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Particulate matter and source identification: A case study of Nigeria

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Abstract

Particulate Matter (PM), an important air pollutant, is one of the causes of death both in developed and developing countries of the world. There has been collaboration, dialogue and consultation with stakeholders who identify the problems and formulate policies to mitigate it. In order for mitigation to be effective, efforts have been put in place by researchers to study PM by identifying and quantifying their various sources. The results have assisted in formulating effective measures to reduce the problem. There is awareness now both in developed and developing countries of the need to reduce air pollution. Several tools for improving air quality have been developed. Many types of research have been carried out on PM using source apportionment methods and the results have been helpful in the places researched. Nigeria has been part of the research work. This paper reviews the efforts that researchers have made in this area, with the aim of better understanding the magnitude of PM pollution in Nigeria, the availability of instrumentation and chemicals, the receptor model used, and the possible sources of PM which could be a threat to public health. The paper, therefore, highlights the aims of research, the methodology, receptor model employed and results. Implications and recommendations of the studies are provided.

Keywords: Air pollution, PM, Receptor model, Health effect, Stakeholders, Mitigations, World

1. Introduction

Globally, air pollution is a health and environmental problem. This arises from acid rain, depletion of the ozone layer and global warming. Some common pollutants are carbon monoxide, nitrogen oxide, ozone, greenhouse gases, lead, sulphur dioxide, toxic air pollutants and particulate matter (PM).

PM pollution is a negative factor affecting man, animals, materials, and the atmosphere [1]. The sudden increase in PM pollution is largely due to increases in urbanization, industrial activities, vehicular movements, burning of biomass and other man-made and natural activities [2].

According to WHO [3], 5.5 million people worldwide die unexpectedly every year due to air pollution. WHO also reported that the impact of PM on total non-trauma deaths in Delhi, India surpassed those of the US. It was observed that 55% of these deaths globally are from India and China [4]. According to the Economic Times, reported by Gopalaswami [4], over 85% of world's population lives in places exceeding the WHO air quality safety limits.

Farao et al. [5] found that PM is one of the pollutants affecting air quality in Europe. Many studies have accounted for a significant relationship between PM and certain ailments such as asthma, chest pains, shortness of breath, nausea, bronchitis, lung cancer, high blood [6]. Epidemiological reports suggested that more than 500,000 Americans die from cardiopulmonary disease annually [6]. According to a UNEP [7] update, particulate matter (PM) is a global environmental problem. PM is classified by size (aerodynamic diameter) and chemical composition. PM can be considered as coarse, fine and ultrafine particulates, with measurements of total suspended particulates (TSP <µ30 µm PM_{10} (coarse, 10µm), and $PM_{2.5}$ (fine, <2.5µm) and ultrafine particles (<0.1µm). In terms of mechanisms of emissions, PM is further classified as primary and secondary particles (Figure 1).

Primary particles include emission from road traffic, road dust, sea spray, burning, industrial (carbon and organic activities, windblown soil, compounds, metals, and metal oxides and ions).

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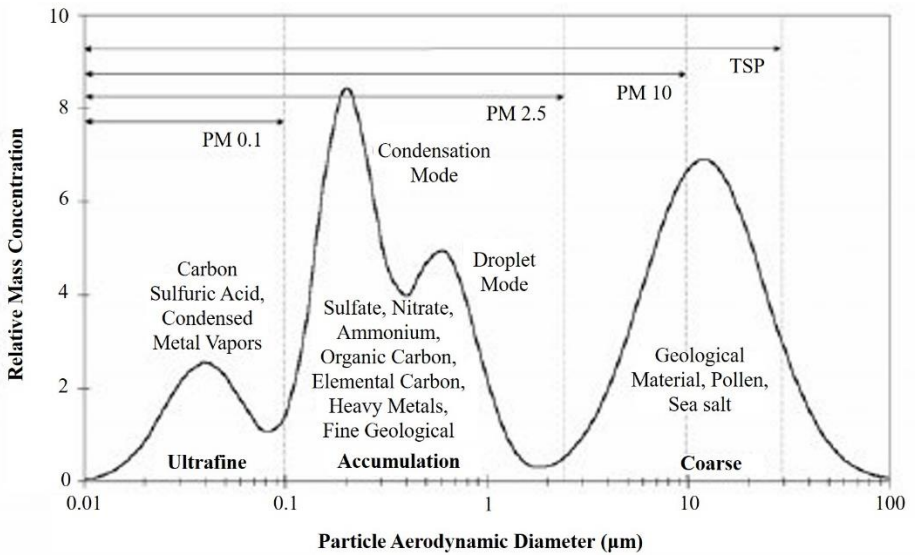

Figure 1 Classification of PM [8]

Table 1 Source Marker Employed in SA (Emission Sources) [8]

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, Cele, Corg, Br, Zn
Automobile gasoline	Cele, Br, Ce, La, Pt, SO_4^{2-}, NO_3^-
Automobile diesel	Corg, Cele, S, $SO_4$2-, NO_3^-
Secondary aerosols	SO_4^{2-}, NO_3^-, NH_4^+

*Marker elements are arranged by priority order

Secondary particles are formed through chemical transformations of gaseous and primary pollutants (NO_2, NH_3 NOx, Certain VOCs, and other materials [8].

2. Source Apportionment (SA)

In measuring the PM in the atmosphere, information is needed about its sources and levels of its contribution to pollution. SA has been useful in the estimation of the contribution of the sources at ambient levels. Many SAs are based on the chemical composition of PM.

The basic steps in SA are (i) ambient sampling, (ii) source profiling (iii) analysis and (iv) reception modeling. In ambient sampling, the following are taken into consideration: selection of sites, the sampler used, and the procedures employed. In any SA study, careful planning, appropriate air sampling with necessary analytical instrumentation, and technical competence are needed to draw appropriate conclusions [8].

Source markers or profiles are one of the tools used in SA. Elements are used for identification of sources. Examples of these are depicted in Table 1.

Figure 2 shows receptor models [9] used in SA. To obtain the ambient levels of PM, the model uses information on measurements at the receptor and chemical profiles of the sources.

Many review papers have been published on PM and SA. Johnson et al., [8] wrote on case studies from developing countries. Ndamitso et al. [10] reported on SA with special reference to case studies in African countries. Likewise, Molina and Molina [11] reviewed the circumstances in nine megacities from developed and developing countries. The Asian Development Bank [12] produced a report on Improving Air Quality Monitoring in Asia. In the report, 69 cities were considered and the Stockholm Environment Institute [13] also released a report on the Strategic Framework for Air Quality Management in Asia. The report identified the problems associated with air pollution and ways to address them. The current work examines cases in Nigeria to enhance the body of knowledge in this area. It examines the aims, sampling methods used, chemical analysis results obtained, conclusions and recommendations of the studies.

3. Case studies

In this review paper, the apportionment analyses presented here include details, results, and recommendations from Kano, Warri, Ibadan, Uyo, Kaduna, Ile-Ife, Lagos and Abuja FCT (Figure 3). The results and recommendations provided by the authors are meant to provide policymakers

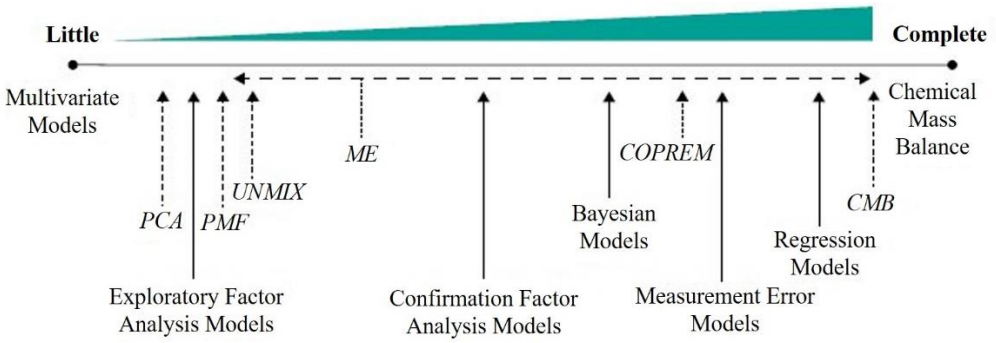

Figure 2: Receptor models [9]

Figure 3 Map showing the study areas depicted by [14]

in Nigeria opportunities to implement cost-effective strategies to control PM pollutant emissions.

3.1 Kano Metropolis

The study was undertaken in Kano metropolis by Okunola et al. [15]. The aim was to assess the impact of traffic volume on metal (Cd and Pb) concentrations and to evaluate the mobility of the metals using sequential extraction. The time frame: Daily collection, December 2009 to September 2010. Ten site locations were earmarked for the collection of particulate dust samples. Sampling equipment consisted of windows and brushes. Chemical analysis: FAAS and Receptor model: Mobility Factor (MF).

The conclusions drawn were:

1. There were interrelationships between the metals (Cd and Pb) and traffic volume.
2. The results (Table 2) for Pb showed that some of the sites have high MF for particulate dust in various seasons (cool, dry, warm and wet).

