Source Apportionment of Particulate Matter for Air Quality Management

Review of Techniques and Applications in Developing Countries

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(ESMAP)

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Abbreviations and Acronyms

AAS	Atomic Absorption Spectrophotometry
ACE-Asia	Asia Pacific Regional Aerosol Characterization Experiment
APCA	Absolute Principal Component Analysis
AQMS	Air Quality Management System
BAM	Beta Attenuation Monitor
BC	Black Carbon
CAMMS	Pressure Drop Tape Sampler
CFC	Chlorofluorocarbons
CMB	Chemical Mass Balance
CO	Carbon Monoxide
CO_2	Carbon Dioxide
COPREM	Constrained Physical Receptor Model
Dichot	Dichotomous Sampler
EC	Elemental Carbon
EF	Enrichment Factor
EPA	U.S. Environmental Protection Agency
ESMAP	Energy Sector Management Assistance Programme
FRM	Federal Reference Method
GAINS	Greenhouse Gas and Air Pollution Interactions and Synergies
GC	Gas Chromatography
GHG	Greenhouse Gas
HPLC	High Performance Liquid Chromatography
IBA	Ion Beam Analysis
IC	Ion Chromatography
ICP	Inductively Coupled Plasma
IES	Integrated Environmental Strategies
IMPROVE	Interagency Monitoring of Protected Visual Environments
INAA	Instrumental Neutron Activation Analysis
INDOEX	Indian Ocean Experiment
MS	Mass Spectrometer
MiniVol™	MiniVol™ Portable Air Sampler
MLR	Multi Linear Regression
μm	Micron

NASA	U.S. National Aeronautics Space Administration
NH_3	Ammonia
NIOSH	U.S. National Institute for Occupational Safety and Health
NO_x	Nitrogen Oxides
OC	Organic Carbon
O_3	Ozone
PAH	Polycyclic Aromatic Hydrocarbons
PCA	Principal Components Analysis
PESA	Proton Elastic Scattering Analysis
PIGE	Particle Induced γ-ray Emission
PIXE	Proton Induced X-Ray Emissions
PM	Particulate Matter
PM_{10}	Coarse Particulate Matter With Diameter < 10μm
$PM_{2.5}$	Fine Particulate Matter With Diameter < 2.5μm
$PM_{0.1}$	Ultra-Fine Particulate Matter With Diameter < 0.1μm
PMF	Positive Matrix Factorization
PP	Power Plant
PSCF	Potential Source Contribution Function
SOA	Secondary Organic Aerosols
SPM	Suspended Particulate Matter
SO_2	Sulfur Dioxide
TEOM®	Tapered Element Oscillating Microbalance
TOR	Thermal Optical Reflectance
TOT	Thermal Optical Transmittance
TSP	Total Suspended Particulates
VKT	Vehicle Kilometer Traveled
VOC	Volatile Organic Compounds
WB	World Bank
WHO	World Health Organization
XRF	X-ray Fluorescence
$\mu g/m^3$	Micro-grams per cubic meter

Executive Summary

1. Building an effective air quality management system (AQMS) requires a process of continual improvement, and the **source apportionment** techniques described in this report can contribute in a cost effective manner to improving existing systems or even as the first step to begin an AQMS. This is good news for many developing country cities where the combination of rapid growth, dirty fuels, and old and polluting technologies are overwhelming the capacities of cities to control air pollution. For these cities, source apportionment offers policymakers practical tools for identifying and quantifying the different sources of air pollution, and thereby increasing the ability to put in place effective policy measures to reduce air pollution to acceptable levels.

2. This report arises from a concern over the lack of objective and scientifically-based information on the contributions of different sources of air pollution – especially for fine **particulate matter** (PM) – in developing countries. PM is the air pollutant of most concern for adverse health effects, and in urban areas alone accounts for approximately 800,000 premature deaths worldwide each year.

3. There are currently two basic approaches to determining the sources of air pollution and specifically, PM: (1) top-down or receptor-based source apportionment methods, and (2) bottom-up or source-based methods. The top-down approach begins by taking air samples in a given area (i.e., via air sampling receptors) and comparing the chemical and physical properties of the sample to the properties of emission sources. Top-down methods offer the promise of providing information on the types of emission sources and their relative contributions to measured air pollution, which in turn helps identify and quantify the sources that would be most effective to control. Advances in sampling and analytic techniques have made source apportionment a logical and cost-effective alternative for developing country cities.

