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The Association of Soil Lead and Children's Blood Lead Levels in Georgia

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Bachelor of Science, Georgia Gwinnett College, 2020

Advisor: Dr. Eri Saikawa, Ph.D.

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Abstract

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The persistent use of lead (Pb) for industrial, commercial, and residential purposes throughout the 19th and 20th centuries has inflicted public risks of exposure and health implications. Despite the regulations on Pb additives, Pb continues to persist in soils, affecting both urban and rural environments. Natural soil Pb levels range between 50 – 400 parts per million (ppm) and children under the age of six are most vulnerable to soil Pb due to their proximity to the ground and frequent hand-to-mouth activities. In this study, we used a community science methodology to collect soil Pb concentrations by organizing soil Screening, Health, Outreach, and Partnership (soilSHOP) events and sought to determine an association between mean soil Pb, mean children's blood Pb levels, median household income, and race on a ZIP code scale in the state of Georgia. Additionally, we intended on raising awareness of soil Pb contamination and empower community members with knowledge of soil Pb. Soil samples from the 2020-2022 soilSHOP were analyzed and mapped along with children's blood Pb level, median household income, and race data. The most significant relationships with mean children's blood Pb levels were mean soil Pb and 2021 median household income. Results also indicated that 13 (5.4%) of the 238 soilSHOP samples collected from within 42 GA ZIP codes exceeded the regional screening level by the Environmental Protection Agency (EPA) for Pb of 400 ppm. However, in terms of the average soil Pb concentrations, 30148 (mean = 2657.5 ppm) and 30315 (mean = 423.46 ppm) were the only ZIP codes that exceeded that level. On the other hand, 14 ZIP codes in Georgia, all outside of the metro Atlanta area, had mean children's blood Pb levels exceeding the CDC threshold of 3.5 μg/dL. There is, therefore, potentially a vast number of children that have blood Pb levels exceeding the threshold. These results indicate that averaging the data on a ZIP code scale does not provide an accurate representation of environmental data and more soilSHOPs should be promoted outside of city limits where the mean blood Pb levels exceed the threshold.

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Background and Introduction

Throughout the 19th and 20th centuries, lead (Pb) was used as a key additive in many products due to its malleability and corrosive resistance. Pb was used in the Roman era in items such as face powders, condiments, weapons, wine, etc. and eventually made way into the U.S. through mining and smelting (Lewis, 1985). By the 20th century, the U.S. became the world's leading producers and consumers of refined Pb and introduced Pb additives to gasoline and paint (Lewis, 1985). Eventually, the persistent use of Pb for industrial, commercial, and residential purposes became recognized as an issue and inflicted public risks of exposure and the health implications associated with it (O'Shea et al., 2021 and Li et al, 2020). Today, Pb has been phased out of many products in the U.S., however, it persists in many urban environments from old paint, dust, and soil sources (Dietrich et al., 2022). According to the Environmental Protection Agency, the natural soil Pb levels range between 50 and 400 parts per million (ppm) (US EPA, 2015). As food insecurity increases, urban gardens are becoming more popular and prone to soil Pb contamination. Urban gardeners typically lack full awareness of soil Pb and fail to recognize the determinants affecting their soils (Taylor et al, 2021).

Soils are a sink and source of Pb-dust for food, water, toys, Pb-based paint, etc., which increases the risk of exposure to many children living in urban areas (Mielke et al., 2007). According to Fillippelli et al. (2018), soil-Pb contamination is most detrimental to children and most Pb exposure is from soil. Soil Pb can be easily tracked into homes and accumulate with dust. Due to children's proximity to surface dust and frequent hand-to-mouth activities, they can absorb up to ten times more Pb than adults (James, H. M. et al., 1985; Ziegler, E et al., 1978; Alexander, F. W et al., 1974). Pb-contaminated house dust was reported as the primary source of variation in children's blood Pb while exterior sources of Pb were found to significantly increase children's blood Pb levels and the probability of those levels exceeding 10 μg/dL (Zahran et. al, 2011). Pb can enter the body through the inhalation and ingestion of soil, dust, as well as water, contaminated plant and animal products (Tebby et al., 2022). Once inside of the body, Pb primarily binds to hemoglobin and is easily distributed throughout the bloodstream (Bertram et al., 2022). As long-term storage, Pb deposits in the bones in significant amounts equating a large source of internalized Pb (Tebby et al., 2022).

There is no safe level of Pb, and, the U.S. Centers for Disease Control (CDC) recently changed the threshold of blood Pb value from 5 μg/dL to 3.5 μg/dL (*CDC updates blood lead reference value, 2022).* 2.5% of the children in the U.S. between the ages of 1 and 5 years of age have blood Pb levels at or above 3.5 μg/dL (*CDC updates blood lead reference value, 2022*). Even at low levels, Pb has been associated with neurological issues such as attention deficit hyperactivity disorder (ADHD), impulsivity, cognitive deficits, IQ decrements, and neuromotor changes (ATSDR, 2019; Caito & Aschner, 2015). Low Pb-levels have been linked with more severe cases connected to immunological and endocrine effects and cardiovascular disease, a major cause of adult mortality in the U.S (Advisory Committee on Childhood Lead Poisoning Prevention, 2012; Lanphear et al., 2018). More specifically for children, the early childhood effects of Pb exposure can vary from neurodevelopment issues (levels as low as 50 μg/L) to death (Chowdhury et al., 2021 and Bertram et al., 2022).

There is a disproportionate effect of soil Pb contamination on minority children living in low- and middle-income areas (Chowdhury et al., 2021). Past studies in the U.S. have found positive relations to Pb contamination and demographic factors. For example, black children have higher elevated blood Pb levels than any other race (O'Shea et al. 2021). In cities such as Chicago, Illinois, and Flint, Michigan, many children in impoverished African American communities have experienced high levels of Pb poisoning (Balotin et al, 2020). In a study by Mielke (2007), African Americans and impoverished populations lived in the most contaminated areas of the city and were affected more by Pb due to their skin pigment. From a physiological standpoint, black children are more prone to having higher concentrations of serum vitamin D, which increases the gastrointestinal absorption of Pb (Mielke et al, 2007). To make matters worse, low-income communities are generally limited in the awareness of soil contaminant risks, partially due to a lack of educational resources (Balotin et al, 2020). To promote environmental justice, efforts have been put into place to improve food insecurity in hopes of supplying secure and healthy sources of produce to less fortunate communities (Balotin et al, 2020).