3.2 Warri [16]

The locations of the study were Warri and Ewu in the far southern part of Nigeria. The samples were collected between January and December 2002. The locations represent urban, industrial and high traffic areas. Sampling collector was a SKC sidekick sampling pump Model 224-50 using a high volume air sampler (25 mm diameter with a pore

Table 2 Particulate Dust and Metal Results from Kano Metropolis [15]

Location	Cd							
	Cool and dry		Hot and dry		Warm and wet		Warm and dry	
	Dust	Soil	Dust	Soil	Dust	Soil	Dust	Soil
1	4.80	3.7	9.40	4.80	12.0	2.9	2.7	3.2
2	5.70	4.5	10.8	5.50	13.5	3.6	3.3	3.5
3	2.80	2.1	5.20	2.80	7.00	1.6	1.5	2.0
4	10.8	8.9	20.3	10.6	24.8	7.1	7.5	6.7
5	10.4	7.8	18.8	10.5	25.1	6.4	6.8	7.5
6	8.90	7.2	15.3	8.80	19.5	6.0	6.4	5.7
7	6.60	5.3	11.8	6.40	14.9	4.4	5.3	4.07
8	13.9	11.0	26.0	13.9	32.9	9.1	8.8	9.2
9	8.70	6.6	15.2	8.50	20.7	5.3	5.5	5.9
10	12.8	9.8	19.7	12.8	25.8	8.1	8.6	9.0
C		0.20		0.2		0.9		1.5
Location	**Pb**							
	Cool and dry		Hot and dry		Warm and wet		Warm and dry	
	Dust	Soil	Dust	Soil	Dust	Soil	Dust	Soil
1	133.7	93.4	90.3	133.4	127.5	76.2	61.5	98.7
2	167.4	121.4	135.2	166.9	182.7	94.9	80.8	122.4
3	189.0	143.2	151.2	188.0	196.2	112.9	95.1	130.0
4	129.1	176.7	218.5	133.5	291.1	141.6	121.7	166.5
5	188.8	896.1	1068.0	1174.2	1408.5	711.1	640.6	866.0
6	156.7	108.6	118.9	156.5	178.7	86.1	75.8	121.2
7	215.3	117.6	137.6	214.7	253.6	90.2	78.1	197.5
8	213.7	115.0	135.0	213.5	247.8	90.5	78.6	199.0
9	161.2	116.1	143.2	160.4	197.2	96.8	86.5	119.2
10	219.5	145.0	164.0	219.0	254.9	117.1	101.9	174.7
C		32.5		30.5		5.5		32.2

Values are mean of triplicate determinations of a sample mixed from three simultaneous soil collections at each site [15]

Table 3 Elemental concentration of total suspended particulate matter (μg m^{-3}) in Warri

Elements	Range	Mean	Enrichment Factor
As	3.01-5.21	3.97±1.00	3288.97
Mn	0.02-0.05	0.01±0.02	0.66
Ni	1.05-2.03	1.17±0.01	44.84
Cd	0.02-0.23	0.12±0.01	3395.82
Se	4.06-6.01	4.65±0.95	39,424.56
V	1.45-2.68	2.09±0.05	153.37
Fe	1.13-1.38	1.18±0.03	1
Pb	1.01-1.04	1.02±0.12	113.42
Cu	0.01-0.09	0.04±0.03	8.48
Al	0.01-0.68	0.19±0.03	0.16
Cr	0.03-0.06	0.02±0.01	1.35
Na	5.06-7.77	6.16±1.14	32.96
K	1.38-2.66	2.00±0.39	15.88
Ca	1.67-3.46	2.23±0.25	0.57

size of 3.0 μm) operated for 8h. Chemical analysis was performed using AAS. TSP was subjected to EF and FA. Measured concentrations of TSP: Warri (1332.7) and Ewu (1327.3 μm^{-3}) (Table 3). Their values were well above the limits of 250 μg m^{-3} [17] and 40-120 μg m^{-3} [3].

3.3 Ibadan [18]

The objectives of the work were to provide information on the seasonal variations of various PM sizes over Ibadan and to investigate the extent to which the metal levels were anthropogenically increased. The sites represent populated areas, lifestyle, vehicular and industrial related activities. Sampling equipment: low volume Gent air sampler (47 mm nucleopore filters). The time frame for the research was from June 2013 (wet months) to February 2014 (dry months) with monthly collection. Instrumentation: ED-XRF Spectroscope (Elements) and optical transmission meter (BC). The mean animal PM concentration (μg m^{-3}) was 24.30 to 32.68 (Table 4). The results suggested that the PM was low compared to other towns in Nigeria. The sources of pollution could be from marine, industrial and secondary sources. Principal sources of Pb and Zn were from refuse burning and Pb from the sea.

3.4 Ibadan [19]

Residential and outdoor airborne PM was determined in the populated areas of Olorunsogo and Alakia in Ibadan. The receptor sites are traffic density, proximity to industry and fuel for domestic cooking. Ten samples of PM 2.5 and PM 2.5-10 were collected between October 2010 and January 2011. A Gent stacked filter was used for the collection. The filters were the nucleopore type with pore

Table 4 PM Concentrations from Ibadan, Nigeria [18]

Site-class	Parameter	$PM_{2.5}$	$PM_{2.5-10}$
Low residential	Mean	24.29	49.2
	Standard deviation	14.04	44.44
	Minimum	8.08	20.14
	Maximum	45.89	142.83
	Median	22.87	30.64
Control	Mean	24.3	38.99
	Standard deviation	12.76	29.35
	Minimum	11.83	9.65
	Maximum	44.81	98
	Median	18.72	33.03
Commercial	Mean	24.89	61.44
	Standard deviation	9.88	40.25
	Minimum	11.35	21.74
	Maximum	42.52	130.93
	Median	25.7	48.99
Industrial	Mean	32.68	78.64
	Standard deviation	15.43	33.17
	Minimum	14.14	26.64
	Maximum	60.82	115.23
	Median	28.62	77.35
High-density traffic	Mean	24.87	58.01
	Standard deviation	14.97	40.48
	Minimum	7.62	17.14
	Maximum	50.1	146.48
	Median	21.92	46.74
High-density residential	Mean	29.78	60.28
	Standard deviation	10.84	27.64
	Minimum	12.55	27.76
	Maximum	46.64	105.7
	Median	29.24	55.48
WHO standard	Annual Mean	10	
EPA	Annual Mean	12	

sizes of 0.4 and 0.8. Elemental analysis was done by ko-Instrumental Neutron Activation Analysis (K_o-INAA) technique. The receptor model was CMB (8.2), yielding the following results:

Indoor $PM_{2.5}$ - 22.20 – 50.0 µg/m^3
$PM_{2.5-10}$ - 9.00 – 24.29 µg/m^3
$PM_{2.5}$ - 50.0 µg/m^3
Wood
Kerosene - 22.20 µg/m^3
Gas - 9.00 µg/m^3

The mean outdoor mass
$PM_{2.5}$ - 53.61 µg/m^3
$PM_{2.5-10}$ - 20.20.0 µg/m^3

Results (Figure 4) suggested that with the total mean mass concentrations of PM, fine particulate ($PM_{2.5}$) were more predominant in the chosen study areas. The receptor model used in this study showed that burning firewood was the most predominant source of PM the study area. Potassium comprised about 34% of the pollutants. Recommendations were made that the Nigerian government establish and encourage indoor monitoring networks to determine the predominant sources of emissions arising from the burning of firewood.

3.5 Uyo [20]

The aim of the study was to assess the level of PM contamination in Uyo. The study was done between October 2012 and May 2013 using an AAS technique for SO_4^{2-}, NO_3^- and PO_4^3 UV-Visible. The sampling points were roads, housing, construction sites and economically developed areas. Dust samples were collected through a direct gravitational deposition using Whatman No. 41 filter paper. Results obtained for EF of metals showed that Fe, Cu, and Zn were in the highest levels (Figure 5). It was concluded that their presence could be due to construction, welding and exhaust emissions in these areas. The CF showed that Fe and Cu were the predominant contaminants in the study areas. These metals could have been the effect of new roof construction in the area. A recommendation was made for constant monitoring.

3.6 Kaduna [21]

A study was conducted to investigate the sources of fine and coarse airborne PM in an urban environment in Nigeria (industrial and agricultural areas). The sample collector for the $PM_{2.5}$ and $PM_{2.5-10}$ was a Gent sampler fitted with nuclepore polycarbonate filters. Timeframe: 12 months over 24 h, four times a week. Chemical analysis: Black Carbon (Optical Transmissometer) and elements (EDXRF). The receptor models used were PMF (EPAPMFV5) and a conditional probability function (CPF). The results showed the average concentrations of $PM_{2.5}$. An agricultural processing site (Kudenda) showed 135.7$\pm$ 4.5 µg/m^{3}and a refinery (NNPC) exhibited 37.2$\pm$ 1.7 µg/m^3. The values are far above the Annual National Ambient Air Quality Standards (NAAQS) of 15 µg/m^3 while the $PM_{2.5-10}$ values of 269.2 $\pm$6.8 and 97.4$\pm$2.4 µg/m^3 also exceeded the

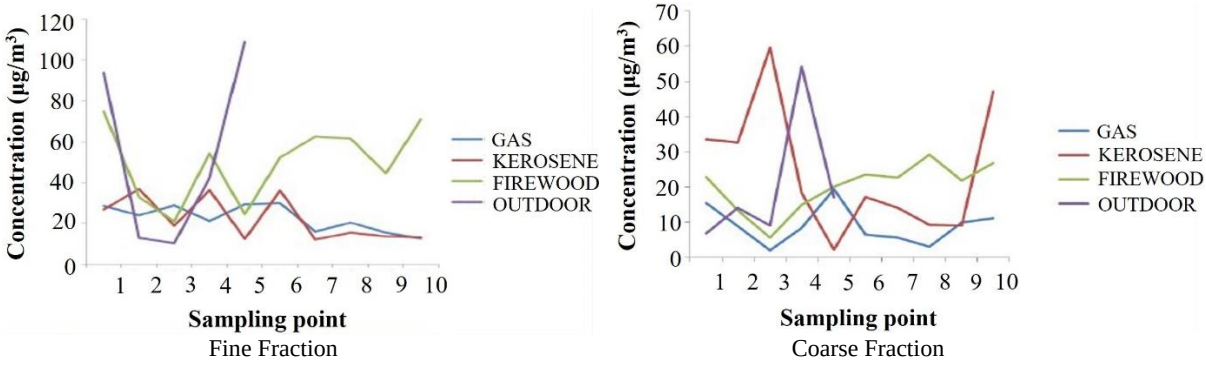

Figure 4 Concentrations of PM (Fine and Coarse) at each site [19]

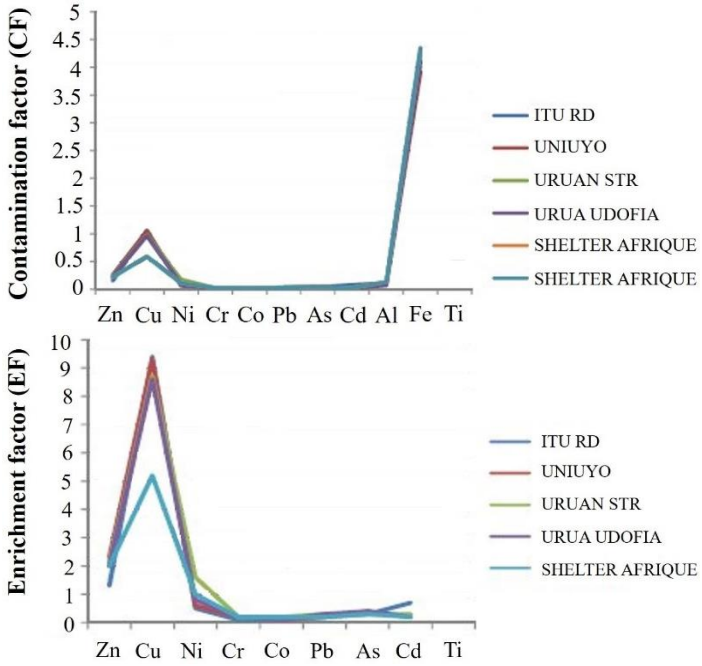

Figure 5 Contamination and Enrichment factors of the trace elements from Uyo

Table 5 Source Contribution for $PM_{2.5}$ and $PM_{2.5–10}$

Source	$PM_{2.5}$		$PM_{2.5-10}$	
	%	Mass (µ gm^{-3})	%	Mass (µ gm^{-3})
Continental Dust	18	6.20	21	11.55
Soil	29	10.36	50	27.37
Vehicular emissions/Motor Vehicles	4	1.56	18	9.87
Residential Oil	49	17.16	-	-
Petrochemical	-	-	11	6.23

