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Urban Particulate Pollution Source Apportionment

Part 1. Definition, Methodology, and Resources

Dr. Sarath Guttikunda

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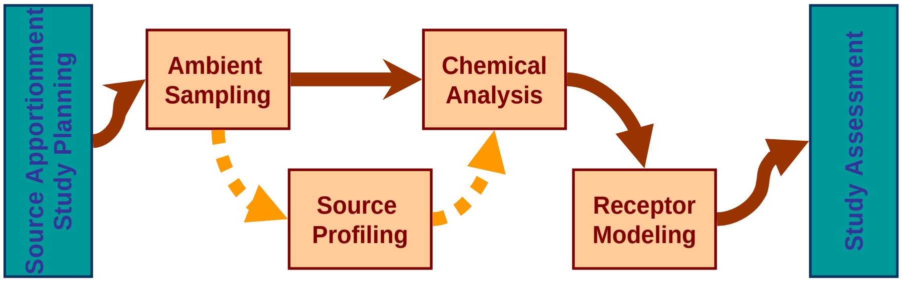

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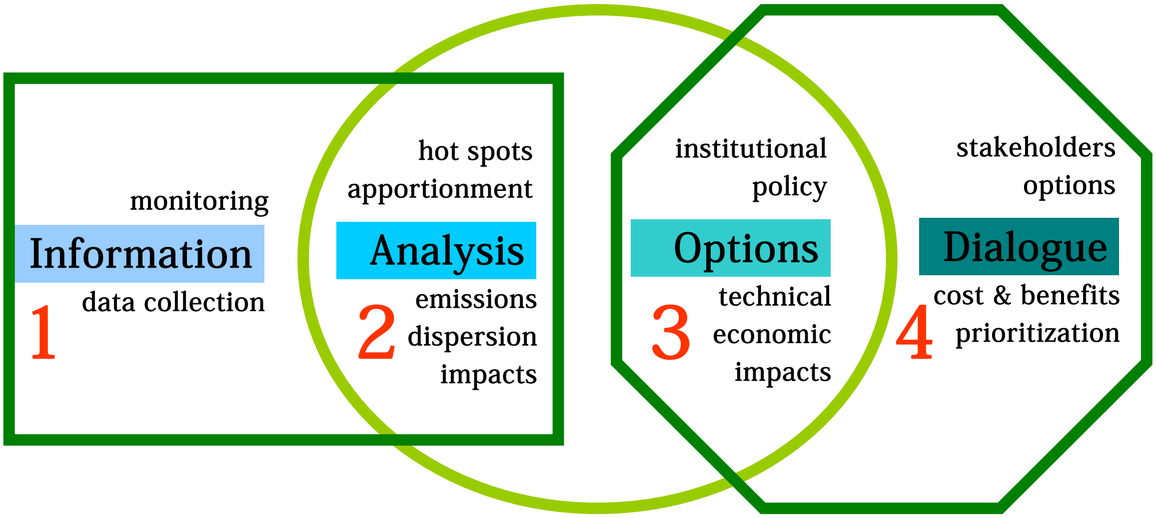
Part 1. Definition, Methodology, and Resources

This paper is a follow-up of SIM Series 010.2008 [1], "What is Particulate Matter – Composition and Science?", which covered the background material on the particulate matter composition, types of sources and their contributions (by mass, also known as emissions inventory), a summary of the contribution of various sources estimated using the monitoring data (also known as the source apportionment), and possible impacts of the particulate matter on local (human health), regional (precipitation patterns), and global (radiative forcing) air quality. This paper will cover the details on source apportionment methodology and resources for conducting an experiment.

Figure 1: Informed Decision Making for Air Quality Management



AQM & Particulate Pollution

[2]The Worldwide, urban population is expected to grow from 2.9 billion in 2000 to 5 billion by 2030[3]. Cities continue to grow, offering employment, better living conditions and basic amenities that are not available in rural areas. The rapid urbanization, however, is accompanied by environmental problems such as pollution, waste management, congestion and imbalance in fragile ecosystems. Unless steps are taken, the declining air quality we are witnessing in many developing country cities suggests that as the population continues to grow air quality (and other environmental indicators) will rapidly deteriorate[4]. The impacts will not only be severe in developing country mega cities (cities with a population of more than 10 million) but also in the growing number of secondary and tertiary cities with a

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[1] See www.urbanemissions.info/simair/simseries.html

[2] Sections of this working paper are part of the "Handbook on Particulate Pollution Source Apportionment", by Guttikunda et al., 2008 (published by the World Bank). Details are available @ www.urbanemissions.info/pmsa.

