Article

Total atmospheric deposit source apportionment: A review

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Abstract

Atmospheric deposition as it is known is the transfer of pollutants to living and non-living things around the world. In most areas, there have been health implications. Part of the methods to measure air quality is source apportionment. This determines the types of pollutant sources and their contributions in the environment. The present paper reviews methods used by various researchers in sampling, analyses, source apportionment and results obtained.

Keywords anthropogenic and non-anthropogenic activities; stainless steel bucket; XRF; PMF; emissions inventory.

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1 Introduction

Air pollution has been a major concern in developed and developing nations due to the health effects on properties, animals, and human life (Tuankrua et al., 2014; Zhang et al., 2011; Zhao and Hasan, 2013). The air we breathe is a mixture of gases, solid and liquid substances, pollution now occurs when the air contains a high proportion of substances that could harm living and non-living things. According to Ahmadlsiyaka et al. (2014), clean air constitutes the fundamental requirement for human health and well-being.

The quality of the atmosphere has deteriorated in the time past in different countries due to urbanization and industrialization (Latif et al., 2011). Anthropogenic and non-anthropogenic activities are the sources of air pollution. Most cities in these countries face severe air pollution. An estimated about 2.4 million people die each year from courses directly attributed to air pollution (WHO, 2002). According to Llayas et al. (2010), air pollutions have the ability to penetrate the gas exchange region of the human lung when inhaled, causing cancer, asthma, cardiovascular and respiratory diseases. Also, it limits the amount of oxygen fed to the foetus through the mother thereby retarding its anthropometric development by reducing its head circumference (Ballester et al., 2010).

Several studies have reported correlations between air pollution and certain diseases which include shortness of breath, sore throat, chest pain, nausea, asthma, bronchitis lung cancer, acidosis, respiratory tuberculosis, etc. All these are associated with total atmospheric depositions, especially Particulate Matter (PM) inhalation (Azimi et al., 2003; Wang et al., 2012; Aleksandropoulou and Lazaridis, 2013; Moses and Orok, 2015; Kchih et al., 2015; American Chemical Society, 2008).

Table 1 Previous studies on atmospheric deposition.

REF	COUNTRY	SAMPLES	MEASUREMENT	INSTRUMENTATION
Abu-Allaban, Abu-Quadais, 2011	Jordan	Dust, Gases	TSP, NO_2, CO, SO_2, PM_{10}	Prediction of impacts by model
Ny and Lee, 2011	Korea	Airborne Particulate Matter samples (PM)	13 metals	ICP-AES
Tsai et al., 2011	Taiwan	$PM_{2.5,}$ $PM_{2.5-10}$	15 metals	ICP-AES
Sun et al., 2011	USA	$PM_{2.5}$	Ionic species TOC, Organic OC, OM	Ion-chromatograph, TOC analyzer, High resolution Aerosol Mass Spect& GC-MS
Manousakas et al., 2013	Greece	PM10	10 elements	ED-XRF
Ahmadlsiyaka et al., 2014	Malaysia	Data on air pollution (2007-2011)	Data	Models
Farao et al., 2014	Italy	PM_{10}, $PM_{2.5}$	Metals Ionic species	EPD-XRF ICP-OES ICP-MS
Xiao et al., 2013	China	PM_{10}, $PM_{2.5}$ (Roadside Rural &Urbans)	Heavy metals	ICP-MS
Kulshrestha et al., 2014	India	$PM_{2.5}$, $PM_{10.5}$	Heavy metals	AAS
Co et al., 2014	Vietnam	Ambient PM $PM_{2.5}$, $PM_{10.5}$	13 element ions	XRF Ion Chromatography
Crilley et al., 2014	Australia	PM_1 particles	21 Elements sodium	PIXE PIGE
Kchih et al., 2015	Tunisia	PM_{10}, $PM_{2.5}$	18 Elements anions	ED – XRF IC
Oluyemi, Asubiojo, 2001	Nigeria	Ambient air PM	17 elements	XRF
James, Ndiokwere, 2006	Nigeria	Total Suspended Particulate Matter	14 elements	AAS
Moses, Orok ,2015	Nigeria	Suspended Particulate Matter	Anions Trace metals	Spectrophotometer AAS

Amodio et al. (2014) reviewed that the atmosphere is the carrier of some natural and anthropogenic organic and inorganic chemicals deposition events, process and remove these chemicals thereby depositing them on the soil and water. The removal mechanisms for metals suspended in air include gravitational dry and wet depositions (Lin et al., 2013). Dry deposition occurs as turbulent diffusion, sedimentation, Brownian diffusion, interception, thermophoresis, and diffusionphoresis. According to Amodio et al. (2014), deposition rates are governed by meteorological factors (wind velocity, relative humidity), particle characteristic (size and shape), and surface characteristics (friction velocity), microscale roughness and temperature.