4. Bottom-up methods begin by identifying pollution sources and estimating emission factors using dispersion models. Utilizing this information and detailed meteorological data an atmospheric dispersion model estimates ambient pollution levels. While bottom-up analysis can provide useful information for air quality management, there are practical reasons to expect inaccuracies. Among the major drawbacks of bottom-up methods are inaccurate or limited knowledge of meteorological conditions, and more fundamentally, the inability to account for unexpected sources, including the long-range transport of pollutants and area sources such as biomass or trash burning. If a pollution source is not in the bottom-up analysis from the beginning, it will not emerge as a pollution source in the results. Bottom-up models also typically depend on information supplied by the pollution sources, such as industry or power plants. However, in order to avoid fines or cleanup expenses, polluters have an incentive to hide the seriousness of their pollution. Relatively simple and inexpensive top-down analyses can help identify and remediate these inaccuracies and an iterative approach of utilizing top-down and bottom-up techniques can improve the quality of the results of both methods.

5. Top-down source apportionment methods are based on the fact that PM sources often exhibit characteristic chemical patterns or profiles of air pollution. For

example, iron and steel mills emit PM that is rich in iron, cement plants emit PM containing calcium, and diesel exhaust contains largely carbonaceous PM. In some cases, specific trace elements, such as metals, can serve as tracers for specific sources. A source apportionment analysis uses outdoor samples of PM and these chemical "fingerprints" of different pollution sources to estimate the contribution of these sources to the total PM problem.

6. A key component needed to conduct a top-down analysis is a collection of "source profiles" of the emission sources that are impacting the urban area being studied. A source profile identifies the chemical fingerprint emitted from individual sources. The more accurate a source profile is, the more likely that accurate results will follow. In a city's early applications of source apportionment, profiles from cities with similar source characteristics can be utilized, but as the analysis becomes more complex, local source profiles should be developed. Source profiles can be measured using the same methods to acquire ambient samples; this is often more cost-effective and accurate than individual emission tests.

7. This report summarizes the ways and means of conducting top-down, source apportionment analyses. Source apportionment methods are shown as a hierarchy, whereby cities can first use simple and inexpensive methods to achieve a broad understanding of the sources of PM. Later, more detailed methods can be used to improve understanding and accuracy. This report also presents results for 16 case studies conducted in developing country cities over the past 5-8 years. As an example, the Qalabotjha, South Africa case found that residential coal combustion is by far the greatest source of air pollution in the region. The resulting policy recommendation was to subsidize the electrification of townships as a way to reduce residential coal use and atmospheric pollution. In Shanghai, China source profiles representative of Shanghai were developed, including for small and medium-size boilers, cement kilns, and road dust. These source profiles are now available for further air pollution studies and reflect the continual improvement of Shanghai's AQMS.

8. Multiple top down analyses can also be done for a city to reflect seasonal variations (e.g., summer versus winter or rainy versus dry). For example, in Xi'an, China, winter coal use contributed 44 percent of the carbonaceous sample, yet domestic coal burning was not an important contributor outside the heating season. Additional analyses in Xi'an found that long range transport from neighboring fast growing areas is an important contributing source of air pollution for the city. In Bangkok, the contribution of biomass combustion to ambient fine PM was very high during the dry season due to the burning of rice straw in the city vicinity.

9. In the case studies, source apportionment analysis was found to be a cost-effective way of identifying contributors to the areas' air pollution. In many instances the source apportionment results provided new information on the sources of emissions as well as a quantitative estimate of the source contribution. Among the emission sources identified by source apportionment techniques and that had been overlooked using the bottom-up models were secondary particulates such as sulfates that are often transported over long distances and area sources including biomass and refuse burning; in some cases these emissions accounted for a dominant share of the total air pollution.

10. Policymakers in rapidly growing urban areas recognize that correctly identifying the sources of air pollution is a vital first step in establishing efficient air pollution control policies. Top-down source apportionment, combined with bottom-up emission inventory techniques, should become a key element for supplying reliable, science-based pollution source data to a well designed AQMS.

