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Special Section:
Community Engaged Research to Action: Examples from GeoHealth

Community-Engaged Assessment of Soil Lead Contamination in Atlanta Urban Growing Spaces

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Key Points:

- We used community-engaged research to measure lead in urban agriculture spaces
- Community members were involved in the entire process from sampling to results
- Community-engaged science built trust and led to the designation of the site as Superfund and later to a National Priorities List

Supporting Information:

Supporting Information may be found in the online version of this article.

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Abstract

Urban agriculture is emerging as a method to improve food security and public health in cities across the United States. However, an increased risk of exposure to heavy metals and metalloids (HMM) exists through interaction with contaminated soil. Community-engaged research (CEnR) is one method that can promote the inclusion of all partners when studying exposures such as HMM in soil. Researchers and community gardeners co-designed this study to measure the concentrations of lead (Pb), using X-Ray Fluorescence (XRF) verified with Inductively Coupled Plasma-Mass Spectrometry (ICP-MS) in soils from 19 urban agricultural and residential sites in the Westside of Atlanta and three rural sites in Georgia. Seventeen other HMM were measured but not included in this study, because they did not pose risks to the community comparable to elevated Pb levels. Pb concentrations were compared to the Environmental Protection Agency (EPA)'s regional screening levels (RSLs) for residential soil and the University of Georgia (UGA) extension service's low-risk levels (LRLs) for agriculture. Soils from the majority of sites had levels below EPA RSLs for Pb, yet above the UGA LRL. However, soil Pb concentrations were three times higher than the EPA RSL on some sites that contained metal refining waste or slag. Our findings led to direct action by local and federal government agencies to initiate the cleanup of slag residue. Studies involving exposures to communities should engage those affected throughout the process for maximum impact.

Plain Language Summary

This study used community-engaged participatory research to explore lead contamination in Atlanta urban growing spaces under two different sets of screening levels, which had not previously been compared in agricultural settings. While most growing sites were below the EPA regional soil screening levels, many were above the University of Georgia extension's agriculture-specific recommendations levels. Strong relationships and communication between researchers, community gardeners, and regulatory organizations led to the discovery of contamination from metal refining waste and a subsequent Federal remediation effort. This study demonstrates the importance, impact, and need to work with community members on issues involving environmental pollution and justice.

1. Introduction

Health effects resulting from exposures to heavy metals and metalloids (HMM) are a globally recognized problem (Martin & Griswold, 2009; Tchounwou et al., 2012), yet these hazards still persist in many urban areas in the United States (US). The common HMM that pose threats to human health are lead (Pb), cadmium (Cd), chromium (Cr), and arsenic (As) (Järup, 2003), with Pb being one of the most harmful to human health and children's neurological development. Over the last 35 years, the Centers for Disease Control and Prevention (CDC) has been continuously lowering the reference value for blood Pb levels (BLLs) in children aged 0–6 years from 10 μg/dL to 5 μg/dL in 2012 and to the current 3.5 μg/dL set in 2021 (Centers for Disease Control, 2022). Still, approximately 86,000 children below 6 years of age were identified with BLLs above 5 μg/dL across the US in 2018 (Centers for Disease Control, 2022). In 2018, 2,333 children below 6 years of age in Georgia were identified with BLLs above 5 μg/dL. This number was derived from a screening rate of about 20%, thus it is likely that the true number is much greater than what is reported (Distler & Saikawa, 2020). Permanent neurologic damage and behavior disorders have been associated with low BLLs, prompting the CDC to state that there is no safe BLL for Pb (Bellinger & Needleman, 2003; Bellinger et al., 1992; Dietrich et al., 2001; Needleman et al., 2002).

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Many studies have shown an increased risk of exposure to HMM among youth in low-income families in urban areas (Filippelli & Laidlaw, 2010; Filippelli & Taylor, 2018; Filippelli et al., 2015; Pamuk et al., 1998), resulting in the estimated societal costs of billions of US dollars (Gould, 2009; Hanna-Attisha et al., 2016; Landrigan et al., 2002; Schwartz, 1994). An estimated $5,600 in medical and special educational services is incurred for each child with a BLL above 5 μg/dL inflicting a financial burden on families with children who meet the criterion and costing the US $50.9 billion annually in lost productivity (Hauptman et al., 2017).

Racial and class disparities in HMM exposures are substantial, with African-Americans and economically disadvantaged individuals bearing the greatest risks (Morrison et al., 2013; Muller et al., 2018; Wheeler & Brown, 2016). Emissions from industrial/power plants, mining, Pb-based paints, Pb-based gasoline, fertilizer, sewage sludge, pesticides, and atmospheric deposition can all lead to elevated soil HMM levels, as soils are the major sink of HMM in the environment (Khan et al., 2008; Wuana & Okieimen, 2011). Another source of HMM in soil can come from slag, the waste from metal refining (Król et al., 2020). Because these sources are often linked to poor and minority communities, exposure to HMM from soil is also an environmental justice issue (Clark et al., 2006).

