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Source Identification and Heavy Metal Analysis of Fine Particulate Matter ($PM_{2.5}$) in an Industrialized Urban Area of Lagos State, Nigeria

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Abstract

Gaseous pollutants and particulate matter are released into the atmosphere at concentrations above their normal ambient level; this is caused by the increasing human activities which eventually have a measurable effect on humans, animals and plants. Particulate matter (PM) which can be inhaled into the human respiratory system is related to most serious health effect including pulmonary and cardiovascular illness. Based on the field study conducted, the concentrations of $PM_{2.5}$ at the different locations vary with respect to anthropogenic sources. The $PM_{2.5}$ levels obtained ranged from 14.00 to 32.67 μg/m^3 during wet season and 18.67 to 34.67 μg/m^3 during dry season. Trace elements especially heavy metals are significant components of $PM_{2.5}$ in industrial environments. The heavy metals are of particular concern due to their persistence in the environmental media and their human toxicity. The Enrichment Factor (EF) analysis showed very high enrichment for the elements; Pb, Cd, Cr, Cu and Ni in the fine fraction ($PM_{2.5}$). The Principal Component Analysis explained two common contributing sources of fine particulates ($PM_{2.5}$) such as entrained soil and combustion.

Keywords: Fine particulate; Anthropogenic; Heavy metal; Fossil and biomass

Introduction

Fine particles ($PM_{2.5}$) are mainly generated by combustion processes including emissions from motor vehicles, combustion of fossil fuel for power generation and large industrial processes such as ore and metal smelting. They may also include natural emissions such as fine windblown soils, sea spray and smoke from biomass burning. The size of particles is directly linked to their potential for causing health problems [1].

Environmental Protection Agency (EPA) such as Federal Ministry of Environment and United State Environmental Protection Agency are concerned about particles that are 2.5 micrometer in diameter ($PM_{2.5}$) or smaller because those are the particles that generally pass through the throat and nose and enter the lungs. Once inhaled, these particles can affect the heart and lungs and cause serious health problems [2].

The main source of airborne particulates includes natural and anthropogenic processes. The most noteworthy anthropogenic sources with regards to quantity stem from incomplete combustion process, such as fossil fuel and biomass burning [3]. The rate of increase of air pollutant concentrations in developing countries such as Nigeria are higher than those in developed countries and hence atmospheric pollution is often severe in cities of developing countries all over the world.

There has been remarkable industrial progress in Nigeria over the last three decades with the establishment of many cottage industries. This rapid industrialization has not been matched with proper planning for the control of environmental pollution problems that are usually associated with such industrial development [4].

Severe air pollution has been identified in overcrowded cities such as Lagos, Port Harcourt, Kaduna, Kano, and Abuja [5]. Both gaseous pollutants and atmospheric particulate matter contribute to the deterioration of air quality [6]. Thus this research is aimed at evaluating the status of $PM_{2.5}$ and provides a base line information and data with respect to heavy and light metals in those study locations.

Materials and Methods

Sample locations

Sampling of $PM_{2.5}$ was conducted in six locations within the Lagos metropolitan area and sampling was done for both wet and dry seasons between July 2017 and April 2018. Tables 1 and 2 show the site codes, coordinates and site descriptions.

Sample collection

The fine particulate matter ($PM_{2.5}$) was collected as described by Gaita et al. [7]. Meteorological parameters such as humidity and temperature were simultaneously measured during the period of sampling. At the end of each sampling day, samples were carefully wrapped in a polyethene bag and kept in a plastic container to avoid contamination prior to metal analysis. Samples were collected in triplicates.

Sample preparation and measurement

In order to determine the concentrations of the metallic elements, a mixture of hydrochloric (HCl) and nitric acid (HNO_3) was used to

extract the metals from the filters. Each filter was cut into smaller pieces (0.5 mm × 2 mm) and put into a 200 ml beaker and 20 ml of Aqua Regia (mixture of HCl and HNO_3 in the ratio of 3:1) was added and digested by heating the beaker containing the glass fibre filter (GFF) and 20 ml aqua regia on a heating mantle at a temperature of 70°C for 2 hours before digestion is complete. The digested samples were analyzed for Pb, Cd, Cr, Ni, Fe and Cu using Shimadzu Atomic Absorption Spectrophotometer (SHIMADZU-GFA 7000A), a single beam type. Air-acetylene flame and hollow cathode lamps with background correction were used for the instrumental analysis and the blank content duly subtracted from the analysis.

