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ORIGINAL ARTICLE

Composition and Source Identification of Chemical Species in Dust from Selected Indoor Environments in Ile-Ife, Nigeria

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Abstract

This study presents the elemental compositions and concentrations of indoor dust and identifies the major sources in some selected indoor environments in Ile-Ife, Nigeria. The dust samples were collected from 16 indoor environments comprising offices, churches, residential and staff quarters using a cyclonic high power vacuum cleaner. The dust samples were analyzed for elemental concentrations using x-ray fluorescences. The data sets were analyzed for the possible sources and their contributions using Principal Component Factor Analysis (PCFA). The result showed that dust samples contained several elements: K, Ca, Ti, Mn, Fe, Ni, Cu, Zn, Ga, As, Rb, Sr, Se, Zr, V, and Sc. The PCFA identified three factors with the percentage variance of 92, 77, 71 and 68%, for the office, church, residential, and staff quarters, respectively, for the combined elemental data of each of the site classes. The identified sources were track-in-soil, road and windblown soil dust, paint debris, household dust from personal care materials, cooking, and cleaning activities. The unintentional track-in-soil due to mobility of the occupants, structural materials, and outdoor air was the major sources contributing to the indoor dust.

Keywords Indoor dust · Compositions · PCFA · Sources · Windblown soil

1 Introduction

Clean indoor air is one of the essential determinants of human healthy life and well-being chiefly due to the large amount of time spent indoor compared to the outdoor. On the average per day, people living in urban areas spend about 80–90% of the whole day in the indoor micro-environment (Sharpe 2004; Schweizer et al. 2007). Indoor air quality (IAQ) is a major concern to residential and commercial sectors of a nation because of its significant bearing on the health as well as the productivity of the occupants (OSHA 2011). In the educational institutions, poor indoor air quality had been reported to have a great influence on the attendance, performance and health of the students (Stranger et al. 2008; Almeida et al. 2011; Popoola et al. 2012; Olujimi et al. 2014). Like the outdoor air pollution, indoor dust can be a major exposure route to some hazardous substances, leading to potential health risks, since dust particles are frequently accumulated in much higher concentrations in the indoors environments than outdoors (Lee et al. 2002). In indoor environment, people suffer greater adverse health effects due to indoor air pollution than from the outdoor (Hunt et al. 2008; Hassan 2012). The exposure to increased level of indoor dust concentration had been linked to both short- and long-term adverse health effects including respiratory illness, pulmonary and cardiovascular effects as well as increased morbidity and mortality rate (Latif et al. 2014).

The IAQ problems could arise not only from a single source but also a combination of several sources within the indoor environment. Such indoor sources are clothing fibers, furniture materials, wet and damp carpet, metal cabinet, materials made of pressed wood products, personal care materials and ventilation system (Turner and Simmonds 2006; Abdul-Wahad 2006). Indoor dust concentration is affected by ambient air concentrations, air exchange rate, penetration factors, dust deposition and resuspension rate. In a complex micro-environment, activities such as cooking, cleaning, renovation and mobility of the occupants

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could influence the indoor dust concentration (Fromme et al. 2007). The indoor–outdoor air exchange is enhanced by doors and windows opening as well as poor ventilation systems. Kumpiene et al. (2011) considered traffic activities and windblown action of the surface soil around the building as the sources of pollutants in the indoor environment. Once dust particles enter the indoor environment, they settle slowly under the influence of gravity. The gravitational settling of the dust particles on a susceptible material surface is capable of accelerating degradation of the materials. This in turn reduces their aesthetic appearances and life span (Hassan et al. 2015).

The characterization of the indoor dust plays a significant role in the determination of chemical composition of the dust particles, since the dust particles had been identified as a store-house for several chemical substances (Lu et al. 2009). Several studies had been carried out on the elemental composition and source identification of airborne dust particles in the outdoor environment of the study area (Oluyemi et al. 1994; Owoade et al. 2012, 2016; Ogundele et al. 2017). However, few studies exist on the indoor environment. Therefore, the main objective of this study was to assess the composition of indoor dust and identify the sources responsible for the indoor dust from various selected indoor environment in Ile-Ife, Nigeria.