Previous studies have revolved around heavy metal and metalloid (HMM) contamination in the Atlanta region, which has been home to historic industrial sites such as the Atlantic Steel Mill (Balotin et al, 2020). In Atlanta's Westside neighborhood, Pb contamination exceeding the Environmental Protection Agency (EPA)'s residential screening level was detected in addition to the discovery of a metal by-product known as slag (Balotin et al, 2020). Due to these findings, Balotin et al. (2020) looked to understand the community's knowledge of Pb and the importance of educational awareness.

Soil Screening, Health, Outreach and Partnership (SoilSHOP) events can be used to increase community and educational awareness. Specifically, they supply screening analysis of chemical elements in soils, while striving to meet community-specific health education and outreach needs in relation to soil contamination (*Soil Screening Information Guide, 2019*). O'Shea et al. (2021) took on a similar approach in their study where community soil screening and health education events took place to promote awareness and actions to reduce Pb exposure in Philadelphia. The purpose of that approach was to determine if home gardeners and children were exposed to high soil Pb levels in the yards (O'Shea et al., 2021). Spatial relationships between soil Pb, elevated blood Pb, and demographic factors were observed, and the strongest correlations were found between elevated blood Pb and the following demographic factors: owner-occupied properties, minority population, black population, and children in poverty (O'Shea et al., 2021).

Another common method in many studies is the use of Geographic Information Systems (GIS). GIS has been used to highlight spatial trends involving children's ages, older homes, former industrial sites, blood Pb concentrations, and soil Pb concentrations (Distler and Saikawa, 2020; Filippelli et al, 2018; Mielke et al, 2007; O'Shea et al, 2021; Tebby et al, 2022; Zahran et al, 2011). Distler and Saikawa (2020) used 20 years of data from the Department of Public Health (DPH) and the U.S. Census Bureau to develop a priority screening index to assess the most prone areas for blood-Pb testing on a map. A cluster of high priority tracts in west Atlanta were found to include the historically black neighborhoods of English Avenue and Vine City, which became a Superfund site due to the dumping of slag. In addition to these neighborhood's high poverty and unemployment rates, they were also identified as high-risk tract areas due to the housing age and the low income level. In this study, soil samples from the community soilSHOP events were analyzed and mapped using GIS to determine an association between mean children's blood Pb levels, mean soil Pb levels, median household income, and race in Georgia Zone Improvement Plan (ZIP) codes. We also intended on raising awareness of soil Pb contamination and empower community members with knowledge of soil Pb.

Materials and Methods

Soil Samples

Between 2018 and 2022, three in-person and two virtual soilSHOPs were held. The in-person soilSHOPs were managed by Saikawa Lab under Emory University and Historic Westside Gardens (Saikawa et al., 2023). The in-person soilSHOPs took place at the Historic Westside Gardens (HWG) community and South DeKalb community center. The soilSHOPs targeted residents in historically Black neighborhoods, such as Vine City and English Avenue (Saikawa et al., 2023). For the in-person soilSHOPs, flyers that contained soil sampling instructions were distributed to promote the events. For the virtual soilSHOP events, soil sampling instructions were posted on the Saikawa Lab's website and participants were provided with the options to mail collected samples to the lab or drop them off at one of the designated soilSHOP locations. In addition to collecting soil samples, each participant completed a survey that requested general information about the sample locations, applied gardening methods, and sampling sites conditions. The surveys were not analyzed in this study, but the ZIP codes provided in the surveys were used and displayed in data, as a reference location of where samples were collected.

The soilSHOP events were held both in-person and virtually to conduct soil screenings and to promote awareness on how to prevent Pb exposure. The virtual soilSHOPs were put into place due to social distance protocols to help accommodate participants during the COVID-19 pandemic. These community events gave participants the opportunity to collect up to two soil samples and have them analyzed for Pb. Participants were instructed to collect, air-dry, and place each sample in a Ziploc bag where they were directly analyzed by a Thermo Scientific handheld X-ray fluorescence (XRF) spectrometer analyzer (*Niton™ XL3T goldd+ XRF Analyzer*). The soil samples were measured in parts per million (ppm) and the final readings for each sample were calculated by running each sample through the XRF at a minimum of four times and determining the average of the four readings.

Children's Blood Pb Level

A total of 186,132 blood Pb levels (μg/dL) of children under the age of six were retrieved from the Georgia DPH between the years of 2020 and 2021. The data was requested at the ZIP code level and contained 94,484 blood Pb level results for the year 2020 and 91,648 children's blood

Pb level (μg/dL) results for the year 2021. In addition to children's blood Pb levels and age, the data set included children's sex, race and whether they had Medicaid. For the purposes of this study, the residential ZIP codes, ages, and races of children were the only factors used. The data also included codes for race and result interpretation. Each of the numbers under the "race" and "result" interpretation categories represented a description of each child and their blood Pb level (μg/dL) results. The race data was converted into percentages using the Interactive Data Language (IDL).

Median Household Income

The 2021 median household income data in the American Community Survey (ACS) did not cover all median household incomes in the Georgia ZIP codes. For this reason, the SimplyAnalytics tool was used to calculate an estimate of median household income by ZIP code from the U.S. Census Bureau. These calculated estimates were based on a simple linear regression model from the previous five years of ACS data. The data for 2021 estimated median household income contained a total sum of 735 Georgia ZIP codes however, the relevant data for all the variables were only provided for 688 Georgia ZIP codes.