Nigerian standard of 60 µg/m^3. The $PM_{2.5/}$ $PM_{2.5-10}$ ratios of the two sites were 0.50 ± 0.16 and 0.38± 0.20. Based on the receptor model used (Table 5), the sources of pollution were residual oil, continental dust, soil and motor vehicles for $PM_{2.5}$. For $PM_{2.5-10}$, the sources were soil, continental dust, vehicular emission, and petrochemical processing. The study can assist in making policy decisions about $PM_{2.5}$ and $PM_{2.5-10}$ in the study areas.

3.7 Ile-Ife [22]

These observations were between May 2011 and April 2012 for $PM_{2.5}$ and $PM_{2.5-10}$ in a scrap iron and steel smelting industry along the Ife-Ibadan highway. A low Gent sampler equipped with a stacked filter unit was used. Instrumentation consisted of a BC Optical Transmissometer and Elemental XRF. The Receptor Model was PMF. The results are depicted in Table 6: $PM_{2.5}$ (14.4-986.5 µg/m^3) and $PM_{2.5-10}$ (11.2-250 µg/m^3). Observations: Values were higher than NAAQS permissible limits. The results were probably due to the use of coking coal, and from the soil, metallurgical processing, electronic wastes, suspended input materials and galvanized steel scrap containing cadmium (Table 7).

3.8 Ile-Ife [23]

This study quantified the ambient PM at four different petroleum stations in Ile Ife, Osun State, Nigeria. The collection of fine and coarse PM was made for 11 h/day for

Table 6 Mass concentrations (μg/m^3) of PM_{10} and $PM_{2.5}$ with ratios of $PM_{2.5}/PM_{10}$ at the sites [22]

	PM 2.5				PM 2.5-10			
	% Sample > MDL	Mean±SD Production site	Mean±SD Outside M1 site	Mean±SD Outside M2 site	% Samples > MDL	Mean±SD Production site	Mean±SD Outside M1 site	Mean±SD Outside M2 site
Mass	100	300±308	222.7±224.9	242.81±230.5	100	381±436	383±588	177±137
Na	100	45±52	23±20	29±33	100	31±42	33±54	13±12
Mg	80	0.17±0.24	0.29±0.68	0.25±0.38	92.3	0.22±0.20	0.48±0.89	0.19±0.17
Al	98	0.51±0.71	2.6±7.8	2±3	100	2.8±5.8	8±16	3.6±3.8
Si	92	1.29±2.14	5.6±18.1	5±8	97.8	5.8±6.4	15±33	5±7
S	100	2.57±2.14	1.3±1.1	1.3±1.4	100	2.7±2.1	1.40±1.17	1.10±0.63
Cl	100	17±18	7.2±6.0	9±10	100	15±14	10±13	5±4
K	100	1.4±1.3	1.6±3.2	1.7±1.8	100	2.3±2.9	3.80±6.49	1.5±1.1
Ca	100	0.24±0.27	0.72±2.12	0.64±1.23	100	2.5±4.6	2.91±5.79	5±7
Sc	70	0.004±0.003	0.0022±0.0016	0.0024±0.0033	57.2	0.0037±0.0048	0.0031±0.0054	1.10±0.63
Ti	100	0.056±0.082	0.23±0.65	0.19±0.29	100	0.45±0.70	0.86±1.67	1.5±1.1
V	72.2	0.003±0.003	0.0018±0.0026	0.0020±0.0026	69.3	0.0077±0.011	0.008±0.12	0.97±0.95
Cr	95.6	0.011±0.014	0.0078±0.0138	0.0081±0.0094	100	0.45±0.70	0.38±0.046	0.0015±0.008
Mn	100	0.31±0.19	0.16±0.21	0.20±0.23	100	0.0077±0.011	0.71±0.69	0.34±0.41
Fe	100	3±4	3.3±7.8	3.3±4.6	100	0.071±0.106	15.7±27.2	0.0028±0.0018
Co	72.2	0.021±0.023	0.018±0.020	0.025±0.033	80.3	0.61±0.67	0.09±0.17	0.029±0.035
Ni	98.9	0078±0.089	0.045±0.040	3.3±4.6	98.9	11±11	0.13±0.21	0.051±0.039
Cu	91.1	0.088±0.091	0.036±0.032	0.025±0.038	96.7	0.16±0.21	0.10±0.16	0.041±0.035
Zn	100	58±63	31.1±29.6	0.057±0.069	100	0.15±0.19	94±164	35±30
Ga	81.1	0.065±0.063	0.030±0.027	0.031±0.028	85.7	119±170	0.03±0.04	0.016±0.015
As	98.9	0.47±0.45	0.20±0.17	0.24±0.25	100	0.06±0.074	0.36±0.53	0.17±0.12
Br	98.9	0.47±0.50	0.18±0.21	0.26±0.31	100	0.64±0.83	0.40±0.53	0.17±0.12
Rb	94.4	0.018±0.021	0.012±0.019	0.015±0.016	96.7	0.032±0.036	0.40±0.75	0.014±0.010
Sr	92.2	0.009±0.009	0.012±0.026	0.012±0.018	96.7	0.028±0.046	0.04±0.06	0.013±0.012
Cd	66.7	0.20±0.24	0.093±0.072	0.12±0.14	50	0.24±0.65	0.037±0.069	0.070±0.074
Sn	74.5	0.47±0.43	0.29±0.19	0.29±0.32	78.1	0.67±1.42	0.14±0.26	0.20±0.22
Sm	90	0.0089±0.0075	0.0052±0.0046	0.0067±0.0057	90	0.050±0.057	0.62±1.28	0.0091±0.0096
Pb	98.9	6±6	2.4±2.4	3.3±3.7	78.1	8.7±12.0	0.017±0.019	2.05±1.64
Bi	71.1	0.029±0.91	0.016±0.017	0.019±0.015	100	0.025±0.039	5.3±8.9	0.007±0.006
BC	100	1.02±0.91	0.56±0.49	0.61±0.60	57.1	0.59±0.57	0.017±0.030	0.20±0.12
Delta-C	100	0.036±0.012	0.054±0.028	0.058±0.030	100	0.050±0.041	0.48±0.61	0.10±0.08

Table 7 Source contributions for $PM_{2.5}$ and $PM_{2.5–10}$ using PMF modeling [22]

Source	$PM_{2.5}$		$PM_{2.5-10}$	
	%	Mass (μgm^{-3})	%	Mass (μgm^{-3})
Soil	10	9.94	18.0	24.63
Suspended input materials			28.0	40.01
Galvanized			1.0	1.45
Metallurgical production and electronic waste	83.0	87.12	53.0	73.97
Coking coal	1.0	0.98		
Electronic waste	6.0	6.40		

three months in 2012 (May-July). A Gent stacked filter sampler was used for the collection. The samples were collected gravimetrically using Whatman polynuclepore filters (flow rates 16 & 18 L min^{-1}). Elemental analysis: PIXE. The results in Figure 6 revealed between 20 and 140 μg/m^3 of fine and coarse PM mass loads. It was concluded that the sources of the pollutants were likely anthropogenic such as, petroleum product production, tyre wear, and vehicular movements. The high level of Pb should be a concern because of its potential carcinogenic effect. The study recommended that future efforts should be on analysis of the organic components of PM at the study sites and the collection of samples should be extended for several years.

3.9 Ile-Ife [24]

The research group conducted and analyzed heavy dust episode (HDE) aerosols. $PM_{2.5}$ and $PM_{2.5-10}$ samples were collected on nuclepore polycarbonate filters using a low Gent sampler. The sampling was done at the top of the Physics Building at Obafemi Awolowo University, Ile Ife. Chemical analysis: Scanning Electron Microscopy (SEM) with Energy Disperse X-ray spectroscopy (EDX), and optical microscopy were used. The results in Figure 7 show the levels of $PM_{2.5}$ (1.24-58.7 μg/m^3) and PM_{10} (8.33-379.2 μg/m^3). Elemental concentration of PM samples (% weight) showed that Al, S_i, and O_2 at the highest levels. This particulate material was assumed to be S_i0_2. The study identified four major classes of particles in the sample originating from mineral dust, calcium-rich dust, NaCl containing agglomerates and alumina-silicate.

