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# Spatio-temporal distribution of metals in household dust from rural, semi-urban and urban environments in the Niger Delta, Nigeria

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**Abstract** Concentrations of metals in household dust samples from rural, semi-urban and urban zones of the Niger Delta in Nigeria were measured during both 2009 and 2014 with the aim of providing information on changes in the concentrations, distribution patterns, sources and risks of metals in these zones. The concentrations of metals in the dust samples were quantified by using inductively coupled plasma atomic emission spectrophotometry (ICP-AES) after digestion with aqua regia. The measured concentrations (mg kg$^{-1}$) of metals in the three zones within the study periods were as follows: <LOQ–21.2; <LOQ–182; 7.90–265; <LOQ–117; <LOQ–471; 3.37–2310; 0.35–7.9; 4.25–365; 6.78–61,600; 219–37,700; and 1180–18,000 for Cd, Pb, Ba, Cr, Ni, Cu, Co, Mn, Zn, Fe and Al, respectively. The results from the two periods indicate significant changes in the concentrations, distribution patterns and risk factors which reflects a deterioration of the quality of the household environment over this time span. The hazard index (HI) values calculated for children were greater than 1 indicating significant non-cancer risks for these subjects in these areas. The HI values for adults were less than 1 and consequently do not pose a significant risk. The carcinogenic risk levels for exposure to metals for both adults and children in these zones were below the range specified as safe by the US EPA ($\times 10^{-6}$ and $\times 10^{-4}$) thereby indicating a low cancer risk. The sources of metals in household dust from these zones include emissions from industries, traffic, artisanal workshops and releases from household furniture, metal-based fittings, metal roofing and pesticides.

Practical implication: This study examined the spatio-temporal distribution, sources and health risks of metals in household dusts from rural, semi-urban and urban environments in the Niger Delta, Nigeria. The distribution patterns suggested that household dust from the semi-urban zone contained higher concentrations of the majority of investigated metals which may be linked to the activities conducted by small-scale industries. Principal component analysis indicated the significance of outdoor contamination (traffic, industries and artisanal workshops) and indoor emission sources and verified the particular kinds of contaminants from the different zones. The human health risk evaluation indicated low risks particularly for adult exposure to metals in the household dust from these zones. The data obtained are useful for designing pollution control strategies and risk management.

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## Introduction

Household dust is a complex matrix that is made up of debris and particulate matter arising from both anthropogenic and terrestrial origins. It is composed of a wide variety of organic, inorganic and biological materials. Household dust particles have different shapes and sizes that range from large hair and textile fibres to ultra-fine particles (Pedersen et al. 2001a, b). Household dust particles are capable of adsorbing pollutants due to their large overall surface areas, and once adsorbed, these substances become non-degradable, or degrade at a rate relatively slower than those adsorbed on outdoor dust (Ong et al. 2007). Therefore, household dust accumulates various contaminants including metals, polycyclic aromatic hydrocarbons and polybrominated diphenyl ethers. It consequently

serves as a useful indicator for evaluating chronic exposure to indoor pollutants.

Indoor dust may accumulate sufficient amounts of contaminants that could be of serious health risk to the more susceptible groups living in the home including infants, toddlers (Latif et al. 2009) and the elderly. Other potential hazards of household dust are associated with its physical, chemical and biological composition. The deposition velocities of the fine or smaller particles are relatively lower than those of coarse particles, and they therefore could have a relatively longer residence time in air as suspended matter thereby causing human respiration problems (Bodin et al. 2000; Matson 2005).

Contaminant levels in household dust are of concern because people spend significant periods of time per day in indoor environments including homes, offices and schools. For example, it has been estimated that adults stay in one indoor environment or another for approximately 88% of the day while for children, it is about 71–79% of the day (Ong et al. 2007; USEPA 2011a). Infants and toddlers are considered the most susceptible groups to the chemical hazards in dust due to their unconscious ingestion of dust which may arise from hand-to-mouth habits and through touching and mouthing of dust-contaminated household items. For this reason, children are more exposed to greater amounts of dust compared with their adult counterparts (Beamer et al. 2008).

The distribution of metals in the human environment is of concern because they are non-degradable under normal conditions, although their speciation may change over time as a result of changes in environmental conditions (Iwegbue et al. 2009, 2015a), and they exhibit a wide range of toxicity and long-term health effects, including cancer, impairment of reproductive and nervous system functions, cardiovascular and renal system disorders, lung damage, skin problems, brittle hair and hair loss (Bocca et al. 2014; Iwegbue et al. 2015a, b, 2016, 2017). Some of them can disrupt the functions of endocrine systems and act as respiratory toxins (Bocca et al. 2014; Iwegbue et al. 2015a, b, 2016, 2017). Exposure to metals during early childhood can inhibit maximal brain growth and differentiation.

Inorganic contaminants such as metals, which are present in soil and suspended particulate matter, can enter the indoor environment and adsorb onto household dust through two main migration routes. These include the infiltration of suspended particulate matter (PM) contained in outdoor air and tracking in of soil from soil adhered to footwear (Thatcher and Layton 1995; Hunt et al. 2006). Unlike the outdoor environment where persistent contaminants are subjected to dilution and dispersion by the action of rain and wind, in the indoor environment, removal or dilution of these pollutants is limited and consequently they tend to accumulate. The concentrations of metals in household dust are influenced by outdoor anthropogenic sources as well as other activities carried out within the indoor environment including smoking, the types of paints used on the walls or type of combustible materials (e.g. oil, gas, kerosene, coal, wood) used for heating within the indoor settings, building materials, house floor types (plastic carpets, rugs, ceramic tiles, cemented or bare floors), the use of pesticides, household hygienic and personal care products, furnishings including deteriorated asbestos in insulation, types of cabinetry or furniture and household heat control systems and humidification devices (USEPA 1996; Abdul-Wahab 2006; Turner and Simmonds 2006; Hassan 2012).

There are a number of studies on metal concentrations of indoor environments from different regions in the literature (Latif et al. 2009; Kurt-Karakus 2012; Hassan 2012; Huang et al. 2014). However, there are few reported studies on the concentrations and health risks of metals in dust from indoor environments in Nigeria. Adekola and Dosumu (2001) reported the concentrations of Cd, Pb, Cu, Ni and Fe in household dust from Ilorin, in the north-central part of Nigeria. The present study determines the spatio-temporal characteristics of metals in household dust from rural, semi-urban and urban environments in the Niger Delta with the aim of providing useful information on the changes in concentrations over time, and the sources and health risks arising from human exposure to metals in these dust particles. This is the first study reporting the concentrations of metals in dust from rural, semi-urban and urban environments and evaluating the health risks arising from human exposure to metals in household dust in Nigeria.

## Materials and methods

### Description of the study area

The study area consists of urban (Warri), semi-urban (Abraka) and rural (Emu-Uno) zones in Delta State, Nigeria (Fig. 1). Warri (latitude 5° 31″ N and longitude 5° 45″ E) has a human population of over 311,970 (National Population Commission Census 2006). Warri and its environs are known for petroleum-related businesses and host the Warri Refinery and Petrochemicals Company, Nigerian Gas Company, the sea port, Delta Steel Company and other oil servicing and food industries. Abraka (longitude 6° 06″ E and latitude 5° 48″ N) is a university cum tourist town and has an estimated human population of about 70,000. Abraka is noted for the beautiful beaches of the River Ethiope. Emu-Uno (longitude 6° 6″ and 6° 42″ E and latitude 6° 31″ and 5° 25″ N) is the traditional headquarters of the Emu Kingdom in the Ndokwa Local Government of Delta State. The Emu Kingdom has a population of 35,000 people. Emu is a typical rural community that hosts the Ebendo/Obedeti oil field. There is a gas flaring point 4–5 km away from the sampling points.

**Fig. 1** Map of the study area
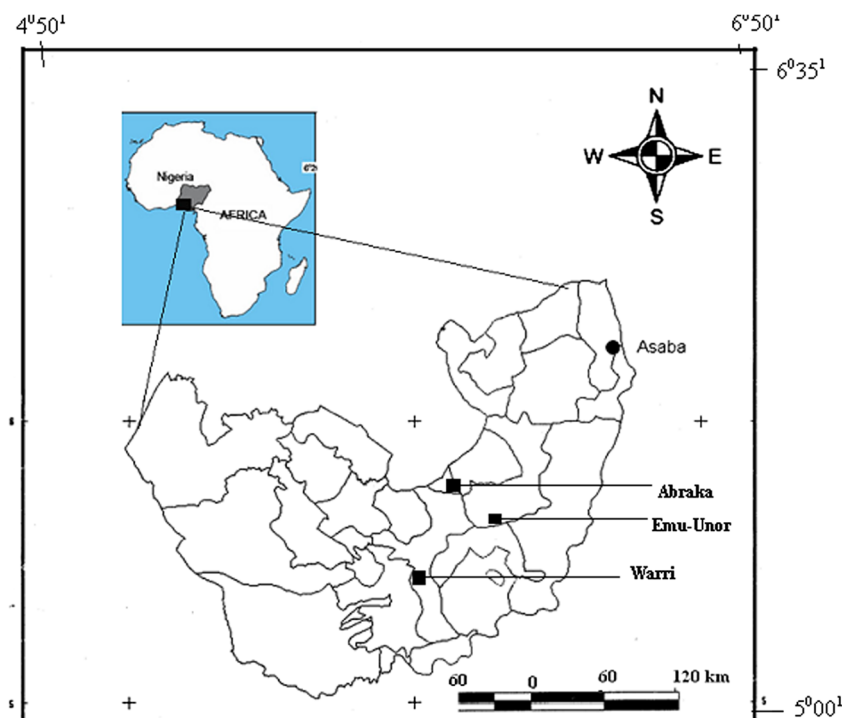


The region experiences heavy rainfall in the months of April to October and a dry season with occasional rainfall in the months of November to April. The mean annual temperature and rainfall in this area are 32.8 °C and 2673.8 mm, respectively. The natural vegetation in the region is characterised by a mosaic of arable farmlands and tree crop plantations, patches of rainforest and freshwater and mangrove swamp forests in some areas (Iwegbue 2013).

**Sample collection**

A total of 90 household dust samples were collected from the urban, semi-urban and rural zones through the months of November to December 2009 while 51 samples were collected in the months of November to December 2014 from the same buildings sampled in 2009, except for those buildings with significant modifications in their structures due to renovation works within the study period. The age of the buildings sampled in the three zones ranged from 0 to 80 years. The houses sampled in the rural area were mostly room and parlour systems with the kitchens, bathrooms and toilets detached from the main building. However, for the semi-urban environment, the houses were a mixture of blocks of flats, room and parlour systems and bed sitters. In the urban environment, the houses sampled were mostly blocks of flats, duplex complexes, bed sitters and a few room and parlour systems. The buildings in the rural zone had cemented floors while those of the semi-urban and urban zones were a mixture of cemented floors, floors with ceramic tiles, plastic tiles and floors with rugs and carpets. The doors of the buildings in the rural zone

were mostly open during the day as evidence to indicate that the residents were indoors, while those of the semi-urban and urban areas were mostly closed during the day. All the buildings sampled in the semi-urban and urban zones had painted walls while 60% of those from the rural zone were painted. A reasonable quantity of household dust was collected from the floor area, ceiling fans, cabinetry and other surfaces by gentle sweeping into a plastic dustpan with a soft plastic brush and packed in a polyethylene bag. Within the same building, dust samples were collected from the different apartments and mixed together as a composite sample for that building. The brushes and dustpans were cleaned after each sample collection with a metal-free detergent solution and rinsed with distilled water. These materials were further rinsed with 0.25 mol $L^{-1}$ HNO$_3$ and cleaned with paper towels. The samples were transported to the laboratory, dried in oven at 105 °C for 24 h and then filtered to pass through a 100-μm sieve.

**Sample digestion and metal analysis**

A mass of 0.5 g of the dust sample was placed in a 150 mL digestion tube followed by the addition of 15 mL of aqua regia (HCl: HNO$_3$, 3:1 ratio). The tube was covered and the mixture was pre-digested overnight. On the following day, the sample was heated to 120 °C for 2 h on a regulated heating block. The digest was allowed to cool to room temperature, the cover and side walls of the digestion tube were carefully rinsed into the digest with a few millilitres of 0.25 M HNO$_3$, and the sample was filtered through Whatman No. 1 filter paper and made up to 25 mL with 0.25 M HNO$_3$ (Radojevic and Bashkin 1999).

This was further filtered through a 0.45-μm filter before analysis for Cd, Pb, Cr, Ni, Cu, Co, Ba, Mn, Zn, Fe and Al by using inductively coupled plasma atomic emission spectrophotometry (Perkin Elmer DV 5300, Shelton, CA, USA). The working conditions of the ICP-AES were as follows: RF power and plasma flow rate 1300 W and 15 L min$^{-1}$, respectively, while the auxiliary argon, nebulizer, and the pump flow rates were 0.2, 0.8 and 1.5 mL min$^{-1}$, respectively. The quantification of metals in the samples was carried out by using an external calibration method consisting of six concentration levels. The working standards were prepared by diluting 1000 mg L$^{-1}$ commercial standards with 0.25 M HNO$_3$. The calibration lines of the metals had $R^2$ values ranging from 0.9997 to 0.9999.

## Quality assurance/control and statistical analysis

All data were subjected to strict quality control procedures. After every ten samples, a procedural blank and a sample spiked with a standard were analysed in order to monitor interferences and cross-contamination. The average blank readings were subtracted from the instrument readings before statistical analysis. The significance of the differences in the observed concentrations of metals within and among sampling locations and between the sampling periods was determined by using analysis of variance (ANOVA) and Tukey's test at $p$ values less than 0.05 ($p < 0.05$). The statistical calculations were carried out by using SPSS version 24. Relationships between metals were established by means of principal component analysis.

## Contamination/pollution index

The contamination/pollution index (CPI) was calculated by using the formula given by Lacatusu (2000).

$$CPI = \frac{Concentration\ of\ metal\ in\ soil}{Reference\ value} \tag{1}$$

The reference values are the guideline values for metals (Cd = 0.8, Pb = 85, Cr = 100, Ni = 36, Cu = 35, Co = 20, Ba = 200, Zn = 140 mg kg$^{-1}$) in soil as specified by the Department of Petroleum Resources of Nigeria (DPR 2002). In the case of Mn, Fe and Al, their crustal abundance values were used as the reference values (Turekian and Wedepohl 1961). The conversion factor used for the CPI varies with the region depending on the regulatory control limits. A CPI value above 1 is associated with the pollution range whereas values below 1 are associated with the contamination range. Metals in the environment may have synergistic, additive or antagonistic effects on human health. For this reason, the multiple pollution index (MPI) was derived from the addition of the CPI values for the individual metals that were above 1.