Statistical Analysis

Descriptive statistics for soil Pb (ppm) and children's blood Pb per ZIP code were created in Microsoft Excel to summarize the data (**Table 1**). To assess relationships between the independent variables (soil Pb levels, 2021 estimated household income, and race) and the dependent variable (Children's blood Pb levels), correlation analyses and multilinear regression models were created using Microsoft Excel. Two correlation models were created to assess variable relationships. The first correlation analysis included all variables in the study. Prior to this analysis, a table based on the ZIP codes used in the soilSHOP data was created. The mean blood Pb level (μg/dL), 2021 estimated household income, and race data were reduced to align with the ZIP codes used in the soilSHOP data (Smaller sample size) **(Table 2a).** To create the second correlation table, the same steps for creating the first model were applied. In Table 2b, the mean soil Pb level data was excluded from the model to assess the variables at a larger sample size. This table was based on the ZIP codes used in the estimated median household income data. A multilinear regression model was created in Microsoft Excel to show the effects between the independent and dependent variables. When creating the table for this model, all variables were included with the exception of the "White" race.

Mapping

All maps were created using Arc GIS Pro Version 2.9.0. The geographic boundaries used in each of the maps included the United States, the state of Georgia, 2021 ZIP codes, and the 2021 official city boundary. Shapefiles for the United States, Georgia, and 2021 ZIP codes were retrieved from the U.S. Census bureau's TIGER/Line Shapefiles Web interface (U.S. Census Bureau, 2021). The 2021 official city boundary shapefile was retrieved from the Department of City Planning GIS (Department of City Planning GIS, 2021). The maps created displayed the mean soil-Pb levels from the 2020 – 2022 soilSHOP data, 2020-2021 children's blood Pb levels in Georgia, 2021 estimated median household income in Georgia, and the percentage of children who were the following races in the year 2021 – American Indian/Alaska Native, Asian, Black/African American, Native Hawaiian/Other Pacific Islander, White, Multiracial, Other, and Unknown.

To create the map for the mean soil-Pb levels (ppm) per ZIP code, the individual soil Pb levels (ppm) from the 2020 and 2022 soilSHOP were merged into one table. The mean soil-Pb levels (ppm) of each ZIP code was calculated by taking the average of the total number of soils Pb levels (ppm) within each ZIP code. The calculated soil Pb level (ppm) averages were then uploaded into Arc GIS pro. In Arc GIS pro, the join and clipping tool were used to create a layer of the data and the symbology feature was used to make the map more visually appealing with the gradual color scheme **(Figure 1).** The same techniques and features were applied to create the maps for 2021 children's blood Pb levels (μg/dL) **(Figure 2),** 2021 estimated median household income **(Figure 3),** and 2021 race **(Figure 4)** (For percentage of race map, the dot symbology was used). The Georgia Plane West projection was then applied to all maps.

Results

Soil Pb samples

238 soil samples within 42 ZIP codes were obtained through the soilSHOP events between the years 2020 and 2022. The descriptive statistics for soil Pb levels per ZIP code are summarized in **Table 1a.** The sample size per ZIP code was relatively small, but we were able to collect many samples for some of the ZIP codes. The most samples were collected from ZIP code 30314 (n = 56) which includes the location of English avenue and Vine City neighborhoods. 13 (5.4%) In the following ZIP codes, we found soilSHOP samples exceeding the regional EPA Pb screening level of 400 ppm: 30148 (5168 ppm), 30307 (659 ppm), 30307 (504 ppm), 30307 (1342 ppm), 30310 (545.60 ppm), 30314 (1192 ppm), 30315 (1363 ppm), 30315 (969 ppm), 30316 (694.20 ppm), 30318 (638.10 ppm), 30318 (533 ppm), 30344 (557.80 ppm). In terms of the average soil Pb concentrations, two ZIP codes exceeded the 400 ppm level: 30148 (mean = 2657.50 ppm) and 30315 (mean = 423.46 ppm).

The correlations amongst all variables in the study were analyzed **(Table 2a)**. The mean soil Pb level indicated the strongest positive correlations for the percentage of "other" race (Correlation coefficient = 0.403) and "white" race (Correlation coefficient = 0.333) and the strongest negative correlation for the percentage of "Unknown" race (Correlation coefficient = -0.265). Unexpectantly, mean soil Pb levels (μg/dL) were negatively correlated with "Black/African American" race

(Correlation coefficient = -0.179) and mean children's blood Pb (μg/dL) (Correlation Coefficient = - 0.077).

The multilinear regression model was created to show the effects of the mean soil Pb, 2021 median household income, and races (American Indian/Alaska Native, Asian, Black/African American, Native Hawaiian/Other Pacific Islander, White, Multiracial, Other, and Unknown) on children's blood Pb levels (μg/dL). The regression model presented an R-square of 0.46. In this model, the only variables significant at the 99th percent confidence level was the percentage of "Black/African American" race (p value = 0.002) with a coefficient of - 0.0140, percentage of "Other" race (p value = 0.009) with a coefficient of - 0.02, and the percentage of "Unknown" race (p value = 0.0004) with a coefficient of - 0.02. The mean soil Pb (p value = 0.097) and 2021 estimated household income (p-value = 0.517) did not express statistical significance on mean children's blood Pb levels (μg/dL) (**Table 3a**.).

Table 1a

Descriptive Statistic for Soil Pb Levels (ppm) from 2020-2022 SoilSHOP (* indicates exceeding soil Pb levels of 400 ppm)