[3] Demographia, 2008. "Population & Urban Statistics". http://www.demographia.com

[4] Science Daily (2008) - Urbanization: 95% Of The World's Population Lives On 10% Of The Land @ http://www.sciencedaily.com/releases/2008/12/081217192745.htm

population of at least 1 million[5]. 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[6]. These advances, which are discussed in this paper, 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[7].

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 (**Figure 1**).

This paper arises from a concern over the lack of information (quantitatively) on the contributions of different source categories of air pollution in developing countries[8] - especially for fine particulate matter (PM), which is the major contributor to the adverse health effects of air pollution[9]. Without reliable and accurate source information, it is difficult for policymakers to formulate rational, effective policies and investments aimed at improving air quality. In SIM 010.2008, a number of sources are described that contribute to the particulate pollution (ranging from domestic combustion to transport sector – direct and indirect) and this discussion with further a methodology to quantify the contribution of those sources, under various conditions.

It is important to note that the health impacts of urban air pollution are not entirely dependent on the particulate pollution. The health impacts observed or estimated are also dependent on other pollutants, such as ozone, hydrocarbons, acidity in the air due to sulfur and nitrogen compounds, carbon monoxide, etc. However, in the developing countries, the particulate matter forms the major contributor and hence the pressure to understand its sources better. Also, during the source apportionment, it is understood that all the pollutants discussed here, contribute in some form or the other to the particulate matter and any regulation or policy measure towards controlling particulate matter has an implicit co-benefit towards to the other pollutants.

Understanding Pollution Sources: There are currently two fundamental approaches to determine and quantify the impacts of air pollution sources—(1) top-down or receptor-based source apportionment and (2) bottom-up or source-based modeling (see **Figure 2**)

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[5] SEDAC – Gridded Population of the World @ http://sedac.ciesin.columbia.edu/gpw;
BBC Urbanization Trends @ http://news.bbc.co.uk/2/shared/spl/hi/world/06/urbanisation/html/urbanisation.stm

[6] A number of informative side events and presentations on air quality management in Asia, were conducted at the Better Air Quality conference, 2008, in Bangkok, Thailand. Details @ www.baq2008.org

[7] An application of the methodology proposed is the case study of Hyderabad, India. Details @ www.urbanemissions.info/hyderabad

[8] See SIM Series 003.2008, "Informed Decision Support for Developing Country Cities" @ www.urbanemissions.info/simair/simseries.html

[9] See a series of publications, including a literature survey, on health impacts of outdoor air pollution and cohort studies @ HEI – www.healtheffects.org; and the SIM Series 006.2008 for methodology on the estimating the health impacts of urban air pollution @ www.urbanemissions.info/simair/simseries.html

Bottom-up approach begins by identifying pollution sources and their emission strengths, which are converted to emissions (via emission factors by category) and then by utilizing meteorological patterns predicting pollution advection (movement) and compositions over time and space. Much is published under this approach to better understand the air pollution at urban, regional, and global levels.

The bottom-up approach results in

- Identification of the potential sources - physically and quantitatively (energy and emission strengths) in the city or the region
- Description of the physical and chemical processes with potential to impact the advection and chemistry of the pollutants, this includes the local topography and meteorological features
- Documentation of the formation of the secondary pollutants, along with the primary (via emissions) such as sulfates, nitrates, ozone, hydrocarbons, etc.
- A baseline mapping of the pollution and hot spots for the area of interest
- Apportionment of the pollution by source

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 may require few atmospheric measurements and relatively simple analysis; simple of course is a relative term, as demonstrated in the coming sections.