The interpretation of the computed CPI and the MPI values was derived from the categorizations of the degree of contamination/pollution based on the index values as follows: very slight contamination (CPI < 0.1); slight contamination (0.10–0.25); moderate contamination (0.26–0.5); severe contamination (0.51–0.75); very severe contamination (0.76–1.00); slight pollution (1.1–2.0), moderate pollution (2.1–4.0); severe pollution (4.1–8.0); very severe pollution (8.1–16.0); and excessive pollution (>16.0) (Lacatusu 2000).

## Enrichment factor

The enrichment factor (EF) of a particular metal in the household dust was calculated as for soils following the equation of Reimann and De Caritat (2000):

$$EF = \frac{C_n\ (test\ element)}{C_n\ (reference)} \div \frac{B_n\ (test\ element)}{B_n\ (reference)} \tag{2}$$

where $C_n$ (test element) is the concentration of the test metal in the sample, $C_n$ (reference) is the concentration of the reference metal in the sample, $B_n$ (test element) is the background concentration of the test metal in crustal rock, and $B_n$ (reference) is the background concentration of the reference metal in crustal rock. In this study, Fe was chosen as the reference element based on the fact that its concentrations were determined during both surveys, i.e. in 2009 and 2014. The crustal abundance values (CAV) for the metals were Cd = 0.3, Pb = 20, Ba = 580, Cr = 90, Ni = 68, Cu = 45, Co = 19, Mn = 850, Zn = 95, Fe = 47,000 and Al = 82,000 (Turekian and Wedepohl 1961) and were used as the background concentrations for estimation of the enrichment factors and index of geoaccumulation. Five contamination categories have been suggested based on enrichment factor values. The categorizations are as follows: deficiency to minimal enrichment (EF < 2); moderate enrichment (2–5); significant enrichment (5–20); very high enrichment (20–40); and extremely high enrichment (>40) (Sutherland 2000; Loska et al. 2003).

## Index of geoaccumulation

The index of geoaccumulation ($I_{geo}$) of metals in these dust samples was evaluated by using the equation:

$$I_{geo} = \log 2 \frac{C_n}{1.5 B_n} \tag{3}$$

where $C_n$ is the measured concentration of the test metal in the dust sample and $B_n$ is the background concentration of the test metal. In this case, the crustal abundance values of the test metals were used as the background concentrations (Turekian and Wedepohl 1961). The factor, 1.5, corrects for possible lithological variations in the background concentrations (Rogan et al. 2010). The Muller index of

**Table 1** Values of the variables for the estimation of human exposure to metals in a residential area

| Variable (unit) | Definition | Value | Reference |
|---|---|---|---|
| $ABS_d$ (unitless) | Dermal absorption factor | 0.03 for As and 0.001 for other metals | USEPA 2011b |
| AF (mg cm$^{-2}$) | Soil-to-skin adherence factor | Resident, 0.2 for child and 0.07 for adult | USDOE 2011 |
| $AT_{ca}$ (day) | Averaging time for carcinogenic effects | LT × 365 for resident | USDOE 2011 |
| $AT_{nc}$ (day) | Averaging time for non-carcinogenic effects | ED × 365 for resident and recreation | USDOE 2011 |
| BW (kg) | Average body weight | 15 kg for child and 60 kg for adult | MHC 2008 |
| ED (year) | Exposure duration | 30 for adult resident and 6 for child resident | USDOE 2011 |
| EF (day year$^{-1}$) | Exposure frequency | 350 for residential and 75 for recreation | USDOE 2011 |
| IngR (mg day$^{-1}$) | Dust ingestion rate for receptor | Resident, 60 for children and 30 for adult | USDOE 2011 |
| InhR (m$^3$ day$^{-1}$) | | 20 for children and 7.6 for adult | Van den Berg 1995; Kurt-Karakus, 2012 |
| LT (year) | Lifetime | 52 years for Nigeria | WHO 2006 |
| PEF (m$^3$ kg$^{-1}$) | Soil-to-air particulate emission factor | $1.36 \times 10^9$ | USDOE 2011; US EPA 2011b |
| SA (cm$^2$ event$^{-1}$) | Skin surface area available for exposure | Resident, 2800 for child and 5700 for adult | USDOE 2011 |

geoaccumulation $I_{geo}$ has seven classes ranging from unpolluted to very seriously polluted. The interpretations for the geoaccumulation index are given as follows: $I_{geo} < 0$—practically unpolluted (class 1), 0–1—unpolluted to moderately polluted (class 2), 1–2—moderately polluted (class 3), 2–3—moderately to strongly polluted (class 4), 3–4—strongly polluted (class 5), 4–5—strongly polluted to very polluted (class 6) and >5—extremely polluted (class 7).

## Human exposure and health risk assessment

Evaluation of the risks arising from human exposure to contaminants in the environment involves a multi-step procedure such as the collection and analysis of primary data, exposure and toxicity assessment and risk characterization (USDOE 2011; USEPA 1989). In this study, Cd, Pb, Cr, Ni, Cu, Co, Ba, Mn, Zn, Fe and Al were identified as the potential hazardous elements that can affect human health due to their toxicological profiles (USDOE 2011; USEPA 2011a), some of which are carcinogenic (e.g. Cd, Cr, Ni, and Pb) while the others exhibit non-carcinogenic risks only. The carcinogenic metals can also exhibit non-carcinogenic risks (USEPA 2002b, 2011b).

Human exposure to metals in household dusts can occur through three main exposure routes: direct oral ingestion of substrate particles (CDI$_{ingestion}$), inhalation of re-suspended dust particles through the nose (CDI$_{inhalation}$) and dermal absorption of metals in the particles adhered to exposed skin (CDI$_{dermal}$). In this study, we considered the carcinogenic and non-carcinogenic risks of the three exposure routes. In the evaluation of the risk, a typical scenario for human exposure to dust in homes was followed, taking cognisance of the

non-carcinogenic hazard exposure for children. The carcinogenic risk was determined as the incremental probability of an individual developing cancer, or cancer-related diseases, over a lifetime from exposure to a potential carcinogen (Salem et al. 2014). The model equations (Eqs. 5–11) of the USEPA (1989, 1997, 2001) and the USDOE (2011) were used to evaluate chronic daily intake, CDI, i.e. average daily dose, ADD, and the carcinogenic and non-carcinogenic risks of metals via the three exposure routes. The CDI$_{UCL}$ (exposure-point upper confidence limit content, mg kg$^{-1}$) is the upper limit of the 95% confidence interval for the mean that gives a measure of the "reasonable maximum exposure" (Hu et al. 2011; USEPA 1989; Zheng et al. 2010a, b). Since the concentrations of most metals in our samples have an approximately non-normal distribution, the 95% upper confidence limit (UCL) was evaluated by using the "adjusted central limit theorem (CLT)" approach (Singh et al. 1997; USEPA 2002a). Although the CLT approach was designed for large normally distributed data sets, it can be applied to a small- or moderate-sized skewed data set. The theorem does not give any information on the required number of samples necessary for attaining normality. However, for a small- or moderate-sized data set, the mean will generally not obey the normal distribution, and skewness of the distribution gives rise to the non-normality (USEPA 2002a; Kurt-Karakus 2012). The 95% UCL concentration ($C_{UCL}$) was evaluated by using Eq. (4).

$$C_{UCL} = X + \left[ Z_\alpha + \frac{\beta}{6\sqrt{n}} \left( 1 + 2 \times Z_\alpha^2 \right) \right] \times \frac{STD}{\sqrt{n}} \quad (4)$$

where $X$ is the arithmetic mean, STD is the standard deviation, $\beta$ is the skewness, $\alpha$ is the probability of making a type 1 error (false positive), $Z_\alpha$ is the $(1 - \alpha)$th quantile of the standard

normal distribution, and $n$ is the number of samples. $Z_\alpha = 1645$ for the 95% confidence level.

The definitions of the terms used and the values for Nigerian specific variables and parameters are provided in Tables 1, 2 and 3. The $C_{UCL}$ term in Eqs. (5) to (10) was based on the $C_{UCL95\%}$ of the data set. The CDI values for the three main exposure routes were calculated as follows:

$$CDI_{ingestion} = \frac{C_{UCL} \times IngR \times EF \times ED}{BW \times AT} \times 10^{-6} \quad (5)$$

$$CDI_{inhalation} = \frac{C_{UCL} \times InhR \times EF \times ED}{PEF \times BW \times AT} \quad (6)$$

$$CDI_{dermal} = \frac{C_{UCL} \times SA \times AF \times ABS \times EF \times ED}{BW \times AT}$$
$$\times 10^{-6} \quad (7)$$

The hazard quotient (HQ) or non-cancer risk (Eq. 8) for the three exposure routes was obtained by dividing the CDI value for each metal by their corresponding reference dose. For the carcinogens, the excess lifetime cancer risk value was estimated as the product of chronic daily intake and the corresponding slope factor (Eq. 9). Since synergistic interactions between some metals may also occur, all risks due to metals are assumed to be additive. Therefore, it is important to evaluate the cumulative non-carcinogenic and carcinogenic risks expressed as the hazard index (HI) (Eq. 10) and total cancer risk (Eq. 11).

$$HQ = \frac{CDI_{nc}}{RfD} \quad (8)$$

$$Risk = CDI_{ca} \times CSF \quad (9)$$

$$HI = \Sigma HQ = HQ_{ingestion} + HQ_{inhalation} + HQ_{dermal} \quad (10)$$

$$Total\ Cancer\ Risk = \Sigma Risk$$
$$= Risk_{ingestion} + Risk_{inhalation} + Risk_{dermal} \quad (11)$$

As a rule, the higher the HQ value is above one (1), the greater is the level of concern. Thus, $HQ \leq 1$ depicts unlikely adverse health effects, whereas $HQ > 1$ denotes the probability of adverse health effects. In general, excess cancer risks $<10^{-6}$ are considered to be negligible, and cancer risks $>10^{-4}$ are considered unacceptable by a number of international regulatory authorities (Guney et al. 2010; USEPA 1989). The USEPA considered a value of $10^{-6}$ as the carcinogenic target risk (a probability of one chance in a million of equally exposed persons developing cancer) (USEPA 2011b).

## Results and discussion

### Concentrations and distribution of metals

The results of the determination of metals in household dusts sampled in 2009 and 2014 and their descriptive statistics are displayed in Table 4. The concentrations of most of the metals in the household dust from the three zones of the Niger Delta have approximately non-normal distributions; therefore, the median concentrations of the metals were adopted for the discussion of the results in this study because they are less sensitive to outliers and are a better measure than the mean for highly skewed distributions. Analysis of variance shows that the differences in the concentrations of the studied metals are significant within a given zone and between zones. There are significant temporal changes ($p < 0.05$) in the characteristic concentrations and distribution patterns of metals in the household environments of the three zones between the two study periods except for Cd and Mn in the urban zone. These changes were more pronounced in the semi-urban and rural zones than the urban zone which point towards a deterioration of the quality of the household environment. The differences between the spatial characteristics of the zones may be attributed to the different geological backgrounds and differences and changes in indoor activities and potential pollution

| Symbol (unit) | Definition |
|---|---|
| $ABS_{GI}$ | Gastrointestinal absorption factor |
| C (mg kg$^{-1}$) | Concentration of metal in soil |
| $CDI_{ingestion}$, $CDI_{inhalation}$, and $CDI_{dermal}$ | Chronic daily intake or dose contacted through oral ingestion (mg kg$^{-1}$ day$^{-1}$), inhalation (mg m$^{-3}$ for non-cancer, and µg m$^{-3}$ for cancer) and dermal contact (mg kg$^{-1}$ day$^{-1}$) with soil particles, respectively |
| $CSF_{ingestion}$ (mg kg$^{-1}$ day$^{-1}$)$^{-1}$ | Chronic oral slope factor |
| $CSF_{dermal}$ | Chronic dermal slope factor = $CSF_{ingestion}$/$ABS_{GI}$ |
| IUR (µg m$^{-3}$)$^{-1}$ | Chronic inhalation unit risk |
| $R_fC_{inhalation}$ (mg m$^{-3}$) | Chronic inhalation reference concentration |
| $R_fD_{ingestion}$ (mg kg$^{-1}$ d$^{-1}$) | Chronic oral reference dose |
| $R_fD_{dermal}$ | Chronic dermal reference dose = $R_fD_{ingestion} \times ABS_{GI}$ |

Table 2 Definitions of parameters for the assessment of human health risk

**Table 3** Toxicological parameters of the investigated metals used for health risk assessment

| Elements | CSF$_{ingestion}$ (mg kg$^{-1}$ d$^{-1}$) | IUR (μg m$^{-3}$) | R$_f$D$_{ingestion}$ (mg kg$^{-1}$ d$^{-1}$) | R$_f$C$_{inhalation}$ (mg m$^{-3}$) | ABS$_{GI}$ |
|---|---|---|---|---|---|
| Cd | | $1.8 \times 10^{-3}$ | $1.0 \times 10^{-3}$ | $1.0 \times 10^{-5}$ | 0.025 |
| Cr | $5.0 \times 10^{-3}$ | $1.2 \times 10^{-2}$ | $3.0 \times 10^{-3}$ | $1.0 \times 10^{-4}$* | 0.013 |
| Ni | | $2.6 \times 10^{-4}$ | $2.0 \times 10^{-2}$ | $9.0 \times 10^{-5}$ | 0.04 |
| Ba | | | $2.0 \times 10^{-1}$ | $5.0 \times 10^{-4}$* | |
| Al | | | 1.0 | $5.0 \ 10^{-4}$ | |
| Fe | | | $7.0 \times 10^{-1}$ | | 1 |
| Zn | | | $3.0 \times 10^{-1}$ | $4.0 \times 10^{-3}$** | 1 |
| Co | | | $3.0 \times 10^{-4}$ | $6.0 \times 10^{-6}$ | 1 |
| Pb | $8.5 \times 10^{-3}$ | $1.2 \times 10^{-5}$ | $3.5 \times 10^{-3}$ | $2.0 \times 10^{-4}$** | 1 |
| Mn | | | $1.4 \times 10^{-1}$ | $5.0 \times 10^{-5}$* | 1 |
| Cu | | | $4.0 \times 10^{-2}$ | $1.4 \times 10^{-3}$* | 1 |
| Reference | USDOE 2011 | USDOE 2011 | USDOE 2011 | USDOE 2011 | USEPA 2011c |

sources (Han et al. 2012). There were considerable variations in the concentrations of metals in the dust samples collected from residential apartments within the same zone (Table 4), which may be associated with the differences in house decoration and domestic heating and lifestyles. In this study, the dust samples from painted apartments had higher concentrations of metals than those from unpainted apartments, while those apartments floored with ceramic tiles had lower concentrations of metals than either those with plastic carpets/rugs or cemented/bare floors. More so, dust samples collected from apartments closer to major roads and those located near workshops or with a workshop within their premises (e.g. mechanical, welding/fabrication and electrical/electronic workshops) showed higher concentrations for the majority of the studied metals. Generally, the concentrations of the majority of the investigated metals in dust samples from the semi-urban zone were higher than those of the rural and urban zones. The reason for this trend may be related to emissions from small- and medium-scale enterprises (SMEs) and artisan workshops. The activities of these SMEs may release significant concentrations of a wide spectrum of pollutants to the environment since most of these SMEs have no pollution control measures and are not under any serious scrutiny by the regulatory agencies compared with their bigger counterparts in the urban zone. Until now, there are no regulatory control limits for metals in dust. Thus, it would be appropriate to use the maximum allowable limit in soil as a basis for comparing our results. Table 5 provides information on the number of samples that exceeded the maximum allowable limit in soil for each metal during the survey periods.

