Exposure to Lead, Arsenic, and Cadmium
in an Inner City Neighborhood

by

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ABSTRACT

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Background: Chronic exposure to low levels of arsenic, cadmium, and lead may result in long-term health issues for humans, especially children and fetuses. Three previous studies have demonstrated higher levels of these toxic metals in blood and urine samples of residents of North Carolina, with two of those studies focused on an area in Durham County populated by residents of a lower socioeconomic status. The objective of this study was to independently confirm the findings of previous studies and, ultimately, to provide the information needed to inform local leaders of this issue so that they can work with researchers to mitigate future health impacts for these residents.

Methods: Arsenic, cadmium, and lead were measured in blood, urine, hand wipe, dust (vacuum and wipe), water, and soil samples for 38 residents. Correlation analyses were conducted to evaluate the potential route of exposure to the toxic metals.

Results: Median levels and interquartile of blood concentrations (µg/dL) for 36 participants for cadmium were 0.03 (0.02–0.09), for arsenic were 0.04 (0.12–0.19), and for lead were 0.69 (0.48–1.10). Median levels and interquartile of urine concentrations (µg/L) for 37 participants for cadmium were 0.36 (0.25–0.59), for arsenic were 8.08 (5.26–15.18), and for lead were 1.63 (0.37–7.08). Soil samples from 35 residences showed levels of cadmium ranging from 0.15 to 2.54 µg/g (0.67 median, 0.40-1.12 interquartile) and lead ranging from 26.79 to 1,610.10 µg/g (100.59 median, 57.93-242.74 interquartile). Wipe (n=37) and vacuum (n=17) dust samples showed cadmium levels ranging from 0.96 to 258.84 µg/L (8.05 median, 2.46-85.21 interquartile) and 0.17 to 3.14 µg/g (1.11 median, 0.85-1.57 interquartile), respectively. Wipe (n=37) and vacuum (n=17) dust samples showed lead levels ranging from 15.97 to 35,740.25 µg/L (447.03 median, 149.63-2,121.69 interquartile) and 21.23 to 334.65 µg/g (54.69 median, 37.87-157.71 interquartile), respectively. Levels of arsenic, cadmium, and lead in water samples from 36 residences were well below acceptance levels for human health safety.

Conclusions: Our data support the previously conducted studies demonstrating elevated urine and blood concentrations of arsenic, cadmium, and lead within areas of North Carolina, specifically Durham County. The exposure pathway remains uncertain but is likely contaminated soil and dust ingested by the residents. This contamination may contribute to developmental and cardiometabolic issues within this subpopulation, particularly among children and fetuses. Public health officials and the research community should continue to assess this situation, while community leaders should take action to educate and inform the residents.

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INTRODUCTION

Toxic metals, such as lead (Pb), cadmium (Cd), and arsenic (As), are naturally occurring or contaminants resulting from anthropogenic activity and persist in the environment for decades. Exposure to low levels of Pb can occur via ingestion of soil contaminated from historical land use or atmospheric deposition (e.g., from lead deposits from vehicles using leaded ethanol, industry emissions from mining and smelting) (Mielke, Gonzales, & Mielke, 2011; Aelion et al., 2012; Rosenfellner, Zehetner, & Gerzabek, 2009; USEPA, 1998); dust from the transfer of contaminated soils into the house and from lead-based paint; and drinking water transported through lead pipes (Advisory Committee for Childhood Lead Poisoning Prevention, 2012; ATSDR, 2007b). Exposure to low levels of As can occur through ingestion of contaminated drinking water and foods (e.g., rice and rice products, juices, grains, fruits, vegetables), and inhalation of contaminated air (e.g., from metal smelters, burning plywood treated with an arsenic-based preservative) (USEPA, 2000; USFDA, 2016; World Health Organization, 2016). Humans can be exposed to low levels of Cd through ingestion of contaminated foods (e.g., shellfish, liver and kidney meats, potatoes, leafy vegetables), inhalation of cigarette smoke, and inhalation of contaminated air in work places associated with battery manufacturing, metal soldering, and welding (CDC, 2013; National Institutes of Health, 2016; World Health Organization, 2006). Some research also shows that children and pregnant women (and, subsequently, the fetuses they carry) of lower socioeconomic status tend to be disproportionally exposed to these toxic metals in soils (Davis et al., 2014; Aelion et al., 2012; Aelion et al., 2013; King et al., 2015; Diawara et al., 2006).