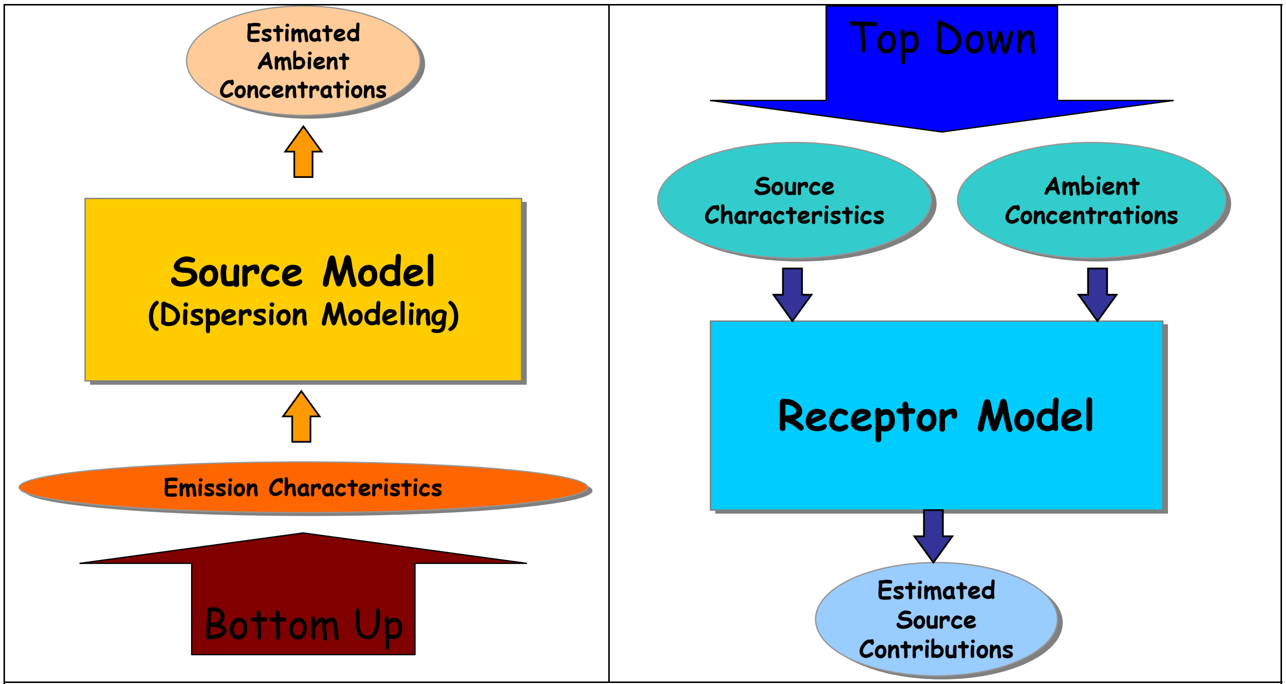

Figure2: Bottom-up and Top-down source apportionment methodologies

Ideally, the two approaches should agree, but this is rarely the case for an initial application and due to the scales of operation. 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[10]. This adds confidence to the selection of air pollution control strategies.

The top-down approach results in

- Identification of the hot spots with critical pollutant levels in the city or the region
- Identification of the chemical composition of the particulate pollution, following the chemical analysis of the measured samples
- Description of the source impact estimates, following receptor modeling based on the source profiles and statistical analysis
- Differentiation of the primary and secondary pollution at the hot spots
- Apportionment of the pollution by source

In a regulatory world, the **top-down approach is more acceptable**, primarily due to the involvement of direct pollution measurements at hot spots, analysis the samples in the lab, and determining (statistically) the contribution of various sources to the pollution at that particular spot. On the downside, the measurement points are few, due to the costs involved in monitoring and chemical analysis, which is (and can be) compensated by a comprehensive bottom-up approach to cover as many hot spots, and a better mapping of the pollution sources in the city.

This paper summarizes a methodology for the source apportionment of particulate matter as one method that is especially relevant to developing countries that need quantitative information on the sources of air pollution and relatively in a cost effective manner.

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[10] See a comprehensive study of source apportionment and emissions modeling conducted for the city of Hyderabad, India, under the IES program in 2006-07 @ www.urbanemissions.info/hyderabad

Source Apportionment Methodology

This review focuses on receptor-based source apportionment methods for particulate (PM) pollution. Receptor models are useful for resolving the composition of ambient PM into components related to emission sources. **Figure 3** presents an outline of steps necessary for a source apportionment study.

This type of analysis requires real time measurements and knowledge of the potential sources. Compared to bottom-up analysis where the knowledge of sources and source strengths, detailed information on meteorology and local conditions is required, the PPSA does not require meteorological data or complex modeling. However, meteorological data helps understand the hotspots and movement of pollutants in the city and hence be a guide in identifying the appropriate measurement locations.