The median concentrations of Cd followed the order: urban > semi-urban > rural in 2009 while in 2014, the order was semi-urban > urban > rural area. The difference in the Cd concentrations between the two sampling periods was not significant. However, in the case of rural and semi-urban zones, the median concentrations of Cd increased remarkably. The median concentrations of Cd in these dust samples were below the regulatory control limit of 0.8 mg kg$^{-1}$ Cd in soil except for the dust samples collected from the semi-urban area in the 2014 sampling campaign. The concentration range for Cd is comparable to Cd levels found in indoor dust in Istanbul, Turkey (Kurt-Karakus 2012), and in the Sydney metropolitan area (Chattopadhyay et al. 2003). Cd in the indoor environment arises from sources including outdoor dust, paint, automobile tyres and/soot attached to these particles, automobile oil and smoking (Hassan 2012).

The median concentrations of Pb in the dust samples varied from 6.57 to 28.5 mg kg$^{-1}$ and from 17.5 to 67.7 mg kg$^{-1}$ for the 2009 and 2014 sampling campaigns, respectively. The difference in the concentrations of Pb between the two sampling periods was significant. The concentrations of Pb in the rural and semi-urban areas in 2014 were approximately three- and fivefold higher than the concentrations observed in 2009, respectively, whereas, in the urban area, there was a depletion in the median concentration of Pb between the two study periods. The elevated concentrations of Pb in the rural and semi-urban zones may be related to the Nigerian government's policy to encourage rapid development of small- and medium-scale enterprises (SMEs) in these zones to curb rural to urban migration. The median concentrations of Pb in these dust samples during the study period were below the 85 mg kg$^{-1}$ limit of Pb in soil specified by the Nigerian Regulatory Authority (DPR 2002). Nevertheless, the concentrations in 12 of the studied dust samples were above the regulatory control limit for Pb in soils (Table 5). The major sources of Pb in household dust include the use of lead-based paints, lead solder, lead pipes (Chattopadhyay et al. 2003; Spalinger et al. 2007), infiltration of lead-contaminated outdoor particulate matter and cigarette smoke (Yocom and

**Table 4** Descriptive statistics for metals in household dust samples (mg kg$^{-1}$)

**2009**

| | Mean | SD | Median | Min | Max | Skew | Kurt | UCL95% |
|---|---|---|---|---|---|---|---|---|
| **Rural** | N = 30 | | | | | | | |
| Cd | 1.40 | 4.06 | 0.27 | ND | 21.2 | 4.06 | 19.5 | 3.63 |
| Pb | 28.6 | 49.9 | 6.57 | ND | 178 | 2.07 | 3.34 | 33.9 |
| Ba | – | – | – | – | – | – | – | – |
| Cr | 2.23 | 3.11 | 0.40 | ND | 10.9 | 1.51 | 2.04 | 4.04 |
| Ni | 1.63 | 3.45 | 0.00 | ND | 11.7 | 1.96 | 3.05 | 3.51 |
| Cu | 87.6 | 412 | 9.67 | 3.37 | 2310 | 5.20 | 30.0 | 166 |
| Co | – | – | – | – | – | – | – | – |
| Mn | 58.1 | 26.2 | 53.9 | 4.25 | 150 | 1.38 | 4.29 | 61.1 |
| Zn | 6220 | 15,500 | 374 | 6.78 | 61,600 | 2.64 | 6.73 | 7682 |
| Fe | 4320 | 3840 | 2940 | 219 | 18,100 | 2.12 | 5.20 | 4614 |
| Al | – | – | – | – | – | – | – | – |
| **Semi-urban** | N = 30 | | | | | | | |
| Cd | 1.17 | 3.19 | 0.51 | 0.11 | 18.0 | 5.06 | 28.6 | 3.41 |
| Pb | 15.4 | 11.6 | 12.8 | 3.63 | 59.9 | 2.26 | 6.78 | 18.0 |
| Ba | – | – | – | – | – | – | – | – |
| Cr | 3.54 | 3.55 | 2.35 | ND | 15.1 | 1.90 | 4.12 | 5.44 |
| Ni | 5.04 | 7.22 | 2.85 | ND | 30.4 | 2.26 | 5.73 | 7.28 |
| Cu | 63.0 | 198 | 19.1 | 6.40 | 1100 | 4.98 | 28.0 | 101 |
| Co | – | – | – | – | – | – | – | – |
| Mn | 61.2 | 24.9 | 59.9 | 24.8 | 114 | 0.29 | -0.59 | 63.1 |
| Zn | 304 | 250 | 186 | 65.0 | 1260 | 2.08 | 6.17 | 324 |
| Fe | 6530 | 4670 | 5030 | 1670 | 21,200 | 1.67 | 2.75 | 6821 |
| Al | – | – | – | – | – | – | – | – |
| **Urban** | N = 30 | | | | | | | |
| Cd | 1.31 | 3.17 | 0.67 | ND | 2.09 | 5.06 | 28.8 | 3.53 |
| Pb | 30.2 | 25.2 | 28.5 | 6.13 | 139 | 2.62 | 10.6 | 34.2 |
| Ba | – | – | – | – | – | – | – | – |
| Cr | 2.77 | 2.02 | 2.63 | ND | 9.52 | 1.40 | 3.19 | 4.52 |
| Ni | 28.4 | 83.4 | 8.2 | ND | 471 | 4.98 | 28.2 | 44.8 |
| Cu | 51.1 | 47.7 | 22.2 | 10.6 | 238 | 2.01 | 6.42 | 56.0 |
| Co | – | – | – | – | – | – | – | – |
| Mn | 68.2 | 57.4 | 60.8 | 22.8 | 357 | 4.18 | 22.0 | 78.4 |
| Zn | 459 | 285 | 401 | 45.6 | 1330 | 0.96 | 1.45 | 470 |
| Fe | 6020 | 2725 | 5940 | 1380 | 11,600 | 0.10 | -0.72 | 6028 |
| Al | – | – | – | – | – | – | – | – |

**2014**

| | Mean | SD | Median | Min | Max | Skew | Kurt | UCL95% |
|---|---|---|---|---|---|---|---|---|
| **Rural** | N = 20 | | | | | | | |
| Cd | 0.98 | 0.76 | 0.73 | 0.15 | 2.75 | 1.12 | 0.34 | 2.67 |
| Pb | 33.7 | 32.0 | 18.9 | 8.35 | 133 | 1.82 | 3.99 | 38.4 |
| Ba | 43.7 | 32.5 | 28.2 | 12.6 | 131 | 1.37 | 1.71 | 47.7 |
| Cr | 22.6 | 12.5 | 18.0 | 9.4 | 54.0 | 1.40 | 1.47 | 25.2 |
| Ni | 10.7 | 8.50 | 7.30 | 2.05 | 28.2 | 1.43 | 1.30 | 13.0 |
| Cu | 39.4 | 43.9 | 20.3 | 8.5 | 165 | 1.83 | 3.28 | 45.0 |
| Co | 2.39 | 2.69 | 1.33 | 0.95 | 7.9 | 2.33 | 6.08 | 4.37 |
| Mn | 134 | 88.8 | 121 | 41.3 | 365 | 1.26 | 1.31 | 141 |
| Zn | 512 | 636 | 343 | 78.9 | 2760 | 2.60 | 8.36 | 600 |
| Fe | 6580 | 4060 | 5580 | 7610 | 18,200 | 1.62 | 2.74 | 6927 |
| Al | 5460 | 3410 | 4250 | 1780 | 11,130 | 1.18 | 0.51 | 5668 |
| **Semi-urban** | N = 10 | | | | | | | |
| Cd | 1.90 | 0.79 | 1.83 | 0.75 | 3.8 | 1.46 | 4.00 | 3.66 |
| Pb | 67.1 | 39.2 | 67.7 | 12.2 | 104 | 0.28 | -0.47 | 69.9 |
| Ba | 75.1 | 58.1 | 60.7 | 29.0 | 225 | 2.18 | 5.49 | 90.3 |
| Cr | 34.2 | 11.1 | 37.1 | 14.4 | 54.9 | 0.02 | 0.81 | 35.9 |
| Ni | 21.2 | 8.1 | 20.9 | 8.00 | 33.2 | -0.05 | -0.21 | 22.8 |
| Cu | 173 | 241 | 108 | 34.8 | 853 | 3.08 | 9.62 | 254 |
| Co | 3.48 | 1.81 | 3.48 | 0.95 | 7.00 | 0.55 | 0.17 | 5.23 |
| Mn | 167 | 63 | 169 | 74.6 | 240 | -0.26 | -1.56 | 167 |
| Zn | 484 | 102 | 485 | 335 | 626 | -0.19 | -1.14 | 483 |
| Fe | 14,500 | 8960 | 13,500 | 5080 | 37,700 | 2.12 | 5.90 | 16,535 |
| Al | 10,600 | 5450 | 11,000 | 3230 | 18,000 | -0.23 | -1.44 | 10,423 |
| **Urban** | N = 21 | | | | | | | |
| Cd | 1.24 | 1.52 | 0.55 | 0.20 | 6.10 | 1.97 | 4.52 | 3.04 |
| Pb | 38.0 | 43.0 | 17.5 | 5.05 | 182 | 1.82 | 5.28 | 43.6 |
| Ba | 62.8 | 67.4 | 29.5 | 7.90 | 265 | 1.73 | 3.36 | 70.2 |
| Cr | 26.8 | 25.7 | 17.3 | 6.45 | 117 | 2.22 | 6.94 | 31.3 |
| Ni | 12.9 | 12.2 | 8.30 | 1.70 | 32.6 | 1.39 | 1.63 | 15.4 |
| Cu | 49.6 | 44.0 | 33.2 | 9.65 | 161 | 1.28 | 1.08 | 54.1 |
| Co | 1.95 | 1.96 | 1.00 | 0.35 | 7.05 | 1.29 | 0.85 | 3.72 |
| Mn | 98.3 | 96.7 | 55.1 | 20.5 | 292 | 1.13 | -0.21 | 105 |
| Zn | 282 | 249 | 149 | 60.3 | 835 | 1.02 | -0.19 | 297 |
| Fe | 6450 | 6330 | 4060 | 1647 | 24,180 | 1.67 | 2.52 | 6980 |
| Al | 4780 | 4500 | 2460 | 1180 | 13,900 | 1.15 | -0.10 | 5035 |

UCL95% upper confidence limit

**Table 5** Number of samples with concentrations above the respective permissible limit in soil

| Metals | 2014 | | | 2009 | | |
|---|---|---|---|---|---|---|
| | Rural ($n = 20$) | Semi-urban ($n = 10$) | Urban ($n = 21$) | Rural ($n = 30$) | Semi-urban ($n = 30$) | Urban ($n = 30$) |
| Cd | 7 (35) | 9 (90) | 7 (33) | 3 (10) | 6 (20) | 12 (40) |
| Pb | 2 (10) | 3 (33) | 2 (10) | 4 (13) | 0 (0) | 1 (3) |
| Ba | 0 (0) | 1 (10) | 0 (0) | N/A | N/A | N/A |
| Cr | 0 (0) | 0 (0) | 1 (5) | 0 (0) | 0 (0) | 0 (0) |
| Ni | 0 (0) | 0 (0) | 1 (5) | 0 (0) | 0 (0) | 3 (10) |
| Cu | 5 (25) | 9 (90) | 9 (43) | 1 (3) | 6 (20) | 14 (47) |
| Co | 0 (0) | 0 (0) | 0 (0) | N/A | N/A | N/A |
| Mn | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) |
| Zn | 17 (85) | 10 (100) | 12 (57) | 26 (87) | 22 (73) | 27 (90) |
| Fe | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) |
| Al | 0 (0) | 0 (0) | 0 (0) | N/A | N/A | N/A |

The values in parentheses represent the percentage

McCarthy 1991). Generally, in the urban environment, coal combustion, vehicular emissions, and industrial activities such as the manufacture of vehicle batteries, glass, radiation shields and soldering, are the main sources of Pb pollution (Ajmone-Marsan and Biasioli 2010; Mielke et al. 2011).

The concentrations of Ba in the household dust ranged from 12.6 to 131, 29 to 225 and 7.9 to 265 mg kg$^{-1}$ for rural, semi-urban and urban zones, respectively. The median concentration of Ba in dust samples from the semi-urban zone was higher than those from rural and urban zones. The difference in the median concentrations of Ba in dust samples from urban and rural zones was not significant ($p < 0.05$). The concentrations of Ba in our samples were below the maximum permissible limit of 200 mg kg$^{-1}$ (DPR 2002). The concentrations of Ba in these samples were lower than previously reported values for household dust (Rasmussen et al. 2001; Turner and Hefzi 2010; Žibret and Rokavec 2010) (Table 6).