Soil Pb has been linked to elevated BLLs in children (Mielke & Reagan, 1998; Zahran et al., 2013), and several pathways exist for exposure to soil Pb. The primary pathway is through soil dust which is consumed via ingestion or inhalation or through foods that hyperaccumulate HMM (Brown et al., 2016). Urban soils contaminated with HMM can be harmful to young children who often ingest soil incidentally by hand-to-mouth or object-to-mouth behavior or even deliberately (Kessler, 2013; Moya & Phillips, 2014). Urban agriculture in areas with HMM contamination poses risks of exposure to soil HMM (Kessler, 2013; Henry et al., 2015; Wortman & Lovell, 2013). Based on these observations, for Pb, the Environmental Protection Agency (EPA) has set a regional screening level (RSL) for residential soils at 400 ppm, while the University of Georgia (UGA) extension service has placed low-risk levels (LRLs) for agriculture at 75 ppm (EPA, 2022; Varlamoff et al., 2016). Although soil Pb contamination can pose high risks of Pb exposure, the awareness of this risk has been low (Balotin et al., 2020). We sought to understand the potential exposures to people consuming urban garden produce using a community science-based approach.

We designed the study in tandem with a community gardening group based in the Westside of Atlanta, a largely low-income, non-white neighborhood (City of Atlanta, 2020). To assess soil safety in the Westside, soil HMM levels were compared against two different existing screening levels. This study employed a community-engaged research (CEnR) method to assess soil HMM levels in urban areas. We called our approach “Community Science,” as opposed to “Citizen Science” to incorporate the voices of community members to be inclusive, as demonstrated in other organizations, such as the National Audubon Society (National Audubon Society, 2018). CEnR studies on HMM in urban soils are rare, despite the benefits this type of research can provide (Johnson et al., 2016). CEnR can be used to promote social justice, increase public knowledge of scientific concepts, and can lead to co-produced policy (Corburn, 2007; Dickinson et al., 2012; Jacobson & Rugeley, 2007).

The main goal of this study was to measure soil HMM levels and sources in a manner that engaged and benefited the community. We worked with community members not only to assess contamination levels, but also to raise awareness of potential HMM exposures through urban gardens. Community members were actively involved in every step of the study from study design, site selection, soil sample collection, and presenting results to funders. Results were reported back as the samples were analyzed and community members were also involved in the interpretation of results and communication.

2. Materials and Methods

2.1. Community Involvement

This project emphasized community engagement. The research team received input from Emory's Health and Exposome Research Center: Understanding Lifetime Exposures (HERCULES) Community Stakeholder Advisory Board (SAB) upon the inception of the project. The SAB provided feedback on how best to approach community members in an inclusive manner and the study design was modified repeatedly to directly involve and benefit the community. This included pairing with the director of the Historic Westside Gardens (HWG), our eventual community research partner. This research project was further developed with significant input from the HWG. We engaged HWG leadership on how we could design a project that would most benefit their members and the broader community.

HWG members were included in the sampling efforts described below, and HWG leaders trained HWG members to collect soil samples in the neighborhood. Workshops on sampling methods and research design were given to HWG members to prepare for this work. HWG members were also integral partners in discovering potential sources of exposure and helped disseminate results. Joint presentations were given at a SAB meeting and at a HERCULES center retreat to all researchers.

2.2. Site Descriptions and Soil Sampling

Community partners provided insight for site selection. Sites were chosen by community members due to their importance for current or future food production with some snowball (chain-referral) sampling with neighbors of initial sites and expanding based on acquaintances (Goodman, 1961). Two sites were added after a community partner discovered slag waste from metal refining. The discovery of slag pieces led to a community desire to understand sites specifically with slag visible on them. A conceptual site model outlining site history and layout (Eaker et al., 2011) was developed with input from site owners and gardeners for each site (Figure S1). Each site was divided into decision units (DU), or sections with potentially different levels of soil contamination due to site history (Interstate Technology & Regulatory Council, 2020).

Each site was sampled according to the Incremental Sampling Method (ISM), which uses a robust subsampling protocol for each DU (Interstate Technology & Regulatory Council, 2020). ISM consisted of first taking three composite samples of 30 subsamples from each DU. The subsamples were taken from random locations in all 30 equal area squares that made up the entire size of the DU. ISM has been shown to provide an accurate mean and 95% upper confidence level (UCL) with three replicates of composited samples if the sampling area is divided into a grid of a minimum 30 sections (Interstate Technology & Regulatory Council, 2020). Four community partners working for HWG were trained in the ISM protocol and took samples from sites where they lived or worked, which were some of the sites selected for the study.

Working together with community members, we collected 355 soil samples (Table 1) between July 2018 and May 2019 and measured the concentrations of Pb and 17 other HMM using X-Ray Fluorescence (XRF). Nineteen urban agricultural and residential sites in the Westside were examined along with three rural background sites in Georgia. Vacant lots and the backyards of residents in the area were chosen as urban sites due to the rise in community and home gardens. All residential site samples from the Westside of Atlanta were further classified as agricultural (actively growing produce) or residential (not actively growing produce) to assess the impact of plant growth on HMM concentrations. A sample was considered actively growing if there were plants intended for ingestion germinated in the soil at the time of sampling. Each of the 302 samples from growing sites was further categorized into raised bed (soil generally from another location added above the native soil and contained in a four-sided structure), mound bed (soil generally from another location added above the native soil but not contained on the sides), or bare soil to assess the effect of bedding practices on overall concentrations. Background sites were selected that were at least 30 miles away from the center of Atlanta and had no known industrial or other potential anthropogenic contaminations. A subset of XRF samples ($n = 37$) was analyzed by Inductively Coupled Plasma-Mass Spectrometry (ICP-MS) for soil concentration confirmation.

