ATMOSPHERIC TRACE METAL CONCENTRATIONS IN SUSPENDED PARTICULATE MATTER (SPM) OF A RURAL RESIDENTIAL AREA IN SOUTHERN NIGERIA

[1]Ukpebor, J. E., [2]*Ukpebor, E. E., [2]Kadiri, V. I., [3]Odiase, J. I., [2]Okuo, J. M. and [2]Ogbeifun, D.

[1]Lancaster Environment Centre, Lancaster University, Lancaster LA1 4YQ, UK
[2]Air Pollution Research Group, Department of Chemistry, University of Benin, Nigeria
[3]Department of Mathematics and Statistics, University of Benin, Benin City, Nigeria
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ABSTRACT

Trace metals are one of the most toxic constituents of atmospheric particulates. The baseline concentrations of Pb, Cd, Zn and Cr in airborne particulates collected at a rural community in southern Nigeria have been evaluated. The particulate samples from where the metals were characterized and quantified, were collected between December 2007 and March 2008, using a Gravimetric technique a portable SKC 506673 High volume Gravimetric sampler. The air particulate samples were collected from the kitchens, living rooms and outdoor environment of five households in the community. The quantification of the trace metals was done using Atomic Absorption spectrometry method, employing HNO_3 based wet digestion. High baseline concentration of SPM were obtained with an outdoor range of 240.74 555.55 μgm^{-3}, living room range of 546.30 955.56 μgm^{-3} and kitchen range of 425.92 1444.00 μgm^{-3}. However, relatively low concentrations of the trace metals were measured in the samples with Zn and Cr being the most abundant. The outdoor and kitchen Zn concentration ranged from < 0.0001 0.0603 μgm^{-3} and 0.0185 0.1171 μgm^{-3} respectively, while the Cr levels were < 0.0001 0.0252 μgm^{-3} (outdoor) and < 0.0001 0.0204 μgm^{-3} (kitchen). The correlation matrix analysis showed a strong positive correlation between the kitchen, living room and outdoor sites, suggesting identical sources of the trace metals. Principal component analysis (PCA) identified two fundamental sources of the metals, which was further confirmed by the hierarchical cluster analysis.

Keywords: Heavy Metals, Suspended Particulate Matter, Rural Area

INTRODUCTION

Understanding the composition of atmospheric particulate matter is crucial for so many reasons. Trace metals are however one of the most toxic constituents of atmospheric particulates. The size and composition of airborne particulates play an important role in determining their health effects (Radojevic and Bashkin, 2007). The particle size for instance relates to how deeply the particles will react in the respiratory system. It also relates to the deposition velocity, which in turn, relates to the residence time in the atmosphere and hence the potential for long range transport in the atmosphere (Radojevic and Bashkin, 2007). Specific components of suspended particulate matter (SPM) include combustion particles (particles of elemental and organic carbon); secondary particles (particles of ammonium sulphate/sulphuric acid and ammonium nitrate); and lastly coarse particles (surface dust re-suspended by traffic activity and made up mainly of inorganic mineral components) (Harrison, 2001).

The components of airborne particles which raise the most health concerns are the trace metals and trace organic compounds. Interest in trace metals relates primarily to their potential toxicity. Metals have a variety of effects upon the human body, mostly at the cellular level. While some metals disrupt biochemical reactions others block essential biological processes, including the absorption of nutrients. Some accumulate in the body giving rise to toxic concentrations after many years of exposure and yet others such as Argon, Beryllium, Cadmium and Chromium are carcinogens (Friberg et al., 1986). Among the trace metals which have stimulated the greatest interest in relation to public health is lead. The health effects of lead have been studied extensively and are well documented (EPA, 1986; Krewski et al., 1989). Young children are especially vulnerable; lead poisoning of children leads to permanent brain damage, causing learning disabilities, hearing loss, and behavioural abnormalities. In adults, lead absorption causes hypertension, blood pressure problems and heart disease (EPA, 1986; Krewski et al., 1989). The main sources of airborne lead are motor vehicles using leaded gasoline, industrial processes such as ferrous and non ferrous metallurgy and coal combustion.

Studies and data on trace metal content of atmospheric particulate matter in Nigeria are scanty. A study conducted around cement factories in Nigeria reported Pb, Zn and Cu ranges of 2.30 9.40 μgm^{-3}, 0.10 14.00 μgm^{-3} and 0.10 0.90 μgm^{-3} respectively (Akeredolu et al., 1994). Furthermore, in a recent study, in Benin City, Nigeria using *Delonix regia* and *Casuarina equisetifolia* to assess the levels of trace metals in the atmosphere (Ukpebor et al., 2010), a Pb range of 20.00 70.00 μg/g was reported. Some of these reported trace metal levels in Nigeria urban centres are worrisome, as they tend to violate existing regulatory standards. However, in the rural communities, limited studies have been conducted on air quality assessment despite the fact that ~ 63% of Nigeria's over 140 million people live in these rural communities (NPC, 2006; NDHS, 2008). Within these communities there exist a very high degree of vulnerability to air quality impairment because of the abundant use of firewood and the re suspension of dust particles from the daily sweepings of these earth roads. Ideriah et al., (2001) reported highly elevated levels of airborne particles in both indoor and outdoor environments in some rural communities in south eastern Nigeria. Furthermore, an observational study by Edet (2003) relying on proxies such as fuel and stove type and time spent near the fire inferred that the significance of air pollution to health was a major health challenge in rural communities in Nigeria.

The scant information on trace metal content of airborne particles from rural communities makes assessing their contributions to the high mortality and morbidity difficult to ascertain. In this study, the baseline concentrations of Pb, Cd, Zn and Cr in particulate matters from outdoors, kitchen and living rooms of a rural community in Nigeria were evaluated. The data obtained were further compared with available regulatory standards to ascertain their compliance and lastly, the data would be made available to government agencies for effective policy formulation and epidemiological studies.

EXPERIMENTAL DATA AND METHODS

Study area

This study was conducted at Iyowa Community in Ovia Northeast Local Government of Edo State, southern Nigeria (Fig. 1). The community is completely rural, sparsely populated; the settlement is linear with a majority of the houses made of mud and a few block houses roofed with rusted iron sheets. The climate is typically humid (39.0 77.5%), with high tropical ambient temperature (28.2 35.8 ^{o}C) and low wind speed (0.4 2.9 m/s) (Table 11). There are two distinct seasons (wet and dry) and an average rainfall of about 1898.0 mm with two distinguishing peaks in July (3313.0 mm) and September (3621.0 mm) (Iyamu, 2004).