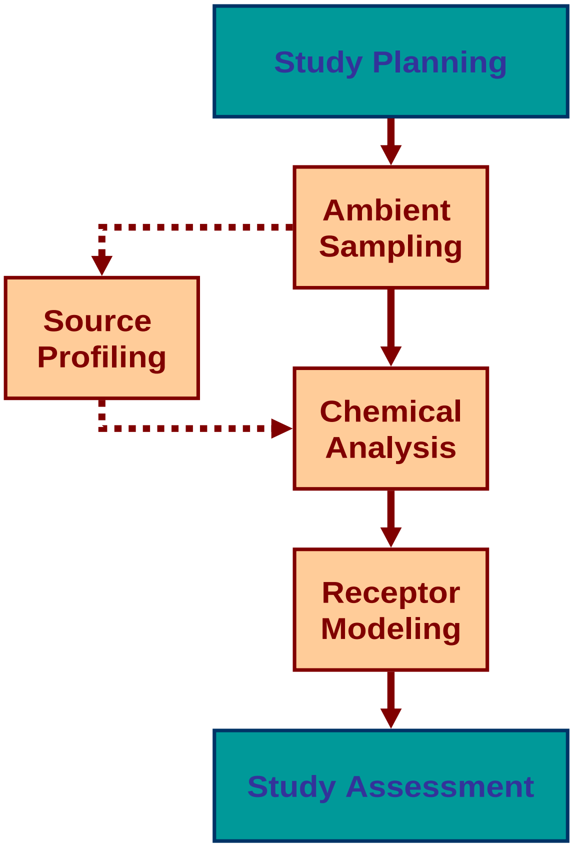

Figure 3: Schematics of particulate pollution source apportionment

Table 1 summarizes the advantages and limitations of a source apportionment study. More detailed representation of the particulate pollution source apportionment is presented in Watson et al., 2002[11].

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[11] Watson et al., 2002. "Receptor modeling application framework for particle source apportionment" Chemosphere, Vol. 49, pp 1093–1136.

Table 1: Strengths and limitations of source apportionment study

Methodology provides..	Methodology limitation includes ..
• Information on the types of sources responsible for the observed pollutants • Estimates of contribution of the sources for multiple locations over multiple time periods • An average source strength at various hot spots • A basis to develop realistic and cost-effective strategies to reduce particulate pollution	• Need to have and apply appropriate geographically-specific source profiles • Not being able to differentiate sources that have similar chemical composition (known as collinear), for example, cooking and open burning, or resuspended road and soil dust • Not being able to measure emission rates of individual sources • Apportionments varying with meteorology

The four primary steps presented in **Figure 3** are described below.

1. Ambient Sampling: Measurements provide fundamental information for evaluating and managing the impact of aerosols on air quality. Data obtained through measurements form the foundation of all approaches used to define and mitigate PM pollution. To provide the measurement data, variety of instruments have been developed and utilized for various purposes[12].

A full understanding of sampling stations and analysis strategies is required before acceptable measurement techniques and approaches can be specified to meet PM measurements.

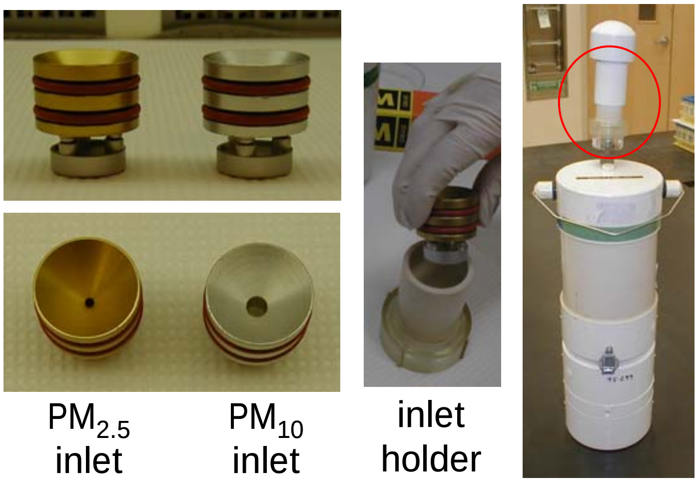

Figure 4: Minivol sampler and PM filter assembly

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[12] A detailed description of variety of the monitoring equipment is presented in "Handbook of Particulate Pollution Source Apportionment Techniques." The World Bank, Washington DC, USA. Details @ www.urbanemissions.info/pmsa

A example of these samplers in use is *MiniVol Portable Air Samplers (Minivol)*[13] (see **Figure 4**), configured to collect $PM_{2.5}$, PM_{10}, or TSP samples. These samplers are designed to collect one size fraction at a time, as displayed in the figure. The MiniVol pump draws air at 5 liters/min through a particle size separator (impactor) and then through a 47mm Quartz and Teflon filters. The PM_{10} and $PM_{2.5}$ separation is achieved by impaction, or a TSP sample can be collected by removing the impactor(s). **Figure 4** presents an assembly of the sampler, which is being widely used for source apportionment studies around the world.

Main advantages of using MiniVol samplers are that they are relatively inexpensive at USD 5,000 per piece (compared to the samplers available in the market), flexible to use for PM_{10} and $PM_{2.5}$, portable, easy to operate and maintain and can be operated by battery (in lose of power supply)[14].

2. Source Profiling: For quantitative purposes, source profiles must contain chemical abundances for a range of components that can be identified appreciably between source and receptor, and that are reasonably constant among different emitters of the same type and operating conditions. Minor chemical components, constituting less than 1 percent of particle mass, are needed for quantitative apportionment as they are more likely to occur with patterns that allow differentiation among sources.

