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Particulate Matter: An Approach To Air Pollution

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ABSTRACT
Particulate matter (PM) is one of the problems faced in environmental science. It has health effects on man and animals in both developed and developing countries. Research and efforts have been on it several years back. Policy statements and efforts have been published. This review paper is an added information on air pollution. In it, efforts were made in discussing these: classification, effects, methodology, case studies and source apportionment. It is hoped that this paper would contribute to existing knowledge on PM.

Keywords: PM, pollution, environment, industrialization, health effects, standards.

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1. Introduction

Air pollution has been of major concern throughout the world due to the health effects on human, animal and materials. This issue is receiving much attention, due to the fact that both in developed and developing countries there has been an increase in urbanization due to higher activities in transportation and industrialization (Abiye *et al.*, 2013). The growing concerns about the health implications of air, water, and soil pollution to ecosystem have led to the establishment of agencies which are saddled with the responsibility of combating the adverse effects (Ezeh *et al.*, 2014). Examples of these organization, agencies and departments are World Health Organisation (WHO), United State Environmental Protection Agency (USEPA), United Nations (UN), and Central Pollution Control Board (CPCB) from India. The local, national and international agencies are working and concentrating on pollutions in the environment and publishing and issuing documents to improve the air quality. (Department of Environmental, Food and Rural Affairs (2015).
The aim of this paper was to give a proper insight on particulate matter. To do this, the following objectives were considered, classification, effects, methodology, case studies and source apportionment.

Atmospheric Deposition

According to Amodio *et al*. (2014), atmospheric deposition has been defined as the transfer of pollutants to terrestrial and aquatic ecosystems. They further classified the deposition as dust, particulate matter (PM) containing heavy metals, polycyclic aromatic hydrocarbons, dioxin, furans, sulphates, nitrates. Table 1 depicts the mechanisms of pollution depositions. In this table, it is noted that deposition occurs in three ways: wet, dry and bulk (total).

Table 1: Mechanisms of deposition

Deposition		
Wet deposition	Rain Washout (Collection only during rain)	Within a cloud
Dry deposition	No Precipitation	Below a cloud
Bulk deposition	Wet and dry deposition Collected together	

Source: Amodio *et al*., 2014

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In this review paper, an effort would be geared towards, one of the atmospheric pollutants PM. The cause, health implication, sampling procedures, analytical methods and sources of emission would be highlighted.

PARTICULATE MATTER

Classification of PM

1. Total suspended Particulates (TSP, with aerodynamic diameter < 30 microns (µm)
2. PM_{10} (with an aerodynamic diameter of less than 10µm (coarse)
3. PM 2.5 (with an aerodynamic diameter of less than 2.5µm (fire)
4. Ultrafine PM is that diameter of less than 0.1microns (Fig 1).

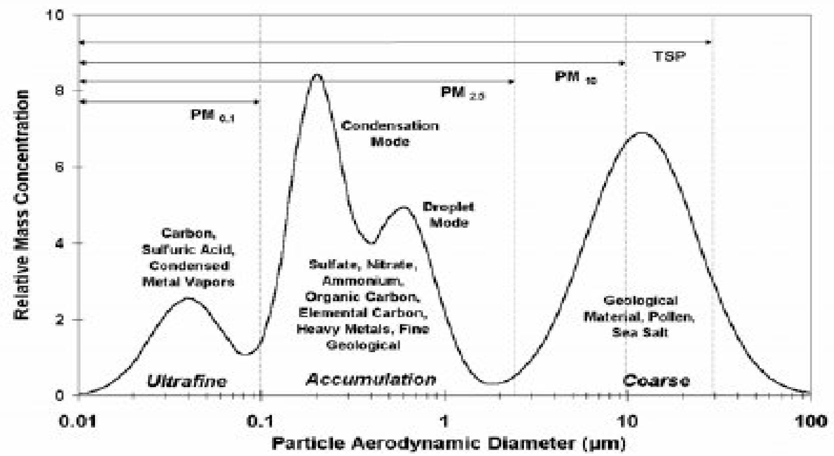

Fig 1: Particle Size Distribution. Source: Johnson *et al.* (2011)

Furthermore, PM can be classified as primary particles which are emitted into the atmosphere through industrial activities, road traffic, road dust, sea spray, and windblown soil, they also contain carbon and an organic compound, metals and metal oxides and ions. Secondary particles are formed through chemical transformation of gaseous. Examples: SO_2 – Sulphates, NO_x – Nitrates, NH_3 – Ammonium ions, VOC's – Secondary Organic Aerosol (Johnson *et al*., 2011).