Report Summary

1. Worldwide, urban population is expected to grow from 2.9 billion in 2000 to 5 billion by 2030. Unless steps are taken, the declining air quality in many developing country cities suggests that as the population continues to grow, air quality will further deteriorate. The impacts will likely be particularly severe in developing country mega cities (cities with a population of more than 10 million). The potential for these rapid changes coupled with a growing demand for cleaner air leaves policymakers facing the need to improve their ability to control air pollution. Fortunately, in recent years major advances have been made in techniques utilized to estimate ambient air pollution levels and identify emission sources. These advances, which are discussed in this report, offer the opportunity for developing countries to implement sophisticated air quality management programs earlier in their development process than was accomplished by their industrial country counterparts.

2. Being able to identify different air pollution sources accurately is a key element in an effective air quality management system (AQMS). An AQMS brings together the scientific activities of determining air pollution emissions, ambient concentrations by pollution type, and resulting health impacts with political and regulatory aspects to formulate a society's reaction to air pollution. This report arises from a concern over the lack of information about the sources of ambient air pollution in developing countries—especially for fine **particulate matter** (PM), which is the major contributor to the adverse health effects of air pollution. Without reliable and accurate source information it is difficult for policymakers to formulate rational, effective policies and investments aimed at improving air quality. This report details source apportionment of PM as one method that is especially relevant to developing countries that need quantitative information on the sources of air pollution.

3. There are currently two fundamental approaches to determining and quantifying the impacts of air pollution sources—(1) top-down or receptor-based source apportionment, and (2) bottom-up or source-based methods. The top-down approach begins by sampling air in a given area and inferring the likely pollution sources by matching common chemical and physical characteristics between source and air pollution samples. Top-down methods offer the promise of quantifying the relative contributions of the different sources to ambient air pollution, where rather little may be currently known. Additionally, top-down methods often require few atmospheric measurements and relatively simple analysis. Bottom-up models begin by identifying pollution sources and their emission factors and then using meteorological patterns to predict ambient pollution levels and compositions. Major limitations of bottom-up approaches are that they are not derived from air pollution samples and the sources of pollution must be pre-identified. Ideally, top-down and bottom-up approaches should agree, but this is rarely the case for an initial application. However, proper analysis of the nature of the

disagreement can result in improvements to both methods, and acceptable agreement is often achieved after several iterations. Together, these methods can provide confidence that the correct pollution sources have been targeted before instituting expensive air pollution control strategies.

4. Both top-down and bottom-up methods are discussed in this report, but the report concentrates on the former as a way to supplement and improve the results of the more traditionally utilized bottom-up methods. The top-down approach can support or call into question the validity of the assumed sources of air pollution in the bottom-up approach, and do so through actual samples of urban air pollution. In urban areas where little may be known about local air pollution, inexpensive, simple top-down techniques can quickly provide useful information on the relative importance of different sources of pollution. Through time more advanced top-down techniques can be implemented to give more certainty in the results and to test results gained via a bottom-up analysis.

5. The main objectives of this study are to review, demonstrate, and evaluate top-down methods to assess and monitor the sources of PM, using a combination of ground-based monitoring and source apportionment techniques referred to as receptor-based methods. These methods offer a cost effective opportunity for urban areas located in developing countries to improve their AQMS by providing an indication of the relative contributions of different, often previously unidentified sources of ambient air pollution.

6. The ultimate objectives of this report are to: (1) provide environmental institutions a guide to practical methods of receptor-based source apportionment (i.e., top-down methods); (2) communicate to policymakers the advantages of top-down methods and how they can be used effectively with or without bottom-up methods in an AQMS; and (3) disseminate broadly the findings and conclusions within the scientific and local/national environmental communities. In order to accomplish these objectives it is necessary to describe the nature and consequences of the major air pollution problem: particulate matter. Because of the seriousness of PM pollution for human health, visibility, climate, and materials damage, this report focuses solely on this type of pollution, while attempting to remain general enough to be applicable to a wider range of air pollutants.