2 Materials and Methods

2.1 Study Area, Sample Collection and Preparation

Table 1 shows the sites and the description of their states. Sampling locations were offices and staff residential quarters within Obafemi Awolowo University (OAU) campus, residential and worship centres outside the campus environment. The selected sites reflected areas of both high and low anthropogenic activities and proximity to the paved and unpaved roads, playground, commercial centre and traffic corridors. In all, the sampling was conducted at sixteen sites in Ile-Ife, Nigeria. The sampling of indoor dust for this study was conducted following the method described by Karamelo (2013). It is simple, fast and the samples obtained are considered fairly representative. A cyclonic high power vacuum cleaner (ModelCV-SH 18A 240UM BL) was used for sampling settled surface dust on the carpet, rugs and bare floor at the selected indoor sites. It had a hose, cyclonic cylinder and equipped with a changeable dust bags which acted as collecting media. At each location, sixteen samples were collected making a total of 64 samples from all the sites. To avoid cross contamination, the vacuum cleaner was cleansed with an electric blower, rinsed with distilled water and acetone after each sampling. Before the elemental analysis, the samples were kept in the zip-lock polythene bags and they were well coded for easy identification.

2.2 Elemental Analysis

The elemental compositions and concentrations of the samples were measured using x-ray fluorescence (XRF) technique. XRF technique provides a rapid and non-destructive method for the quantitative and qualitative measurement of the dust samples. The compact high performance XRF spectrometer has Mo anode. The XRF operating conditions are 25 keV and 50 µA. It operated under a quantitative x-ray analysis system (QXAS). The QXAS includes facilities for data acquisition, spectrum analysis and interpretation and

Table 1 Description of the sampling location environment

Location	Site	Description
Office	A	Second floor of the storey building close to a paved road
	B	Ground floor of the storey building having paved road beside it
	C	Second floor of the storey building near the paved road
	D	Ground floor of storey building close to the paved road
Church	E	Outskirt of the town, beside stream and main road
	F	Remote area, beside a highway
	G	Close to an unpaved road
	H	Centre of the town with heavy traffic and commercial activities
Staff quarters	I	Duplex far from a paved road
	J	Bungalow beside an unpaved road
	K	Bungalow with having a paved road in front
	L	Bungalow with the road paved near it
Residential	M	Remote area with several anthropogenic activities
	N	First floor of a storey building facing unpaved road
	O	Bungalow beside a school having a playground
	P	Bungalow located near the an unpaved road

quantitative analysis. The pelletized samples were mounted on the sample holder and placed at 45° to the beam and each sample was irradiated for 1000 s. A thermoelectrically cooled Si-PIN photodiode was used as detector. The detector has a resolution in the energy range of 3.3–16 keV for Mo, $K_{\alpha,\beta}$ excitation which allowed the determination of elements with characteristic K- and L- lines. The quantitative analysis of the x-ray peaks was carried out using the x-ray fluorescence fundamental parameter approach of the QXAS software package. This converted elemental peak intensities to elemental concentrations. The instrumental detection limits for the measured elements were above 1.05 µg/g. To validate the analytical procedures, the IAEA Soil-7 standard reference material was analyzed for elemental concentrations under the same experimental procedures and conditions. The measured values were compared with their respective certified values. To determine the significant differences of the average elemental concentration of the four sites, a one-way analysis of variance (ANOVA) was employed using Microsoft Excel® (Microsoft Corporation, 2007).

2.3 Principal Component Factor Analysis (PCFA)

The multivariate statistical technique involving principal component factor analysis (PCFA) was applied to identify the major sources responsible for indoor dust and their contributions. Prior to PCFA model run, elemental concentrations data were first treated. Polissar et al. (1998) rule was employed to handle the null and below the detection limits (BDL) data points. Such data points were replaced with the median value of each species. This permitted a better treatment of data rather than discarding such species from the elemental concentrations data. The species showing more than 50% of BDL values were excluded, while those below 50% were retained. Cu was excluded from the combined elemental concentration data prior to PCFA analysis because it's concentration was below detection limit in about 85% of the samples. The elemental concentrations data of samples from the office, church, staff quarters and residential locations were merged together to have a large data size and since they reflect similar site characteristics.

In the PCFA, a number of correlated parameters are replaced by small numbers of independent factors (principal components). Varimax rotation was applied to maximize the number of values that are close to either zero or unity in the factor loading without changing the total variance as well as the variance of the single element in the factor loading (Kothai et al. 2008). After rotation, elements originating from the same source are all found in the same factor with a high weight and the factor can be associated with that specific source. In each of the factors, only the factor loading with absolute value greater than 0.5 (> 50% species association) was considered for the interpretation (Kothai et al. 2008). The PCFA analysis was conducted using statistical package for social science (SPSS version16.0) computer software.