ZIP	MEAN (ppm)	SAMPLE #	MAX (ppm)	MIN (ppm)
30008	46.00	2	62.00	30.00
30022	7.70	1	7.70	7.70
30030	42.75	18	277.80	5.00
30032	50.77	3	104.80	18.40
30033	28.96	8	41.00	11.80
30038	37.50	2	41.00	34.00
30045	22.00	1	22.00	22.00
30060	20.60	1	20.60	20.60
30062	15.83	3	19.00	10.00
30067	17.40	5	28.00	12.00
30071	6.50	2	13.00	13.00
30075	18.00	1	18.00	18.00
30080	7.00	2	14.00	14.00
30096	9.60	1	9.60	9.60
30097	14.00	1	14.00	14.00
30102	13.00	1	13.00	13.00
30114	15.50	2	18.00	13.00
30135	10.80	1	10.80	10.80
30148*	2657.50	2	5168.00*	147.00
30253	10.40	1	10.40	10.40
30274	39.60	1	39.60	39.60
30281	17.00	1	17.00	17.00
30306	13.23	4	52.90	52.90
30307	320.93	11	1342.00*	34.00
30309	7.05	2	7.70	6.40
30310	105.13	28	545.60*	18.00
30311	91.93	6	298.00	15.80
30312	131.15	2	147.10	115.20
30314	163.15	56	1337.00*	15.00
30315*	423.46	7	1363.00*	70.40
30316	190.81	10	694.20*	28.40
30317	35.30	10	78.20	20.70
30318	174.54	18	638.10*	30.30
30319	47.50	2	61.00	34.00
30322	22.61	10	40.00	9.00
30331	249.60	1	249.60	249.60
30338	8.35	11	18.20	5.70
30339	20.95	2	22.10	19.80
30344	118.30	13	557.80*	29.20
31601	109.00	1	109.00	109.00
31602	13.95	2	17.10	10.80
31625	2.60	5	7.00	6.00

Table 1b

Descriptive Statistic of Mean Children's Blood Pb Levels Exceeding 3.5 µg/dL

#	ZIP Code	Blood Pb levels (µg/dL)	Soil Pb levels (ppm)	Median Household Income (USD)	Highest % Race	American Indian Alaska Native	Asian	Black or African American	Native Hawaiin or Other Pacific Islander	White	Multiracial	Other	Unknown
1	30747	5.6	N/A	36693.56	White	0	0	8.33	0	66.67	0	5.56	19.44
2	30821	7.16	N/A	52796.19	Black	0	0	66.67	0	33.33	0	0	0
3	30828	3.52	N/A	34871.33	Black	0	0	52.94	0	11.76	0	11.76	23.53
4	30808	3.9	N/A	44880.58	White	0	0	18.18	0	50	0	13.64	18.18
5	30805	3.96	N/A	39847.07	White	0	0	23.53	0	70.59	0	0	5.88
6	30833	3.6	N/A	35447.08	Black	0	0	62.26	0	32.08	0	0	5.66
7	30904	3.59	N/A	34273.20	Black	0.52	0.52	54.69	0	21.35	0	3.65	19.27
8	30426	4.06	N/A	41461.80	White	0	0	26.32	0	47.37	0	5.26	21.05
9	30477	4.34	N/A	33532.65	Black	0	0	50	0	30	0	10	10
10	31711	3.6	N/A	43050.38	Black, White	0	0	40	0	40	0	0	20
11	31070	3.56	N/A	74421.27	White	0	0	28.57	0	57.14	0	14.29	0
12	31735	3.53	N/A	53978.74	White, Black, Other	0	0	33.33	0	33.33	0	33.33	0
13	39854	4.13	N/A	34043.78	Black	0	0	37.04	0	29.63	0	9.26	24.07
14	31094	3.5	N/A	52592.36	White, Unknown	0	0	0	0	50	0	0	50

The mean soil Pb levels of the soilSHOP samples were mapped accordingly with the ZIP codes of where each sample was collected **(Figure 1)**. The highest mean soil Pb levels (μg/dL) was found in ZIP code 30148 (2657.5 ppm), outside of the city boundary. Most mean soil-Pb levels (ppm) outside of the city boundary were consistent with mean soil Pb level (ppm) below 75.0 ppm (Green) **(Figure 1)**. Within the city boundary, most ZIP codes were consistent with moderate mean soil-Pb levels (ppm) between the ranges of 75.0 - 275.0 ppm (Yellow) and 275.0 - 400.0 ppm (Orange).

Children's Blood Pb and Race

In 2021, blood test screenings and racial records for 89,260 children under 6 were obtained from DPH. This data was collected from 836 ZIP codes in Georgia. The mean children's blood Pb data were calculated and mapped by ZIP code. The data were reduced to ZIP codes included in the soilSHOP and 2021 estimated median household income data (ZIP codes based on soilSHOP data). A strong positive relationship was expected between mean soil Pb level (ppm) and mean children's blood Pb level (μg/dL), however, there was a low negative correlation coefficient between the variables (Correlation coefficient = – 0.077) (**Table 2a)**. The most significant correlations were the positive correlation of mean blood Pb level (μg/dL) and percentage of "White" race (Correlation coefficient = 0.423, p-value = 0.004) and mean blood Pb level (μg/dL) negatively correlated with "Unknown" race (Correlation coefficient = - 0.369, p-value = 9.18E-4).

752 of the ZIP codes and mean children's blood Pb levels (μg/dL) were mapped in ArcGIS pro. The map displays the mean blood Pb (μg/dL) for children in 2021. To show the blood Pb level (μg/dL) ranges that each of the results fell between, graduated colors ranging from light blue to dark purple (low – high) were used to represent the ranges of blood Pb levels (μg/dL) in each ZIP code (**Figure 2**). 14 ZIP codes in Georgia, all outside of the metro Atlanta area, had mean children's

blood Pb levels exceeding the CDC threshold of 3.5 μg/dL (**Table 1b**, **Figure 2**). Within the city boundaries most of the ZIP codes had mean children's blood Pb levels (μg/dL) between the ranges of 1.42 - 1.83 μg/dL.

The 2021 race data was obtained from the DPH and converted into percentages to display on a map. The purpose of mapping the 2021 races were to show how abundant each race (American Indian/Alaska Native, Asian, Black/African American, Native Hawaiian/Other Pacific Islander, White, Multiracial, Other, and Unknown) was in the year 2021 per ZIP code **(Figure 4).** In the year 2021, the percentage of "Black/African American" race exemplified strong correlations with the percentage of "White" and "Other" race. Amongst all races in **Table 2a** (n = 42 ZIP codes), the percentage of "Black/African American" race indicated a strong negative correlation with the percentage of "White" (Correlation coefficient = -0.561) and "Other" races (Correlation coefficient = -0.583). On a significantly larger scale (n = 687 ZIP codes), an even stronger negative correlation was shown between percentage of "Black/African American" and "White" races (Correlation coefficient = -0.611) **(Table 2b).** However, the percentage of "Black/African American" had a weaker correlation with the percentage of "Other" race (Correlation coefficient = -0.123).

