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AMBIENT AIR PARTICULATE MATTER IN LAGOS, NIGERIA: A STUDY USING RECEPTOR MODELING WITH X-RAY FLOURESCENCE ANALYSIS

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ABSTRACT. The need for comprehensive air pollution studies in Lagos cannot be overemphasized in view of the level of industrialization of the city and its nearness to the ocean. Air particulate samples collected with a high-volume air sampler at three locations in Lagos, Nigeria were analyzed by the combination of wavelength-dispersive X-ray fluorescence and atomic absorption spectroscopy methods. Elemental concentrations were subjected to factor analysis for source identification and chemical mass balance model was used for source apportionment. Prominent among sources identified with the ranges of their contributions at the sites are: soil 35-54%, marine 26-34%, automobile exhaust 0.3-3.5%, refuse incineration 2-3%, and regional sulphate 2-12%.

KEY WORDS: Ambient air particulate matter, Air pollution in Lagos (Nigeria), Receptor modeling, Wavelength-dispersive X-ray flourescence, Atomic absorption spectroscopy

INTRODUCTION

Urban air pollution is fast becoming an issue of regional as well as global concern. The threat posed to human life and property by air pollution makes it mandatory to device control measures to combat it. This would be facilitated by establishing reliable information about the source-receptor relationship of the pollutants. In this regard, identification and apportionment of sources by means of multivariate techniques has gained wide acceptance. Application of receptor models for source identification and apportionment have been intensified in countries like United States of America, Canada, and some countries in Europe and Asia. In most of the studies, factor analysis (FA) and chemical mass balance (CMB) were used as complementary models, that is: FA for source identification while CMB is then used for source apportionment.

One of the earliest extensive CMB works was done by Kowalczyk *et.al.* [1] in the study of particulates in Washington D.C. Seven sources identified were included in the CMB namely: soil, coal, limestone, oil, refuse, motor vehicle and marine. The result produced a good agreement between observed and calculated concentrations for most elements except Cr, Ni, Cu and Mn which might have sources different from those stated above. In the study of Toronto aerosol, Pringle and Jervis [2] used receptor models for identification and apportionment of sources of the aerosols to six major contributing sources namely; soil, road salt, mobile source, refuse, oil and arsenic. Okamoto *et al.* [3] in Japan used factor analysis-multiple regression model for source apportionment of aerosol. Five factors obtained with FA suggested that soil and automobile sources were highly correlated so, the road dust was used as sum of soil and automobile source type.

Among major contributing sources to ambient air particulate matter in some major cities in the world are: soil or entrained dust, vehicular exhaust, marine (in a city situated close to an ocean) and industry. Some of the prominent marker elements already established are: Pb and Br for vehicular exhaust particularly where leaded gasoline being used or Br from fresh automobile exhaust [4]; Zn for tyre wear [2]; Ca is a marker element for cement work. When the source was not included in

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CMB but construction was going on in the vicinity, it led to underestimation of Ca concentration [1]. Mn is a marker element for steel industry and can also be attributed to burning of coal [5].

In Nigeria, Lagos is of particular interest for air pollution studies because of its high population density coupled with intense industrial and commercial activity [6]. In our preliminary work on Lagos aerosol, we reported the elemental concentration and source identification of air particulates from a site in Lagos [7]. In the report, five contributing sources were identified for coarse particulates while six sources were identified for the fine particulates by the use of factor analysis (FA) method. The sources identified were: soil, marine, automobile vehicular exhaust, and regional sulphate for coarse particulate and soil, automobile vehicular exhaust, marine, and three unidentified industrial sources for the fine particulates. In this report, further work was done to establish the actual contribution of the sources identified to the total suspended particulate matter at two different sites within Lagos metropolis by the use of chemical mass balance model.

EXPERIMENTAL

Site description. The locations of the three sites are indicated in Figure 1. Site 1 is at the top of a commercial building at Ikeja, an industrial area in Lagos as described earlier [7]. Site 2 is located at Yaba - within the premises of the Federal Ministry of Health Central laboratory. This is a commercial centre as well as a high population density residential area. The site is not close to any industrial estate but at a distance of about 3 km north of the sea. Site 3 is located at Eti-Osa Local Government Secretariat, Ikoyi, an area of medium/low population density. This area is also not close to any industrial estate but very close to the Atlantic ocean and the lagoon.

Figure 1. Map of Lagos metropolis showing the sampling sites.