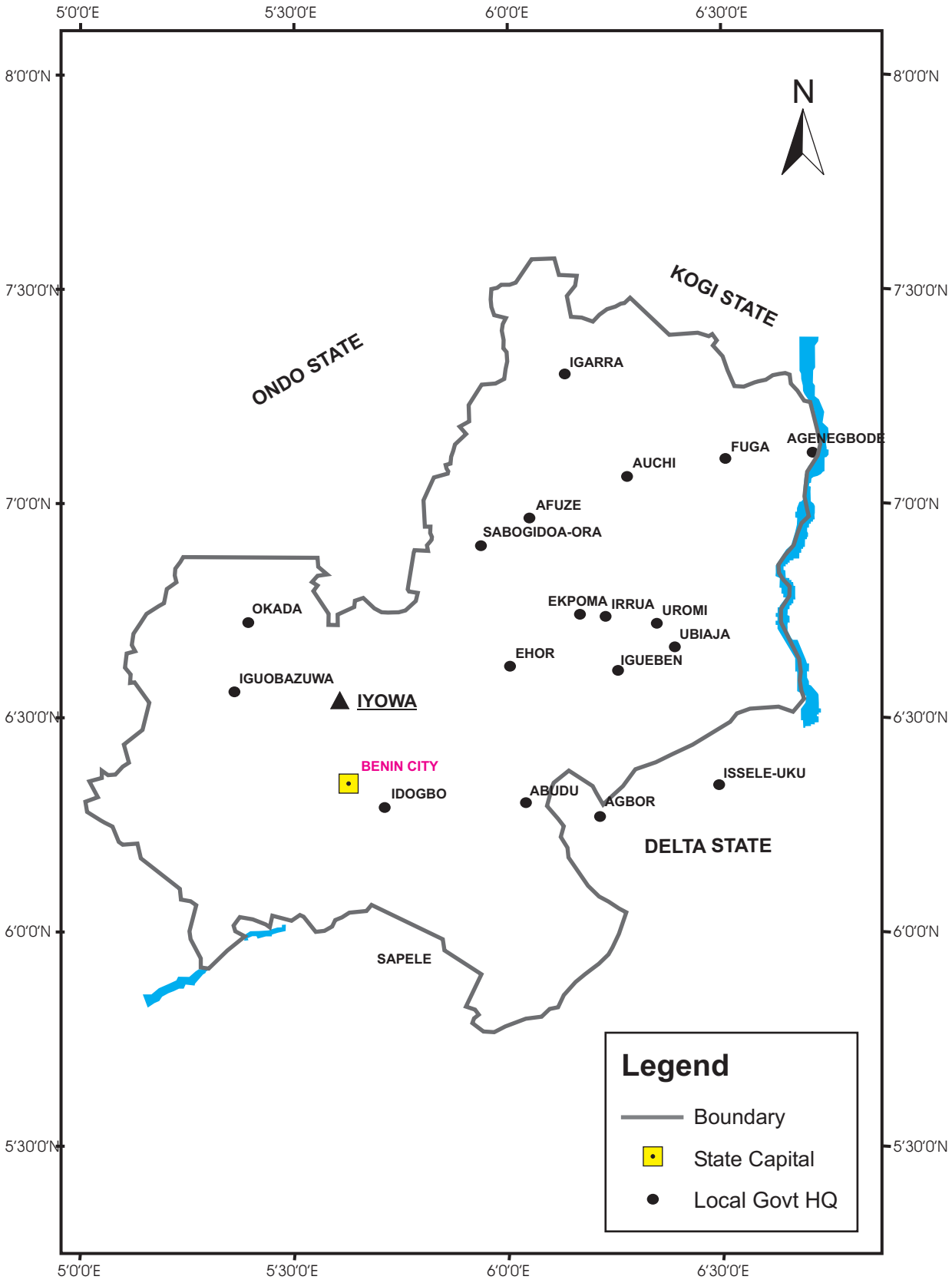

Figure 1: Edo State Map Showing Iyowa Community

The vegetation is natural and predominantly rain forest and the main source of water are streams and rain. Electricity supply is erratic and the means of transportation include motor cycles and bicycles. The predominant occupation is farming while cooking in this community is done exclusively by the use of firewood and crop residues. Lighting in the night is more by the use of kerosene lamps.

Remarkably, health records from the community health centre, reveals a high prevalence of air pollution related health problems (e.g. catarrh, cough, asthma and emphysema).

Selection of Homes/Sites

Selection of households for this study was based completely on voluntary participation. Five households were selected to represent the five quarters of the community. Characteristics of the house and its occupants were collected using a standard environmental inventory questionnaire (Lebowitz et al., 1989). Household level parameters collected included kitchen type, fuel type, household ventilation, cooking duration and other potential sources of particulates inside homes such as outdoor combustion sources, cigarette smoking and mosquito coils. Information on sex, age, and smoking habits were reported in a daily diary. It provided information about the daily activity pattern (number of hours spent in cooking at home, and time spent on other activities).

Table 1 represents the description of the characteristics of the homes and kitchen. The outdoor sites were geo referenced by using GARMIN GPS MAP 765 chart plotting receiver.

Table 1: Description and Characteristics of the Households and Kitchens Assessed.

Household	Code	Coordinates	Kitchen type and configuration	Fuel type	Building type	Ventilation
A	AK AP AO	N06°28.494 E005°36.155	Detached kitchen made of bamboo and palm leaf	Wood	Cement wall house with zinc roof	Good with doors and windows
B	BK BP BO	N06°28.357 E005°36.195	Detached kitchen made of wood and clay	Wood	mud house with unceiled roof	Poorly ventilated apartment
C	CK CP CO	N06°28.349 E005°36.172	Detached kitchen made of palm leaves and bamboo sticks	Wood	Mud house with zinc roof	Fairly good
D	DK DP DO	N06°28.309 E005°36.176	In built and attached kitchen	Wood	Mud house With zinc roof	Poor
E	EK EP EO	N06°28.419 E005°36.161	Detached kitchen made of wood and Clay	Wood	Cement wall house with zinc roof	Well ventilated with doors and windows

K = Kitchen, P = Living room O = Outdoor

Data Collection

SPM High Volume Gravimetric Sampler

Airborne particles were collected on Whatman glass fibre filters using a portable high volume gravimetric sampler (SKC UK Model no. 506673). The sampler was placed on a tripod with height of ~ 1.5 and 2.0 m at each sampling spot. The sampling unit consists of a gas pump, a filter holder manifold connected to the sampling pump by a Teflon tube. A gas flow rate meter with a rate of 0 5 $Lmin^{-1}$ was used to measure the air flow rate during sampling. Before sampling, all unloaded glass fibre filters were dried in a desiccator at room temperature and their initial weights were taken. The particulates were collected on the pre weighed filter by pumping 2.5 $Lmin^{-1}$ volume of air through it for 8 hrs. Sampling was done between December 2007 and March 2008 on alternate days at the sampling sites (1 m from the fire source, 0.8 m from the front of the house and at the centre of the living room). After sampling, the loaded filter was again dried in a desiccator and reweighed to determine the final weight. The concentration of the airborne particles in the air was determined gravimetrically. The duration of sampling and the average flow rate were recorded (Shaw, 1987; UNEP/WHO, 1994). This measuring approach was done according to

EN12341 (CEN, 1999), the reference method defined in EU Directive 1999/30/EC. The collection efficiency of this technique under field conditions in the tropics, has recently been ascertained (Ukpebor et al., 2006).

