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Trace Element Soil Contamination at Urban Community Gardens in Washington, DC

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Abstract

In recent years, urban gardening has become a popular form of environmental, food, and social justice. Urban community gardens such as those in Washington, DC can reduce the environmental footprint of food production, provide access to healthy produce in "food deserts," and provide other social, educational, and even financial benefits. However, the rising popularity of urban gardening has put many people in close contact with urban soils, which are likely to contain various contaminants due to concentrated human activity over extended periods of time. This study investigates heavy metal soil contaminants found in community gardens located in Washington, DC. 45 soil samples taken from various locations and depths at 13 community gardens across Washington, DC were analyzed for trace element content using x-ray fluorescence (XRF). While most of the soil samples analyzed fell below US EPA action levels for common contaminants such as lead, cadmium, cobalt, copper, and zinc, some samples showed concentrations high enough to merit some concern. High concentrations of Pb (above the US EPA action level of 400 ppm), which can cause serious health problems in children, was found in the native soil of three garden sites. The bioavailability of Pb and risk of danger to humans depends on many factors which will be explored in this paper. Because of the potential for direct exposure and ingestion of contaminated soil, this study also reviews potential measures to avoid contamination when gardening on urban soils in Washington, DC to ensure the safety of these valuable social, nutritional, and environmental resources.

Introduction

Sustainable agriculture is a topic that has garnered significant interest over the past few decades. In a warming world, reducing the environmental costs of agriculture demands unique solutions to minimize the use of nonrenewable resources, reduce the amount of carbon emissions and land area required to grow food, and maximize efficiency of food production. For cities such as Havana, Cuba (which currently produces almost all of its food in city limits), growing food in many small slivers across the city has been a way to make better use of empty space (Cruz and Medina, 2011). Indeed, many cities across the United States have also seen a rapid increase in urban gardens over the past few decades, from 6,020 gardens in 1996 to over 18,000 today (ACGA, 1996; ACGA, 2012). One such city, Washington, DC, currently has around 40 community gardens which are very popular with residents in all areas of the city, making it a great case study for many kinds of community garden research.

For some communities in Washington, DC, urban community gardens serve as a form of social justice ("food justice") in addition to the environmental benefits. As with many cities and even rural areas around the country and the world, there are parts of Washington, DC with limited access to food that is both healthy and affordable, and these areas almost always correspond with areas of lower average income. Known as "food deserts," these regions are defined as any point in a city which is greater than one mile from a grocery store. Although opening new grocery stores is one obvious solution, there are other ways of increasing food access. Historically, times of food shortage and conservation (World War and World War II, for example) were met with what was known as "Victory Gardening," where residents grew vegetables in small patches vacant land around cities (Higgins, 2011). The modern trend towards

