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Characterization of metals in indoor dusts from electronic workshops, cybercafés and offices in southern Nigeria: Implications for on-site human exposure

Chukwujindu M.A. Iwegbue[a,*], Grace Obi[b], Onoriode O. Emoyan[a], Eze W. Odali[a], Francis E. Egobueze[c], Godswill O. Tesi[a], Godwin E. Nwajei[a], Bice S. Martincigh[d]

[a] Department of Chemistry, Delta State University, P.M.B. 1, Abraka, Delta State, Nigeria
[b] Department of Chemistry, Federal University of Petroleum Resources, Efurrun, Delta State, Nigeria
[c] Environment and Quality Control Department, Nigerian Agip Oil Company, Port Harcourt, Nigeria
[d] School of Chemistry and Physics, University of KwaZulu-Natal, Westville Campus, Private Bag X54001, Durban 4000, South Africa

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ABSTRACT

The levels of Cd, Pb, Cr, Ni, Cu, Co, Ba, Mn, Zn, Al and Fe were evaluated in indoor dusts from electronic workshops, cybercafés and offices in southern Nigeria. The study was aimed at providing information on the distribution patterns, and the associated risks that may arise from exposure of humans to these metals in indoor dusts from the three work environments. The dust samples were digested with aqua-regia and analyzed for the metal concentrations by inductively coupled plasma-atomic emission spectrometry (ICP-AES). The metal concentrations ($mg\ kg^{-1}$) in the indoor dusts from these work environments ranged from 0.2 to 20.5 Cd, 0.6–4810 Pb, 8.65–2210 Cr, 1.85–209 Ni, 6.75–2820 Cu, 0.25–19.6 Co, 22.7–597 Mn, 6.65–140 Ba, 43.3–7310 Zn, 1040–16,800 Al and 969–78,300 Fe. The metal distribution patterns in these dust samples followed the order: electronic workshops > cybercafés > offices. The concentrations of Cd, Pb and Cu in significant proportions of the dust samples from the electronic workshops and cybercafés surpassed their respective permissible limits in soils. The health risk assessment suggests considerable non-cancer risks arising from childhood contact with Pb in dust from the electronic workshops while no considerable non-cancer risk is associated with the adult and child exposure to dust from the cybercafés and offices. The results indicated that Cr and Pb are the main elements responsible for the non-carcinogenic risk arising from childhood exposure to electronic workshop dusts. The carcinogenic risk due to exposure of humans to metals in these dust samples were within the range regarded as safe by the USEPA.

1. Introduction

Contamination of indoor environments by metal-laden dust particles is a serious concern since metals are persistent and bio-accumulative pollutants. Human exposure to high concentrations of metals can cause deleterious and irreversible health effects because a number of them can accumulate in the fatty tissues of humans, affect the reproductive, renal, respiratory, circulatory and central nervous systems, and cause internal organ dysfunction. For example, Pb can induce irreversible neurological damage, developmental and behavioural disorders, especially in children, while Cd and Pb can also disrupt important nuclear functions including DNA repair and replication, and gene expression via inhibition of nuclear uptake, homeostasis and the functions of essential metal ions (Menzie et al., 2009; Hassan, 2012). There is convincing evidence that metals are discharged into the environment from primitive e-waste processing and recycling activities (Wong et al., 2007) since elevated concentrations were found in environmental matrices (air, dust, plants, soil and sediments) close to e-waste recycling sites (Song and Li, 2014).

Indoor dust represents an important source of toxicant exposure for the general population, and especially young children. It serves as a sink and storehouse for metals, toxic organic compounds such as PAHs, PBDEs, PCBs, dioxins, bisphenols and phthalates, and particle-bound matter. Trace elements are significantly enriched in indoor environments in comparison with their outdoor abundances (Rasmussen, 2004). The concentrations and types of metals in indoor environments are influenced by the nature of outdoor activities such as industrial and traffic emissions, and the nature of the indoor settings and the activities

* Corresponding author.
E-mail address: cmaiwegbue@delsu.edu.ng (C.M.A. Iwegbue).

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therein. The occurrence of metals in dust from indoor environments, for example, homes, offices, schools, workshops, etc., is consequently of major public health concern because of their persistent and toxic natures, and the considerable amounts of time that people spend indoors (up to 90% on a daily basis) (Kurt-Karakus, 2012).

The electrical/electronics sector represents the largest and fastest growing manufacturing business in the world (Liu et al., 2013). As a result of this growth, there is an increasing need for maintenance, repair, and replacement of worn parts in various devices. During the process of repair, large quantities of parts or electronics (e-waste) are discarded due to the advent of newer generation and constant upgrade of devices/electronics. Electrical workshops thus bear close resemblance to e-waste recycling workshops, which are acknowledged sources of metals in the environment. Monitoring of indoor contaminants in dusts from workplace environments is of strategic importance in evaluating possible health risks arising from occupational exposure. Dust and compounds/particles adsorbed to dust may enter the human body through direct inhalation of suspended and re-suspended particles, unconscious ingestion of dust particles, ingestion of dust contaminated foods, and particles bound to surfaces indoors, on the skin, and absorption through the skin (Butte and Heinzow, 2002).