The median concentrations of Cr ranged from 0.4 to 2.63 and 17.3 to 37.1 mg kg$^{-1}$ for the 2009 and 2014 sampling periods, respectively. The median concentrations of Cr in the rural and semi-urban zones in 2014 were 15-fold higher than the median concentrations of Cr observed in these zones during 2009. The concentrations of Cr observed in the two sampling periods were below the maximum 100 mg kg$^{-1}$ allowable concentration of Cr in soil specified by the Nigerian Regulatory Authority (DPR 2002) except for one sample collected in the urban zone in 2014 (Table 5). The sources of Cr and Ni in household dust include outdoor dusts, the use of Cr- and Ni-coated household items, Cr and Ni plating in automobiles, and from yellow paints on roads (Madany et al. 1994). The burning of mosquito coils and incense are other important sources of Cr and Ni in household dust (Lin and Shen 2003, 2005).

Nickel was found in the dust samples during the two sampling periods at concentrations that varied from not detected to 471 mg kg$^{-1}$. The concentrations of Ni in the household dust samples from the three zones were below the maximum allowable concentration of Ni in soils (DPR 2002) apart from four samples from the urban area (Table 5). The difference in the median concentrations of Ni in the urban area during the two sampling periods was not significant ($p < 0.05$). However, the mean concentration decreased twofold during the study period. The median concentration of the dust samples from the semi-urban zone increased ninefold over the study period. The concentrations of Ni were less than the limit of quantitation (LOQ) in the majority of indoor dusts from the rural area in 2009; however, nickel was found in six samples at concentrations in the range of 4.64 to 11.7 mg kg$^{-1}$ in this year.

The median concentrations of Cu in the three zones during the two sampling periods varied significantly ($p < 0.05$). The 2014 median concentrations of Cu in the rural, semi-urban and urban zones were two-, six- and twofold higher than concentrations of Cu observed in 2009, respectively. Sources of Cu in the indoor environment include outdoor dust, attrition from automobiles (diesel engines) (Al-Rajhl et al. 1996) and the use of copper-based germicides or biocides in homes. Other sources of Cu, Cr and Zn in household dust include leaching of these metals from Cu-based wood preservation chemicals, including copper sulphate, and mixtures of Boliden salt (BIS-salt), zinc sulphate and chromated copper arsenate (CCA) typically used in the preservation of wood for furniture, cabinetry and roofing (Bhattarcharya et al. 2002; Iwegbue et al. 2012; Iwegbue 2014). Copper concentrations surpassed the regulatory control limit of 35 mg kg$^{-1}$ for Cu (DPR 2002) in 25% (rural), 90%

**Table 6**　A comparison of the metal concentrations in dust samples (mg kg$^{-1}$) with those reported in other studies

| Location | Cd | Pb | Cr | Ni | Cu | Co | Mn | Zn | Fe | Al | Ba | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Saudi Arabia | 1.51 (1.38)[a] | 35.5 (26.0)[a] | 37 (31) | 26.1 (19.9)[a] | 91.1 (75.8)[a] | 10.4 (9.8)[a] | — | 396 (349)[a] | — | — | 426 (371)[a] | Turner and Hefzi 2010 |
| Slovenia | 15–9.7 | 242–777 | 114–724 | 93.6–388 | 175–265 | 5.2–19.1 | 252–1330 | 325–1950 | — | — | 115–443 | Žibret and Rokavec 2010 |
| Sydney, Australia | 0.3–109 | 18.2–16,600 | 4.9–425 | 4.8–549 | 19.3–1100 | — | 6.3–624 | 100–9930 | 23–141,000 | — | — | Chattopadhyay et al. 2003 |
| Istanbul, Turkey | 0.4–20 | 3.0–230 | 2.8–190 | 120–2600 | 60–1800 | 2.4–19 | 7.7–600 | 210–2200 | — | — | — | Kurt-Karakus 2012 |
| Ottawa, Canada | 1.12–34.94 | 50.20–3225.66 | 33.5–330.3 | 16.0–243 | 59.36–601.47 | 3.27–22.67 | 136.9–423.5 | 239.1–1840.0 | 7060–40,350 | 12,700–51,100 | 190–1480 | Rasmussen et al. 2001 |
| Chile (Bolivian Altiplano) Mining district | 4.60–101.34 | 66.6–8413.45 | — | — | 30.30–471.23 | — | — | 119.30–2295.22 | — | — | — | Fonturbel et al. 2011 |
| Chile (Bolivian Altiplano) Peripheral district | 4.19–10.31 | 48.57–2415.25 | — | — | 23.9–617.20 | — | — | 132.00–843.38 | — | — | — | Fonturbel et al. 2011 |
| Nigeria (Ilorin) | 0.001–0.38 | 2.34–10.17 | — | 0.38–2.19 | 0.19–1.99 | — | — | — | 28.60–45.40 | — | — | Adekola and Dosumu 2001 |
| UK | 0.6–4.9 | 56.8–358 | — | 27.2–97.1 | 71.799 | — | 286–1190 | 286–1190 | 4980–180,000 | 3850–23,800 | — | Turner and Simonds 2006 |
| Malaysia | 0.09–0.29 | 0.81–0.95 | — | 0.41–1.00 | — | — | — | 0.34–0.53 | 0.63–0.76 | — | — | |
| Hong Kong | 2.2–38.5 | 71.5–308.4 | — | — | 240.2–806.1 | — | 168.0–283.3 | 1108–2119.7 | — | — | — | Tong and Lam 2000 |
| Egypt | 1.3–8.8 | 85.3–120 | — | — | — | — | 138–237 | — | 1016–7885 | — | — | Rasheed 2008 |
| Nigeria (rural zone) | ND–212 | ND–178 | ND–54 | ND–28.2 | 3.4–2310 | 0.95–7.9 | 4.3–365 | 6.0–61,600 | 219–18,100 | 1780–11,100 | 12.6–131 | This study |
| Nigeria (semi-urban zone) | 0.1–1.8 | 3.6–104 | ND–54.9 | ND–33.2 | 6.4–1100 | 1.0–7.0 | 24.8–240 | 65–1260 | 1670–37,700 | 3230–18,000 | 29–225 | This study |
| Nigeria (urban zone) | ND–6.1 | 5.1–182 | ND–117 | ND–32.6 | 9.7–161 | 0.4–7.1 | 20.5–357 | 45.6–1330 | 1380–24,200 | 1180–13,900 | 7.9–265 | This study |

[a] Arithmetic mean with geometric mean value in parentheses

(semi-urban) and 43% (urban) of the dust samples collected in 2014 as against 3% (rural), 20% (semi-urban) and 47% (urban) in the 2009 survey (Table 5). The concentrations of Cu found in the dust samples were comparable to Cu levels reported for indoor dust in the literature (Kim and Fergusson 1993; Rasmussen et al. 2001; Lisiewicz et al. 2000; Tong and Lam 2000; Chattopadhyay et al. 2003; Žibret and Rokavec 2010; Hassan 2012; Kurt-Karakus 2012).

The levels of cobalt in the household dust samples varied from 0.35 to 7.05, 0.95 to 7.00 and 0.95 to 7.9 mg kg$^{-1}$ for the urban, semi-urban and rural zones, respectively. The Co status of the household dust samples was not studied in the 2009 survey; however, the difference observed in the concentrations of Co from the three zones was not significant ($p < 0.05$). The levels of Co found in the indoor dust samples were below the control limit of 20 mg kg$^{-1}$ Co in soil specified by the Nigerian Regulatory Authority (DPR 2002). The concentrations of Co found in dust samples from these zones were lower than the levels of Co detected in indoor dust in the literature (Table 6) (Turner and Hefzi 2010).

The concentrations of Mn in the dust samples followed the order: urban > semi-urban > rural in the 2009 survey, but the concentrations were higher in the rural and urban areas in 2014. On average, the concentrations of Mn in the dust samples were below the crustal abundance value of 850 mg kg$^{-1}$ (Turekian and Wedephol 1961). The principal sources of Mn in household dust include the use of household cleaning agents, automobile emissions and outdoor dust.

The concentrations of Zn varied significantly with respect to the three zones during the two sampling campaigns. The concentration range of Zn in the household dust samples varied from 6.78 to 61,600 mg kg$^{-1}$ in 2009 and from 78.9 to 2760 mg kg$^{-1}$ in 2014. The median concentration of Zn decreased threefold in the urban zone but increased threefold in the semi-urban zone over the study duration. However, there was no significant variation in the median concentrations of Zn in the rural zone during the two sampling periods. The sources of Zn in household dust include attrition from tyres, outdoor dust and leaching of Zn from rusted or corroded zinc roofing materials. Other important sources in the household environment include rubber underlay, galvanised iron roofing and carpets (Kim and Fergusson 1993). The concentrations of Zn in a significant proportion (57 to 100%) of the samples collected from the three zones during the two surveys (Table 5) were above the maximum allowable limit of 140 mg kg$^{-1}$ Zn in soil (DPR 2002).

Iron and aluminium are the most abundant elements in these dust samples. The maximum concentrations of Fe and Al observed in these dust samples from the three zones were below their respective crustal abundance values. In the 2009 survey, the distribution pattern for Fe followed the order: urban > semi-urban > rural area whereas in 2014, the concentration of Fe and Al followed the order: semi-urban > rural > urban area. Apart from natural sources of Al and Fe in the dust samples, other sources of Fe include iron works and leaching of Al and Fe from household materials.

Despite the variations in the sampling designs and statistics, sampling units and number of samples investigated, a comparison of the concentration ranges of metals found in household dust from this study with those reported for other regions (including those from arid, temperate and tropical environments) showed that for most metals, the data correspond with those obtained in different urban and suburban settings with no specific point sources of metals, and where different analytical procedures (digestion) or methods of instrumental analysis of dust samples were carried out (Table 6). It has been shown that household dust in arid regions is characterised by lower metal concentrations than that from temperate and tropical environments because of the diluent effects of trace metal-impoverished desert sand grains on contaminated indoor and outdoor particles. This dilution makes the effects of heterogeneous indoor metal sources not as pronounced as in the case of temperate or tropical environments (Turner and Hefzi 2010). Cd, Pb, Ni, Cu and Fe concentrations in the present study were higher than levels previously reported in the north-central part of Nigeria (Adekola and Dosumu 2001). Lower concentrations of Co were found in our samples compared with those reported in the literature (Rasmussen et al. 2001; Žibret and Rokavec 2010; Kurt-Karakus 2012).

## Contamination/pollution index

The CPIs estimated for the metals in the three environments are displayed in Table 7. The CPI values obtained for Pb, Cr, Ni, Co and Ba in the majority of the dust samples from these three zones were less than 1 which indicates that these dust samples were contaminated with these metals. On the contrary, the CPI values for metals such as Cd, Cu, and Zn in most of the samples examined were above 1. The CPI provides information on how the measured concentrations of metals in the environment relate to the country's regulatory control limits. It can also be useful in ranking polluted sites and determining the contribution of an individual metal to the extent of pollution at the site. The CPI for cadmium in the majority of these dust samples falls within the slight contamination to severe contamination range with 33% of the urban, 22% of the semi-urban and 10% of the rural samples having CPI values greater than 1 (i.e. pollution range), but in the 2014 sampling campaign, the CPI values of Cd were above 1 in 35, 90 and 33% of the samples from urban, semi-urban and rural zones, respectively. For Pb, only six samples had CPI values greater than 1. Only 17 and 24% of the samples had CPI

**Table 7**  Descriptive statistics for the contamination/pollution index of metals in household dust samples

| | 2009 | | | | | | 2014 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | SD | Median | Min | Max | % > 1 | Mean | SD | Median | Min | Max | % > 1 |
| **Rural** | | | | | | | | | | | | |
| Cd | 1.75 | 5.07 | 0.34 | 0.00 | 26.5 | 10 | 1.22 | 0.93 | 0.91 | 0.19 | 3.44 | 35 |
| Pb | 0.34 | 0.59 | 0.08 | 0.00 | 2.09 | 13 | 0.40 | 0.37 | 0.22 | 0.10 | 1.57 | 5 |
| Ba | | | | | | | 0.22 | 0.16 | 0.14 | 0.06 | 0.65 | 0 |
| Cr | 0.02 | 0.03 | 0.00 | 0.00 | 0.11 | 0 | 0.23 | 0.12 | 0.18 | 0.09 | 0.54 | 0 |
| Ni | 0.05 | 0.10 | 0.00 | 0.00 | 0.33 | 0 | 0.31 | 0.24 | 0.21 | 0.06 | 0.90 | 0 |
| Cu | 2.43 | 11.46 | 0.27 | 0.09 | 64.1 | 7 | 1.09 | 1.19 | 0.56 | 0.17 | 4.58 | 25 |
| Co | | | | | | | 0.12 | 0.13 | 0.07 | 0.04 | 0.56 | 0 |
| Zn | 44.4 | 111 | 2.67 | 0.05 | 440 | 87 | 3.66 | 4.43 | 2.45 | 0.56 | 19.68 | 85 |
| MPI | 55.6 | 123 | 3.20 | 1.14 | 469 | 87 | 6.11 | 6.77 | 3.52 | 1.07 | 26.95 | 85 |
| **Semi-urban** | | | | | | | | | | | | |
| Cd | 1.46 | 3.99 | 0.64 | 0.14 | 22.5 | 21 | 2.37 | 0.94 | 2.29 | 0.94 | 4.75 | 90 |
| Pb | 0.18 | 0.14 | 0.15 | 0.04 | 0.70 | 0 | 0.79 | 0.44 | 0.80 | 0.14 | 1.62 | 30 |
| Ba | | | | | | | 0.38 | 0.27 | 0.31 | 0.15 | 1.12 | 10 |
| Cr | 0.04 | 0.04 | 0.02 | 0.00 | 0.15 | 0 | 0.34 | 0.11 | 0.37 | 0.14 | 0.55 | 0 |
| Ni | 0.14 | 0.21 | 0.08 | 0.00 | 0.87 | 0 | 0.61 | 0.22 | 0.60 | 0.23 | 0.95 | 0 |
| Cu | 1.75 | 5.51 | 0.53 | 0.18 | 30.69 | 21 | 4.80 | 6.34 | 2.99 | 0.97 | 23.68 | 90 |
| Co | | | | | | | 0.18 | 0.09 | 0.18 | 0.05 | 0.35 | 0 |
| Zn | 2.17 | 1.78 | 1.33 | 0.46 | 9.00 | 72 | 3.46 | 0.69 | 3.47 | 2.39 | 4.47 | 100 |
| MPI | 5.03 | 7.10 | 2.57 | 1.06 | 33.0 | 86 | 10.9 | 7.47 | 9.45 | 2.39 | 31.91 | 100 |
| **Urban** | | | | | | | | | | | | |
| Cd | 1.64 | 3.96 | 0.83 | 0.00 | 22.80 | 37 | 1.56 | 1.86 | 0.69 | 0.25 | 7.63 | 33 |
| Pb | 0.36 | 0.30 | 0.34 | 0.06 | 1.63 | 3 | 0.45 | 0.49 | 0.21 | 0.00 | 2.14 | 10 |
| Ba | | | | | | | 0.31 | 0.33 | 0.15 | 0.04 | 1.33 | 5 |
| Cr | 0.03 | 0.02 | 0.03 | 0.00 | 0.10 | 0 | 0.27 | 0.25 | 0.17 | 0.06 | 1.17 | 5 |
| Ni | 0.81 | 2.38 | 0.23 | 0.00 | 13.46 | 13 | 0.37 | 0.34 | 0.24 | 0.05 | 1.34 | 5 |
| Cu | 1.42 | 1.33 | 0.62 | 0.29 | 6.61 | 47 | 1.38 | 1.19 | 0.92 | 0.27 | 4.47 | 43 |
| Co | | | | | | | 0.10 | 0.10 | 0.05 | 0.02 | 0.35 | 0 |
| Zn | 3.28 | 2.04 | 2.86 | 0.33 | 9.47 | 90 | 2.01 | 1.74 | 1.06 | 0.43 | 5.96 | 57 |
| MPI | 6.38 | 5.27 | 5.75 | 1.17 | 29.0 | 90 | 6.97 | 5.72 | 5.44 | 1.03 | 16.8 | 62 |