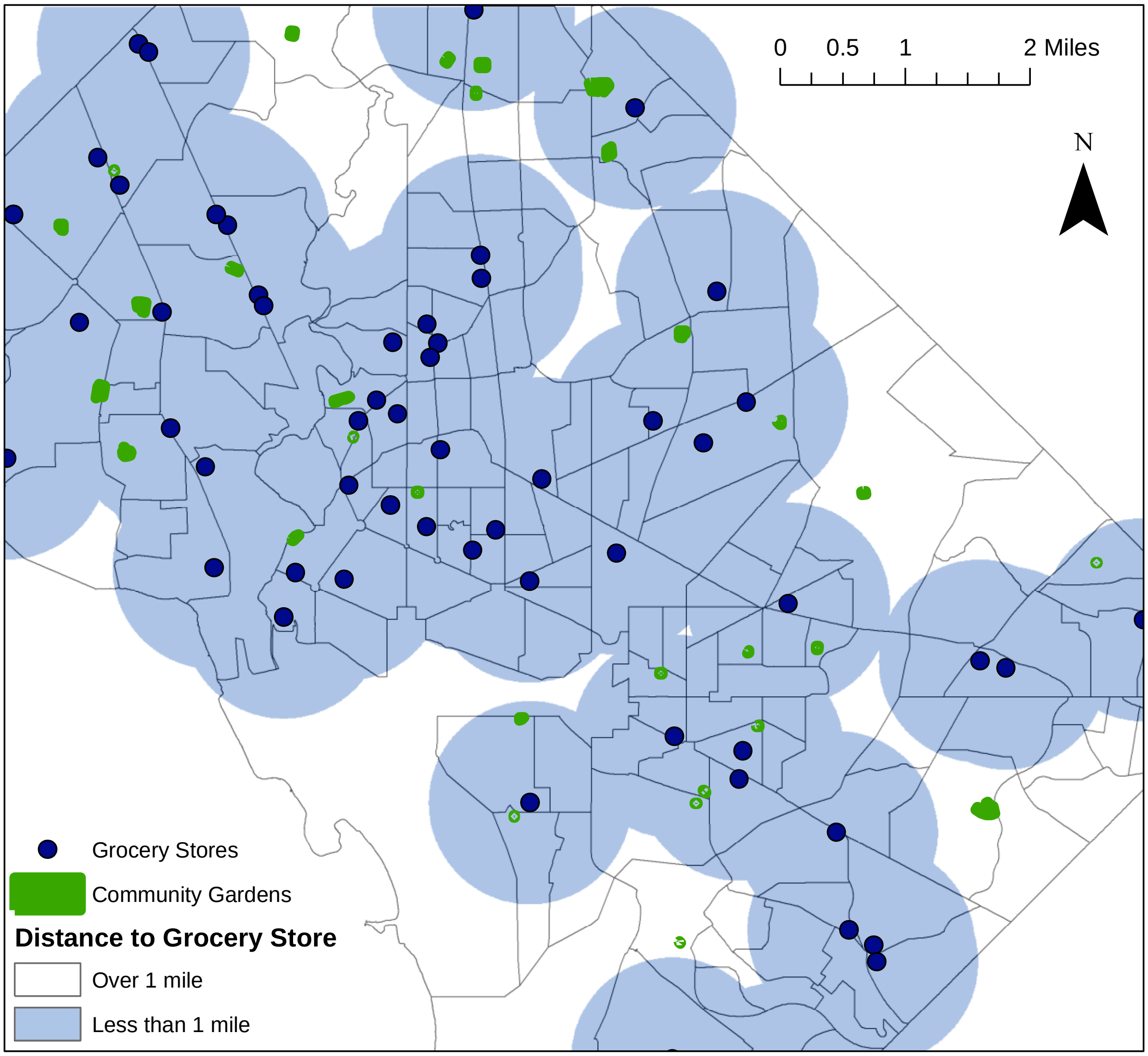

Fig. 1. Map showing "food deserts" and community garden locations. Note the four gardens located in food deserts, and the many other gardens located near the boundaries of food deserts. Map generated by Adam Long using ArcGIS 10 and data from data.dc.gov.

urban gardening could be a part of the solution to the inequality of food access seen in Washington, DC and other cities across the United States.

This model for urban organic farming is a form of sustainable agriculture that has proliferated in recent years, and now urban organic farms can be found in almost any city across the United States. Many of these farms and gardens serve as educational centers for children and

adults to learn about environmental, nutritional, and food justice issues and to connect people to the food that they eat. More importantly for some, these gardens serve as a real source of food, helping to save money and eat more healthily. Indeed, studies have also shown that community gardens “improve the environment, build amenities, revitalize neighborhoods, and have direct benefits to residents’ food access and nutrition” (US EPA, 2011). However, urban farms have a unique set of challenges due to their proximity to large human populations and industrial centers. This proximity means that soils at urban farms are more likely to contain contaminants from earlier industrial activity, waste dumping, vehicle exhaust fumes, nearby factories, and other chemical residues (Ajmone-Marsan, 2010).

As such, it is important to investigate soil contamination in order to determine the risk involved in gardening or farming on land in urban environments and the steps that should be taken to minimize that risk. This study will use soil analysis, verbal questionnaires, and research to learn about the history of each garden site, potential contamination sources in the past and present, and the implications of this data and information. The primary hypothesis is that the soils at gardens in DC will have high levels of certain heavy metal contaminants, indicating anthropogenic sources. GIS analysis will also help to ascertain any spatial correlations of soil contaminants. Another hypothesis is that contaminants from past industry or dump sites near the garden may be seen in the soil of that garden site.

Methods

First, beginning in May of 2012, contact information was found for the managers of the 36 farms and community gardens located in the boundaries of Washington, DC. E-mails were sent out to each manager, and phone calls were placed to those without e-mail and those who did

not respond via e-mail. Over the course of many weeks, contact was made with the managers of about 20 gardens, and soil was collected from a total of 13 of those gardens. Of the 13 sites, one is a school garden, one is an educational program farm, four are community gardens located on National Park Service land, and the other seven sites are community gardens on privately and publicly owned land. These gardens also contained a variety of plot types, including raised beds, row crops, and in-ground plots.

When at a farm or garden site, a short verbal questionnaire was given to the owner or manager to collect background information on the history of the farm, the types of beds used (in-ground beds, raised beds, etc.), the sources of soil used (original soil from the site, imported soil, compost created on site, etc.), and any information about local traffic patterns, industry, and potential past sources of contamination. Then, at each site, between 6 and 12 sampling locations were identified across a wide variety of locations, depths, and soil types. For example, samples were taken from the topsoil of garden beds or plots, the subsurface soil (often the native clay) beneath beds, and soil beneath pathways. At some sites, a series of samples was collected along a transect perpendicular to the roadway.

Each sample was extracted using a combination of 17 inch soil sampling probe (see Fig. 2), a small hand shovel, and large digging shovels. Large rocks, sticks, and pieces of trash

Fig. 2. Photograph of a typical soil profile in the sampling probe – darker, organic rich, well-worked topsoil overlying an orange clay-rich layer of “native” soils which often contain debris like glass, bricks, and pieces of metal.

were removed such that each sample could entirely fill a clean 4 fluid ounce glass jar. Each jar was sealed with a plastic lid and labeled with a number corresponding to a set of field notes. At the time of sample collection, a Garmin GPSmap62s set to average waypoints was placed within a few inches of the location of sample collection and left for at least one minute. Additionally, after each sample was collected, a ruler was used to measure the minimum and maximum depth from which that soil sample was collected, recorded as a range of depths. A brief summary of the plant life, soil characteristics, soil compaction (using the finger press method and recorded as loose, soft, firm, or compact), and other unique features of that sample collection site were noted.

After collection of the soils from one garden site was complete, the jars were opened and placed on a tray in a standard oven set at 300° F (about 150°) for two to four hours to sterilize and dry out the samples. After cooling, the samples were tested for pH. First, 10.0 grams of soil from each sample was mixed with 10 mL of distilled water in a clean glass jar, stirred vigorously, and then allowed to sit for at least ten minutes. An Oakton EcoTestr pH 2 electronic pH meter was then used to measure the pH which was recorded alongside the other information collected on site. Finally, soil color was characterized for each sample using a 1998 edition Munsell Soil Color Charts notebook by holding the chart up to the soil sample and comparing the chart colors to the soil color until the closest match was found.

After all the steps above were completed, each sample was funneled into a 4 ounce WhirlPak bag labeled with a two character abbreviation of the farm or garden’s name (for example, Walker Jones School Garden becomes “WJ”) and then followed by a two digit number corresponding to the number assigned when the sample was originally collected. Therefore, the sample from the King’s Court Garden assigned number 5 was labeled as “KC05.” Each sample as then split into two bags, and one set of bags was mailed to Claremont and the other was

checked as luggage on an airline flight to help prevent loss of samples during transportation. Luckily, both packages made it back to the lab in Claremont, California, where the duplicate samples were recombined prior to testing.