After sampling, the glass fiber filters were transferred into containers brought to the laboratory and stored in the dark prior to extraction/analysis for heavy metals. The filters were placed in a beaker to which 20 mL of 0.25 M HNO_3 was added (Bagiroz, 2002; Bozlaker, 2002). The solution was then concentrated to about 5 mL on a hot plate at 150 ^{o}C to 180 ^{o}C. After this, 10 mL of 1:1 HNO_3 was further added and the extract was filtered through a Whatman filter paper. The beaker and filter paper was washed with successive aliquot of 0.25 M HNO_3. The filtrate and washings were finally transferred into a 50 mL volumetric cylinder and made up to the mark with the dilute HNO_3. Unused filters from the same batch were extracted in the same way to determine the blank values (Basha et al., 2010). Samples were analyzed using Flame Atomic Absorption Spectrophotometer (AA 6701 Shimadzu) and standard quality control solutions were used (USEPA, 2001). Detection limits for the metals was 0.0001 μgm^{-3}.

Meteorological Data: The rural community of Iyowa has no weather station, consequently air temperatures, relative humidity and wind speeds were measured simultaneously during the sampling duration. These parameters significantly affect the ambient concentrations and spatial distributions of SPM and therefore would be relevant in the interpretations of the measured data.

Measurements were taken every half hour from 8.00 a.m. to 8.00 p.m. on alternate days. The air temperature/humidity was measured using RS humidity/Temperature meter with resolution of 0.1% RH and 0.1^{o}C (Model RS 1364, RS Component Ltd UK). Wind speeds were also measured using an LM 8000 Anemometer (Heatmiser UK) with a resolution of 0.1 ms^{-1}.

Statistical analysis: The results of pollutant concentrations obtained were subjected to inter correlation matrix, principal component factor analysis and cluster analysis using Microsoft office Excel 2007 and SPSS 16.0.

RESULTS AND DISCUSSION

Heavy metals concentration in airborne particulate matter is of serious environmental concern, because of the health implications of their high doses in the atmospheric environment. The baseline levels of Pb, Cd, Zn and Cr obtained at Iyowa village during the study are summarized in Tables 2, 3 and 4.

Outdoor Heavy Metals Concentration

The outdoor particulate matter concentration used for the quantification of the trace metals ranged from 240.74 - 555.55 μgm^{-3}. These values clearly violated the WHO regulatory limit of 150 230 μgm^{-3} (WHO, 2000); while some of the values obtained violated the Nigeria Federal Ministry of Environment statutory limit of 250 μgm^{-3} (FEPA, 1991).

However, relatively low baseline concentrations of the trace metals were measured in the front of the homes examined. Lead was not found in measurable quantities in households A, B and D. In locations C and E, the mean Pb concentrations were 0.0015 μgm^{-3} and 0.0029 μgm^{-3} respectively. Zinc gave the highest concentration of the trace metals studied with a range of < 0.0001 0.0603 μgm^{-3}. The highest Cd mean concentration of 0.0039 μgm^{-3} was measured in household B. In location C, Cd was not detected. Chromium was also present at very low levels with the highest mean concentration of 0.0252 μgm^{-3} measured in site E. The concentrations of the characterized metals were within the typical rural concentration ranges (Table 5) and also within the available WHO limits for Pb (0.5 μgm^{-3}) and Cd (0.005 μgm^{-3}) (WHO, 2000). The typical rural Pb, Cd and Zn concentration ranges are 0.02 2.0 μgm^{-3}, 0.0001 1.0 μgm^{-3} and 0.003 0.1 μgm^{-3} respectively. There are no national limits for trace metals in Nigeria.

Table 2: Concentration of Outdoor Heavy Metals and Particulate Matter at Iyowa (μgm^{-3})

	Monitoring Stations				
Metal	**AO**	**BO**	**CO**	**DO**	**EO**
Pb	< 0.0001	< 0.0001	0.0015 ± 0.0002	< 0.0001	0.0029 ± 0.0003
Zn	0.0340 ± 0.0010	0.0395 ± 0.0012	0.0603 ± 0.0009	0.0595 ± 0.0013	< 0.0001
Cd	0.0022 ± 0.0009	0.0039 ± 0.0012	< 0.0001	0.0023 ± 0.0008	0.0010 ± 0.0004
Cr	< 0.0001	0.0187 ± 0.0024	0.0136 ± 0.0019	0.0045 ± 0.0007	0.0252 ± 0.0016
SPM	333.34 ± 28.20	240.74 ± 19.65	323.98 ± 20.61	555.55 ± 37.23	303.84 ± 29.64

n = 8 **detection limits for Pb, Zn, Cd, Cr = 0.0001 μgm^{-3}**

Table 3: Kitchen Concentration of Heavy Metals and Particulate Matter at Iyowa (μgm^{-3})

	Monitoring Stations				
Metal	**AK**	**BK**	**CK**	**DK**	**EK**
Pb	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
Zn	0.0282 ± 0.0009	0.0450 ± 0.0013	0.0522 ± 0.0024	0.1171 ± 0.0097	0.0185 ± 0.0070
Cd	0.0034 ± 0.0006	0.0035 ± 0.0011	0.0043 ± 0.0014	0.0013 ± 0.0008	0.0030 ± 0.0004
Cr	< 0.0001	0.0204 ± 0.0015	0.0065 ± 0.0007	< 0.0001	0.0171 ± 0.0020
SPM	925.93 ± 47.34	1444.00 ± 53.74	1067.80 ± 51.73	425.93 ± 40.71	1222.22 ± 48.43

n = 8 **detection limits for Pb, Zn, Cd, Cr = 0.0001 μgm^{-3}**

Table 4: Living Room Concentration of Particulate Heavy Metals and Particulate Matter at Iyowa (μgm^{-3})

