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Urban Air Pollution

South Asia Urban Air Quality Management Briefing Note No. 4

What Do We Know About Air Pollution?—India Case Study

Governments in South Asia are urged to address urban air pollution as a matter of high priority in its most affected cities. In order to devise effective intervention measures, however, we need to understand which sources are responsible for the high exposure of the general public to air pollution. Tata Energy Research Institute (Teri) in Delhi recently reviewed the information available since 1990 in India to answer this question [1]. Their report shows that gaps in data and analysis are sufficiently large to make answering this important question difficult. This briefing note summarizes key findings in that report.

Particulate matter is the most serious pollutant in large cities in South Asia. There are many sources of particulate pollution: large industrial plants, medium- and small-scale industries, refuse burning, households burning biomass for cooking and heating, vehicular exhaust, re-suspended road dust, construction, particles migrating from other regions, and naturally occurring dust. These sources emit particles of varying sizes—small particles affect public health much more than large particles. It is important to have a good understanding of the level of exposure of the general public to particulate air pollution, and of the relative contributions of these different sources (referred to as source apportionment).

Available Data on Ambient Concentrations

Ambient air quality has been monitored in India since 1967. There were 204 monitoring stations in operation in 2001. Sulfur dioxide (SO_2), nitrogen dioxide (NO_2) and total suspended particles (TSP) have been historically monitored on a regular basis. Respiratory suspended particulate matter (RSPM), with the particle diameter cut-off somewhere near 10 microns (µm), has been added recently at a number of monitoring stations, totaling 77 by the end of 2000. TSP is much less relevant to the health impact of air pollution than RSPM and smaller particles. For this reason the trend worldwide is to focus increasingly on measuring the concentration of smaller particles which can penetrate deeper into human respiratory systems. For example, the US Environmental Protection Agency (EPA) discontinued monitoring of TSP in 1987 in favor of PM_{10} (particles smaller than 10 µm), and achieved its first year of nation-wide monitoring of $PM_{2.5}$ (smaller than 2.5 µm) in 1999.

The available data in India show that pollutant concentrations are typically within the national ambient air quality standards [2] with the exception of particles. A recent case study [3] monitored RSPM twice a week at 10 stations in Delhi over a 13-month period between July 2000 and July 2001. The mean RSPM concentrations averaged 204 $\mu g/m^3$, considerably above the US annual PM_{10} standard of 50 $\mu g/m^3$. The correlations between NO_2 and RSPM concentrations were extremely weak, suggesting that sources other than road traffic were contributing significantly to ambient RSPM.

There is essentially no information on background particulate concentrations. This information would be important for devising effective mitigation measures and setting realistic targets, because it matters a great deal whether high ambient concentrations are a result of human activities in the city, or as a result of naturally occurring particles, or even particles migrating from other regions. If background concentrations are high, imposing strict controls on human activities in an attempt to reduce air pollution may yield much smaller benefits than anticipated.

Discussions with practitioners in air quality monitoring suggest that quality assurance and quality control needs strengthening. The areas that call for attention include not only the accuracy and reproducibility of the measurements but also data analysis; timely publication of, and access to, raw data; re-examination of site-selection in light of changes in land use patterns; the actual (as opposed to stipulated) monitoring frequency; and the positioning of the instruments at a given site.

With respect to how data are used, there is often a tendency to collect data at "hot spots," and to base city-wide policies on the data collected at sites that rank among the most polluted. However, such an approach is *not optimal* for addressing air pollution at the least cost to society.

Identifying Sources

Broadly speaking, there are two approaches to quantifying the contributions of pollution sources to human exposure.

1. The first approach, dispersion modeling, starts with emissions from different sources (emissions inventory) and calculates ambient concentrations in the vicinity of the "receptor" (where ambient concentrations are measured). The final results should match the measured ambient concentrations, but are often significantly below them. Ambient concentrations are used to calibrate the models for running future scenarios.
2. The second approach, receptor modeling, analyzes particles in the atmosphere at a given location and matches their characteristics with those of chemically distinct source types (finger-printing).

These two approaches should give the same results, but examples of conducting and comparing studies using the two approaches are rare even in developed country cities where much more detailed data are available (see Box-1). The two approaches—constructing an emissions inventory followed by dispersion modeling in the first, and chemical mass balance receptor modeling in the second—and their applications to cities in India are discussed below.

