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Growing Greens and Soiled Soil: Trends in Heavy Metal Contamination in Vegetable Gardens of San Francisco

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GROWING GREENS AND SOILED SOIL:
TRENDS IN HEAVY METAL CONTAMINATION IN VEGETABLE GARDENS
OF SAN FRANCISCO

A Thesis

Presented to

The Faculty of the Department of Environmental Studies

San José State University

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

by

Jennifer Gorospe

May 2012

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The Designated Thesis Committee Approves the Thesis Titled

GROWING GREENS AND SOILED SOIL:
TRENDS IN HEAVY METAL CONTAMINATION IN VEGETABLE GARDENS
OF SAN FRANCISCO

by

Jennifer Gorospe

APPROVED FOR THE DEPARTMENT OF ENVIRONMENTAL STUDIES

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ABSTRACT

GROWING GREENS AND SOILED SOIL: TRENDS IN HEAVY METAL CONTAMINATION IN VEGETABLE GARDENS OF SAN FRANCISCO

by Jennifer Gorospe

As urban dwellers prioritize eating locally grown foods to reduce environmental impacts, benefit the local economy, and bring fresh produce to the table, urban gardening has emerged as a popular approach to improving food security. Researchers have shown previously that urban landscapes can accumulate environmental toxins at levels that may be unsafe for human health, with socioeconomically disadvantaged communities often shouldering an unequal burden of exposure. In order to identify and predict likely risk to gardeners, in this study, soil samples from 91 vegetable gardens in the city of San Francisco were analyzed for 16 heavy metals. A majority of the gardens exceeded the California Human Health Screening Level for arsenic (74%), cadmium (84%), and lead (62%), including nine gardens with lead levels above the hazardous toxic waste threshold for California. Cadmium and lead concentrations increased with home age, suggesting that older house paint is a major source of these metals. Contrary to findings in many other cities, the majority of gardens with hazardous lead levels in San Francisco were located in higher income and predominantly White neighborhoods, with no associations found with existing industrial contamination. Encouragingly, community gardens and raised beds had significantly lower average metal concentrations than backyard and in-ground gardens, respectively. Overall, the goal of this study is to illustrate the importance of providing access to soil testing and related education in order to support urban gardeners in their efforts to grow and consume healthy produce.

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List of Abbreviations and Acronyms

Government Agencies

Cal/EPA: California Environmental Protection Agency
DTSC: California Department of Toxic Substances Control
EPA: U.S. Environmental Protection Agency

Safe Level Guidelines

Biosolids: Land Application of Biosolids for Home Vegetable Gardens
Clean Water Act, EPA
CHHSL: California Human Health Screening Level
California Office of Environmental Health Hazard Assessment, Cal/EPA
RSL: Regional Screening Level for Superfund Sites,
Residential Soil, Region 9, EPA
TTLC: Total Threshold Limit Concentration of Toxic Substances
Characteristics of Hazardous Waste
Title 22, California Code of Regulations, Section 66261
California Department of Toxic Substances Control

Ten Most Common Heavy Metals in This Study

As:	Arsenic	Cu:	Copper
Ba:	Barium	Ni:	Nickel
Cd:	Cadmium	Pb:	Lead
Co:	Cobalt	V:	Vanadium
Cr:	Chromium	Zn:	Zinc

Miscellaneous Abbreviations

LOD: Limit of Detection
LOQ: Limit of Quantification
ppm: Parts per million

Introduction

Urban areas offer many desirable amenities, including jobs, schools, access to transit, the arts, and a diversity of cultures. In regions where human activity is concentrated, however, levels of environmental contaminants are often elevated (Aelion, Davis, McDermott & Lawson, 2009; Diamond & Hodge, 2007). Public health and environmental justice researchers have explored urban environmental health issues, including the sources of exposure to toxins, models for estimating risk, and disparities in exposure between different socioeconomic, racial, and ethnic groups. Much of this research has focused on lead exposure, in that lead affects many of the essential systems of the human body (Centers for Disease Control and Prevention, 2010). Lead-focused studies have covered a range of concerns from blood lead levels (Hernandez-Avila et al., 1996; Lanphear, Burgoon, Rust, Eberly & Galke, 1998) to the legacy of leaded gasoline (Hafen & Brinkmann, 1996; Mielke, Laidlaw & Gonzales, 2010). Risk assessment models have been used to predict negative health effects due to exposure to environmental toxins, including heavy metals (Morello-Frosch, Pastor & Sadd, 2001; Pastor, Morello-Frosch & Sadd, 2005). The findings of Morello-Frosch et al. (2001), Pastor et al. (2005), and others, who have compared exposure rates between groups, have shown that racial and ethnic minorities and lower income communities are often the groups most exposed to environmental contaminants nationwide (Diawara et al., 2006; Downey, Dubois, Hawkins & Walker, 2008).

