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Assessment of Child Blood Lead Levels in a Philadelphia Community, 2014

FINAL REPORT

National Center for Environmental Health
Agency for Toxic Substances and Disease Registry

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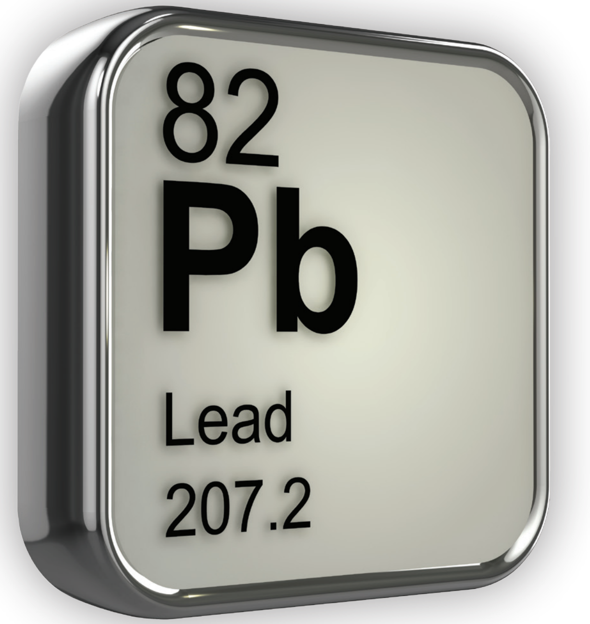
Introduction



Lead is an environmental toxicant that affects virtually every system in the body (ATSDR 2007). In children, lead decreases intelligence, growth and hearing; causes anemia; and can cause attention and behavior problems (CDC, 1991). Young children are particularly susceptible to lead poisoning because they absorb far more lead from their environments than do adults and because their central nervous systems are still developing (CDC 2005). For children under 6 years of age, the Centers for Disease Control and Prevention (CDC) has defined an elevated BLL as ≥5 micrograms per deciliter (µg/dL), but there is evidence for subtle effects at even lower levels (CDC 2005). The CDC Advisory Committee on Childhood Lead Poisoning Prevention recommended that CDC replace the use of a reference value with an upper value limit based on the 97.5% of the BLL distribution in U.S. children: 5 µg/dL (CDC 2012). Sources of lead exposure include lead-based paint, industrial emissions, cottage industries (e.g. informal battery recycling), lead soldered cans and water pipes, lead glazed ceramics, and traditional medicines (CDC, 2002a; CDC, 2005).

Several urban neighborhoods in Philadelphia, Pennsylvania, have a history of soil lead contamination due, in part, to lead-emitting industry as well as the legacy of lead-based paint and leaded gasoline emissions. The point source of interest for this study was the John T. Lewis site (a.k.a., Anzon facility), where a large emitter formerly operated in the Kensington community of Philadelphia (Figure 1). Lead paint was produced at the site from 1849 to 1996. The facility used numerous kilns, oxidizing furnaces, and corroding beds to make its lead-containing products. Over the years, plant emissions, equipment malfunctions, and fires at the facility released lead-containing particulates into the surrounding community. The John T. Lewis facility was closed in 1996 and eventually redeveloped into a multi-use commercial complex/shopping center. Residential structures in the study area have long been co-located alongside other industrial, commercial, and service facilities in this neighborhood, where as many as 12 were suspected to have operated in the past (Figure 1).

During July 2014, the CDC, Agency for Toxic Substances and Disease Registry (ATSDR), and City of Philadelphia Department of Public Health (PDPH) conducted a study in Philadelphia. The community areas have been subject to various environmental and public health investigations since the 1970s. However, previous investigations were limited by their use of convenience samples. We conducted a study to quantify the risk of elevated BLLs among children using a representative population-based survey design. The objectives of the study were to: 1) describe child BLLs in the target communities; 2) identify risk factors and sources of lead exposure among these children; 3) describe environmental lead levels among enrolled households; and 4) compare study findings with existing data sources. The U.S. Environmental Protection Agency (EPA) Region 3 collaborated with the public health agencies and provided funding to conduct the study.

The target communities comprised ZIP codes 19125 and portions of 19122, 19123, 19133 and 19134. The neighborhoods in the study area are Kensington, Olde Kensington, Port Richmond, Northern Liberties, and Fishtown (Figure 1). The demographic characteristics in the study area (using complete ZIP code level data) are as follows: percent pre-1950 housing: 85.0–88.0%; median household value: $159,900–$193,200; percent rental housing: 30.6–35.1%; percent households with African Americans: 5.9–43.1%; and percent households with children <5 years: 6.0–7.6% (U.S. Census 2011). Using Philadelphia tax assessor data, Figure 2 depicts the age of housing in the study area. There is a concentration of housing built before 1900 surrounding the site of interest, and extending toward the northwest.

Methods

Study Design

This 2014 study included a simple random sample used to select and enroll a target of 111 households with children 8 years of age and younger, many living within a 0.8 km (0.5 miles) radius surrounding a legacy point source (the area most affected by historic emissions), personal and household risk factor questionnaires were administered to children's parent or guardian, and environmental samples were obtained from enrolled households. The 0.8 km (0.5 miles) radius study target range is defined as nearby the point source based on EPA modeling of air emissions from the point source facility using a 1987 lead emissions inventory report (H. Schmidt personal communication, May 2, 2013). The study population included children who lived at the same Philadelphia address on average, 2 days per week and for at least the prior 8 months. The study protocol received approval from CDC and PDPH institutional review boards. OMB Control no.: 0920-0008.

Using tax assessor data prepared by PDPH, addresses were randomly selected from the full roster of residential addresses as starting points for each data collection team. If the first selected address was ineligible, the data collection teams went to the next address on the same side of the street, in descending order, and then up the opposite side until the quota of households was met or until the street ended. If the quota was not met when the street ended, the team went to another street on its list, which was mapped in a clockwise direction to better ascertain location of teams at all times. To enumerate, the data collection teams noted the outcome of each household visit (i.e., eligible, ineligible, refused, vacant). A household was defined as ineligible for participation if no children younger than 8 years lived at the residence, the residence was unoccupied, address was not a residence, a resident was unwilling to complete the screening process or no one was home and the recruitment team was not able to visit the home three different times. A household was recorded as "occupied but the residents not at home" only after the team had visited the household at least 3 times over 2 days. To increase participation rates, PDPH note cards with a phone number were left at vacant households. Participating families received a $15 gift certificate to a home improvement chain store to thank them for their time and effort. A household (i.e., an area that included at least 1 bedroom, 1 bathroom, and a kitchen) with a specified address including apartment number, was defined as the sampling unit. We randomly enrolled one household from addresses with more than one family with a child <8 years.

A data collection team comprised at least one CDC/ATSDR staff member or one trained field epidemiology fellow, one EPA staff member or EPA contractor, one other health care professional, and in some cases a local public health graduate student. Team members were trained prior to data collection in cultural sensitivity, data collection, venous

blood drawing, environmental sampling, conducting visual assessment of the interior/exterior of the household, referrals, and personal safety. Several team members were fluent in Spanish language. Approximately 10 teams were used during the 2-week study period (July 15–31, 2014). Teams conducted fieldwork from late morning to evening, including weekends. Local community leaders and law enforcement officials were notified about the study. The study was announced at community meetings and shared with the media.

The sample size required for the blood lead survey was approximately 167 children or an estimated 111 households. The number of expected households was obtained by dividing 1.5 from 167 to account for families with more than 1 child (U.S. Census 2010). Based on PDPH surveillance data and previous studies, we estimated that 4% of children would have a BLL ≥5 µg/dL. We conservatively expected to identify 7 children with BLLs ≥5 µg/dL and 4 children with BLLs ≥10 µg/dL during the random sampling. Sample sizes were calculated to provide a large enough sample so that the margin of error around the geometric mean and prevalence estimate [95% confidence interval (CI)] was ±2.6%. The random sample size calculation is reported in Appendix A.

Blood Lead Survey

Trained study team members (i.e., pediatric phlebotomists) collected venous blood samples in the household among children enrolled in the study per study protocol (Appendix B). Venous blood specimens were collected in EDTA tubes (tubes containing the commonly used anticoagulant ethylenediaminetetraacetic acid) and were analyzed for lead content 24–48 hours after collection by the Philadelphia Public Health Laboratory using Perkin Elmer's Atomic Absorption Analyzer (PerkinElmer Norwalk, Connecticut; www.perkinelmer.com). The lower limit of detection for blood lead was 0.1 µg/dL. For quality assurance purposes, one blood lead venous specimen was rejected as unsuitable for analysis because of insufficient quantity. The rejected sample contained less than 50% of the recommended draw volume (i.e., <1.5 mL in a 5 mL tube designed to collect 3 mL of blood).

Health Education

At the time of sample collection, an informational sheet was given to the households to inform consenting parents/guardians who to contact if they have questions, concerns or problems. They also received a folder of healthy housing educational information provided by EPA and PDPH, including documents about lead poisoning prevention in the home and environment.

Environmental sampling and analyses

Enrolled households were offered environmental sampling (soil, water, and interior dust). Soil sampling consisted of the collection of one composite exterior soil sample from five soil areas in the residential yard per U.S. Department of Housing and Urban Development (HUD) soil sampling protocol, where resident children younger than 8 years were said to play (HUD 2012). Whenever possible, soil samples were collected from areas of bare soil. A soil lead hazard for play areas is defined as bare soil with lead equal to or exceeding 400 parts per million (micrograms per gram) (EPA 1994a, EPA 2001). A 5-mL "grab" water sample was collected from the tap used for drinking/cooking. An unacceptable water lead level was defined as at or above the EPA action level, 0.015 parts per million (ppm) or 15 µg/L (EPA 1991). Two composite dust wipe samples were collected from the floor using a square grid, specifically in the area where the resident child younger than 8 years reportedly played and from the entryway of the house. An elevated dust floor measurement was defined as 40 µg/ft2 (HUD 1999). A third composite dust wipe sample was measured and collected from the bedroom window sill(s) of resident children younger than 8 years. An elevated dust window measurement was defined as 250 µg/ft2 (HUD 1999). A rough schematic sketch of the residence was made and measurements were recorded.

The laboratory (Bureau Veritas North America, Novi, MI Laboratory) performed lead analysis of soil, dust wipes, and drinking water samples utilizing Inductively Coupled Plasma (ICP), Inductively Coupled Plasma/Mass Spectrometry (ICP/MS) and atomic absorption/cold vapor instrumentation to determine contaminate concentrations in the ppm and parts per billion ranges. Methods used were SW-6010 (soil and dust) (EPA 1990), OSHA ID 125-G (lead dust wipes) (OSHA 2003), and EPA 200.8 (lead in drinking water) (EPA 1994b).

Results to study participants

Child BLL results were provided via U.S. mail to the parent or legal guardian within 1 week from date of sample collection. Letters explained results to participants and outlined steps to coordinate medical follow-up, if needed. Confirmatory venous testing was conducted for children with a BLL of 10 µg/dL or more based on CDC guidelines (CDC 2002b). Environmental sampling results with an explanation of findings were provided via U.S. mail to parents or legal guardians within 5 months from sample collection date.

Comparison with Existing Data

To determine the percent of children in the study with a previous blood lead test, we matched child data enrolled in the study to historic PDPH blood lead surveillance records. Surveillance records were identified by matching the enrolled child's name, gender, birthdate and address (if needed) to records in the PDPH blood lead surveillance database. For children enrolled in the survey but for whom a venous blood sample was not obtained, the historical blood lead surveillance records were abstracted from PDPH for descriptive analysis, but not included in modeling analyses.

We compared BLLs of children in this study with existing PDPH BLL surveillance reports from the same neighborhoods and neighborhoods with similar socioeconomic characteristics (based on ZIP code). The comparison ZIP codes included 19120, 19129, 19145, 19146, 19147 and 19148. Similarly, we extracted historic PDPH home environmental inspection data from households having a child with a BLL ≥20 µg/dL (pre-2013 action level) and in households having a child with a BLL ≥10 µg/dL (2013–present action level) including lead dust wipes collected both pre- and post-lead abatement activities to compare with study interior dust results. We report the highest result by sampling location (i.e., floor, windowsill and window well) by household.

We compared study soil sampling results with data collected from community soilSHOP (Soil Screening, Health, Outreach and Partnership) events. During soilSHOP events, individuals bring a self-collected sample of soil from their yards. The soil sample is then screened for lead, free of charge, with a handheld X-ray fluorescence (XRF) instrument that provides a quick, real-time soil lead screening result (Vaouli 2015). SoilSHOP participants collect a five-point soil composite sample from the top 2 inches if collected from child's play area or top 6 inches if from a garden area. The soil sample was homogenized, dried and placed in a 1-quart freezer bag. Participants bring the prepared soil sample, which is screened through the plastic bag with the XRF instrument. The sample is screened through the bag in three different places. The average screening result is calculated, recorded and provided to the participant who brought the sample. XRF instruments are maintained and calibrated according to manufacturer instructions.

Statistical Analysis

Data were entered into Epi Info (Epi Info version 7.2.0.1, CDC, Atlanta, Georgia), and 100% of records were completely reentered to confirm accuracy of data entry. Data were analyzed using SAS version 9.3 (SAS Institute Inc., Cary, North Carolina) and SUDAAN version 11.0.0 (Research Triangle Institute, Research Triangle Park, North Carolina) software.