NATURE AND CONSEQUENCES OF PARTICULATE MATTER

7. Particles in the air are classified by aerodynamic diameter size and chemical composition, and are often referred to as PM or aerosols. PM is generally measured in terms of the mass concentration of particles within certain size classes: total suspended particulates (TSP), PM_{10} or coarse (with an aerodynamic diameter of less than 10 micron), $PM_{2.5}$ or fine (with an aerodynamic diameter of less than 2.5 micron), and ultra fine particles (those with a diameter of less than 0.1 micron). The distinction between the coarse and fine particles is important because they have different sources, formation mechanisms, composition, atmospheric life spans, spatial distribution, indoor-outdoor ratios, temporal variability, and health impacts. Some PM occurs naturally, originating from dust storms, forest and grassland fires, living vegetation, sea spray, and

volcanoes, and some PM originates as a result of human activities, such as fossil fuel combustion, industrial emissions, and land use.

8. In terms of mechanisms of formation, PM can be classified into two categories, primary and secondary particles. Primary particles are emitted directly into the atmosphere from a number of manmade and natural sources such as fuel combustion, biomass burning, industrial activities, road dust, sea spray, volcanic activity, and windblown soil. Secondary particles are formed through the chemical transformation of gaseous primary pollutants such as sulfur dioxide (SO_2), nitrous oxides (NO_x), certain volatile organic compounds (VOCs), and ammonia (NH_3). The resulting secondary particles are usually formed over several hours or days and usually fall within the fine PM range. This small size allows these pollutants to be transported over very long distances. Some of these particles are volatile and move between gaseous and particle phases. For example, VOCs may change into secondary particles through photochemical reactions that also create ground-level ozone or smog conditions. Ambient concentrations of secondary particles are not necessarily proportional to quantities of primary gaseous emissions since the rate at which particles form may be limited by factors other than the concentrations of the precursor gases (e.g., temperature and relative humidity). By measuring the ambient concentrations of PM directly, receptor-based source apportionment techniques can help identify the sources of both primary and secondary PM.

9. The health impacts of air pollution depend on the pollutant type, its concentration in the air, length of exposure, other pollutants in the air, and individual susceptibility. There is little evidence that there is a threshold below which PM pollution does not have adverse health effects, especially for the most susceptible populations — children and the elderly. The adverse health impacts of air pollution can be substantial. For example in China in 1995, the air pollution resulting from fuel combustion is estimated to have caused 218,000 premature deaths (equivalent to 2.9 million life-years lost), 2 million new cases of chronic bronchitis, 1.9 billion additional restricted activity days, and nearly 6 billion additional cases of respiratory symptoms (World Bank, 1997). The primary culprit is believed to have been fine PM.

10. Of course, much of the adverse health impacts of urban air pollution manifest themselves through diseases such as lung cancer, cardiovascular and respiratory conditions including infections. The World Health Organization (2002) estimated that urban PM accounts for about 5 percent of trachea, bronchus, and lung cancer cases, 2 percent of deaths from cardio-respiratory conditions, and 1 percent of respiratory infections. Worldwide this amounts to about 0.8 million deaths annually, and the burden occurs primarily in developing countries (WHO, 2002).

11. While some developing countries still monitor only TSP, a growing number of urban centers are focusing on finer fractions—PM_{10}, $PM_{2.5}$, and/or $PM_{0.1}$. This shift is important because of the association of fine particles with more damaging health effects. Also, the shift allows a better understanding of the environmental fate of

the particulates being studied (e.g., the finer particles' ability to be transported long distances because they remain in the atmosphere longer).