3 Results and Discussion

3.1 Elemental Analysis Results of Soil-7 Standard Reference Material (µg/g)

Table 2 shows the results of the certified and measured elemental concentrations values of IAEA Soil-7 standard reference material. The measured/certified value ratio for all the elements was about 1. However, a number of elements were about 2–5% overestimated including Ca, K and Fe. Olise et al. (2010) had earlier reported that overestimation could be caused by possible overlapping or summed peaks problems, which depends on detectors energy resolutions. The adjacent x-ray peak interference could also be responsible for overestimation. These could be extended to XRF results in this study. Generally, the measured values were in good agreement with the certified values for the respective elements indicating the validity of the XRF analytical technique used in this study.

3.2 Average Elemental Concentration Results

Table 3 shows the samples composition (K, Ca, Ti, Mn, Fe, Ni, Cu, Zn, Ga, As, Rb, Sr, Se, Zr, V and Sc) with their respective average elemental (± standard deviation) of the dust sampled from office, residential, staff quarters and church (worship centre). Calcium had the highest average concentration values of 19,700 ± 1100, 12,300 ± 510 and 11,400 ± 1400 in office, residential and quarters, respectively, while Fe had 18,900 ± 350 as the highest average concentration in the church site. As had the lowest average concentrations values in all the sites.

Table 2 Elemental concentrations of IAEA Soil-7 standard reference material results (µg/g)

Elements	Certified value	Obtained value
K	12,100 ± 350	12,157 ± 321
Ca	163,000 ± 260	163,930 ± 245
Ti	3000 ± 64	3020 ± 45
Cr	2 ± 0.1	2 ± 0.1
Fe	25,700 ± 110	25,810 ± 102
Cu	11 ± 0.2	11 ± 0.2
Mn	631 ± 15	635 ± 18
Zn	104 ± 5	105 ± 3
Zr	185 ± 14	186 ± 18

Table 3 Average elemental concentration (± SD) results (μg/g)

Elements	Office Mean ± SD	Church Mean ± SD	Residential Mean ± SD	Quarters Mean ± SD
K	1720 ± 403	1160 ± 570	1160 ± 200	1320 ± 410
Ca	19,700 ± 1100	12,400 ± 800	11,400 ± 1400	12,300 ± 510
Ti	1690 ± 334	1760 ± 320	16,100 ± 670	12,700 ± 840
Mn	291 ± 54	351 ± 43	3900 ± 150	24 ± 177
Fe	13,900 ± 280	18,900 ± 350	16,600 ± 530	10,100 ± 970
Ni	10 ± 4	11 ± 3	13 ± 4	9.51 ± 1
Cu	5 ± 1	5 ± 1	0.1 ± 0.01	9 ± 2
Zn	260 ± 60	230 ± 69	290 ± 40	241 ± 83
Ga	11 ± 4	10 ± 3	5 ± 2	10 ± 2
As	3 ± 1	2 ± 1	3 ± 1	4 ± 2
Rb	8 ± 2	9 ± 2	12 ± 4	14 ± 2
Sr	121 ± 60	74 ± 21	77 ± 27	96 ± 12
Se	7 ± 2	11 ± 2	7 ± 2	12 ± 2
Zr	116 ± 22	120 ± 38	77 ± 21	130 ± 30
V	150 ± 32	190 ± 48	136 ± 64	140 ± 5
Sc	560 ± 84	1050 ± 69	567 ± 72	520 ± 74

The concentration of crustal elements (Fe, Ca, Sc, Ti and K) accounted for about 85% of the total elemental concentrations in each of the sites and they were generally found to be higher than anthropogenic elements (Ni, As, and Se). This might be attributed to the fact that crustal elements are dominant and common in the crustal dust (Kothai et al. 2011). Anthropogenic elements such as Cr, Pb and Cd were not detected in all the samples, their concentrations might be below the detection limit of the XRF used in this study. A p value of 0.56 (significant at $p > 0.05$ level) was obtained for the ANOVA analysis of the mean elemental concentrations. This implies that there is no significant variation in the average elemental concentrations of the four sites. The elemental compositions and concentrations might be influenced by indoor activities and infiltration from the outdoor pollution sources. The average elemental concentration values of Mn, Ni, As, and V in the four sites were several orders of magnitude higher than the recommended threshold limit of 0.150, 0.066, 0.0025, and 1.0 $\mu g/m^3$, respectively, stipulated by World Health Organization (WHO 2000).

3.3 Principal Component Factor Analysis Results

Table 4 shows the factor loadings of the principal component after the Varimax orthogonal rotation obtained by the PCFA analysis of the combined elemental concentrations of each of the sites of the sampling locations. Three factors were obtained with the cumulative variance of 92, 77, 71 and 68% for the office, church (worship centre), residential and staff quarters, respectively, for the combined elemental data of each of the site classes.