Table 2: Marker Elements Associated with Various Emission Sources

Emission Source	Marker Elements*
Soil	Al, Si, Sc, Ti, Fe, Sm, Ca
Road dust	Ca, Al, Sc, Si, Ti, Fe, Sm
Sea salt	Na, Cl, Na^+, Cl^-, Br, I, Mg, Mg^{2+}
Oil burning	V, Ni, Mn, Fe, Cr, As, S, SO_4^{2-}
Coal burning	Al, Sc, Se, Co, As, Ti, Th, S
Iron and steel industries	Mn, Cr, Fe, Zn, W, Rb
Non- Ferrous metal industries	Zn, Cu, As, Sb, Pb, Al
Glass industry	Sb, As, Pb
Cement industry	Ca
Refuse incineration	K, Zn, Pb, Sb
Biomass burning	K, C_{ele}, C_{org}, Br
Automobile gasoline	C_{ele}, Br, Ce, La, Pt, SO_4^{2-}, NO_3^-
Automobile diesel	C_{org}, C_{ele}, S, SO_4^{2-}, NO_3^-
Secondary aerosols	SO_4^{2-}, NO_3^-, NH_4^+

** Marker elements are arranged by priority order*

Examples of markers include an abundance of potassium (K) for biomass source, aluminum (Al) and silicon (Si) for fugitive dust source, sulfate ions (SO_4) for coal and diesel combustion, which can be further differentiated with other ion and metal fractions in the source profiles. **Table 2** presents an array of ions and metals that are abundant in various sources.

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[13] Minivol Sampler - http://airmetrics.com/products/minivol/index.html

[14] It is important to keep note that this is presented as an example and this example is in no manner an endorsement of the sampler nor the methodology

It is important that the source profiles are location specific because of local fuel characteristics and combustion technology[15]. However, because of lack of institutional and financial resources, not all studies include this step of developing local source profiles. In most cases, the source apportionment studies utilize source profiles developed under similar urban characteristics (hence the dotted line in **Figure 2**).

The dependency and accuracy of the results based on the borrowed source profiles is always questionable, but it is also important to note that by doing a first iteration, one can develop a baseline of results to compare, while the local source profiles are being developed and further the analytical results.

3. Chemical Analysis: The filters (Quartz and Teflon for analyzing a mix of pollutants) from ambient sampling are analyzed for mass, elements, ions, and carbon. Elements, ions ($SO_4^=$, NO_3^-, Cl, NH_4^+, Na, K), organic carbon (OC), and black carbon (BC) are sufficient to account for most of the particle mass, with reasonable assumptions about unmeasured oxides and hydrogen contents.

Table 3: Common analytical techniques for PM Samples

Measurement	*Suitable Analytical Technique*
Particle mass	Gravimetric analysis, β-gauge monitoring
Elements (Na, Mg, Al, Si, P, S, Cl, K, Ca, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Ga, As, Se, Br, Rb, Sr, Y, Zr, Mo, Pd, Ag, Cd, In, Sn, Sb, Ba, La, Au, Hg, Ti, Pb and U)	X-Ray Fluorescence, Proton Induced X-ray Emission, Instrumental Neutron Activated Analysis, Inductively Coupled Plasma Spectroscopy, Emission Spectroscopy, Atomic Absorption Spectrophotometry
Ions (F^-, Cl^-, NO_2^-, PO_4^{3-}, Br^-, SO_4^{2-}, NO_3^-, K^+, NH_4^+, and Na^+)	Ion Chromatography
Ions (Cl^-, NO_2^-, SO_4^{2-}, NO_3^- and NH_4^+)	Automated Colorimetric Analysis
Total Carbon	Thermal Combustion Method
Individual organic compounds	Solvent Extraction Method followed by Gas Chromatography - Mass Spectroscopy
Total Carbon, Elemental Carbon, Organic Carbon, Carbonate Carbon	Thermal Manganese Oxidation Method, Thermal Optical resistance or Thermal/Optical Transmission Method
Absorbance (light absorbing carbon)	Optical Absorption, Transmission Densitometry, Integrating Plate or Integrating Sphere Method

Source: Chow, et al., 1995

Additional properties such as molecular organic compounds, operationally defined carbon fractions, isotopic abundances, and single particle characteristics further distinguish source contributions from each other, even though they may not constitute large mass fractions. A

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[15] A library of source profiles for a variety of fuel characteristics and combustion technologies exist with groups such as Desert Research Institute, Reno, USA, which a pioneering institution on source apportionment studies.

more detailed description of chemical analysis methods is presented in *Chow et al., 1995*[16]. Common methods utilized with a brief description of common chemical analysis methods are presented in **Table 3**.