Household Income

The correlation of variables shown in **Table 2b** are based on 687 Georgia ZIP codes from the estimated median household income data. In this correlation analysis, soil Pb levels (ppm) were excluded. 2021 Estimated median household income had a weak negative correlation with mean children's blood Pb levels (μg/dL) (Correlation coefficient = -0.272, p-value = 0.5) but a moderately strong negative correlation with the percentage of "Black/ African American" race (Correlation coefficient = -0.621) **(Table 2a).** Additionally, a strong positive correlation was found between estimated median household income and "Unknown" race (Correlation coefficient = 0.520) (**Table**

2a). In the model based on the larger sample size (ZIP codes from median household income data), estimated household income also had a weak negative correlation with mean blood Pb (Correlation coefficient = -0.201) and a stronger positive correlation with "Unknown" race (Correlation coefficient = 0.404) (**Table 2b**). Unlike the results in the correlation model presented in **Table 2a**, there was a weaker correlation between estimated median household income and the percentage of "Black/African American" race (Correlation coefficient = -0.257) (**Table 2b**). In 2021, the highest estimated median household income areas are in ZIP codes on the outside of the city limit (**Figure 4**). Inside the city boundary, the low estimated household incomes ($12,834.23 - $35,035.33) appear in most of the mid-southern ZIP codes of the boundary while the highest median household incomes ($88,417.86 - $156,748.93) are in the northern parts of the city boundary (**Figure 4**).