2.3. Soil and Slag Analysis

Each composite sample was oven-dried after removing visible debris and sieved to 100 μm filling a small plastic bag with at least 5 g needed for later digestions. Hazardous levels of Pb (>400 ppm) were found on some sites that contained metal refining waste or slag and thus 34 pieces of slag were additionally sampled for analysis. Slag was crushed via sledge hammer, subsampled randomly, and crushed to a fine powder with a mill before analysis. All soil and slag samples were first analyzed using the XRF. Each sample was measured a minimum of four times with the XRF and only samples with a mean relative standard deviation (RSD) of 35% or lower were used for analysis as per EPA methods (Adams, 2017).

Thirty-seven soil samples with Pb concentrations ranging from 200 to 1,000 ppm as measured by XRF were also analyzed using ICP-MS for specific HMM content and correlation with field measurements. Approximately 0.2 g of sieved soil samples were digested for 3 hr at 95°C in pre-cleaned 100 ml beakers covered with glass watch glasses using 10 mL of ultra-purity grade acid (Ultrix grade, Fisher) and 3 mL of ultra-pure hydrogen peroxide according to EPA Method 3050B (EPA, 1996). After the digestion was completed, the samples

Table 1
Number of Samples Analyzed by XRF for Each Site and Category by Site

Site name (coded)	Sample count
Rural Background 1	11
Rural Background 2	19
Rural Background 3	9
Residential 1	6
Residential 2	19
Residential 3	3
Residential 4	35
Residential 5	9
Residential 6	3
Residential 7	9
Residential 8	3
Residential 9	8
Residential 10	9
Residential 11	3
Urban agricultural 1	12
Urban agricultural 2	44
Urban agricultural 3	24
Urban agricultural 4	106
Urban agricultural 5	9
Slag 1	9
Slag 2	5

By category

Category	Sample count
Rural background	39
Total urban samples	302
Slag soil	14
Slag pieces	32
No bed	64[a]
Raised bed	92[a]
Mound bed	146[a]
Actively growing	127[a]
Not actively growing	175[a]

Note. Sample counts from all sites and for notable categories used in mean comparisons. Each sample refers to one aggregate sample of 30 subsamples from one decision unit (DU) from a site. Ideally, three samples are taken from each DU, but some samples were lost or contaminated.

[a] Counts from a subset of data that was only the urban samples.

were adjusted to a final volume of 10 mL and spiked with internal standards. Five mL of the sample solution were centrifuged at 4,000 rpm for 20 min. The supernatant was removed and stored in a cleaned sample tube for subsequent ICP-MS analysis. Prior to the ICP-MS analysis, the samples were diluted to a specific volume with 2% nitric acid (ultra-purity). The samples were quantified against a 7-point calibration curve. Analytical blank and quality control samples were prepared and quantified alongside the samples. NIST material (SRM2709a) was also prepared and included in the analytical run to ensure the accuracy of the calibration curve prepared. Background levels for HMM were subtracted from measured values to get final concentrations.

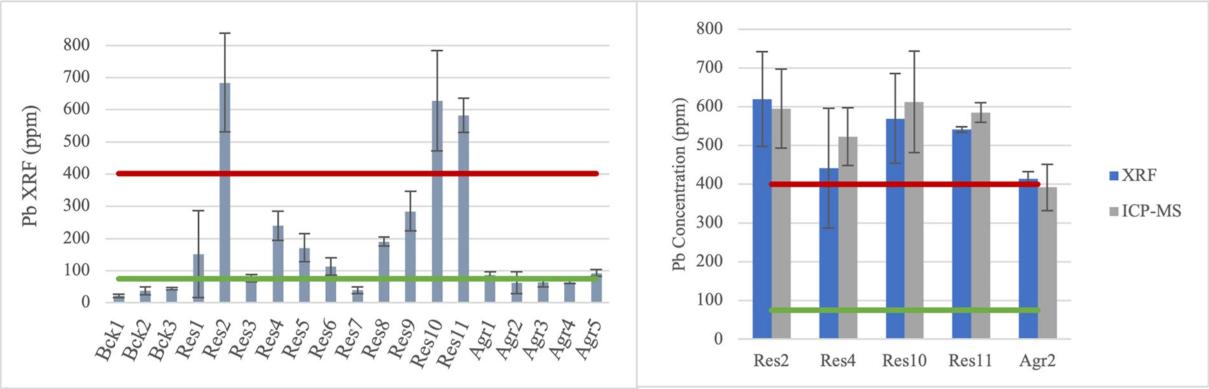

Figure 1. Mean 95% upper confidence levels (UCL) for lead (Pb) in rural background (Bck), residential (Res), and urban agricultural (Agr) sites is displayed in the graph on the left. The subset of samples analyzed by both X-ray fluorescence (XRF) and inductively coupled plasma mass spectrometry (ICP-MS) is displayed in the graph on the right. EPA regional screening levels (RSL) are denoted by red lines and UGA low risk levels (LRLs) are denoted in green. Error bars are 95% confidence intervals of the mean in the XRF graphs and one standard deviation of distributions in XRF/ICP-Ms graphs due to limited ICP-MS sample size.

2.4. Statistics

All statistics were carried out in Microsoft Excel and R version 3.5.1 (R Core Team, 2020). A 95% upper confidence limit (UCL) for all XRF data was calculated using the following formula:

$$\mathrm{UCL} = \mu + \mathrm{Tin}v(0.1, n - 1) * \left(\frac{\mathrm{SD}}{\sqrt{n}}\right)$$

where μ is the mean of all readings, Tin$v$ is the inverse of the Student's t-distribution, 0.1 is the 1-sided p-value for a 95% confidence interval, n is the number of XRF readings, and SD is the standard deviation of XRF readings. UCLs were used in place of means for all data analysis in order to compare with EPA RSLs. Overall UCLs were calculated for each site using the average of each sample UCL. All XRF data were quantified using a five-point standard curve. UCL was used because this is the statistical metric the EPA uses for site assessment, and we wanted to match that process as closely as possible.