PM, total phosphorus, Ca^{2+}, Mg^{2+} and K^{+} are much more present in dry deposition whereas Na^{+}, total nitrogen, NO_3^{2-} and SO_4^{2-} are present in wet deposition. In higher precipitation regime areas, wet deposition is linked to local pollution levels (Balestrini et al., 2000) and dominates deposition processes of micropollutants in the highly industrialized areas (Gambaro et al., 2009). Aerosol like organic micropollutants (Polycyclic aromatic hydrocarbons (PAHS), Polychlorobiphenyls (PCBs), Polybromodiphenyl ethers (PBDEs), and dibenzofurans are also present in the atmosphere. These aerosols remain in the atmosphere until removed by either wet or dry depositions. In Schlesinger (1997), the prominent source of aerosols in the atmosphere at a global scale is dust and others are soil and marine erosion and the anthropogenic sources.

Due to the importance of air pollution, this had led many types of research to be delved upon. The list in Table 1 is an example of contributions to environmental pollution.

In other to control or combat air pollution, use of source apportionment is on the increase (Yu et al., 2013; Roy and Sigh, 2014; Feng et al., 2015) in this regard, identification and apportionment of source by means of multivariate technique has gained wide acceptance (Oluyemi and Asubiojo, 2001). It is used to identify and quantify the contribution of different sources to the atmospheric pollutants. The technique requires different levels of knowledge about the sources acting on a specific site and their emission profiles (Kchih et al., 2015). Without the adequate knowledge of sources of pollution, policy makers would have the difficulty in making necessary policies and decisions to tackle the pollution problems.

This paper tends to contribute to knowledge on air quality management (Fig. 1) to achieve this, the write-up reviews methods used in sampling, analyses and source apportionment.

2 Experiments

2.1 Sampling methods

Total Atmospheric Deposits (TAD) consists of organic and inorganic pollutants, for this reason, the sampling methods and areas of sampling differ. The atmospheric organic pollutants are PAHs, PCBs, PBDEs and PCDDs/Fs all these need different and specialized collection. The list of collectors of these organic pollutants is shown in Table 2.

The inorganic pollutants – ions, metals also are collected using suitable collectors (Table 3). These collectors are suitable for wet and dry particles. The collectors are mainly bottles/plastics and funnels of suitable diameters.

2.2 Size of the collector

Most researches were conducted on high buildings, but areas where there is non-availability of this building, ground surfaces can be used. The most important fact is that the height must be sufficient enough to avoid sampling losses resulting from splashing. The diameter of the opening area and the volume of the collector should be adequate enough to collect all the precipitation until the sampling is terminated. The recommended height is between 1.5m – 2.5m and the diameter 100-250cm (funnel). The inner part of the collectors is made of inert materials to avoid metal contaminations due to ground. Deionized water or acid (1%) can be used to rinse the containers during and after collections.

Table 2 List of different organic samples collectors.

S/N	Collections	PAHs	PCBs	PCDDs/Fs
1.	Glass funnel-bottle bulk collector	X		X
2.	Stainless steel bucket	X	X	X
3.	Stainless steel platter	X		
4.	Stainless steel funnel attached to a glass filter setup	X		
5.	Funnel connected to absorber Cartridge (Amberlites /PA-743)	X	X	X
6.	Automatic wet-only collectors	X		
7.	Funnel connected to absorber cartridge (XAD-2) Two vessels equipped with rain sensor		X	X
8.		X		

Source: Amodio et al. (2014).

Table 3 Metals and ions pollutant collectors.

	Collectors	Metals	Ions
1.	HDPE Funnel –bottle collector	X	X
2.	HDPE bucket collector	X	X
3.	HDPE automatic wet-only collector	X	
4.	HDPE automatic wet-dry collectors		X
5.	PVC dry deposition plate	X	X
6.	Water surface sampler (WSS)	X	X
7.	PE sheets and boxes	X	

Source: Amodio et al. (2014).

2.3 Sampling periods

The periods vary from a week to a month (Jareb et al., 2009; Alahmn et al., 2012; Kumar et al., 2014). After collections, samples can be stored in desiccators or refrigerators prior to analyses.