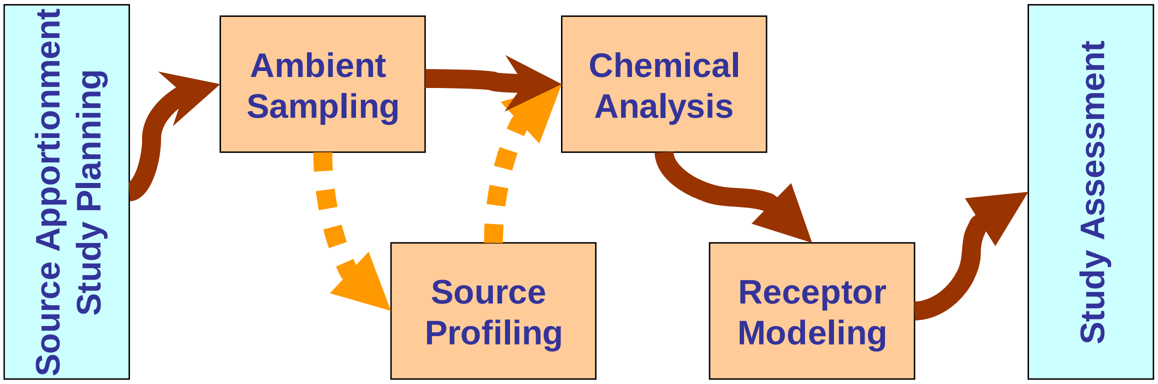
12. The adverse impacts of PM pollution extend beyond the direct health impacts discussed above. For example, air pollution particles scatter and absorb solar radiation depending on their chemical composition or refractive index resulting in direct contributions to climate change by reducing ground-level solar radiation. The so-called aerosol indirect effect is the change in cloud properties resulting from the excessive number of airborne particles. This effect can potentially change the hydrological cycle, impacting rain patterns. Particulate pollution can also impact visibility (i.e., via haze or smog), damage buildings, and destroy vegetation.

TOP-DOWN SOURCE APPORTIONMENT OF EMISSIONS

13. Top-down source apportionment methods are useful in gaining scientific understanding of a city's air pollution problem. In particular, top-down methods can quantify the relative contributions of different sources to the overall PM problem. Because these methods can be applied relatively quickly and inexpensively, they are particularly relevant for application in developing country cities.

14. Source apportionment methods are based on the fact that different emission sources have characteristic chemical patterns or profiles of air pollution. For example, iron and steel mills emit PM that is rich in iron, cement plants emit PM containing calcium, and diesel exhaust contains largely carbonaceous PM. In general, specific elements, such as metals can serve as tracers of pollution from different industrial processes. Source apportionment aims to explain the chemical composition of ambient PM samples as a combination of contributions from different sources. In doing so, source apportionment quantifies the relative contributions of these different sources. Figure 1 presents the steps needed to perform a top-down source apportionment or receptor study. Ambient samples are collected in locations of interest in an urban region, and these samples are analyzed for their chemical composition. Profiles of the composition of different sources can also be analyzed, or source profiles can be used from other urban areas. Quantitative methods or receptor modeling are then used to estimate the relative contributions of different sources to the total PM measured in the first step. A successful study therefore requires careful planning, appropriate air sampling and analytical equipment, and an appropriate level of technical competence to complete the necessary steps and draw appropriate conclusions.

Figure 1: Steps Required to Perform a Top-down Source Apportionment Study



15. A receptor-based source apportionment study provides:

(i) information on the types of sources responsible for the observed pollutants,

(ii) estimates of the percentage contribution of the sources for different locations during a given time period, and

(iii) a basis for evaluating realistic and cost-effective strategies to reduce PM pollution.

16. Because top-down methods are based on ambient data, the first steps in a successful PM sampling program are selection of sampling sites, selection of a suitable sampler and size range, and selection of filter media amenable to the desired physical and chemical analyses. The sampling sites need to represent an urban area's zones (e.g., residential, industrial, roads, commercial, parks, sources, background) and be representative of population impacts. The number of samples should be sufficient to represent the range of meteorological and emissions conditions. A properly formulated conceptual model reduces the cost and time of source apportionment by facilitating selection of: monitoring locations well suited for the tasks at hand; the size range of particles to be monitored; the species to be analyzed in ambient PM; and the number of samples to be taken and analyzed.

17. A key component needed to conduct a top-down analysis is a collection of source profiles reflective of the emission sources impacting the urban area being studied. A source profile identifies the quantities of specific air pollutants (elements and ions) emitted from individual sources. These profiles are pivotal in estimating the contribution of various pollution sources to ambient concentrations. The more accurate a source profile, the more likely that quality results will follow. Source profiles can be obtained locally, but most of the source profiles currently available are from industrial countries, where the mix of fuels used and combustion technologies employed may be different from those utilized in developing countries. Some studies are underway to determine source profiles for developing countries, but this avenue of research is still in its infancy.

The dotted arrows in Figure 1 indicate that a customized source profile (the ideal situation) can be developed for a particular urban area or source profiles can be utilized from other studies of areas with similar source characteristics.