PM is known to be the major contributor to the adverse health effects of the air pollution. Several studies have been carried out on this subject matter. Alahmr *et al.* (2012) studied air pollution as a dust falls around semi-urban areas in Malaysia, Ikamaise *et al.* (2013) worked on total suspended particulate matter in Calabar air basin. In the case of Change *et al.* (2013), they worked on $PM_{2.5}$ in Guangzhou, Co *et al.* (2014) had their study on ambient particulate matter of a mountainous site, Moses and Orok (2015) studied suspended particulate matter in Uyo, Nigeria, while Ezeh *et al.* (2012) concluded their study on PM_{10} and $PM_{2.5}$ samples obtained in Ikoyi, Lagos, Nigeria. In all these case studies, it was confirmed that the emitted PM are released directly from secondary processes.

Effects of PM

PM has been confirmed to have health implications on the human. Onabowale and Owoade (2015), stated that about 28% of the sickness and death is caused by indoor air particulate in developing countries. This was collaborated by the results of the studies carried out by WHO (2014). WHO (2014), attributed more than 7 million death to the impact of PM (indoor and outdoor). In India, (Delhi) air pollution has been reported to cause between 10,000 to 30,000 deaths every year (Gopalaswami, 2016), acute and chronic problems are due to inhalation of PM_{10} and $PM_{2.5}$ (Ezeh *et al.*, 2012), and damage to respirative organs (Moses and Orok, 2015)

Ontario Ministry of the Environmental and Climate Change (2010), reported that the greatest effect on health is from $PM_{2.5}$. This has resulted in hospitalization. Affected people (Old and Children) with asthma, cardiovascular and lung diseases are most vulnerable to fine PM. Duration of exposure has an effect on the sickness. According to the Economic Times Quoted by Gopalaswami (2016), it was noted

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that over 85% of the world's population lives in an area tagged by World Health Organization to be unsafe. The air pollution there is above the safe level. This showed that more than 5.5million people die prematurely due to the effect of pollution. The findings concluded that out of this deaths, half was from China and India. In a related development, Chang *et al.* (2013) and Obioh *et al.* (2013) attributed the role of fine PM on poor visibility, corrosion, damage to vegetation and soiling. Apart from the damage done to materials, PM also disturbs the atmospheric chemistry and the radiation balance by scattering and absorbing solar radiation and also alter the formation of cloud droplets.

Sources of PM

It is worthy of note that many types of research are based on PM_{10}, $PM_{2.5,}$ and sub-micron PM, while some are still based on total suspended particulates (TSP). Particulate pollution varies widely across countries in composition, distribution and sources. The assessment of PM concentrations and sources depend largely on the local sources within urban areas and long-range transport of the air pollutants. The PM sources in developing countries are much wider than those from developed (Industrial country). This is because of the increase and fast transition between rural and urban economies.

Sources of PM in the urban and rural are different, while in rural cooking with solid fuels is rampant so also biomass burning, but in the urban, it is fossil fuel. In the reviewed of Johnson *et al.* (2011), it was noted that major sources of pollution in urban places are heating and household cooking, using traditional fuels, animal husbandry, industrial processes, burning of fossil fuels. In developing countries most especially Africa, Latin America and Asia, oil, biomass and coal are the main source of pollution. Both in industrial and developing countries of the world, a major source of PM has been motor vehicles, this is due to the fuel used in powering them like diesel. In fact in developing countries, due to economic hardship most vehicles used are old, they do not meet clean emission standards. As a result, they tend to be more polluting.