2.4 Sampling

2.4.1 Number of stations

According to Roy and Singh (2014), the number of sampling stations depends on:

* Objectives of the monitoring
* Total area to be covered
* Variability of Pollutant concentrations over the study area
* Population density per unit area and health status.
* In highly industrial zone the number of status for PM must be increased.
* In regions with the irregular terrain, there should be more number of stations.

2.4.2 Selection of monitoring stations

* Security, physical access and availability of electricity
* Area of population exposure
* Existing meteorological parameters
* Particular method and instrument used for sampling

All these guidelines can be ignored due to field condition.

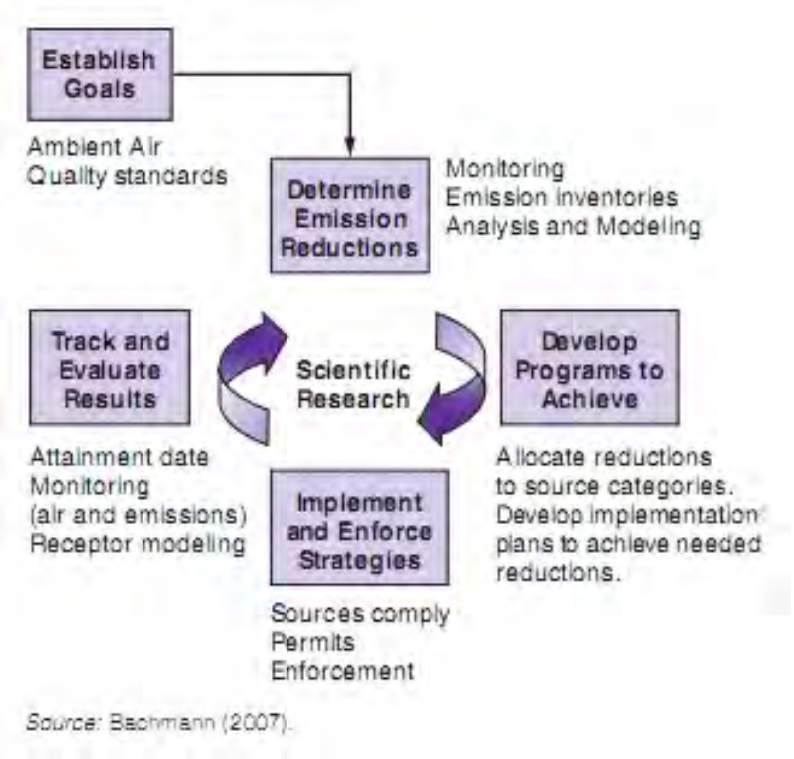

Fig. 1 Air quality management theory.

2.4.3 Sampling

Before measurement can be taken, data would be obtained this would be used to mitigate the PM or TAD pollution. Various samples and equipment have been used for different purposes. A mini vol portable air sampler is an example of one of sampler used for collection of samples. It is configured to collect $PM_{2.5}$, PM_{10} or TSP Samples. For TAD the single sampler would consist of a funnel, glass or plastic container enclosed in an enclosure. The physical and chemical characteristics are different. In developing countries, it may not be possible to make these samples available because of the cost, in this case, an alternative would be ideal for the sampling.

2.4.5 Source profiling

This must contain chemical abundances over a range of components that can be identified in between the source and receptor that is constant among different emitters of the same type and operation conditions (Guttikunda, 2009)

2.4.6 Source markers

Particulate deposition pollution differs widely in composition, sources and spatial distribution in different cities across different countries (developed and developing). Source makers have been studied widely. Major sources of air pollution are depicted in Table 4.

2.5 Chemical analytical methods

PM samples are analyzed for elements carbon, irons, and mass examples are SO_4^{2-}, Cl^-, NH_4^+, Na, K, NO_3^-, organic carbon (OC) etc. Additional properties can be considered.

Table 5 shows the methods used in the measurement of the pollutants.

Table 4 Source makers associated with emission sources.