	Monitoring Stations				
Metal	**AP**	**BP**	**CP**	**DP**	**EP**
Pb	0.0003 ± 0.0001	< 0.0001	< 0.0001	< 0.0001	0.0003 ± 0.0001
Zn	0.0336 ± 0.0012	0.0505 ± 0.0019	0.0537 ± 0.0023	0.1013 ± 0.0086	< 0.0001
Cd	0.0039 ± 0.0005	0.0022 ± 0.0007	0.0016 ± 0.0008	< 0.0001	0.0057 ± 0.0014
Cr	0.0053 ± 0.0014	0.0123 ± 0.0082	0.0233 ± 0.0094	0.0033 ± 0.0008	0.0234 ± 0.0017
SPM	814.45 ± 31.84	654.23 ± 27.44	955.56 ± 41.22	629.45 ± 33.20	546.30 ± 28.74

n = 8 **detection limits for Pb, Zn, Cd, Cr = 0.0001 μgm^{-3}**

Table 5: Typical Concentrations of Some Trace Metals in Air

	Concentration range (μgm^{-3})	
Metal	**Urban**	**Rural**
Pb	0.1 – 10.0	0.02 – 2.0
Cd	0.0005 – 0.5	0.0001 – 0.1
Zn	0.02 – 2.0	0.003 – 0.1
Fe	0.1 – 10.0	0.04 – 2.0
Cu	0.05 – 1.0	0.001 – 0.1

Source: Radojevic and Bashkin 2007

However, WHO has regulatory limits for Pb and Cd and they are 0.5 μgm^{-3} and 0.005 μgm^{-3} respectively. Pb and Cd data from this study also complied with the above limits. There are no standards for Cr and Zn.

Spatial variations were not evident in the trace metal distributions, with identical concentrations reported in all the outdoor sampling sites. Factors responsible for spatial and ambient concentrations of air pollutants which could also be responsible for the trend in this community, include emission strength, emission rate, emission conditions and atmospheric dispersion conditions (Baumbach et al., 1995). At all the sites, dispersion conditions were similar characterized by low wind speed, high ambient temperature and moderately humid atmosphere (Table 6). Anthropogenic sources of trace metals were observed to be low in the community. The main anthropogenic sources of trace metals include metal manufacturing industries, fossil fuel (petroleum, coal, gas) combustion, burning of solid waste and incinerators. At Iyowa, these anthropogenic trace metal sources are not prevalent, especially motor vehicles which have previously been indicted (Ukpebor et al., 2010) as being responsible for the high Pb concentrations in urban centres in Nigeria. Instead, what is rife at Iyowa is the abundant combustion of biomass (firewood) for cooking and frying cassava which is the economic mainstay of the inhabitants of this village. Other likely trace metal sources in the community include emissions from very few motorcycles, cassava milling machine and the re-suspension of dust particles while sweeping and fugitive harmattan dust from the trans sahara desert.

A similar study of trace elements in air particulate in the rural village of Bagauda, northern Nigeria (Beavington and Cawse, 1978), reported a similar trend of low metals levels. Just as observed in location CO, Cd was not detected in the Baguada study, but Pb, Cr and Zn mean concentrations were 0.012 μgm^{-3}, 0.007 μgm^{-3} and 0.015 μgm^{-3} respectively and they came basically from re-suspended dust. In comparison to the study by Rizzio et al (1999) in the rural - residential area of Ispra (Italy), higher levels of Pb (0.098 μgm^{-3}) and Zn (0.149 μgm^{-3}) were reported. However, Cd (0.0005 μgm^{-3}) and Cr (0.0065 μgm^{-3}) mean values were identical to the values reported in our study. The Pb, Cr and Zn concentration obtained from a related study at rural location of Delhi (India) (Shridhar et al., 2010), were several orders of magnitude higher than the values measured at Iyowa. Just as reported in location CO in our study, Cd was not detected in their study. The bulk of the metallic burden in Delhi, came from resuspended and wind blown dust (Shridhar et al., 2010).

Meteorology During the Sampling Period

The sampling was done between December 2007 and March 2008, dry season period of the year. As expected therefore, high ambient temperatures were recorded at all the sampling locations with a range of 28.2 - 35.8 ^{o}C (Table 6). Relative humidity which measures the degree of wetness and dryness of the atmosphere was found to be moderate with an average range of 49.2 - 58.6%. Low wind speeds were measured at all the sites with a range of 0.4 - 2.9 ms^{-1}.

Table 6: Ambient Temperature, Relative Humidity and Wind Speed During Sampling

	Ambient temperature (°C)		Relative humidity (%)		Wind speed (ms^{-1})	
Household	**Range**	**Mean**	**Range**	**Mean**	**Range**	**Mean**
A	31.3 – 34.4	33.0	39.0 – 66.2	49.2	0.8 – 2.7	1.9
B	28.2 – 34.5	33.1	47.2 – 54.4	51.0	0.5 – 2.6	1.2
C	29.8 – 35.0	34.3	42.2 – 61.8	51.7	0.4 – 2.9	1.7
D	28.5 – 34.7	32.0	46.2 – 77.5	58.6	0.6 – 2.7	1.4
E	28.2 – 35.8	32.7	43.2 – 69.0	52.5	0.4 – 2.8	1.5

Indoor Concentrations of Trace Metals

Kitchen Area

Table 3 represents the particulate mass and the trace metals concentration measured in the kitchens of households A, B, C, D and E. The SPM mass ranged from 425.93 - 1444.00 μgm^{-3} and these values are a factor of between 2 and 7 greater than the available WHO and FMENV limits. In contrast to the above trends, the elemental concentrations were found to be low. Pb was not detected in any of the kitchen's air samples while Cr was only found in measurable quantities in locations BK, CK and EK with mean concentrations of 0.0224 μgm^{-3}, 0.0065 μgm^{-3} and 0.0121 μgm^{-3} respectively. Zinc again was the highest with a range of 0.0185 - 0.1171 μgm^{-3}. Cd gave a range of 0.0013 - 0.0043 μgm^{-3}. There was no difference in their spatial distribution and the measured values when compared with the WHO limits for Pb and Cd, can be safely inferred to be low. The metal levels were also within their typical rural concentration ranges (Table 5). Most of the reported studies on the rural levels of trace metals, were outdoor investigations (Beavington and Cawse, 1978; Purghart-Galli et al., 1990; Ayrault et al., 2010; Shridhar et al., 2010), consequently, the data from this study could not be compared with previous literature values. Nevertheless, data generated here would form the basis for future assessment.