According to literature cited, it was observed that the most contributors to PM include vehicles, industrial activity, household fuel, power sector, fugitive dust and unprocessed biomass fuel like wood, dung and crop residues (Alahmr *et al.* (2012), Dallman *et al.* (2014), Crilley *et al.* (2004), Onabowale and Owoade (2015), Fawole *et al*. (2016), Owoade *et al.* (2015) and Orogade *et al*. (2016). Dust storms, smoke from forests and grass fires, volcanic activities and spring dust have been noted to raise the PM levels above WHO guidelines.

In conclusion, anthropogenic and non-anthropogenic activities are the causes of elevated PM in the atmosphere. No doubt PM has affected the air quality management program.

Air Quality Index

The Air Quality Index (AQI) is a pointer that determines the degree of pollution in an area or monitoring location by calculation. The pollutants determined are particulate matter, ground-level ozone, sulfur dioxide, carbon monoxide and nitrogen dioxide. Each of these pollutants have an air quality standard which is used to calculate the overall AQI for the city (AirNow, 2016). AQI is used to assist someone in understanding what local air quality means to one's health (Fig 2).

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Air Quality Index (AQI) Values	Levels of Health Concern	Colors
When the AQI is in this range:	*...air quality conditions are:*	*...as symbolized by this color:*
0 to 50	Good	Green
51 to 100	Moderate	Yellow
101 to 150	Unhealthy for Sensitive Groups	Orange
151 to 200	Unhealthy	Red
201 to 300	Very Unhealthy	Purple
301 to 500	Hazardous	Maroon

a. General Quality Index for the Pollutants

AQI Value	Actions To Protect Your Health From Particle Pollution
Good (0–50)	None
Moderate (51–100*)	Unusually sensitive people should consider reducing prolonged or heavy exertion.
Unhealthy for Sensitive Groups (101–150)	The following groups should reduce prolonged or heavy exertion: • People with heart or lung disease • Children and older adults
Unhealthy (151–200)	The following groups should avoid prolonged or heavy exertion: • People with heart or lung disease • Children and older adults Everyone else should reduce prolonged or heavy exertion.
Very Unhealthy (201–300)	The following groups should avoid all physical activity outdoors: • People with heart or lung disease • Children and older adults Everyone else should avoid prolonged or heavy exertion.

* For particles up to 2.5 micrometers in diameter: An AQI of 100 corresponds to 35 micrograms per cubic meter (averaged over 24 hours).

For particles up to 10 micrometers in diameter: An AQI of 100 corresponds to 150 micrograms per cubic meter (averaged over 24 hours).

b. PM Quality Index Chart

Fig 2: Air Quality Index. Source: AirNow (2016).

AQI is represented numbers - 0 to 500 with 0 representing good air and 500 representing hazardous air. The AQI is broken down into six categories, each color coded with the number scale.

- Good (green) is for numbers 0 through 50 and means satisfactory air quality
- Moderate (yellow) is 51-100 and is for acceptable air quality
- Unhealthy for Sensitive Groups (tan) is 101-150 and means sensitive individuals with sensitive skin may be affected
- Unhealthy (red) is 151-200 and almost everyone may experience problems.
- Very unhealthy (pink) 210-300 is a health alert, where everyone may have health problems
- Hazardous (purple) over 300 numbers may contribute to emergency health problems and will affect most people (AirNow, 2016).

Calculation of Index

An index for any given pollutant is its concentration expressed as a percentage of the relevant standard, or:

$$\text{Index} = \frac{\text{Pollutant Concentration}}{\text{Pollutant Standard Level}} \times 100$$

Where:

100 = The pollutant is currently at a concentration equal to an environmental standard level.

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Pollutant Standard Level = 50 μg/m3 24 hours of PM_{10} readings

80 μg/m3 hourly average PM_{10} reading

Regulatory Standards and Events

The international, national and local communities are aware of the implications of PM to man, animal and materials to this fact, efforts have been geared up to reduce the sources of this air pollution. WHO, UNICEF, and other international bodies have put in efforts even more to the cause of reduction to PM into the atmosphere. Safety limits have been formulated to act as standards for the threshold. In the same effort, national and local governments have put in place research centers and regulatory bodies to oversee, research and to set emission standards.