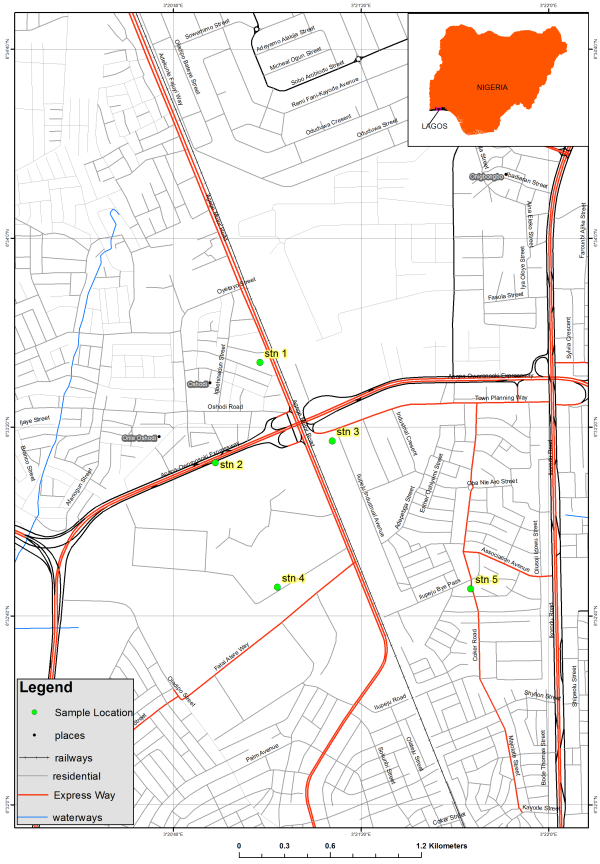

Figure 1: Map of Lagos state showing the sampling sites.

Locations 1 to 5 are busy industrial areas while location 6 which is a busy non industrial area was used as the control site (Figures 1 and 2).

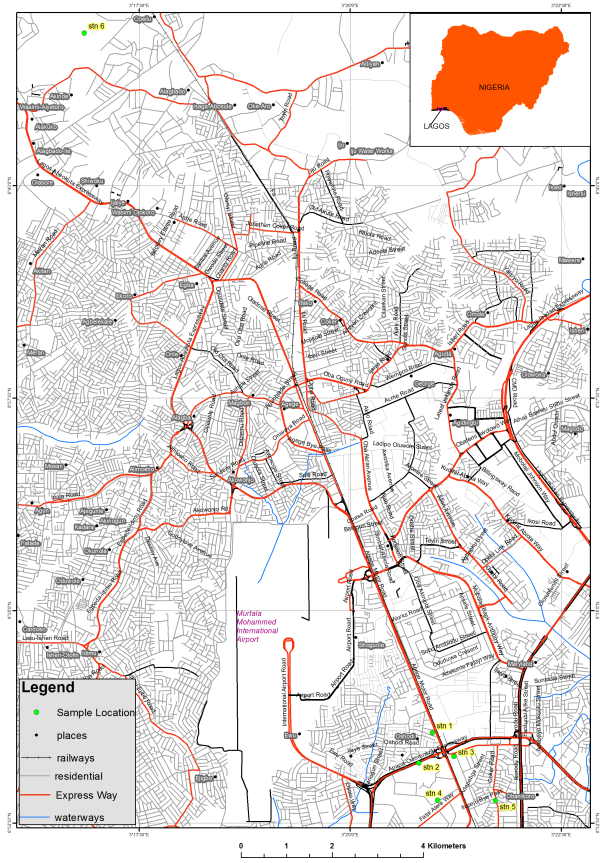

Figure 2: Map of Lagos state showing the control sites.

Results and Discussion

The $PM_{2.5}$ levels obtained ranged from 14.00 to 32.67 µg/m^3 during wet season and 18.67 to 34.67 µg/m^3 during dry season. Variation in anthropogenic activities in those locations could be a major contributing factor to the observed differences in particulate matter levels in the various locations.

Variables	Location 1	Location 2	Location 3	Location 4	Location 5	Control
Day 1	30	20	22	23	23	10
Day 2	33	12	14	23	25	15
Day 3	35	18	19	19	22	17
Mean	32.67 ± 5.03	16.67 ± 4.16	18.33 ± 4.04	21.67 ± 2.31	23.33 ± 1.53	14.00 ± 3.61

Table 1: $PM_{2.5}$ concentration (µg/m^3) in the different sampling locations for wet season.

Variables	Location 1	Location 2	Location 3	Location 4	Location 5	Control
Day I	33	25	27	29	28	18
Day 2	35	19	16	27	30	17
Day 3	36	21	23	21	25	21
Mean	34.67 ± 1.53	21.67 ± 3.06	22.00 ± 5.57	25.67 ± 4.16	27.67 ± 2.52	18.67 ± 2.08

Table 2: $PM_{2.5}$ concentration ($\mu g/m^3$) in the different sampling locations for dry season.

Trace elements especially heavy metals are significant components of $PM_{2.5}$ in industrial environments. These elements are of particular concern due to their persistence in the environmental media and their human toxicity. In particular, non-biodegradability of heavy metals leads to their accumulation in the environment.