Living Room

Most people spend a large amount of their time indoors, which makes indoor spaces important micro-environments when addressing risks from air pollution (WHO, 2000). Consequently, the living room concentrations of these metals were quantified. The trace metal data from this exercise (Table 4) were found to be relatively low. However, the particulate matter data measured in these living rooms depicted enhanced concentrations, with SPM range of 546.30 - 955.56 μgm^{-3} obtained which exceeded by a factor of 2- 3 the available WHO and FMENV regulatory limits. Pb was found in measurable quantities only in locations AP and EP, with the same mean value of 0.0003 μgm^{-3}. The mean Zn, Cd and Cr concentrations for the rooms, were 0.0478 μgm^{-3}, 0.0003 μgm^{-3} and 0.0135 μgm^{-3} respectively. These values are once more within their typical rural concentration range (Table 5) and the available WHO limits.

As observed for the outdoor and kitchen trace

metals data, there was no remarkable differences in the spatial distributions of the measured metals. This of course suggests similarities in their sources and strength. Some of the identified sources of these metals indoors, include outdoor sources re-suspended dust, firewood smoke, motorcycles and cassava milling engine exhaust emissions. Some of the metals are also envisaged to have come from indoor sources which include emissions from tobacco smoke, soot from hurricane lanterns and locally made naked lamps and particles from the walls of the mud houses. Ideriah et al., (2001) in their study on indoor and outdoor concentrations of SPM in rural areas, observed that mud walls contributed significantly to indoor SPM levels (152.6 1037.2 μgm^{-3}) and by extrapolation indoor levels of trace metals. Comparative analysis of the measured living room data with literature, was difficult as a result of scanty relevant data.

Comparison of kitchen and living room trace metals concentrations

Ratios obtained from the calculations of the kitchen and living room levels are shown in Table 7. There was no observed distinct trend in their distributions. Pb was not detected in most of the kitchens and living rooms assessed. In households A and B, Zn was higher in the living room. In location C, it was evenly distributed in both kitchen and living room. In apartment D, the kitchen Zn level was now higher than the living room concentration. Cd was higher in the kitchens of households B and C. In apartments A and E, the living room values were slightly higher.

Table 7: Comparison of Kitchen and Living Room Heavy Metals Levels (μgm^{-3})

Household		Pb Conc.	Pb K/P ratio	Zn Conc.	Zn K/P ratio	Cd Conc.	Cd K/P ratio	Cr Conc.	Cr K/P ratio
A	Kitchen	< 0.0001	-	0.0282	0.7	0.0034	0.9	< 0.0001	-
	Living room	0.0003		0.0336		0.0039		0.0003	
B	Kitchen	< 0.0001	-	0.0450	0.9	0.0035	1.6	< 0.0001	-
	Living room	< 0.0001		0.0505		0.0022		< 0.0001	
C	Kitchen	< 0.0001	-	0.0522	1.0	0.0043	2.7	< 0.0001	-
	Living room	< 0.0001		0.0537		0.0016		< 0.0001	
D	Kitchen	< 0.0001	-	0.1171	1.2	0.0013	-	< 0.0001	-
	Living room	< 0.0001		0.1013		< 0.0001		< 0.0001	
E	Kitchen	< 0.0001	-	0.0185	-	0.0030	0.5	< 0.0001	-
	Living room	< 0.0001		< 0.0001		0.0057		0.0003	

K = kitchen, P = living room

For most of the homes, Cr was present at levels lower than the detection limits of the equipment used. A possible explanation for this trend is that both microenvironments contributed evenly to the trace metal levels in the community.

Comparison of Living Room and Outdoor Trace Metal Concentration.

The living room/outdoor ratio of Zn ranged from 0.9 - 1.7. In household A, the ratio was 1, which implies an even distribution at both locations. In apartments B and C, the living room Zn values slightly exceeded the outdoor values (Table 8), while in house E, the metal was not detected. Except for household E, where the outdoor concentration of Pb was higher than the living room, Pb was either not present or randomly distributed in the other homes. The living room concentration of Cd was higher than the living room levels for most of the homes. The erratic trend in the living room/outdoor levels of the trace metals once again reflects the probable varied sources of trace metals in this community.

Table 8: Comparison of Living Room and Outdoor Heavy Metals Levels (μgm^{-3})

Household		Pb Conc.	Pb K/P ratio	Zn Conc.	Zn K/P ratio	Cd Conc.	Cd K/P ratio	Cr Conc.	Cr K/P ratio
A	Kitchen	0.0003	-	0.0336	1.0	0.0039	1.8	0.0053	-
	Living room	< 0.0001		0.0340		0.0022		< 0.0001	
B	Kitchen	< 0.0001	-	0.0505	1.3	0.0022	0.8	0.0123	0.7
	Living room	< 0.0001		0.0395		0.0039		0.0187	
C	Kitchen	< 0.0001	-	0.0537	0.9	0.0016	-	0.0233	1.7
	Living room	0.0015		0.0603		< 0.0001		0.0136	
D	Kitchen	< 0.0001	-	0.1013	1.7	< 0.0001	-	0.0033	0.7
	Living room	< 0.0001		0.0595		0.0023		0.0045	
E	Kitchen	0.0003	0.1	< 0.0001	-	0.0057	5.7	0.0234	0.9
	Living room	0.0029		< 0.0001		0.0010		0.0252	