*MPI* multiple pollution index

values for Zn in the contamination range for the 2009 and 2014 sampling campaigns, respectively. In the case of Cu, 23% of the samples in 2009 and 45% of the samples in 2014 had CPI values in the pollution range. The multiple pollution index (MPI) for these metals ranged from 1.06–469 for 2009 and from 1.07–31.91 in 2014 with a significant contribution or with greatest impact from Zn followed by Cu and Cd. The MPI values indicate that Zn, Cd and Cu are the major pollutants in these dust samples.

**Enrichment factor**

The enrichment factors for metals in the dust samples are displayed in Table 8. The degree of enrichment or depletion of specific metals in the dust samples was

evaluated relative to the concentration of Fe as the reference element and the average crustal rock concentrations as the background levels. An EF value close to 1 can be considered as of natural origin while values greater than 10 indicate anthropogenic origins (Nolting et al. 1999; Pekey 2006). An EF value <10 is less critical because such small enrichment may be associated with variations in the sample composition and that of the reference material used in the EF calculation (Pekey 2006). In the current study, the EF values of Cd and Zn in the majority of the investigated samples from the three zones were greater than 10 which suggested noncrustal origins of these elements. In the case of Pb and Cu, 4–22% of the samples in 2009 and 33–71% of the samples in 2014 had EF values exceeding 10. The

**Table 8** Descriptive statistics for the enrichment factor of metals in household dust samples

| | 2009 | | | | | | | 2014 | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | SD | Median | Min | Max | % > 1 | % > 10 | Mean | SD | Median | Min | Max | % > 1 | % > 10 |
| **Rural** | | | | | | | | | | | | | | |
| Cd | 41.1 | 101 | 14.12 | 0.00 | 530 | 23 | 63 | 26.9 | 8.72 | 28.8 | 5.70 | 41.4 | 5 | 95 |
| Pb | 13.0 | 23.2 | 4.68 | 0.00 | 125 | 77 | 20 | 14.9 | 10.7 | 11.0 | 4.70 | 47.8 | 40 | 60 |
| Ba | | | | | | | | 0.71 | 0.48 | 0.54 | 0.29 | 2.15 | 10 | 0 |
| Cr | 0.37 | 0.60 | 0.05 | 0.00 | 2.37 | 10 | 0 | 2.35 | 0.73 | 2.13 | 1.49 | 4.67 | 100 | 0 |
| Ni | 0.29 | 0.65 | 0.00 | 0.00 | 2.28 | 13 | 0 | 1.34 | 0.51 | 1.36 | 0.57 | 2.73 | 70 | 0 |
| Cu | 18.2 | 75.9 | 2.95 | 0.78 | 426 | 87 | 3 | 7.39 | 7.62 | 5.07 | 2.65 | 38.1 | 85 | 15 |
| Co | | | | | | | | 0.98 | 0.45 | 0.83 | 0.52 | 2.49 | 30 | 0 |
| Mn | 0.99 | 0.45 | 1.02 | 0.30 | 2.55 | 50 | 0 | 1.38 | 0.38 | 1.33 | 0.66 | 2.02 | 85 | 0 |
| Zn | 580 | 1646 | 63.5 | 2.88 | 8698 | 3 | 97 | 70.7 | 42.2 | 57.65 | 26.7 | 209 | 0 | 100 |
| Al | | | | | | | | 0.48 | 0.09 | 0.48 | 0.38 | 0.67 | 0 | 0 |
| **Semi-urban** | | | | | | | | | | | | | | |
| Cd | 42.6 | 115 | 16.5 | 1.08 | 642 | 24 | 76 | 35.1 | 18.4 | 29.3 | 17.4 | 73.5 | 0 | 100 |
| Pb | 8.53 | 11.7 | 5.67 | 1.50 | 66.3 | 76 | 24 | 14.9 | 4.42 | 13.1 | 8.90 | 24.0 | 10 | 90 |
| Ba | | | | | | | | 0.66 | 0.47 | 0.49 | 0.31 | 2.00 | 10 | 0 |
| Cr | 0.40 | 0.48 | 0.23 | 0.00 | 2.14 | 10 | 0 | 2.05 | 0.87 | 1.76 | 1.16 | 3.93 | 100 | 0 |
| Ni | 0.84 | 1.30 | 0.29 | 0.00 | 5.10 | 24 | 0 | 2.10 | 2.01 | 1.20 | 0.69 | 6.88 | 60 | 0 |
| Cu | 13.2 | 41.2 | 3.49 | 0.42 | 230 | 76 | 17 | 18.0 | 15.8 | 10.8 | 6.02 | 57.7 | 40 | 60 |
| Co | | | | | | | | 0.87 | 0.24 | 0.87 | 0.56 | 1.31 | 50 | 0 |
| Mn | 0.64 | 0.29 | 0.61 | 0.21 | 1.62 | 10 | 0 | 0.99 | 0.28 | 0.87 | 0.70 | 1.64 | 40 | 0 |
| Zn | 27.3 | 18.9 | 24.1 | 3.22 | 83.9 | 7 | 93 | 52.0 | 33.9 | 34.2 | 17.4 | 123 | 0 | 100 |
| Al | | | | | | | | 0.47 | 0.21 | 0.49 | 0.14 | 0.77 | 0 | 0 |
| **Urban** | | | | | | | | | | | | | | |
| Cd | 40.2 | 98.9 | 18.0 | 0.00 | 567 | 17 | 80 | 37.3 | 17.5 | 34.1 | 12.3 | 92.0 | 0 | 100 |
| Pb | 13.2 | 11.7 | 9.82 | 2.58 | 64.6 | 50 | 50 | 20.9 | 25.2 | 14.6 | 0.10 | 103 | 29 | 67 |
| Ba | | | | | | | | 1.06 | 0.51 | 1.01 | 0.41 | 2.88 | 52 | 0 |
| Cr | 0.28 | 0.24 | 0.20 | 0.00 | 1.12 | 3 | 0 | 3.28 | 1.12 | 3.09 | 1.59 | 6.27 | 100 | 0 |
| Ni | 3.12 | 6.53 | 0.95 | 0.00 | 34.6 | 40 | 7 | 2.04 | 0.84 | 2.15 | 0.59 | 3.71 | 86 | 0 |
| Cu | 13.7 | 26.9 | 6.70 | 1.33 | 153 | 60 | 40 | 13.0 | 8.55 | 9.38 | 4.38 | 40.6 | 57 | 43 |
| Co | | | | | | | | 0.97 | 0.25 | 1.00 | 0.44 | 1.52 | 48 | 0 |
| Mn | 0.70 | 0.47 | 0.59 | 0.31 | 2.60 | 17 | 0 | 1.11 | 0.25 | 1.13 | 0.48 | 1.54 | 67 | 0 |
| Zn | 43.2 | 29.8 | 38.2 | 5.00 | 149 | 3 | 97 | 58.6 | 37.0 | 49.1 | 14.6 | 181 | 0 | 100 |
| Al | | | | | | | | 0.45 | 0.14 | 0.41 | 0.27 | 0.78 | 0 | 0 |

sources of these metals include a variety of pollution emission sources, including vehicular emissions, incineration, construction works, and fossil fuel combustion. Because Pb has been phased out as an additive in petrol, vehicular Pb emissions principally come from wear rather than fuel combustion, although there are trace levels of Pb in fuel (Smichowski et al. 2008). In the 2009 survey, 48 to 57% of the dust samples were significantly enriched with Cd; 13–27% were highly enriched with Cd, while 3–6 samples from each zone were extremely highly enriched with Cd. This indicates that the concentration of Cd in these dust samples arose from non-crustal sources. The EF values for Ba, Cr, Ni,

Co and Mn in our samples were less than 10 which suggest that crustal sources were the main contributors of these metals in the household dust.

### Index of geoaccumulation

The index of geoaccumulation ($I_{geo}$) is another useful tool for evaluating metal contamination in the environment by comparing the post-industrial metal inputs with pre-industrial concentrations. As shown in Table 9, the calculated $I_{geo}$ values for Ba, Cr, Ni, Co, Mn, Fe and Al were less than 1 in all the samples collected during the two sampling campaigns. This implies that the dust

**Table 9**  Descriptive statistics for the geoaccumulation index of metals in household dust samples

| | 2009 | | | | | | 2014 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | SD | Median | Min | Max | % > 1 | Mean | SD | Median | Min | Max | % > 1 |
| **Rural** | | | | | | | | | | | | |
| Cd | −0.65 | 2.32 | −0.66 | −5.49 | 5.56 | 10 | 0.72 | 1.10 | 0.69 | −1.59 | 2.61 | 30 |
| Pb | −1.51 | 1.94 | −2.13 | −4.32 | 2.57 | 13 | −0.30 | 1.10 | −0.67 | −1.85 | 2.15 | 15 |
| Ba | | | | | | | −4.64 | 0.93 | −4.95 | −6.11 | −2.73 | 0 |
| Cr | −3.33 | 3.23 | −3.95 | −10.40 | 0.00 | 0 | −2.75 | 0.68 | −2.91 | −3.85 | −1.32 | 0 |
| Ni | −0.99 | 1.89 | 0.00 | −7.00 | 0.00 | 0 | −3.60 | 0.98 | −3.81 | −5.64 | −1.70 | 0 |
| Cu | −2.60 | 1.64 | −2.80 | −4.32 | 5.10 | 10 | −1.39 | 1.24 | −1.74 | −3.43 | 1.29 | 10 |
| Co | | | | | | | −4.06 | 1.02 | −4.43 | −5.25 | −1.35 | 0 |
| Mn | −4.63 | 0.83 | −4.56 | −8.23 | −3.09 | 0 | −3.52 | 0.87 | −3.40 | −4.95 | −1.80 | 0 |
| Zn | 2.06 | 2.83 | 1.39 | −4.39 | 8.76 | 63 | 1.24 | 1.20 | 1.27 | −0.85 | 4.27 | 65 |
| Fe | −4.47 | 1.17 | −4.58 | −8.33 | −1.97 | 0 | −3.63 | 0.73 | −3.66 | −4.76 | −1.96 | 0 |
| Al | | | | | | | −4.70 | 0.80 | −4.83 | −6.08 | −3.15 | 0 |
| **Semi-urban** | | | | | | | | | | | | |
| Cd | 0.36 | 1.15 | 0.18 | −2.03 | 5.32 | 17 | 1.97 | 0.56 | 2.02 | 0.74 | 3.08 | 90 |
| Pb | −1.27 | 0.91 | −1.23 | −3.05 | 1.00 | 0 | 0.86 | 1.04 | 1.16 | −1.30 | 2.20 | 50 |
| Ba | | | | | | | −3.83 | 0.87 | −3.86 | −4.91 | −1.95 | 0 |
| Cr | −4.67 | 2.08 | −5.27 | −7.35 | 0.00 | 0 | −2.06 | 0.50 | −1.87 | −3.23 | −1.30 | 0 |
| Ni | −3.03 | 2.28 | −3.88 | −6.48 | 0.00 | 0 | −2.38 | 0.62 | −2.29 | −3.67 | −1.62 | 0 |
| Cu | −1.57 | 1.41 | −1.82 | −3.40 | 4.03 | 3 | 0.76 | 1.10 | 0.68 | −0.96 | 3.66 | 20 |
| Co | | | | | | | −3.24 | 0.81 | −3.05 | −4.91 | −2.03 | 0 |
| Mn | −4.52 | 0.65 | −4.41 | −5.86 | −3.49 | 0 | −3.04 | 0.59 | −2.92 | −4.10 | −2.41 | 0 |
| Zn | 0.72 | 1.00 | 0.38 | −1.13 | 3.15 | 41 | 1.73 | 0.30 | 1.77 | 1.23 | 2.13 | 100 |
| Fe | −3.73 | 0.90 | −3.81 | −5.40 | −1.74 | 0 | −2.48 | 0.75 | −2.38 | −3.79 | −0.90 | 0 |
| Al | | | | | | | −3.75 | 0.90 | −3.46 | −5.22 | −2.74 | 0 |
| **Urban** | | | | | | | | | | | | |
| Cd | 0.70 | 1.11 | 0.56 | −0.97 | 5.34 | 23 | 0.67 | 1.45 | 0.29 | −1.17 | 3.76 | 29 |
| Pb | −0.39 | 1.09 | −0.07 | −2.45 | 2.21 | 7 | −0.96 | 2.61 | −0.78 | −9.23 | 2.60 | 19 |
| Ba | | | | | | | −4.47 | 1.38 | −4.88 | −6.78 | −1.71 | 0 |
| Cr | −5.79 | 1.68 | −5.67 | −9.81 | 0.00 | 0 | −2.78 | 1.08 | −2.97 | −4.39 | −0.21 | 0 |
| Ni | −2.78 | 1.71 | −3.47 | −4.98 | 2.21 | 3 | −3.53 | 1.25 | −3.62 | −5.91 | −1.12 | 0 |
| Cu | −0.94 | 1.24 | −1.61 | −2.67 | 1.82 | 3 | −0.94 | 1.19 | −1.03 | −2.81 | 1.25 | 10 |
| Co | | | | | | | −4.50 | 1.32 | −4.83 | −6.35 | −2.02 | 0 |
| Mn | −4.46 | 0.73 | −4.39 | −5.81 | −1.84 | 0 | −4.30 | 1.28 | −4.53 | −5.96 | −2.13 | 0 |
| Zn | 1.36 | 1.05 | 1.49 | −1.64 | 3.22 | 63 | 0.47 | 1.20 | 0.06 | −1.24 | 2.55 | 38 |
| Fe | −3.74 | 0.80 | −3.57 | −5.67 | −2.60 | 0 | −3.95 | 1.14 | −4.12 | −5.42 | −1.54 | 0 |
| Al | | | | | | | −5.18 | 1.18 | −5.61 | −6.68 | −3.12 | 0 |

samples from these three zones were practically uncontaminated with these particular metals. However, there are a few points in the data set that have $I_{geo}$ values above 1, especially for Cd, Pb, Cu and Zn. For example, three samples of dust collected from the rural zone in 2009 had $I_{geo}$ values for Cd in the strongly polluted to extremely polluted category, while 40% of the dust samples from the urban zone had $I_{geo}$ values for Zn between the range of 2 and 4 (moderately to strongly

polluted category), and 13% of the dust samples from the rural zone had $I_{geo}$ values for Zn in the extremely polluted category.