An example order of chemical analysis steps is as follows

- Teflon filters were analyzed for gravimetric mass and metals using XRF
- Quartz filters were analyzed for ions using ion chromatography and automated calorimetry
- Organic and elemental carbon using thermal/optical reflectance
- Soluble potassium using atomic absorption spectrometry.

Gravimetric analysis is used exclusively to obtain mass measurements of filters. The basic method of gravimetric analysis is straightforward - the net PM mass on a filter is determined by weighing the filter before and after sampling with a gravimetric balance in a temperature and relative humidity controlled environment, to remove liquid water while avoiding particle volatilization on the filters.

Ion Chromatography is for analyzing anions (fluoride, phosphate, chloride, nitrate, and sulfate) and cations (potassium, ammonium, and sodium). Ion analysis methods require a fraction of the filter to be extracted in deionized distilled water and then filtered to remove insoluble residues prior to analysis, to provide results for several ions with a single analysis. This methodology has low detection limits, most common method, and an important stage for sample analysis.

Atomic Absorption Spectrophotometry is useful for identifying limited elements. The analytical technique is of destructive type, where the samples have to be digested or extracted with acid solutions. Several simple ions, such as sodium, magnesium, potassium, and calcium, are best quantified by this method.

X-ray fluorescence analyzes the filter by irradiated with a beam of X-rays to determine the elements present. The principle behind this technique is that a portion of scattered X-rays gets absorbed by the elements contained in the sample. Because of their higher energy level, they will cause ejection of the inner-shell electrons and energy release. The energy given off is in the form of X-rays (hence X-ray fluorescence (XRF)). Many elements can be measured simultaneously with the quantity of each element determined from the intensity of the X-rays. This analytical technique is non-destructive, has a detection limit higher than other analytical techniques, requires minimal sample preparation and is relatively inexpensive.

Thermal-Optical methods are currently in use for the analysis of carbonaceous aerosols. Thermal-optical analyzers operate by liberating carbon compounds under different temperature and oxidation environments. A small portion is taken from a quartz filter and placed in the sample oven purged with inert gas such as helium. In general, thermal-optical methods classify carbon as ‘organic’ or ‘elemental.’ Organic carbon is non-light absorbing

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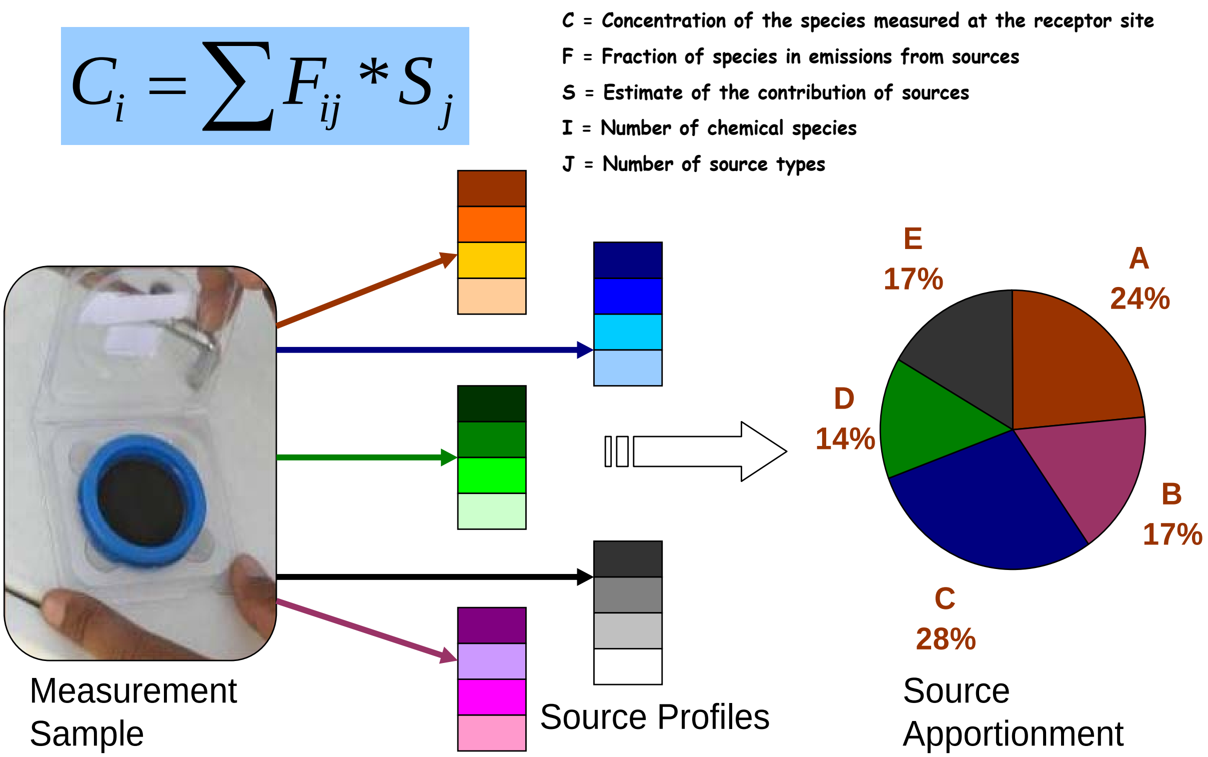
[16] Chow, et al.,1995. “Critical Review: Measurement Methods to Determine Compliance of Ambient Air Quality Standards for Suspended Particles.” J. Air and Waste Management Assoc., 45, 320-385.