Descriptive statistics were used to assess household and child characteristics. Linear regression techniques were used to examine risk factors for elevated BLLs among children with venous blood collection (n=104) obtained from the household and child questionnaires and environmental sampling. BLL concentrations were markedly right-skewed and were natural log-transformed for linear regression statistical analyses. Geometric mean is reported for the BLL results. Geometric mean and ratio of geometric mean estimates were back-transformed. Risk factors assessed included: child age and gender; child activities and health conditions; previous renovation activity in the household; frequency of painting the residence; observed condition of interior/exterior of household; all resident smoking status; mother's education level; lead-related occupation or activities; use of household remedies, herbal remedies, or folk medicines; receipt of public or Section 8 housing; receipt of various public assistance; house ownership status; year residence was built; and distance to the point source of interest (in feet). The year each residence was built and structure type were abstracted from the Philadelphia Office of Property Assessment website (http://property.phila.gov/). Based on a previous study, age of the child was selected as a potential confounding variable (Bernard 2003).

Bi-variable analyses were conducted to assess each risk factor's association with elevated BLLs. Risk factors significantly associated ($P < .05$) with elevated BLLs were then evaluated in multivariable analyses. Child BLL results used in the analysis were from venous samples collected in the household (n=104). The first multivariable analysis assessed each risk factor along with the selected confounding variable (age of child) and the assessment of potential interaction between age and the main effect. Statistically significant risk factors (at the $P < .10$ level) identified in the first multivariable analysis were included in the second multivariable analysis. During the second multivariable analysis, we used a forward-selection strategy to add 1 risk factor variable at a time to the most predictive model, including the a priori confounder (age of child), until all risk factors in the model were statistically significant ($P < .05$). Interactions between risk factors and the confounding variable were assessed during both analyses. Self-reported household cleaning frequency was significantly related to log of BLL. However, previous studies have indicated potential misclassification or recall bias for self-reported household cleaning frequency (Goldberg, 1993; Bédard 2014). Therefore, we did not consider the cleaning frequency variable in multivariable modeling. Variables describing children reported to have asthma symptoms and children with asthma as told by a health care provider were highly correlated and only the latter variable was considered in multivariable modeling. Similarly, child receipt of public services [i.e., government medical insurance, food stamps and Women, Infant and Children (WIC)] were also highly correlated and only receipt of government medical insurance was considered in multivariable modeling. Variance inflation factors were used to assess collinearity between variables in the predictive models.

Because assessment of environmental lead exposure and its relationship to child BLLs was the motivating factor for this investigation, a second predictive analysis was conducted. Multivariable logistic regression techniques were employed to examine environmental lead sampling risk factors for BLLs ≥5 µg/dL among children with a venous blood collection (n=104). Risk factors considered were environmental sampling results and the child's age. Additionally, an indicator variable (range: 0–4) that counted the number of environmental samples with lead levels equal to or above HUD and EPA standards in each household was used to predict BLLs ≥5 µg/dL among children. The Cochrane Armitage test was used to test for trend for this indicator analysis.

Geographic analysis

Eckel and colleagues (2001) identified the 12-suspected lead-emitting facilities in the study area. Additional industries, approximately 50, involved with materials or processes such as dyes, glass, brass, batteries, boiler manufacturing, metals processing, and shipbuilding also appear in the study area at different time periods based on a survey of historic land use maps for the years 1895, 1910, 1942 and 1962 (Greater Philadelphia GeoHistory Network 2015). However, these facilities were not included in the spatial analyses due to limited information about the duration and nature of their operations. It is likely at least a portion of these industries worked with lead and released lead into the environment during operations, perhaps to a lesser degree than lead paint manufacturers or smelters. We compared the spatial relationship among the 12 point sources with data collected from enrolled children and their respective households. We obtained geographic coordinates of the homes surveyed by matching the street addresses to records in the Philadelphia tax assessor's database. If coordinates were not available in the tax assessor's database, we geocoded the addresses using Centrus Desktop v5.0 geocoder (Pitney-Bowes, Lanham, MD, USA). We used ArcGIS (ESRI 2011. ArcGIS Desktop: Release 10. Redlands, CA: Environmental Systems Research Institute) for mapping and analysis. Maps were created to visualize the lead testing results, suspect historical lead-emitting facilities and age of housing. Global Moran's I was run as an indicator of the degree to which high lead values clustered across the study area. Global Moran's I tested for overall spatial clustering of values without locating any clusters themselves. For blood, soil and dust samples, SaTScan™ v8.0 (Kulldorff 2009) was used to assess statistically significant ($P < .05$) geographic clusters of blood lead values ≥5 µg/dL and environmental sampling lead values above HUD and EPA standards.

Results

A total of 122 households and 163 children less than 8 years were enrolled. Of the 5111 households visited, 4458 (87.2%) were ineligible for participation. Of the remaining 653 households, 593 were eligible for enrollment. The response rate was 20.6% (n=122). The refusal rate was 40.3% (n=239). Reasons for refusal were the inability to get parental or legal guardian consent (n=189), not interested due to also living in another household (n=10), "just moved", "about to move", home recently renovated (n=26), or the child had recently been tested for blood lead (n=14). Residents of the remaining 232 homes could not be reached during the study period after at least three visits to the home. Three children from 3 households were excluded from the analyses because insufficient questionnaire data were obtained. The analytic dataset comprised 119 households and 160 children less than 8 years (Figure 3).

Child characteristics

The average age of children was 3.6 years. Fifty-eight (36.2%) children were 12–35 months of age, and among those with available gender information, 79 (49.4%) were female; most children (n = 133; 83.1%) were born in Philadelphia (Table 1). The most commonly reported racial groups were black or African American (n = 79; 49.4%) and white (n = 33; 20.6%). Twenty-two children (13.8%) were reported to have asthma (as told by a health care provider) and most (n = 140; 87.5%) were up-to-date on vaccinations. One hundred and three children (64.3%) were reported to eat or mouth non-food items. Only 10 (6.3%) children were reported to use household/herbal remedies or folk medicines. Many children (n = 57; 22.8%) were currently receiving or had received government medical insurance (Medicaid), receiving food stamps (n = 57; 22.8%), and were enrolled in WIC (n = 54; 21.6%). Seventy-three (45.6%) children were reported to spend >20 hours per week outside their household. The most common locations were day care center (n = 30; 41.1%) and school (n = 19; 26.0%; Table 1).

Household Characteristics

The median occupancy was four persons per household (range, 2–18). The majority of homes were built before 1950 (n = 108, 90.8%). Many homes (n = 60, 50.4%) were built between 1920 and 1939; 31 homes (26.0%) were built before 1900. Among the 119 households, 69 (58.0%) of the families owned the residence and 111 (93.3%) households were a 2- or 3-story masonry row house. Most households used municipal water for drinking and cooking (n = 104; 87.4%). The mean distance the residence was to the point source of interest was 4096 feet (0.8 miles or 1.3 kilometers). The parent or legal guardian reported that 105 (88.2%) of the households had a child who played outside. Ninety-nine (83.2%) households had a mother who completed high school or obtained a GED (general education degree) (Table 2).

Blood lead level results

Among the 160 children, 13 (8.1%) had no evidence of a previous blood lead test. The mean age of the 13 children was 2.4 years and ranged 6–73 months. Among the 104 children tested for blood lead in their household, their geometric mean BLL was 2.0 µg/dL [95% CI, 1.7–2.3 µg/dL]) and 13 (12.5%) had BLLs ≥5 µg/dL (2 who had BLLs ≥10 µg/dL) (Figure 4). Ninety-one (87.5%) of these 104 children had a previous blood lead test on average 30.6 months prior to the study blood lead test. Among the 42 children who did not have a venous blood lead sample collected as part of this study but whose BLL results were abstracted from historical surveillance data, none had BLLs ≥5 µg/dL. Their mean age was 3.6 years (range 10 to 82 months) and the average time to their prior blood lead test was 2.1 years.

Environmental characteristics

Complete (i.e., all five) environmental lead sampling results were collected for 58.8% of households. Among the 119 households, 116 (97.5%) had a tap water assessment, 98 (82.4%) had a dust front door floor assessment, 94 (79.0%) had a dust window assessment, 71 (59.7%) had a dust child play area floor assessment, and 70 (58.8%) had soil assessment (Table 3). Households without a soil sample collected either did not have a yard or did not have soil present in the yard. No households had lead water levels above the EPA action level for drinking water, 50 (71.4%) households exceeded the screening level for soil (Figure 5), 24 (24.5%) households had an elevated front door floor-dust lead level (Figure 6), 20 (28.2%) households had an elevated child play area floor-dust lead level (Figure 7) and 13 (13.8%) households had an elevated window-dust lead level (Figure 8). Nine duplicate water samples that were randomly collected, stored in separate containers and analyzed, showed no variation in results from their matched pair. Seventy-four dust wipe control samples were collected. Results of the dust wipe control samples were all below limit of detection (<0.5 µg).

Risk Factors

Twenty-five households (21.0%) were remodeled during the previous 6 months; 19 (15.9%) had a resident who was a current smoker; 23 (19.3%) had a resident with an occupation involving lead; and 15 (12.6%) had a resident with a lead-related hobby (Table 2). Other notable risk factors reported were as follows: 44 (37.0%) households reported using plates, bowls, or food storage containers made of ceramic or earthenware; 12 (10.1%) households had visible exterior paint deteriorations; 15 (12.6%) households had visible window exterior paint deteriorations; 13 (10.9%) households had visible interior paint deteriorations; and only 4 (3.3%) households had evidence of car repair or work on machinery in the yard.

In analyses adjusting for child's age, the log of the child's BLL was independently significantly associated with front door floor dust lead level (P = .0079), home built before 1900 (P = .0151), rental housing (P = .0327), deterioration of exterior household paint (P = .0187), deterioration of indoor paint (P = .0010), mother's education achievement less than high school or GED (P = .0053), household renovation during the previous six months (P = .0146), daily household cleaning (P = .0013), child with asthma symptoms (P = .0042), child with asthma (as told by a health care provider) (P <.001), child receipt of government medical insurance (Medicaid) (P = .0065), child receipt of food stamps (P = .0021), and child receipt of WIC (P = .0116) (Table 4).

In the final model, the log of the child's BLL was significantly associated with dust front door lead content ≥40 µg/ft^2 (P = .0027), home built before 1900 (P = .0017), and child receipt of government medical insurance (Medicaid) (P = .0149) (Table 5). A collinearity assessment did not identify significant correlations between variables in any of the models.

Results from the logistic regression analysis examining environmental sampling results, show the proportion of children with a BLL ≥5 µg/dL was significantly higher among those with elevated lead in interior floor dust by the entryway (Table 6). The age-adjusted odds of a BLL ≥5 µg/dL were 4.5 times higher (95% CI = 1.2, 16.6) for those with elevated floor dust by the front door compared to those living in households without elevated lead in their environmental sample. There were no significantly different odds of BLL ≥5 µg/dL by lead level in water, soil or other interior dust samples. The age-adjusted odds ratios of a BLL ≥5 µg/dL associated with having present any one or more, 2 or more, or 3 or more elevated environmental lead samples, all in reference to having less elevated lead samples are presented in Table 7. Households with any two environmental samples with elevated lead content had a 4.1 times higher odds (95% CI = 1.2, 14.0, P = .0256) of having a BLL ≥5 µg/dL compared to those with one or less elevated environmental sample. Finally, households with any 3 environmental samples with elevated lead content had 6.5 times higher odds (95% CI = 1.4, 29.5, P = .0150) of having a BLL ≥5 µg/dL, compared to those with 2 or less lead elevated environmental samples. There is a statistically significant positive trend (P = .007) between number of samples with elevated lead content and the odds of having a BLL ≥5 µg/dL.

Spatial Analysis

Blood lead, soil and dust lead results were spatially distributed across the entire study area without a clear foci (Figures 4–8). The results of Moran's I for each of the sample types (blood, dust and soil) indicated only a slight clustering effect. Among blood, dust and soil samples collected during the survey, SaTScan results reported no statistically significant spatial clusters. SaTScan output did identify some clusters of high values, but they were not statistically different from clusters that might have occurred in random distributions of values. These less significant clusters were located across the study area without any foci.

Comparison to existing data

During 2014, based on PDPH child blood lead surveillance data, the percent of children with BLLs ≥5 µg/dL was lower (range 5.3–12.8%) in all but one of the five study ZIP codes compared to children tested in our study (12.5% with BLLs ≥5 µg/dL) (Table 8) (PDPH 2015). The most current published U.S. geometric mean estimate from the National Health and Nutrition Examination Survey (NHANES) (among children 1–5 years of age) is 1.3 µg/dL (95% CI, 1.3–1.4) (CDC 2013). During 2007–2014, the national estimate of percentage of children 1–5 years of age with BLLs ≥5 µg/dL is 1.9% (CDC 2016).

We extracted 3600 dust wipe results from 295 households in the study and comparison ZIP codes. Environmental inspection records were collected between July 21, 2005 and March 4, 2014. Demographic characteristics among children whose household inspection records were extracted are presented in Table 9. On average, each child in the environmental inspection data was represented by 12.2 dust wipe samples, 49.2% of the children were male (14.9% had unknown gender); 41.0% had their first blood lead test at age 1 year; and 52.2% of children had their first dust wipe sample 4 to 12 months from the time of highest BLL test (Table 9). Compared with PDPH environmental inspection sampling results our study found higher lead exceedances on floor dust wipe (24.5% floor front door and 28.2% floor dust child play area vs 7.4% inspection data) and window sill (13.8% vs. 5.1%, P = .0005). Mean lead levels from the highest sample result by sample location within household were comparable to study floor results (66.2 µg/ft^2 floor front door and 49.3 µg/ft^2 floor dust child play area vs. 47.8 µg/ft^2) but differed by window sill results (396.4 µg/ft^2 vs. 215.7 µg/ft^2 P = .0359) (Table 10).