Chemical Species	Markers
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+} V, Ni, Mn, Fe, Cr, As, S, SO_4^{2-}
Oil burning	Al, Sc, Se, Co, As, Ti, Th, S Mn, Cr, Fe, Zn, W, Rb
Coal burning	Zn, Cu, As, Sb, Pb, Al Sb, As, Pb
Iron & Steel industries	Ca K, Zn, Pb, Sb
Non-ferrous metal industries (smelters)	K, C_{ele}, C_{org}, Br, Zn,
Glass industry	Guaicols&Syringols
Cement industry	
Refuse incineration	
Biomass burning	
Automobile gasoline (exhaust)	C_{ele}, Br, Ce, La, Pt, SO_4^{2-}, NO_3^-, PAHs
Automobile diesel (exhaust)	C_{org}, C_{ele}, S, SO_4^{2-}, NO_3^-
Secondary aerosols	SO_4^{2-}, NO_3^-,NH_4^+

Source: Chowdhury et al. (2009), and Guttikunda (2009).
Marker elements are arranged by priority order.

3 Source Apportionment

This is a technique developed to determine where the pollution is coming from and how much each of the sources is contributing to the ambient air quality.

The application of source apportionment (Table 6) is a tool used by policymakers for identifying and qualifying the different sources of air pollution which increase the ability to put in place effective policy measures to reduce air pollution to minimum limits. Also, source apportionment tells us what sources of pollution are and how much each source contributes to total pollution. A study will determine these contributions, thus eliminating the tendering to overemphasize certain sources or underemphasize

3.1 Dispersion model

In this model, a pollutant emission rate and meteorological information are inputted to a mathematical model that disperses the emitted pollutant concentration at a point in space and time (Chowdhury et al., 2009).

There are two ways to conduct source apportionment. One is a top-down approach, which involves collecting samples and analyzing them in a laboratory and other is a bottom-up approach, which uses existing data and survey method.

In a top-down approach, accurate results for specific locations (where samples are collected) are obtained. These are then averaged to get a city-level profile. In the bottom-up approach depending on the existing data, pollution values for any part of the city are obtained (Guttikunda, 2011).

Source apportionment is a big area of concern in the field of atmospheric deposition in recent times. Fig. 2 depicts the diagram showing the various methods for source apportionment.

Table 5 Chemical analytical methods for samples.

Measurement	Analytical methods
Total Carbon	Thermal Combustion Method
Ions (F-,Cl-,NO_2^-, PO_4^{3-}, Br^-, SO_4^{2-} NO_3^-, K^+, NH_4^+, Na^+	IC & AC
Particle mass	Gravimetric analysis, β-gauge monitoring
Absorbance (light absorbing carbon)	Optical absorption, Transmission Densitometry, Integrated Plate or Integrated Sphere Method
Total Carbon, elemental carbon, organic Carbon, carbonate carbon, thermal carbon Fractions	Thermal manganese, Oxidation method, TOR, TOT method
Elements-Na, Mg, Al, Si, P, S, Cl, K, Ca Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Ga, As Sc, Br, Rb, Sr, Li, Zr, Mo Pd, Ag, Cd In, Sn, Sb, Ba, La, An, Ti, Pb and U.	XRF, PIXE, INAA, ICP Emission spectroscopy AAS, IC
Light element (B, F^-, Na, Mg, Al	PIGE
Organic compounds PAHs	GC-MS Gas Chromatography- Mass Spectrometer High Performance Liquid Chromatography

IC-Ion Chromatography, CA - Colorimetric Analysis, TOT - Thermal Optical Transmission, TOR – Thermal Optical Resistance, XRF- x-ray Fluorescence, PIXE-Proton Induced X-ray Emission, INAA - Instrumental Neutron Activated Analysis, ICP – Inductively Coupled Plasma, AAS - Atomic Absorption Spectrophotometer, AC- Automated Colorimetric Analysis, PIGE- Particle Induced γ-ray Emission).

3.2 Receptor model

This is a mathematical procedure for identifying and qualifying sources of ambient air contaminants reception, primarily on the basis of concentration measurement at the receptor (ambient samples). This model describes the past and measurements are required before results are obtained. Some of the models already used for to apportion of air pollution have been documented in over two hundred atmospheric reports. Selected examples are the chemical mass balance, aerosol equilibrium, eigenvector, edge detection, enrichment factor, multiple linear regression, neural network and aerosol evolution.