carbon that is volatilized in helium as the temperature is stepped to a preset maximum (850°C). Elemental carbon is light-absorbing carbon and any non-light absorbing carbon evolved after pyrolysis. Depending on the sampling environment, carbonates are also analyzed in the sample.

Gas Chromatography-Mass Spectrometer is a complex system used for quantitative and qualitative analysis of organic compounds. This instrument separates chemical mixtures and identifies the components at a molecular level. The gas chromatography separates the mixture into individual substances when heated. The heated gases are carried through a column with an inert gas (such as helium). As the separated substances emerge from the column opening, they flow through the mass spectrometry to identify compounds by the mass of the analyze molecule.

4. Receptor Modeling: This step involves quantitative assessment of source contributions to the measured ambient samples based on the degree to which source profiles can be combined to reproduce ambient concentrations. The receptor model attributes primary particles to their source types and determines the chemical form of secondary aerosol when the appropriate chemical components have been measured.



$$C_i = \sum F_{ij} * S_j$$

C = Concentration of the species measured at the receptor site
F = Fraction of species in emissions from sources
S = Estimate of the contribution of sources
I = Number of chemical species
J = Number of source types

Figure 5: Depiction of receptor modeling

A variety of receptor models and methodologies are available with varying levels of benefits and limitations, e.g., chemical mass balance, enrichment factors, multiple linear regression, eigen vector analysis, time series, and positive matrix factorization. A simplified description of receptor modeling is depicted in **Figure 5**.

Figure 5, can be depicted as follows. When a sample filter is chemically analyzed, the results of fraction of chemical species are processed through a series of source profiles (developed for individual sources, identified by color and) and statistically analyzed using the biomarkers presented in **Table 2**, to estimate the possible contribution of these individual sources (the pie diagram on the right).

Mathematically, the process of receptor modeling can be explained as below. Based on the number of samples, analytical data collected on the samples, and the information on source profiles, a mass balance equation for receptor modeling from the m chemical species in the n samples originating from p independent sources can be described as $X_{ij} = \sum_{k=1}^{p} C_{ik} S_{kj}$ where: X_{ij} is the i^{th} elemental concentration measured in the j^{th} sample; C_{ik} is the gravimetric concentration of the i^{th} element in the material from the k^{th} source; and S_{kj} is the total airborne mass concentration of the material from the k^{th} source contributing to the j^{th} sample.

The most common methods utilized for receptor modeling are the Chemical Mass Balance (CMB) model, positive matrix factorization, principal component analysis, factor analysis, and constrained physical receptor model. **Table 4** summarizes model requirements, advantages, and limitations. The **CMB model**[17] is one of several receptor models that have been widely applied to source apportionment studies. Latest CMB is version 8.2, a Windows-based and includes menu-driven operation. Model requires speciated source profiles of potential contributing sources and the corresponding ambient data from analyzed samples collected at a single receptor site.

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[17] Watson, et al., 1997. "Chemical Mass Balance Receptor Model version 8: User's Manual." Prepared for USEPA, Research Triangle Park, NC, by DRI, USA. Latest version of the model is available @ http://www.epa.gov/scram001/receptor_cmb.htm

Table 4: Review of CMB 8.2 – requirements, strengths, and limitations

Model Requirements	Strengths	Limitations
~ Source and receptor measurements of stable aerosol properties that can distinguish source types. ~ Source profiles (mass abundances of physical and chemical properties) that represent emissions pertinent to the study location and time. ~ Uncertainties that reflect measurement error in ambient concentrations and profile variability in source emissions. ~ Sampling periods and locations that represent the effect (e.g., high PM, poor visibility) and different spatial scales (e.g., source dominated, local, regional).	~ Simple to use and windows based. ~ Quantifies major primary source contributions with element, ion, and carbon measurements. ~ Quantifies contributions from source sub-types with single particle and organic compound measurements. ~ Provides quantitative uncertainties on source contribution estimates based on input data uncertainties and colinearity of source profiles. ~ Can quantify secondary sulfate contributions from single sources with gas and particle profiles when profiles can be “aged” by chemical transformation models.	~ Completely compatible source and receptor measurements are not commonly available. ~ Assumes all observed mass is due to the sources selected in advance, which involves some subjectivity. ~ Does not directly identify the presence of new or unknown sources. ~ Typically does not apportion secondary particle constituents to sources. Must be combined with profile aging model to estimate secondary PM. ~ Much co-linearity among source contributions without more specific markers than elements, ions, and carbon.