Fig. 3. Eight powder press pellets loaded into the XRF.

Upon returning to Claremont on August 4th, 2012, a set of soil samples from each garden site was analyzed for trace heavy metal contamination using the XRF housed in the Pomona College geology department. First of all, three or four representative samples were chosen from each site, and any gravel, glass, sticks, or other non-soil particles were removed by hand, and then each soil sample was powdered for 40 seconds using a Rocklabs tungsten carbide ring mill. This broke down soil clods, organic material, and any remaining small rocks and fully homogenizes the soil into a fine powder. Then, two separate 5±.0006 g aliquots of each sample powder were each mixed with 1±.0006 g of Brikett Blend cellulose binder, and then compressed into duplicate pellets using a SPEX 3630 X-Press powder press set to hold 30 tons of pressure for five minutes. These duplicate pellets were then labeled and loaded into the XRF for analysis (see Fig. 3), using the ProTrace calibration designed for detecting trace elements to a few parts per million (ppm).

One garden with particularly high contamination values was also chosen as a detailed case study site. An addition four soil samples were powdered, pressed, and analyzed from this garden, for a total of seven samples. These seven powders were also analyzed for their organic

content by measuring out 10±1 g of soil into a graphite crucible and combusting it in a Nabertherm More Than Heat 30-3000° C oven at 450° C for two hours. The loss on ignition (LOI), which approximates organic content, was calculated by calculating the difference in mass between the powder inserted into the oven and remaining sample after combustion.

The powders resulting from the LOI analysis were then used for a second round of XRF analyses using the glass bead method. For this method, 3.5±.0004 g of the combusted soil powder was mixed with 7±.0004 g of lithium tetraborate flux and fused in the same oven at 1000° C for 30 minutes, creating a glass "bead." These beads were then powdered in the Rocklabs ring mill, refused in the oven at 1000° C, and polished to create a smooth surface for analysis. The beads were inserted into the XRF and analyzed using the Geology Beads calibration method which detects most major elements and many trace elements. These data were compared with the data from the soil powder press pellets to verify accuracy.

A GIS analysis has also been conducted to show patterns of garden contamination across Washington, DC. Each soil sample location was plotted in ArcGIS and the depth of sampling, pH, and contaminant concentrations were added to each point. This dataset was layered with existing spatial datasets for population density, major streets, and more to determine the existence of spatial correlations for trace contaminants such as lead.

Results and Discussion

Overall Results

Three or four representative samples from each of 13 gardens were analyzed for trace element concentration using the ProTrace calibration method. This analysis method returned values in

ppm for 40 elements with lower limit of detection (LLD) levels between about 0 and 20 ppm. However, a coefficient of variation (COV) calculated between to the two aliquots of each soil sample showed that many elements varied by over 20% across the two samples of the same exact soil. Chromium, for example, had anomalies as great as 89.9% for one sample which had a value of 289.5 ppm for one aliquot and 1300 ppm for the other, despite being from a single, fully homogenized soil sample powder. Because of the pervasive variation in some data, important soil contaminants such as chromium, arsenic, and cadmium had to be disregarded for this study.

The most significant soil contaminant remaining after disregarding the erratic data was lead (Pb), which will be the primary focus of the second part of the discussion. Because "neither FDA nor USDA have standards that regulate the quality of soil as a growing medium," US EPA residential soil screening level (SSL) action values, as well as some limits set by other governmental agencies, will be used to determine thresholds for the human danger of soil contamination in DC community gardens (US EPA, 2011).

A few elements with acceptable COVs, such as cobalt, zinc, copper, and barium, were of some interest when compared with various SSL values. Cobalt (Co) from natural geologic sources is seen in soils across the world with an average concentration of 10 ppm, although "higher levels of Co are in heavy loamy soils" like the native soils across most of DC (Kabata-Pendias, 2010). Relatively high concentrations of Co were seen across all of the gardens in DC, ranging from 14.8 ppm to 58.3 ppm with an average of 29.7 ppm for 41 distinct soil samples. This is above the EPA SSL value of 23 ppm, the level at which the trace element is deemed a contaminant of concern. According to the Dutch Soil Cleanup (Interim) Act, however, levels above 50 ppm are only cause for moderate concern and additional study, but immediate remediation is not recommended until levels reach 300 ppm (Beyer, 1990). Although high

concentrations of Co can have “effects on the lungs, including asthma, pneumonia, and wheezing,” low amounts of Co are actually necessary for human life and are important for the body’s synthesis of vitamin B-12. Of course, as with many metals in the soil, Co toxicity increases as soil acidity increases (MOE, 2001). However, given that only 5.1% of the samples collected had concentrations above 50 ppm, Co is unlikely to a contaminant of concern.

Zinc is well below the EPA SSL value of 23,000 ppm with an average concentration of 140.3 ppm. A few samples, however, exceeded the moderate limit of 500 ppm limit set by the Dutch protocols and thus might be cause for concern. These samples were all from one garden which will be discussed in more detail in the Hill East Community Garden Case Study section. Copper was also seen at levels below both the EPA SSL value and the Dutch limit for immediate remediation, although five samples were slightly above the moderate concern level in the Dutch system. Copper is also a necessary nutrient in trace amounts. Barium is also seen in levels that would be of moderate concern under the Dutch method, but barium is also a naturally occurring element with relatively low toxicity. Lead values in a few gardens, however, are well above the EPA limit of 400 ppm and slightly higher the Dutch value of 600 ppm for immediate remediation, and will be discussed in detail in the following section.