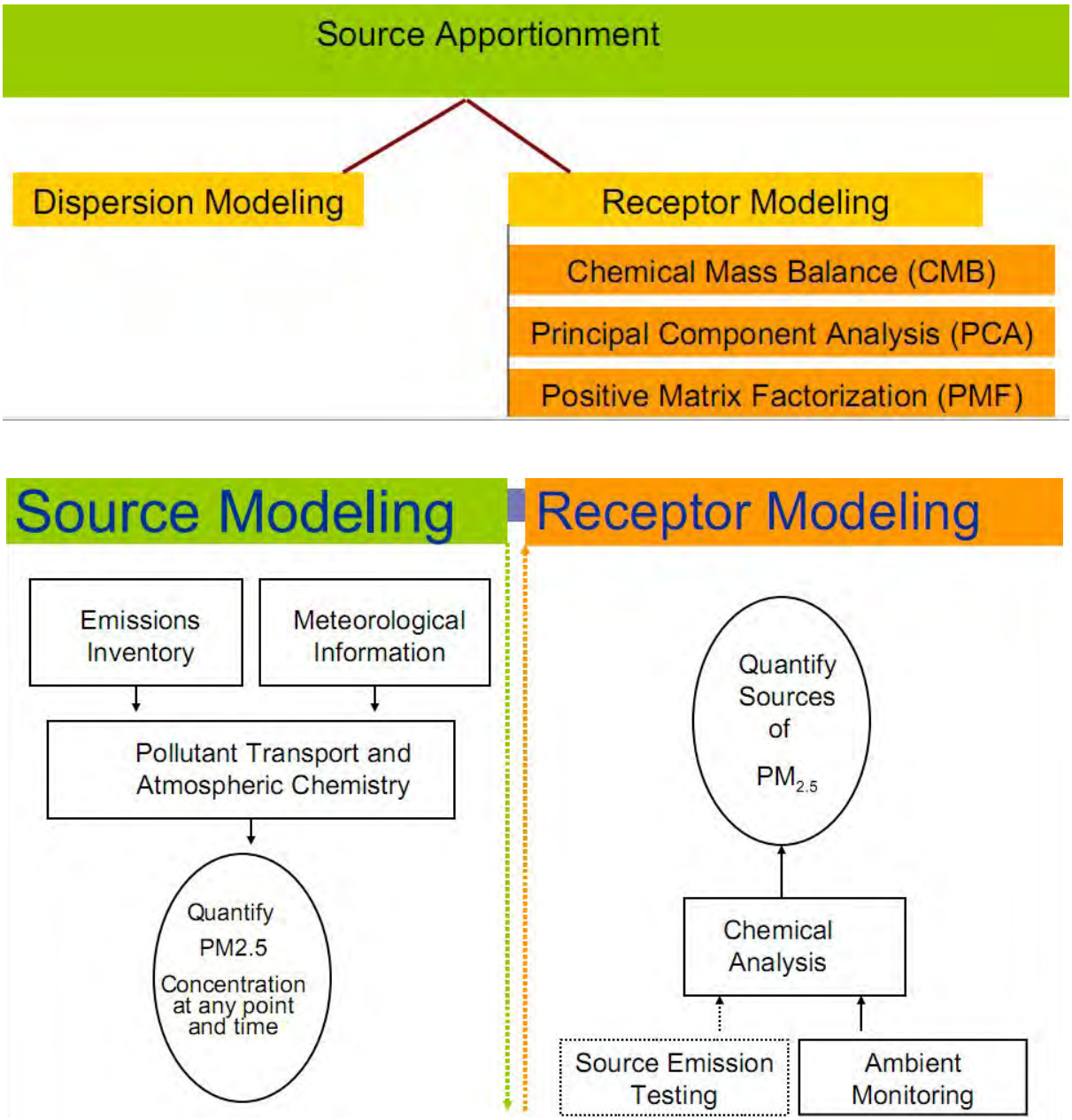

Fig. 2 Source appointment.

4 Approaches of Source Apportionment

In this paper, some of the approaches would be discussed. Fig. 3 shows the approaches employed to estimate pollution sources.

4.1 The Chemical Mass Balance (CMB)

CMB model is a solution to linear equations that expresses each receptor chemical concentration as a linear sum of products of source profile abundances and source contributions (Hidy and Venkataraman 1996; Roy and Singh, 2014). According to Chowdhury et al. (2009), the ambient concentration of each tracer compound is reconstructed from the best fit linear combination of source emission profiles. With CMB sources contributions are estimated.

CMB model (Version 8.2) is a receptor model that has been widely applied to source apportionment. The basic idea behind this model is that composition patterns of emission from various classes of sources are different for one to identify their contributions by measuring concentrations of different species in samples obtained at a receptor site, hence requiring precise information regarding the chemical composition for each source category in a city or region. The output from this includes the fraction contribution from each source and associated uncertainties. In most studies, factor analysis (FA) and CMB were used as a complementary model, FA is used for source identification while CMB is then used for source apportionment (Oluyemi and Asubiojo, 2001).