3.10 Ile-Ife [25]

The influence of regional and local fires upon coarse fractions of PM was examined. Samples were collected in 2006, 2007, 2010 and 2013. Sampling equipment was a Gent stacked filter. The filter was a nuclepore polycarbonate type. Chemical analysis included XRF spectrometry and optical transmissometry. The receptor models were CPF and PMF. The measured concentrations are shown in Tables 8-10, from two locations, Obafemi Awolowo University

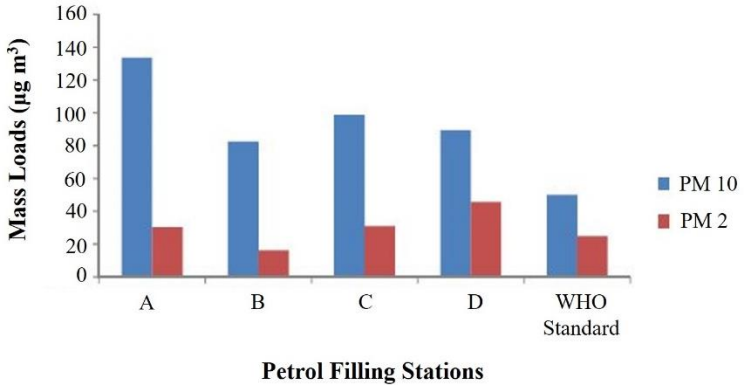

Figure 6 Average $PM_{2.5}$ and PM_{10} mass loads [23]

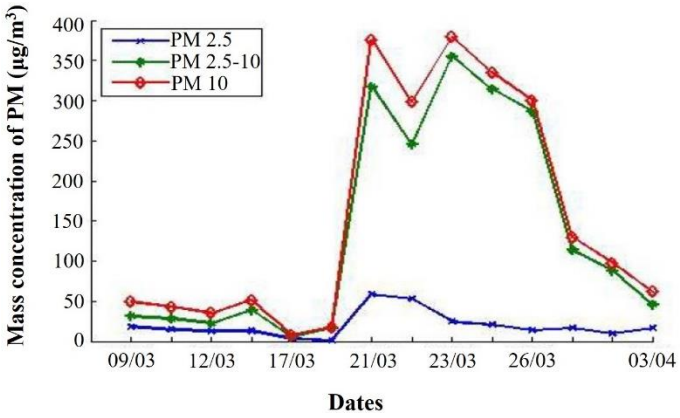

Figure 7 Time series plot of the mass concentration of PM fractions before, during and after the HDE [24]

Table 8 Results of particulate matter ($PM_{2.5}$ and $PM_{2.5-10}$) (mg/m^3) during Harmattan and non-Harmattan periods on the roof of the Physics Department Building, OAU Ile – Ife.

	PM2.5					PM2.5-10				
	% Sample > 20 MDL	2006	2007	2010 Harm	2010 non harm	% samples for PMF > MDL	2006	2007	2010 harm	2010 non harm
Mass	100	26±17	27±16	19±9	11±8	100	2.37±2.46	208±406	103±206	36±31
Na	96	0.17±0.11	0.32±0.21	0.17±0.14	0.19±0.20	96	1.23±1.21	1.72±1.87	0.93±0.73	0.99±0.86
Mg	86	0.06±0.06	0.08±0.07	0.04±0.04	0.026±0.018	98	0.97±1.18	0.87±1.48	0.29±0.48	0.11±013
Al	100	0.54±0.53	0.67±0.53	0.32±0.35	0.12±0.14	100	9.3±10.7	6.72±10.97	2.57±4.1	0.49±1.32
Si	99	1.27±1.25	1.54±1.37	0.81±1.24	0.23±0.27	100	25.6±31.2	18.8±30.5	6.98±13.5	0.91±1.32
P	0	0.010±0.005	0.012±0.005	0.010±0.005	0.007±0.005	0	0.03±0.16	0.04±0.04	0.026±0.015	0.027±0.020
Si	59	ND	ND	ND	ND	Feb-00	0.25±0.17	0.23±0.17	0.19±0.13	0.16±0.07
Cl	0	ND	ND	ND	ND	99	0.33±0.39	0.65±0.66	0.57±0.48	0.66±0.51
K	100	0.57±0.15	0.73±0.37	0.54±0.25	0.26±0.18	100	3.42±3.20	3.11±3.77	1.46±1.64	0.53±0.51
Ca	100	0.26±0.23	0.33±0.27	0.19±0.035	0.07±0.005	100	4.43±5.27	4.1±5.2	1.6±1.64	0.39±0.46
Ti	98	0.001±0.001	0.053±0.039	0.04±0.06	0.018±0.013	99	0.96±1.12	0.67±0.95	0.35±0.55	0.072±0.14
V	83	0.002±0.001	0.001±0.001	0.001±0.001	0.001±0.001	65	0.005±0.005	0.005±0.002	0.007±0.007	0.002±0.002
Cr	58	0.002±0.002	0.002±0.002	0.0001±0.001	0.001±0.001	94	0.015±0.018	0.015±0.018	0.006±0.008	0.003±0.003
Mn	99	0.016±0.010	0.015±0.010	0.012±0.015	0.005±0.003	96	0.20±0.22	0.15±0.20	0.077±0.132	0.016±0.027
Fe	99	0.36±0.33	0.37±0.26	0.32±0.52	0.10±0.09	99	7.6±9.1	5.2±7.1	2.7±5.1	0.55±0.99
Ni	54	0.004±0.002	0.004±0.002	0.003±0.001	0.003±0.001	72	0.011±0.009	0.011±0.012	0.006±0.005	0.006±0.003
Cu	42	ND	ND	ND	ND	53	0.014±0.010	0.014±0.026	0.006±0.005	0.007±0.003
Zn	78	0.017±0.006	0.002±0.019	0.017±0.008	0.002±0.001	49	0.035±0.012	0.044±0.032	0.05±0.02	0.051±0.41
Ga	0	ND	ND	ND	ND	0	0.005±0.005	0.013±0.039	0.003±0.003	0.003±0.001
As	55	0.002±0.001	0.002±0.001	0.0013±0.001	0.002±0.001	37	0.003±0.002	0.005±0.004	0.0048±0.0041	0.003±0.001
Br	73	0.003±0.001	0.003±0.001	0.003±0.002	0.003±0.002	73	0.007±0.005	0.006±0.004	0.007±0.011	0.004±0.003
Rb	59	0.002±0.001	0.002±0.001	0.002±0.001	0.001±0.001	80	0.017±0.020	0.011±0.013	0.018±0.039	0.004±0.003
Sr	77	0.005±0.002	0.005±0.003	0.003±0.004	0.002±0.001	92	0.05±0.06	0.036±0.041	0.012±0.008	0.006±0.005
Pb	90	0.006±0.002	0.006±0.005	0.005±0.003	0.006±0.006	83	0.018±0.010	0.014±0.011	0.012±0.008	o.o1o±0.009
BC	100	0.39±0.08	0.37±0.002	0.42±0.07	0.37±0.09	100	0.51±0.24	0.43±0.18	0.23±0.18	0.18±0.13

Table 9 Results of particulate matter ($PM_{2.5}$ and $PM_{2.5-10}$) (concentration in mg/m^3) from multiple sites at Obafemi Awolowo University Teaching Hospital Complex, Ile-Ife.

Element	% Sample for PMF>MDL PM2.5	PM2.5 Auditorium	PM2.5-10	PM2.5 Phase 1	PM2.5-10	PM2.5 Phase 2	PM2.5-10	% Sample for PMF> MDL PM2.5-10
Na	99	0.64±0.41	1.28±0.49	0.48±0.32	1.34±0.47	0.66±0.44	1.34±0.76	100
Mg	94	0.08±0.04	0.22±0.09	0.06±0.03	0.29±0.12	0.053±0.018	0.14±0.047	99
Al	96	0.46±0.60	1.50±1.11	0.27±0.19	2.45±1.30	0.10±0.09	0.52±0.38	99
Si	98	0.93±0.92	3.37±2.33	0.58±0.56	5.41±3.31	0.23±0.18	1.02±0.66	99
S	100	0.55±0.14	1.14±0.28	0.51±0.16	1.31±0.39	0.62±0.25	1.12±0.28	100
Cl	100	0.16±0.15	0.69±0.29	0.14±0.21	0.85±0.39	0.65±0.45	0.65±0.45	100
K	100	0.38±0.21	0.77±0.36	0.27±0.10	1.02±0.52	0.44±0.13	0.44±0.13	99
Ca	100	0.14±0.11	0.76±0.39	0.10±0.06	1.16±0.65	0.053±0.035	0.33±0.22	99
Ti	98	0.04±0.11	0.17±0.10	0.03±0.02	0.32±0.16	0.011±0.009	0.074±0.052	99
V	73	0.001±0.001	0.002±0.001	0.001±0.001	0.002±0.002	0.001±0.001	0.002±0.001	61
Cr	83	0.001±0.002	0.004±0.003	0.001±0.001	0.007±0.004	0.001±0.001	0.002±0.001	96
Mn	100	0.033±0.12	0.062±0.13	0.009±0.004	0.07±0.03	0.006±0.003	0.019±0.011	100
Fe	100	0.30±0.31	1.48±0.82	0.21±0.13	2.89±1.32	0.091±0.067	0.62±0.39	96
Ni	68	0.004±0.007	0.007±0.007	0.003±0.003	0.007±0.004	0.003±0.001	0.005±0.002	75
Cu	60	0.010±0.023	0.015±0.023	0.011±0.03	0.021±0.038	0.005±0.002	0.011±0.003	50
Zn	98	0.38±0.39	0.58±0.51	0.28±0.35	0.59±0.52	0.38±0.31	0.50±0.38	99
As	80	0.005±0.04	0.007±0.004	0.004±0.003	0.008±0.004	0.005±0.005	0.007±0.006	50
Br	88	0.004±0.003	0.008±0.006	0.004±0.005	0.009±0.008	0.005±0.002	0.007±0.002	72
Rb	67	0.001±0.001	0.003±0.002	0.001±0.001	0.004±0.002	0.001±0.001	0.002±0.001	87
Sr	80	0.004±0.005	0.009±0.007	0.003±0.001	0.012±0.006	0.002±0.001	0.005±0.002	84
Pb	98	0.030±0.026	0.040±0.033	0.022±0.027	0.043±0.035	0.033±0.028	0.038±0.033	96
BC	100	0.16±0.04	0.20±0.05	0.16±0.054	0.24±0.07	0.14±0.03	0.18±0.04	100
PM	100	20.7±7.5	70.8±16.5	266±6.1	92.5±22.4	49.7±7.4	49.7±7.4	

Table 10 Source contribution obtained from the modeling for combined $PM_{2.5}$ and $PM_{2.5-10}$ at all the sites [25]

Source	$PM_{2.5}$		$PM_{2.5-10}$	
	%	Mass (μg m^{-3})	%	Mass (μg m^{-3})
Vehicular emissions	12	1.11±0.07	-	-
Crustal/soil	44	4.26±0.15	-	-
Distant Savannah burning	26	2.57±0.07	-	-
Scrap processing	18	1.71±0.03	5	1.80±0.04
Tire wear	-	-	2	0.58±0.09
Sea salt	-	-	22	8.22±0.18
Soil + Biomass burning	-	-	71	26.29±0.84

(OAU) and Obafemi Awolowo University Teaching Hospital Complex (OAUTH). The samples showed mass fractions exceeding the NAAQS standards. The receptor model indicates four sources for both types of PM, including the soil, biomass burning, scrap processing, and vehicle emissions. All the samples contained high levels of Saharan dust.