Lead Trends

Lead is a common and pervasive environmental contaminant which can have toxic effects on the human brain, especially for young children. Adults who receive higher doses of Pb can also suffer from lead poisoning symptoms. Ingestion of Pb in water and food accounts for an average dietary intake of between 100 to 250 µg per day for young adults (Mahaffey, 1977), which is at or below tolerable daily intake levels determined by the Joint Executive Council on Food

Additives (JECFA), "a collaboration of the World Health Organization and the Food and Agriculture Organization" (Clark et al., 2008). However, regular contact with contaminated soils like those in many urban areas increases the risk of additional lead exposure through inhalation and ingestion of soil containing lead. Thus, lead contamination in soils at urban gardens such as those in Washington, DC, where gardeners regularly come into direct contact with soil and consume produce that may had adhered soil particles, can pose a health risk.

Determining the exact amount of risk depends on many factors including the bulk Pb concentration in the soil. For the 13 gardens visited for this study (n = 45 samples), the average Pb concentration was 129.4 ppm, ranging from 16.2 to 869.4 ppm. The average LLD was 1.9 ppm and the average COV was 2.0 ppm. For soils collected from an average of greater than 20 cm depth (which are often native clays), the average Pb level across all gardens was 166.3 ppm. For topsoil (less than 20 cm depth), the average Pb concentration was 78.7 ppm (see Table 1 for all data). Studies have established that the upper limit of Pb concentration in an unpolluted soil is 70 ppm (Davies, 1977), which indicates that the topsoils in community gardens in DC have, at the very least, only 8.7 ppm Pb from anthropogenic sources (pollution) on average. Similarly, this means that soils at depth tend to have a minimum of 96.3 ppm Pb from anthropogenic sources on average. In most cases, however, the Pb content from natural sources is much less, with an average of 19 ppm across United States soils and 27 ppm across world soils (Kabata-Pendias, 2010; Ruby et al., 1999). This supports the hypothesis that Pb concentration is higher in urban soils due to various anthropogenic contamination sources.

Although background Pb levels are often from parent rocks (Kabata-Pendias, 2010), anthropogenic Pb contamination is seen in most urban environments. This contamination is primarily from lead-based paint, which was "used on 89% of exterior residential structures built

Table 1
Depth of collection, pH, and trace element concentration for all samples analyzed using the powder press method.

Sample Name	Min. Depth (cm)	Max. Depth (cm)	Av. Depth (cm)	pH	Co (ppm)	Cu (ppm)	Zn (ppm)	Pb (ppm)
13-13	28.0	30.5	29.3	8.2	28.0	21.0	56.6	26.1
13-14	15.0	20.5	17.8	7.4	43.1	52.0	65.3	30.7
13-20	10.0	12.5	11.3	9.4	37.1	26.2	192.8	50.1
CG03	40.5	51.0	45.8	6.6	27.0	16.6	56.4	46.4
CG04	2.5	12.5	7.5	6.7	58.0	39.8	87.9	22.9
CG07	7.5	12.5	10.0	8.1	20.4	32.1	135.4	127.6
FS03	30.5	45.5	38.0	6.6	15.9	69.5	43.4	16.2
FS04	7.5	10.0	8.8	6.4	27.0	19.2	75.5	67.2
FS08	7.5	12.5	10.0	6.9	24.5	22.7	77.1	51.9
HE08	18.0	28.0	23.0	7.4	23.4	73.4	404.5	492.3
HE11	25.5	35.5	30.5	7.9	18.8	159.3	606.7	446.4
HE12	2.5	5.0	3.8	7.5	52.3	50.1	168.7	53.4
HE17	28.0	33.0	30.5	6.9	23.8	58.0	403.6	869.4
HE18	10.0	12.5	11.3	7.0	38.8	48.3	191.1	61.4
HE23	25.5	28.0	26.8	7.3	17.1	21.5	101.8	58.95
HE24	7.5	10.0	8.8	7.4	38.9	34.1	156.1	61.55
HG13	28.0	33.0	30.5	8.0	17.4	19.8	79.9	74.2
HG18	25.5	25.5	25.5	7.8	25.3	23.1	143.3	139.8
HG21	15.0	25.5	20.3	7.4	22.6	46.8	287.2	249.7
KC01	33.0	38.0	35.5	7.7	18.4	35.8	235.0	482.9
KC06	33.0	43.0	38.0	7.9	19.5	15.1	63.4	62.9
KC07	23.0	28.0	25.5	7.0	36.5	102.7	374.6	324.2
ML17	38.0	43.0	40.5	7.4	15.6	25.9	42.2	23.1
ML18	5.0	7.5	6.3	7.5	23.7	24.4	79.0	61.8
ML19	15.0	20.5	17.8	8.1	23.2	22.0	36.8	39.5
ML22	28.0	35.5	31.8	7.7	22.1	17.7	47.0	31.7
NS02	30.5	38.0	34.3	7.4	33.0	22.0	90.7	43.2
NS03	45.5	56.0	50.8	7.6	24.2	17.0	73.1	62.4
NS06	5.0	43.0	24.0	7.1	19.3	13.0	47.6	18.9
RC01	28.0	38.0	33.0	7.1	25.8	26.8	90.4	33.1
RC02	15.0	23.0	19.0	7.1	38.5	31.5	108.9	58.4
RC07	23.0	35.5	29.3	6.9	37.3	30.0	220.1	50.4
WE03	28.0	30.5	29.3	6.4	38.9	92.6	121.5	104.0
WE04	18.0	20.0	19.0	7.1	34.8	38.3	84.7	44.1
WE09	35.5	48.0	41.8	7.0	38.5	40.8	71.7	63.0
WG11	20.5	25.5	23.0	7.8	28.8	24.3	148.2	151.9
WG23	25.5	30.5	28.0	7.5	32.8	28.5	201.5	214.2
WG24	12.5	18.0	15.3	7.4	46.6	61.6	204.2	143.8
WJ03	15.0	15.0	15.0	6.1	43.7	70.2	213.4	117.5
WJ05	56.0	56.0	56.0	7.1	33.7	20.9	105.7	208.1
WJ06	15.0	18.0	16.5	6.6	34.4	77.5	226.9	199.9
WJ07	0.0	2.0	1.0	6.4	30.5	52.6	198.7	173.0
WN16	7.5	10.0	8.8	5.5	25.7	17.0	53.6	85.7
WN19	0.0	2.5	1.3	7.6	34.6	35.7	99.3	45.7
WN20	25.5	30.5	28.0	5.4	19.3	17.4	32.4	32.0