Significant differences between site locations or traits (between growing and non-growing spaces as well as between raised beds, mound beds, and bare soil sites) were determined using a Student's t-test with an α value of 0.05. Each site was compared via t-test to two different screening levels; the EPA residential soil RSLs and UGA LRLs. All project partners, including those from the community, were informed of XRF protocols and statistical analyses before discussing results in order to be transparent about how data were acquired and analyzed. Correlations between XRF and ICP-MS data were calculated using Pearson product-moment correlation.

3. Results

3.1. Pb Under Different Screening Levels by Site

Three of the 11 urban residential sites had mean UCLs of Pb that were above the EPA RSL of 400 ppm (Figure 1). Although none of the five urban agricultural site UCLs were above the Pb RSL, all except for one residential site and two of five urban agricultural sites were above the UGA LRL of 75 ppm Pb in agricultural soil. On the contrary, all three rural background sites had UCLs lower than UGA LRLs for Pb. Based on comparisons to the two screening levels, there are large discrepancies in the number of sites deemed as low risk for Pb. 75% of all samples exceeded the UGA LRL for soil Pb, and 19% of the samples exceeded the EPA RSL.

Overall UCLs were lower for Pb at sites with crops growing compared to those with no food crop cultivated. The overall UCL was 94.4 ppm (95% CI = 74.9, 113.9) at growing sites and 205.5 ppm (95% CI = 167.9, 243.1) without anything growing, both of which are above the UGA LRL but below the EPA RSL.

3.2. Effects of Growing Practice on Lead Concentrations

Overall Pb UCLs were significantly lower in raised beds (104 ppm (95% CI = 83.9, 125.8)) and mound beds (66.2 ppm (95% CI = 59.8, 72.7)), compared to bare soil (308.7 ppm (95% CI = 247.1, 370.3)) throughout urban

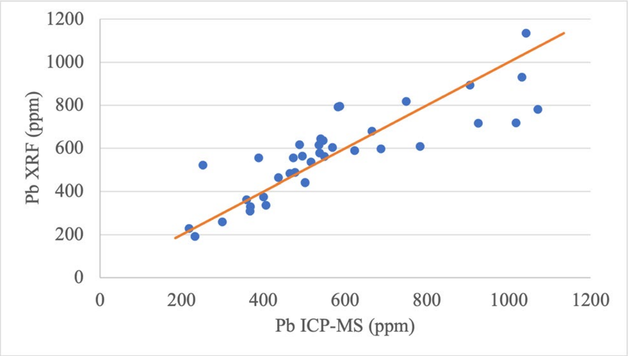

Figure 2. Correlation between X-ray fluorescence (XRF) and inductively coupled plasma mass spectrometry (ICP-MS) measurements of Pb ($R^2 = 0.72$). Orange line represents an ideal 1:1 relationship between XRF and ICP-MS measurements and blue dots represent observed concentrations from both instruments. All concentrations are in ppm.

agricultural soil samples. Mound beds had overall UCLs lower than UGA LRLs and were lower than raised bed UCLs, most likely because they were in larger gardens or farms farther from buildings and paint. Raised beds and bare soil were below EPA RSLs, but above UGA LRLs.

3.3. XRF and ICP-MS Correlations

We selected 37 soil samples that measured high in Pb (>200 ppm) via XRF to be measured for all HMM by ICP-MS as well. Soil Pb measured by XRF and ICP-MS for these subset samples are shown in Figure 1. XRF and ICP-MS measurements of Pb correlated well ($r = 0.85$ and mean percent bias of 4.4% higher for XRF, Figure 2), supporting previous findings (Clark et al., 1999).

3.4. Impact of Slag on Heavy Metal Concentrations

Based on XRF data, we found Pb concentrations to be significantly higher in samples from sites containing metal refining slag (Figure 3). Two lots with slag were discovered by a community partner near other measured urban sites and were assessed with assistance from members of EPA Region 4 and the Georgia Department of Public Health. Pb concentrations were much higher in soils at the slag sites (1,383 ppm (95% CI = 557.3, 2,209)) compared to other urban samples (158.8 ppm (95% CI = 134.8, 182.8)), and were even higher than the crushed and sieved fragments of slag (1,290 ppm (95% CI = 813.0, 1,769)). The overall UCLs of Pb in these soils with slag were three times higher than the EPA RSL and 18 times higher than the UGA LRL.

4. Discussion and Conclusions

Our results highlight the discovery of high level Pb contamination in urban soils through a community-engaged approach. Slag in the Westside of Atlanta has increased Pb concentrations in residential soil, and we found three sites that had UCLs far exceeding the EPA RSL (Figure 1). These findings have prompted the EPA to designate Westside Atlanta as a Superfund site and engage in a cleanup process (United States Environmental Protection Agency Superfund Site, 2021). More community-engaged screening opportunities should be explored in regard to systemic soil HMM contamination, because these elevated concentrations may be widespread in other low-income and minority neighborhoods (McClintock, 2012). Due to the risk that HMM presents, especially in underserved communities, a better method to assess multiple toxicant risks in urban growing spaces needs to be explored.