Pb and Cd exposure to humans can cause harmful cardiovascular effects (e.g., hypertension), decreased kidney function, and reproductive problems (USEPA, 2015; ATSDR, 2008; Satarug & Moore, 2004; Satarug & Moore, 2012); As exposure can lead to skin disorders and elevated risks for diabetes, hypertension, and several types of cancer (CDC: Environmental Health, 2009; Hong, Song, & Chung, 2014; Naujokas et al., 2013; Gribble et al., 2012). Children and fetuses are sensitive populations more severely impacted by exposure to toxic metals (USDHHS, 2014). Children who are exposed over long periods of time to low levels of Pb may experience behavior and learning disabilities, lower intelligence quotient (IQ), slowed growth, hearing problems, anemia, attention deficit hyperactivity disorder, and other neurological effects (Prins et al., 2010; Gilbert & Weiss, 2006; USEPA, 2015a; Wang et al., 2009; Cho et al., 2010); and As may lead to lower IQ scores and possibly increased mortality in young adults (CDC: Environmental Health, 2009; Vahter, 2008; Wasserman et al., 2014; Wang et al., 2007). There is conflicting research on the effects of chronic exposure of low levels of Cd in children. While some studies have found that chronic low-level exposure of Cd in children may lead to lower IQ scores (Tian et al., 2009; Kippler et al., 2012), other studies show that it does not cause developmental or behavior issues (USDHHS, 2012; Ciesielski et al., 2012; Rodríguez-Barranco et al., 2013).

Three studies have reported that pregnant women, and subsequently the fetuses they carry, in North Carolina have been chronically exposed to low levels of metals (e.g., Cd, Pb, As, mercury) (Sanders et al., 2012; Edwards et al., 2015; King et al., 2015); two of these three studies were specifically conducted in Durham County (Edwards et al., 2015; King et al., 2015). In one of the studies conducted in Durham County, North Carolina, King et al. (2015) identified geographical "hot spots" where residents were

potentially chronically exposed to low levels of both Pb and Cd, possibly through inhalation and ingestion of contaminated soil. King et al. (2015) conducted statistical and spatial analysis of concentrations of Pb, Cd, As, and mercury in peripheral blood and urine collected during routine physician visits for prenatal care of 310 expecting mothers. They also compared the analytical results to the sociodemographic and lifestyle factors of the participants, finding that the majority of these participants in the hot spots were of a lower socioeconomic status. However, these findings have not been independently confirmed. Moreover, the potential routes of exposure could not be assessed given the size of the data set; this information is critical to informing prevention and intervention efforts. Thus, to confirm the body burden of these metals, we measured levels of Pb, Cd, and As in participants' blood and urine in this study of 38 residents living in an area in which elevated Pb and Cd levels had been found. To identify potential sources of exposure, we assessed these metals in environmental compartments in and around homes, including drinking water, floor dust, and surface soil. To elucidate the route of exposure, we also measured these metals in hand wipes.

METHODS

Study Participants

The focus of this study was to evaluate the relationship between levels of specific toxic metals in human samples and environmental media within identified hot spots in Durham County, North Carolina. Informed by the results from the King et al. study (2015), researchers went door-to-door to 103 eligible households (located in the following census tracts: 2, 9, 10.1, 10.2, and 11) from November 2014 to February 2015 to request participation in a more focused study. From those eligible households, 38 households enrolled with a total of 91 individuals and a response rate of 46%. Some households and individuals were excluded from participation in the study because 1) participants were taking medicines to thin blood (1 person), 2) participants did not complete the enrollment process (1 person), or 3) a language barrier existed between the study participants and researchers (3 people; data collection instruments were available in English only). All 38 households had geocodable addresses.