before 1978," and leaded gasoline emissions, 92% of which occurred between 1970 and 1983 (Clark et al., 2008). Other sources of Pb include "electronic products, e-wastes, … car batteries, glass, radiation shields, and soldering" (Ajmone-Marsan, 2010). Many gardens, particularly those in the Capitol Hill region, have a history of use as dump sites and parking lots, which could have been a source of Pb and other contaminants in addition to the more common paint and leaded gasoline sources. Also, erratic Pb concentrations across the city and across individual gardens, even at similar depths and soil types, may indicate that the source is more likely to be point pollution, such as a dumped car battery or spilled paint, and less likely to be emissions, which are more evenly distributed across an area. While it is very difficult to determine exactly what sources lead to the Pb contamination in these garden soils, the magnitude of the Pb concentration in many gardens is almost certain evidence of anthropogenic contamination.

Once soil Pb levels rise above 400 or 500 ppm (depending on the system used), the contamination is considered potentially hazardous to human health. However, the actual amount of lead that is bioavailable, "a crucial factor in determining exposure and health risks," ranges between 30% and 50% (Clark et al., 2008). Many factors, some of which are not fully understood, control the bioavailability of Pb in soil, including soil organic matter (SOM) content, soil composition, phosphorus (P) content, the species of Pb in the soil, and soil acidity. Some studies, such as one by Jin et al. (2005), argue that SOM is one of the most important factors in determining Pb bioavailability because accumulation of SOM in the top layer of soils generally contains high levels of Pb. However, no correlation was seen between the percentage of SOM and Pb concentration in seven samples from Hill East Community Garden.

The mineral and elemental composition of soils can also affect Pb bioavailability. The most common Pb ion in soils is Pb^{2+}, which behaves similarly to some alkaline-earth metals by

replacing K, Ba, Sr, and Ca in soil particles and minerals common in clays. The high clay content of native DC soils means that the Pb in DC gardens could become incorporated into a mineral and thus less bioavailable. P compounds, particularly in rocks, are also "very effective in reducing the Pb bioavailability" by incorporating Pb and thus immobilizing it (Kabata-Pendias, 2010). Similarly, Pb is more bioaccessible as a part of other species, such as PbO, $PbCO_3$, and elemental Pb (which quickly forms a PbO rim). Lead-based paints, for example, "release small particles of lead, which are likely to be highly bioavailable" due to small particle size and the high solubility of PbO and $PbCO_3$. Tetraethyl lead emissions from leaded gasoline also alter to PbO and $PbCO_3$, making them more highly bioavailable (Ruby et al., 1999). Since the primary sources of Pb in the DC gardens area likely to be paint, gasoline emissions, and elemental lead from various items dumped on the land previously, much of the forms of lead resulting from these sources of pollution are bioavailable and thus can pose a health risk to humans.

Soil acidity is another very important factor in the bioavailability of many metals in the soil. Many studies indicate that high soil acidity increases the solubilization and thus the bioavailability of Pb (Jin et al., 2005; Kabata-Pendias, 2010; Clark et al., 2008). As soil acidity decreases, the number of free Pb ions increases by "about two orders of magnitude with each unit drop of pH," increasing the bioavailability of Pb (Jin et al., 2005). However, it is important to note that solubility alone "is not predictive of bioavailability" (Mahaffey, 1977). The soils analyzed for this study had average pH of 7.3 across all depths, with topsoils tending to be slightly more neutral than deep soils. Regional variations did occur, with some gardens containing more acidic soils on average and many containing more alkaline soils. For example, the most acidic garden had an average soil pH of 5.8, and the most alkaline had an average of 8.4, again including samples from all depths and soil types. Because the deeper and more

contaminated soils tend to be more alkaline, the health risk of Pb contamination in these gardens could be slightly reduced.

Plant tissues, especially roots, do bioaccumulate Pb from contaminated soil, but ingestion of this produce only accounts for 2 to 3% of estimated lead intake in children ages one to six. The “primary pathway of human exposure to Pb is through the ingestion of soil,” according to a model by Clark et al., which assumes soil Pb concentration of 2000 ppm and ingestion of 100 mg per day on 40% of the days of year, which would result in an average Pb intake of 80 µg per day. This is slightly above the tolerable daily intake (TDI) level of 42 – 70 µg per day for children ages one to six, as determined by JECFA, and accounts for 72–91% of average Pb intake in these children (Clark et al., 2008). Children commonly accompany their parents to community gardens in DC, and so should care should be taken to minimize the potential for soil ingestion by educating their children and taking remediation steps discussed in the conclusion of this paper.

Another risk factor for gardens that have soils with high Pb content is the average grain size of the soil. Many studies have proved that Pb concentration in smaller soil grains (less than 100 µm) can be over twice as high as the concentration in the overall soil, and Pb absorption by the body is greater from these small particles (Clark et al., 2008; Kabata-Pendias, 2010; Mahaffey, 1977). Importantly, these small grains are “generally considered wind transportable,” which means that contaminated soil from pathways could be blown into beds, onto produce, and even accidently ingested or inhaled. Additionally, tests by Clark et al. showed that produce washed in a “kitchen-mimicking style” contains nearly double the amount of Pb as properly washed produce due the Pb-rich fine particles. For the gardens in DC, the more highly contaminated subsurface clays, which are often more exposed in pathways and margins, are composed primarily of fine-grained particles, posing risks for gardeners in DC.