Samples	Pb	Cd	Ni	Fe	Cu	Cr
LTN1	0.89 ± 0.10	ND	ND	0.75 ± 0.20	ND	0.47 ± 0.19
LTN2	0.85 ± 0.16	0.85 ± 0.18	ND	0.47 ± 0.06	ND	0.38 ± 0.13
LTN3	0.36 ± 0.13	0.34 ± 0.06	ND	0.20 ± 0.12	ND	ND
LTN4	0.35 ± 0.05	0.44 ± 0.25	ND	0.59 ± 0.22	ND	0.54 ± 0.15
LTN5	0.34 ± 0.12	ND	ND	0.54 ± 0.01	ND	ND
Control	ND	ND	ND	ND	ND	ND

Table 3: Concentrations of the heavy metals in $PM_{2.5}$ (in $\mu g/m^3$) during wet season.

The elemental concentration of $PM_{2.5}$ in the different locations for both wet and dry seasons was depicted on Tables 3 and 4 respectively. Pb was found to be more in location 1 followed by Fe and then Cr.

Samples	Pb	Cd	Ni	Fe	Cu	Cr
LTN1	0.91 ± 0.07	0.21 ± 0.02	0.11 ± 0.01	0.87 ± 0.19	0.11 ± 0.02	0.51 ± 0.19
LTN2	0.88 ± 0.11	0.93 ± 0.15	0.19 ± 0.02	0.61 ± 0.16	0.19 ± 0.03	0.46 ± 0.12
LTN3	0.56 ± 0.23	0.50 ± 0.19	0.13 ± 0.01	0.33 ± 0.08	0.11 ± 0.01	0.11 ± 0.01
LTN4	0.51 ± 0.25	0.54 ± 0.19	0.22 ± 0.02	0.69 ± 0.18	0.18 ± 0.03	0.60 ± 0.12
LTN5	0.55 ± 0.23	0.16 ± 0.05	0.13 ± 0.02	0.64 ± 0.14	0.16 ± 0.04	0.12 ± 0.02
Control	ND	ND	ND	ND	ND	ND

Table 4: Concentrations of the heavy metals in $PM_{2.5}$ (in $\mu g/m^3$) during dry season.

This may be as a result of the high vehicular activity and industrial emission in that area. The use of Pb containing anti knocking gasoline additives played a dominant role in the buildup of atmospheric Pb levels. Also the presence of paint and stainless steel industries in the area is an indication of the high concentration of Pb, Fe and Cr.

The concentration of Pb and Cd was higher in location 2 and 3 followed by Fe and then Cr. This may be as a result of high vehicular activities and industrial fume discharge in those areas. Comparing locations 1 and 2 it was observed that the concentrations of Pb in both locations are very close. This signifies that the activities resulting in Pb emission in location 1 are almost the same to that of location 2.

The concentration of Pb in locations 3, 4 and 5 are almost the same while the concentration of Fe in locations 4 and 5 are also close. In location 4, the concentration of Fe is higher followed by Cr, Cd and then Pb. This could however be due to the presence of stainless steel foundry industry present in those areas. In location 5 with Fe being the dominant metal present is an indication that fumes were emitted from several units such as sinter/pellet plant and blast furnace in iron and steel industries present in that area. The concentrations of all the heavy metals in the control site for both wet and dry seasons were below detection limit. This suggests that there are no activities taking place in that location that involves the emission of particulate matter with heavy metals contamination.

Enrichment factor

In order to determine the different pollution sources and trace down the extent of anthropogenic contribution, a fundamental study of the chemical composition is necessary [8]. Soil and anthropogenic sources were delineated using computations of enrichment factor (EF). Enrichment factor (EF) is widely used to identify the anthropogenic source of metallic elements and it is generally applied to show the degree of enrichment of a given element compared to the relative abundance of that element in crustal materials [9]. Enrichment factors (EFs) were calculated to discriminate the crustal source from the anthropogenic sources of atmospheric heavy and light metals [10-12].

The Enrichment Factor (EF) is commonly defined by the following relation:

$$EF=[(E/R)_{sample}/(E/R)_{crustal}] \quad \ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Where E represents considered element, and R is the reference element for crustal material.

$(E/R)_{sample}$ is the concentration ratio of E to R in the particulate matter sample, and $(E/R)_{crustal}$ is the mean concentration ratio of E to R in the crust.

The EF values close to unity indicate crusted origin, those less than 1.0 suggest a possible mobilization or depletion of metals, whereas EF>1.0 indicates that the element is of anthropogenic origin [13]. Five contamination categories are recognized and interpreted as suggested by Birth [14]. In this study Fe was used as a reference element to determine the EF with respect to crustal abundance.