For the office site class, the first factor is highly loaded (> 0.8) with K, Ca, Ti, Sr, Sc and Fe with the maximum percentage variance of 50%. The high loadings of these elements in the office might be due to their abundance in the earth crust (Hunt et al. 2011; Hassan 2012). They might be originated from loose fragments of the crustal material that were used for the building (Fromme et al. 2008). The office's walls were plastered with cement which had been reported to have Ca as one of the major elemental components of gypsum (Olujimi et al. 2014). Some of the offices' floors were covered with rug that served as reservoir for dust and track-in soil by the mobility of staff, students and visitors during the working hours. This factor can, therefore, be associated with soil derived dust. The second factor is moderately loaded with Mn and Se with 30% as the percentage variance. Manganese oxide and Cadmium Selenide were used primarily as pigment in paints to enhance the durability and for speed drying (Kulshrestha et al. 2014). All the walls of the offices were painted and dust from the wall could contain Mn and Se. The debris from the paint might be the probable sources that contributed to this factor, hence it is identified as paint debris. The third factor featured high loadings of Ni, Zn and V with 11% as percentage variance. Air laden with emission due to vehicular and fuel combustion sources from outside might leak into the offices and contributed to the indoor dust, though the contribution of this factor might be small. This factor might be linked to outdoor emission such as vehicular sources.

In the case of the church site class, the first factor exhibited high loadings of K, Ca, Ti, Fe, Rb, Sr and Sc. The unintentional transport of the soil particles on the footwear of the worshipers followed by the subsequent deposition within the worship centres might be the principal route that

Table 4 PCFA results of the indoor dust for the office, residential, church and staff quarters

Elements	Office			Church		
	Factor 1	Factor 2	Factor 3	Factor 1	Factor 2	Factor 3
K	**0.824**	−0.371	0.428	**0.856**	0.453	0.251
Ca	**0.910**	−0.291	−0.296	**0.814**	−0.298	0.371
Ti	**0.889**	0.452	−0.207	**0.974**	0.198	0.107
Mn	−0.183	**0.590**	−0.418	0.094	**0.542**	**0.835**
Fe	**0.829**	0.350	−0.106	**0.854**	−0.463	0.354
Ni	−0.365	−0.165	**0.917**	0.259	**0.682**	−0.684
Zn	−0.040	0.227	**0.960**	−0.103	**0.970**	0.220
Ga	0.395	−0.303	−0.221	0.475	−0.594	−0.284
As	0.111	0.025	0.307	0.179	0.243	−0.953
Rb	−0.395	0.336	0.455	**0.672**	0.328	0.065
Sr	**0.964**	−0.256	0.077	**0.581**	0.185	−0.052
Se	−0.259	**0.639**	0.228	−0.945	0.225	−0.204
Zr	−0.359	0.309	0.213	0.212	0.193	0.475
V	−0.229	0.363	**0.903**	0.106	−0.018	**0.994**
Sc	**0.973**	0.225	0.049	**0.887**	0.432	0.160
Variance	8.04	3.29	3.42	5.02	4.36	2.97
% Variance	50.28	30.55	11.40	31.35	27.26	18.56
	Residential			Quarters		
	Factor 1	Factor 2	Factor 3	Factor 1	Factor 2	Factor 3
K	−0.738	**0.576**	0.366	0.418	**0.703**	0.366
Ca	**0.901**	0.414	−0.130	**0.739**	−0.897	0.057
Ti	**0.975**	0.088	0.206	**0.509**	0.437	0.435
Mn	0.244	**0.872**	−0.423	−0.094	**0.898**	0.116
Fe	**0.544**	−0.436	−0.717	**0.724**	−0.656	0.211
Ni	0.043	0.031	**0.918**	0.409	**0.649**	0.138
Zn	−0.378	0.296	−0.012	0.190	**0.893**	0.409
Ga	0.148	−0.972	0.184	0.397	0.261	−0.233
As	−0.0670	**0.503**	0.208	0.192	0.338	**0.921**
Rb	0.421	**0.842**	0.337	−0.188	−0.913	0.123
Sr	0.316	−0.066	−0.396	−0.612	−0.715	−0.184
Se	0.368	−0.704	−0.205	0.398	0.335	**0.831**
Zr	0019	−0.808	0.389	−0.612	−0.149	−0.777
V	0.060	0.102	**0.903**	0.212	**0.915**	0.208
Sc	**0.869**	0.365	−0.335	**0.524**	0.486	0.097
Variance	5.32	3.29	2.85	4.71	4.43	1.75
% Variance	33.22	20.56	11.78	29.44	27.66	11.00