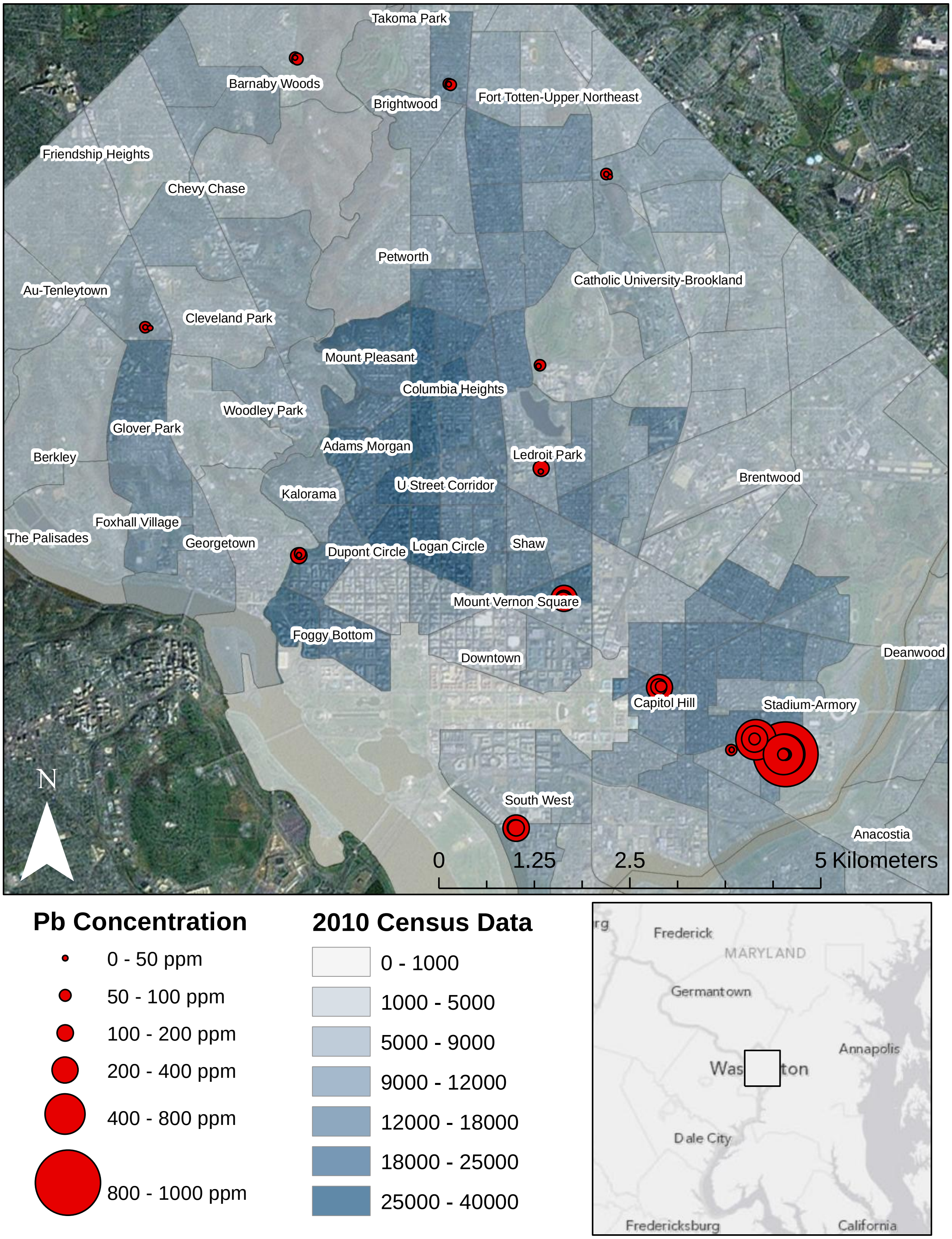

Fig. 4. Map showing Pb concentrations at the 13 garden sites in Washington, DC. Background polygons depict population density in terms of people per square mile. Map created by Adam Long in ArcGIS 10.

Spatial Trends – GIS Analysis

Across Washington, DC, there are very obvious trends in soil properties analyzed for this study. The most prominent trend, displayed in Fig. 4, is that of Pb concentration, which is significantly higher in the southeastern portion of the city, and near harmless baseline levels in the northwest region of the city. Gardens in central and southeast DC are very close to downtown and thus are more likely to experience higher car traffic. Additionally, large populations have inhabited those downtown areas for many decades, increasing the time available for accumulation of Pb from other pollution sources. Also, it is important to note that the four most northern and western gardens, which have the lowest Pb concentrations, are the only gardens in the study located on National Park Service land. Often, this land has been undeveloped for decades if not centuries. So, in addition to being located further from downtown, these gardens are on much more pristine land than the gardens closer to the downtown. Although there is some correlation with population density, it is not significant which could imply that non-residential sources (such as industrial waste) account for some of the Pb contamination.

Hill East Community Garden Case Study

Hill East Community Garden is located in the Capitol Hill neighborhood of Washington, DC in an alley centered between C, D, 17th, and 18th streets SE (see Fig. 5). Local residents believe that the land used to be a WWII “Victory Garden,” but all gardening activities on the space ceased by the 1980s, when the land was used as a dump and a parking lot. In the early 2000s, neighbors got together and began planning a community garden, and Hill East’s first season was in 2004. The garden is made up of 36 raised beds (visible in Fig. 4 as darker colored rectangles), and most are

Table 2
Depth of collection, pH, and trace element concentration for Hill East samples analyzed using the powder press method.