Elements	Location 1	Location 2	Location 3	Location 4	Location 5	Control
Pb	2799.07	4244.84	4305.96	1407.47	1492.13	-
Cd	0	282965.17	264982.46	117526.1	0	-
Fe	1	1	1	1	1	-
Cr	324.2	426.6	0	486.53	0	-

Table 5: Enrichment factor analysis during wet season.

Tables 5 and 6 show that the majority of these metals in the air came from the emissions of non-crustal sources such as anthropogenic sources. The high value of Pb, Cd, Cu, Ni and Cr could be due to vehicular and industrial emissions break pad and tyre wears, and municipal waste incineration in the area. In particular, Cd in $PM_{2.5}$ had extremely high EF values of 117526.10-282965.17 and 38389.33-463890.03 for both wet and dry season respectively indicating extreme contamination by anthropogenic Cd sources.

Elements	Location 1	Location 2	Location 3	Location 4	Location 5	Control
Pb	2468.56	3427.78	7712.58	1963.45	2005.36	-
Cd	38389.33	242121.04	463890.03	90128.22	39548.27	-
Ni	95.9	237.5	556.11	238.03	155.57	-
Fe	1	1	1	1	1	-
Cu	130.06	326.46	670.42	285.64	269.39	-
Cr	303.13	394.49	335.21	456.85	100.3	-

Table 6: Enrichment factor analysis during dry season.

High Cd concentration in those locations may be associated with industrial emissions especially from steel production units because a large amount of Cd plated steel scraps are recycled in these areas. Other possible sources include open burning of municipal waste containing Cd batteries and plastics containing Cd pigments, vehicular emissions including tyre abrasions and cigarette smoking.

Though all the metals both heavy and light are extremely severely enriched with Cd having much more higher value, is an indication that the pollution on the different locations are more of anthropogenic sources. However locations 1 to 5 are industrial areas where a lot of anthropogenic activities leading to industrial fume emission, vehicular and automobile exhaust emission, municipal waste incineration, cooking, frying, biomass/wood burning and agricultural practices etc., are taking place.

The enrichment factors of the light metals are also severe which suggests that the pollution source is not only of natural origin but a combination of natural and anthropogenic origin with the anthropogenic origin having the highest percentage of contributing factors.

Principal component analysis

Source identification analysis of particulate matter was performed based on the principal component analysis method which is widely used to factorize the input concentration data of different species having a linear relationship between total mass concentration and the individual concentrations [15,16].

Elements	Factors		
	1	2	Communality
Pb	-0.891	-0.013	0.793
Cd	-0.86	0.359	0.869
Fe	0.62	-0.012	0.385
Cr	0.586	-0.35	0.466
Eigen Values		4.897	1.402
% of Variance	61.217	17.52	
Possible source	Automobile/road dust	Biomass burning	

Table 7: Principal component analysis during wet season.

Tables 7 and 8 show that the Principal Component Analysis (PCA) with varimax rotation was used in order to identify the possible sources contributing to heavy and light metals in ambient air particles in the study areas for wet and dry seasons. Factors with eigen values greater than 1.0 were used to identify major elements associated with different sources.

The factor loadings from PCA analysis at the sampling sites for $PM_{2.5}$ particles were identified. From the PCA, two factors were extracted which explained 78.74% and three factors which explained 81.53% of the total variance for both wet and dry seasons respectively. In addition, those metals with high positive loads further indicate that the degree of pollution with these metals was affected not only by the intrinsic properties of fine particulate matter but also, more importantly, by human activities.

Elements	Factors			Communality
	1	2	3	
Pb	0.752	-0.536	-0.106	0.864
Cd	-0.208	-0.864	0.387	0.941
Ni	0.107	-0.056	0.932	0.884
Fe	0.888	0.305	0.096	0.89
Cu	0.153	0.117	0.877	0.807
Cr	0.785	-0.185	0.456	0.858
Eigen Values	4.058	2.425	1.67	
% of Variance	40.58	24.254	16.697	
Possible Source	Automobile emissions/ Industrial fumes	Road dust suspension	Vehicular fumes/Waste incineration	

Table 8: Principal component analysis during dry season.

Conclusion

Fine particulate matter ($PM_{2.5}$) is mainly generated through natural and anthropogenic sources. The $PM_{2.5}$ levels obtained ranged from 14.00 to 32.67 μg/m^3 during wet season and 18.67 to 34.67 μg/m^3 during dry season and the samples were analyzed and trace elements such as Pb, Cd, Cr, Ni, Fe, Cu, were determined. The enrichment factor analysis showed very high enrichment for the elements; Pb, Cd, Cr, Cu, Ni, in the fine fraction ($PM_{2.5}$). Principal component analysis explained three common contributing sources of fine particulates ($PM_{2.5}$) such as entrained soil, sea salt and combustion.

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