3.11 Lagos [26]

The study was carried out in three different locations in Lagos namely in Ikeja (an industrial area), Yaba (commercial & highly populated) and Ikoyi (medium or low population density). Air PM samples were collected using a Sierra Anderson high volume sampler fitted with a cascade impactor with Whatman 41 cellulose acetate filter paper. The analysis was carried out with wavelength Dispersive X-ray equipment. Na was determined using AAS. The receptor models were FA and CMB. TSP measured concentration (Table 11) ranges were determined in Ikeja (66-379μg/m^3), Yaba (48-288 μg/m^3) and Ikoyi (31-129 μg/m^3). The SA showed that anthropogenic wood burning, sea spray, incineration, vehicle emissions, and industrial combustion were the sources of pollution in the study areas. The source proportions originated from the soil (29.6-54.1%), marine environment (26.2-34.2%), vehicle exhaust (0.3-4.0%) and regional SO_4^{2-} (1.9-12.1%). The study suggested that the TSP values obtained satisfied the Nigerian ambient air quality standard of 250 μg/m^3.

3.12 Lagos [27]

PM_{10} and $PM_{2.5}$ fractions, as well as their elemental composition, from Ikoyi, Lagos were studied. The daily sampling time varied between 8 and 20 h. The sampler was a Gent stacked filter sampler. Multi-element analysis was done using a PIXE spectrometer. A six week study produced the following results: $PM_{2.5}$ (4-7 μg/m^3) and (41-53 μg/m^3). The two mass fractions were lower than the $PM_{2.5}$ (25 μg/m^3) and PM_{10} (50 μg/m^3) levels recommended by the WHO (Table 12). The results revealed a range of elemental concentrations (Table 13). The high values were found to be above the recommended limits. The Cd level in these areas is cause for alarm and must be reduced. This calls for urgent action by the regulatory bodies and government agencies in Nigeria. The study recommends an effective monitoring network, especially in the megacities of Nigeria.

3.13 Lagos [28]

This study was aimed at characterizing and identifying the sources of airborne particulate matter ($PM_{2.5}$ and $PM_{2.5-10}$) at various sites in Lagos. Four receptor sites were used. All samples were collected using a Gent low volume air sampler. The $PM_{2.5}/PM_{10}$ ratio was determined. Sampling

Table 11 TSP, elemental concentrations and their enrichment factors at three sites in Lagos

Element	Concentration (ng/m^3)								
	Site 1			Site 2			Site 3		
	Range	Mean	EF	Range	Mean	EF	Range	Mean	EF
Na	590-3210	1915	23	527-4263	2310	40	1144-3577	2199	33
Mg	223-382	328	8	335-462	405	8	339-530	433	8
Al	267-1067	657	1	257-1243	758	1	315-1315	832	1
Si	408-1267	855	0.3	480-1919	1153	0.4	550-2331	1422	0.4
S	225-1510	876	332	553-1413	942	328	348-897	1673	197
Cl	581-2876	332	1931	803-3662	1888	2158	365-2544	1673	1599
K	115-809	4-82	3.9	313-1352	719	5.3	246-822	621	4
Ca	401-2206	1042	0.8	520-2108	1263	0.9	812-2311	1474	0.9
Ti	70-256	162	3.5	56-308	181	3.4	65-237	153	2.6
V	7-29	7-29	22	10-33	21	20	13-25	17	16
Cr	26-79	55	66	41-84	61	65.4	45-67	55	54
Mn	11-76	27	3.6	13-39	25	2.9	8-42	28	2.8
Fe	478-1717	1119	3.2	461-3014	1495	3.6	525-1935	1252	2.9
Co	3-64	11	166	3-15	10	123	3.12	8	100
Cu	37-108	77	460	41-147	80	444	32-72	48	241
Zn	14-272	63	161	22-170	61	121	7-248	62	117
Br	15-57	35	815	12-73	35	814	3-28	13	271
Pb	11-195	81	932	20-181	88	1016	2-89	23	237
TSP	66-379	176		48-288	188		31-129	92	

TSP=Total Suspended Particulates

Table 12 The results obtained for two PM fractions compared to WHO quality guidelines [27]

Week	$PM_{2.5}$	PM_{10}
1	7±4	41±6
2	6±5	42±7
3	6±5	41±3
4	4±1	50±5
5	5±2	53±13
WHO 24 h air Quality guideline (AQG)	25	50

Table 13 Concentrations of Elements in the particulate samples [27]

Element	PM10 (ng m^{-3})		PM2.5 (ng m^{-3})	
	Mean (SD)*	Range	Mean (SD)*	Range
Si	4086 (63)	652-14331	259 (184)	36-1583
S	1262 (6)	182-2245	327 (6)	137-642
Cl	4484 (4)	113-6547	156 (16)	85-287
K	850 (8)	8-2479	126 (8)	37-278
Ca	3473 (2)	3473-9055	74 (13)	21-295
Ti	103 (28)	0.9-447	2 (8)	0.5-15
V	9 (4)	2-25	4 (5)	0.2-12
Cr	39 (10)	8-79	28 (8)	10-45
Mn	20 (23)	20-61	3 (6)	0.2-9
Fe	892 (1)	70-2880	79 (3)	47-152
Co	4 (7)	1-13	0.5 (0.8)	0.07-2
Ni	10 (3)	0.6-27	6 (2)	3-11
Cu	50 (10)	17-135	913 (6)	27-1564
Zn	58 (17)	8-422	3 (1)	0.9-16
Br	24 (6)	1-58	4 (5)	1-15
Sr	26 (52)	1-58	4 (3)	2-25
Zr	24 (7)	26-74	7 (4)	4-41
Ag	71 (29)	51-114	37 (60)	26-180
Cd	135 (42)	55-353	28 (5)	19-163
Ta	17 (60)	7-40	8 (4)	0.6-24
Pb	18 (4)	7-53	1 (0.4)	1-17

(SD)* means standard deviation

was carried out twice every fortnight from February to October 2010. Instrument Analysis was a ko-INAA. The receptor model was PCFA. Table 14 shows the observed PM mass concentration. Source identification is shown in Tables 15-19. The results suggested that biomass burning and industrial emissions produced fine particles whereas sea salt, traffic-related particles, biomass burning and industrial emissions were identified as the sources of the coarse fraction.

3.14 Lagos [29]

The elemental composition of aerosols from Mushin, Lagos, Nigeria was studied. Mushin area has high-density traffic, residential areas, motor parts manufacture, electronic spare parts markets, and several other industries. A Gent stack filter sampler was used for collection of particles. PIXE and Proton Induced X-ray emission (PIGE) were used for elemental determination. EF was approximated. Table 20 shows the results of the PM and PM ratio, while Table 21 depicts elemental concentrations and EF values of PM. The results suggested the most elements were produced by anthropogenic activities.

Table 14 Summary of $PM_{2.5}$ and $PM_{2.5–10}$ mass concentrations

Site-class	Parameter	PM 2.5 (µg/m^3)	PM 2.5-10 (µg/m^3)
Residential	Mean	28.01	64.5
	Standard deviation	15.15	21.84
	Median	31.98	56.1
	Maximum	49.86	109.13
	Minimum	6.43	40.86
Heavy traffic	Mean	30.88	48.27
	Standard deviation	6.84	12.41
	Median	29.89	48.65
	Maximum	44.43	66.44
	Minimum	20.25	30.88
Marine	Mean	25.27	26.11
	Standard deviation	12.18	15.62
	Median	23.93	28.15
	Maximum	44	53.29
	Minimum	2.86	4.43
Industrial	Mean	25.55	28.18
	Standard deviation	15.93	11.57
	Median	20.5	28
	Maximum	66.57	46.83
	Minimum	12	12.71

Table 15 PCFA on $PM_{2.5}$ and $PM_{2.5–10}$ elemental concentration (mg/g) at the industrial site-class

	PM2.5 (Fine)					PM2.5-10 (Coarse)		
Element	**Factor 1**	**Factor 2**	**Factor 3**	**Communality**	**Element**	**Factor 1**	**Factor 2**	**Communality**
As	-	-	-	-	As	-0.316	-0.942	0.698
Br	0.314	0.073	0.946	0.376	Br	0.88	0.374	0.889
Ce	0.839	0.508	0.197	0.995	Ce	0.896	0.443	0.987
K	0.957	0.001	0.22	0.985	K	0.789	0.597	0.989
La	0.841	0.504	0.197	0.995	La	0.834	0.549	0.998
Mo	0.957	0.199	0.213	0.984	Mo	0.818	0.57	0.995
Na	0.319	0.944	0.085	1	Na	0.963	0.224	0.869
Sb	0.035	0.999	0.006	0.995	Sb	0.902	0.429	0.983
Sm	0.806	0.561	0.19	0.996	Sm	0.823	0.563	0.996
Zn	0.9	0.083	0.209	0.996	Zn	0.847	0.529	0.999
Variance	4.938	2.908	1.154			6.813	3.037	
% Variance	54.87	32.31	12.82			68.13	30.37	
Possible origin	Industrial/ Biomass burning	Traffic-related/ sea salt	Traffic emission			Traffic-related/ Sea salt	Industrial/ Biomass Burning	

Table 16 PCFA on $PM_{2.5}$ and $PM_{2.5–10}$ elemental concentration (mg/g) at the marine site-class

	PM2.5 (Fine)					PM2.5-10 (Coarse)			
Element	**Factor 1**	**Factor 2**	**Factor 3**	**Communality**	**Element**	**Factor 1**	**Factor 2**	**Factor 3**	**Communality**
As	0.793	0.474	0.282	0.895	As	0.866	0.489	-0.044	0.996
Br	0.679	0.707	0.117	0.982	Br	0.215	0.75	0.595	0.964
Ce	0.642	0.755	0.113	0.945	Ce	0.981	-0.015	0.148	1
K	0.727	0.683	-0.055	0.989	K	0.749	0.621	0.19	0.998
La	0.921	0.371	-0.107	0.962	La	0.445	0.893	0.048	0.997
Mo	-0.163	0.063	0.968	0.917	Mo	0.902	0.048	-35	1
Na	0.254	0.993	0.086	0.792	Na	0.88	0.147	0.401	0.99
Sb	0.937	0.284	-0.199	0.961	Sb	0.115	0.182	0.974	0.996
Sm	0.927	0.307	-0.213	0.972	Sm	0.728	0.067	0.069	0.998
Zn	0.836	0.402	-0.287	0.997	Zn	-0.436	0.805	0.333	0.995
Variance	5.407	3.165	1.232			4.84	3.141	1.643	
% Variance	54.07	31.65	12.32			48.4	31.41	16.43	
Possible origin	Industrial related	sea salt	Industrial emission			Sea salt/ Industrial	Traffic emission	Traffic-related	