4.2 Constrained Physical Receptor Model (COPREM)

This was developed by Wahlin (2003). It is a hybrid physical receptor model, it is also a combination of CMB and multivariate models. This model (COPREM) is based on CMB model, which needs the composition profile sources in advance, but incorporates the ability of multivariate mathematics to fit the chemical species in the source profiles (Johnson et al., 2011).

4.3 Positive Matrix Factorization (PMF)

According to Johnson et al. (2011), Paatero and Tapper developed PMF method which uses the uncertainty of measured data to provide an optional weighing across the sources. The PMF is a statistical tool to determine a mix of PM sources impacting a receptor location. Analysis of correlation between measured concentrations of element assuming that correlated elements are from the same source. When PMF is applied, it requires that error estimates for data chosen judiciously so that the estimates reflect the quality and reality of each of the data points. The advantages and constraints are

1. It has the strength to handle missing and below detection limit data. This is done by the adjustment of the corresponding error estimates.
2. It provides source factors
3. This model does not determine the number of contributing source types
4. When the source factors are demonstrated to be similar to measured source profiles, PMF solutions are plausible.
5. Constraints on the results such as non-negativity of the factors are integrated into the computational process.

Yu et al. (2013) in their study determined the source profiles and source contributions to PM2.5based on their knowledge of the variation of the elemental concentrations, their periodicity, correlation with other elements and meteorological parameters.

4.4 The Principal Component Analysis (PCA)

Assumptions are used when using this model. The most common one is the number of factors to be used. These factors are not always physically realistic, as negative values may appear among factor loading and factor scores.

Results in PCA do not represent a minimum variance solution, reason being that the method is based on incorrect weighting by assuming unrealistic standard deviations for the variables in the data matrix.

Finally, this model is not capable of handling missing and below – detection limits. Sometimes obtained in some analyses were carried out in developing countries.

PCA allows better interpretation and assessment of the inter-relations of the set of data under study (Vieira, 2012; Wahid et al., 2013; Zhang, 2011).

4.5 Enrichment Factors (EF)

This factor is a model used in the study determination of inorganic and organic component measurements of some species.

It is limited to semi-quantitative measurements. It is more useful for source or process identification studies than qualification studies.

The model is inexpensive, simple because no software is needed. It shows or points out the presence or absence of emitters and finally provides evidence of secondary PM formation and changes in source profiles between source and receptor.

4.6 The UNMIX modeling

This model was developed by Henry (2000). It uses a multivariate method. UNMIX has a relation to PCA. It always takes a geometric approach that exploits the covariance of the ambient data. A two-element scatter plots of the ambient data explains this model. For instance, a straight line and high correlation for two elements (e.g., Co versus Pb) can indicate a single source for both species (water), while the slope of the line gives information on the composition of the water source. In the same data set, Zn may not plot on a straight line against Pb, indicating other sources of Zn in addition to water. The points defining this edge represent ambient samples collected on days when the only significant source is Pb. Same as PCA, UNMIX may produce some negative results which are meaningless (Johnson et al., 2011).

4.7 Multi Linear Regression (MLR) model

It is useful for hundred (100) or more samples with a marker species measurement at a receptor. There is a minimal co-variation among marker species due to common dispersion and transport.

MLR operates without source profiles. The abundance of marker species in a source is determined by the inverse of the regression coefficient. It apportions secondary PM to primary emitters when primary markers are independent variables and secondary component is dependent.

MLR requires a large number of measurements, limited to sources or source areas with markers and marker species must be from only the sources or sources types examined.

4.8 Aerosol Equilibrium (AE)

This model is useful in total (gas plus particle) SO_4^{2-}, NO_3^-, NH_4^+ and other alkaline or acidic species over periods with low temperature and relative humidity variability. AE estimates partitioning between gas and particle phases for NH_3, HNO_3, and NH_4NO_3 and also allows for the evaluation of effects of precursor gas reduction on ammonium nitrate levels.

Sensitivity to aerosol is not quantified. There is no availability for short duration samples. Model is highly sensitive to temperature and relative humidity.