K = kitchen, P = living room

Table 9: Correlation Matrix for Heavy Metals

	AK1	AK2	AP1	AP2	AP3	AO1	AO2	BK1	BK2	BP1	BP2	BO1	BO2	CK1	CK2	CP1	CP2	CO1	CO2	DK1	DK2	DP1	DP2	DO1	DO2	EK1	EK2	EP1	EP2	EO1
AK1	1.000	0.989	0.503	1.000	1.000	1.000	.998	0.970	0.534	1.000	0.785	0.906	0.871	0.972	0.986	0.859	0.944	0.911	0.995	1.000	1.000	1.000	0.998	0.997	0.990	-0.510	0.832	-0.503	-0.496	-0.500
AK2	0.989	1.000	0.517	0.993	0.989	0.989	0.997	0.943	0.598	0.989	0.745	0.865	0.853	0.945	1.000	0.819	0.911	0.871	0.974	0.989	0.991	0.989	0.982	0.997	0.970	-0.511	0.783	-0.547	-0.510	-0.570
AP1	0.503	0.517	1.000	0.598	0.503	0.503	0.511	0.566	0.940	0.503	0.814	0.671	0.784	0.561	0.519	0.738	0.620	0.665	0.550	0.503	0.505	0.503	0.550	0.511	0.500	0.567	0.735	0.567	0.560	0.561
AP2	1.000	0.993	0.598	1.000	1.000	1.000	0.999	0.965	0.520	1.000	0.774	0.897	0.855	0.967	0.990	0.850	0.937	0.902	0.993	1.000	1.000	1.000	0.996	0.999	0.987	-0.519	0.821	-0.519	-0.507	-0.519
AP3	1.000	0.989	0.403	1.000	1.000	1.000	0.998	0.970	0.534	1.000	0.785	0.906	0.871	0.972	0.986	0.859	0.944	0.911	0.995	1.000	1.000	1.000	0.998	0.997	0.990	-0.510	0.832	-0.503	-0.496	-0.500
AO1	1.000	0.989	0.503	1.000	1.000	1.000	0.998	0.970	0.534	1.000	0.785	0.906	0.871	0.972	0.986	0.859	0.944	0.911	0.995	1.000	1.000	1.000	0.998	0.997	0.990	-0.510	0.832	-0.503	-0.496	-0.500
AO2	0.998	0.997	0.511	0.999	0.998	0.998	1.000	0.960	0.518	0.998	0.768	0.889	0.855	0.962	0.995	0.842	0.931	0.894	0.988	0.998	0.999	0.998	0.993	1.000	0.983	-0.512	0.811	-0.525	-0.504	-0.535
BK1	0.970	0.943	0.566	0.965	0.970	0.970	0.960	1.000	0.630	0.970	0.909	0.981	0.955	1.000	0.937	0.947	0.996	0.984	0.988	0.970	0.968	0.970	0.984	0.959	0.995	-0.509	0.942	-0.572	-0.585	-0.567
BK2	0.534	0.598	0.940	0.520	0.534	0.534	0.518	0.630	1.000	0.534	0.895	0.760	0.817	0.624	0.592	0.825	0.695	0.752	0.503	0.534	0.530	0.534	0.590	0.516	0.551	0.541	0.841	0.643	0.565	0.602
BP1	1.000	0.989	0.503	1.000	1.000	1.000	0.998	0.970	0.534	1.000	0.785	0.906	0.871	0.972	0.986	0.859	0.944	0.911	0.995	1.000	1.000	1.000	0.998	0.997	0.990	-0.510	0.832	-0.503	-0.496	-0.500
BP2	0.785	0.745	0.814	0.774	0.785	0.785	0.768	0.909	0.895	0.785	1.000	0.970	0.980	0.906	0.737	0.990	0.943	0.967	0.834	0.785	0.782	0.785	0.824	0.766	0.868	0.508	0.992	0.551	0.538	0.539
BO1	0.906	0.865	0.671	0.897	0.906	0.906	0.889	0.981	0.760	0.906	0.970	1.000	0.981	0.980	0.858	0.994	0.995	1.000	0.940	0.906	0.903	0.906	0.932	0.887	0.956	-0.536	0.989	0.519	-0.506	0.525
BO2	0.871	0.853	0.784	0.865	0.871	0.871	0.865	0.955	0.817	0.871	0.980	0.981	1.000	0.953	0.848	0.988	0.973	0.981	0.903	0.871	0.870	0.871	0.899	0.864	0.926	-0.523	0.977	0.585	-0.506	0.554
CK1	0.972	0.945	0.561	0.967	0.972	0.972	0.962	1.000	0.624	0.972	0.906	0.980	0.953	1.000	0.939	0.955	0.995	0.982	0.989	0.972	0.970	0.972	0.986	0.961	0.995	-0.516	0.939	-0.580	-0.592	-0.575
CK2	0.986	1.000	0.519	0.990	0.986	0.986	0.995	0.937	0.592	0.986	0.737	0.858	0.848	0.939	1.000	0.811	0.904	0.864	0.970	0.986	0.988	0.986	0.978	0.996	0.965	-0.510	0.775	-0.553	-0.511	-0.480
CP1	0.859	0.819	0.738	0.850	0.859	0.859	0.842	0.957	0.825	0.859	0.990	0.994	0.988	0.955	0.811	1.000	0.979	0.993	0.900	0.859	0.856	0.859	0.891	0.841	0.922	-0.530	0.998	0.521	0.501	0.519
CP2	0.944	0.911	0.620	0.937	0.944	0.944	0.931	0.996	0.695	0.944	0.943	0.995	0.973	0.995	0.904	0.979	1.000	0.996	0.970	0.944	0.942	0.944	0.964	0.930	0.981	-0.527	0.968	-0.582	-0.500	-0.577
CO1	0.911	0.871	0.665	0.902	0.911	0.911	0.894	0.984	0.752	0.911	0.967	1.000	0.981	0.982	0.864	0.993	0.996	1.000	0.944	0.911	0.908	0.911	0.936	0.893	0.960	-0.547	0.987	0.507	-0.517	0.513
CO2	0.995	0.974	0.550	0.993	0.995	0.995	0.988	0.988	0.503	0.995	0.834	0.940	0.903	0.989	0.970	0.900	0.970	0.944	1.000	0.995	0.994	1.000	0.998	0.997	0.998	-0.549	0.879	-0.523	-0.529	-0.513
DK1	1.000	0.989	0.503	1.000	1.000	1.000	0.998	0.970	0.534	1.000	0.785	0.906	0.871	0.972	0.986	0.859	0.944	0.911	0.995	1.000	1.000	1.000	0.998	0.997	0.990	-0.510	0.832	-0.503	-0.496	-0.500
DK2	1.000	0.991	0.505	1.000	1.000	1.000	0.999	0.968	0.530	1.000	0.782	0.903	0.870	0.970	0.988	0.856	0.942	0.908	0.994	1.000	1.000	1.000	0.997	0.998	0.989	-0.510	0.828	-0.508	-0.498	-0.507
DP1	1.000	0.989	0.503	1.000	1.000	1.000	0.998	0.970	0.534	1.000	0.785	0.906	0.871	0.972	0.986	0.859	0.944	0.911	0.995	1.000	1.000	1.000	0.998	0.997	0.990	-0.510	0.832	-0.503	-0.496	-0.500
DP2	0.998	0.982	0.550	0.996	0.998	0.998	0.993	0.984	0.590	0.998	0.824	0.932	0.899	0.986	0.978	0.891	0.964	0.936	0.999	0.998	0.997	0.998	1.000	0.993	0.997	-0.457	0.867	-0.542	-0.541	-0.539
DO1	0.997	0.997	0.511	0.999	0.997	0.997	1.000	0.959	0.551	0.997	0.766	0.887	0.864	0.961	0.996	0.841	0.930	0.893	0.987	0.997	0.998	0.997	0.997	1.000	0.982	0.512	0.809	-0.527	-0.505	-0.537
DO2	0.990	0.970	0.500	0.987	0.990	0.990	0.983	0.955	0.516	0.990	0.863	0.956	0.926	0.995	0.965	0.922	0.981	0.960	0.998	0.990	0.989	0.990	0.997	0.982	1.000	-0.597	0.902	-0.572	-0.577	-0.568
EK1	-0.510	-0.511	0.567	-0.519	-0.510	-0.510	-0.512	-0.509	0.541	-0.510	0.508	-0.536	-0.523	-0.516	-0.510	-0.530	-0.527	-0.547	-0.549	-0.510	-0.510	-0.510	-0.457	-0.512	-0.597	1.000	0.501	0.953	0.996	0.880
EK2	0.832	0.783	0.735	0.821	0.832	0.832	0.811	0.942	0.841	0.832	0.992	0.989	0.977	0.939	0.775	0.998	0.968	0.987	0.879	0.832	0.828	0.832	0.867	0.809	0.902	0.501	1.000	0.566	0.536	0.574
EP1	-0.503	-0.547	0.567	0.519	-0.503	-0.503	-0.525	-0.572	0.643	-0.503	0.551	0.519	0.585	-0.580	-0.553	0.521	-0.582	0.507	-0.523	-0.503	-0.508	-0.503	-0.542	-0.527	-0.572	0.953	0.566	1.000	0.976	0.980
EP2	-0.496	-0.510	0.560	-0.507	-0.496	-0.496	-0.504	-0.585	0.565	-0.496	0.538	-0.506	-0.506	-0.592	-0.511	0.501	-0.500	-0.517	-0.529	-0.496	-0.498	-0.496	-0.541	-0.505	-0.577	0.996	0.536	0.976	1.000	0.919
EO1	-0.500	-0.570	0.561	-0.519	-0.500	-0.500	-0.535	-0.567	0.602	-0.500	0.539	0.525	0.554	-0.575	-0.480	0.519	-0.577	0.513	-0.513	-0.500	-0.507	-0.500	-0.539	-0.537	-0.568	0.880	0.574	0.980	0.919	1.000