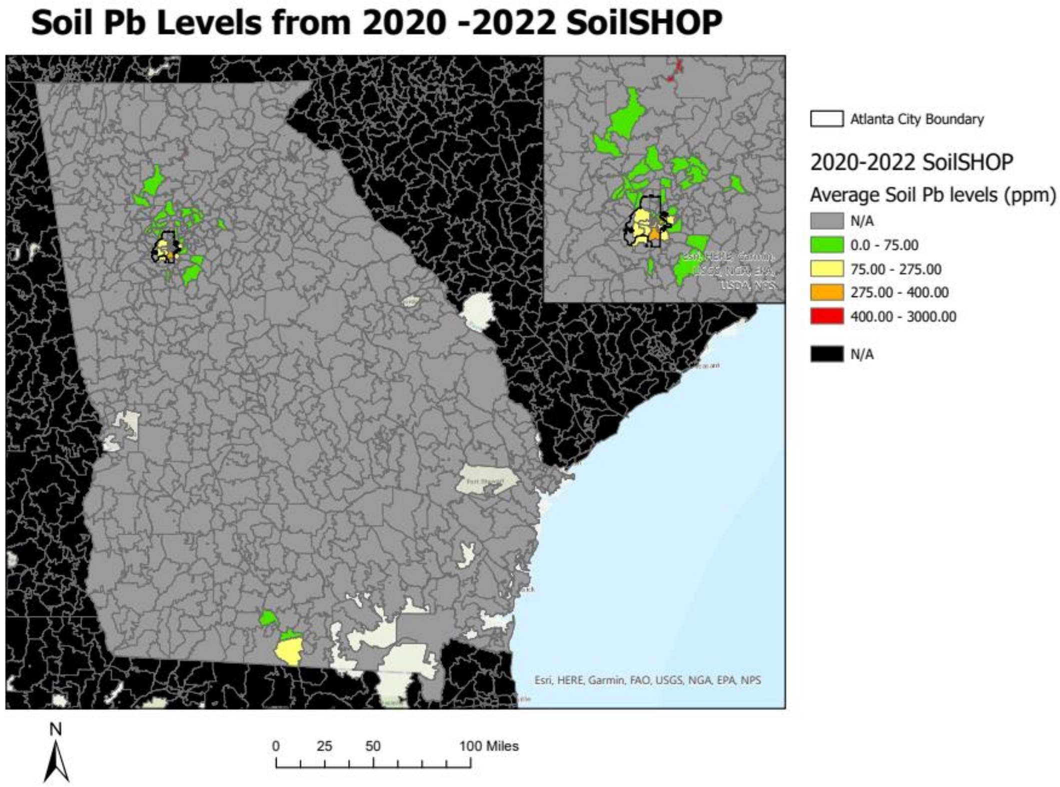

Figure 1. Mean Soil Pb Level concentrations of soilSHOP samples in Georgia

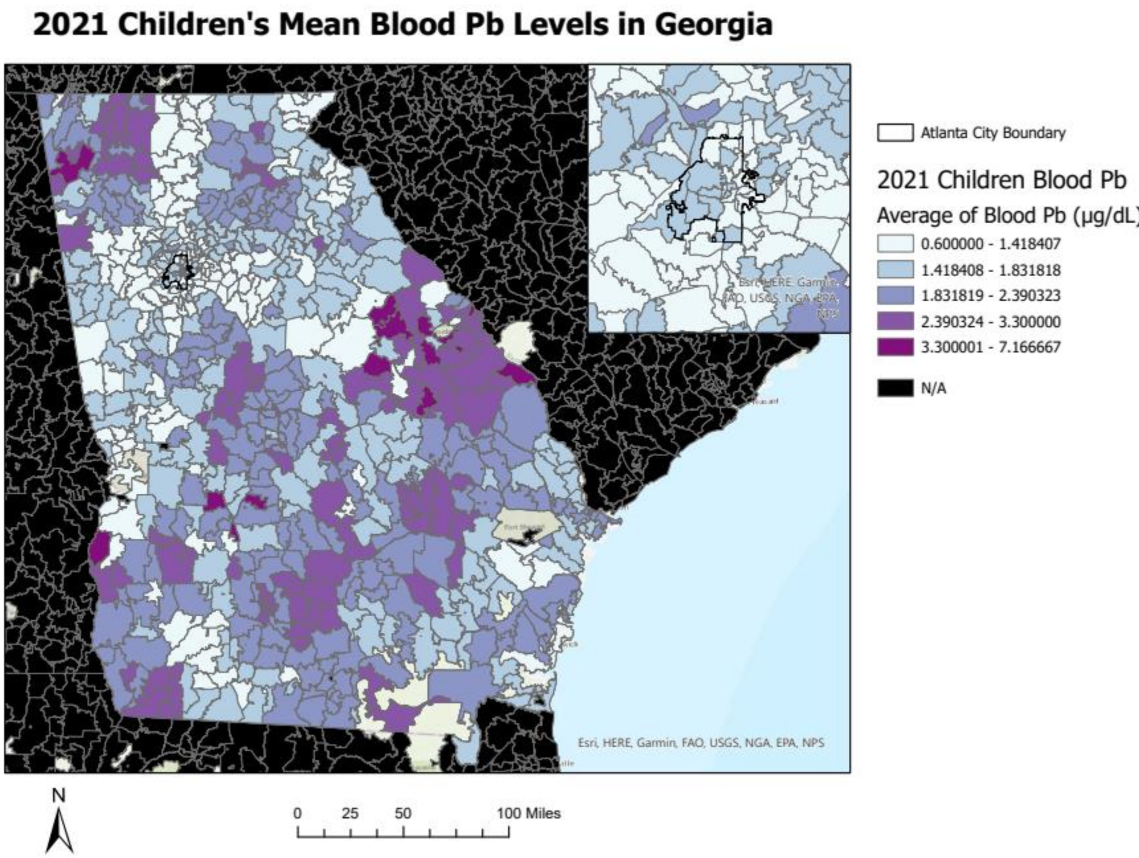

Figure 2. 2021 Children's Mean Blood Pb Levels in Georgia

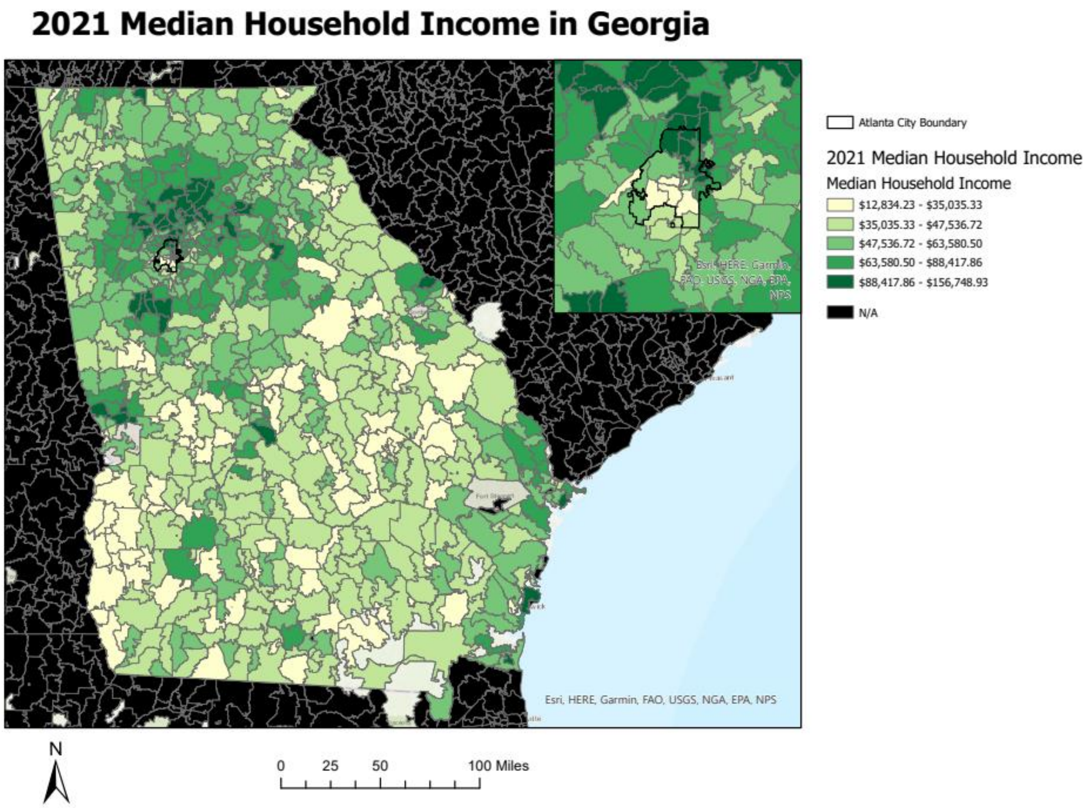

Figure 3. 2021 Median Household Income in Georgia

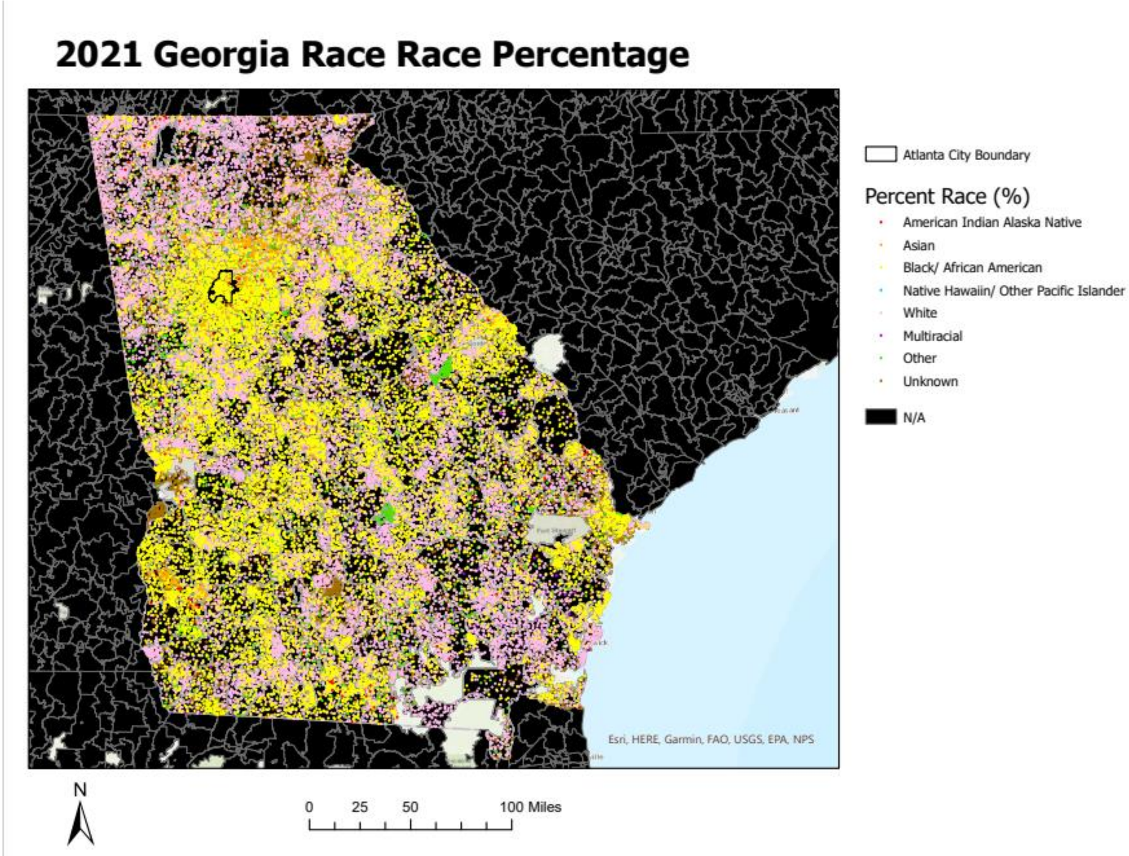

Figure 4. 2021 Percentage of Races in Georgia

Table 2a

Correlation Among All Variables in this Study

	Mean Soil Pb	2021 Median HH income	American Indian Alaska Native	Asian	Black/African American	Native Hawaiin or Other Pacific Islander	Multiracial	Other	Unknown	White	Children Blood Pb
Mean Soil Pb	1										
2021 Median HH income	-0.193	1									
American Indian Alaska Native	-0.107	-0.075	1								
Asian	-0.141	0.409	0.061	1							
Black/African American	-0.179	-0.621	0.045	-0.316	1						
Native Hawaiin or Other Pacific Islander	-0.084	0.431	0.012	0.043	-0.224	1					
Multiracial	-0.137	0.271	0.047	0.135	-0.166	0.552	1				
Other	0.403	0.141	0.006	0.241	-0.583	0.282	0.173	1			
Unknown	-0.265	0.520	-0.149	-0.011	-0.366	-0.075	0.005	-0.355	1		
White	0.333	0.091	0.066	0.020	-0.561	0.161	0.014	0.451	-0.367	1	
Mean Children Blood Pb	-0.077	-0.272	0.223	-0.055	0.083	-0.156	-0.219	-0.060	-0.369	0.423	1

The coloring in **Tables 2a** indicates the strength and type of correlation between variables. The green coloring indicates a positive correlation and red indicates a negative correlation amongst between variables. The darker the color tone, the stronger the relationship between the variables. Numerically, the strongest relationships are expressed by coefficient values with 1 being the strongest coefficient.

Table 2b

Correlation Among Variables in this Study Excluding Mean Soil Pb based on Household Income ZIP Codes

	2021 Household Income	*American Indian Alaska Native*	*Asian*	*Black or African American*	*Native Hawaiin or Other Pacific Islander*	*White*	*Multiracial*	*Other*	*Unknown*	*Mean Blood Pb*
2021 Household Income	1									
American Indian Alaska Native	-0.041	1								
Asian	0.252	0.017	1							
Black or African American	-0.257	0.018	-0.012	1						
Native Hawaiin or Other Pacific Islander	0.118	0.021	0.037	0.029	1					
White	-0.144	-0.023	-0.211	-0.611	-0.104	1				