Along with residents of many other urban areas, San Franciscans are concerned with the local environment and quality of life issues. For example, ongoing efforts by

local residents and government officials resulted in the recent closure of two outdated fossil fuel burning power plants (Arce, 2011). San Franciscans have also prioritized providing access to fresh and healthy food to all residents. Along with millions of Americans, many San Franciscans are struggling to keep healthy and nutritious food on the dinner table. In their 2010 annual report, the San Francisco Food Security Task Force reported that over 22,000 free school lunches are served to children every day, fewer than two thirds of local seniors receive the food assistance they need, and the number of local families receiving food stamps increased 18% from the previous year (Boule & Jones, 2010). In response, local residents have come together to form action groups, such as the Food Guardians, to work with local agencies and improve food security for at-risk communities (City and County of San Francisco, 2010).

Urban dwellers turn to growing their own fruits and vegetables for a variety of reasons, including home-grown produce being both less expensive and fresher than that available at local markets. This trend is unlikely to change, especially as food insecurity continues to rise. Thus, concerns related to the health and safety of urban gardening evoke such questions as:

- Is it wise to eat from gardens in areas where contamination is known or can be reasonably expected?
- Where do heavy metals in gardens come from?
- What can urban gardeners do to minimize heavy metals in their garden soil?

To date, relatively few scientific studies have been conducted to document heavy metal levels in existing U.S. urban gardens. Two recent studies on urban garden soils

took place in neighborhoods with known elevated lead levels in the Chicago (Finster, Gray & Binns, 2004) and Boston (Clark, Brabander & Erdil, 2006; Clark, Hausladen & Brabander, 2008) areas. Over 75% of the gardens tested in those studies had lead levels above the threshold considered safe for exposure by children under 6 years old by the U.S. Environmental Protection Agency (EPA) (2011b).

Clark et al. (2008) identified lead-based paint particulates as the primary contributor of lead to the Boston area gardens; however, contamination of urban soils has also been linked to land use (Alloway, 2004; Zhang, 2006). Specifically, researchers have paid significant attention to the distance to roadways (Manta, Angelone, Bellanca, Neri & Sprovieri, 2002; Markus & McBratney, 1996) and to industrial facilities (Aelion et al., 2009; Diawara et al., 2006). While heavy metal contamination of the urban environment has been appropriately studied as an issue of great importance to human health, the question of whether urban garden soils are a significant pathway of exposure to heavy metals remains unsatisfactorily answered.

Background

Heavy Metals: A Primer

The term “heavy metals” is an informal expression that refers to a loosely defined group of naturally occurring elements that exhibit metallic properties. Although there is no consensus as to what specific elements are heavy metals, the California Code of Regulations, Title 22 lists 17 metals of concern for the management of hazardous waste (Environmental Health Standards for the Management of Hazardous Waste, 2005).

These heavy metals, referred to as the ‘CAM17’ metals, include antimony, arsenic, barium, beryllium, cadmium, chromium, cobalt, copper, lead, mercury, molybdenum, nickel, selenium, silver, thallium, vanadium, and zinc. The CAM17 metals, excluding mercury, are the focus of this study.

Levels of heavy metals, like many environmental toxins, can be elevated in urban soils as a direct result of human activities. Sources in urban areas can include airborne particulates from industry or vehicle emissions, contaminated fill, construction and demolition, aging paint, runoff, fires, and other historical land uses, with site specific garden soil contamination resulting from fertilizer and pesticide use, building gardens on brownfields, and the introduction of toxins through individual gardeners’ actions (Alloway, 2004; Diamond & Hodge, 2007; Douay, Roussel, Fourrier, Heyman & Chateau, 2007). While much of the existing research on exposure to heavy metals through soil has focused on lead, a growing number of studies have been designed with a broader focus that includes other metals such as arsenic, cadmium, chromium, cobalt,

copper, mercury, nickel, vanadium, and zinc (Diawara et al., 2006; Manta et al., 2002; Markus & McBratney, 1996; Sipter, Rozsa, Gruiz, Tatrai & Morvai, 2008).