18. Source profiles may consist of a wide range of chemical components, including elements, ions, carbon fractions, organic compounds, isotopic abundances, particle size distributions and shapes. In top-down analysis, whatever is measured at the source must also be measured at the receptor, and vice versa. Source markers are sought that are abundant in one type of source, but are minimally present in other source types. These markers must also have relatively stable ratios with respect to other components in the source profile. For example, biomass burning has a strong signal in potassium (K), while dust contains aluminum (Al) and silicon (Si). Carbonaceous materials measured along with elements include: (1) organic, elemental (light absorbing or black carbon), and carbonate; (2) thermal carbon fractions that evolve from PM at different temperatures; and (3) specific compounds present in the organic carbon fraction.

19. Organic marker compounds have become more useful as many toxic elements formally used as markers are removed from emission sources (e.g., lead from gasoline engine exhaust). Analysis using organic marker compounds can be quite useful when identifying contributions of sources that emit primarily carbonaceous particles. For example, this type of analysis can distinguish between diesel and gasoline exhaust (see Figure A3.4) and between soil dust and road dust. Organic compounds are also useful in distinguishing emissions from ethanol fueled versus gasoline fueled vehicles. Studying the organic component of sources is also important because this complex mixture of organic compounds, many of which can cause cancer and genetic mutations, makes up approximately 30 to 50 percent of the $PM_{2.5}$ in urban environments. By utilizing modern extraction methods, organic compounds can be measured at costs comparable to those for elements, ions, and carbon.

20. Physical and chemical analyses of the characteristic features of particulate matter include shape and color, particle size distribution (number), and chemical compounds. Temporal and spatial variation of these properties at receptors also helps to assign pollution levels to source types. Although most of these features can be used to identify source types, the only measures that can be used to determine quantitatively a source contribution to ambient PM levels are component concentrations described in the source profiles.

21. Several different technologies and methods exist for sampling atmospheric PM, analyzing its chemical composition, and performing receptor modeling. Each system has its strengths and weaknesses. A chosen system needs to be matched with the anticipated needs of an urban air source apportionment study. For example, if biomass burning is suspected to be a major problem area for a particular urban area, a system strong in detecting biomass burning tracers needs to be selected. Source apportionment study planning (Figure 1) plays a critical role in system selection. The analytical measurements should be selected based on the resources available for the study, species to be measured and the types and number of ambient samples to be collected. It is again

noted that the sampling and analysis should be planned together as certain analytical measurements cannot be performed unless the samples have been collected in a specific way using a specific filter.

22. Advantages of source apportionment are that it:

- i determines if selected monitoring sites or hot spots exceed compliance levels;
- ii identifies critical pollutants of concern;
- iii may differentiate the chemical composition of PM (e.g., the primary and secondary contributions);
- iv describes source impact estimates;
- v identifies sources which would be most effective to control; and
- vi avoids the uncertainties associated with the emission inventories and meteorological inputs required for the bottom-up approach.

23. Limitations of source apportionment include:

- i. the need to have and apply appropriate source profiles which match emission sources with ambient air pollution;
- ii. in some cases not being able to differentiate sources that have similar chemical composition (known as collinear), for example, cooking and open burning, or resuspended road dust and soil dust; and
- iii. not being able to fully account for possible nonlinearities due to chemistry and the formation of secondary aerosols.

SOURCE APPORTIONMENT CASE STUDIES IN DEVELOPING COUNTRIES

24. Figure 2 presents the results of fifteen source apportionment case studies conducted in developing country urban areas across the globe, which utilized the techniques described above. Many other receptor model studies are referenced in the bibliography. The cases were conducted by a wide variety of universities and government agencies, and the motives for the studies varied widely.[1] For example, the Qalabotjha, South Africa study was conducted exclusively for policy decisions on energy use in the urban area. The objective was to convince authorities to subsidize electrification of townships as a way of reducing residential coal use (low-grade coal is by far the least expensive form of energy in South Africa). The source apportionment study confirmed that residential coal combustion was by far the greatest source of air pollution, accounting for 61 percent of $PM_{2.5}$ and 43 percent of PM_{10} at the three Qalabotjha monitoring sites. In contrast, the Shanghai project developed source profiles representative of Shanghai, such as small and medium size boilers, cement kilns, and dust on representative roads. These source profiles are available for future air pollution studies.