4.9 Time Series (TS)

It means a sequential measurement of one or more chemical markers. It is used for one hundred (100) or thousand (1000s) of individual measurements. Spikes related to nearby source contributions are shown. Association with highly variable wind directions is possible. TS depends on sample duration, shows diurnal, day-to-day, seasonal, and inter-annual changes in the presence of a source.

However, it does not quantify source contributions, requires continuous monitors and the filter methods are impractical (Watson 2002).

4.10 Aerosol Evolution (AEV)

The model is used for estimation of emission locations and rates, meteorological transportation times and directions and also in meteorological conditions (e.g. wet, dry) along a transport pathway. AEV can be used parametrically to generate several profiles for typical transport/meteorological situations that can be used in a CMB. The limitations are:

1. High data intensive and input measurement measurements are often unavailable.
2. Derivations of relative, rather than absolute, concentrations
3. Level or complexity may not adequately represent profile transformations.

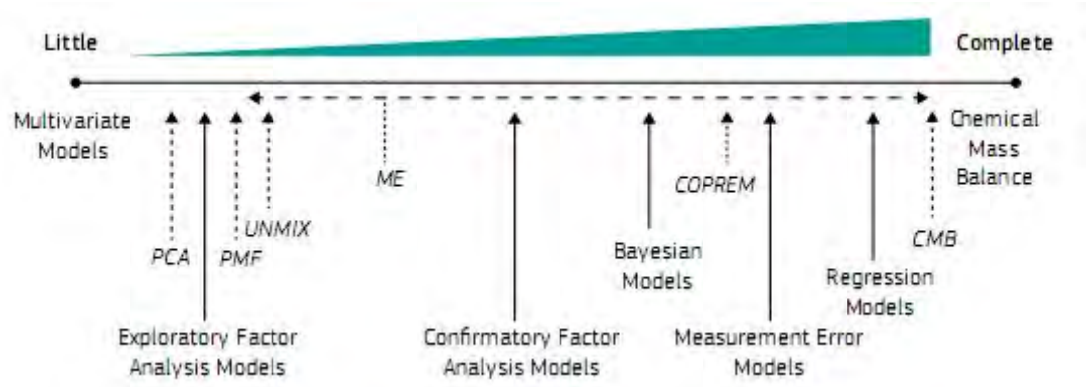

Fig. 3 Models used in the estimation of pollution sources (Source: Viana et al., 2008).

5 Choices of Source Apportionment Methods

Johnson et al. (2011) suggested that before a source apportionment is selected, apportionment techniques should be fully developed, and made technically available in the public domain and preparation toward regulatory application. It is highly essential to know how much time, a number of people and money is needed to commence and maintain an assessment of sources contributions. Consideration should be given to a collection of PM when designing a reception-based study. If factor analysis is to be used, at least 50 samples are needed for each size fraction.

In the case of CMB, the number of samples is not as important. In most studies CMB is the most common receptor model used for a number of source apportionment studies.

Here the current published studies are reviewed (Table 6). It focuses on the detail, site characterization, equipment, analysis, receptor model applied and experiment time frame. The choices made on the analysis techniques and methodologies; sampling period and data accuracy should be considered when interpreting the data.

In this paper, thirteen current studies are presented. The studies depicted different tools and methods used in the source apportionment. It is important that when conducting a study or studies a good understanding of the goals of the analysis, methods advantage and limitations should be ensured.

The chemical techniques used in all cases (AAS, XFF, EDXRF PIGE, PIXE, IC, ICP- AES, GC – MS, HR – AMS, GFAAS) are expensive and non-available. Developing countries need to partner with developed world for the easy accessibility to these techniques. The availability of this equipment would be a valuable resource for the top-down and bottom-up studies.

The most receptor models used in the case studies are PMF, PCA, and EF. The use of more models in source apportionment can improve the characterization of samples rather than the use of one.

Apart from source apportionment study, quality emission inventories and source profiles (Fig. 4) are important in the determination of the sources of analysis based one mission strengths and to analyze the samples based on the profiles for their contribution to the ambient particulate pollution (Guttikunda, 2009).

Table 7 depicts the key factors for effective source apportionment study.

Table 6 Studies reviewed.