In 2011, there was a severe haze event in Beijing due to high PM level (between 71.9 102.2μg/m^3) this caused poor visibility and adverse effect on human health (Lang *et al.*, 2012; Yuan *et al*., 2012). To this effect, Ambient Air Quality Standard (NAAQS) was proposed in China in the beginning of 2012 for the first time.

Copalaswami (2016), reported that in 2014 WHO declared Delhi to be the worst polluted city in the world due to the elevated level of PM. It was recorded as $PM_{2.5}$ (295μg/m^3) and PM_{10} (470μg/m^3) which are far above Air Quality limit of 430-435μg/m^3). The safety standard is prescribed by Central Pollution Control Board (CPCB) of India.

In 1988, there was an event where toxic wastes were reportedly dumped in a village called Koko in the eastern part of Nigeria. To avoid the repeated dumping, Federal Environmental Protection Agency was established, it was saddled with the monitoring and regulation of environmental pollution in the country. Now, FEPA has transformed into The National Environmental Standards and Regulations Enforcement Agency (NESREA) saddled with enforcing all environmental laws, guidelines, policies, standards and regulations in Nigeria, as well as enforcing compliance with provisions of international agreements, protocols, conventions and treaties on the environment to which Nigeria is a signatory (NESREA, 2016).

In one of the studies at receptor sites in Lagos, Nigeria the PM levels were reported higher than the 150 μg/m^3 set by NAAQS. The authors reported between 150 and 240μg/m^3 for $PM_{2.5}$ and 370-600μg/m^3 for PM_{10} (Owoade *et al.*, 2013). Minka and Ayo (2014) documented that in harmattan period at the northern part of Nigeria, 400 – 1200 kg/ha dust particles were deposited as compared to 100-400kg/ha in the Southern part. According to Taiwo *et al.* (2015) most of the PM results collected (TSP, 1033-40,000 PM_{10} μg/m^3) and also PM_{10} ranged between 118.3-132.0μg/m^3) in Nigeria were far above recommended values (USEPA, 40μg/m^3) for PM_{10} and (WHO, 90μg/m^3 for TSP).

Recently, there has been signs of improvements in some megacities of developed countries with relationship to PM this is due to the implementation of Urban Air Quality Management plan (UAQMP) (Gulia *et al.*, 2015). According to European Environmental Agency (EEA, 2014) report, between 1990 and 2009 pollutants have reduced to 16% (PM_{10}) and 21% ($PM_{2.5}$). Despite concerted efforts, it has also been pointed out that 18 to 49% of the population in these countries are still endangered to exposure to PM_{10} values exceeding the standards limits (EEA, 2014). In the US mega cities the high values for PM concentration obtained in 1999 had by 2010 reduced by about 38%, but in some areas, the safety limits are being violated (USEPA, 2012). However, the average trend of $PM_{2.5}$ has remained less constant or more from 1997 to 2009 (Gulia *et al*., 2015).

In Singapore, Japan, and Hong Kong the people are facing serious PM problem due to an increase in motorized transport (Edesess, 2011).

Relationship of PM with Meteorological factors

Wind speed and direction have been termed the fundamental parameters in the movement of air contaminants. All these are inter linked to temperature. In other words, the greater the wind speed, the greater the turbulence and the more rapid and complete the dispersion of contaminants in the air (Guttikunda and Gurjar, 2012).

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Based on the study of Guttikunda and Gurjar (2012) using models it was observed that there was a relationship between the two. The higher wind speeds were responsible for driving part of the pollution out of the city limits. Sarasamma and Narayanan (2014) revealed the micrometeorological parameters such as wind speed, wind direction, temperature, atmospheric pressure and relative humidity have a great effect on the movement of PM as well as the concentration level at any particular area. Langner *et al.* (2011) in their book, wrote that deposition rates are governed by meteorological factors (wind velocity, relative humidity), particle characteristics (size and shape), and surface characteristics (friction velocity, microscale roughness, and temperature).