Multiracial	0.120	-0.009	0.039	-0.017	0.024	0.028	1			
Other	0.102	-0.004	0.065	-0.123	0.063	-0.285	0.044	1		
Unknown	0.404	-0.030	0.111	-0.338	0.052	-0.355	-0.104	-0.128	1	
Mean Blood Pb	-0.201	0.021	-0.097	-0.013	-0.037	0.149	-0.128	-0.148	-0.055	1

The coloring in **Table 2b** indicates the strength and type of correlation between variables. The green coloring indicates a positive correlation and red indicates a negative correlation amongst between variables. The darker the color tone, the stronger the relationship between the variables. Numerically, the strongest relationships are expressed by coefficient values with 1 being the strongest coefficient.

Table 3a

Multilinear Regression Model for the Mean Children Blood Pb Levels in Georgia (Based on ZIP Codes of Collected SoilSHOP Samples)

Dependent Variable: Mean Children Blood Pb Level		
	Coefficient	**P-value**
Mean Soil Pb	0.000	0.097
2021 Median Household income	0.000	0.517
American Indian Alaska Native	0.103	0.439
Asian	-0.012	0.416
Black/African American	-0.014	0.002
Native Hawaiin or Other Pacific Islander	-0.155	0.683
Multiracial	-0.086	0.270
Other race	-0.020	0.009
Unknown race	-0.018	9.18E-4
White race	15.76	0.004
Observations	41	
R Square	0.461	
Adjusted R Square	0.304	
Standard Error	0.268	
F Statistic	2.942	
Significance F	0.012	

Discussion

Food insecurity is a major factor when determining community health. In 2020, this issue affected 13.8 million households in the United States. To reduce food insecurity, urban agriculture has become more popular. However, this increases the risk of exposure to Heavy Metal and Metalloid (HMM) contaminants such as Pb (Saikawa et al., 2023). Many communities are unaware of the determinants, effects, and exposure levels that urban agriculture introduces. The soilSHOP was put into place to address the issue of food insecurity, as well as to promote soil screening for Pb in the state of Georgia. The intent of the soilSHOPs were to increase community awareness about Pb exposure and to intervene with the living conditions of residents (Saikawa et al., 2023). For communities facing extreme levels of Pb, soilSHOPs not only help increase recognition of those sites but also help get organizations such as the EPA involved in addressing environmental issues.