S/N	Receptor Model	Locations	Analysis	Duration Ref.	Equipment Use	References
1.	PMF	Belgrade	Elements	June 2002 – Dec 2006	AAS, FAAS GFAAS	Tasic et al., 2009
2.	PCA,EF	Ulsan City, Korea	PM_{10} 13 metals	April 2008 - Jan 2009	ICP-AES	Ny and Lee, 2011
3.	PMF	Urban Sites, USA	$PM_{2.5}$, Aerosol Lonic species C TOC	2004-2005	HR-AMS IC	Sun et al., 2011
4.	PCA-MLR PSCF	Ordos City, China	PM_{10}, $PM_{2.5}$ Elements	Sept 2005	ICP-AES	Wang et al., 2012
5.	PCA	Central, Taiwan	TSP, metallic elements Hg	24h	ICP-AES AAS	Huang et al., 2012
6.	EF CPF	Megalopolis , Greece	PM_{10}, Elements	April 2009 – March 2010	EDFXRF	Manousakas et al., 2013
7.	PCA	Brisbare, Australia	PM_1, Elements	Oct 2010 - Aug 2012	PIGE PIXE	Crilley et al., 2014
8.	PMF	Ferrara, Haly	PM_{10}, $PM_{2.5}$ Elements ancons, cations	Jan – Feb, 2011, June 2011, Jan-Feb 2012 May-June, 2012	ICP-OES, ICP-MS EPO-XRF IC	Farav et al., 2014
9.	PCA,DA FA,HAC A ANN, MLR	Kuala Terengganu, Malaysia	Air quality Co, 0_3, PM_{10} SO_2, NO_2 Temp, Wind Speed	2007- 2011	Data treatment	Ahmadlsiyalca et al., 2014
10.	CF, EF	Uyo, Nigeria	Dust particle elements ions	November - March 2014	AAS Spectrophotom eter	Moses and Orok, 2015
11.	CMB, PMF PCA	Spain	Emission profiles compositions Elements.			Pandolfi et al., 2008
12.	Igeo, EF CF, PCA	Tema and Accra, Ghana	Dusts Heavy metals	October 2008 - March 2009	EDXRF	Atiemo et al., 2011
13.	Igoe, EF CF	Ketu-South, Ghana	Soil Samples Heavy metals	March 2011	XRF	Addo et al., 2012

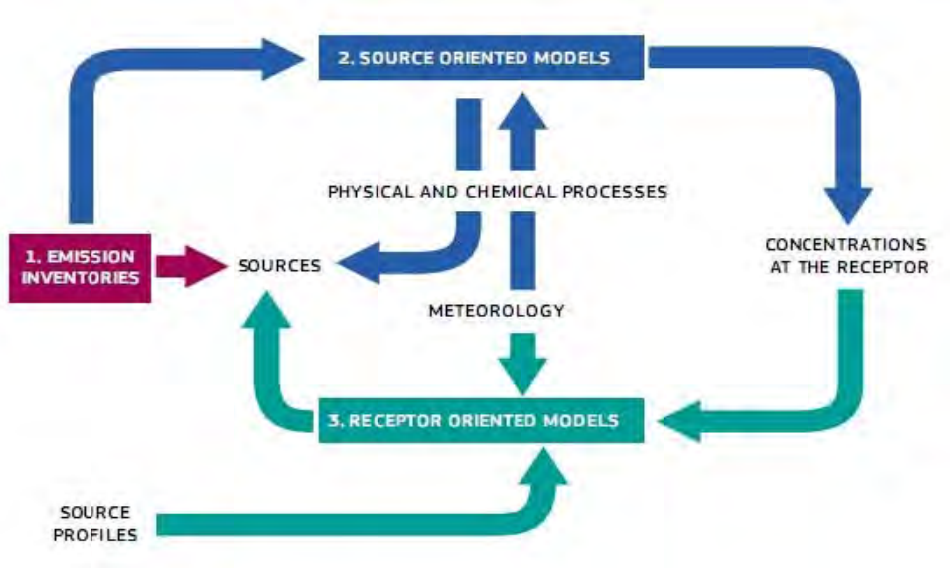

Fig. 4 Various methods for source apportionment (Source: Belis et al., 2014).

Table 7 Key factors for effective source apportionment study.

Steps	Explanations
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 the type of sampler available.
Samplers	Type of sampler and filter media is based on the availability of compactible 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 and 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 location receptors including determining the location of possible hot spots.
Source Profile	Locally specific 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.

Source: Guttikunda (2009).

The time frame for the case studies ranged between 24h and 3 years. A long time frame will always take care of every season. It is important to conduct sampling every season because pollution and meteorological conditions vary between seasons and this affect the ambient pollution. A multi-season study provides accurate results on average. It is a good method if samplings are carried out simultaneously in all locations. This will make a comparison of pollution and sources between locations possible.

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