We analyzed one sample per household for the 38 families and selected the youngest member of the household to collect specimen samples for analysis. Participants fasted and blood, urine, and hand wipe samples were collected from the participants while they were in their homes early in the morning. Samples of the residents' soil, water, and dust (vacuum and wipe) also were collected to assist in identification of potential sources of exposure. The Institutional Review Board at North Carolina State University approved the study protocol for data and specimen collection and analysis. Participants provided written informed consent, and participants under the age of 18 consented after parental consent was granted.

Data and Specimen Collection

Trained sampling teams collected demographic data and specimens from the participants and their associated houses by following prescribed standard operating procedures. Samples were collected from participants' homes including soil, water, and dust. Sampling teams used a trowel to collect one soil sample at each residence; four cups were collected from the top ¼ to ½ inch of soil from the yard or

public space surrounding a multi-unit complex, preferably in areas without existing vegetation. The teams also collected one water sample, typically from the most commonly used faucet (e.g., kitchen). For residences with carpeted floors, sampling teams collected one dust sample in the most frequently used room by vacuuming the carpet twice by using a Dirt Devil Simpli-Stik Lightweight Bagless Stick Vacuum (SD20000RED) and Dirt Devil F25 dust cup filters (2SV1102000). Sampling teams measured the size of the rooms that were vacuumed and questioned the residents on details such as the type of carpet and the approximate date the room was previously vacuumed. For residences with hard floors, sampling teams used a Kimwipe (4-1/2 x 8-1/2 inches) to collect a sample from the most frequently used room. They taped a template to prevent slippage and wiped floors in an "S" or "Z" pattern while applying pressure to the fingertips (not the palms) over the entire 10 cm by 10 cm surface. After making the first pass through, the sampling team member folded the wipe in half with the collected dust side folded inward and repeated the procedure in the same sampling area; this procedure was followed two more times. For blood and urine samples, trained phlebotomists made appointments to collect overnight fasting urine and blood. Hand wipes also were collected during the visit for the residents by using a ghost wipe from Environmental Monitoring Systems, Inc. (product 800317) and having the residents wiping both hands for 30 seconds. Researchers at Duke University analyzed the soil, water, dust (wipe and vacuum), and hand wipe samples using the method described in Meurer et al. (1999). Self- or interviewer-administered questionnaires were completed to collected demographic data such as race, gender, age, and income and education levels.

Measurement of metals in human blood and urine samples
Urine and cold blood samples were processed in a similar manner as each other. Samples were maintained in a frozen state until they were transferred to Ohio State University, equilibrated to room-temperature, homogenized, and ~0.2 mL aliquots were pipetted into trace-metal clean test tubes and verified gravimetrically to ±0.001 mg using a calibrated mass balance as previously described (Darrah et al., 2009; DeLoid et al., 2014; McLaughlin, Darrah, Holland, 2011; Sprauten et al., 2012). Samples were then spiked with internal standards consisting of known quantities (10 and 1 ng/g, respectively) of indium (In) and bismuth (Bi) (obtained from SCP Science), used to correct for instrumental drift. The solutions were then diluted using water purified to 18.2 MΩ/cm resistance (by a Milli-Q water purification system, Millipore, Bedford, Mass., USA) and acidified using ultra-pure 12.4 mol/L hydrochloric acid to result in a final concentration of 2 % hydrochloric acid (by volume; HCl). All standards, including aliquots of the certified NIST 955c, and procedural blanks were prepared by the same process.