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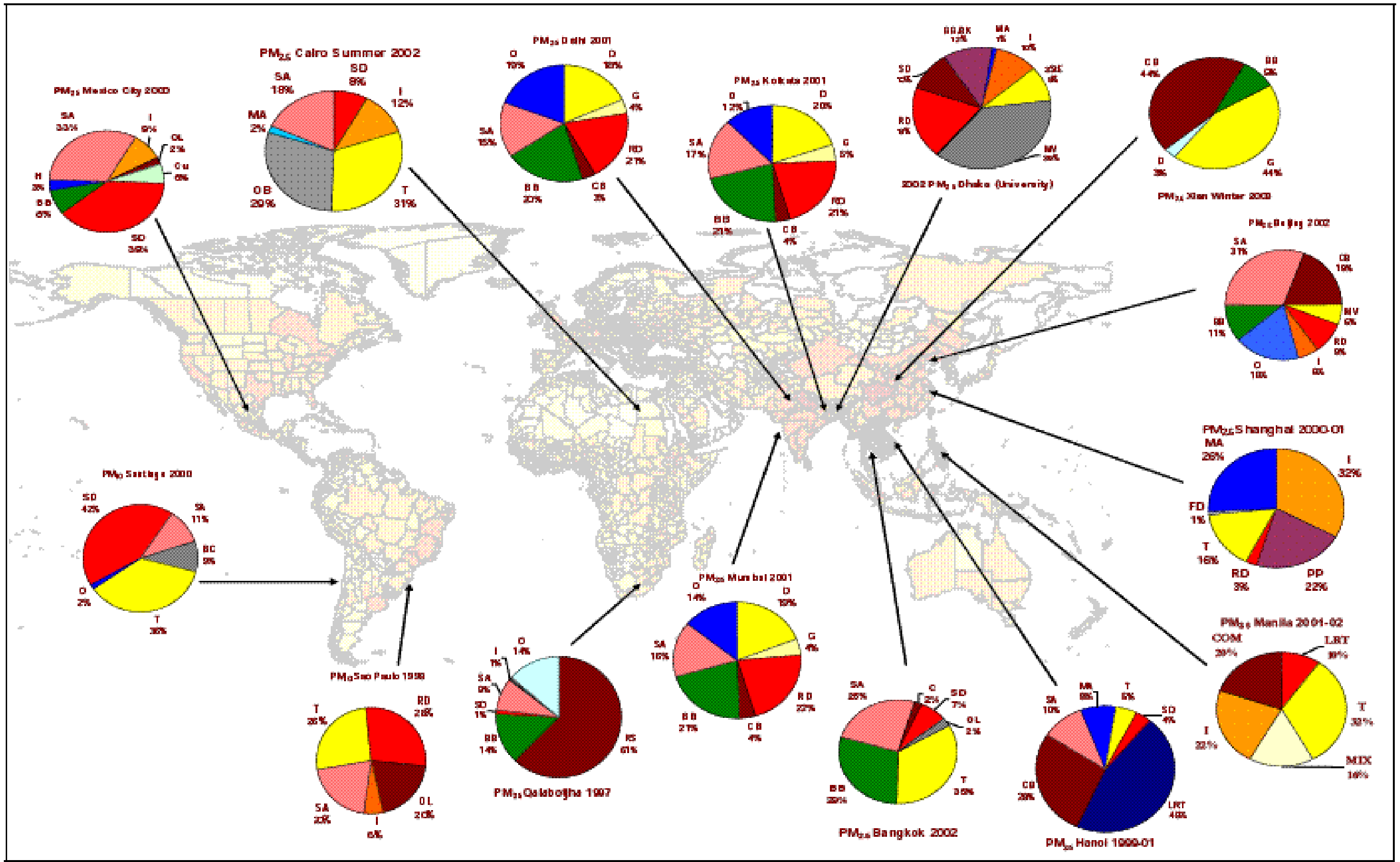
[1] See Chapter 4 for details of these studies.