Our research also has important policy implications. EPA has soil screening levels for various HMM, including Pb, but they are usually different from those recommended for growing produce such as the UGA LRL. The UGA LRL takes into account the increased exposure pathways agricultural activities can lead to, compared to residential soil contamination. However, multiple classifications of contaminated soil can be confusing and could hamper the promotion and implementation of urban agriculture for those who would benefit the most (Cutts et al., 2017). With more awareness on the existence of potential soil contamination, as well as strategies to mitigate these problems in urban agriculture settings, health risks can be reduced and urban space used more beneficially in these communities. While it is the opinion of the authors of this paper that the advantages of urban agriculture may outweigh the risks of contaminated soil (Brown et al., 2016), the majority of studies using EPA RSLs are more likely to conclude lower estimates for exposure risk. More studies to determine soil HMM concentrations and to assess existing exposure risk, especially in growing areas would help bridge this knowledge gap.

This study did indicate some growing practices that could help reduce soil HMM concentrations to below EPA RSLs or UGA LRLs. Raised and mound

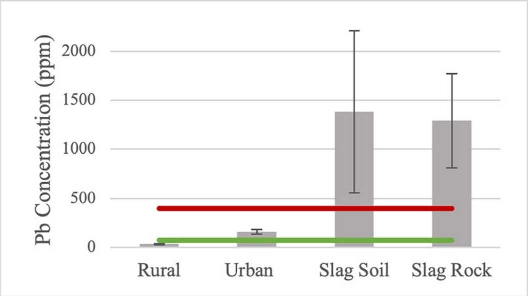

Figure 3. X-ray fluorescence (XRF) mean upper confidence limits (UCLs) of lead (Pb) between rural background, urban samples, slag site soils, and slag pieces. All results are in parts per million (ppm). 95% confidence intervals are presented as error bars. EPA regional screening levels (RSLs) are denoted by a red line and UGA low risk levels (LRLs) are denoted in green.

beds had lower Pb concentrations than native soil. Our results may have been due to cleaner imported soil with higher organic matter happening to be used more in mound beds than in raised beds (Laidlaw et al., 2018). Policies that allocate funding for urban agricultural programs in areas at high risk for soil Pb contamination should focus on providing materials and external sources of soil for beds. For example, one community partner in our study lowered the concentration of Pb in one of their beds from above the EPA RSL to below the UGA LRL by putting new soil into the bed and planting new flowers. Adding new topsoil to a raised or mound bed is one potential low-cost method to reduce Pb exposure on a large scale in urban areas endemic with contamination, as long as added soil is low in HMM concentrations (Laidlaw et al., 2017). Using gloves while gardening, washing hands afterward, and removing dust and soil from clothes before coming into the house are other ways to reduce exposure while gardening (Kessler, 2013). These low-cost remediation techniques should also continue to be promoted through avenues such as extension offices (Varlamoff et al., 2016) or outreach programs. Lower-cost remediation techniques can reduce exposure through dilution and decreased contact with contaminated soil while preventing the need for extensive regulations or disruptive remediation such as soil removal, which could reduce urban agriculture growth (Kessler, 2013). These programs could include crediting programs to help growers market crops from clean soil locations.

This study also found XRF to be well-correlated with ICP-MS methods for Pb with concentrations greater than 200 ppm, indicating the XRF's potential as a low-cost, high throughput soil testing tool for elevated levels of Pb. These results indicate the efficacy of XRF as a low-cost, fast-throughput alternative to laboratory methods for Pb, as found by previous research comparing the two methods (Weindorf et al., 2011; Wu et al., 2012). Future studies assessing soil with XRF should account for bias by analyzing at minimum a subset of samples using highly sensitive and specific methods such as ICP-MS. Often, studies do not validate XRF results with more accurate laboratory methods (Carr et al., 2008; Higueras et al., 2012; Krishna & Govil, 2007), unless the intent of the research is a methods comparison. Using this comparison in the present study allowed for increased confidence in the field results, which was critical given the potential impact the elevated levels could have on the community.

Despite our community-based approach and the identification of significant Pb sources, our study has some limitations. The major limitation of this study is the small sample size. Small sample size in some of our analyses (e.g., $n = 6$ for raised bed samples analyzed via ICP-MS) prevented strong conclusions, and more samples should be analyzed in future studies. However, given the corroborating evidence found by the EPA throughout the neighborhood following the conclusion of our study, we have high confidence that soil is an important risk factor for childhood Pb exposure in West Atlanta.

As soon as slag with a dangerous level of Pb concentrations was found in the neighborhood, the team went searching in the neighborhood for other areas with visible slag. While we were unable to discover the historical source of the slag given how long it had likely been in the lots, we were able to engage state and national environmental health agencies with the community. The research team found several properties with slag in the neighborhood and worked closely with the EPA and Georgia Department of Public Health to share results. The EPA then activated a robust investigation leading to clean-up efforts. The EPA started the investigation for approximately 60 lots in the neighborhood, which was soon expanded to 368 lots in December 2019 (Miller, 2019). The boundary then doubled to 1,087 lots by February 2020. Scientists and HWG leaders together held a door-to-door campaign to raise awareness within the neighborhood and to increase the number of residents providing access of their lots to be sampled by the EPA. In May 2021, the investigation area doubled again to 2097 lots, and it has been designated a Superfund site and was listed on the National Priorities List in March 2022. The discovery of and subsequent EPA-funded cleanup might not have been possible without the community focus of this study.