Table 17 PCFA on $PM_{2.5}$ and $PM_{2.5–10}$ elemental concentration (mg/g) at the traffic site-class

	PM 2.5 (Fine)					PM 2.5-10 (Coarse)		
Element	**Factor 1**	**Factor 2**	**Factor 3**	**Communality**	**Element**	**Factor 1**	**Factor 2**	**Communality**
As	0.018	0.881	0.473	0.996	As	0.942	0.319	0.698
Br	0.926	0.648	0.116	0.892	Br	0.295	0.937	0.889
Ce	0.686	0.376	0.007	0.998	Ce	0.995	0.103	0.987
K	0.694	0.676	0.235	0.996	K	0.679	0.733	0.989
La	0.627	0.722	0.278	0.995	La	0.796	0.604	0.998
Mo	-0.096	0.327	0.939	0.996	Na	0.219	0.973	0.995
Na	0.96	0.274	-0.06	0.999	Sb	0.381	0.922	0.869
Sb	0.961	-0.075	-0.264	1	Sm	0.875	0.483	0.983
Sm	0.682	0.685	0.243	0.996	Zn	0.828	0.562	0.996
Zn	0.845	0.521	0.111	0.997				0.999
Variance	52.36	3.244	1.396			4.701	4.24	
% Variance	52.36	32.44	13.96			52.23	47.11	
Possible origin	Traffic emission/ Sea salt	Coal combustion	Industrial emission			Traffic-related Industrial Emission	Traffic emission	

Table 18 PCFA on $PM_{2.5}$ and $PM_{2.5–10}$ elemental concentration (mg/g) at the residential site-class

	PM 2.5 (Fine)					PM 2.5-10 (Coarse)			
Element	**Factor 1**	**Factor 2**	**Factor 3**	**Communality**	**Element**	**Factor 1**	**Factor 2**	**Factor 3**	**Communality**
As	0.371	0.164	0.859	0.923	As	0.167	0.855	0.459	0.841
Br	0.955	0.125	0.255	0.955	Br	0.42	0.075	0.841	0.661
Ce	0.99	0.12	-0.023	0.885	Ce	0.292	0.93	-0.083	0.952
K	0.59	0.805	0.058	0.762	K	0.692	0.565	0.403	0.961
La	0.889	0.453	-0.033	0.826	La	0.896	0.357	0.247	0.934
Mo	-0.212	-0.254	0.886	0.799	Na	0.483	0.863	0.13	0.998
Na	0.867	0.495	0.029	0.931	Sb	0.772	0.317	0.488	0.935
Sb	0.188	0.979	-0.073	0.801	Sm	0.915	0.304	0.164	0.852
Sm	0.998	0.141	-0.017	0.915	Zn	0.857	0.257	0.425	0.974
Zn	0.123	0.99	-0.064	0.834					0.841
Variance	4.991	3.178	1.04			3.971	4.24	1.611	
% Variance	49.91	31.78	16.04			44.12	47.11	17.9	
Possible origin	Traffic emission	Biomass burning/ Traffic-related	Coal combustion/ Industrial emission			Traffic-related Industrial	Sea salt/ Industrial emission		

Table 19 PCFA on $PM_{2.5}$ and $PM_{2.5–10}$ elemental concentration (mg/g) at the industrial site-class

	PM 2.5 (Fine)					PM 2.5-10 (Coarse)			
Element	**Factor 1**	**Factor 2**	**Factor 3**	**Communality**	**Element**	**Factor 1**	**Factor 2**	**Factor 3**	**Communality**
As	0.371	0.164	0.859	0.923	As	0.167	0.855	0.459	0.841
Br	**0.955**	0.125	0.255	0.955	Br	0.420	0.075	0.841	0.661
Ce	**0.990**	0.120	-0.023	0.885	Ce	0.292	0.930	-0.083	0.952
K	0.590	**0.805**	0.058	0.762	K	0.692	0.565	0.403	0.961
La	0.889	0.453	-0.033	0.826	La	0.896	0.357	0.247	0.934
Mo	-0.212	-0.254	0.886	0.799	Na	0.483	0.863	0.130	0.998
Na	0.867	0.495	0.029	0.931	Sb	0.772	0.317	0.488	0.935
Sb	0.188	0.979	-0.073	0.801	Sm	0.915	0.304	0.164	0.852
Sm	**0.998**	0.141	-0.017	0.915	Zn	0.857	0.257	0.425	0.974
Zn	0.123	**0.990**	-0.064	0.834					
Variance	4.991	3.178	1.604			3.971	3.052	1.611	
% Variance	49.91	31.78	16.04			44.12	33.91	17.9	
Possible origin	Traffic emission	Biomass burning/ Traffic-related	Coal combustion/ Industrial emission			Traffic-related	Sea salt/ Industrial emission	Traffic emission	

Key signature tracers are in bold

Table 20 PM and PM ratios [29]

Weeks	PM 2.5 (µm m^{-3})	PM10 (µm m^{-3})	PM 2.5/PM 10 (%)
1	10±3	53±7	19
2	18±6	71±11	25
3	9±3	50±6	18
4	12±4	61±5	20
5	5±1	50±4	20
WHO Air Quality Guideline (AQG)	25	50	

Table 21 Elemental concentrations and EF values of PM [29]

Elements	Typical crustal rock (µg/g)	PM 10-2.5 (ngm-3)			PM 2.5 (ngm-3)		
		Mean (SD*) (ng/m^3)	Range (ng/m^3)	EF	Mean (SD*) (ng/m^3)	Range (ng/m^3)	EF
Na	6300	683 (10)	164-1389	14-92	45 (7)	21-219	26-59
*ssNa	6300	166 (2)	7-401	4	8 (1)	1-33	3-4
*nssNa	6300	517 (8)	157-988	10-88	37 (6)	6-20	22-56
Mg	5000	163 (6)	50-315	4-36	17 (5)	5-60	9-18
Al	71000	477 (6)	20-1151	1	22 (4)	4-95	1
Si	305400	1092 (8)	54-2643	1	61 (4)	23-194	0.5-1
P	**	16 (4)	4-39	**	13 (4)	2-30	**984-2119
S	310	341 (5)	119-814	162-1368	136 (4)	37-408	43-115
*ssS	310	57 (1)	14-117	23-160	4 (1)	2-18	940-2004
*n-ssS	310	284 (4)	105-697	139-1202	132 (3)	35-390	680-4970
Cl	100	852 (2)	180-747	1078-6390	50 (3)	28-91	32-40
K	4000	223 (5)	53-551	8-47	55 (3)	9-173	1-2
Ca	137000	636 (25)	52-1482	1	53 (13)	14-184	1
Ti	5000	59 (5)	4-155	2-3	5 (2)	0.2-9	36-45
V	100	9 (1)	0.2-26	16-7	2 (0.5)	0.2-6	37-178
Cr	100	2 (1)	0.2-4	2-7	3 (1)	1-5	3-4
Mn	850	8 (1)	0.3-20	1	1 (0.1)	0.2-3	2-3
Fe	38000	437 (6)	19-11260	2	1 (0.1)	6-79	**
Ni	**	6 (1)	4-21	**	13 (0.4)	0.4-3	75-355
Cu	20	3 (0.2)	1-5	15-178	0.8 (0.2)	0.4-2	404-1065
Zn	50	24 (1)	5-44	54-355	2 (0.2)	3-27	**
Se	**	0.3 (0.1)	0.1-2	**	0.9 (0.3)	0.1-1	747-3550
Br	5	5 (0.4)	2-11	136-1420	0.3 (0.3)	1-5	**
Rb	**	2 (0.5)	0.2-5	**	0.4 (0.1)	0.1-1	**
Sr	**	3 (0.6)	1-7	**	0.6 (0.1)	0.1-1	**
Zr	**	3 (1)	0.3-10	**	4 (0.7)	0.1-1	
Cs	**	0.6 (0.2)	0.3-1	**		0.3-1	
Pb	10	5 (2)	0.2-19	17-117		0.2-13	355-972

Table 22 PM mass loads

Weeks	PM 2.5 (µm m^{-3})	PM 10 (µm m^{-3})	PM 2.5/PM 10 (%)
1	12±3	46±6	26
2	15±4	68±10	22
3	13±2	59±5	22
4	5±1	45±5	11
5	6±2	64±4	9
WHO Air Quality Guideline (AQG)	25	50	

3.15 Lagos [30]

A study of multi-elemental and source determination of PM measured daily at Ikoyi, Lagos was undertaken between August and September 2007. A Gent stacked filter sampler was employed for sampling. PIXE was used for chemical characterization. The PCA receptor model was used for the SA and identification. Five sources (soil dust, sea spray, heavy oil combustion, industrial and construction activities) were found. Six $PM_{2.5}$ sources were identified. The receptor model employed in the study showed that the sources of $PM_{2.5}$ were anthropogenic (industrial or related sources), including heavy oil combustion.

3.16 Lagos [31]

Analysis was undertaken at Ikeja, the capital of Lagos State, Nigeria. This site represents a medium density residential and high-density industrial areas. A Gent stacked filter sampler was used in collecting air particulate samples. PIXE-PIGE was performed for elemental analysis. PCA was the SA used in the study. PM mass loads are shown in Table 22, while Table 23 depicts elemental concentrations and EF. The study revealed that soil dust, sea spray, and a combined burning of industrial biomass and heavy oil as sources for $PM_{10-2.5}$ and $PM_{2.5}$. The authors expect the results to serve as a guide for future work.