Key Issues to Effective Source Apportionment Study

Besides the decision to conduct the source apportionment study, critical inputs needed are quality emission inventories and source profiles, as both play the role in the determination of the sources to analyze based on the emission strengths and to analyze the samples based on the profiles for their contribution to the ambient particulate pollution.

Table 5: Decisions for an Effective Source Apportionment Study

Steps	Description
Background	Specific information on trends in pollution, types of sources, potential hot spots, physical characteristics of the city, criteria pollutants of interest, and local capacity to conduct source apportionment.
Site Location	Numbers of sites and decisions on locations with good representativeness of city sources and pollutant mix.
Sampling Frequency	Frequency of sampling is partly determined by the study objectives. For example, continuous samplers used for compliance will be operating every day, while others may operate only on a seasonal basis. This decision also depends on the type of sampler available.
Samplers	Type of sampler and filter media is based on the availability of compatible chemical analysis techniques
Chemical Analysis	Availability of instruments and capacity to operate. Often the academic institutions in the region have the capacity to undertake such analytical tasks, but if not, this task can be outsourced.
Receptor Modeling	Selection of a receptor model. (This will also influence the type of chemical analysis required for data.)
Emission Inventory	While emission inventories are not directly utilized in a top-down analysis, they are useful in estimation of source strengths and identification of source profiles to help ensure efficient and effective receptor modeling. For example, having an emission inventory can assist in determining where to locate receptors including determining the location of possible hot spots.
Source Profiles	Locally specific source profiles are desired, but availability of profiles from representative regions may be acceptable.
Decision Making	Based on the apportionment results, review of possible technical, institutional, economic, and policy measures.

Unfortunately, these are lacking for many developing country cities. However, bottom-up and top-down analyses are not all or nothing activities[18].

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[18] See the SIM series working papers for notes and references on emissions inventory and modeling.

An effective AQMS can be viewed as a process of growth from relatively weak systems utilizing relatively primitive analytical techniques and data to highly effective systems utilizing sophisticated techniques. This is the case for three reasons.

Firstly, in the absence of a developed management system, useful information can be generated from first level, back-of-the-envelope, inexpensive analysis. With this type of analysis, development of emission inventories and source profiles can rely on information from regions with similar characteristics. That is, an area can begin their AQMS with off-the-shelf inputs and local ambient measurements. From this base, an iterative process of repeated model improvement can be utilized to develop more sophisticated emission inventories and source profiles which include region-specific information. The iterative process of improving the models is based on analyzing the inconsistencies that result from each round of bottom-up and top-down analyses. This eventually leads to a high quality evaluation system where the top-down and bottom-up analyses approach convergence. However, the process cannot stop here. Measurements should continue and models need to change as the pollution characteristics of the region being managed changes. That is, the management system needs to reflect the changing economic activity of the urban area being managed. Finally, as improved evaluation technology and analytical techniques become available the system needs to be updated to reflect the improvements.

Secondly, the technical capacity to conduct both top-down and bottom-up studies in developing countries is still an issue. For the majority of the top-down analyses, the analysis was conducted outside of the region. For example, the Desert Research Institute's (Reno, Nevada USA) Environmental Analysis Facility, a pioneering institute in source apportionment. On one hand, collaborations like these help develop local capacity, since a local institution is always involved in the process of sample collection, filter management, and final estimation of sources. On the other hand, the capability to conduct a full scale study in the receptor region is desirable. One of the main barriers is the chemical analysis stage, where access to and operational training on equipment such as XRF, IC, etc., are often times lacking. Fortunately, the tools and techniques needed to conduct these studies are becoming more widely available, which facilitates developing countries acquiring the technical capacity to conduct all aspects of source apportionment studies.

Thirdly, there is an acute need for source apportionment analysis in developing countries, and with proper training and capacity development (both technical and financial) source apportionment can make a valuable contribution in attempts to reduce air pollution. Utilization of source apportionment techniques is expanding, especially in Africa and Asia, and these techniques are increasingly aiding environmental compliance and answering policy-relevant questions like what sources to target for pollution abatement efforts, where to target (e.g., suspected hot spots), and how to target.