We identified 292 soilSHOP results in the study area collected during 2012–2016 (Figure 9). Almost half (n = 137, 46.9%) were below the limit of detection for lead. The mean lead level for the remaining 155 samples was 311 ppm (range 6.4 ppm–4300 ppm), lower than the 761 ppm soil lead mean identified in the present study.

Discussion

In Philadelphia, all children are recommended to be tested for lead at ages 12 months and 24 months or at 36–72 months if there is not proof of prior screening (PDPH 2013). In this population-based study, we found 90% of the enrolled children had been tested at least once, indicating robust outreach by Philadelphia Department of Public Health and pediatric health care providers serving these neighborhoods. Given the age of Philadelphia's housing stock, Philadelphia pediatric health care providers can continue routine testing of all children for blood lead particularly among low income, Medicaid-eligible and Medicaid-enrolled children.

In the majority of study neighborhoods, we found a higher proportion of children with BLLs ≥5 µg/dL (12.5%) compared to citywide Philadelphia child blood lead surveillance data (range: 5.3–12.8%) The geometric mean BLL among study children younger than 8 years (2.0 µg/dL [95% CI, 1.7–2.3]) is also modestly higher than the most recent published U.S. estimate (among children <6 years of age) (1.3 µg/dL [95% CI, 1.3–1.4]).

We identified three factors in age-adjusted multivariable analyses that predicted an association with higher geometric mean BLLs among children: floor dust (front door entryway) lead content ≥40 µg/ft^2; residence built prior to 1900; and a child currently or ever receiving government medical insurance (i.e., Medicaid).

Lead from all environmental sources (e.g., dust, soil, water) contribute to a child's total lead exposure. Often, these exposures co-occur, making it difficult to identify and quantify the individual contribution of each lead source to a child's total lead burden. Our data suggest that the most important indicator of lead exposure for these children was lead dust at the entryway. Interior dust lead is a well-documented predictor of elevated child BLLs. Paint chips (Su 2002) and deteriorated paint from inside the residence directly contaminate house dust. Entryway dust is an integrated measure of dust contributed from both interior and exterior lead sources. Child ingestion of lead contaminated dust occurs in several ways, including hand-to-mouth behavior, ingesting contaminated food, and mouthing objects contaminated with lead dust. Sixty-four percent of children in our study were observed by their parent/guardian to eat or mouth non-food items. Spalinger and colleagues (2007) characterized entryway dust lead concentrations in northern Idaho communities where historic mining and smelting occurred. They found significantly lower background house dust lead levels (even after stratifying by age of home) for demographically similar towns unaffected by the mining industry in northern Idaho compared to Bunker Hill Superfund Site historic mining and smelting communities. A recent study by Zota and colleagues (2016) which examined 53 infants' homes near the Tar Creek Superfund Site (Oklahoma, USA) reported

doubling of mean dust lead levels was associated with 36–49% higher 12-month child BLLs, after adjusting for cord blood lead level. These study results indicate that historical industrial lead emission can increase lead levels in household dust, which is consistent to what was observed in our study, although there are other lead sources in the urban environment.

We found 71% of households assessed for soil lead exceeded EPA standards. Soil and street dust can be transported inside the home and contribute to interior house dust (Lioy 2002). Paint chips from the residence exterior and lead contaminated residential soil, can contaminate house dust by tracked in soil particles (Yoshinaga 2014). In our study, soil lead levels or proximity to the J.T. Lewis point source were not a significant predictor of BLLs ≥5 µg/dL in age-adjusted, bi-variable analysis. However, almost a third of our study soil samples were collected from a mix of concrete and exposed soil, which may have made reduced the potential for tracking into the household. Previous studies elsewhere have estimated that 30–40% of total indoor dust comes from outdoor soil (Stanek 1995; Murgueytio 1998). In an ecologic study conducted in New Orleans, Zahran and colleagues (2013) indicate that variation among 55,551 child BLLs was explained by independent soil lead sample location for samples collected near houses (19%), busy street soils (22%), side street soils (39%) and open spaces (20%). A recent study showed that community and neighborhood soil sources, in addition to yard soil, contribute independently to total lead uptake and bioavailable lead in house dust (von Lindern 2016).

We identified living in a residence built prior to 1900 was associated with higher geometric mean BLLs among children. Age of housing as a predictor for child BLLs is well understood. The age of a home where a child resides is a risk factor for high BLLs used by child health care providers to target blood lead testing. Lanphear and colleagues (1998a) studied community characteristics associated with children <6 years of age having a BLL ≥10 µg/dL living in Monroe County, New York. They found housing built pre-1950 was associated with percent of children with BLLs ≥10 µg/dL compared to children with BLLs <10 µg/dL who resided in housing built post-1950. From a national survey, Jones and colleagues (2009) reported the odds of a child aged 1 to 5 years having a BLL of ≥10 μg/dL was 5.9 times higher in children living in a pre-1950 constructed housing compared to children living in post-1978 constructed housing. Finally, using the National Health and Nutrition Examination Survey (NHANES III 1991–1994), Pirkle and colleagues (1998) reported increasing mean BLLs among children between the ages of 1–5 years, by the year in which their houses were built. Mean BLLs were 3.8 μg/dl for children living in houses built prior to 1946, 2.8 μg/dl for children living in houses built 1946–1973, and 2.0 μg/dl for children living in houses built after 1973. About 92 percent of all lead in paint is contained in housing built prior to 1950 (HUD 2000).

The Federal government in 1978 banned residential lead-based paint (CPSC 1977). Older houses built before the ban are more at risk for elevated lead dust concentrations. Among households assessed for lead dust in our study, one-fourth exceeded standards for floor dust by the entryway and 28% exceeded standards for floor dust where the child was said to play. Ninety-one percent of study households were built prior to 1950. Our findings are consistent with other U.S. studies that have reported older home construction as a predictor of interior dust lead levels. Sutton and colleagues (1995) reported that California homes built before 1920 were three times more likely to have lead dust concentrations ≥270 ppm compared to post-1950 homes. Based on a nationally representative sample of 2065 household floors, Gaitens and colleagues (2009) reported significantly higher lead dust concentrations ($p < .001$) in homes constructed pre-1978 compared to homes constructed post-1978. Finally, a study by Pellizzari and colleagues (1999) reported that in the Great Lakes region of the U.S. that lead levels in surface dust wipes tended to be significantly higher in pre-1940 homes (mean lead level = 1075 ppm) compared to post 1980 homes (mean lead level = 128 ppm). Homes built before 1940 typically have higher concentrations of lead in paint, ranging from 10–50% (Rabin 1989; HUD 1995; Gaitens 2009). Lead use in house paints was unregulated until 1955, when the paint industry adopted a voluntary standard of no more than 1% lead by weight of nonvolatile solids for paint for interior usage followed by the 1978 ban (American National Standards Institute, 1955; HUD 1990).

We identified children from households currently or ever receiving government medical insurance (i.e., Medicaid) had higher geometric mean BLLs than those who did not receive it. Current or previous receipt of Medicaid is a proxy for low-income households. These households are likely older, poorly maintained and frequently contain lead-based paint hazards (Wengrovitz and Brown 2009). Numerous reports have described the relationship between low-income housing and elevated BLLs (CDC 2004; Lanphear 1998b; Reyes 2006; Dixon 2009; Krieger 2002). Nationally, children in low-income families are experiencing decreases in BLLs and thus the disparity between Medicaid-eligible children and non-Medicaid-eligible children is lessening (Wengrovitz and Brown 2009).

We found environmental lead levels to be above current regulatory standards in a large proportion of survey households. We were able to compare study interior dust lead results to historic Philadelphia Department of Public Health inspection data back to 2005. Interestingly, we found that although the highest dust lead levels were comparable, study floor dust lead levels were on average, more than 3 times higher and window dust lead levels almost twice as high compared to historic investigations, however mean values were comparable when considering the highest test result by household. This may be indicative of the particularly old houses in our sample compared to other Philadelphia neighborhoods or it may be due to variations in environmental sampling and analytic techniques between our study and the Philadelphia Department of Public Health inspections. It may also suggest that legacy-polluting facilities are a contributing factor to elevated interior dust levels. Further study may elucidate reasons for the discrepancy (e.g., comparison of similarly collected environmental lead samples from other neighborhoods with similar housing stock). When comparing study soil lead results to previous soilSHOP results, there is a two-fold increase in study average soil lead levels (i.e., 761 ppm vs 311 ppm). These results are challenging to compare since content analysis (lab-based vs. XRF), sample preparation, conditions at time of sample collection, and sample location all varied, which may affect the accuracy of the results. Further, SoilSHOP results are biased. Residents self-select to participate, and often choose to participate because they are gardeners who want information about the safety of their garden soil. Soil sample results collected from established gardens may be low since the soils are likely to have been amended for healthy crop growth for one or more gardening seasons compared to urban soils collected from areas that have not received amendments. Since the 1970s, numerous environmental sampling events have taken place in the vicinity of the former John T. Lewis facility to evaluate the effects of emissions (Versar 1987, TerraGraphics 1993, Air Management Services 2016). Average soil lead levels from residential and public areas closest to the former facility ranged from 600 to 2,600 ppm during a 1987 assessment (Versar 1987). Soil lead sampling results from residential yards conducted by the EPA in 2009 and 2011 showed levels ranging between 1,168 and 2,508 ppm (Tetra Tech 2009, EPA 2011).

The study area included at least twelve suspect historic lead-emitting point sources of interest. Our findings validate a 2001 study by Eckel and colleagues, which reported soil lead concentrations above EPA residential risk-based screening levels (≥400 ppm) around five former Philadelphia lead-smelting sites. We identified higher than anticipated environmental lead soil and dust results likely due to a combination of pollution from suspect legacy lead-emitting sites and deteriorating old housing stock. In age-adjusted, bi-variable analyses, we found higher geometric mean BLLs among children living in households with deteriorating interior and exterior paint and with recent home renovation. Study teams reported observing home renovation and gentrification activity in the study neighborhoods. Reinforcing the impact of elevated lead environmental sampling results on BLLs among children in the study, we found households with any two or three elevated lead samples significantly predicted BLLs ≥5 µg/dL among children compared to those with no or only 1 elevated environmental lead result. These results underscore efforts to make housing lead safe by addressing all lead hazards in and around the home, given that children living in households with the highest lead burden (i.e., 2 or more lead sources) were likeliest to have BLLs ≥5 µg/dL.

There are recommendations for residents living in these study communities. Parents or guardians can reduce their own and their children's exposure to lead in soil and from other sources, such as deteriorating lead paint. Information and resources for Philadelphia residents are available via the City of Philadelphia's Lead and Healthy Homes Program (www.phila.gov/health/childhoodlead). Children should regularly wash their hands, face and feet, especially before eating and drinking or after playing outside, to remove potential lead dust and soil. To reduce potential exposure to lead dust (especially at entryway), regular floor cleaning can reduce exposure. Parents can damp/wet mop floors and damp dust counters and furniture regularly. Parents can also eliminate paint chips or dust in windowsills by cleaning these areas regularly with a damp/wet mop. Use of a vacuum with a high efficiency particulate filter (HEPA) may also be useful, as it keeps most vacuumed dust within a canister. Several actions can help reduce soil being tracked into the house such as use of door mats, removal of (or cleaning of) shoes before entering the household, use of ground coverings/barriers in the yard and planting of grass and shrubs over bare soil (ATSDR 2007b, Dixon 2006).

Our study had limitations. First, participation in our survey was lower than desired. We had many refusals (40%) due to the transitional nature of several study neighborhoods (e.g., vacancy during renovation, gentrification, lack of parental interest in joining study, challenges with address identification). Anecdotal reports from field teams indicate many parents refused enrollment because their children were previously tested. Second, we were not able to assess possible differences between children who did and did not participate in the study. Third, several of our reference databases were not directly comparable to study data. For example, city environmental inspection data included households of children with BLLs ≥10 or ≥20 (we had only 2 such children), city environmental inspection data included both pre- and post-clearance dust sample results, some of which may have been collected after cleaning and thus may have created a negative bias. SoilSHOP results were collected and analyzed differently than in our study. Fourth, we potentially observed an upward bias of child BLLs due to summertime sampling. Blood lead levels in children tend to be higher during the summer months, a situation that may be related to differential seasonal distribution of household lead dust as well as higher child exposure to outdoor dust/soil associated with increased outdoor activity (Kennedy 2016; Yin 2000). Fifth, in our multivariable predictive analyses, we identified three factors that predicted higher child geometric mean BLLs. These results should not be interpreted as clinically significant because higher geometric mean BLLs do not coincide with recommended BLLs for the management of children with elevated BLLs (i.e., BLLs ≥5 µg/dL) (http://www.phila.gov/health/pdfs/ChildhoodLead/Guide%20for%20Clinicians_December%202017%20update.pdf). However, BLLs <5 µg/dL are not without consequences for children: they are not clinically significant in the short-term but are an important part of the child's medical information.

Nevertheless, this was a comprehensive, randomly sampled survey that included a face-to-face survey, venous BLL testing, environmental lead sampling, and visual housing inspection. We were able to compare our findings to several other data sources, which strengthened assessment of community lead risk factors.