Table 23 Elemental concentration and EF [31]

PM 10-2.5				PM 2.5					
Element	**Comp. 1 Soil Dust**	**Comp. 2 Sea Spray**	**Comp. 3 Industrial**	**Element**	**Comp. 1 Soil Dust**	**Comp. 2 Sea Spray**	**Comp. 3 Biomass Burning**	**Comp. 4 Gasoline Oil Combustion**	**Comp. 5 Industrial**
Ti	0.91	-	-	Al	0.95	-	-	-	-
Al	0.91	-	-	Si	0.91	-	-	-	-
Si	0.91	-	-	Ca	0.90	-	-	-	-
Fe	0.9	-	-	Fe	0.88	-	-	-	-
V	0.89	-	-	K	-	-	0.67	-	-
Mn	0.86	-	-	Zn	-	-	-	-	0.94
Ca	0.82	-	-	Cu	-	-	-	-	0.94
K	0.75	0.53	-	Na	-	0.91	-	-	-
Ni	0.69	-	-	Cl	-	0.74	-	-	-
S	0.69	0.53	-	S	-	-	0.50	--	0.64
Cu	0.64	-	0.57	Cr	-	-	0.72	-	-
Cr	0.57	-	0.56	Br	-	0.72	-	-	-
Na	-	0.94	-	Zr	-	-	-	-	-
Cl	-	0.93	-	Ni	-	-	0.54	0.53	-
Br	-	0.74	-	Ti	0.51	-	-	-	-
Zn	-	-	0.88	V	-	-	-	0.84	-
Pb	-	-	0.86	Mn	-	-	-	0.69	0.88
%Var.	75	9	7	Pb	40	17	10	9	6

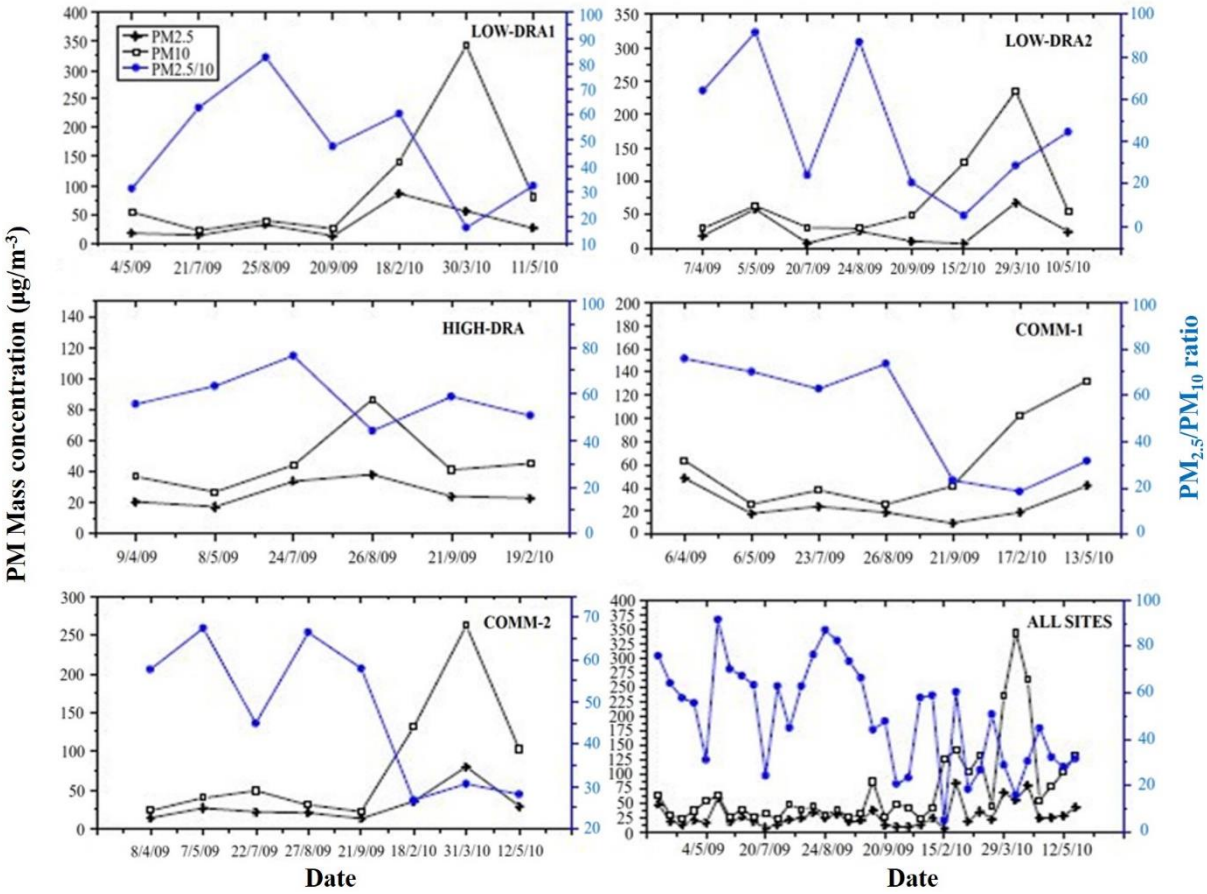

Figure 8 Particulate matter variation at urban locations [32]

3.17 Abuja [32]

The goal of this work was to assess the mass concentration and elemental nature of airborne particulate matter in the study area. The purpose was to provide information on the air quality of the receptor area. Samples of $PM_{2.5,}$ and PM_{10} were collected using a Gent stacked filter sampler for an average of 10 h, once a month between April 2009 and May 2010. PIXE analysis was performed to quantify the elemental results. Figure 8 depicts the results as $PM_{2.5}$ (7-86 µg/m^3), PM_{10} (22-343 µg/m^3) and $PM_{2.5}/PM_{10}$ (0.16-0.92). In some areas, the mass concentrations were slightly above the air quality guidelines (WHO). $PM_{2.5}$ was more than $PM_{2.5}$ results from Turkey, but lower than

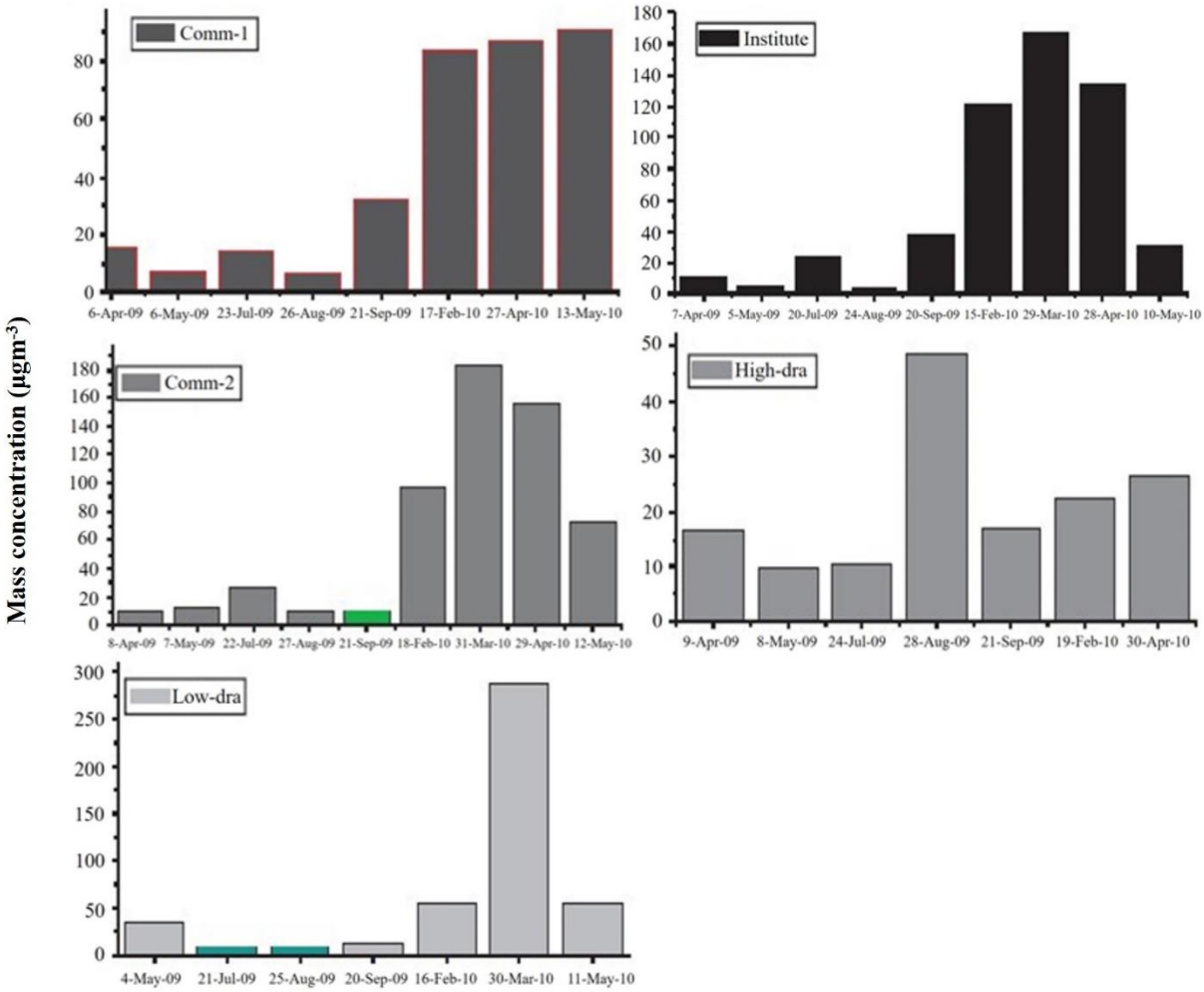

Figure 9 Time Series of PM Mass Variation During the Sampling Period [33]

values obtained from countries such as Greece, Lebanon, and Egypt. The elevated results from the dust were suggested to arise from the use of firewood as a commercial energy source and by residents of the area.

3.18 Abuja [33]

The air quality of the receptor site (Abuja, Federal Capital Territory) was investigated with the aim of finding the sources of pollution in the city. The categories of the sampling were: High (high-dra) and low (low-dra) density residential, commercial and institutional areas. The sampler was a Gent stacked filter fitted with nuclepore polycarbonate filters (47 mm diameter) with an 8 mm pore size. The receptor model was PMF. Chemical analysis was done using an IBA technique. The results indicate three pollution sources, crustal, biomass/fuel burning and vehicular movements (Figures 9, 10 and Table 24). The study concluded that transport-related pollution was highly significant with possible severe health implications.

3.19 Mega Cities [34]

Atmospheric screening for PM (PM_{10} & $PM_{2.5}$) in six megacities (Abuja, Aba, Lagos, Kano, Maiduguri, and Port Harcourt) Nigeria was undertaken. The aim was to provide baseline information on air pollution in these areas. A Gent stacked filter sampler was used. The sampling period was September and October 2009. Sampling was done once a day at all the sites. The choice of location was driven by urban infrastructure (high-density residential, low-density residential, industrial and commercial). The results (Table 25) show that Aba has the highest PM levels. The reason was due to the presence of the 2nd largest market in Nigeria and the use of unpaved and paved roads. Results from Kano and Maiduguri confirmed that the two towns are close to the dust-prone Sahara desert in the northern part of the country. The study revealed that PM mass concentrations exceed WHO limits.