Safe Levels

Negative health effects from chronic or extreme exposure to heavy metals have been widely documented. These negative effects include the effect of lead on the nervous system, especially in children, and the contribution of cadmium to lung cancer and kidney damage (Centers for Disease Control and Prevention, 2010). Various government agencies have published guidelines of the heavy metal levels they deem safe in soil for various land use types, such as residential and industrial areas. There is no consensus between agencies, however, as to what quantities and/or duration of exposure is actually safe. The EPA's Land Application of Biosolids for Home Vegetable Gardens (Standards for the Use or Disposal of Sewage Sludge, 40 C.F.R. § 503.13, 1997; U.S. Environmental Protection Agency, 1995) is the only set of guidelines in the U.S. which specifically considers risks from the consumption of home-grown vegetables (Table 1).

Other regulatory thresholds of metals that are relevant to gardeners include the EPA's Regional Screening Levels (RSLs) (2011b) and the California Environmental Protection Agency's (Cal/EPA) Human Health Screening Levels (CHHSLs) (2010) for residential soil (Table 1). RSLs represent target levels of each metal in soil at remediated Superfund sites and are intended to reflect tolerable exposure for risk in areas where children under six years old play (EPA, 2011a). The RSLs have been used as the baseline safe levels in several studies on residential soils (Clark et al., 2008; Finster et al., 2004; Lanphear et al., 1998).

Table 1. *Recommended Limits of Heavy Metals in Soil (ppm)*

	Total Threshold Limit (TTLC) for Toxic Substances ^a	Land Application of Biosolids for Vegetable Gardens ^b	Regional Screening Level ^c (RSL)	Cal. Human Health Screening Level ^d (CHHSL)
Metal Levels				
Antimony	500	-	31	30
Arsenic	500	41	39	0.07
Barium	10,000	-	15,000	5,200
Beryllium	75	-	160	16
Cadmium	100	39	70	1.7
Chromium	2,500	-	120,000	100,000
Cobalt	8,000	-	23	660
Copper	2,500	1,500	3,100	3,000
Lead	1,000	300	400	80
Mercury	20	17	23	18
Molybdenum	3,500	-	390	380
Nickel	2,000	420	1,500	1,600
Selenium	100	100	390	380
Silver	500	-	390	380
Thallium	700	-	0.78	5
Vanadium	2,400	-	390	530
Zinc	5,000	2,800	23,000	23,000

Table 1. *Recommended Limits of Heavy Metals in Soils (ppm) (Continued)*

Total Threshold Limit (TTLC) for Toxic Substances ^a	Land Application of Biosolids for Vegetable Gardens ^b	Regional Screening Level ^c (RSL)	Cal. Human Health Screening Level ^d (CHHSL)
Details			
Above this level, soil is considered hazardous waste in California.	For compost made from sewage sludge. Considers incidental soil ingestion and eating produce.	Safe for children under 6 at remediated Superfund sites. Considers ingesting soil.	“Below thresholds of concern for...human health.” Considers ingesting soil.
Agency			
California Code of Regulations, Title 22	EPA Clean Water Act 40 CFR Part 503.13	EPA Region 9	Cal/EPA Office of Environmental Health Hazard Assessment
^a Environmental Health Standards for the Management of Hazardous Waste (2005)			
^b Standards for the Use or Disposal of Sewage Sludge, 40 C.F.R. § 503.13 (1997)			
^c EPA (2011b)			
^d Cal/EPA (2010)			

The CHHSLs consider exposure through “incidental soil ingestion, dermal contact, and inhalation of vapors or dust,” and represent concentrations “below thresholds of concern for risks to human health” (Cal/EPA, 2005, p. 5). While the consumption of produce is not a factor considered in the CHHSLs, they are the most recently developed guidelines and likely the most conservative estimation of what levels are safe. The Department of Toxic Substances Control (DTSC) recommends that the EPA’s Region 9 adopt the CHHSLs for arsenic and lead since the corresponding RSLs represent a risk for cancer that is 4 times greater (DTSC, 2011b). The EPA’s 1997 Biosolids guideline levels are higher than the CHHSLs for arsenic, cadmium, and lead, even though the CHHSLs do not consider ingestion of produce, as the Biosolids levels do.

The Total Threshold Limit Concentrations (TTLCs) define what levels of heavy metals and other substances are considered hazardous waste in California (Environmental Health Standards for the Management of Hazardous Waste, 2005). The TTLCs are a useful point of reference for “unsafe” levels in general, although they consider characteristics such as pH, ignitability, likelihood of exploding, and general toxicity, rather than direct impacts on human health.