We sought to characterize community lead risks with numerous suspect legacy lead-emitting sites. We did not identify distance to the point source of interest to be predictive of elevated lead sampling in the environment or elevated child BLLs. All household water lead level results were below the EPA action level indicating water did not likely contribute to childhood lead exposure. However, grab water samples collected during the visit do not provide an overall assessment of a child's exposure to lead in water because water lead levels can vary considerably throughout the day and evening. We are not able to directly tie elevated BLLs to any point source; however, we did observe higher than anticipated soil lead and interior dust lead results. This observation has potentially multifactorial contributions: old housing stock; living in a community with legacy polluting facilities; low-income households; and recent household renovation activities.

Conclusion

This study provides insight into the determinants of BLLs in a random sample of children living in urban Philadelphia neighborhoods with a history of lead-related industry. We found a higher proportion of children with BLLs ≥5 µg/dL compared to Philadelphia child surveillance data in the same study ZIP codes and compared with the most recent published U.S. estimates: six times the percent of children with BLLs ≥5 µg/dL and modestly higher geometric mean BLLs. Most children enrolled in our study had previously been tested for blood lead, indicating robust outreach by Philadelphia Department of Public Health and pediatric health care providers and widespread acceptance of blood lead testing by parents and guardians. We identified three factors that were associated with higher geometric mean BLLs among children: leaded dust at the front door entryway; residence built prior to 1900; and a child currently or ever receiving Medicaid. Additionally, we found households with two or more elevated environmental lead samples significantly predicted child BLLs ≥5 µg/dL compared to those with no or only 1 elevated environmental lead result. We did not identify a spatial relationship between household and child blood lead sampling results and proximity to historic suspect lead-emitting facilities. Continued child blood lead surveillance, blood lead testing and case investigations are recommended in the study communities. Although BLLs for low-income children have decreased substantially on a national level, in Philadelphia, pediatric health care providers can be especially vigilant screening Medicaid-eligible and Medicaid-enrolled children, and children living in very old housing.

Authors

Timothy Dignama, Division of Environmental Hazards and Health Effects, National Center for Environmental Health, Centers for Disease Control and Prevention,

Ana Pomales, Region 3; Agency for Toxic Substances and Disease Registry

Lora Werner, Region 3; Agency for Toxic Substances and Disease Registry

Claire Newbern, Philadelphia Department of Public Health

James Hodge, Division of Emergency and Environmental Health Services, National Center for Environmental Health, Centers for Disease Control and Prevention

Jay Nielsen, Division of Emergency and Environmental Health Services, National Center for Environmental Health, Centers for Disease Control and Prevention

Aaron Grober, Division of Community Health Investigations, Agency for Toxic Substances and Disease Registry

Karen Scruton, Division of Community Health Investigations, Agency for Toxic Substances and Disease Registry

Rand Young, Division of Toxicology and Human Health Studies, Agency for Toxic Substances and Disease Registry

Jack Kelly, Region 3, Environmental Protection Agency

Mary Jean Brown, Division of Emergency and Environmental Health Services, National Center for Environmental Health, Centers for Disease Control and Prevention

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Table 1: Characteristics and potential risk factors for lead exposure among children enrolled in blood lead study, Philadelphia, 2014 (N=160)

Child characteristic	Number (%)
Blood lead level source	
Collected in household	105* (65.6)
Abstracted from surveillance data	42 (26.3)
Not identified in surveillance data (no previous blood lead test)	13 (8.1)
Gender	
Male	69 (43.1)
Female	79 (49.4)
Missing	12 (7.5)
Age (months)	
<12	10 (6.3)
12–23	29 (18.1)
24–35	29 (18.1)
36–47	25 (15.6)
48–59	28 (17.5)
60–71	23 (14.3)
≥72	16 (10)
Missing	0
Race	
Asian	20 (12.5)
Black or African American	79 (49.4)
White	33 (20.6)
Multi-racial (more than 1 race)	13 (8.1)
Missing	15 (9.4)
Number of children <6 years of age sampled in household	
1	119 (74.3)
2	30 (18.8)
3	8 (5.0)
4	2 (1.2)
5	1 (0.6)
Twin in household	
Yes	5 (3.1)
No	155 (96.9)
Child birth place	
Philadelphia	133 (83.1)
Other	18 (11.3)
Missing	9 (5.6)
Type of services child currently or ever received (respondents could choose > 1 answer) (n = 250)	
Government Medical Insurance (Medicaid)	57 (22.8)
Public Housing	4 (1.6)
Section 8 Voucher	2 (0.7)
Food Stamps	57 (22.8)
Women Infant Children Program (WIC)	54 (21.6)

*One sample excluded due to insufficient quantity

Child characteristic	Number (%)
Other Form of Public Assistance	7 (2.8)
None/Missing	69 (27.6)
TOTAL	250 (100)
Asthma symptoms such as shortness of breath, coughing, or wheezing	
Yes	33 (20.6)
No	117 (73.1)
Missing	10 (6.3)
Asthma (told by a health care provider)	
Yes	22 (13.8)
No	128 (80.0)
Missing	10 (6.3)
Up-to-date vaccinations (parent/guardian reported)	
Yes	140 (87.5)
No	5 (3.1)
Don't Know	2 (1.2)
Missing	13 (8.1)
Child spends >20 hours/week anywhere other than household	
Yes	73 (45.6)
No	76 (47.5)
Missing	11 (6.9)
Where child spends >20 hours/week outside household (n = 73)	
Day care center	30 (41.1)
Babysitter	6 (8.2)
Home of relative	11 (15.1)
Home of friend	1 (1.4)
School	19 (26.0)
Other	6 (8.2)
TOTAL	73 (100)
Potential Child Exposures	
Use of household remedies, herbal remedies or folk medicines (e.g., Azarcon and Greta)	
Yes	10 (6.3)
No	136 (85.0)
Don't Know	2 (1.2)
Missing	12 (7.5)
Observation of child eating or mouthing non-food items	
Yes	103 (64.3)
No	48 (30.0)
Missing	9 (5.7)

*One sample excluded due to insufficient quantity

Table 2: Household characteristics among children enrolled in blood lead study, Philadelphia, 2014 (N=119)

Household characteristic	Number (%) N=119
Number of residents	
2	5 (4.2)
3	34 (28.6)
4	29 (24.3)
5	21 (17.6)
>5	27 (22.7)
Missing	3 (2.5)
Ownership Type	
Owner occupied	69 (58.0)
Rental	43 (36.1)
Public housing	2 (1.7)
Publicly subsidized (Section 8)	1 (0.8)
Other	0
Missing	4 (3.3)
Structure Type	
Apartment 5–100 Units Masonry	3 (2.5)
Residential Condominium 3+Stories	1 (0.8)
Row House 2 Story Masonry	70 (58.8)
Row House 2 or 3 Story Frame	3 (2.5)
Row House 3 Story Masonry	41 (34.4)
Missing	1 (0.8)
Year Built	
<1900	31 (26.0)
1900–1919	15 (12.6)
1920–1939	60 (50.4)
1940–1959	7 (5.9)
>1959	5 (4.2)
Missing	1 (0.8)
Mother's level of education	
None	0
Eighth grade or less	2 (1.7)
Some high school	11 (9.2)
High school graduate or GED	23 (19.3)
Some college or trade school	29 (24.3)
College or higher	47 (39.5)
Don't know	2 (1.7)
Missing	5 (4.2)
Distance to point source of interest, quartiles (feet)	
<2302	32 (26.9)
2303–3738	28 (23.5)
3739–5122	26 (21.8)
>5122	33 (27.7)
Missing	0

Household characteristic	Number (%) N=119
Description of Yard/Soil Sampling Area	
No soil sample collected	49 (41.2)
Bare soil	5 (4.2)
Grass cover	9 (7.6)
Cement/concrete	7 (5.9)
Mix of bare soil and cover (e.g., grass/rubble/cement)	38 (31.9)
Does not have yard	1 (0.8)
Other	1 (0.8)
Missing	9 (7.6)
Potential Household Lead Exposure	
Home remodeled inside or outside during the last 6 months	
Yes	25 (21.0)
No	85 (71.4)
Don't Know	2 (1.7)
Missing	7 (5.9)
Any plates, bowls, or food storage containers made of ceramic or earthenware	
Yes	44 (37.0)
No	61 (51.2)
Don't know	9 (7.6)
Missing	5 (4.2)
Lead occupation of anyone in household	
Smelting	1 (0.8)
Auto repair	6 (5.0)
Work on or use of firing ranges	4 (3.3)
Painting	6 (5.0)
Manufacturing of ceramics	0
Manufacturing of electrical components or electrical equipment	3 (2.5)
Manufacturing of batteries	0
Wire and cable production	0
Pottery making	0
Stained glass	0
Other	3 (2.5)
None of above	39
Missing	57
Lead hobby of anyone in household (multiple answers allowed)	
Automobile repair	4 (3.3)
Metal recycling	1 (0.8)
Making fishing sinkers	1 (0.8)
Stained glass	1 (0.8)
Ceramics/pottery	0
Shooting guns	5 (4.2)
Jewelry making	3 (2.5)
None of above	91
Missing	13 (10.9)

Household characteristic	Number (%) N=119
Source of water used for drinking/cooking	
Public water system/piped municipal source	104 (87.4)
Bottled and public water system/piped municipal source	10 (8.4)
Public water system/piped municipal source & rain water collection	1 (0.8)
Missing	4 (3.3)
Anyone smoke tobacco inside the house	
Yes	19 (15.9)
No	94 (79.0)
Missing	6 (5.0)
Frequency household is swept or cleaned	
Daily	63 (52.9)
At least weekly	47 (39.5)
At least monthly	4 (3.3)
Less than once a month	1 (0.8)
Never	0
Don't know	0
Missing	4 (3.3)
Frequency interior of house is painted	
More than once a year	7 (5.9)
Once a year	30 (25.2)
Every two years	24 (20.1)
Every five years	34 (28.6)
Don't remember	16 (13.4)
Missing	8 (6.7)
Frequency exterior of house is painted	
More than once a year	1 (0.8)
Once a year	4 (3.3)
Every two years	3 (2.5)
Every five years or more	21 (17.6)
Don't remember	52 (43.7)
Never (brick)	28 (23.5)
Missing	10 (8.4)
Condition of the dwelling exterior paint	
Intact	96 (80.7)
Peeling	3 (2.5)
Chipping	2 (1.7)
Cracking	3 (2.5)
Chalking	0
More than one of the above deteriorations	4 (3.3)
Missing	11 (9.2)
Condition of the dwelling exterior window paint	
Intact	87 (73.1)
Peeling	8 (6.7)
Chipping	1 (0.8)

Household characteristic	Number (%) N=119
Cracking	1 (0.8)
More than one of the above deteriorations	5 (4.2)
Missing	17 (14.3)
Condition of the dwelling interior paint	
Intact	93 (78.1)
Peeling	7 (5.9)
Chipping	4 (3.3)
Cracking	1 (0.8)
More than one of the above deteriorations	1 (0.8)
Missing	13 (10.9)
Do(es) child(ren) play outside house	
Yes	105 (88.2)
No	8 (6.7)
Don't know	1 (0.8)
Missing	5 (4.2)
Parent wash or child wash his/her hands before he/she eats	
Yes, often	77 (64.7)
Yes, sometimes	31 (26.0)
Rarely	2 (1.7)
No, never	4 (3.3)
Don't know	0
Missing	5 (4.2)
Evidence of car repair or work on machinery in the yard (such as dismantled cars, old machinery or dismantled household appliances)	
Yes	4 (3.3)
No	101 (84.9)
Don't know	0
Missing	14 (11.8)

Table 3: Household environmental lead sampling results, Philadelphia, 2014 (N=119)

Environmental Sample Type	Number of HHs Sampled	Min/Max	Mean	Median	Number of HHs Exceeding Elevated Lead Level (%)	Elevated Lead Level Threshold
Soil Composite	70	40º–7,700 ppm (or mcg/g)	760.6 ppm (or mcg/g)	595.0 ppm (or mcg/g)	50 (71.4%)	400 ppm (or µg/g)
Water	116	<1.0–3.9 mcg/L	N/A	N/A	0	15 mcg/L
Dust Floor (Front Door)	98	5.2–2,322.6 µg/ft^2	66.2 µg/ft^2	17.7 µg/ft^2	24 (24.5%)	40 µg/ft^2
Dust Floor (Child Play Area)	71	5.0–631.7µg/ft^2	49.3 µg/ft^2	13.9 µg/ft^2	20 (28.2%)	40 µg/ft^2
Dust Window (Child Room)	94	1.6–17,999.9 µg/ft^2	396.4 µg/ft^2	31.2 µg/ft^2	13 (13.8%)	250 µg/ft^2

HH = Household

Table 4: Bi-variable linear regression, age-adjusted estimates of the association between log of blood lead level and other study variables, Philadelphia, 2014 (N=104)