Meteorological parameters which cause the dilution of pollutants rates of chemical reactions and the removal processes such as dry and wet deposition are important factors affecting the particle concentration in the ambient air (Johnson *et al*., 2014)

Sampling and Analytical Techniques

The choice of suitable analytical method for atmospheric deposition depends on the parameter of choice. For analysis of atmosphere deposition, Amodio *et al.* (2014) divided the procedure into three parts namely, dry, wet and occult (Bulk) depositions. They listed different collectors for organic pollutants, inorganic, mercury, biodeposition, and particulate matter. The sampling and analytical techniques interested in this review is PM.

Sample Collectors (Samplers)

Table 2 depicts the sample collectors reviewed in this paper. All the sample collectors are placed on a stand at about 1.5 – 2m high above the ground. This is just to avoid splashing of rain or water into the sample collector (To avoid contamination). The simple collector used in each study (1-5) are just an HDPE. Funnel and container to retain water and PM. The funnel is fitted into the mouth of the container and the container placed on the stand and fixed on it.

It is possible to collect dry and wet depositions separately using the samples equipped with two polyethylene buckets and a lid controlled by a rain sensor, which moves depending on the beginning and the end of the rain event.

Typical sampling periods, in fact, vary from one week to one month, depending on meteorological condition. After the deposition collection, the sample is transferred to the laboratory in the sampling bottle (wet only and bulk) or bucket (Bargerhoff), filtered and analyzed.

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Table 2: List of Samplers Used in Sample Collection

Sampler	Study	Location	Collection Periods	References
1. Funnel – Open Polyethylene Cylinder	Atmospheric Bulk deposition (TAD)	Belgrade	June 2002 – Dec. 2006 (monthly)	Tasic *et al.* (2009)
2. Collecting Glass Bottles	PM Deposition	Port of Koper Slovenia	Oct. 2005 – Oct. 2006	Jereb *et al.* (2009)
3. HDPE Funnel Connected to a polyethylene bottle	Total Atmospheric Deposition	Cedex, France	Nov. 1999 – April 2000 May 2000 – July 2000 (monthly)	Azimi *et al.* (2003)
4. Polyethylene bottles Equipped with a funnel	Dust Fall	Selangor, Malaysia	July – October 2010	Alahmr *et al.* (2012)
5. HDPE funnel-bottle Collector				
6. Water Surface sampler With open surface area Continuously recirculated Water	Dry Deposition	Mediterranean Climate area	-	Amodio *et al.* (2014)
7. Polyethylene Sheets And boxes (1-1.5m^2) And a brush	Airborne Particulate	Xi'an, Shaanxi China	-	Amodio *et al.* (2014)
8. High Volume Air Sampler. Flow rate of 1.2m^3/min	Suspended Particulate Matter	Chawara in Kerala, South India	2011	Sarasamma and Narayanan, 2014
9. Direct gravitational Deposition in to a filter	Suspended Particulate Matter	Uyo, Nigeria	Oct. 2012 – Mar 2013	Moses and Orok, 2015

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Paper				
10. High Volume Gravimetric Sampler and the 10M Multi fraction dust Sampler	Particulate Matter	Benin, Nigeria	Nov. 2009 – Feb. 2010	Ediagbonya *et al.* (2013)
11. Gravimetric High Volume Air Sampler with Whatman Cellulose filter paper	Total Suspended Particulate Matter	Calabar, Nigeria	2 years	Ikamaise *et al.* (2013)
12. Dichotomous Sampler And Airmetrics MiniVol Sampler	Ambient Particulate Matter	Vietnam	Sept. 2005 – Jan. 2006 April 2010	Co *et al.* (2014)
13. Dual-Channel Sequential Sampler Operating at a Flow rate of 2.3m^3/h	Desert Dust PM_{10} & $PM_{2.5}$	Tunis, Tunisia	2008	Kchih *et al.* (2015)

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Analytical Techniques used in PM studies

Table 3 depicts the analytical techniques used in the determination of PM. The choice of instrumentation depends on the choice of researchers and availability.