Working with and for the community from grant writing through results and action allowed this project to make a tangible impact that might not have otherwise been possible. Strong communication at every step of the process by the Emory team and various community organizations greatly increased the impact of this study. By focusing on social inclusion, carrying out a project in an underserved neighborhood, and making information available throughout the project (Meenar & Hoover, 2012), a unique partnership was formed to tackle this environmental justice issue. The discovery of the slag could potentially lead to a longitudinal study, which is needed to assess the racial and income disparities in exposure to environmental dumping and pollution more effectively (Mitchell et al., 2011). Future studies on soil contamination in urban spaces should focus on engaging communities as much as possible to expand the scientific and policy implications.

The conclusions drawn in this manuscript were based on soil measurements but were greatly enhanced by community engagement. The information gathered has been used to initiate outreach activities regarding soil testing, best practices for gardening in potentially-contaminated soil, and resources on remediation for those with contaminated soil. Projects regarding phytoremediation of soil, testing of Pb blood lead levels, and spatial analysis to determine potential sources of HMM have been initiated due to this research partnership, partly due to the request from community partners. Results were presented by community partners and researchers together in academic and public settings after project completion, including the project's funding agency's annual retreat. These provided community partners the opportunity to share their findings with the broader community and create dialogs for future research and outreach.

This study showed that community engagement throughout improved the scientific, behavioral, and policy implications. Our study exemplifies an important case to use community science whenever possible. The results of this study can further help inform the EPA and CDC policies regarding HMM for urban agriculture and in residential areas as well as future CEnR projects in other disciplines.

Conflict of Interest

The authors declare no conflicts of interest relevant to this study.

Data Availability Statement

All the data are available in an open-access public repository in Mendeley Data (https://data.mendeley.com/datasets/wm7p38cnwf/2).

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References

Adams, G. (2017). “Superfund X-ray fluorescence field operations guide”.

Balotin, L., Distler, S., Williams, A., Peters, S. J., Hunter, C. M., Theal, C., et al. (2020). Atlanta residents' knowledge regarding heavy metal exposures and remediation in urban agriculture. *International Journal of Environmental Research and Public Health*, *17*(6), 2069. https://doi.org/10.3390/ijerph17062069

Bellinger, D. C., & Needleman, H. L. (2003). Intellectual impairment and blood lead levels [1] (multiple letters). *New England Journal of Medicine*, *349*, 500–502.

Bellinger, D. C., Stiles, K. M., & Needleman, H. L. (1992). Low-level lead exposure, intelligence and academic achievement: A long-term follow-up study. *Pediatrics*, *90*(6), 855–861. https://doi.org/10.1542/peds.90.6.855

Brown, S. L., Chaney, R. L., & Hettiarachchi, G. M. (2016). Lead in urban soils: A real or perceived concern for urban agriculture? *Journal of Environmental Quality*, *45*(1), 26–36. https://doi.org/10.2134/jeq2015.07.0376

Carr, R., Zhang, C., Moles, N., & Harder, M. (2008). Identification and mapping of heavy metal pollution in soils of a sports ground in Galway City, Ireland, using a portable XRF analyzer and GIS. *Environmental Geochemistry and Health*, *30*, 45–52. https://doi.org/10.1007/s10653-007-9106-0

Centers for Disease Control. (2022). *Childhood lead poisoning prevention program. National surveillance data*. U.S. Department of Health and Human Services. CDC.

City of Atlanta (2020). *Westside promise zone. City Atlanta*. Economic Development.

Clark, H. F., Brabander, D. J., & Erdil, R. M. (2006). Sources, sinks, and exposure pathways of lead in urban garden soil. *Journal of Environmental Quality*, *35*(6), 2066–2074. https://doi.org/10.2134/jeq2005.0464

Clark, S., Menrath, W., Chen, M., Roda, S., & Succop, P. (1999). Use of a field portable X-ray fluorescence analyzer to determine the concentration of lead and other metals in soil samples. *Annals of Agricultural and Environmental Medicine*, *6*, 27–32.

Corburn, J. (2007). Community knowledge in environmental health science: Co-producing policy expertise. *Environmental Science & Policy*, *10*(2), 150–161. https://doi.org/10.1016/j.envsci.2006.09.004

Cutts, B. B., London, J. K., Meiners, S., Schwarz, K., & Cadenasso, M. L. (2017). Moving dirt: Soil, lead, and the dynamic spatial politics of urban gardening (p. 9839).

Dickinson, J. L., Shirk, J., Bonter, D., Bonney, R., Crain, R. L., Martin, J., et al. (2012). The current state of citizen science as a tool for ecological research and public engagement. *Frontiers in Ecology and the Environment*, *10*(6), 291–297. https://doi.org/10.1890/110236

Dietrich, K. N., Douglas, R. M., Succop, P. A., Berger, O. G., & Bornschein, R. L. (2001). Early exposure to lead and juvenile delinquency. *Neurotoxicology and Teratology*, *23*(6), 511–518. https://doi.org/10.1016/S0892-0362(01)00184-2

Distler, S., & Saikawa, E. (2020). A new screening index to better target low-level lead exposure in Atlanta, Georgia. *Scientific Reports*, *10*(1), 18087. https://doi.org/10.1038/s41598-020-75000-0

Eaker, J., Lux, R., McEvoy, K., DeRose, N., Britton, R., Lazar, B., et al. (2011). *Technical Guidance for Preparation and Submission of a Conceptual Site Model* (Vol. 47).

EPA. (1996). Method 3050B—Acid digestion of sediments, sludges, and soils. (p. 12).