Exposure variable	N	Geometric Mean* BLL (95% CI)	Beta (SE)	Ratio of geometric means (95% CI)	p Value
Age, years (continuous)	104	1.95 (1.67, 2.32)	-0.01 (0.04)	N/A	0.8416
Child gender					
Female	54	1.90 (1.48, 2.41)	0.17 (0.17)	1.19 (0.85, 1.65)	0.3028
Male	47	2.25 (1.80, 2.77)			
Yard soil lead content					
≥400 ppm (μg/g)	38	2.39 (1.86, 3.10)	0.40 (0.20)	1.49 (0.99, 2.23)	0.0539
<400 ppm (μg/g)	22	1.62 (1.17, 2.20)			
Dust floor (front door) lead content					
≥40 μg/ft^2	25	2.83 (2.03, 3.94)	0.53 (0.20)	1.70 (1.15, 2.51)	0.0079
<40 μg/ft^2	63	1.67 (1.35, 2.05)			
Dust floor (child play area) lead content					
≥250 μg/ft^2	23	2.59 (1.93, 3.46)	0.09 (0.19)	1.09 (0.75, 1.58)	0.6459
<250 μg/ft^2	45	2.39 (1.90, 3.00)			
Dust window (child room) lead content					
≥250 μg/ft^2	14	2.89 (1.90, 4.39)	0.39 (0.24)	1.48 (0.91, 2.36)	0.1082
<250 μg/ft^2	67	1.95 (1.60, 2.39)			
Distance to point source, quartiles (feet)					
<2302	20	1.39 (0.85, 2.27)	-0.44 (0.28)	0.64 (0.37, 1.13)	0.1209
2303–3738	27	1.82 (1.46, 2.25)	0.17 (0.16)	1.19 (0.62, 1.16)	0.3002
3739–5122	29	2.44 (1.70, 3.52)	0.13 (0.22)	1.14 (0.73, 1.77)	0.5661
>5122	30	2.16 (1.68, 2.75)	ref	ref	ref
Year built					
<1900	23	2.72 (2.10, 3.53)	0.41 (0.17)	1.51 (1.08, 2.10)	0.0151
≥1900	83	1.80 (1.48, 2.18)			
Ownership type					
Rental/public housing/Section 8	52	2.29 (1.92, 2.75)	0.37 (0.17)	1.45 (1.03, 2.01)	0.0327
Owned	50	1.60 (1.21, 2.12)			
Exterior paint condition of household					
Intact	75	1.77 (1.49, 2.10)	0.56 (0.23)	1.75 (1.09, 2.77)	0.0187
Peeling, chipping, cracking and/or chalking	19	3.10 (2.01, 4.71)			
Exterior paint condition of windows					
Intact	75	1.79 (1.51, 2.12)	0.24 (0.25)	1.27 (0.77, 2.10)	0.3438
Peeling, chipping, cracking	19	2.27 (1.42, 3.63)			
Interior paint condition of household					
Intact	80	1.72 (1.43, 2.03)	0.59 (0.18)	1.80 (1.27, 2.56)	0.0010
Peeling, chipping, cracking	16	3.10 (2.29, 4.14)			
Mother's education					
< high school diploma/GED	16	2.86 (2.12, 3.90)	0.52 (0.18)	1.68 (1.17, 2.41)	0.0053
≥ high school	81	1.72 (1.40, 2.08)			

*Least Squares Mean (Conditional Marginal)

Exposure variable	N	Geometric Mean* BLL (95% CI)	Beta (SE)	Ratio of geometric means (95% CI)	p Value
Child plays outside house					
Yes	93	1.95 (1.63, 2.34)	0.11 (0.24)	1.12 (0.71, 1.79)	0.6278
No	8	1.73 (1.13, 2.66)			
Interior of house painted					
Every 2 years or less	21	1.97 (1.60, 2.44)	-0.23 (0.25)	0.79 (0.48, 1.31)	0.3667
Every 2+ years	57	1.57 (1.00, 2.48)			
Exterior of house painted					
Every 5 years or less	20	1.90 (1.31, 2.75)	0.08 (0.27)	1.08 (0.64, 1.84)	0.7682
Never	28	2.05 (1.45, 2.94)			
Household renovated during previous six months					
Yes	23	2.48 (1.92, 3.19)	0.42 (0.17)	1.52 (1.08, 2.12)	0.0146
No	72	1.63 (1.32, 2.00)			
Evidence of car repair or machinery work in yard					
Yes	3	1.72 (1.11, 2.69)	-0.13 (0.25)	0.88 (0.53, 1.45)	0.6074
No	32	1.95 (1.65, 2.34)			
Household cleaning					
Daily	57	2.45 (1.99, 3.00)	-0.55 (0.17)	0.58 (0.42, 0.80)	0.0013
Weekly or monthly	45	1.42 (1.11, 1.82)			
Any plates, bowls, or food storage containers made of ceramic or earthenware					
Yes	29	2.08 (1.60, 2.66)	0.07 (0.18)	1.07 (0.76, 1.52)	0.6946
No	67	1.93 (1.54, 2.44)			
Lead hobby of anyone in household					
Yes	11	2.48 (1.43, 4.31)	0.28 (0.29)	1.32 (0.74, 2.39)	0.3376
No	88	1.88 (1.55, 2.25)			
Lead occupation of anyone in household					
Yes	18	2.10 (1.45, 3.03)	0.32 (0.24)	1.38 (0.85, 2.20)	0.1906
No	31	1.52 (1.13, 2.05)			
Anyone smoke tobacco inside household					
Yes	19	2.56 (1.75, 3.74)	0.39 (0.21)	1.48 (0.97, 2.27)	0.0673
No	79	1.72 (1.43, 2.08)			
Child washes hands before eating					
Often	70	2.05 (1.70, 2.51)	-0.23 (0.20)	0.79 (0.54, 1.85)	0.2558
Sometimes, rarely or never	32	1.65 (1.17, 2.29)			
Observation of child eating or mouthing non-food items					
Yes	73	2.08 (1.70, 2.53)	0.17 (0.17)	1.18 (0.84, 1.67)	0.3182
No	32	1.75 (1.31, 2.32)			
Use of household remedies, herbal remedies or folk medicines					
Yes	5	2.85 (2.16, 3.73)	0.49 (0.17)	1.63 (1.17, 2.29)	0.0042
No	96	1.73 (1.43, 2.12)			
Child has asthma symptoms such as shortness of breath, coughing, or wheezing					
Yes	25	2.85 (2.16, 3.73)	0.49 (0.17)	1.63 (1.17, 2.29)	0.0042
No	78	1.73 (1.43, 2.12)			

*Least Squares Mean (Conditional Marginal)

Exposure variable	N	Geometric Mean* BLL (95% CI)	Beta (SE)	Ratio of geometric means (95% CI)	p Value
Child has asthma (as told by a health care provider)					
Yes	16	3.60 (2.71, 4.80)	0.72 (0.17)	2.05 (1.48, 2.86)	<0.001
No	87	1.75 (1.46, 2.10)			
Child currently or ever received government-sponsored medical insurance					
Yes	42	2.53 (2.08, 3.06)	0.43 (0.15)	1.53 (1.13, 2.10)	0.0065
No	61	1.65 (1.29, 2.08)			
Child currently or ever received food stamps					
Yes	46	2.61 (2.12, 3.19)	0.52 (0.16)	1.68 (1.21, 2.31)	0.0021
No	57	1.55 (1.22, 1.97)			
Child currently or ever received Women Infant Children Program (WIC)					
Yes	36	2.56 (2.03, 3.19)	0.41 (0.16)	1.51 (1.09, 2.05)	0.0116
No	67	1.70 (1.36, 2.12)			

*Least Squares Mean (Conditional Marginal)

Table 5: Multi-variable linear regression, age-adjusted estimates of the association between log of blood lead level and other study variables, Philadelphia, 2014 (N=104)

Exposure variable	Geometric Mean* BLL (95% CI)	Beta (SE)	Ratio of geometric means (95% CI)	p Value
Age, years (continuous)	1.95 (1.67, 2.32)	0.02 (0.05)	N/A	0.6162
Dust floor (front door) lead content				
≥40 μg/ft^2	2.89 (1.16, 2.16)	0.56 (0.18)	1.75 (1.22, 2.51)	0.0027
<40 μg/ft^2	1.65 (1.11, 1.35)			
Year built				
<1900	2.69 (2.10, 3.46)	0.42 (0.16)	1.52 (1.09, 2.10)	0.0117
≥1900	1.79 (1.46, 2.18)			
Child currently or ever received government medical insurance (Medicaid)				
Yes	2.41 (2.08, 2.83)	0.39 (0.16)	1.48 (1.08, 2.20)	0.0149
No	1.63 (1.26, 2.14)			

*Least Squares Mean (Conditional Marginal)

Table 6: Median, 25th and 75th percentile blood lead level and age-adjusted odds ratio of blood lead levels ≥5 μg/dL by environmental lead sampling result, Philadelphia, 2014 (N=104)

Environmental Sample Type	N (%)	Median BLL (μg/dL) (IQR)	BLL ≥5 μg/dL Odds Ratio (95% CI)
Dust floor (front door) lead content			
Elevated (>40 μg/ft2)	25 (24.0)	3.1 (1.9, 5.3)	4.5 (1.2, 16.6)
Not Elevated (≤40 μg/ft2)	63 (60.6)	1.7 (1.1, 2.9)	ref
Not collected	16 (15.4)	2.1 (1.1, 3.5)	NA
Yard soil lead content			
Elevated (>400 ppm)	38 (36.5)	2.9 (1.5, 4.4)	5.3 (0.6, 47.0)
Not Elevated (≤ 400 ppm)	22 (21.2)	1.8 (1.0, 2.4)	ref
Not collected	44 (42.3)	2.2 (1.2, 3.5)	NA
Dust in play area lead content			
Elevated (>40 μg/ft2)	23 (22.1)	2.9 (1.6, 4.8)	1.4 (0.4, 5.3)
Not Elevated (≤40 μg/ft2)	45 (43.3)	2.5 (1.5, 4.3)	ref
Not collected	36 (34.6)	1.5 (1.0, 2.4)	NA

Environmental Sample Type	N (%)	Median BLL (µg/dL) (IQR)	BLL ≥5 µg/dL Odds Ratio (95% CI)
Dust on window (child room) lead content			
Elevated (>250 µg/ft2)	14 (13.5)	3.9 (2.3, 4.8)	1.7 (0.4, 7.7)
Not Elevated (≤250 µg/ft2)	67 (64.4)	1.9 (1.1, 3.2)	ref
Not collected	23 (22.1)	1.9 (1.2, 2.9)	NA
Tap water			
Elevated (≥15 µg/L)	0 (0)	NA	NA
Not Elevated (<15 µg/L)	101 (97.1)	2.1 (1.2, 3.6)	
Not collected	3 (2.9)	1.8 (0.3, 4.7)	

Table 7: Median, 25th and 75th percentile blood lead level and age-adjusted odds ratio of blood lead levels ≥5 µg/dL by number of elevated environmental lead sampling results, Philadelphia, 2014 (N=104)

Number of Environmental Sample Results	N (%)	Median BLL (µg/dL) (IQR)	BLL ≥5 µg/dL Odds Ratio (95% CI)	P value
One or more elevated lead sample types				
Zero	39	1.8 (1.0, 2.9)	ref	0.0990
Yes	61	2.4 (1.5, 4.3)	3.8 (0.8, 18.5)	
Not collected	4	2.5 (1.8, 3.5)	NA	
Two or more elevated lead sample types				
Zero or one	74	1.8 (1.1, 2.9)	ref	0.0256
Yes	26	3.3 (1.7, 5.3)	4.1 (1.2, 14.0)	
Not collected	4	2.5 (1.8, 3.5)	NA	
Three or more elevated lead sample types				
Two or less	90	1.8 (1.1, 2.9)	ref	0.0150
Yes	10	3.3 (1.7, 5.3)	6.5 (1.4, 29.5)	
Not collected	4	2.5 (1.8, 3.5)	NA	

One-sided Cochran-Armitage trend test P=0.007

Table 8: Philadelphia Department of Public Health blood lead level surveillance data in study ZIP codes (2014)

ZIP Code	Number of children with blood lead levels ≥5 µg/dL	Number of children screened	Percent of children screened with BLL ≥5µg/dL (%)
19122	47	470	10.0
19123	17	318	5.3
19125	31	526	5.9
19133	143	1,117	12.8
19134	188	2,225	8.4
Total	426	4,656	9.1

Table 9: Selected characteristics of children included from extracted environmental inspection data, Philadelphia, dates (N=295)

Gender	N	Percent
Male	145	49.2
Female	98	33.2
Unknown	8	2.7
Missing	44	14.9
Age At First Blood Lead Test (years)		
<1	84	28.5
1	121	41.0
2	31	10.5
3	9	3.1
4	7	2.4
5	3	1.0
≥6	4	1.4
Missing	36	12.2
Time from Highest BLL Result to First Dust Wipe Sample		
Recorded Before Dust Wipe Sample Date	9	3.1
0–3 Months	63	21.4
4–6 Months	77	26.1
7 Months–1 Year	77	26.1
>1–2 Years	49	16.6
>2 Years	20	6.8

Table 10: Selected characteristics of dust wipe samples from extracted PDPH environmental inspection data, Philadelphia, 2005–2014

Location	Failed* n (%)	Passed n (%)	Total N	Mean**	Total N**
Floor	103 (7.4)	1,295 (92.6)	1,398	47.8 µg/ft^2	294
Window Sill	59 (5.1)	1,097 (94.9)	1,156	215.7 µg/ft^2	292
Window Well	88 (8.4)	958 (91.6)	1,046	610.7 µg/ft^2	282
Total	250 (6.9)	3,350 (93.1)	3,600	N/A	868

*Dust wipe samples failed if they exceeded: 40 µg/ft2 on floors; 250 µg/ft2 on windowsills; or 400 µg/ft2 on window wells
**Highest result by sampling location within household. Samples reported as < the limit of detection were assigned their limit of detection value (µg/ft^2)