Approach 1

Emissions inventory

Emissions inventories have been developed in large cities such as Delhi and Mumbai. However, they are limited by the lack of availability of needed data and are hence sketchy for the following reasons.

- Emission factors suited to Indian cities are often not available. In their absence, the factors from North America or Europe are used after some adjustments, but they could seriously under-estimate emission levels in South Asia. One consequence is that emission factors used vary markedly from study to study, sometimes differing several-fold.
- Industrial emissions depend on a number of factors, including how the plants are run and maintained. When the emission factors are based on the data provided by manufacturers (of boilers, for example) who tend to assume very good equipment maintenance, the factors may be seriously under-estimated.
- The numbers multiplying the emission factors, such as the amount of fuel used, can be estimated only roughly in many cases. When the amounts of transport fuels sold in a city are compared to those calculated from the vehicle fleet data, for example, they have been known to differ markedly.
- For certain source categories—re-suspended road dust, refuse and leaf burning, generators, to mention a few—data are typically not available. As a result, they may be under-estimated or omitted altogether, and correspondingly those from other sources are over-estimated in relative percentage terms.

Two important points are worth flagging. The first is that an emissions inventory, however accurate, should not be the basis of policy formulation. What ultimately should drive policy is not which source is emitting more, but which source is likely to lead to greater exposure to health-damaging pollutants. A coal-fired power plant at the edge of a city with a tall stack may in absolute tonnage be the largest emitter of particles, but may be contributing less—from the point of view of overall human exposure—than, for example, all the households burning biomass.

A common mistake is not only to rank different sources based on an emissions inventory, but to add up all the pollutants (regardless of their toxicity to human health) in

Box 1. Confounding conventional wisdom: Lessons from the United States

One of the most extensive comparisons of the two approaches to source apportionment is a study in Colorado, USA [4] which examined source contributions to $PM_{2.5}$. The available emissions inventory indicated that diesel accounted for two-thirds of on-road vehicle $PM_{2.5}$ emissions and gasoline the remaining one-third. However, the use of the chemical mass balance model suggested that diesel actually accounted for only a third and gasoline two-thirds, and that $PM_{2.5}$ emissions from gasoline vehicles were seriously under-estimated, both with respect to diesel and on an absolute basis. The discrepancy was due mainly to the presence of gasoline "smokers" and high emissions during cold start.

A recent study conducted in southern California [5] found that some gasoline-fueled passenger cars emit as much as 1.5 grams per kilometer, an emission level normally associated with heavy-duty diesel vehicles. Comprising only 1 to 2 percent of the light-duty vehicle fleet, these gross polluters were estimated to contribute as much as one-third to the total light-duty particulate emissions. It is possible that the proportion of "smoking" gasoline vehicles is much larger in South Asia.

weight before doing so. This almost always leads to the conclusion that road traffic is by far the largest contributor to urban air pollution, because in absolute tonnage, carbon monoxide (CO) dominates all other pollutants, and the majority of CO is from vehicles. But the toxicity of CO is much lower on a weight basis than those of other pollutants, so that these results cannot be correlated with health effects.

The second point is that the science of the health impact of particulate air pollution increasingly points to the importance of ultra-fine particles, and significant contributions of combustion processes to the size fractions now considered most damaging to public health. A study in the United Kingdom reported that road traffic nationally contributed 25% of primary PM_{10} emissions, but the relative importance of road traffic emissions increased with decreasing particle size and road transport accounted for an estimated 60% of $PM_{0.1}$ [6]. The question of which sources are contributing most to public health damage depends critically on the particle size range for which source apportionment studies are carried out.

Dispersion modeling

A limited number of studies have carried out dispersion modeling in India. Most have not looked at the chemical transformation of pollutants (such as secondary particulate formation from sulfates and nitrates). The majority have examined pollutant concentrations—typically CO, NO_2 or lead when leaded gasoline was still used in India—along traffic corridors. The objective of these studies, which met with varying success, was not to quantify source contributions, but to compare model outputs with the actual concentration measurements at selected locations in order to validate the models. As such, dispersion modeling in India is in its early stages of policy relevance.