Heavy Metals and Gardens

While acceptable levels for chronic exposure are unresolved, researchers have used soil testing, absorption analyses, and risk assessment models to assess if gardens serve as significant pathways of exposure to heavy metals. Through a study that examined urban gardens in two Chicago neighborhoods, Finster et al. (2004) found that more than 75% of garden soil samples had lead concentrations greater than the RSL of

400 parts per million (ppm). The mean for these gardens was 800 ppm, 10 times greater than the CHHSL for lead. In the Boston area, Clark et al. (2008) tested soil from 141 gardens in two neighborhoods. Lead levels from this study ranged from 80 to 3680 ppm, with a mean of 950 ppm. Only 12% of the study's gardens were below the RSL for lead. While both of these studies were conducted in areas where the children were known to have elevated blood lead levels, the findings verify that the lead levels in some gardens are above what is considered safe for young children by the EPA.

Bioaccumulation and Bioavailability

Exposure to heavy metals through garden-related activities occurs through ingestion of soil (hand to mouth) and through eating crops that have metals in their tissues or on their surfaces. In analyzing the mechanisms involved in the accumulation of metals in the tissues of various crops, researchers have found that crops accumulate and sequester metals uniquely (Ebbs, Talbott & Sankaran, 2006; Grant, Buckley, Bailey & Selles, 1998; Pillay & Jonnalagadda, 2007). For example, in general, lead tends to accumulate in roots more than the shoots, leaves, and fruits of many crops (Finster et al., 2004). More specifically, Sipter et al. (2008) showed that vegetable crops absorb cadmium and zinc from the soil at higher rates than lead, and that sorrel and carrots are greater accumulators of these metals than beans and squash. Golia, Dimirkou, and Mitsios (2008) found that tomatoes are poor accumulators of cadmium, with lettuce and potatoes accumulating cadmium at only slightly higher rates. Finster et al. also looked at how different methods of washing produce could reduce the consumption of lead particulates located on the surface of crops. Results indicated that lead-containing dust

on urban-grown crops, especially leafy greens, could be a considerable source of exposure, although most of the lead dust was easily removed by scrubbing plant surfaces with soap and water (Finster et al.). Bassuk (1986) also found that by washing lettuce leaves that had been exposed to leaded gasoline emissions in either a 1% vinegar solution or a 0.05% soap solution was effective at removing a majority of surface lead.

Once prepared and eaten, our bodies absorb only a percentage of the metals contained in our food. Intawongse and Dean (2006) modeled the human gastrointestinal tract and reported that between 45 and 62% of cadmium, copper, and zinc in certain vegetables were available for absorption as a result of digestive processes. Nutrition can also influence absorption rates, with diets deficient in iron (Mahaffey, 1990) and calcium (Farias et al., 1996; Hernandez-Avila et al., 1996) having been linked to elevated blood lead levels.

The quantity of a particular heavy metal in soil that is bioavailable to plant crops varies based on factors such as soil type, the presence and quantity of other metals, and pH. The relationship is complex, with no simple rule of thumb to help a gardener limit their exposure. With regards to pH, perhaps the simplest factor to control, Golia et al. (2008) found absorption levels of cadmium, chromium, lead, and nickel by crops negatively correlated with soil pH. Madejon, Madejon, Burgos, Perez de Mora, and Cabrera (2009) found significant negative correlations with soil pH and the bioavailability of cadmium, copper and zinc. Additionally, Grant et al. (1998) found that cadmium absorption by crops tended to decrease with increasing pH, with factors such as crop type and soil characteristics influencing the rate of absorption.

Heavy Metals in Soils

Direct contact with soil may be a more significant pathway of exposure to heavy metals than consumption of produce, especially for young children. Clark et al. (2008) modeled different exposure pathways for children aged two to six. The conclusion of the study was that the consumption of garden produce contributed only between 2 and 3% of a child's daily intake of lead, whereas the ingestion of soil, including garden soil, represented between 72 and 91% of their daily lead intake. Although not specifically studying garden soil, Lanphear et al. (1998) found that blood lead levels of children in Rochester, NY were specifically tied to the level of lead in the soil around their home. Between homes with a low level of soil lead (1 ppm) and homes with soil lead greater than the RSL (400 ppm), Lanphear et al. found a 12% increase in the number of children with blood lead levels over the Center for Disease Control's action level of 10 µg/dl.

Regardless of the source of contamination, chronic exposure to soil with unsafe heavy metal levels and the consumption of produce grown in these soils is not desirable. Researchers (Hough et al., 2004; Sipter et al., 2008; Zheng, Wang & Zheng, 2007), the EPA (2011a), and Cal/EPA (2005) all estimate risk of exposure to heavy metals in soil by calculating hazard quotients. A hazard quotient is a ratio of the average daily dose of a toxin to its reference dose, as predetermined by government agencies. The hazard index is the sum of hazard quotients calculated for all toxins an individual is exposed to, from all possible pathways. If the hazard index is > 1 for a community, residents are at risk for negative health effects at some point during their lifetime. Hough et al. (2004) estimated that 11% of typical gardeners in the UK had a hazard index > 1 , and Zheng et al. (2007)

calculated a hazard index > 1 for adults and children who ate produce from gardens in a Chinese town that had an active zinc plant.