EPA. (2022). Regional screening levels (RSLs)—User's guide. https://www.epa.gov/risk/regional-screening-levels-rsls-users-guide

Filippelli, G. M., & Laidlaw, M. A. S. (2010). The elephant in the playground: Confronting lead-contaminated soils as an important source of lead burdens to urban populations. *Perspectives in Biology and Medicine*, *53*(1), 31–45. https://doi.org/10.1353/pbm.0.0136

Filippelli, G. M., Risch, M., Laidlaw, M. S. A., Nichols, D. E., & Crewe, J. (2015). Geochemical legacies and the future health of cities: A tale of two neurotoxins in urban soils. *Elementa*, *3*, 1–19. https://doi.org/10.12952/journal.elementa.000059

Filippelli, G. M., & Taylor, M. P. (2018). Addressing pollution-related global environmental health burdens. *GeoHealth*, *2*(1), 2–5. https://doi.org/10.1002/2017gh000119

Goodman, L. A. (1961). Snowball sampling. *The Annals of Mathematical Statistics*, *32*(1), 148–170. https://doi.org/10.1214/aoms/1177705148

Gould, E. (2009). Childhood lead poisoning: Conservative estimates of the social and economic benefits of lead hazard control. *Environmental Health Perspectives*, *117*(7), 1162–1167. https://doi.org/10.1289/ehp.0800408

Hanna-Attisha, M., LaChance, J., Sadler, R. C., & Schnepp, A. C. (2016). Elevated blood lead levels in children associated with the flint drinking water crisis: A spatial analysis of risk and public health response. *American Journal of Public Health*, *106*(2), 283–290. https://doi.org/10.2105/ajph.2015.303003

Hauptman, M., Bruccoleri, R., & Woolf, A. D. (2017). An update on childhood lead poisoning. *Clinical Pediatric Emergency Medicine*, *18*(3), 181–192. https://doi.org/10.1016/j.cpem.2017.07.010

Henry, H., Naujokas, M. F., Attanayake, C., Basta, N. T., Cheng, Z., Hettiarachchi, G. M., et al. (2015). Bioavailability-based in situ remediation to meet future lead (Pb) standards in urban soils and gardens. *Environmental Science & Technology*, *49*(15), 8948–8958. https://doi.org/10.1021/acs.est.5b01693

Higueras, P., Oyarzun, R., Iraizoz, J., Lorenzo, S., Esbri, J., & Martinez-Coronado, A. (2012). Low-cost geochemical surveys for environmental studies in developing countries: Testing a field portable XRF instrument under quasi-realistic conditions. *Journal of Geochemical Exploration*, *113*, 3–12. https://doi.org/10.1016/j.gexplo.2011.02.005

Interstate Technology & Regulatory Council. (2020). Incremental sampling methodology update.

ITCR. (2012). Technical and regulatory guidance incremental sampling methodology. *Incremental Sampling Methodology*, *191*.

Jacobson, M., & Rugeley, C. (2007). Community-based participatory research: Group work for social justice and community change. *Social Work with Groups*, *30*(4), 21–39. https://doi.org/10.1300/j009v30n04_03

Järup, L. (2003). Hazards of heavy metal contamination. *British Medical Bulletin*, *68*(1), 167–182. https://doi.org/10.1093/bmb/ldg032

Johnson, S., Cardona, D., Davis, J., Gramling, B., Hamilton, C., Hoffmann, R., et al. (2016). Using community-based participatory research to explore backyard gardening practices and soil lead concentrations in urban neighborhoods. *Progress in Community Health Partnerships: Research, Education, and Action*, *10*(1), 9–17. https://doi.org/10.1353/cpr.2016.0006

Kessler, R. (2013). Urban gardening: Managing the risks of contaminated soil. *Environmental Health Perspectives*, *121*(11–12), 326–333. https://doi.org/10.1289/ehp.121-a326

Khan, S., Cao, Q., Zheng, Y. M., Huang, Y. Z., & Zhu, Y. G. (2008). Health risks of heavy metals in contaminated soils and food crops irrigated with wastewater in Beijing, China. *Environmental Pollution*, *152*(3), 686–692. https://doi.org/10.1016/j.envpol.2007.06.056

Krishna, A. K., & Govil, P. K. (2007). Soil contamination due to heavy metals from an industrial area of Surat, Gujarat, Western India. *Environmental Monitoring and Assessment*, *124*(1–3), 263–275. https://doi.org/10.1007/s10661-006-9224-7

Król, A., Mizerna, K., & Bożym, M. (2020). An assessment of pH-dependent release and mobility of heavy metals from metallurgical slag. *Journal of Hazardous Materials*, *384*, 121502. https://doi.org/10.1016/j.jhazmat.2019.121502

Laidlaw, M., Alankarage, D. H., Reichman, S. M., Taylor, M. P., & Ball, A. S. (2018). Assessment of soil metal concentrations in residential and community vegetable gardens in Melbourne, Australia Chemosphere Assessment of soil metal concentrations in residential and community vegetable gardens in Melbourne, Australia. *Chemosphere*, *199*, 303–311. https://doi.org/10.1016/j.chemosphere.2018.02.044

Laidlaw, M. A. S., Filippelli, G. M., Brown, S., Paz-Ferreiro, J., Reichman, S. M., Netherway, P., et al. (2017). Applied Geochemistry Case studies and evidence-based approaches to addressing urban soil lead contamination. *Applied Geochemistry*, *83*, 14–30. https://doi.org/10.1016/j.apgeochem.2017.02.015

Landrigan, P. J., Schechter, C. B., Lipton, J. M., Fahs, M. C., & Schwartz, J. (2002). Environmental pollutants and disease in American children: Estimates of morbidity, mortality, and costs for lead poisoning, asthma, cancer, and developmental disabilities. *Environmental Health Perspectives*, *110*(7), 721–728. https://doi.org/10.1289/ehp.02110721

Martin, S., & Griswold, W. (2009). Human health effects of heavy metals. (pp. 1–6).