Figure 1: Twelve suspect lead-emitting historical facilities in the study area, Philadelphia, 2014

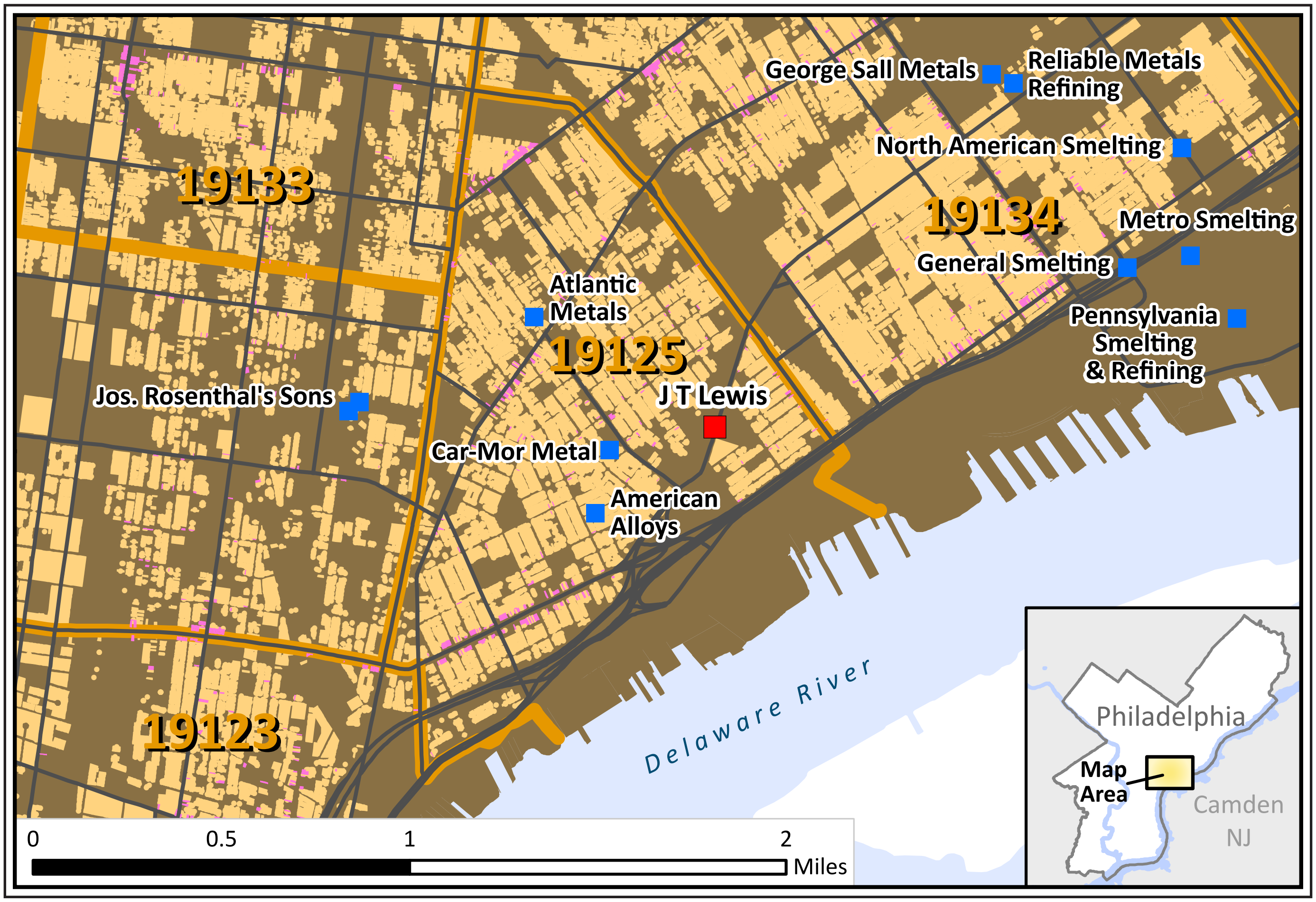


Figure 1: Image showing location of former John T. Lewis facility and 11 suspected lead-emitting historical facilities. The 12 former lead-emitting facilities are located in the study area.

Figure 2: Age of housing in study area, Philadelphia, 2014

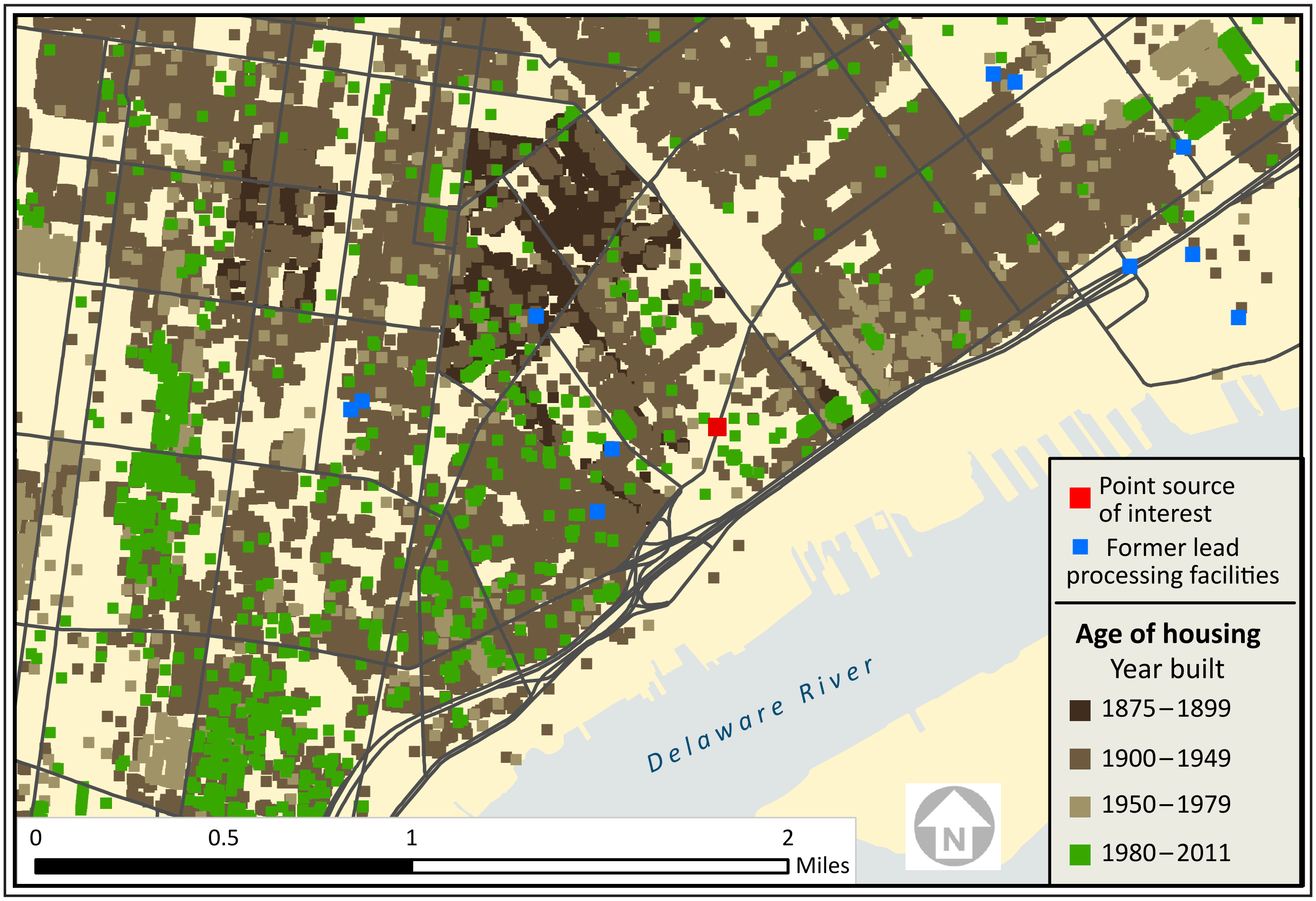
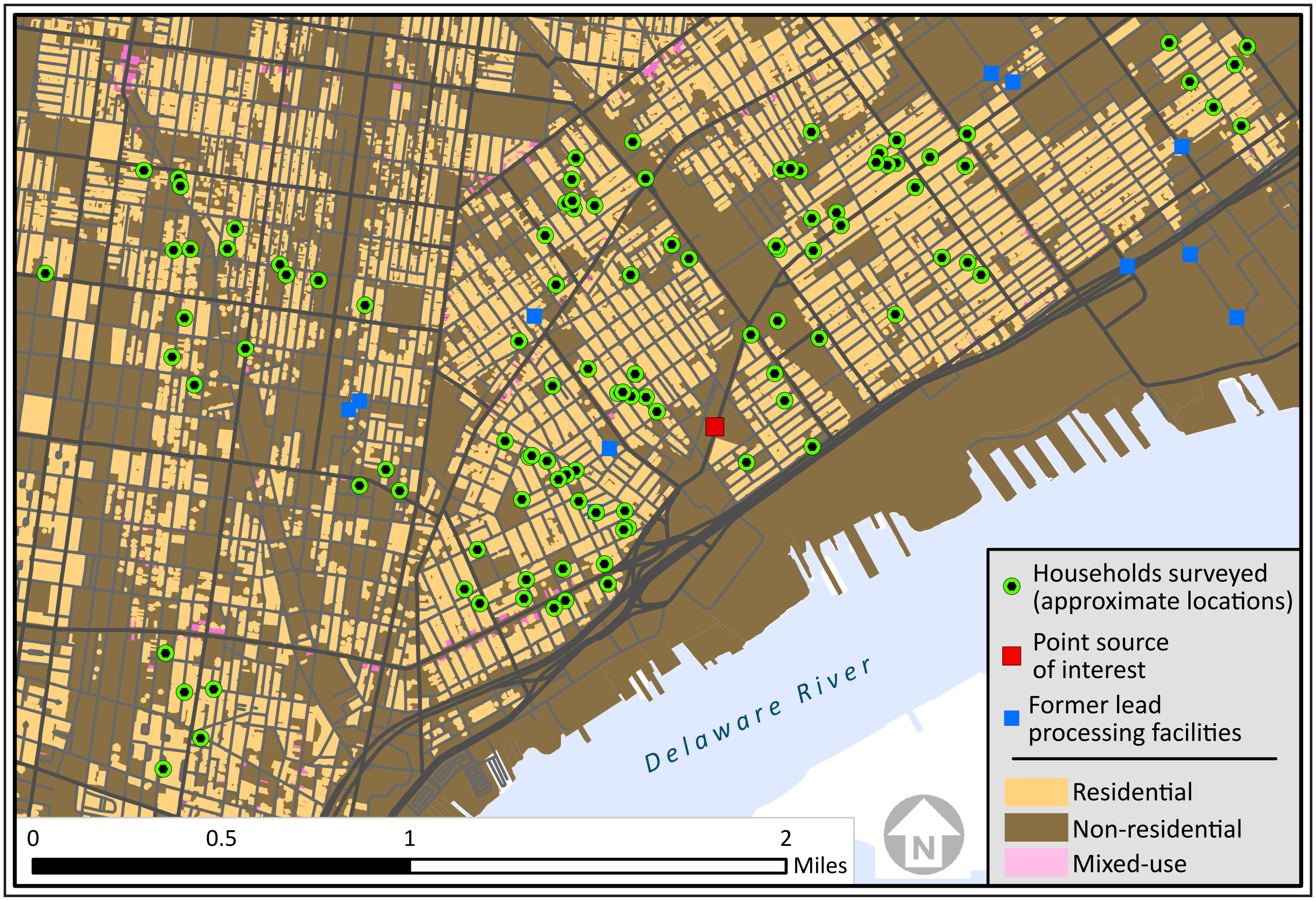


Figure 2: Image showing the age of housing across the study area. The majority of the houses located in the immediate vicinity of the former John T. Lewis facility were built between 1875 and 1949.

