dialogue, it captures what people believe to be the dominant pollution source (regardless of what monitoring or modelling data show). In most cities, transport is perceived as the primary culprit, shaped by visible exhaust, noise, and the volume of public discourse around vehicles. This perception gap between scientific evidence and public understanding has real consequences for policy: it can drive attention and resources toward visible sources while less visible but equally significant contributors such as agriculture, industry, or residential burning, go under-scrutinized.

An effective air quality management plan draws on all four dimensions, but pollution apportionment remains the anchor. It is the closest representation of what people are exposed to, and therefore the most direct basis for setting priorities, designing interventions, and measuring progress.

9. Pollutants and Their Chemical Nature

Understanding the chemical nature of pollutants is essential.



$PM_{2.5}$ is of particular concern because of its small size and carrying capacity for toxic chemical components including heavy metals and biological material. An effective $PM_{2.5}$ management plan cannot focus solely on its direct emissions. The plan must also address the gaseous pollutants that drive secondary $PM_{2.5}$ formation -- particularly SO_2 and NO_2. Through a series of atmospheric reactions, these gases form sulphates and nitrates in aerosol form, linked to $PM_{2.5}$ related health burden. In the developing world, where coal and diesel remain dominant fuels, these secondary components account for a large share of $PM_{2.5}$ story, making management of gases as central as tackling primary particles like black carbon and organic carbon. Chemical speciation data, like $PM_{2.5}$'s elemental and ionic composition, serve as diagnostic fingerprints for identifying emission sources.

Another chemically active pollutant of concern is Ozone, which is not emitted directly from any source. When sunlight hits a mix of nitrogen oxides and volatile organic compounds, it triggers a chain of photochemical reactions that produce ozone as a byproduct. This is why ozone levels tend to spike on hot, sunny, and still days -- exactly the kind of day people want to spend outdoors. Once in the air, ozone aggressively irritates the respiratory system, inflaming the airways, reducing lung function, and making breathing painful, particularly for people with asthma and other respiratory ailments. Unlike the protective ozone layer in the stratosphere, which shields the Earth from ultraviolet radiation, ground-level ozone is a pollutant that poses a direct threat to human health.

As more affordable and portable sensors advance monitoring technology, researchers and policymakers gain increasingly nuanced insights into the full chemical complexity of ambient air.

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