Table 3: Analytical Techniques used in PM deposition studies

	Analytical Technique	Determination
1.	Gravimetric analysis, β-gauge Monitoring	Particulate matter
2.	X-Ray Fluorescence, Proton - induced X-ray emission, Instrumental Neutron Activated Analysis Inductively Coupled Plasma Spectroscopy, Emission Spectroscopy, Atomic Absorption Spectrophotometry.	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, U).
3.	Ion Chromatography	Ions (F^-,Cl^-,$N0_2^-$, $P0_4$,$^{3-}$,B_r^-, $SO4^{2-}$, $N0_3^-$, K^+, NH_4^+, and Na^+)
4.	Automated Colorimetric analysis	(Cl^-,$N0_2^-$, $S0_4^{2-}$,NO_3^-,NH_4^+)
5.	Thermal Combustion method	Total carbon
6.	Solvent Extraction method followed by Gas Chromatography-mass Spectroscopy.	Individual Organic Compounds
7.	Thermal Manganese Oxidation Method, Thermal Optical Resistance or Thermal/Optical Transmission method.	Total Carbon, Elemental Carbon, Organic Carbon, Carbonate Carbon.
8.	Optical Absorption, Transmission Densitometry, Integrating Plate or Integrating Sphere method.	Absorb and (light absorbing Carbon).

Source: Guttikunda, (2009), Amodio *et al*. (2014)

As shown in Table 3 the various analytical methods used in PM studies are Thermal/Optical transmission method, Optical absorption method, Chromatography, Colorimetry, Gas chromatography, Gravimetric analysis, X-ray emission, Atomic absorption spectrophotometry, and Instrumental Neutron - activated analysis.

Particulate Matter Results

Table 4 depicts the results obtained from ambient samplings. It was observed that most of the results exceeded WHO limits.

Table 4. Particulate Matter Results obtained from different locations of the world

S/N	LOCATION	PM	REF
1.	Post of Koper, Slovenia	>350mg/m a day	Jereb *et al*. 2009
2.	Taiwan	$PM_{2.5}$ (25.76-60.99μg/m^3)	Tsai *et al*., 2011

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		$PM_{2.5-10}$ – 19.21 – 40.27μg/m³ PM_{10} -55.55-90.93μg/m³	
3.	Malaysia	53.08 – 131.50mg/m²/day	Alahmr *et al.*, 2012
4.	Guangzhou, China	$PM_{2.5}$ 54.5-395.1μg/m³	Chang *et al.*, 2013
5.	Benin City, Nigeria	Suspended PM-173.61-520.83μg/m³ Inhalable Suspended- 555.56-2,013μg/m³	Ediagbonya *et al.*, 2013
6.	Calabar, Nigeria	TSP -108.98-269.93μg/m³	IKamaise *et al.*, 2013
7.	Lagos, Nigeria	$PM_{2.5}$ -28.01-3088μg/m³ $PM_{2.5-10}$ – 26.11-64.50μg/m³	Owoade *et al.*, 2013
8.	Lagos, Nigeria	$PM_{2.5}$ -5.0-18.0μg/m³ PM_{10} -50.0-71.0μg/m³	Ezeh *et al.*, 2014
9.	Brisbane, Australia	PM_{10} -11 ± 7μg/m³	Crilley *et al.*, 2014
10.	Vietnam	$PM_{2.5}$ -25-51μg/m³ PM_{10} -33-67μg/m³	Co *et al.*, 2014
11.	Tunisia	$PM_{2.5}$ -2.5μg/m³ PM_{10} -54-56μg/m³	Kchih *et al.*, 2015
12.	Ile-Ife, Nigeria	$PM_{2.5}$ -11-27μg/m³ $PM_{2.5-10}$ -36-237μg/m³	Owoade *et al.*, 2016
13.	Ile-Ife, Nigeria	$PM_{2.5}$ -1.24-58.7μg/m³ PM_{10} -8.33-379.2μg/m³	Fawole *et al.*, 2016
14.	WHO	$PM_{2.5}$ -25μg/m³ PM_{10} 50μg/m³	Gopalaswami 2016