4. Case studies' implications and recommendations

The results seen in these case studies (Table 26) show that the PM of most urban cities exceeds the WHO threshold limits. This means that urgent policies should be implemented to combat this public health problem.

It is clear that urbanization, industrialization, population growth, vehicular movement, and housing are increasing. It is necessary for the federal, state and local governments to address these issues as a form of urban management.

The common SA receptor models used in studies are CMB, PMF, and PCA. In pollution apportion studies, it is noteworthy that there are other good models. There is a need

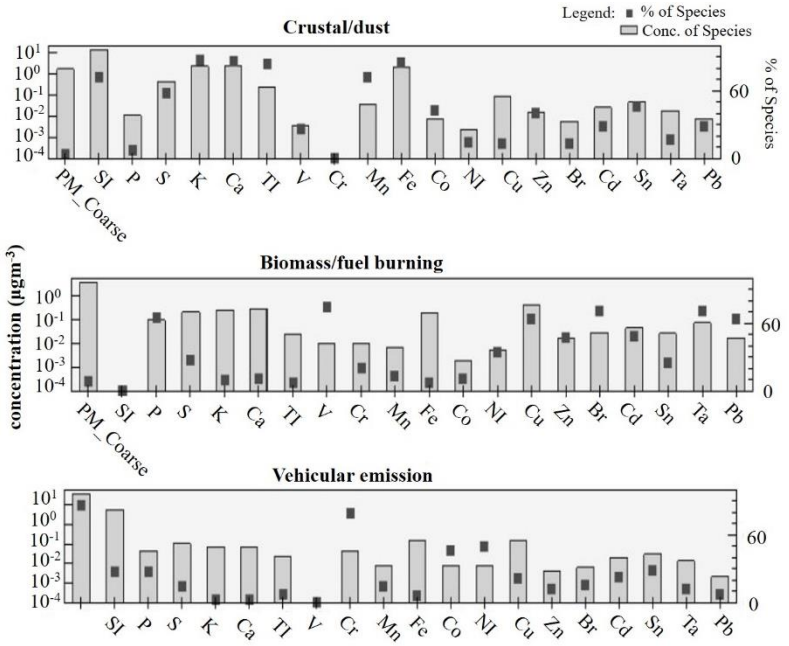

Figure 10 Source Profile of PM for Abuja Urban [33]

Table 24 Contribution of factors by individually modeled variables [33]

	% of each species apportioned to each factor			
	Crustal/dust	**Biomass/fuel burning**	**Vehicular emissions**	**Signal/noise ratio**
Si	72.8	----	27.2	0.706
P	7.3	64.7	28.0	0.634
S	57.8	27.9	14.3	0.511
K	87.6	9.6	2.7	0.710
Ca	86.6	10.9	2.5	0.692
Ti	84.6	7.7	7.7	0.776
V	25.9	74.1	----	0.605
Cr	----	20.5	79.5	0.732
Mn	7.2	13.0	14.9	0.639
Fe	85.8	7.9	6.3	0.823
Co	43.3	10.7	45.9	0.619
Ni	15.0	34.9	50.2	0.570
Cu	14.0	64.4	21.6	0.997
Zn	40.8	47.2	12.0	0.699
Br	13.9	70.6	15.5	0.832
Cd	28.2	49.2	22.5	0.211
Sn	46.2	25.5	28.3	0.930
Ta	16.2	70.6	12.5	0.548
Pb	28.3	63.9	7.8	0.658
PM	4.2	8.8	87.0	0.917

to introduce these models in subsequent studies. There will be a need for proper training and capacity development. Nigeria needs to be environmentally compliant with international health standards.

The above case studies only compare results with international standards like WHO and UNEP. Few studies use standards formulated in Nigeria, despite the establishment of Nigerian Environmental Standards and Regulator Enforcement Agency (NASPEA), which is charged with the responsibility of setting guidelines and enforcing environmental quality standards. Efforts should be made by the national government to ensure the workability of this agency.

The majority of the chemical analysis reported in the studies of this problem are collaborative, which needed samples to taken abroad or outside the region. Many researchers who could have embarked on local PM pollution research could not do so owing to unavailability of funds and equipment. Assistance from the government, private sector, philanthropists, and international donors is needed to aid researchers in the country.

The most prominent particulate matter sources are biomass burning, field burning, industrial activities, vehicular movements, construction, and paved and unpaved roads. There is a need to implement environmental management strategies and clean up technologies to reduce dust pollution.

In developing countries, such as Nigeria, there is a dearth of PM pollution knowledge. A greater percent of the populace is illiterate. The majority are not aware of the health implications of this problem, so, information dissemination should be increased. Local languages should be the medium of communication. In developing effective

Table 25 Daily concentrations (mg m^{-3}) of $PM_{2.5}$ and PM_{10} particulates at receptor sites [34]

	PM2.5	PM10
Lagos		
6º 36' 16.76''N and 3º 20' 12.99'' E (IND)	30	103
6º 36' 16.76''N and 3º 20' 12.99'' E (HND)	35	143
6º 36' 16.76''N and 3º 20' 12.99'' E (COM)	14	49
6º 36' 16.76''N and 3º 20' 12.99'' E (LDR)	12	18
Overall average	23	78
Port Harcourt		
4º 47' 5.36''N and 7º 0' 19.63'' E (COM)	65	178
4º 48' 46.23''N and 7º 3' 47.84'' E (IND)	36	192
4º 47' 34.12''N and 7º 0' 34.29'' E (LDR)	3	123
4º 48' 15.59''N and 6º 58' 28.87'' E (LDR)	20	56
Overall average	2	137
Aba		
5º 7' 18.35''N and 7º 22' 51.01'' E (HDR)	30	577
5º 6' 42.26''N and 7º 23' 49.26'' E (IND)	78	926
5º 6' 45.57''N and 7º 22' 26.45'' E (COM)	248	422
5º 7' 26.65''N and 7º 21' 55.71'' E (LDR)	53	285
Overall average	102	553
Abuja		
9o 4' 48.83''N and 7º 30' 1.36'' E (LDR 1)	12	25
9o 4' 50.43''N and 7º 29' 31.78'' E (LDR 1)	10	28
9o 4' 0.00''N and 7º 28' 59.99'' E (COM 1)	10	42
9o 41' 7.14''N and 7º 27' 57.54'' E (COM 1)	13	22
9o 1' 39.43''N and 7º 29' 41.81'' E (HDR)	24	41
Overall average	14	38
Maiduguri		
11º 58' 30.77''N and 13º 9' 14.03'' E (COM)	10	342
11º 48' 5.13''N and 13º 9' 40.60'' E (LDR)	13	37
11º 50' 58.36''N and 13º 10' 39.93'' E (IND)	23	370
11º 50' 24.49''N and 13º 9' 19.90'' E (HDR)	22	237
Overall average	17	246
Kano		
11º 58' 21.87''N and 8º 35' 21.50'' E (LDR)	41	125
11º 59' 56.19''N and 8º 29' 25.65'' E (HDR)	85	757
11º 58' 26.51''N and 8º 30' 32.66'' E (IND)	43	61
11º 59' 43.67''N and 8º 33' 30.99'' E (COM)	83	416
Overall average	63	340

Table 26 Summary Results of the case studies

S/N	Geographical Location	Pollution Concentration	Receptor Model used	Emission Sources	Year	References
1	Kano Metropolis	Cd (29.49-92.7%) Pb (26-76.4%)	Mobility Factor (MF)	Dusts and traffic related activities	2009 - 2010	Okunola et al. [15]
2	Warri Ewu	TSP (1332.7 µm-3) TSP (1327.3 µm-3)	PCA	Industrial and traffic activities	2002	
3	Ibadan	PM2.5 (7.26 - 60.82 µm-3) PM2.5-10 (9.65 - 130.93 µm-3)			2013 - 2014	Akinlade et al. [18]
4	Ibadan	Indoor (22.20 – 50.0µg/m3) Outdoor (PM2.5 - 53.61µm-3) (PM2.5-10 - 20.20 µm-3)	CMB (8.2)	Traffic activities and oil combustion	2010 - 2011	Onabowale and Owoade [19]
5	Uyo			construction works, welding mechanic workshop and exhaust emission	2012 - 2013	Moses and Orok [20]
6	Ile-Ife	$PM_{2.5}$ (14.4-986.5µg/m^3) $PM_{2.5-10}$ (11.2-250µg/m^3)	PMF	coking coal, soil, metallurgical industry, electronic waste, suspended input materials and galvanized steel scrap biomass burning	2011 - 2012	Owoade et al. [22, 25]
7	Kadunna	PM2.5 (37.2± 1.7 - 135.7+ 4.5 µg/m3 PM2.5-10 (97.4+2.4 -269.2 +6.8 µg/m3)	PMF	Residual oil, Continental dust, Soil and Motor vehicles Soil, Continental dust, vehicular emission and petrochemical		Orogade et al. [21]
8	Lagos	31-129µg/m^3 48-288µg/m^3 66-379µg/m^3	CMB (8.2) PMF, PCFA	anthropogenic sources, wood burning, Soil, Marine, exhaust, sea spray, vehicular emission industrial activities		Ezeh et al. [26-31]
9	Abuja	$PM_{2.5}$ (7-102µg/m^3), PM10 (22-343µg/m3)	PMF	Crustal sources, biomass/fuel burning and vehicular movements		Abiye et al. [32-33]
10	Megacities (Abuja, Aba, Lagos, Kano, Maiduguri, Port Harcourt	$PM_{2.5}$ (20-102µg/m^3), PM10 (18-927µg/m3)		Unpaved and paved roads		Obioh et al. [34]

air quality management systems, overcoming knowledge gaps is critical [8]. Whenever new policies and standards are released, efforts should be made to disseminate them to all, both the literate and illiterate.

5. Conclusions

From the foregoing discussion, it was observed that the problems and the outlook of PM pollution are unique. The authors only presented their findings. None of the reviewed studies provided a single plan or strategy to reduce PM in the various locations. It is necessary for the stakeholders in Nigeria to put in place policy measures that are tailored to each city's challenges.

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