Sample collection. Air particulate samples were collected at those sites in Lagos with a Sierra Anderson high volume air sampler (U.S.A.) fitted with a cascade impactor. The collection medium was Whatman 41 cellulose acetate filter paper which was treated with vaseline in hexane (10 g/100 cm^3) solution to reduce particle bounce-off of particulates on impaction surface [8]. Loaded and unloaded filters were conditioned inside a desiccator for 24 hours at room temperature before weighing. About 1000 m^3 of air was sampled at each occasion. For better interpretation of our data, samples were collected into two main fractions: coarse 10-1.5 μm and fine ≤ 1.5 μm in diameter.

Analysis. Filters were analyzed with Siemens' Wavelength Dispersive X-ray equipment model SRS-300 (Erlangen, Germany), coupled with two modes of detectors: scintillation counter and flow counter. Sodium content of each sample was determined with Perkin Elmer Atomic Absorption Spectrometer model 2380 (Washington D.C., U.S.A). Aerosol loaded filter samples were digested with a mixture of boiling concentrated nitric and perchloric acids in a teflon beaker inside a fume cupboard. The mixture were then evaporated to dryness and re-dissolved with 1 cm^3 of concentrated nitric acid plus 10 cm^3 of water with gentle warming. A detailed method of sample preparation and analysis has been described earlier [9].

The accuracy and precision of the applied analytical procedures was ascertained by the analysis of the Commission of European Communities (CEC) certified reference materials with wavelength dispersive XRF equipment. The results of the parallel analysis of concentrations of elements in certified reference materials are given in Table 1.

Table 1. Analysis of standard reference materials.

Elements	EEC standard reference material used	Certified value (μg/m^3)	Concentration obtained (μg/m^3)	Percentage deviation
Mg	056K85	10.24	10.63	3.81
Al	6/500	3.78	3.48	7.94
Si	6/500	6.77	6.44	4.87
S	050K2	2.30	2.15	6.52
Cl	051L8	10.02	9.41	6.09
K	034C84	5.70	5.68	0.35
Ca	007E2	4.00	3.91	2.25
Ti	012A2	1.40	1.39	0.71
Cr	012A2	1.40	1.39	0.71
Fe	012A2	1.40	1.38	1.43
Ni	012A2	1.40	1.36	2.86
Zn	012A2	1.40	1.38	1.42
V	034B9	0.72	0.73	1.39
Mn	034B9	0.71	0.72	1.41
Co	034B9	0.71	0.72	1.41
Br	065B9	1.89	1.78	5.82
Pb	036B9	0.89	0.84	5.67

Receptor models. Enrichment Factor (E_f) was calculated for all elements by using the following equation:

$$E_f = \left\{\frac{\text{Concentration of } X_i \text{ in sample}}{\text{Concentration of Al in sample}}\right\} \div \left\{\frac{\text{Concentration of } X_i \text{ in crustal rock}}{\text{Concentration of Al in crustal rock}}\right\}$$

where X_i = the element of interest. Al was used as normalizing element and average elemental content of crustal rock was used as normalizing matrix [10].

Elemental concentrations of coarse particulate matter (CPM) and fine particulate matter (FPM) from each of the sites were subjected to factor analysis (FA) by using SAS statistical package [11]. In order to determine the number of factors to retain in our result, the value of variance after rotation were examined and only factors with variance equal to or greater than one after rotation were considered significant to be retained [12].

The modified form of the chemical mass balance (CMB) model developed by Dzubay *et al.* [13] was used for source apportionment of the SPM. In taking the decision of the sources to include in the CMB, three criteria were taken into consideration. They are: (i) the result of the factor analysis, (ii) the knowledge of the environment and emission points around the sampling site and (iii) the result of the combination of sources that give the best fit.

RESULTS AND DISCUSSION

The range and means of gross elemental concentrations together with the mean enrichment factors calculated for the three sites in Lagos are presented in Table 2.

Table 2. Range of elemental concentrations and their enrichment factors from three sites in Lagos.

Element	Concentrations (ng/m^3)								
	Site 1			Site 2			Site 3		
	Range	Mean	E_f	Range	Mean	E_f	Range	Mean	E_f
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	1.0	257-1243	758	1.0	315-1315	832	1.0
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	1613	1931	803-3662	1888	2158	365-2544	1673	1599
K	115-809	482	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	20	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 particulate.