Sample Name	Min. Depth (cm)	Max. Depth (cm)	Av. Depth (cm)	pH	Co (ppm)	Cu (ppm)	Zn (ppm)	Pb (ppm)
HE08	18.0	28.0	23.0	7.4	23.4	73.4	404.5	492.3
HE11	25.5	35.5	30.5	7.9	18.8	159.3	606.7	446.4
HE12	2.5	5.0	3.8	7.5	52.3	50.1	168.7	53.4
HE17	28.0	33.0	30.5	6.9	23.8	58.0	403.6	869.4
HE18	10.0	12.5	11.3	7.0	38.8	48.3	191.1	61.4
HE23	25.5	28.0	26.8	7.3	17.1	21.5	101.8	58.95
HE24	7.5	10.0	8.8	7.4	38.9	34.1	156.1	61.55

lined with plastic or agricultural cloth. Pathways between the beds are lined with plastic covered in mulch. No previous soil testing has been done at this site.

For the seven samples analyzed from this garden, the average Pb concentration was 291.9 ppm, with topsoils averaging only 58.8 and deeper clay soils averaging 602.7 ppm (or 466.8 ppm if outlier sample HE23 is included). All samples collected fall into a slightly basic pH range of 6.9 to 7.9, which means that the increased risk of Pb in acidic soils may not be an issue at this garden site. There is also come correlation between levels of Pb and Zn, possibly because "rubber tire wear and the combustion of lubricating oil are included in zinc emission sources," which would support the hypothesis that automobiles are a source of urban garden soil contamination (Komai, 1982). The health implications of zinc will be discussed below.

In addition to powder press soil pellets, these seven samples were also tested for SOM and then fused into glass beads for the XRF, as discussed in the methods. Overall, the SOM content was in a normal range, from 6.8% to 21.6%, with an average of 12.5%, with the topsoils containing about 6% more

Table 3
LOI or SOM, Pb concentrations for both bead and pellet methods, and the percentage difference between the concentrations for the two methods for all seven samples from Hill East.

Sample Name	LOI (SOM)	Bead Pb (ppm)	Pellet Pb (ppm)	% Difference
HE08	11.4%	578.3	491.4	15.0%
HE11	10.2%	566.0	452.2	20.1%
HE12	21.6%	83.5	54.4	34.9%
HE17	10.3%	1032.6	869.4	15.8%
HE18	18.5%	84.0	61.4	26.9%
HE23	6.8%	80.2	59.0	26.5%
HE24	8.4%	72.6	61.6	15.2%