Concentrations of metals Cd, Pb, and As were measured in nanograms per gram of blood weight, and then converted to µg/dL blood volume, to facilitate comparison with other studies. We used a Perkin Elmer DRC II (Dynamic Reaction Cell) axial field inductively coupled plasma mass spectrometry (ICP-MS) at the University of Massachusetts-Boston (Darrah et al., 2009; DeLoid et al., 2014; McLaughlin, Darrah, Holland, 2011; Sprauten et al., 2012). To clean and reduce memory effects, sample lines were sequentially washed with 18.2 MΩ cm resistance (by a Milli-Q water purification system, Millipore, Bedford, Mass., USA) water for 90 seconds and a 2 % nitric acid solution for 120 seconds between analyses. Procedural blanks were analyzed within each block of 10 samples, to monitor and correct for

instrumental and procedural backgrounds. Calibration standards used to determine metals in blood included aliquots of 18.2 MΩ cm resistance H_2O, National Institute of Standards and Technology (NIST) 955c SRM, and NIST 955c SRM spiked with known quantities of each metal in a linear range from 0.025 to 10 ng/g. Standards were prepared from 1000 mg/L single element standards obtained from SCP Science, USA. Method detection limits were calculated according to the two-step approach using the t99SLLMV method (USEPA, 1993) at 99 % CI (t = 3.71). The MDLs yielded values of 690, 58, 48 pg/g for As, Cd, and Pb, respectively. Limits of quantification (LOQ) and limits of detection (LOD) and according to Long and Winefordner (1983) were less than 71 pg/g and 210 for As, 6.9 pg/g and 23 pg/g for Cd, and 5.9 pg/g and 17.2 pg/g for Pb.

Measurement of metals in soil, water, dust (wipe, vacuum) and hand wipe samples

The trace elements in the water samples were analyzed after calibration using serial dilutions of NIST 1643e standard spiked with U and Th.

Ghost wipe samples were digested with ultra-pure HNO_3 (Fisher Optima) and double-distilled water (resistivity >18.2 MU*cm). For measurement of total Pb, Cd, and other trace elements, 0.034 g of soil and dust floor samples were digested and following procedures described in Meurer et al. (1999). Reference materials used for instrument calibration and standardization included USGS certified geochemical reference materials G2, W2, BIR, SCO, SDO, AGV, RGM and SDC. All digestion processes of the dust samples were prepared using ultra-pure HNO_3 and HF reagents (Fisher Optima) and double-distilled water. All plastic polyethylene bottles and tubes were soaked and cleaned with pure 1N HCl and 1N HNO_3, and then rinsed with deionized water. All the trace elements were analyzed via a VG Plasmaquad 3 inductively coupled plasma mass spectrometer (ICP-MS) in the analytical facilities at Duke School of Environment (USA).

Statistical Analysis

Spearman's correlation coefficient estimates among the metals (Pb, Cd, As) and samples (blood, urine, water, soil, dust-wipe, dust-vacuum, hand wipe) and corresponding p-values were calculated using Statistical Analysis System software.

RESULTS

Table 1 displays a summary of characteristics of the study participants. Thirty-three of the 38 participants were African American (89%), 2 were White (5%), 1 was Hispanic (3%), and 1 self-described as bi- or multi-racial (3%). Of the participants who responded, 24 of the 25 participants aged 20 years or older reported completing a high school education. Fifty-five percent of the participants were female and of the participants 20 years or older and who provided income information, more than half reported an annual household income level of less than $25,000.

Table 1. Characteristics of Study Participants

Characteristics	N
Age	
0-19	11
20+	27
Gender	
Female	21
Male	17
Race	
Black	33
White	2
Hispanic	1
Biracial or multiracial	1
Income level*	
Less than $10,000	11
$10,000 - $24,999	5
$25,000 - $49,999	6
Don't know	1

*Only participants 20 years or older were included

Cd, As, and Pb found on hands, in blood, and in urine

Hand wipes were collected from 36 study participants to assess levels of metals that could be ingested. Levels of Cd, As, and Pb from hand wipes were higher for participants 19 years or younger (n=10) than the participants 20 years and older (n=26 for Cd, n = 27 for As and Pb), which was expected because individuals ≤ 19 years tend to spend more time on the ground and engage in hand-to-mouth activities more frequently. The geometric mean (ng/g) for Cd was 9.06 for ≤ 19 years and 7.40 for 20+ years, As was 152.15 ≤ 19 years and 138.14 for 20+ years, and Pb was 158.60 ≤ 19 years and 146.55 for 20+ years (Table 2).