### Health risk assessment

The health risks (both non-carcinogenic and carcinogenic) associated with exposure to metals in dust samples from the study areas in the Niger Delta are presented in Tables 10 and

**Table 10** Hazard index derived from metal exposure in indoor dust

| | Rural | | | | Semi-urban | | | | Urban | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | HQ$_{ingestion}$ | HQ$_{inhalation}$ | HQ$_{dermal}$ | HI | HQ$_{ingestion}$ | HQ$_{inhalation}$ | HQ$_{dermal}$ | HI | HQ$_{ingestion}$ | HQ$_{inhalation}$ | HQ$_{dermal}$ | HI |
| **Child** | | | | | | | | | | | | |
| **2009** | | | | | | | | | | | | |
| Cd | $1.39 \times 10^{-2}$ | $3.41 \times 10^{-4}$ | $5.20 \times 10^{-3}$ | $1.95 \times 10^{-2}$ | $1.31 \times 10^{-2}$ | $3.20 \times 10^{-4}$ | $4.88 \times 10^{-3}$ | $1.83 \times 10^{-2}$ | $1.35 \times 10^{-2}$ | $3.32 \times 10^{-4}$ | $5.05 \times 10^{-3}$ | $1.89 \times 10^{-2}$ |
| Pb | $3.71 \times 10^{-1}$ | $1.59 \times 10^{-4}$ | $3.47 \times 10^{-4}$ | $3.72 \times 10^{-1}$ | $1.97 \times 10^{-1}$ | $8.45 \times 10^{-5}$ | $1.84 \times 10^{-4}$ | $1.97 \times 10^{-1}$ | $3.75 \times 10^{-1}$ | $1.61 \times 10^{-4}$ | $3.50 \times 10^{-4}$ | $3.75 \times 10^{-1}$ |
| Cr | $5.17 \times 10^{-2}$ | $3.80 \times 10^{-5}$ | $3.71 \times 10^{-3}$ | $5.54 \times 10^{-2}$ | $6.95 \times 10^{-2}$ | $5.11 \times 10^{-5}$ | $4.99 \times 10^{-3}$ | $7.45 \times 10^{-2}$ | $5.77 \times 10^{-2}$ | $4.25 \times 10^{-5}$ | $4.15 \times 10^{-3}$ | $6.19 \times 10^{-2}$ |
| Ni | $6.74 \times 10^{-3}$ | $3.67 \times 10^{-5}$ | $1.57 \times 10^{-4}$ | $6.93 \times 10^{-3}$ | $1.40 \times 10^{-2}$ | $7.61 \times 10^{-5}$ | $3.26 \times 10^{-4}$ | $1.44 \times 10^{-2}$ | $8.59 \times 10^{-2}$ | $4.68 \times 10^{-5}$ | $2.00 \times 10^{-3}$ | $8.84 \times 10^{-2}$ |
| Cu | $1.59 \times 10^{-2}$ | $1.11 \times 10^{-4}$ | $1.48 \times 10^{-4}$ | $1.60 \times 10^{-2}$ | $9.70 \times 10^{-2}$ | $6.79 \times 10^{-4}$ | $9.05 \times 10^{-4}$ | $9.77 \times 10^{-2}$ | $5.39 \times 10^{-2}$ | $3.77 \times 10^{-5}$ | $5.03 \times 10^{-3}$ | $5.43 \times 10^{-2}$ |
| Mn | $1.67 \times 10^{-2}$ | $1.15 \times 10^{-3}$ | $1.56 \times 10^{-5}$ | $1.79 \times 10^{-2}$ | $1.73 \times 10^{-2}$ | $1.19 \times 10^{-3}$ | $1.61 \times 10^{-5}$ | $1.85 \times 10^{-2}$ | $2.15 \times 10^{-2}$ | $1.47 \times 10^{-3}$ | $2.00 \times 10^{-5}$ | $2.30 \times 10^{-2}$ |
| Zn | $9.82 \times 10^{-1}$ | $1.81 \times 10^{-3}$ | $9.17 \times 10^{-4}$ | $9.85 \times 10^{-1}$ | $4.15 \times 10^{-1}$ | $7.63 \times 10^{-5}$ | $3.87 \times 10^{-4}$ | $4.16 \times 10^{-1}$ | $6.01 \times 10^{-2}$ | $1.11 \times 10^{-4}$ | $5.61 \times 10^{-4}$ | $6.03 \times 10^{-2}$ |
| Fe | $2.53 \times 10^{-1}$ | $0.00$ | $2.36 \times 10^{-4}$ | $2.53 \times 10^{-1}$ | $3.74 \times 10^{-1}$ | $0.00$ | $3.49 \times 10^{-4}$ | $3.74 \times 10^{-1}$ | $3.30 \times 10^{-1}$ | $0.00$ | $3.08 \times 10^{-4}$ | $3.31 \times 10^{-1}$ |
| Total | $1.85$ | $3.64 \times 10^{-3}$ | $1.07 \times 10^{-2}$ | $1.87$ | $8.23 \times 10^{-1}$ | $1.86 \times 10^{-3}$ | $1.09 \times 10^{-2}$ | $8.36 \times 10^{-1}$ | $9.98 \times 10^{-1}$ | $2.63 \times 10^{-3}$ | $1.20 \times 10^{-2}$ | $1.01$ |
| **2014** | | | | | | | | | | | | |
| Cd | $1.02 \times 10^{-2}$ | $2.51 \times 10^{-4}$ | $3.82 \times 10^{-3}$ | $1.43 \times 10^{-2}$ | $1.41 \times 10^{-2}$ | $3.44 \times 10^{-4}$ | $5.25 \times 10^{-3}$ | $1.96 \times 10^{-2}$ | $1.16 \times 10^{-2}$ | $2.86 \times 10^{-4}$ | $4.35 \times 10^{-3}$ | $1.63 \times 10^{-2}$ |
| Pb | $4.20 \times 10^{-1}$ | $1.80 \times 10^{-4}$ | $3.92 \times 10^{-4}$ | $4.21 \times 10^{-1}$ | $7.66 \times 10^{-1}$ | $3.28 \times 10^{-4}$ | $7.15 \times 10^{-4}$ | $7.67 \times 10^{-1}$ | $4.77 \times 10^{-1}$ | $2.05 \times 10^{-4}$ | $4.46 \times 10^{-4}$ | $4.78 \times 10^{-1}$ |
| Ba | $9.14 \times 10^{-3}$ | $8.96 \times 10^{-5}$ | $0.00$ | $9.23 \times 10^{-3}$ | $1.73 \times 10^{-2}$ | $1.70 \times 10^{-4}$ | $0.00$ | $1.75 \times 10^{-2}$ | $1.35 \times 10^{-2}$ | $1.32 \times 10^{-4}$ | $0.00$ | $1.36 \times 10^{-2}$ |
| Cr | $3.22 \times 10^{-1}$ | $2.37 \times 10^{-4}$ | $2.31 \times 10^{-2}$ | $3.45 \times 10^{-1}$ | $4.58 \times 10^{-1}$ | $3.37 \times 10^{-4}$ | $3.29 \times 10^{-2}$ | $4.92 \times 10^{-1}$ | $4.00 \times 10^{-1}$ | $2.94 \times 10^{-4}$ | $2.87 \times 10^{-2}$ | $4.29 \times 10^{-1}$ |
| Ni | $2.49 \times 10^{-2}$ | $1.36 \times 10^{-4}$ | $5.82 \times 10^{-4}$ | $2.57 \times 10^{-2}$ | $4.37 \times 10^{-2}$ | $2.38 \times 10^{-4}$ | $1.02 \times 10^{-3}$ | $4.50 \times 10^{-2}$ | $2.96 \times 10^{-2}$ | $1.61 \times 10^{-4}$ | $6.90 \times 10^{-4}$ | $3.04 \times 10^{-2}$ |
| Cu | $4.33 \times 10^{-1}$ | $3.03 \times 10^{-5}$ | $4.04 \times 10^{-5}$ | $4.37 \times 10^{-1}$ | $2.43 \times 10^{-1}$ | $1.70 \times 10^{-4}$ | $2.27 \times 10^{-4}$ | $2.45 \times 10^{-1}$ | $5.19 \times 10^{-1}$ | $3.63 \times 10^{-5}$ | $4.84 \times 10^{-4}$ | $5.23 \times 10^{-1}$ |
| Co | $5.58 \times 10^{-1}$ | $6.84 \times 10^{-4}$ | $5.21 \times 10^{-4}$ | $5.59 \times 10^{-1}$ | $6.68 \times 10^{-1}$ | $8.19 \times 10^{-4}$ | $6.24 \times 10^{-4}$ | $6.70 \times 10^{-1}$ | $4.75 \times 10^{-1}$ | $5.82 \times 10^{-4}$ | $4.43 \times 10^{-4}$ | $4.76 \times 10^{-1}$ |
| Mn | $3.87 \times 10^{-2}$ | $2.66 \times 10^{-3}$ | $3.62 \times 10^{-5}$ | $4.14 \times 10^{-2}$ | $4.57 \times 10^{-2}$ | $3.13 \times 10^{-3}$ | $4.26 \times 10^{-5}$ | $4.89 \times 10^{-2}$ | $2.89 \times 10^{-2}$ | $1.98 \times 10^{-3}$ | $2.70 \times 10^{-5}$ | $3.09 \times 10^{-2}$ |
| Zn | $7.68 \times 10^{-2}$ | $1.41 \times 10^{-4}$ | $7.17 \times 10^{-5}$ | $7.70 \times 10^{-2}$ | $6.18 \times 10^{-2}$ | $1.14 \times 10^{-4}$ | $5.77 \times 10^{-5}$ | $6.19 \times 10^{-2}$ | $3.79 \times 10^{-2}$ | $6.97 \times 10^{-5}$ | $3.54 \times 10^{-5}$ | $3.80 \times 10^{-2}$ |
| Fe | $3.80 \times 10^{-1}$ | $0.00$ | $3.54 \times 10^{-4}$ | $3.80 \times 10^{-1}$ | $9.06 \times 10^{-1}$ | $0.00$ | $8.46 \times 10^{-4}$ | $9.07 \times 10^{-1}$ | $3.82 \times 10^{-1}$ | $0.00$ | $3.57 \times 10^{-4}$ | $3.83 \times 10^{-1}$ |
| Al | $2.54 \times 10^{-1}$ | $1.07 \times 10^{-2}$ | $0.00$ | $2.64 \times 10^{-1}$ | $4.66 \times 10^{-1}$ | $1.96 \times 10^{-2}$ | $0.00$ | $4.86 \times 10^{-1}$ | $2.25 \times 10^{-1}$ | $9.47 \times 10^{-3}$ | $0.00$ | $2.35 \times 10^{-1}$ |