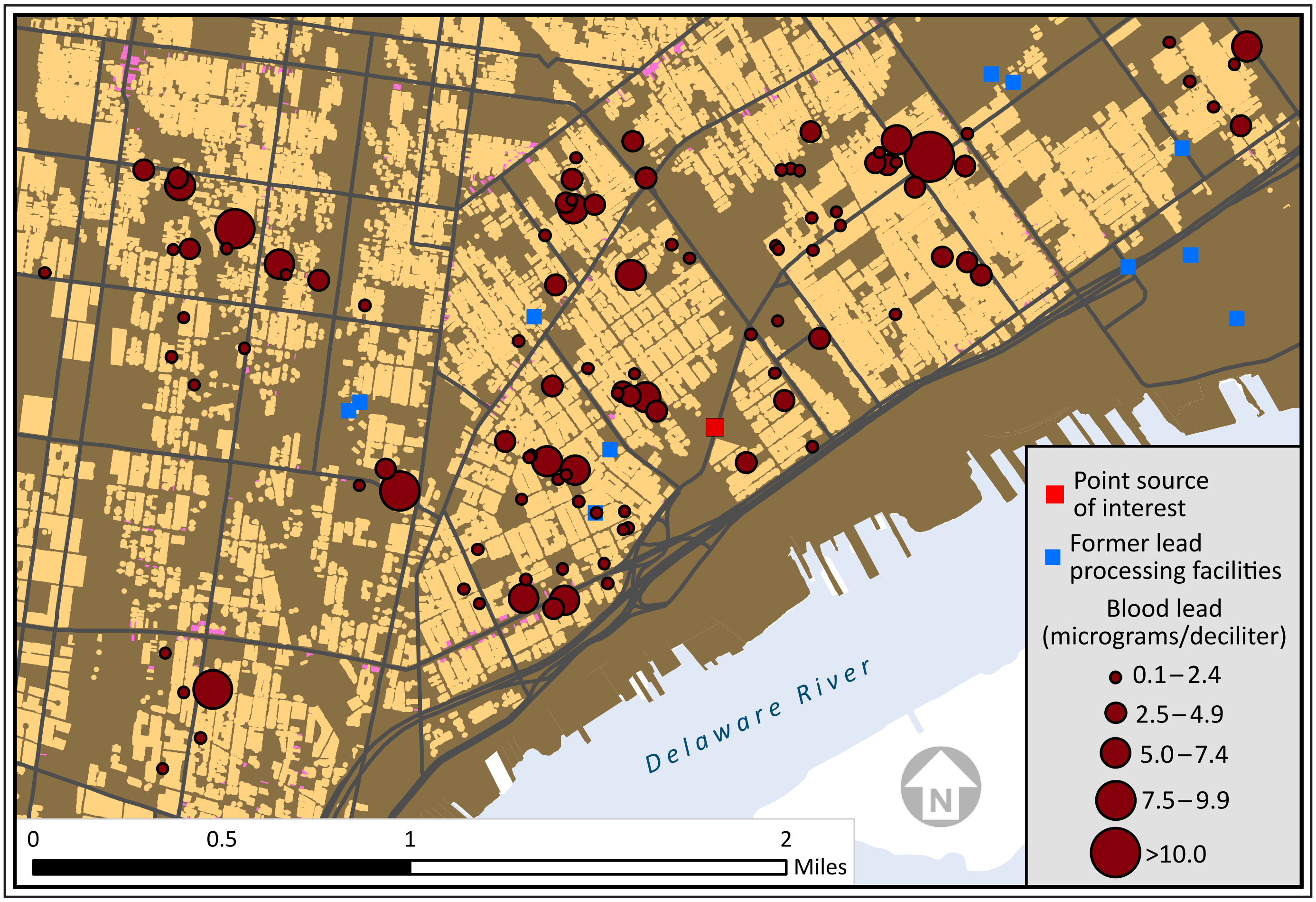
Figure 3: Households surveyed (N=119) and suspect lead-emitting historical facilities (N=12) in the study area, Philadelphia, 2014*



**Households surveyed are not shown in their true locations. The figure was created by offsetting each surveyed home in a random direction and a random distance up to 800 feet. This method retains the general pattern of the actual distribution, while preserving the confidentiality of study participants.*

Figure 3: Image showing the location of households located around the former John T. Lewis facility which participated in the study. A total of 119 households were surveyed. Most participating households are located within a mile radius around the former John T. Lewis facility.

Figure 4: Blood lead sampling results in the study area, Philadelphia, 2014 (N=104)*



**Households surveyed are not shown in their true locations. The figure was created by offsetting each surveyed home in a random direction and a random distance up to 800 feet. This method retains the general pattern of the actual distribution, while preserving the confidentiality of study participants.*

Figure 4: Image showing spatial distribution of children's blood lead levels in the study area including the 12 former lead emitting facilities. A total of 104 blood lead results are showing. The blood lead level results ranged from 0.1 to over 10 micrograms per deciliter (µg/dL). No spatial relationship between child blood lead sampling results and proximity to historic suspect lead-emitting facilities is observed.

Figure 5: Soil lead sampling results in the study area, Philadelphia, 2014 (N=70)

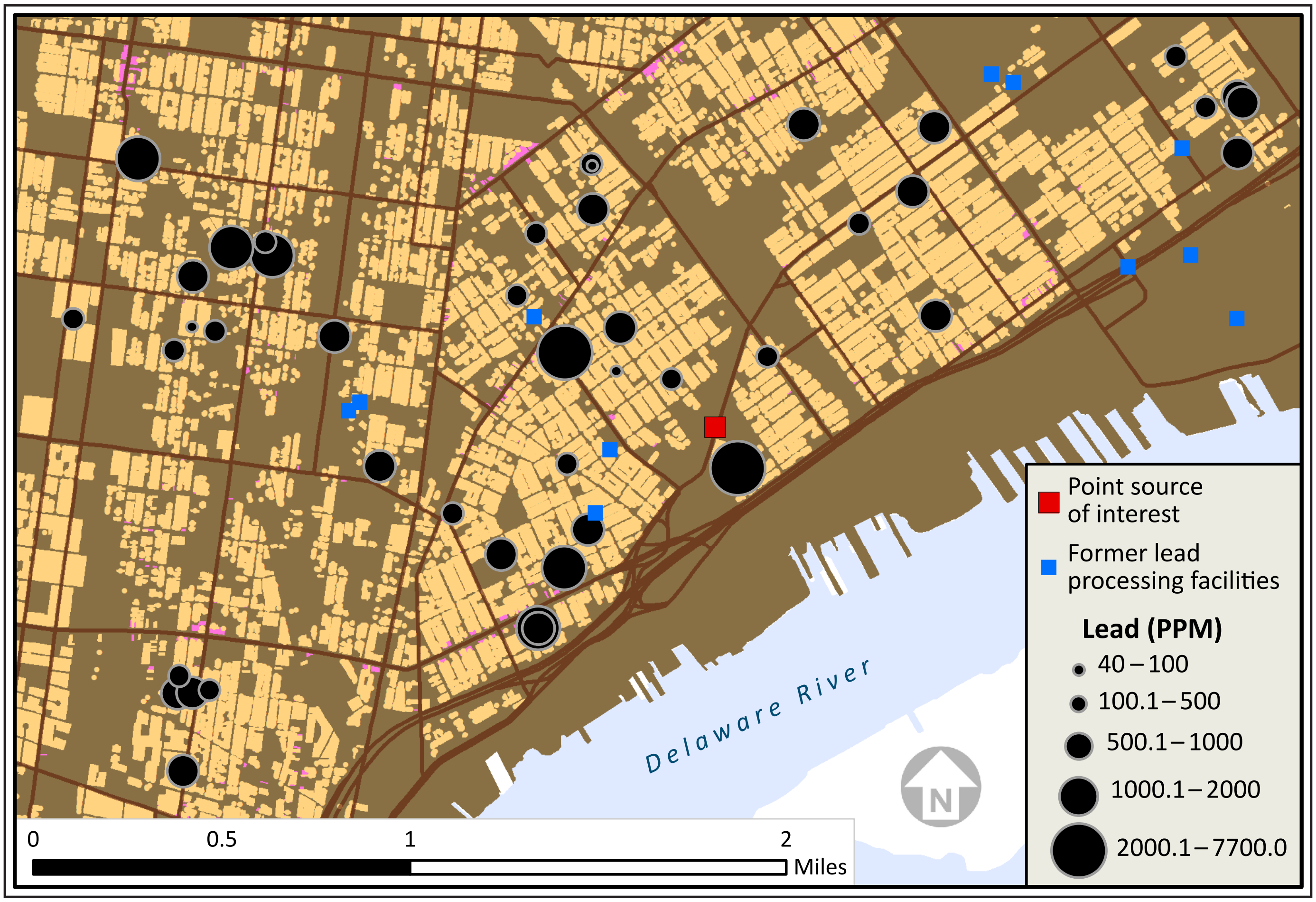


Figure 5: Image showing spatial distribution of soil lead results across the study area including the 12 former lead-emitting facilities. A total of 70 soil lead sample results are shown. Soil lead level results ranged from 40 to 7,700 parts per million (ppm). No spatial relationship between soil lead sample results and proximity to historic suspect lead-emitting facilities is observed.

Figure 6: Front door floor-dust lead sampling results in the study area, Philadelphia, 2014 (N=98)

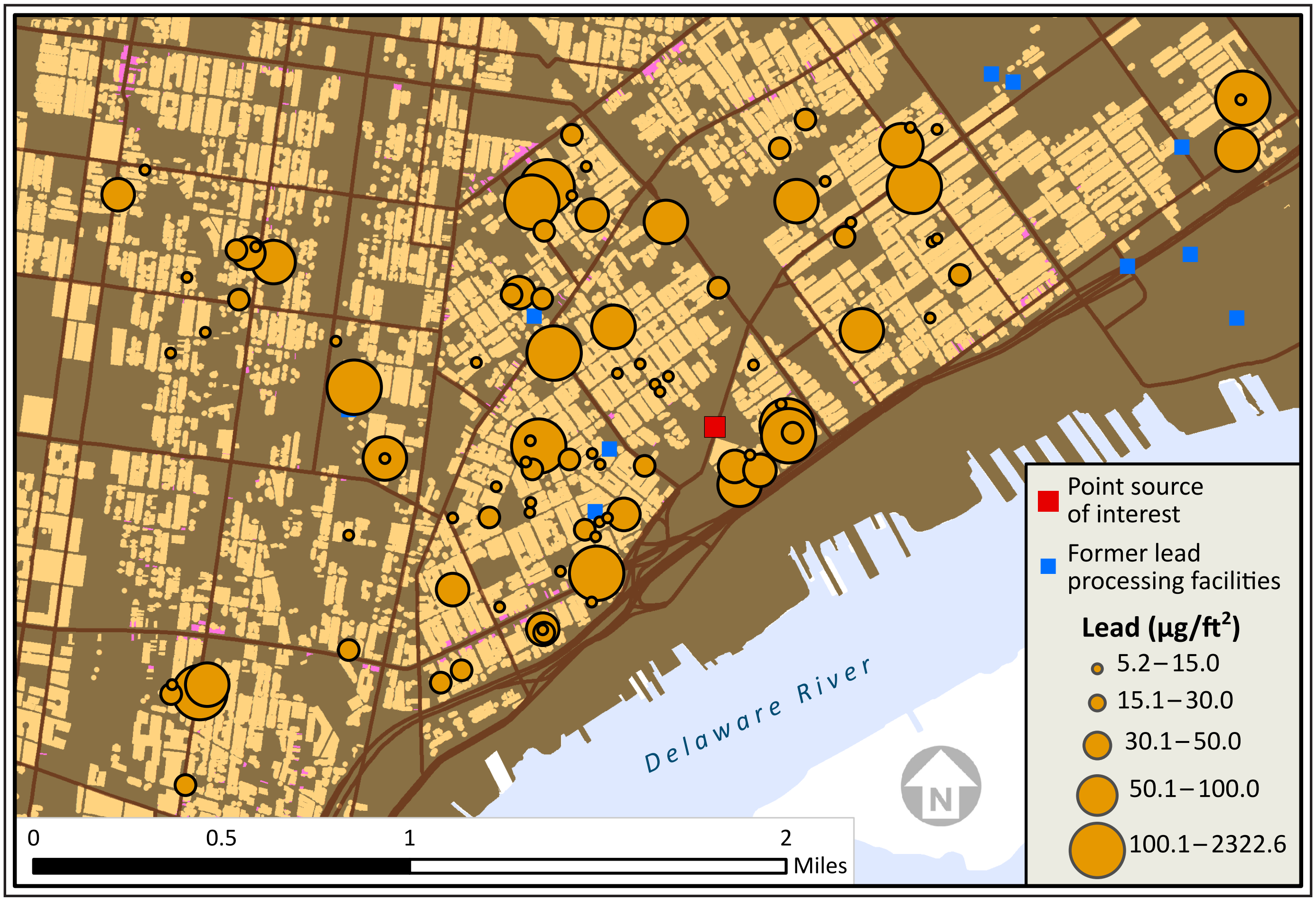


Figure 6: Image showing spatial distribution of front door floor-dust lead sampling results across study area including the 12 former lead-emitting facilities. A total of 98 front door floor-lead results are shown. The results ranged from 5.2 to 2,322.6 micrograms per square foot (µg/ft²). No spatial relationship between front door floor-dust lead and proximity to historic suspect lead-emitting facilities is observed.