Among all study participants from whom blood concentrations were measured, geometric mean values (μg/dL) for Cd were Cd 0.04, for As were 0.18, and for Pb were 0.80. Levels of Cd, As, and Pb in blood samples were higher for participants 20+ years (n=25) in comparison to participants ≤ 19 years (n=11); the geometric mean (μg/dL) for Cd was 0.02 for ≤ 19 years and 0.05 for 20+ years, As was 0.16 for ≤ 19 years and 0.19 for 20+ years, and Pb was 0.59 for ≤ 19 years and 0.92 for 20+ years (Table 2).

Among all study participants from whom urine concentrations were measured, geometric mean values (μg/L) for Cd were 0.38, for As were 9.63, and for Pb were 1.52. Levels of Cd and Pb in urine samples were higher for participants 20+ years (n=26) in comparison to participants ≤ 19 years (n=11), but levels of As were higher for the ≤ 19 years than 20+ years. The geometric mean (μg/L) for Cd was 0.35 for ≤ 19 years and 0.39 for 20+ years, As was 10.56 for ≤ 19 years and 9.24 for 20+ years, and Pb was 1.19 for ≤ 19 years and 1.71 for 20+ years (Table 2).

Table 2. Measured Levels of Metals in Human Health Samples by Age (≤19 and 20+ Years Old)

Human Health Samples	Age (Years)	Cd (geometric mean; interquartile range)	As (geometric mean; interquartile range)	Pb (geometric mean; interquartile range)
Hand wipes (ng/g)	≤ 19 (n = 10)	9.06 (6.00-17.21)	152.15 (136.92-177.29)	158.60 (78.60-232.81)
	+ 20 (n=26 for Cd, n = 27 for As & Pb)	7.40 (3.99-13.09)	138.14 (127.24-157.24)	146.55 (79.56-251.62)
Blood (µg/dL)	≤ 19 (n = 11)	0.02 (0.02-0.02)	0.16 (0.12-0.19)	0.59 (0.45-0.94)
	+ 20 (n = 25)	0.05 (0.02-0.10)	0.19 (0.15-0.23)	0.92 (0.53-1.47)
Urine (µg/L)	≤ 19 (n = 11)	0.35 (0.25-0.49)	10.56 (7.24-16.20)	1.19 (0.32-4.41)
	+ 20 (n = 26)	0.39 (0.25-0.63)	9.24 (4.05-14.53)	1.71 (0.40-8.02)

Cd, As, and Pb in water, soils, and dust

In order to evaluate potential sources of metals exposure for the residents, we analyzed the levels of Pb and Cd in soil and dust (wipes and vacuum) and the levels of Cd, As, and Pb in water as shown in Table 3. We tested for levels of As, Cd, and Pb in water among 36 residences, and all results were well below acceptance levels for human health safety. Soil samples were analyzed from 35 residences and Cd levels ranged from 0.15 to 2.54 µg/g (0.67 median, 0.40-1.12 interquartile) and Pb ranged from 26.79 to 1,610.10 µg/g (100.59 median, 57.93-242.74 interquartile).