| Total | $2.14$ | $1.51 \times 10^{-2}$ | $2.89 \times 10^{-2}$ | $2.18$ | $3.69$ | $2.53 \times 10^{-2}$ | $4.17 \times 10^{-2}$ | $3.76$ | $2.13$ | $1.32 \times 10^{-2}$ | $3.51 \times 10^{-2}$ | $2.18$ |
| **Adult** | | | | | | | | | | | | |
| **2009** | | | | | | | | | | | | |
| Cd | $1.74 \times 10^{-3}$ | $3.24 \times 10^{-5}$ | $9.26 \times 10^{-4}$ | $2.70 \times 10^{-3}$ | $1.63 \times 10^{-3}$ | $3.04 \times 10^{-5}$ | $8.69 \times 10^{-4}$ | $2.53 \times 10^{-3}$ | $1.69 \times 10^{-3}$ | $3.15 \times 10^{-5}$ | $9.00 \times 10^{-4}$ | $2.62 \times 10^{-3}$ |
| Pb | $4.64 \times 10^{-2}$ | $1.51 \times 10^{-5}$ | $6.17 \times 10^{-5}$ | $4.72 \times 10^{-2}$ | $2.46 \times 10^{-2}$ | $8.03 \times 10^{-6}$ | $3.28 \times 10^{-5}$ | $2.50 \times 10^{-2}$ | $4.69 \times 10^{-2}$ | $1.53 \times 10^{-5}$ | $6.23 \times 10^{-5}$ | $4.76 \times 10^{-2}$ |
| Cr | $6.46 \times 10^{-3}$ | $3.61 \times 10^{-6}$ | $6.61 \times 10^{-4}$ | $1.31 \times 10^{-3}$ | $8.69 \times 10^{-4}$ | $4.85 \times 10^{-6}$ | $8.89 \times 10^{-4}$ | $1.76 \times 10^{-3}$ | $7.22 \times 10^{-4}$ | $4.03 \times 10^{-6}$ | $7.38 \times 10^{-4}$ | $1.46 \times 10^{-3}$ |
| Ni | $8.43 \times 10^{-4}$ | $3.49 \times 10^{-6}$ | $2.80 \times 10^{-5}$ | $1.16 \times 10^{-3}$ | $1.75 \times 10^{-3}$ | $7.23 \times 10^{-6}$ | $5.80 \times 10^{-5}$ | $2.40 \times 10^{-3}$ | $1.07 \times 10^{-3}$ | $4.45 \times 10^{-6}$ | $3.57 \times 10^{-4}$ | $1.48 \times 10^{-3}$ |
| Cu | $1.99 \times 10^{-3}$ | $1.06 \times 10^{-5}$ | $2.64 \times 10^{-5}$ | $2.12 \times 10^{-3}$ | $1.21 \times 10^{-3}$ | $6.45 \times 10^{-6}$ | $1.61 \times 10^{-5}$ | $1.29 \times 10^{-3}$ | $6.73 \times 10^{-4}$ | $3.58 \times 10^{-6}$ | $8.95 \times 10^{-6}$ | $7.18 \times 10^{-4}$ |
| Mn | $2.09 \times 10^{-4}$ | $1.09 \times 10^{-4}$ | $2.78 \times 10^{-6}$ | $3.21 \times 10^{-4}$ | $2.16 \times 10^{-4}$ | $1.13 \times 10^{-4}$ | $2.87 \times 10^{-6}$ | $3.32 \times 10^{-4}$ | $2.68 \times 10^{-4}$ | $1.40 \times 10^{-4}$ | $3.57 \times 10^{-5}$ | $4.12 \times 10^{-4}$ |
| Zn | $1.23 \times 10^{-1}$ | $1.72 \times 10^{-4}$ | $1.63 \times 10^{-4}$ | $1.26 \times 10^{-1}$ | $5.19 \times 10^{-2}$ | $7.24 \times 10^{-6}$ | $6.90 \times 10^{-4}$ | $5.33 \times 10^{-2}$ | $7.52 \times 10^{-2}$ | $1.05 \times 10^{-5}$ | $1.00 \times 10^{-4}$ | $7.72 \times 10^{-2}$ |
| Fe | $3.16 \times 10^{-3}$ | $0.00$ | $4.20 \times 10^{-5}$ | $3.20 \times 10^{-3}$ | $4.67 \times 10^{-2}$ | $0.00$ | $6.21 \times 10^{-5}$ | $4.73 \times 10^{-2}$ | $4.13 \times 10^{-2}$ | $0.00$ | $5.49 \times 10^{-5}$ | $4.18 \times 10^{-2}$ |
| Total | $2.47 \times 10^{-2}$ | $3.46 \times 10^{-4}$ | $1.91 \times 10^{-3}$ | $2.71 \times 10^{-2}$ | $1.18 \times 10^{-2}$ | $1.77 \times 10^{-4}$ | $1.94 \times 10^{-3}$ | $1.39 \times 10^{-2}$ | $1.40 \times 10^{-2}$ | $2.49 \times 10^{-4}$ | $2.14 \times 10^{-3}$ | $1.64 \times 10^{-2}$ |
| **2014** | | | | | | | | | | | | |
| Cd | $1.28 \times 10^{-3}$ | $2.38 \times 10^{-5}$ | $6.80 \times 10^{-4}$ | $1.98 \times 10^{-3}$ | $1.76 \times 10^{-3}$ | $3.27 \times 10^{-5}$ | $9.34 \times 10^{-4}$ | $2.72 \times 10^{-3}$ | $1.46 \times 10^{-3}$ | $2.71 \times 10^{-5}$ | $7.75 \times 10^{-4}$ | $2.26 \times 10^{-3}$ |
| Pb | $5.25 \times 10^{-3}$ | $1.71 \times 10^{-5}$ | $6.99 \times 10^{-5}$ | $5.34 \times 10^{-3}$ | $9.57 \times 10^{-3}$ | $3.12 \times 10^{-5}$ | $1.27 \times 10^{-4}$ | $9.73 \times 10^{-3}$ | $5.97 \times 10^{-3}$ | $1.95 \times 10^{-5}$ | $7.94 \times 10^{-5}$ | $6.07 \times 10^{-3}$ |
| Ba | $1.14 \times 10^{-4}$ | $8.51 \times 10^{-6}$ | $0.00$ | $1.23 \times 10^{-4}$ | $2.17 \times 10^{-4}$ | $1.61 \times 10^{-5}$ | $0.00$ | $0.00$ | $1.68 \times 10^{-4}$ | $1.25 \times 10^{-5}$ | $0.00$ | $1.81 \times 10^{-4}$ |
| Cr | $4.03 \times 10^{-3}$ | $2.25 \times 10^{-5}$ | $4.12 \times 10^{-3}$ | $8.17 \times 10^{-3}$ | $5.73 \times 10^{-3}$ | $3.20 \times 10^{-5}$ | $5.86 \times 10^{-3}$ | $1.16 \times 10^{-2}$ | $5.00 \times 10^{-3}$ | $2.79 \times 10^{-5}$ | $5.12 \times 10^{-3}$ | $1.01 \times 10^{-2}$ |
| Ni | $3.12 \times 10^{-4}$ | $1.29 \times 10^{-5}$ | $1.04 \times 10^{-4}$ | $4.28 \times 10^{-4}$ | $5.47 \times 10^{-4}$ | $2.26 \times 10^{-5}$ | $1.82 \times 10^{-4}$ | $7.51 \times 10^{-4}$ | $3.70 \times 10^{-4}$ | $1.53 \times 10^{-5}$ | $1.23 \times 10^{-4}$ | $5.08 \times 10^{-4}$ |
| Cu | $5.42 \times 10^{-3}$ | $2.88 \times 10^{-6}$ | $7.20 \times 10^{-6}$ | $5.78 \times 10^{-3}$ | $3.04 \times 10^{-3}$ | $1.62 \times 10^{-5}$ | $4.05 \times 10^{-5}$ | $3.24 \times 10^{-3}$ | $6.48 \times 10^{-3}$ | $3.45 \times 10^{-6}$ | $8.62 \times 10^{-6}$ | $6.91 \times 10^{-3}$ |
| Co | $6.98 \times 10^{-3}$ | $6.50 \times 10^{-5}$ | $9.28 \times 10^{-5}$ | $7.13 \times 10^{-3}$ | $8.36 \times 10^{-3}$ | $7.78 \times 10^{-5}$ | $1.11 \times 10^{-4}$ | $8.54 \times 10^{-3}$ | $5.94 \times 10^{-3}$ | $5.53 \times 10^{-5}$ | $7.90 \times 10^{-5}$ | $6.07 \times 10^{-3}$ |
| Mn | $4.84 \times 10^{-4}$ | $2.53 \times 10^{-5}$ | $6.44 \times 10^{-6}$ | $7.43 \times 10^{-4}$ | $5.71 \times 10^{-4}$ | $2.98 \times 10^{-4}$ | $7.59 \times 10^{-5}$ | $8.76 \times 10^{-4}$ | $3.61 \times 10^{-4}$ | $1.88 \times 10^{-4}$ | $4.80 \times 10^{-5}$ | $5.54 \times 10^{-4}$ |
| Zn | $9.60 \times 10^{-4}$ | $1.34 \times 10^{-5}$ | $1.28 \times 10^{-5}$ | $9.86 \times 10^{-4}$ | $7.72 \times 10^{-4}$ | $1.08 \times 10^{-5}$ | $1.03 \times 10^{-4}$ | $7.93 \times 10^{-4}$ | $4.74 \times 10^{-4}$ | $6.62 \times 10^{-6}$ | $6.30 \times 10^{-5}$ | $4.87 \times 10^{-3}$ |
| Fe | $4.74 \times 10^{-3}$ | $0.00$ | $6.31 \times 10^{-5}$ | $4.81 \times 10^{-3}$ | $1.13 \times 10^{-2}$ | $0.00$ | $1.51 \times 10^{-4}$ | $1.15 \times 10^{-2}$ | $4.78 \times 10^{-3}$ | $0.00$ | $6.36 \times 10^{-5}$ | $4.84 \times 10^{-3}$ |
| Al | $2.72 \times 10^{-3}$ | $1.01 \times 10^{-3}$ | $0.00$ | $3.73 \times 10^{-3}$ | $5.00 \times 10^{-3}$ | $1.86 \times 10^{-3}$ | $0.00$ | $6.86 \times 10^{-3}$ | $2.41 \times 10^{-3}$ | $8.99 \times 10^{-4}$ | $0.00$ | $3.31 \times 10^{-3}$ |
| Total | $2.74 \times 10^{-2}$ | $1.43 \times 10^{-3}$ | $5.15 \times 10^{-3}$ | $3.40 \times 10^{-2}$ | $4.69 \times 10^{-2}$ | $2.40 \times 10^{-3}$ | $7.43 \times 10^{-3}$ | $5.39 \times 10^{-2}$ | $2.76 \times 10^{-2}$ | $1.26 \times 10^{-3}$ | $6.25 \times 10^{-3}$ | $3.51 \times 10^{-2}$ |