The enrichment factors (E_f) calculated for the three sites show that the E_f of Al, Si, Ca, Ti, Mn and Fe are less than 4 in the sites studied. This shows that anthropogenic contributions to these elements in Lagos atmospheric environment are minimal. K a marker element for wood burning has a significant E_f (5.13) in site 2 (Yaba). Site 2 is a medium-population density commercial/ residential area, where a considerable number of residents use firewood for cooking. This may be responsible for the enrichment of K.

The high E_f of Na is due to the influence of the sea as Lagos is situated on the coast of the Atlantic ocean. The E_f of Cl is much higher (above 1000), because besides sea spray, enrichment of Cl could be due to many factors such as incineration, vehicular exhaust/oil combustion and industry. Enrichment of S is attributed to secondary aerosols originating from industrial emissions.

The high enrichment of Br and Pb at the three sites in Lagos is believed to be due to the heavy motor traffic (leaded gasoline is still in use in Nigeria) while the high enrichment of V is believed to be due to industrial/residual fuel combustion. Cr and Zn also have high enrichment factors. These two elements are contained in some essential motor parts hence they are attributed to wear and tear of vehicles.

Factor analysis. The factor loadings for coarse and fine particulates at sites 1 and 2 together with the variance of each factor and the probable source/sources are presented in Tables 3-6.

Table 3. Factor loading[*] for site 1 coarse particulate matter.

Element	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Communality
Si	0.94	-	-	-	-	0.985
Al	0.93	-	-	-	-	0.911
Ti	0.92	-	-	-	-	0.983
Fe	0.89	-	-	-	-	0.980
V	0.86	-	-	-	-	0.906
Ca	0.82	-	-	-	-	0.802
K	0.58	-	-	0.54	-	0.855
Na	-	0.93	-	-	-	0.921
Cl	-	0.92	-	-	-	0.936
Mn	0.48	0.63	-	0.45	-	0.883
Br	-	-	0.94	-	-	0.931
Mg	0.51	-	0.68	-	-	0.796
S	-	-	-	0.81	-	0.798
Pb	-	-	0.58	0.63	-	0.801
Zn	-	-	-	-	0.87	0.962
Variance	5.87	2.72	1.93	1.83	1.10	
% Variance	43.6	20.2	14.3	13.6	8.2	
Possible source	Soil	Marine	Traffic	Traffic/ incineration	Traffic/ industry	

[*] Values less than 0.40 are replaced with "-".

Table 3 shows the results of factor analysis of CPM from site 1. Five factors were identified. Factor 1 has high factor loadings for Si, Al, Ti, Fe, V and Ca with moderate loadings for K, Mn and Mg. This represents contributions from the soil referred to as crustal factor. Factor 2 shows high loadings for Na and Cl which is believed to be due to sea spray. Factor 3, with high loadings for Br, Mg and Pb is attributed to automobile exhaust. Mg is not a part of the exhaust but is present as an artifact. Factor 4 is loaded in K, Mn, S and Pb. This could be due to refuse incineration/industrial factor. Pb might come from a battery making industry nearby while K and Mn might be due to incineration. Factor 5 has a high loading for Zn which might be due to emissions from industrial activities or tyre wear.

For FPM at site 1, five factors were identified (Table 4). The first factor has high loadings for crustal elements (Ti, Si, Al, Fe, V and Ca) and it is identified as contributions from the soil. Factor 2 with high loadings for Pb, K, S, Cl and Mn is attributed to municipal incineration. Factor 3 is loaded in Br, which correlates negatively with Mn. This could be as a result of fresh automobile exhaust. Factor 4, a unique factor for Zn, could be due to tyre wear or industry. Factor 5 with high loadings for Na and a weak correlation with V could not be ascribed to any particular source.

Table 4. Factor loading[*] for site 1 fine particulate matter.

Element	Factor1	Factor 2	Factor 3	Factor 4	Factor 5	Communality
Si	0.98	-	-	-	-	0.979
Fe	0.97	-	-	-	-	0.964
Al	0.96	-	-	-	-	0.978
Ti	0.95	-	-	-	-	0.972
Ca	0.82	-	-	-	-	0.835
V	0.71	-	-	-	0.41	0.896
Pb	-	0.89	-	-	-	0.826
K	-	0.88	-	-	-	0.893
S	-	0.87	-	-	-	0.849
Cl	-	0.75	-	-	-	0.781
Br	-	-	0.88	-	-	0.896
Mn	-	0.62	-0.63	-	-	0.839
Zn	-	-	-	0.94	-	0.919
Na	-	-	-	-	0.85	0.933
Variance	5.17	3.44	1.50	1.35	1.09	
% Variance	41.2	27.4	12.0	10.8	8.7	
Possible source	Soil/dust	Incineration	Fresh auto exhaust.	Traffic	-	

[*] Values less than 0.40 are replaced with "-".