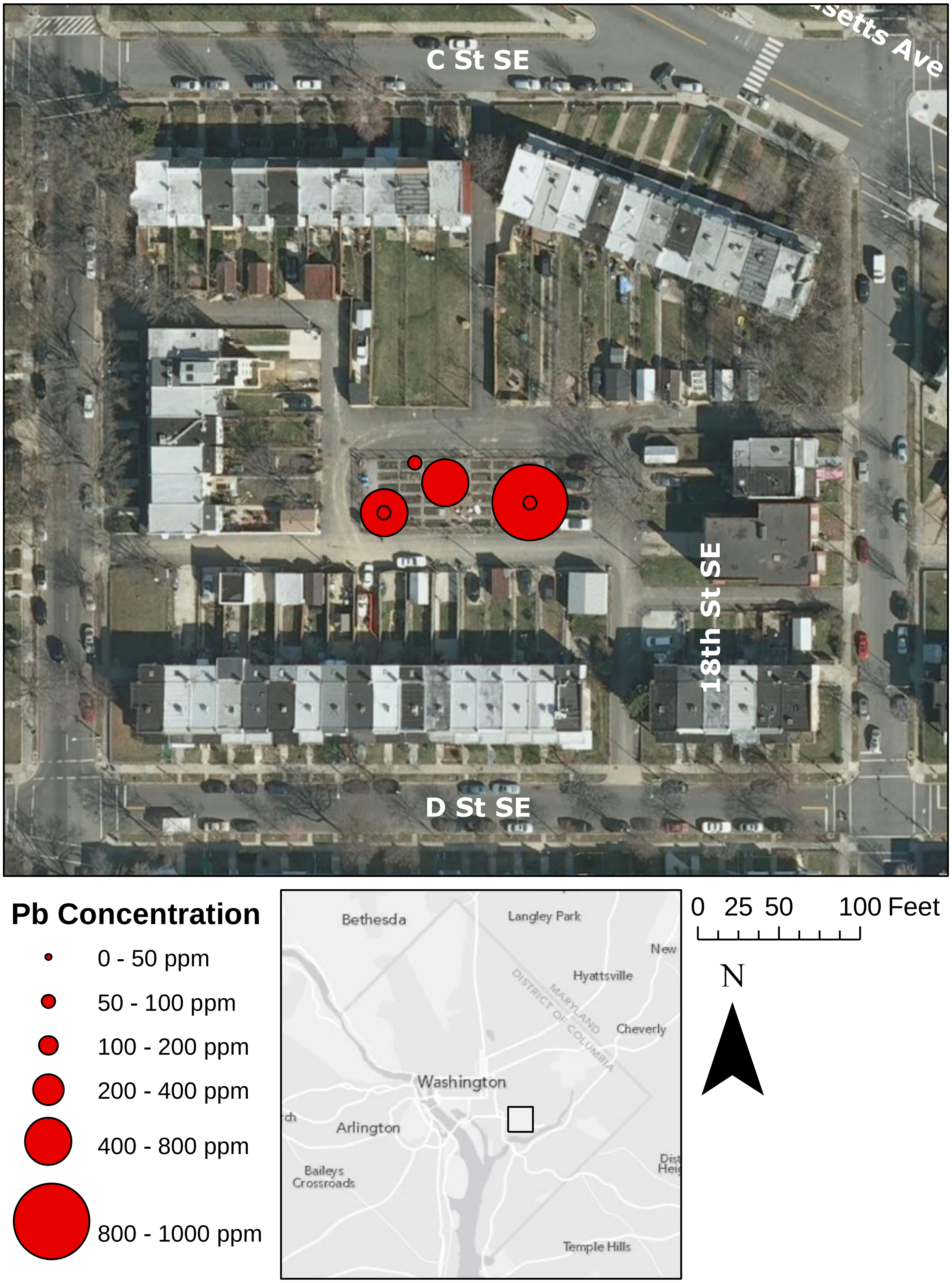

Fig. 5. Map showing a satellite view of the Hill East Community Garden with symbols representing the concentration of Pb at various sampling locations. Map created by Adam Long using ArcGIS 10.

organic matter than the deeper clays, on average, due to many years of gardeners working and amending topsoils with mulch (see Table 3). Overall, the element concentrations seen in the beads were of a similar magnitude to the concentrations determined using the pellet method, but they were all slightly higher due to the loss of SOM. However, the difference in reported Pb concentrations is not directly correlated to the percent loss of SOM, as on might expect, which could be due to experimental error, analytical error, or interference of other elements in the XRF spectra.

Overall, the implications of these lead concentrations largely mimic what was discussed in the overall lead trends section above. Even though the concentrations of Pb are over the US EPA limit of 400 ppm (and in one case twice as high), those numbers are only seen in deep soils, many of which are very compact and separated from the topsoil by a semi-permeable layer, which can help to prevent human contact with these soils. Gardeners at Hill East should be careful to prevent contact with the native clay soils and avoid mixing topsoil with these native soils. Further remediation steps could be taken and will be outlined in the conclusion.

In addition to Pb, zinc levels at Hill East were found to be higher than the average concentration in soils across DC, and may be a cause for concern. In urban settings, high levels of zinc in the soil are commonly seen near galvanized steel power structures and in other areas where galvanized steel is present or has been dumped (Ajmone-Marsan, 2010). Although trace amounts of zinc are vital to plant life, zinc can become toxic to plants at levels between 100 and 500 ppm. However, clays and SOM common in DC soils “are capable of holding Zn quite strongly” thus potentially limiting its bioavailability (Kabata-Pendias, 2010). For humans, zinc is often taken as a dietary supplement and is considered to be relatively nontoxic if ingested, however, ingesting amounts in excess of 100 mg per day can cause problems can occur (Fosmire,

1990). Because maximum Zn concentrations at Hill East were only about 600 ppm, gardeners would have to ingest over 1 kg of soil per week on a regular basis before they would notice any negative effects. This is highly unlikely, so while these zinc concentrations may have toxic effects on plants, they are not likely to cause harm to humans.

Conclusion

Overall, while the implications of high amounts of lead in soil can be serious for human health, the Pb concentrations in Washington, DC community gardens are most often in deep soils, many of which are very compact, which can help to prevent human and plant contact. While gardeners should take care to avoid mixing in the native orange clays with their topsoil, in general, the highest levels of Pb are not low enough that some recontamination of raised beds would cause significant problems. In the gardens closer to downtown, more care should be taken to prevent recontamination of topsoils using techniques that will be described below. Of course, as always, it is recommended that gardeners thoroughly wash their produce before consumption to remove any small particles of soil that might contain Pb.

The most commonly employed option for avoiding contact with contaminated soil is the construction of lined raised beds, which was seen in many urban community garden sites in Washington, DC. However, as mentioned above, studies have shown that fine dust with attached Pb can recontaminate soil in a short time period, and so other options must be pursued (Clark et al., 2008). Hill East Community Garden, which had some of the highest lead levels, built lined raised beds in addition to lining pathways with plastic, cloth, and mulch. Since topsoil Pb levels were still low even eight years after construction of this garden, it would appear that this method can help to prevent the Pb concentrated in soils underneath beds and paths from escaping and

recontaminating the topsoil, although further research should be done in a few years to see how topsoil Pb levels have changed over time.

Other remediation methods include “the excavation of soil, the application of soil/ground cover or barriers (e.g., pavement or grass), and the application of chelating agents or biosolids to remove/sequester Pb.” However, removing all of the contaminated soil at a garden and replacing it with uncontaminated soil is not a permanent solution due to windblown recontamination, and this method is extremely expensive. An easier alternative for raised bed gardens is to simply remove the top 3 – 5 cm of soil from a plot each year before any soil mixing is done, and then to carefully replace it with compost (Clark et al., 2008). Because Pb solubility and bioavailability correlates with pH, liming can help to “precipitate Pb as hydroxides, phosphates, or carbonates, as well as promote the formation of Pb-organic complexes that are rather stable,” which could also help to reduce the health risk of soils with high Pb. Although some argue that plants which accumulate Pb can be used to help remove Pb from the soil, others counter that this effect is negligible and that Pb soil pollution is essentially “irreversible” (Kabata-Pendias, 2010). Thus, learning to work around soil Pb contamination either by avoiding work in areas with high concentrations or using remediation methods is a recommended course of action.

Future work would involve investigating the mineralogy of DC soils to calculate what percentage of the Pb could have been from natural mineral sources versus what is conclusively anthropogenic. Studies could also be done using the EPA’s Site Specific SSL guidelines to create an SSL for the DC gardens, which would better help characterize the actual health risk involved for the average gardener working in or near contaminated soils. More detailed and complex studies could also be done to test samples from additional DC gardens, track Pb concentration

over time, created detailed soil profiles showing Pb concentration and depth, and to test for the actual bioavailability and actual intake of Pb among gardeners.

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