PM and Source Apportionment

Source Apportionments (SA) studies are conducted to identify and quantity the impact of different sources of air pollutants at receptor sites (Gulia *et al.*, 2015). Based on the results obtained from evaluation, information can be gathered which will assist in the formulation and implementation of policies. SA studies are carried out using methods of analyses like chemical and morphological composition of pollutants. Chemical characterization is an important method in SA studies. It focuses on obtaining chemical parameters of the PM which depends on sources and their emission rates. To apportion the sources, receptor models are used, which quantify pollutant concentrations based on the ambient air pollutant data.

SA is an important tool for developing and developed countries. This has assisted the developed world to formulate policies which have assisted them to reduce the PM in their countries. The rate at which anthropogenic sources causes high PM had been reduced drastically. Efforts have been geared up by developing countries to reduce the rate of increase in PM. Countries like India, China, Nigeria and the rest have embarked upon similar studies and researches.

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There are many multivariate receptor models used in SA. Examples are Factor Analysis (FA), Principal Component Analysis (PCA), Eigenvector method, Positive Matrix Factors action (PMF), UNIMIX, Enrichment Factor (EF), Time Series Analysis, Multi-Linear engine (ME) analysis and species series analysis. PCA and FA are used to identify sources of PM, metals and can quantify estimation of the sources, identify dominant sources categories and the results obtained by Varimax rotated factor analysis for coarse and fine particles. PCA and FA assist in interpretation and assessment of the inter-relations of the set of data under study.

Lastly, the correlation coefficient, factor loading and score obtained from FA are utilized to draw inferences about artificial and natural occurrence of the various trace elements (Roy and Singh, 2014). Fig 3 depicts the types of approaches to quantify PM sources.

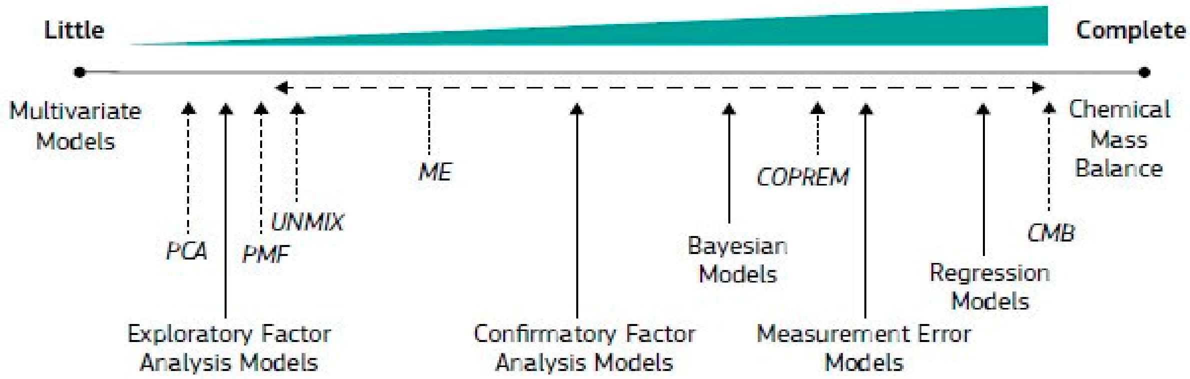

Fig 3: Types of Receptor Approaches to quantify PM sources
Source: Johnson et al. (2011)

SA is synonymous to sources markers (source profiles). Elements are used to identify emission sources of pollutants. Table 5 shows the elements depicting the emission sources. The ratio between two metal concentrations represents the characteristics of a particular source which is an important input for receptor models.

Table 5. Maker Elements Depicting the 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, Zn
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^+

Source: Johnson *et al*. (2011)

CONCLUSION

It can be concluded that PM is a global problem. Developing countries too like the developed ones should see this as a joint task to tackle and so collaborative efforts should be put in place with stakeholders throughout the world. The knowledge of PM and AQI is important

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