Table 5 gives the factor loadings for CPM at site 2. Four factors were identified. Factor 1 has high loadings for K, Fe, Ti, Si, V, Al, Mn, Ca and S. This factor is believed to be due to contribution from the soil. Factor 2 loaded in Na and Cl is obviously due to marine influence. Factor 3 is loaded in Br and Pb. This is due to vehicular emission. Factor 4 is unique for Zn and it is attributed to tyre wear.

Five factors were retained in the factor analysis of FPM from Site 2 (Table 6). Factor 1 with high loading in Ti, Fe, Al, Si, Ca, V and Mn represents soil contribution. The second factor loaded in S and K is due to refuse incineration. Factor 3 is highly loaded in Br and Pb. This is obviously due to vehicular exhaust. Factor 4 gives a good correlation between Na and Cl. This is ascribed to marine influence. Factor 5 is unique for Zn and is attributed to tyre wear or industry.

Table 5. Factor loading* for coarse particles from site 2.

Element	Factor 1	Factor 2	Factor 3	Factor 4	Communality
K	0.96	-	-	-	0.977
Fe	0.95	-	-	-	0.988
Si	0.94	-	-	-	0.989
V	0.93	-	-	-	0.945
Al	0.89	-	-	-	0.957
Mn	0.86	-	-	-	0.891
Ti	0.84	-	-	-	0.880
Ca	0.68	-	-	-	0.957
S	0.64	-	-	-	0.704
Na	-	0.96	-	-	0.940
Cl	-	0.93	-	-	0.974
Br	-	-	0.98	-	0.972
Pb	-	-	0.88	-	0.955
Zn	-	-	-	0.86	0.934
Variance	6.91	2.67	2.13	1.35	
% Variance	52.9	20.4	16.3	10.3	
Possible source	Soil	Marine	Vehicular exhaust	Traffic	

*Values less than 0.40 are replaced with "-".

Table 6. Factor loading* for fine particles from site 2.

Element	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Communality
Si	0.98	-	-	-	-	0.997
Al	0.98	-	-	-	-	0.986
Ti	0.97	-	-	-	-	0.982
Fe	0.96	-	-	-	-	0.984
Ca	0.95	-	-	-	-	0.935
V	0.90	-	-	-	-	0.950
Mn	0.83	-	-	-	-	0.951
S	-	0.91	-	-	-	0.953
K	-	0.74	-	-	-	0.967
Pb	-	-	0.94	-	-	0.951
Br	-	-	0.84	-	-	0.911
Na	-	-	-	0.86	-	0.948
Cl	-	-	-	0.66	-	0.928
Zn	-	-	-	-	0.95	0.942
Variance	6.57	1.94	1.94	1.59	1.34	
% Variance	49.1	14.5	14.5	11.9	10.0	
Possible source	Soil / Dust	Incineration	Vehicular Exhaust.	Marine	Traffic	

*Values less than 0.40 are replaced with "-".

Chemical mass balance

The CMB results are presented in Tables 7-10.

Site 1 (Ikeja). The CMB model performed on the coarse particles from site 1 (Table 7), results in the mass apportionment of the 13 elements into four contributing sources. The sources are: soil, marine, vehicular exhaust and regional sulphate. These are the sources that are either obtained prominently in the FA of the coarse particulates from the site or added as a result of criteria (iii) above.

Table 7. Mass apportionment of coarse particulates from site 1.

Elements	Soil	Marine	Vehicular exhaust	Regional SO_4^{2-}
Na (1295)	70	607	-	3
Al (442)	372	-	1	-
Si (532)	1114	-	1	-
S (185)	19	65	1	99
Cl (916)	2	783	1	-
K (175)	156	27	-	-
Ca (643)	201	27	1	-
Ti (111)	59	-	-	-
Mn (10)	4	-	-	-
Fe (765)	357	-	1	-
Zn (23)	3	-	-	-
Br (5)	-	4	2	-
Pb (14)	3	-	6	-
Total (%)	46.1	29.6	0.3	2.0

*The number in parentheses represents the average measured concentration (in ng.m^{-3}).