contributed to dust containing crustal elements. Moreover, structural materials of the wall as well as the floor of the church building could also contribute to the soil derived dust in the worship centres. During sweeping and general cleaning activities, there is the possibility of remobilization of the previously settled dust, leading to increased level of the soil derived dust within the church building. The combination of K, Ca, Ti, Fe, Rb and Sr in this factor indicated the chemical signatures for soil dust (Fergussion and Kim 1991; Ingrid et al. 2014). This factor is, therefore, identified as soil/crustal dust. The second factor is loaded with Mn, Ni and Zn with percentage variance of 27%. Several equipment in the church are of metallic materials. Corrosion, rusting, wear and tears of metallic materials and equipment in the church might have contributed to Ni and Zn, since they had been reported as components of steel (Mbengue et al. 2014; Taiwo et al. 2014), hence this factor is attributed to metal debris. The third factor is dominated by V and Mn with 27% as the percentage variance. The churches are located close to the unpaved road and busy highways to ensure easy access for the worshipers. There were tendency for indoor dust to be affected greatly by the emissions from traffic activities. Mn is used in unleaded gasoline as Methylcyclopentadienyl manganese tricarbonyl (MMT) to improve the octane number and as antiknocking agent (Kulshrestha et al. 2014). The possible sources of Mn and V could be resuspension of the previously settled vehicular emission along the road and street which might have penetrated into the worship centres. This factor is associated with street dust.

In the residential site class, the first factor, accounting for 33% as percentage variance, has high loadings of Ca, Ti, Fe and Sc. Due to age and deterioration of the building, soil particles could be introduced from warped windows, doors and cracks in the floors and walls of the building. Apart from the structural components of the building, activities such as cleaning and dusting could increase the soil particles in the indoor environment. This factor is associated with soil dust. The second factor featured moderate loading of K and As and very high loadings of Rb, Sr and Mn with the percentage variance of 23%. In the indoor environment, different cooking activities (baking, roasting, frying and toasting), use of insecticide and chemical used for the general cleaning of the house might contribute to this K and As loading (Turner and Simmonds 2006; Roy et al. 2009), while fractional part of the indoor dust content might be explained by corresponding outdoor sources such as refuse and waste burning, since waste management is often conducted in an ad-hoc manner in the study area. Most of the selected houses in this study relied on opened windows for ventilation. This could serve as passage for transport of dust from the outside to the indoor. This factor could be linked to dust penetration from outdoor solid waste and burning activities. The third factor is loaded with V and Ni with percentage variance of 17.8%. Nickel and V are considered as indicators of fuel combustion (Kothai et al. 2008). They might find their way to the indoor environment from fuel combustion generated in the ambient air. Several houses used auto-power generator to supplement power supply from the national grid and this could be the likely source that contributed to fuel combustion factor in the indoor environment. Apart from fuel combustion activities, jewelry and stainless steel utensils used in kitchen could also contribute Ni, though at low levels (Cempel and Nickel 2006).

For the staff quarters site class, the first factor showed high loading of Ti, Fe, Sc and Ca with high percentage variance of 29%. These elements could originate from soil dust tracked-in by the occupants and debris from wall, floor and plaster (Nor et al. 2012). The second factor explained 28% percentage variance with moderate loadings of Mn, K, Zn, V and Ni. In the university staff quarters, there is absence of any major activities that could contribute to high loading of the species in this factor except few anthropogenic activities. The likely sources of these elements might be from the biomass burning from the outside and windblown dust. The dust from cosmetics materials used in personal care and beauty might contribute to Zn in this factor (Turner and Simmonds 2006). The third factor exhibited high loading of As and Se with 11% as the percentage variance and attributed to household dust. The probable sources could be from sanitation facilities and the household products.

4 Conclusions

In this study, the elemental composition and concentrations of the indoor dust samples collected in office, residential, church and staff quarters had been carried out. K, Ca, Ti, Mn, Fe, Ni, Zn, Cu, As, Rb, Sr, Se and V were measured using x-ray fluorescence analysis. The possible sources contributing to the indoor dust were also identified. The identified sources were crustal/soil dust (track-in-soil due to occupant mobility and structural materials of the building), paint debris, infiltration of the outdoor emission (street and road dust, vehicular emission), cooking, personal care products and house cleaning activities. The contribution of each of the identified indoor sources are influenced by both indoor and outdoor activities as well as air exchange rate between the indoor and outdoor environments.

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Compliance with Ethical Standards

Conflict of interest The authors declare that no conflict of interest exists

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