Wipe and vacuum dust samples were analyzed for Cd for 37 and 17 residents, respectively, and levels ranged from 0.96 to 258.84 µg/L (8.05 median, 2.46-85.21 interquartile) for wipe samples and 0.17 to 3.14 µg/g (1.11 median, 0.85-1.57 interquartile) for vacuum samples. Dust samples for Pb ranged from 15.97 to 35,740.25 µg/L (447.03 median, 149.63-2,121.69 interquartile) for wipes and 21.23 to 334.65 µg/g (54.69 median, 37.87-157.71 interquartile) from the vacuum. Levels of Cd and Pb in dust wipe samples were higher for participants ≤ 19 years (n=11) in comparison to participants 20+ years (n=26); the geometric mean (µg/L) for Cd was 19.62 for ≤ 19 years and 1.82 for 20+ years and Pb was 720.09 for ≤ 19 years and 497.56 for 20+ years. Levels of Cd and Pb in vacuum dust samples also were higher for participants ≤ 19 years (n=7) in comparison to participants 20+ years (n=10); the geometric mean (µg/g) for Cd was 1.22 for ≤ 19 years and 0.75 for 20+ years and Pb was 101.97 for ≤ 19 years and 49.03 for 20+ years.

Table 3. Measured Levels of Metals in Environmental Compartments (Soil, Dust, Water)

Metal	Samples	Ref. [a]	N	Min.	25th Percentile	Median	75th Percentile	Max.
As	Soil	NA	NA	NA	NA	NA	NA	NA
	Dust – wipe and vacuum	NA	NA	NA	NA	NA	NA	NA
	Water (µg/L)[b]	2	36	0.01	0.03	0.04	0.07	0.11
Cd	Soil (µg/g)	1.1	35	0.15	0.40	0.67	1.12	2.54
	Dust – wipe (µg/L)	NA	37	0.96	2.46	8.05	85.21	258.84
	Dust – vacuum (µg/g)	NA	17	0.17	0.85	1.11	1.57	3.14
	Water (µg/L)[b]	<5	36	0.00	0.00	0.01	0.01	0.69
Pb	Soil (µg/g)	400	35	26.79	57.93	100.59	242.74	1,610.10
	Dust – wipe (µg/L)	NA	37	15.97	149.63	447.03	2,121.69	35,740.25
	Dust – vacuum (µg/g)	NA	17	21.23	37.87	54.69	157.71	334.65
	Water (µg/L)[b]	15	36	0.00	0.05	0.13	0.29	1.12

[a]As levels from ATSDR, 2007a; Cd levels from ATSDR, 2012; Pb levels from USEPA, 2016 and ATSDR, 2007b.

[b]Nondetect values in the water samples were treated by using the average IDL divided by the square root of two.

Several Spearman correlation coefficients computed for each pairwise combination of metals within specific samples were positive. Cadmium and lead were positively covaried for soil (0.498, $p<0.0023$), hand wipes (0.729, $p<0.0001$), and dust wipes (0.880, $p<0.0001$).

DISCUSSION

In this study, we confirmed the findings of previous studies reporting chronic human exposure to low levels of metals in North Carolina (Sanders et al., 2012; Edwards et al., 2015; King et al., 2015). The King et al. study (2015) identified hot spots in Durham County where elevated levels of metals were found in the soil, blood, and urine samples. We reproduced their findings among a sample of residents in the same region and expanded the frame to include all residents, not only pregnant women.

Among all study participants for whom blood concentrations were measured, the median and interquartile ranges for blood levels (µg/dL) of Cd were 0.03 (0.02–0.09), of As were 0.04 (0.12–0.19), and of Pb were 0.69 (0.48–1.10). For reference, the Centers for Disease Control and Prevention (CDCP) state "normal" blood levels for Cd as 0.0315 µg/dL (≥1 year of age; geometric mean), As as 0.01 µg/dL, and Pb as 5.0 µg/dL (ATSDR, 2012; ATSDR, 2007c; NIOSH, 2015). Nineteen (50%), 31 (82%), and 1 (3%) participant(s) exceeded the CDCP "normal" levels for Cd, As, and Pb in blood, respectively. Among individuals aged 20 years or older, the geometric mean values of Cd in blood were higher than observed in the general US population, as reported in the National Health and Nutrition Examination Study (NHANES), and comparable levels were observed for Pb in blood in the two groups (Table 4; USDHHS, 2017). Our results showed levels of Cd in blood samples comparable or higher to the hot spots and overall results reported by King et al. and higher levels of As and Pb among the non-pregnant residents living in this region (Table 4). These results, therefore, confirm the findings of recent studies conducted with residents in North Carolina (Sanders et al., 2012; Edwards et al., 2015; King et al., 2015).