The following are the percentage contribution of various sources to the observed elemental concentrations of the coarse fraction of air particulates from site 1: soil (46.1%), marine (29.6%), vehicle exhaust (0.3%) and regional sulphate (2.0%). The total apportioned concentration is 78% of the observed elemental concentrations of the coarse fraction.

In the computation, concentrations of Na, Ca, Ti, Mn, Fe and Zn were underestimated, while the concentration of Si was overestimated. Underestimation of elemental concentrations indicates that those elements are more prominent in the environment than calculated by CMB. The reasons for such observation could be: (i) one major source of the element is not included in the CMB calculation, and (ii) the particular element's concentration in the source signature might be less than the actual concentration of the element from that particular source.

Ti, Mn and Fe are crustal elements. Underestimation of these could be because their actual concentrations in soil dust at site 1 (Ikeja) are much higher than their concentrations in the soil signature input of the CMB programme. In addition, there could be additional contributions to Ti from some paint factories nearby, and to Fe/Mn from some metal smelting factories in the area. The latter reason is quite plausible because Enrichment Factors of Ti, Fe and Mn were in some cases as high as 4.4, 5.0 and 11.6, respectively, at this site (Table 2).

In the case of Ca, its underestimation in the calculation would likely be due to significant cement contribution (Ca is a marker element for cement) from building construction, which was not one of the factors considered in the CMB calculation.

For Zn, as discussed earlier, a significant contributor might be tyre wear factor. However, the source signature for this factor is not well known and hence, not included in CMB programme. Non-inclusion of this source signature most probably accounts for the underestimation of Zn. The slight underestimation of Pb could be due to some nearby lead-smelting factories, which make additional contribution besides vehicle exhaust (the only Pb source supplied in the CMB programme) to the Pb concentration.

The reason for overestimation of Si in the calculation is not clear, but it could be that the Si concentration in the soil signature used in the CMB is much higher than Si concentration in Ikeja soil dust.

A fine particle CMB based on Na, Al, Si, S, Cl, K, Ca, Ti, V, Mn, Fe, Zn, Br and Pb was carried out on elemental concentration of fine particulates from Ikeja which resulted in the apportionment of 82.8% of the observed mass concentration into six sources viz: soil/dust (29.6%), marine (27.8%), oil combustion (4.9%), incineration (2.5%), vehicle exhaust (4.0%), and regional sulphate (14.0%) (Table 8).

Table 8. Mass apportionment of fine particulates from site 1.

Elements	Soil	Marine	Oil combustion	Incineration	Vehicular exhaust	Regional SO_4^{2-}
Na (598)	69	601	22	10	-	-
Al (215)	215	-	5	-	1	-
Si (302)	363	2	15	3	3	-
S (695)	3	64	82	4	18	522
Cl (734)	1	775	-	43	17	-
K (315)	63	27	1	11	-	-
Ca (365)	89	27	20	-	8	-
Ti (46)	13	1	1	-	-	-
V (11)	-	-	11	-	-	-
Mn (16)	2	-	-	-	2	-
Fe (320)	193	-	11	-	10	-
Zn (39)	-	-	7	15	1	-
Br (31)	-	4	-	-	22	-
Pb (68)	1	-	10	9	68	2
Total (%)	29.6	27.8	4.9	2.5	4.0	14.0

The number in parentheses represents the average measured concentration (in ng.m^{-3}).

K, Ca, Ti and Mn were underestimated in the result. Potassium is a marker element from wood combustion. It comes out strongly in the second factor ascribed to incineration in the factor analysis (Table 4). Its underestimation is perhaps because there is no wood combustion signature in the CMB input. The underestimation of Ca and Ti is probably due to the absence of cement factor and paint pigment manufacture inputs in the CMB programme as stated for the coarse particulates from this site. As explained above, Mn is underestimated because a steel work factor was not included in the CMB. Mn could come from steel industry or coal. In Lagos, there is no indication of any coal burning hence, it is assumed that Mn comes from steel industry.

Site 2 (Yaba). Thirteen elements and four sources were included in the CMB of the coarse particulates from Site 2. The elements are: Na, Al, Si, S, Cl, K, Ca, Ti, Mn, Fe, Zn, Br and Pb. While the sources included are: soil/dust, marine, vehicle exhaust and regional sulphate (Table 9). 82% of the observed concentration were apportioned by CMB as follows: soil (54.1%), marine (26.2%), vehicle exhaust (0.3%) and regional sulphate (1.9%). Si was overestimated while Na, Ca and Zn were underestimated for similar reasons stated for the result of coarse particulates from site 1.