25. Two of the studies, Santiago and Sao Paulo, focused on PM_{10}. The other studies concentrated on fine particulate matter ($PM_{2.5}$). The most common source identified in most of the urban areas was *dust emissions*. Dust sources include: resuspended dust from paved roads, unpaved roads, construction, demolition, dismantling, renovation activities, and disturbed areas. When dust sources are caused by sporadic or widespread activities due to wind or vehicle travel, they can often be difficult to quantify. Additionally, there are no specific emission factors established that can be applied to all the urban areas. However, by providing information on the proportion of dust in a measured sample, top-down source apportionment methods can provide a estimate of the contribution dust emissions make to air pollution at the receptor sites.

Figure 2. Source Apportionment Results for Select Urban Areas.



BB=Biomass Burning; CB = Coal Burning; D=Diesel; G=Gasoline; RD= Road Dust; Sa=Secondary Aerosols; O=Others; I=Industry; MV=Motor Vehicles; T=Transport; OL=Oil Burning; SD=Soil Dust; BC=Black Carbon; Cu=Copper; H=Hydrogen; RS=Residential; LRT=Long Range Transport; MA=Marine; PP=Power Plant; FD=Fugitive Dust; 2StE=2-Stroke Engine; BK=Brick Kiln; C=Construction

26. In addition to the studies summarized in Figure 2, this report presents results of an in-depth analysis conducted in Hyderabad, India (which is the fifth largest

city in India).[2] The study began with development of a bottom-up emission inventory. The results of the emission inventory and subsequent air quality modeling indicated that the primary source of PM_{10} emissions in Hyderabad is the transportation sector (~62 percent) with the industrial sector being the second largest source of PM_{10}. The subsequent top-down study utilized three monitoring sites and found that for PM_{10} the average contribution of mobile sources (petrol, CNG, and diesel) ranged from 49.2 percent to 58 percent. For $PM_{2.5}$ mobile sources contributed 49.4 percent to 56.0 percent making it the dominant PM source in the region.

27. The Hyderabad study was intended to create a more comprehensive approach to the region's air pollution challenges. The receptor-based, source apportionment modeling complemented the emission inventory phase of the study to improve the overall quality of the air pollution information available to regulators and policymakers. One of the most significant challenges of the receptor-based study was the lack of local source profiles for the Hyderabad area. A composite of profiles from other similar areas was utilized, and these profiles were selected from a data base in such a way as to yield reasonable statistics for the collection sites utilized in the study. While an acceptable practice, it is clearly preferable to generate customized profiles specific to the region. At least some of the most important and critical profiles should be obtained locally including local soil dust, vehicle profiles, and major industries in the region.

POLICY IMPLICATIONS

28. Policymakers in rapidly growing urban areas increasingly recognize that addressing air quality issues is an urgent priority but often lack sufficient information on the sources of air pollution and must compete for resources with other high-priority concerns. Receptor-based source apportionment techniques, coupled with bottom-up analysis, can supply reliable, science-based information on pollution sources for air quality management. In the past, bottom-up analyses have overestimated some pollution sources while missing entirely other important contributors. Without properly identifying the sources of pollution it is difficult for policymakers to formulate rational, effective policies and make informed investment decisions related to air quality improvements.

29. Top-down source apportionment can provide meaningful information on the relative contributions of different sources, in places where little is known about the local air pollution problem, with relatively little effort, and at low cost. Consequently, these methods are particularly relevant for developing nations. These top-down analyses can subsequently be improved by collecting more ambient samples, and by using more sophisticated methods of analysis. Likewise, in locations where emission information is more extensive but based on bottom-up methods, top-down source apportionment provides an important test for the accuracy of the bottom up results.

30. Fortunately, bottom-up and top-down analyses are not all or nothing activities. That is, attaining effective air quality management systems can be viewed as a

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[2] See Chapter 5 for details of this study.

process of growth from relatively elementary systems utilizing relatively simple analytical techniques to effective systems utilizing sophisticated ones. Developing country cities that have not previously developed an AQMS can begin with top-down assessments, while cities with more experience can augment existing systems and include receptor based modeling. The accumulated knowledge from the growing body of bottom-up and top-down analyses allows air quality managers to improve their AQMS more quickly than in the past. Developing country policymakers can thus make use of traditional bottom-up approaches as well as newer top-down methods to better identify and quantify air pollution sources, which is a fundamental first step in effectively addressing growing air pollution problems.