McClintock, N. (2012). Assessing soil lead contamination at multiple scales in Oakland, California: Implications for urban agriculture and environmental justice. *Applied Geography*, *35*(1–2), 460–473. https://doi.org/10.1016/j.apgeog.2012.10.001

Meenar, M., & Hoover, B. (2012). Community food security via urban agriculture: Understanding people, place, economy, and accessibility from a food justice perspective. *Journal of Agriculture, Food Systems, and Community Development*, *3*, 143–160. https://doi.org/10.5304/jafscd.2012.031.013

Mielke, H. W., & Reagan, P. L. (1998). Soil is an important pathway of human lead exposure. *Environmental Health Perspectives*, *106*, 217–229. https://doi.org/10.2307/3433922

Miller, A. (2019). Danger in the ground: Lead contaminates westside Atlanta neighborhood. *The Atlanta Journal-Constitution*.

Mitchell, G., Norman, P., Mohai, P., & Saha, R. (2011). Which came first, people or pollution ? A review of theory and evidence from longitudinal environmental justice studies which came fi rst, people or pollution? A review of theory and evidence from longitudinal environmental justice studies.

Morrison, D., Lin, Q., Wiehe, S., Liu, G., Rosenman, M., Fuller, T., et al. (2013). Spatial relationships between lead sources and children's blood lead levels in the urban center of Indianapolis (USA). *Environmental Geochemistry and Health*, *35*(2), 171–183. https://doi.org/10.1007/s10653-012-9474-y

Moya, J., & Phillips, L. (2014). A review of soil and dust ingestion studies for children. *Journal of Exposure Science and Environmental Epidemiology*, *24*(6), 545–554. https://doi.org/10.1038/jes.2014.17

Muller, C., Sampson, R. J., & Winter, A. S. (2018). Environmental inequality: The social causes and consequences of lead exposure. *Annual Review of Sociology*, *44*(1), 263–282. https://doi.org/10.1146/annurev-soc-073117-041222

National Audubon Society. (2018). Why we're changing from “citizen science” to “community science”.

Needleman, H. L., McFarland, C., Ness, R. B., Fienberg, S. E., & Tobin, M. J. (2002). Bone lead levels in adjudicated delinquents: A case control study. *Neurotoxicology and Teratology*, *24*(6), 711–717. https://doi.org/10.1016/S0892-0362(02)00269-6

NIST. SRM 2709a—San Joaquin soil baseline trace element concentrations.

Pamuk, E., Makuc, D., Heck, K., Reuben, C., & Lochner, K. (1998). *Socioeconomic status and health chartbook. Health*. Center for Diseases Control and Prevention.

R Core Team, R. (2020). A language and environment for statistical computing. *R Foundation for Statistical Computing*.

Schwartz, J. (1994). Societal benefits of reducing lead exposure. *Environmental Research*, *66*(1), 105–124. https://doi.org/10.1006/enrs.1994.1048

Tchounwou, P. B., Yedjou, C. G., Patlolla, A. K., & Sutton, D. J. (2012). *Heavy metals toxicity and the environment Paul*. Springer Basel. https://doi.org/10.1007/978-3-7643-8338-1

United States Environmental Protection Agency, & Superfund Site. (2021). Westside lead Atlanta.

Varlamoff, S., Lessl, J., Sonon, L., Bauske, E., & Urban, G. (2016). Assessing soils for contamination.

Weindorf, D. C., Zhu, Y., Chakraborty, S., Bakr, N., & Huang, B. (2011). Use of portable X-ray fluorescence spectrometry for environmental quality assessment of peri-urban agriculture. *Environmental Monitoring and Assessment*, *184*(1), 217–227. https://doi.org/10.1007/s10661-011-1961-6

Wheeler, W., & Brown, M. J. (2016). Blood lead levels in children aged <5 Years - United States, 2007-2013. *Morbidity and Mortality Weekly Report*, *63*(55), 66–72. https://doi.org/10.15585/mmwr.mm6355a6

Wortman, S. E., & Lovell, S. T. (2013). Environmental challenges threatening the growth of urban agriculture in the United States. *Journal of Environmental Quality*, *42*(5), 1283–1294. https://doi.org/10.2134/jeq2013.01.0031

Wu, C., Tsai, H. T., Yang, K. H., & Wen, J. C. (2012). How reliable is X-ray fluorescence (XRF) measurement for different metals in soil contamination. *Environmental Forensics*, *13*(2), 110–121. https://doi.org/10.1080/15275922.2012.676603

Wuana, R. A., & Okieimen, F. E. (2011). Heavy metals in contaminated soils: A review of sources, chemistry, risks and best available strategies for remediation. *ISRN Ecology*, *1–20*.

Zahran, S., Laidlaw, M. A. S., McElmurry, S. P., Filippelli, G. M., & Taylor, M. (2013). Linking source and effect: Resuspended soil lead, air lead, and children's blood lead levels in Detroit, Michigan. *Environmental Science & Technology*, *47*(6), 2839–2845. https://doi.org/10.1021/es303854c