Table 9. Mass apportionment of coarse particulates from site 2.

Elements	Soil	Marine	Vehicular exhaust	Regional SO_4^{2-}
Na (1725)	105	680	-	4
Al (497)	560	-	-	-
Si (688)	1625	-	1	-
S (224)	29	72	2	120
Cl (1093)	3	877	1	-
K (280)	235	31	-	-
Ca (809)	303	31	1	-
Ti (117)	88	-	-	-
V (8)	2	-	-	-
Mn (9)	6	-	-	-
Fe (981)	536	-	1	-
Zn (23)	5	-	-	-
Br (5)	-	4	3	-
Pb (18)	5	-	8	-
Total (%)	54.1	26.2	0.3	1.9

[*] The number in parentheses represents the average measured concentration (in ng m^{-3}).

The source concentration profiles of soil, marine, oil combustion, incineration, vehicle exhaust and regional sulphate were applied to fine particulates (Table 10). 93% of the observed concentration were apportioned into the six contributing sources as follows: soil (35.5%), marine (34.2%), oil combustion (4.9%), incineration (2.9%), vehicle exhaust (3.5%) and regional sulphate (12.1%).

K, Ca, Ti and Mn were underestimated. The reason for the underestimation of K could be due to the fact that the sampling site is located in a commercial/residential area for medium income people. In the area, many residents use firewood for cooking, most especially the operators of local food canteens. The strong K signature most likely comes from wood combustion. The underestimation of Ca is due to cement from building construction as explained earlier.

Ti was underestimated like in site 1. There is no paint manufacturing industry in the neighbourhood of this site. It is believed that the fine particle Ti is due to the long-range transport of aerosol from the industrial estate around Ikeja.

Table 10. Mass apportionment of fine particulates from site 2.

Elements	Soil	Marine	Oil combustion	Incineration	Vehicular exhaust	Regional SO_4^{2-}
Na (528)	107	605	25	13	-	-
Al (262)	334	-	6	1	2	-
Si (466)	562	2	18	3	3	-
S (718)	5	64	97	6	18	534
Cl (795)	1	781	-	59	17	-
K (438)	98	28	1	15	-	-
Ca (469)	138	27	24	-	8	-
Ti (64)	21	1	1	-	-	-
V (13)	-	-	13	-	-	-
Mn (16)	3	-	-	-	2	-
Fe (519)	299	-	13	-	10	-
Zn (38)	1	-	8	21	1	-
Br (29)	-	4	-	-	23	-
Pb (72)	2	-	11	12	70	2
Total (%)	35.5	34.2	4.9	2.9	3.5	12.1

•The number in parentheses represents the average measured concentration (in ng m^{-3}).

Site 3 (Ikoyi). Samples collected at site 3, located at Ikoyi, a distance of about 1/2 km from the Atlantic ocean were also analyzed and the result subjected to factor analysis and chemical mass balance resulting in the apportionment of 84% of the observed coarse particulates as follows: soil (50.4%), marine (27.3%), incineration (2.5%) and regional sulphate (1.9%). 93.6% of the observed concentration of fine particulates from this site was apportioned into five sources as follows: soil (56.9%), marine (24.4%), incineration (4.5%), vehicular exhaust (0.7%) and regional sulphate (8.1%). It is interesting to note that there is no significant difference in the elemental concentrations of the samples collected at this site and the other two sites in Lagos because, this third site at Ikoyi area is of low population density which is also devoid of industrial establishments.

CONCLUSION

This study of suspended particulate matter (SPM) at three sites in Lagos between 1989 and 1991 shows that the mean levels of SPM in the sites were 176 ± 78, 188 ± 64, 92 ± 36 $\mu g/m^3$ at Ikeja, Yaba and Ikoyi, respectively. These values satisfy the Nigerian ambient air quality standard of 250 $\mu g/m^3$.

From the results of the factor analysis of the three sites in Lagos, four sources are very prominent in their contributions to air particulate loading in Lagos metropolis. They are soil, marine, automobile traffic and incineration.

There are no major differences in elemental composition of the SPM, contributing factors and relative contributions of the different factors at the three sites of Lagos. Apparently, there is efficient mixing of airborne particulate matter at the sampling levels (about 9 m). Thus measurement of air particulate concentration (at or greater than 9 m) at any location in the Lagos area is fairly representative of the airshed in the metropolis.

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