**Table 11**  Cancer risk from metal exposure in indoor dust

| | Rural | | | | Semi-urban | | | | Urban | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $\text{Risk}_{\text{ingestion}}$ | $\text{Risk}_{\text{inhalation}}$ | $\text{Risk}_{\text{dermal}}$ | Total cancer risk | $\text{Risk}_{\text{ingestion}}$ | $\text{Risk}_{\text{inhalation}}$ | $\text{Risk}_{\text{dermal}}$ | Total cancer risk | $\text{Risk}_{\text{ingestion}}$ | $\text{Risk}_{\text{inhalation}}$ | $\text{Risk}_{\text{dermal}}$ | Total cancer risk |
| **Child** | | | | | | | | | | | | |
| **2009** | | | | | | | | | | | | |
| Cd | 0.00 | $7.09 \times 10^{-13}$ | 0.00 | $7.09 \times 10^{-13}$ | 0.00 | $6.65 \times 10^{-13}$ | 0.00 | $6.65 \times 10^{-13}$ | 0.00 | $6.89 \times 10^{-13}$ | 0.00 | $6.89 \times 10^{-13}$ |
| Pb | $1.27 \times 10^{-7}$ | $4.41 \times 10^{-14}$ | $1.19 \times 10^{-9}$ | $1.29 \times 10^{-7}$ | $6.76 \times 10^{-8}$ | $2.34 \times 10^{-14}$ | $6.31 \times 10^{-10}$ | $6.83 \times 10^{-8}$ | $1.29 \times 10^{-7}$ | $4.45 \times 10^{-14}$ | $1.20 \times 10^{-9}$ | $1.30 \times 10^{-7}$ |
| Cr | $8.94 \times 10^{-9}$ | $5.26 \times 10^{-12}$ | $6.42 \times 10^{-9}$ | $1.54 \times 10^{-8}$ | $1.20 \times 10^{-8}$ | $7.07 \times 10^{-12}$ | $8.63 \times 10^{-9}$ | $2.07 \times 10^{-8}$ | $9.99 \times 10^{-9}$ | $5.88 \times 10^{-12}$ | $7.17 \times 10^{-9}$ | $1.72 \times 10^{-8}$ |
| Ni | 0.00 | $9.91 \times 10^{-14}$ | 0.00 | $9.91 \times 10^{-14}$ | 0.00 | $2.05 \times 10^{-13}$ | 0.00 | $2.05 \times 10^{-13}$ | 0.00 | $1.26 \times 10^{-12}$ | 0.00 | $1.26 \times 10^{-12}$ |
| Total | $1.36 \times 10^{-7}$ | $6.11 \times 10^{-12}$ | $7.61 \times 10^{-9}$ | $1.44 \times 10^{-7}$ | $7.97 \times 10^{-8}$ | $7.97 \times 10^{-12}$ | $9.27 \times 10^{-9}$ | $8.89 \times 10^{-8}$ | $1.39 \times 10^{-7}$ | $7.88 \times 10^{-12}$ | $8.38 \times 10^{-9}$ | $1.47 \times 10^{-7}$ |
| **2014** | | | | | | | | | | | | |
| Cd | 0.00 | $5.21 \times 10^{-13}$ | 0.00 | $5.21 \times 10^{-13}$ | 0.00 | $7.15 \times 10^{-13}$ | 0.00 | $7.15 \times 10^{-13}$ | 0.00 | $5.93 \times 10^{-13}$ | 0.00 | $5.93 \times 10^{-13}$ |
| Pb | $1.44 \times 10^{-7}$ | $4.99 \times 10^{-14}$ | $1.35 \times 10^{-9}$ | $1.46 \times 10^{-7}$ | $2.63 \times 10^{-7}$ | $9.09 \times 10^{-14}$ | $2.45 \times 10^{-9}$ | $2.65 \times 10^{-7}$ | $1.64 \times 10^{-7}$ | $5.67 \times 10^{-14}$ | $1.53 \times 10^{-9}$ | $1.65 \times 10^{-7}$ |
| Cr | $5.57 \times 10^{-8}$ | $3.28 \times 10^{-11}$ | $4.00 \times 10^{-8}$ | $9.58 \times 10^{-8}$ | $7.93 \times 10^{-8}$ | $4.67 \times 10^{-11}$ | $5.70 \times 10^{-8}$ | $1.36 \times 10^{-7}$ | $6.92 \times 10^{-8}$ | $4.07 \times 10^{-11}$ | $4.97 \times 10^{-8}$ | $1.19 \times 10^{-7}$ |
| Ni | 0.00 | $3.67 \times 10^{-13}$ | 0.00 | $3.67 \times 10^{-13}$ | 0.00 | $6.43 \times 10^{-13}$ | 0.00 | $6.43 \times 10^{-13}$ | 0.00 | $4.35 \times 10^{-13}$ | 0.00 | $4.35 \times 10^{-13}$ |
| Total | $1.36 \times 10^{-7}$ | $6.11 \times 10^{-12}$ | $7.61 \times 10^{-9}$ | $1.44 \times 10^{-7}$ | $7.97 \times 10^{-8}$ | $7.97 \times 10^{-12}$ | $9.27 \times 10^{-9}$ | $8.89 \times 10^{-8}$ | $1.39 \times 10^{-7}$ | $7.88 \times 10^{-12}$ | $8.38 \times 10^{-9}$ | $1.47 \times 10^{-7}$ |
| **Adult** | | | | | | | | | | | | |
| **2009** | | | | | | | | | | | | |
| Cd | 0.00 | $3.37 \times 10^{-13}$ | 0.00 | $3.37 \times 10^{-13}$ | 0.00 | $3.16 \times 10^{-13}$ | 0.00 | $3.16 \times 10^{-13}$ | 0.00 | $3.27 \times 10^{-13}$ | 0.00 | $3.27 \times 10^{-13}$ |
| Pb | $7.97 \times 10^{-8}$ | $2.10 \times 10^{-11}$ | $1.06 \times 10^{-9}$ | $8.08 \times 10^{-8}$ | $4.23 \times 10^{-8}$ | $1.11 \times 10^{-11}$ | $5.62 \times 10^{-10}$ | $4.28 \times 10^{-8}$ | $8.04 \times 10^{-8}$ | $2.12 \times 10^{-11}$ | $1.07 \times 10^{-9}$ | $8.15 \times 10^{-8}$ |
| Cr | $5.59 \times 10^{-9}$ | $2.50 \times 10^{-12}$ | $5.72 \times 10^{-9}$ | $1.13 \times 10^{-8}$ | $7.52 \times 10^{-9}$ | $3.36 \times 10^{-12}$ | $7.69 \times 10^{-9}$ | $1.52 \times 10^{-8}$ | $6.25 \times 10^{-9}$ | $2.79 \times 10^{-12}$ | $6.39 \times 10^{-9}$ | $1.26 \times 10^{-8}$ |
| Ni | 0.00 | $4.71 \times 10^{-14}$ | 0.00 | $4.71 \times 10^{-14}$ | 0.00 | $9.76 \times 10^{-14}$ | 0.00 | $9.76 \times 10^{-14}$ | 0.00 | $6.00 \times 10^{-13}$ | 0.00 | $6.00 \times 10^{-13}$ |
| Total | $8.53 \times 10^{-8}$ | $2.38 \times 10^{-11}$ | $6.78 \times 10^{-9}$ | $9.21 \times 10^{-8}$ | $4.98 \times 10^{-8}$ | $1.49 \times 10^{-11}$ | $8.25 \times 10^{-9}$ | $5.80 \times 10^{-8}$ | $8.67 \times 10^{-8}$ | $2.49 \times 10^{-11}$ | $7.46 \times 10^{-9}$ | $9.42 \times 10^{-8}$ |
| **2014** | | | | | | | | | | | | |
| Cd | 0.00 | $2.47 \times 10^{-13}$ | 0.00 | $2.47 \times 10^{-13}$ | 0.00 | $3.40 \times 10^{-13}$ | 0.00 | $3.40 \times 10^{-13}$ | 0.00 | $2.82 \times 10^{-13}$ | 0.00 | $2.82 \times 10^{-13}$ |
| Pb | $9.02 \times 10^{-8}$ | $2.37 \times 10^{-11}$ | $1.20 \times 10^{-9}$ | $9.14 \times 10^{-8}$ | $1.64 \times 10^{-7}$ | $4.32 \times 10^{-11}$ | $2.18 \times 10^{-9}$ | $1.66 \times 10^{-7}$ | $1.02 \times 10^{-7}$ | $2.70 \times 10^{-11}$ | $1.36 \times 10^{-9}$ | $1.04 \times 10^{-7}$ |
| Cr | $3.48 \times 10^{-8}$ | $1.56 \times 10^{-11}$ | $3.56 \times 10^{-8}$ | $7.05 \times 10^{-8}$ | $4.96 \times 10^{-8}$ | $2.22 \times 10^{-11}$ | $5.07 \times 10^{-8}$ | $1.00 \times 10^{-7}$ | $4.33 \times 10^{-8}$ | $1.93 \times 10^{-11}$ | $4.43 \times 10^{-8}$ | $8.76 \times 10^{-8}$ |
| Ni | 0.00 | $1.74 \times 10^{-13}$ | 0.00 | $1.74 \times 10^{-13}$ | 0.00 | $3.06 \times 10^{-13}$ | 0.00 | $3.06 \times 10^{-13}$ | 0.00 | $2.07 \times 10^{-13}$ | 0.00 | $2.07 \times 10^{-13}$ |
| Total | $1.25 \times 10^{-7}$ | $3.97 \times 10^{-11}$ | $3.68 \times 10^{-8}$ | $1.62 \times 10^{-7}$ | $2.14 \times 10^{-7}$ | $6.60 \times 10^{-11}$ | $5.29 \times 10^{-8}$ | $2.67 \times 10^{-7}$ | $1.46 \times 10^{-7}$ | $4.68 \times 10^{-11}$ | $4.56 \times 10^{-8}$ | $1.91 \times 10^{-7}$ |

11, respectively. A number of studies in the literature have adopted the USEPA model equations for the estimation of the HI of metals, including for Pb (Olawoyin et al. 2012; Chabukdhara and Nema 2013; Salem et al. 2014; Kexin et al. 2015; Yang et al. 2015; Islam et al. 2016; Ying et al. 2016). The HI values for the exposure of adults to metals in the dusts from the three zones were less than 1 during the two survey periods. This indicates no significant non-carcinogenic risk due to the concentrations of metals in the household dust from these zones for adults. However, in the case of exposure of children to these metals in the household dust, HI values greater than 1 for the rural and urban zones in 2009 and in all the three zones in 2014 were obtained. This indicates a considerable non-cancer risk for children in these zones and also implies that children would suffer a much higher risk than their adult counterparts in these household environments. This can be explained by children's hand-to-mouth habits and crawling behaviours which make them more susceptible to contaminants in dust (Robert et al. 2009). In 2014, Pb, Cr, Co, Fe and Al were the main contributors to the HI values as opposed to Pb, Zn and Fe in 2009. The HQ$_{ingestion}$ term made a greater contribution to the HI values than the HQ$_{dermal}$ and HQ$_{inhalation}$ terms for the different subject groups. Based on the three exposure pathways, all the individual metals showed HI indices less than the safe level of 1. The HI values obtained in this study were comparable to HI values reported for metals in indoor dust in the literature (Kurt-Karakus 2012; Huang et al. 2014). Even though the HIs based on the UCL$_{95\%}$ were within the safe limit or not of human health concern, exposure to high concentrations of Pb can impair growth and neurological functions (Ferreira-Baptista and De Miguel 2005). Additionally, Cd is a cumulative poison that can impair kidney function and reproductive development (de Burbure et al. 2003; Kurt-Karakus 2012). Although Zn is required for plant, animal and human metabolism, long-term exposure to Zn-

contaminated dust is associated with anaemia, bloody urine, kidney and liver dysfunctions, icterus and vomiting (Tahmasbian et al. 2014). However, in this study, the HI values for Cd, Cu and Zn were less than 1.

The total and individual carcinogenic risks arising from ingestion, inhalation and dermal contact of these dust particles were lower than $10^{-6}$ for the different subject groups (Table 11). The individual cancer risk values for both groups followed the order: ingestion > dermal > inhalation. The USEPA (1996) expressed the belief that an excess cancer risk value smaller than $1 \times 10^{-6}$ can be considered negligible for incremental lifetime cancer risk (ILCR) whereas ILCR values greater than $1 \times 10^{-4}$ are sufficiently large enough for remedial actions. Therefore, cancer risk is considered significant when the values are greater than $1 \times 10^{-4}$ (Hu et al. 2011). Since the carcinogenic risk levels due to metal exposure from household dusts from the rural, semi-urban and urban zones in this study were all much lower than the range considered safe by the USEPA ($1 \times 10^{-6}$ and $1 \times 10^{-4}$), we can conclude that there is a negligible cancer risk from metal exposure in indoor dust in these zones. However, human exposure risk to metals may be increased through other sources (not accounted for in this study) such as ingestion of foods, water, and exposure to exterior soils and street dust. Kurt-Karakus (2012) obtained similar safe limit results from exposure to indoor dust in Istanbul, Turkey. Since there are no Nigerian specific exposure parameters, the uncertainty in the risk assessment undertaken in this study is associated with the limited number of household dust samples investigated and the assumed values of receptor parameters in the USEPA models, which may not be the same as in the Nigerian situation. However, this does not rule out the need to provide

**Table 12**  PCA factor loadings after varimax rotation with Kaiser normalization for household dust samples

| Metals | Rural zone | | | Semi-urban zone | | | | Urban zone | | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| | Component | | | Component | | | | Component | | |
| | Factor 1 | Factor 2 | Factor 3 | Factor 1 | Factor 2 | Factor 3 | Factor 4 | Factor 1 | Factor 2 | Factor 3 |
| Cd | .931 | −.050 | .091 | −.216 | .660 | −.019 | −.375 | .940 | −.097 | −.014 |
| Pb | .873 | −.119 | .317 | .135 | .871 | −.042 | .097 | .938 | .176 | −.028 |
| Cr | −.249 | .626 | .082 | .112 | .044 | .916 | .063 | −.232 | .667 | .034 |
| Ni | −.112 | .881 | .165 | −.443 | −.319 | .519 | .080 | .133 | .075 | .788 |
| Cu | .101 | .789 | −.116 | −.069 | −.076 | .076 | .804 | −.165 | −.056 | .759 |
| Mn | .107 | −.022 | .920 | .795 | −.018 | .460 | −.081 | .065 | .568 | −.269 |
| Zn | .949 | −.127 | .167 | .702 | .251 | −.180 | .355 | .073 | .700 | .049 |
| Fe | .376 | .173 | .800 | .690 | −.345 | −.069 | −.313 | .157 | .758 | .118 |
| Variance (%) | 41.18 | 24.27 | 13.18 | 23.40 | 20.73 | 15.90 | 15.70 | 41.18 | 24.27 | 13.18 |

information on the likely potential human health risks associated with human exposure to metals in household dust in the study area.

## Principal component analysis

The PCA factor loadings of metals after rotation with Kaiser normalization for the rural, semi-urban and urban zones are displayed in Table 12. Principal component analysis is used to reduce the complexity in the data set and provides useful information about the relationships between the variables and their source contributions. In this study, PCA was used to study the correlation between the metals in the household dust samples collected from each of the zones. The data were not log transformed before the principal component analysis.

**Rural zone** In the rural zone, three factors were extracted and were responsible for 78.63% of the total variance. Factor 1 accounted for 41.18% and had significant loadings in Cd, Pb and Zn. Factor 1 represents anthropogenic metals that are associated with tyre attrition, traffic emissions, combustion processes, incineration, paint, etc. Factor 2 represents 24.27% of the total variance and had significant positive loadings in Cu, Cr and Ni. These anthropogenic metals are associated with different pollution sources such as agriculture, industries, traffic as well as leaching from wood preservatives used in household furniture. However, in the rural zone, traffic activities are of very low consequence in the pollution status of the environment. Therefore, factor 2 relates to emissions from agricultural activities and emissions from SMEs as well as that of oil industries. Factor 3 accounted for 13.18% of the total variance and was heavily dominated by Fe and Mn. Natural weathering is the most important source of these elements in the environment, although anthropogenic sources of Fe and Mn do exist, which include leaching from metallic scrap, iron works and iron-based household items. The use of Mn compounds as ingredients in household cleaning agents, and as additives to increase the octane rating of fuel, are the main anthropogenic sources of Mn (El-Hassan et al. 2006; Iwegbue et al. 2012). Therefore, factor 3 consists of metals that are both of natural and anthropogenic origin.

**Semi-urban zone** In the semi-urban zone, four components were extracted and accounted for 74.92% of the total variability of the data set. Factor 1 represented 23.4% of the total variance with significant positive loadings in Fe, Mn and Zn. Natural sources are the common sources of Fe and Mn in the environment. The correlation of Zn with Fe and Mn may possibly indicate that the occurrence of Zn in the Fe-Mn oxide/hydroxide surfaces is the main retention mechanism of Zn in the dust samples. Zinc and Mn are also associated with traffic emissions. As mentioned earlier, anthropogenic sources of Mn include its use in household cleaning agents,

and as an additive used to increase the octane rating of fuel especially diesel, while Zn is associated with attrition of vehicle tyres and its use as an additive in lubricating oil in the form of zinc diphosphate. Factor 2 accounted for 20.73% of the total variance and was heavily weighted by Cd and Pb. Factor 2 represents metals that are associated with traffic emissions as mentioned earlier. Factor 3 accounted for 15.09% of the total variance and had significant positive loadings in Cr and Ni. Factor 4 represented 15.7% of the variance with a significant positive loading in Cu. Factor 4 indicates that the sources of Cu in the dust from the semi-urban environment differed from those of the other metals.

**Urban zone** In the urban zone, three components were identified representing 78.63% of the variability of the data. Factor 1 constituted 41.18% of the total variance and was heavily weighted by metals such as Cd, Pb and Zn. These anthropogenic metals are related to traffic emissions as discussed earlier. Factor 2 represents 24.27% of the total variance with significant positive loadings in Fe, Mn, Cr and Zn. Apart from anthropogenic sources of these metals, such as traffic/industrial emissions, leaching of Cr and Zn from wood preservation chemicals used in household furniture, Fe and Mn from household metallic substances, and household cleaning agents respectively, factor 2 suggests the occurrence of Cr and Zn in the Fe-Mn oxide/hydroxide forms in these dust samples. Factor 3 represents 13.18% of the variability in the data set and was dominated by Cu and Ni.

## Conclusions

The results of this study indicate that the concentrations of the investigated metals were below their respective maximum allowable concentrations in soil as specified by the Nigerian regulatory authority except for Cd, Pb, Cu and Zn in some samples. However, the observed changes in the concentrations and distribution patterns of the studied metals between the two study periods were significant, and more pronounced in the rural and semi-urban zones than the urban zone. The risk factors (cancer and non-cancer risks) were within acceptable limits for the adult scenario while the non-cancer risk factors were below the acceptable limit (1) in the case of the child. It is pertinent to note that there was a considerable increase in these risk factor values between the two periods which points to a deteriorating household environmental quality.

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