Multivariate Analysis of the Trace Metals

The concentrations of the trace metals (Zn, Cd, Cr, Pb) obtained from all the sampling sites (outdoor, living room and kitchen) were combined and subjected to inter correlation, principal component analysis and factor analysis using SPSS 16.0. This was done to elucidate relationships among the sampling sites and to identify the sources contributing to trace metal levels in this community. The strong positive correlation obtained in the distribution of the trace metals between the kitchen, living room and outdoor of households A, B, C and D (Table 9), suggest similarities in the source(s) of the metals. However there was a weak correlation between the kitchen, living room and outdoor of household E, indicative of a different trace metal source. In order to identify the source(s) contributing to trace metals emissions at the sampling locations, the obtained data were further subjected to factor analysis with varimax rotation and only sampling locations with high extraction communalities (Table 10) were retained for the analysis. To ascertain the number of factors to be retained in our study, only factors with eigenvalues = 1 were considered significant as suggested by Roscoe et al., (1982). Three factors were identified (Figs 2 and 3) as the main sources of the trace metals which were further confirmed by the hierarchical cluster analysis (Table 11). Cluster 1 comprises the kitchen, living room and outdoor of households A, B, C, and E and the outdoor of household D. Cluster 2 is made up of kitchen and living room of household D. The identified trace metals sources in the community are emissions from firewood combustion, harmattan dust, re-suspended dust during sweepings, particles from deteriorating roofing sheets and emissions from motorcycles and cassava milling machine exhausts. Re-suspended and wind blown dust appeared to be the dominant sources of trace metals in the community.

Table 10: Communalities of Heavy Metals at all the Sampling Locations (Indoor and Outdoor)

	Initial	**Extraction**
AK1	1.000	1.000
AK2	1.000	0.981
AP1	1.000	0.861
AP2	1.000	1.000
AP3	1.000	1.000
AO1	1.000	1.000
AO2	1.000	0.996
BK1	1.000	0.997
BK2	1.000	0.999
BP1	1.000	1.000
BP2	1.000	0.997
BO1	1.000	0.989
BO2	1.000	0.995
CK1	1.000	0.997
CK2	1.000	0.974
CP1	1.000	0.993
CP2	1.000	0.994
CO1	1.000	0.990
CO2	1.000	0.997
DK1	1.000	1.000
DK2	1.000	1.000
DP1	1.000	1.000
DP2	1.000	1.000
DO1	1.000	0.995
DO2	1.000	0.999
EK1	1.000	0.963
EK2	1.000	0.982
EP1	1.000	0.992
EP2	1.000	0.988
EO1	1.000	0.919

Extraction method: Principal Component Analysis

Table 11: Cluster Membership

Case	2 Clusters
AK1	1
AK2	1
AP1	1
AP2	1
AP3	1
AO1	1
AO2	1
BK1	1
BK2	1
BP1	1
BP2	1
BO1	1
BO2	1
CK1	1
CK2	1
CP1	1
CP2	1
CO1	1
CO2	1
DK1	1
DK2	2
DP1	2
DP2	2
DO1	1
DO2	1
EK1	1
EK2	1
EP1	1
EP2	1
EO1	1