Among all study participants for whom urine concentrations were measured, the median and interquartile ranges for urine levels (µg/L) of Cd were 0.36 (0.25–0.59), of As were 8.08 (5.26–15.18), and of Pb were 1.63 (0.37–7.08). The CDCP state that normal urine levels (µg/L) are 0.185 for Cd (≥6 years of age, geometric mean), 100 for As, and 0.677 for Pb (≥6 years of age, geometric mean) (ATSDR, 2012; ATSDR, 2007a; ATSDR, 2007b). Therefore, 32 (84%) participants had above-normal Cd urine levels, 1 (3%) participant had an above-normal As level, and 21 participants (55%) had above-normal Pb levels. Among residents aged 20 years or older, the geometric mean values for Cd, As, and Pb levels in urine were higher than those in the general US population reported by NHANES (Table 4; USDHHS, 2017). The increased levels of Cd, As, and Pb in urine suggest that exposure is not isolated but likely chronic.

Table 4. Reference and Reportable Values for Blood (µg/dL) and Urine (µg/L) Metal Values

Blood metal values (µg/dL)						
Population		Time Frame	Measure	Cd	As	Pb
US age 20+ yrs (CDC, 2017)		2013-2014	Geometric Mean (95% CI)	0.0297 (0.0280-0.0315)	N/A	0.967 (0.921-1.02)
Pregnant women in Durham County (King et al.)	Overall	2009-2011	Geometric Mean	0.03	0.05	0.38
	Cd-cluster			0.05	0.05	0.51
	Pb-cluster			0.04	0.05	0.42
Present study 20+ yrs		2014-2015	Geometric Mean (95% CI)	0.05 (0.04-0.8)	0.19 (0.16-0.24)	0.92 (0.62-1.36)
Urine metal values (µg/L)						
Population		Time Frame	Measure	Cd	As	Pb
US age 20+ yrs (CDC, 2017)		2013-2014	Geometric Mean (95% CI)	0.156 (0.146-0.167)	6.49 (5.72-7.36)	0.297 (0.280-0.315)
Present study 20+ yrs		2014-2015	Geometric Mean (95% CI)	0.39 (0.27-0.57)	8.57 (5.24-13.99)	1.75 (0.88-3.48)

CI = Confidence interval

All water samples were below acceptable levels for As, Cd, and Pb. Soil samples were analyzed for Cd and Pb only. The median level of Cd in soil (0.67 mg/kg) was below higher end of the "normal" range (i.e., soil not contaminated by anthropogenic sources) of 0.06 to 1.1 mg/kg, but 10 residences exceeded the higher end of the range at of 1.1 mg/kg (ATSDR, 2012). EPA's remedial level for Pb in soils is 400 µg/g, and soil samples collected at five residences exceeded the EPA limit (USEPA, 2016). Levels of Cd and Pb in the hand wipe and dust (wipe and vacuum) samples were higher among ≤19 years old than 20+ years old, which might be expected as younger people tend to spend more time on the floor.

Based on the findings from the King et al. study (2015), we suspected ingested soil and house dust as the route of exposure. We examined the correlation of the three metals among the study participants and found a significant Spearman correlation between Cd and Pb in soil, dust wipes, and hand wipes. This data confirms the findings from the King et al. study (2015) which also showed that Cd and Pb covaried in environmental samples. Our correlation analysis did not confirm soil and house dust as the route of

exposure because correlations between environmental media and biological samples were not significant; more analysis is needed to determine the route of exposure.