Figure 7: Child play area floor-dust lead sampling results in the study area, Philadelphia, 2014 (N=71)

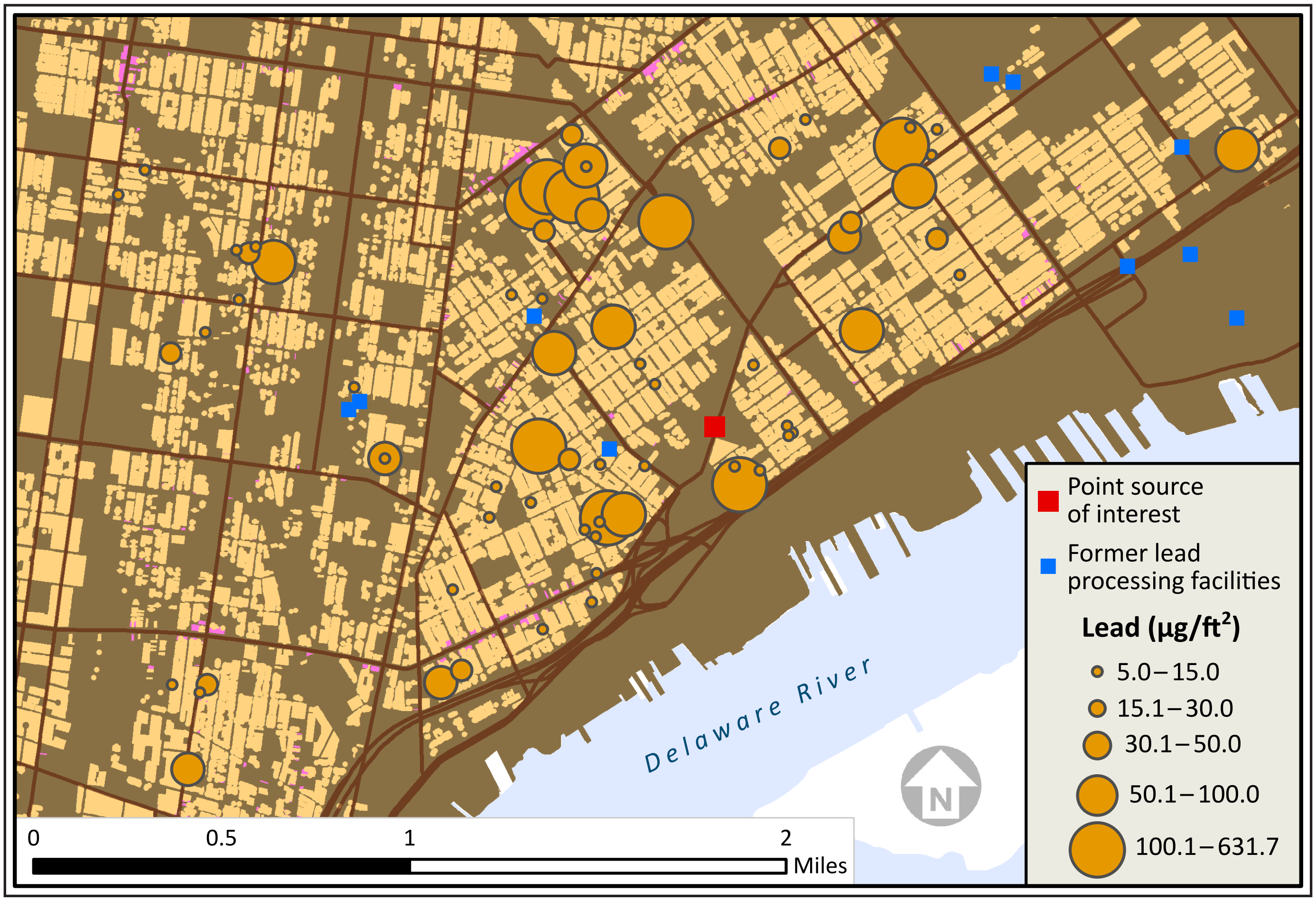


Figure 7: Image showing spatial distribution of floor-dust lead sampling results collected from child's play area. A total of 71 dust lead results from the front door are shown. Dust lead results range from 5.0 to 631 micrograms per square (µg/ft²). No spatial relationship between front floor dust-lead from child's playing area and proximity to historic suspect lead-emitting facilities is observed.

Figure 8: Window-dust lead sampling results in the study area, Philadelphia, 2014 (N=94)

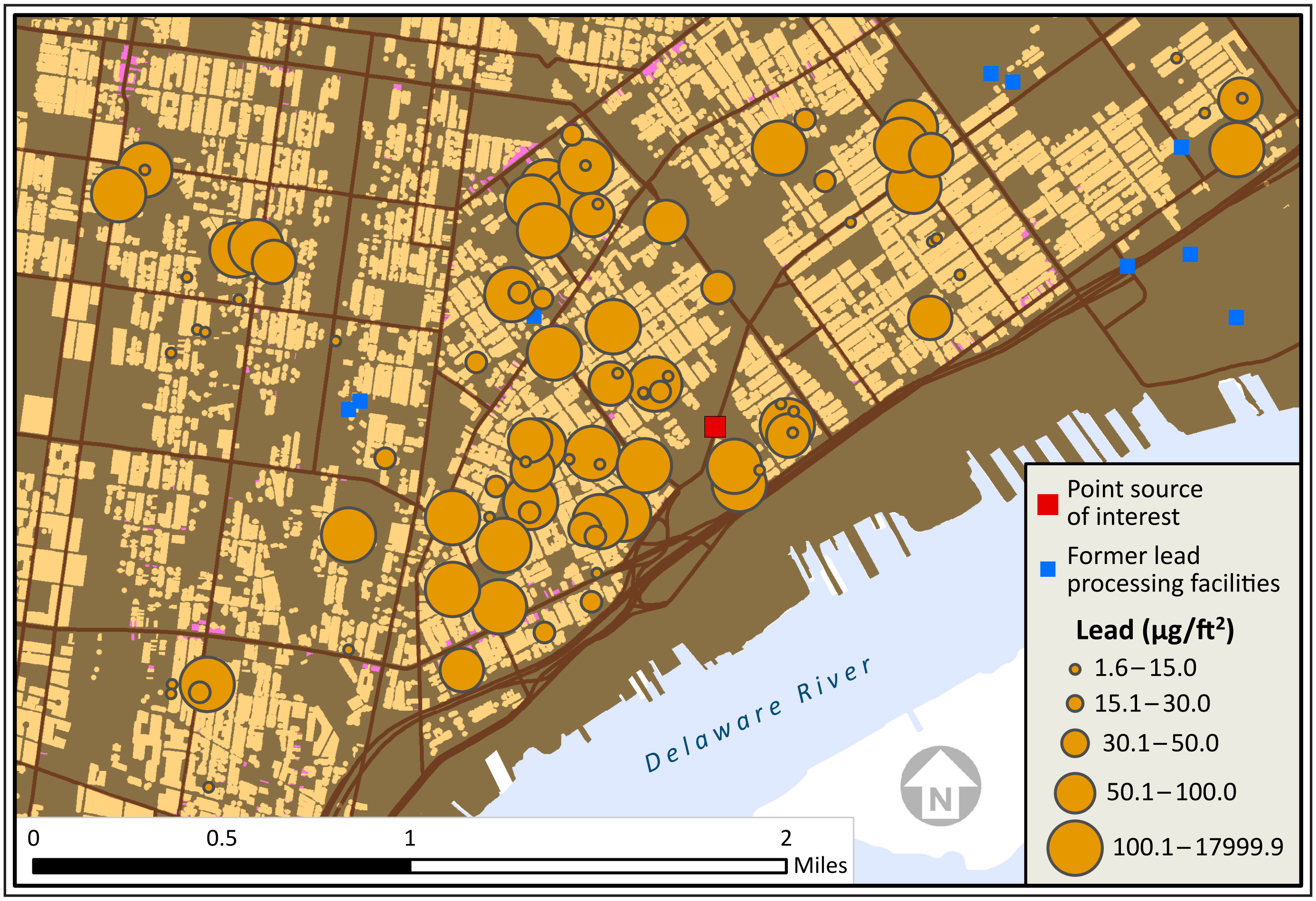


Figure 8: Image showing spatial distribution of dust-lead sampling results collected from windowsill in child's bedroom. A total of 94 dust lead sampling results are shown. Results range from 1.6 to 17.999 micrograms per square foot (µg/ft²). No spatial relationship between dust-lead from child's window sill and proximity to historic suspect lead-emitting facilities is observed.

Figure 9: SoilSHOP lead sampling results in the study area, Philadelphia, 2012–2016 (N=292)

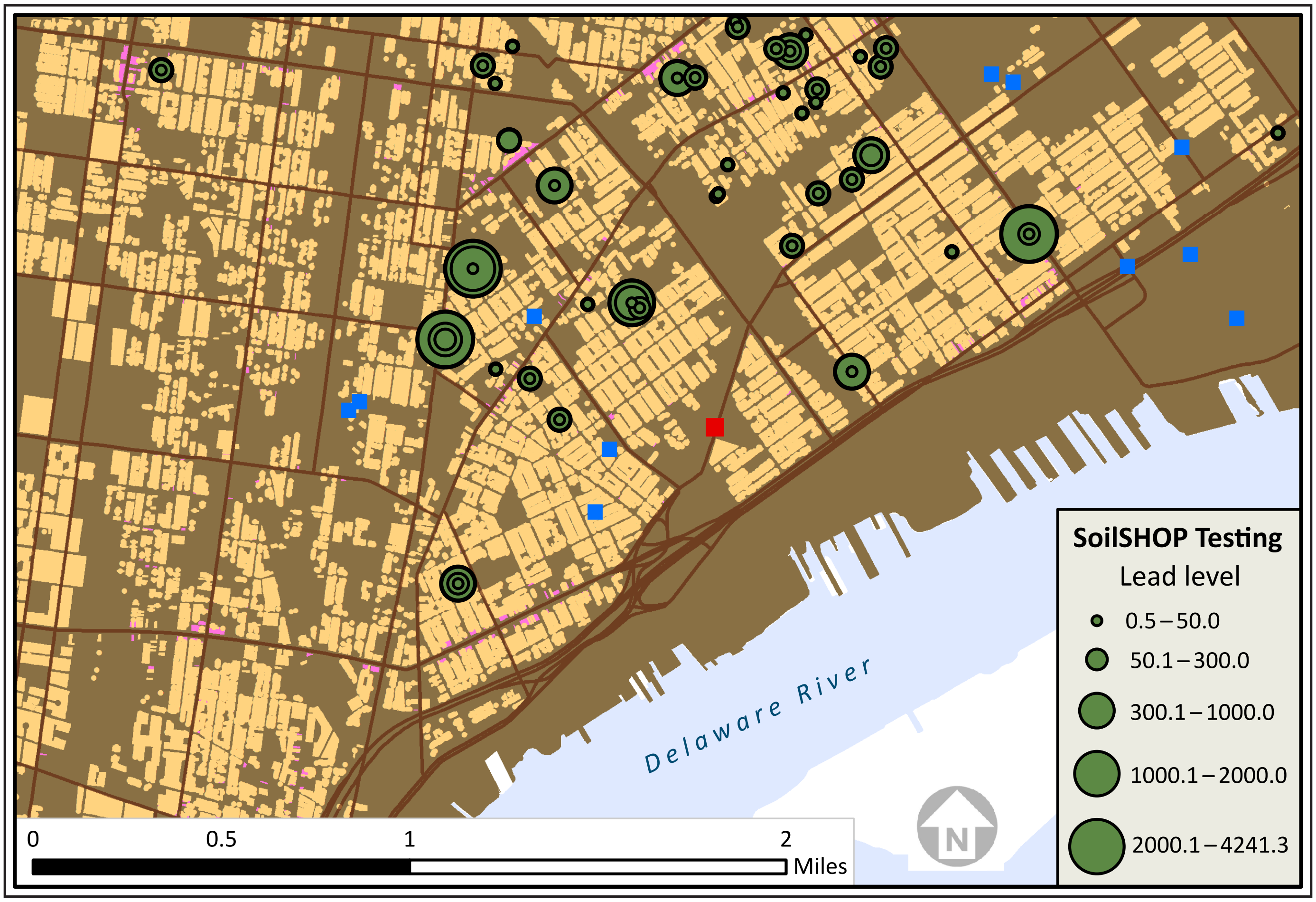


Figure 9: Image showing distribution of soil lead results collected from soilSHOP events. A total of 292 soil lead samples are shown. Soil lead results range from 0.5 to 4,241 parts per million (ppm). No spatial relations between soil lead results and proximity to historic suspect lead-emitting facilities is observed

Appendix A

Sample size calculation:

Population size (for finite population correction factor or fpc) (N): 700

Hypothesized % frequency of outcome factor in the population (p): 4% ± 2.6

95% confidence interval as % of 100 (absolute ± %)(d): 2.6%

Design effect (DEFF) (for random sample = 1): 1

Sample size was calculated using the following equation:

Sample size $n = [DEFF*Np(1-p)]/[(d2/Z21-\alpha/2*(N-1)+p*(1-p)]$

$n = [1*700*0.04(1-0.04)]/[(1.96*(700-1)+0.04*(1-0.04)] = 167$

Appendix B

Blood Collection Procedure:

- Apply a tourniquet to the upper arm. Select a vein for venipuncture. Placing the tourniquet as high up on the upper arm will help the vein become more evident.
- After a vein has been selected, remove the tourniquet and cleanse the antecubital space (inside bend of the elbow) of the forearm with an alcohol pad. Allow to air dry or pat dry with a sterile gauze pad. Place the tourniquet on the arm as before and locate the selected vein. Insert the butterfly needle and secure it in place with an adhesive bandage. If phlebotomy fails after two attempts, discontinue further attempts and record this on the form.
- Collect one EDTA purple top tube. Allow all tubes to fill to the stated volume on the tube. The EDTA purple top tube will fill to the black line on the paper label and should be mixed well after collection or placed in a tube rocker. Label each tube with a participant ID.
- After all tubes have filled to their stated capacity and the last tube has been removed from the needle holder, remove the needle in a swift motion and apply pressure with a gauze pad to the venipuncture site. Have the participant apply pressure over the gauze for approximately 5 minutes. Label each tube with the appropriate bar-coded label.
- After mixing well, label and place the EDTA tube in one of the storage boxes provided. Ensure tubes remain at 10–32 °C / 50–90 °F, and analyze them within 24 hours of collection. Do NOT store in a refrigerator.
- All excess blood collection materials (lancets, tubes, swabs, wipes, and gloves) will be collected in biohazard bags/bins and given to the Indonesia MOH for biohazard disposal.
- Quality Assurance:
  - » Blood specimens with visible clots shall be rejected as unsatisfactory for analysis.
  - » Venous specimens collected in EDTA tubes and are less than 50% of the recommended draw volume (i.e., <1.5 mL in a 5 mL tube designed to collect 3 mL blood) shall be rejected as unsatisfactory for analysis.