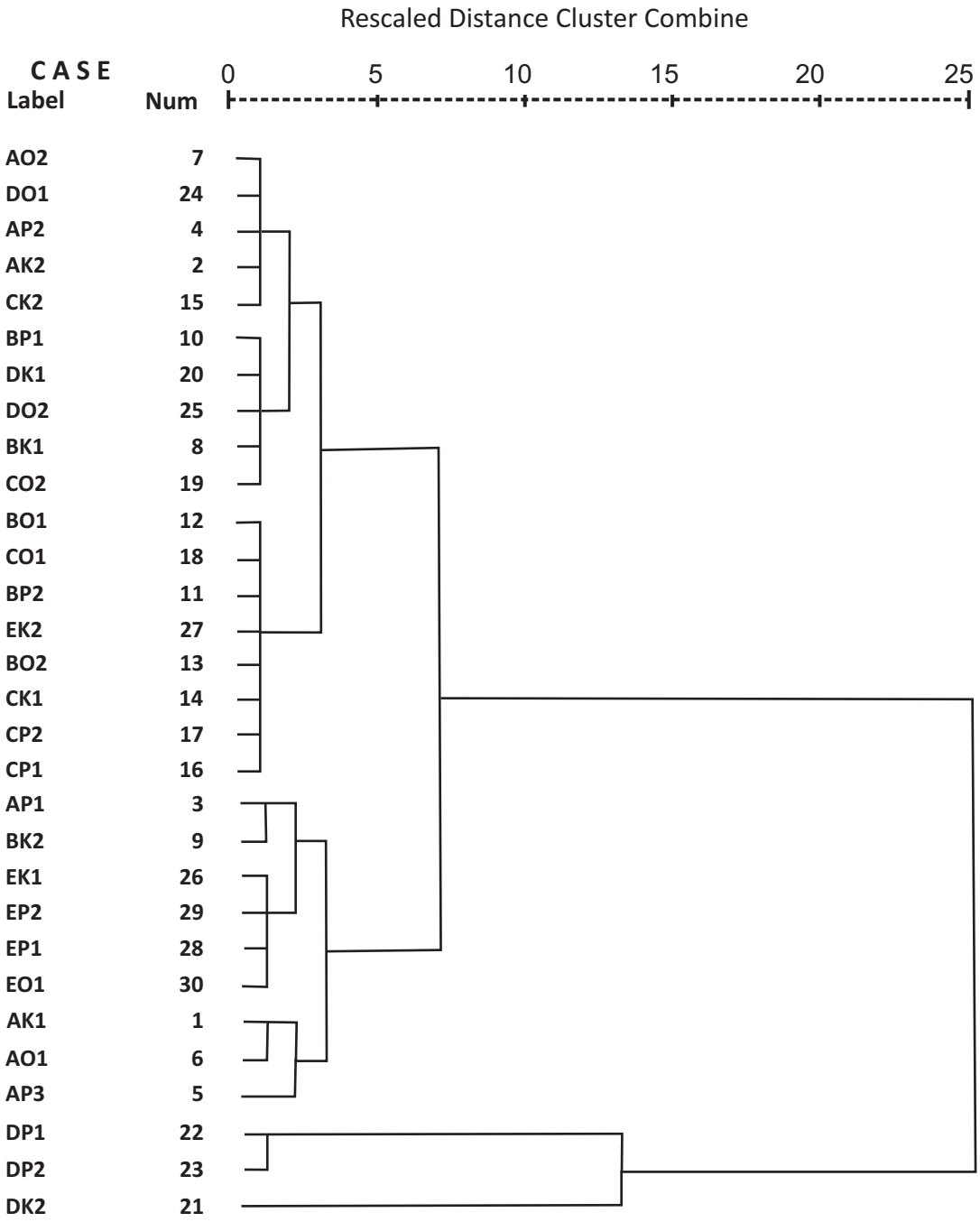

Figure 2: Dendrogram Using Average Linkage (between Groups) for Heavy Metals at Different Sampling Locations.

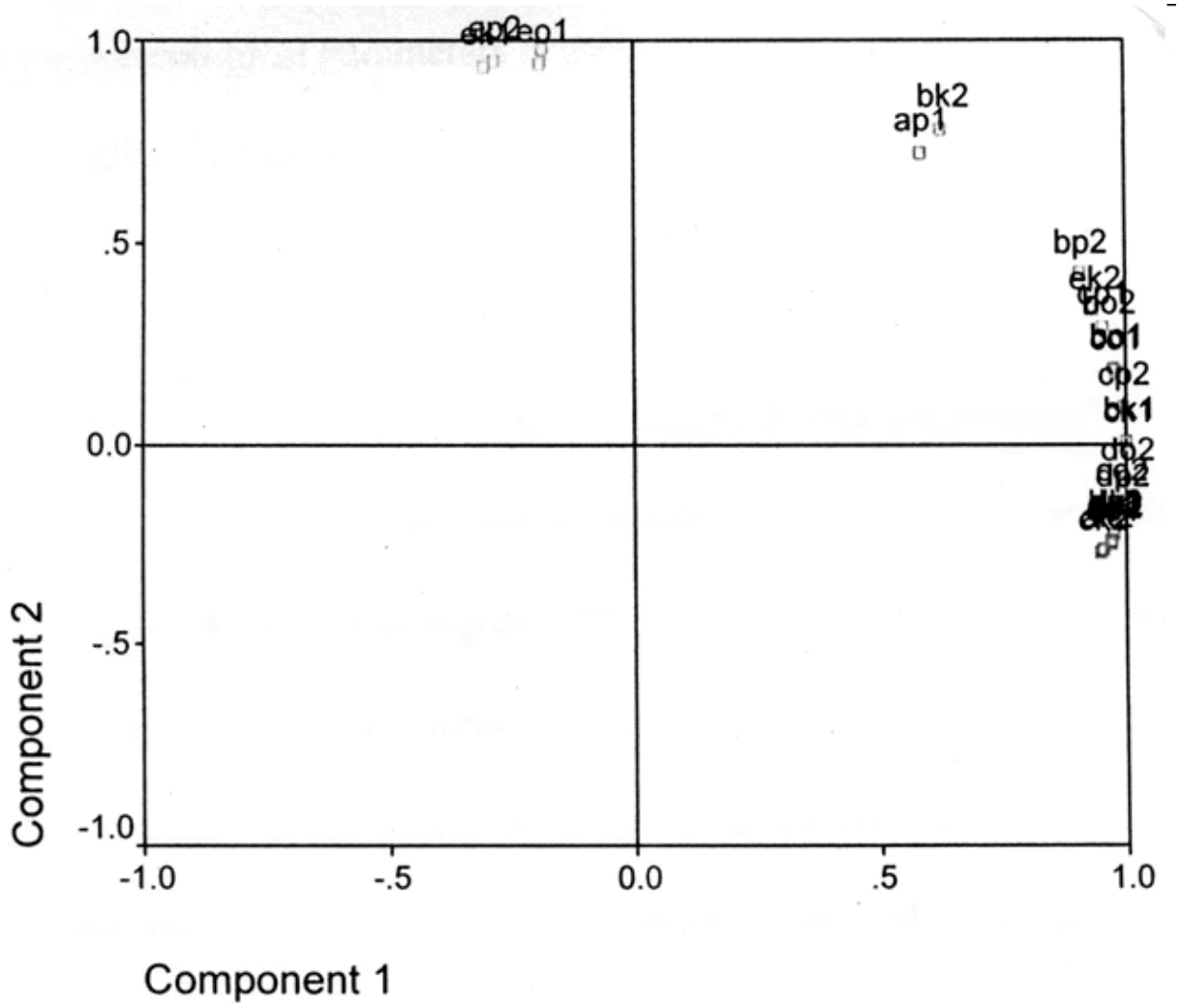

Figure 3: Principal Component Analysis Plot of Heavy Metals Concentration at the Different Sampling Locations

CONCLUSION

This study on the trace metal content of air particulate matter collected from a rural community in Nigeria, revealed a high particulate mass but relatively low baseline levels of Pb, Zn, Cd and Cr. Spatial variability in the measured data was not apparent, while the outdoor, kitchen and living room concentrations were similar. The concentration ranges of the metals were typical of rural concentration ranges and re-suspended and windblown dust was identified as the dominant sources of trace metals in the community.

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