Studies on metal concentrations in dusts from indoor environments such as homes, e-waste recycling workshops, schools, laboratories and offices have been documented in the literature (Rasmussen et al., 2001; Chattopadhyay et al., 2003; Nwajei and Iwegbue, 2007; Leung et al., 2008; Latif et al., 2009; Turner and Hefzi, 2010; Adekola and Dosumu, 2001, Žibret and Rokavec, 2010; Han et al., 2012; Hassan, 2012; Kurt-Karakus, 2012; Liu et al., 2013; Huang et al., 2014; Xu et al., 2015; Iwegbue et al., 2017). Many of the previous reports on metals in indoor dusts were focused on American, Asian and European environments. There are none on indoor dusts from offices, electronic repair workshops and cybercafés in Nigeria and most other African countries or a study comparing human exposure risks from these work environments. The existence of previous reports on metals in indoor dusts does not preclude the need for constant monitoring of indoor environment quality and occupational hazard management or the need for noting short- and long-term changes in environmental quality.

The objective of this study was to determine the concentrations and distribution of eleven metals, namely, Cd, Pb, Cr, Ni, Cu, Co, Mn, Ba, Zn, Fe and Al, in dust from indoor environments where electrical/electronic devices are repaired or used extensively, cybercafés and offices. This study provides useful information for the African situation, which is under-represented in the literature, and serves as a useful guide on the risks of human contact with metals in dust particles, which is needed for developing indoor pollution control schemes, and occupational safety/hazard management.

2. Materials and methods

2.1. Sample collection

Indoor dust samples were collected from 18 electronic workshops and 15 cybercafés in Abraka and Warri, and 16 offices on the three campuses of Delta State University, in Abraka, Nigeria. The equipment in the offices included 1–3 computers, scanners, printers, photocopiers, duplicating machines, typewriters, and functional television sets. The floor types were mainly cemented floors (10%), talazooed floors (5%), rugged floors (20%) and ceramic tiled floors (65%). The cybercafés surveyed contained from 15 to 500 computers, scanners, photocopiers, printers, Reuters and other transmission equipment. The floor types for the cybercafés were either cemented or floors with ceramic tiles. The electronic workshops contained television and radio sets, video machines, computers, fans, photocopiers and other electrical equipment that required servicing, and also those that had reached their end-of-life which are often utilized to repair other equipment. The floor types for the electronic workshops were basically cemented floors, however, a number of the workshops surveyed were housed in metallic shipping containers. The doors of the electronic workshops and offices are usually kept open during working hours. The ages of the buildings for these work environments varied between 5 and 60 years. The dust samples were collected over a period of 2 months (November to December 2014) when its prevalence was expected to be greatest. The dusts were collected in substantial amounts by gentle sweeping of ceiling fans, floors, shelves and table surfaces, window edges, and other cabinetry surfaces with a soft plastic brush into a plastic dustpan and packed in acid-washed polyethylene bags. After each sampling, brushes and dustpans were thoroughly washed with 0.25 mol L^{-1} nitric acid solution and wiped with paper towel (Iwegbue et al., 2017). The samples were conveyed to the laboratory in cooler boxes containing ice and were subsequently dried in oven at 50 °C for 1 day. The oven-dried samples were sieved through a 100 µm mesh size sieve and stored in the refrigerator at 4 °C prior to digestion.

2.2. Sample preparation and procedure for metal analysis

Each dust sample (0.5 g) was mixed with 10 mL of a mixture of HCl and HNO_3 in a ratio of 3:1, covered and allowed pre-digest overnight. Then, the sample was placed on a regulated hotplate and digested at 125 °C for 2 h. The digest was cooled, filtered through a 0.45 µm filter and subsequently diluted with 0.25 M HNO_3 to 25 mL (Radojevic and Bashkin, 1999). The metal concentrations (Cd, Pb, Cr, Ni, Cu, Co, Ba, Mn, Zn, Fe and Al) in the sample solutions were quantify with ICP-AES (Perkin Elmer DV5300, Shelton, CA, USA). The ICP-AES was programmed as follows: the radiofrequency power was set at 3000 W, and the flow rates of the plasma, auxiliary argon, nebulizer and pump were fixed at 15, 0.2, 0.8 and 1.5 mL min^{-1} respectively.

2.3. Quality control and data analysis

In this study, strict quality control measures were adopted to assure the integrity of the data. For every 10 samples, cross-contamination and interferences were monitored by using procedural blanks and samples spiked with known standards. The analytical procedure was validated by analysing a certified reference material, CRM-320. The recovery of metals from the certified reference material ranged between 95.6–101.3%. The average blank readings for the investigated metals were used to correct the instrument readings prior to statistical analysis. Analysis of variance (ANOVA) was used to establish the differences in metal concentrations within the same work environment while Tukey's test was applied to illustrate the significance of the differences in metal concentrations observed in the three work environments. Values less than 0.05 ($p < 0.05$) were considered statistically significant. Pearson's correlation and principal component analysis were used to establish inter-elemental relationships and their sources. The statistical calculations were performed with the SPSS software version 24.

2.4. Assessment of degree of pollution

2.4.1. Contamination/pollution index (C/PI)

The equation of Lacatusu (1998) was used to evaluate the C/PI.

$$C/PI = \frac{Concentration\ of\ metal\ in\ \ dust}{Reference\ value} \quad (1)$$

The guideline values for metals in soil as stipulated by the Nigerian regulatory authority were used as the reference values for each metal (see Table 1 for values) (DPR, 2002). Since the Nigerian regulatory authority has not established maximum allowable concentrations for Al, Fe and Mn, in soil, their crustal abundance values (CAV) were adopted as the respective reference values (Turekian and Wedepohl, 1961). The C/PI values differ from one region to another because of regional differences in the regulatory control limits (Iwegbue et al.,