Approach 2

The first step in any chemical mass balance receptor modeling is detailed chemical analysis of receptor and source samples. The level of detail required is considerable, presenting difficulties. For source attribution, source profiles are needed. It would be straightforward if one compound or element served as a tracer for a single source type, and that tracer was not present in any other source type, but this is rarely the case. It may even be that sources cannot be "fingerprinted": similar sources may not have similar profiles, or different source categories may have similar profiles.

The majority of the studies conducted in India to date have focused on trace metal and water-soluble element analysis. Because of the widespread availability of leaded gasoline in India until 2000, a number of studies examined lead in particles along traffic corridors.

Carbon analysis, in contrast, has not been conducted until recently, the first study being carried out only in 2000-2001. Carbon analysis is useful for estimating combustion-generated particles. Comparison of black (also called elemental) carbon and organic carbon may help to distinguish between the combustion of biomass and fossil fuels. Trace organic analysis (identifying key hydrocarbons) is an important tool in receptor modeling, but this has not been carried out in India for small particles.

Carbon analysis of 15 RSPM samples collected in Delhi between August 2000 and February 2001 [1] showed that total carbon constituted 36% of RSPM. Total carbon averaged 122 $\mu g/m^3$, and black carbon 72 $\mu g/m^3$. These figures are high by any measure, and the high proportion of black carbon points to significant contributions from the combustion of fossil fuels.

Summary of source apportionment of particles in India

No more than a dozen source apportionment studies appear to have been conducted in India, and most of them identify major sources without quantification. The two main approaches to source apportionment mentioned above have been utilized. The majority have concentrated on TSP. The selection of TSP, which includes a large fraction of coarse particles, tends to highlight the importance of wind-blown dust and other natural sources of particles at the expense of anthropogenic sources, although the latter are much more damaging to public health.

There has been only one study attempting to investigate source contributions to PM_{10} [7]. About 20 elements were measured in Mumbai over a year and factor analysis was carried out identifying four pollution sources: re-suspended dust, refuse and vegetation burning, sea-salt and road traffic. As expected, soil-derived dust was found to be a major source of larger size particles whereas refuse burning and road traffic were identified as major sources of smaller size particles.

Similarly, only one study appears to have built upon an emissions inventory and dispersion modeling to quantify source contributions. The Urban Air Quality Management Strategy in Asia, URBAIR, used a multisource Gaussian model to estimate TSP concentration distributions in Mumbai [8]. Based on the estimates of PM_{10}/TSP ratios for different sources, the study suggested that 30% each of PM_{10} was from background and vehicle exhaust, respectively, 20% from road dust re-suspension, 15% from area sources (domestic fuel combustion, small industries, stone crushing and refuse burning), and 3% from large and medium-size industrial plants. These estimates contain large uncertainties and should be interpreted with caution.

There has been one study [9] using chemical mass balance to examine source contributions to TSP in Mumbai. The US EPA chemical mass balance receptor model was used. Model results were unsatisfactory at highly polluted sites, suggesting that US EPA profiles were not suitable for India.

Another study [10] used particle size distribution data rather than chemical analysis to attribute sources. Particle size is sometimes indicative of emission sources, with coarse particles typically from mechanical processes and finer particles from combustion and secondary particulate formation. The study divided particles ranging in size from 0.05 to 25 µm into four size groups, with the smallest size fraction corresponding to secondary particles and products of combustion, and the largest to dust and marine aerosols.

Conclusions

Data that can be used for policy formulation in urban air quality management are scarce in India. How to make best use of the available information, and how to bridge the gaps in data and analysis are the two challenges facing researchers and policymakers.

- Based on epidemiological evidence, monitoring of TSP is increasingly abandoned in favor of PM_{10} and $PM_{2.5}$ elsewhere in the world. These smaller particles should be monitored regularly in the future.
- Regular monitoring of PM_{10} and $PM_{2.5}$, while being an important first step, has a limited role to play in policy appraisal because it can merely signal that there is a problem. Monitoring needs to be supplemented by studies to identify sources and assess effects on public health. No single methodology will answer all or even most questions, and instead a wide range of approaches will be needed. Collaboration between government agencies and scientific institutes to this end should be given high priority.
- The most important gap in the work to date in India on particulate source apportionment is the near-complete lack of data on emissions from the area sources listed above under URBAIR. This gap has led to a potentially biased focus on emissions control in the transport sector, and can be systematically addressed in a relatively short time.
- Those findings from other countries that challenge the conventional wisdom (Box 1) should inform researchers and policymakers.

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