The statistical analysis of the variables in this study was not as expected. The only significance displayed in the model were the percentage of "Black/African American" race (p-value = 0.002), "Other" race (p-value = 0.009), and "Unknown" race (p-value = 0) (**Table 3a**). The percentage of "Black/ African American" race (Coefficient = -0.014) indicated an inverse relationship with mean children's blood Pb level. Instead of the percentage of "Black/African American" race increasing with children's blood Pb levels (μg/dL), a decrease in mean children's blood Pb levels (μg/dL) were found in ZIP codes with high percentages of "Black/African American" race (**Table 3a**). Those results are not supportive of what the earlier studies have shown – Black children have the highest blood Pb levels compared to other races. For example, O'Shea et al., (2021) found a strong correlation between the percentage of children with elevated blood Pb levels (μg/dL) and the percentage of minority children. The reason for those results could be due to the heterogeneity of the ZIP code scale along with the transition of "White" race predominance in earlier years to "Black" race predominance in more recent years. Aside from strong correlations between races, 2021 estimated median household income was found to be negatively correlated with the percentage of "Black/African American" race **(Table 2a).** This correlation shows an inverse relationship as well between the 2021 estimated median household income and the percentage of "Black/African American" race. The results found in the correlation support previous findings of Black/African American children residing in lower household income or impoverished areas (O'Shea et al., 2021).

The state of Georgia in 2021 had ZIP codes with higher mean blood Pb levels (μg/dL) outside of Atlanta's city boundary, with blood Pb level (μg/dL) ranging between 2.39 - 3.30 μg/dL (Moderately high) and 3.30 - 7.16 μg/dL (High) (**Figure 2**). All ZIP codes that contained mean children's blood Pb levels exceeding the 3.5 μg/dL threshold were outside of the city boundary (**Table 1b**). Our results show that there is potentially a vast number of children that have blood Pb levels exceeding the 3.5 μg/dL threshold. Within the city boundary, most ZIP codes had mean blood Pb levels (μg/dL) that fell within the ranges of 0.60 - 1.42 (Low range) μg/dL and 1.83 - 2.39 μg/dL (medium). No ZIP codes with mean children blood Pb levels exceeding the 3.5 (μg/dL) threshold were within the city boundary. This shows that children living in the more rural areas may be dealing with more cases of elevated blood Pb levels (μg/dL) than children living in urban areas. Many Pb studies take place in urban areas, however conducting more studies in rural areas could help gain a broader perspective on blood Pb levels and sources. With the highest mean blood Pb levels (μg/dL) being detected outside of the Atlanta city boundary, organizing community soilSHOP events in rural areas could help promote soil screening and awareness on a broader scale.

The data collected for the soilSHOP events held a smaller sample size compared to the other data observed. Children's mean blood Pb levels (μg/dL), 2021 estimated median household income, and race data **(Figures 2-4)** covered more Georgia ZIP codes than the soilSHOP data **(Figure 1)**. The disproportion in soil sample numbers per ZIP code were due to the limited number of virtual and physical soilSHOP events that took place outside the Vine city and English Avenue neighborhoods. In addition to limited advertising outside of the city boundary, the disproportion in soil sample numbers may also be a major factor for most ZIP codes within the city boundary having mean soil Pb levels (ppm) above 75.0 ppm (mid-range). The highest mean soil Pb level (ppm) was found in ZIP code 30148 having a mean of 2657.5 ppm (outside city limits). The most samples were collected in ZIP code 30314 (n = 56) with the highest soil Pb level at 1337.0 ppm and a mean soil Pb level (ppm) at 163.15 ppm (**Table 1a**). Although only one ZIP code outside of the city limits was found to have an extremely high mean Pb level (ppm) (**Table 1a**), there may be other ZIP code locations that display similar levels.

During this investigation, we were able to deduce the correlation of high blood Pb levels in association to ZIP codes. Due to this structure of data, we found the results to be inconsistent with the results of similar research studies (O'Shea et al., 2021). One of the greatest limitations in this study was the use of ZIP codes to explain associations between mean soil Pb levels (ppm), children's mean blood Pb levels (μg/dL), estimated median household income, and percentage of race. The results for the variables showed that averaging the data on a ZIP code scale does not provide an accurate representation of environmental data. Previous studies have shown better explanations of Pb related data with census tracts and block groups than with ZIP codes (Distler and Saikawa, 2020). Due to limited timing, ZIP codes were used because they were already provided in the soilSHOP data. When analyzing each of the soilSHOP samples, the ZIP codes of the sample's location were recorded. To reduce the probability of inaccurate results, future studies should use census tracts and census block groups. We believe when trying to capture a more accurate representation of high Pb levels, the use of Census tracts may help identify more high-risk areas at a smaller scale. Creating a smaller centralized area of examination would likely create a more defined and accurate representation of variables and their relationships as shown in Distler and Saikawa (2020) study.

Within ZIP code 30314 are the neighborhoods of English Avenue and Vine city. In 2022, these historically black neighborhoods were declared an EPA superfund site (Westside Lead Site) and listed on the National Priority List (NPL) due to detections of high Pb levels (ppm) in the soils of multiple residential properties (*WESTSIDE LEAD Site Profile, n.d.*). Prior to those recent establishments, the Westside neighborhoods have been central locations for the community soilSHOPs and have helped promote soil screening, health awareness and even cleanup outside of the community. The establishment of the Superfund in the Westside, in combination with our soilSHOP efforts led to another recent establishment of the Buckhead Slag Superfund Site (*BUCKHEAD SLAG SITE Site Profile,* n.d.). This Superfund site came about after a Buckhead resident reached out to organizers of the soilSHOP regarding slag findings at the property. After testing the resident's soil, high soil Pb levels (ppm) were detected and reported to the EPA. As awareness grows among the residents, we are now constantly receiving requests to hold soilSHOPs at different communities in Atlanta and also in New Orleans. These recent accomplishments exemplify how community SoilSHOPs not only help promote soil screening and health within communities but also outside of communities.

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