The elevated levels of Pb found in the soil, particularly at the five residences where EPA's remedial limit was exceeded, are concerning. EPA completed the final step in phasing out leaded gasoline in 1996 (USEPA, 2015b), but soils in urban residential areas have demonstrated levels of Pb deposit from vehicles in areas with increased traffic volume, which may result in elevated levels of Pb in children's blood (Mielke, Gonzales, & Mielke, 2011; Aelion et al., 2012, Rosenfellner, Zehetner, & Gerzabek, 2009). The study area is bound by major roadways to the north and east with other major roadways nearby and is an area impacted by higher traffic density and road coverage. The dispersal of vehicle exhaust particles that bind to the local soils could serve as a significant contributor to soils and dust with higher levels of Pb. Traffic patterns (e.g., congestion, acceleration and deceleration with stop/go scenarios) have been found to impact specific locations with elevated levels of heavy metals (Ewen, Anagnostopoulou, & Ward, 2009), and Mielke et al. (2011) found deposits from leaded gasoline had more impact on childhood lead exposure than the dust from leaded paint. We did not assess if leaded gasoline could have been a possible contributor to the higher levels of Pb measured in the soils, but it is a source warranting future consideration.

Reducing exposure to low levels of toxic metals is critical for this defined population in Durham County and for other vulnerable populations living in areas with low-level contamination. Actions to reduce exposure to Pb, As, and Cd include using a vacuum and wet mopping, wet-wiping window frames, regularly washing hands and children's toys, removing shoes before entering residences, and covering exposed soil with mulch (CDC, 2014). Most of these prevention measures can be accomplished by the individual residents provided they are educated on the appropriate steps to take and have the time and resources to implement these steps frequently. However, it can be challenging to ensure the correct healthcare professionals are informed of the risks for affected populations and to educate affected populations who may not fully comprehend the risks or have access to resources to mitigate risks.

Limitations of this study include the small sample size and the lack of samples collected to assess Pb levels in wall paint. Lead paint was banned for residential use in 1978 by the U.S. Consumer Product Safety Commission (16 Code of Federal Regulations CFR 1303). Although the dates of construction of the houses in this study are not known with certainty, many houses in the area were generally built in the 1920s and 1930s, and many also serve as rental properties. The application of non-lead-based paints in these houses since 1978 may have sealed the walls and reduced exposure to this source of Pb, but because lead paint was not tested specifically, the source of Pb in house dust remains uncertain.

CONCLUSION

Our study data support findings of previous studies conducted in North Carolina and specifically in Durham County, reporting chronic exposure to low levels of Cd, As, and Pb. Chronic exposure to low levels of Cd, As, and Pb correspond to increased risk factors for cardiometabolic and neurological diseases in children and adults. These studies should inform future prevention and intervention efforts

to reduce the risk of exposure within this population. Additional studies with larger sample sizes are required to further confirm the findings and elucidate the route of exposure.

LIST OF ABBREVIATIONS AND ACRONYMS

As   arsenic
ATSDR   Agency for Toxic Substances and Disease Registry
Cd   cadmium
CDCP   Centers for Disease Control and Prevention
CI   confidence interval
cm   centimeter
g   gram
HCl   Hydrochloric acid
ICP-MS inductively coupled plasma mass spectrometry
IDL   instrument detection limit
LOD   limits of detection
LOQ   limits of quantification
mg   milligram
mL   milliliter
MΩ/cm ohms per centimeter
mol/L   moles per liter
NC   North Carolina
ng/g   nanogram per gram
NHANES National Health and Nutrition Examination Study
Pb   lead
pg/g   pictogram per gram
SRM   standard reference material
Th   thorium
U   uranium
µg/dL   microgram per deciliter
µg/L   microgram per liter
USEPA   United States Environmental Protection Agency
USGS   United States Geological Survey

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