Sources of Heavy Metals in Urban Soils

As a way to reduce exposure, researchers have sought to identify specific sources of heavy metals in urban soils. The influence of vehicle emissions on soil lead levels has been analyzed frequently; with many studies showing lead levels being elevated near high traffic roads (Manta et al., 2002; Markus & McBratney, 1996; Zhang, 2006). Surprisingly, some studies have found that the legacy of leaded gasoline is not as influential as many studies indicate. For example, Hafen and Brinkmann (1996) reported only a very weak negative correlation between lead levels and distance from an urban interstate highway. They also found lead levels increasing with distance from the highway in over half of their transects, indicating that vehicle-related lead deposition was not the only source of lead in the area (Hafen & Brinkmann).

The results of two other studies support the notion that leaded gasoline plays a limited role in urban soil contamination. In analyzing lead particulates taken from urban garden soils, Clark et al. (2008) found that between 40 and 80% of soil lead was derived from lead-based paint, with a combination of leaded gasoline and other sources comprising the residual lead that was found. Additionally, Norra, Weber, Kramar, and Stuben (2001) found mean lead levels in the city of Karlsruhe, Germany to be higher in residential areas than in high traffic areas and industrial zones. Germany, along with many European nations, began phasing out lead-based paint in the 1920s, which may explain why lead levels around homes built before 1920 were found to have the highest

overall lead levels in the study. Average lead levels by land use type in Karlsruhe were 160 ppm for homes built before 1920, 120 ppm across all residential areas, 117 ppm in high traffic areas, 112 ppm in industrial zones, and 111 ppm in gardens (Norra et al.). The authors cited the background lead level in soils across Europe as 11.4 ppm.

As indicated by the findings by Norra et al., land use history and zoning can be related to the contamination of urban soils. In a case study of New York City, Maantay (2001) found that industrial areas inhabited by Whites/Anglos and affluent residents were frequently re-zoned, thus pushing the burden of industrial uses onto less affluent residents and communities of color living in and around the remaining industrial zones. Not surprisingly, industrial facilities themselves have been the focus of many inquiries into metal contamination in urban areas. In non-garden soils of Pueblo, Colorado, Diawara et al. (2006) surveyed metal contamination near ore smelting facilities and found elevated lead levels in low-income Hispanic and African American neighborhoods. Aelion et al. (2009) found significant negative correlations between the distance to many industrial facilities and soil lead levels of barium, chromium, lead, and nickel.

While potential sources of contaminants in urban areas seem endless, are urban soils really more contaminated than soils in less densely populated areas, such as the rural communities that grow most of the county's food? In a comparison of soils collected from two rural areas and one urban area, Aelion et al. (2009) found lower mean concentrations of 8 different metals, including arsenic, chromium, lead, and nickel in the two rural areas. A long history of illegal dumping of industrial waste, however, has plagued many rural areas. In 1899, the federal government passed the first law aimed at

controlling the quality of the country's waterways. The Refuse Act made it illegal to dump "foreign substances and pollutants" into navigable waterways without a permit, although the law was not properly enforced until the early 1970s (Degler, 1971).

Individuals began filing lawsuits against polluters at the beginning of the twentieth century, which resulted in many polluting industries relocating to less populated areas such as the Mid-West and northeastern states (Colten, 1994). In moving to less populated areas, businesses could pollute with little oversight or outcry, and avoid lawsuits over contamination issues (Colten). While it is unlikely that food found in grocery stores today has been grown on sites where dumping of industrial wastes has occurred, it is a reminder that rural areas are not necessarily pristine.

Patterns in Exposure

Research has shown that, in California and nationwide, certain demographic and socioeconomic groups have the highest rates of exposure to environmental toxins.

Morello-Frosch et al. (2001) examined rates of exposure to airborne toxins, community health statistics, and neighborhood demographics in Southern California in order to create a snapshot of cumulative risk by ethnic group. Their findings indicated that communities of color had the highest risk of developing cancer through exposure to environmental toxins. Hispanics had an estimated lifetime risk for cancer of 65 individuals out of every 100,000 people, while African Americans and Asians both had a risk of 63 per 100,000. Anglos/Whites had the least risk of developing cancer, at 49 per 100,000. Pastor et al. (2005) scrutinized the relationship between ethnicity and exposure to airborne toxins throughout California. The researchers observed that as air pollution

levels increased in census tracts, Hispanic populations increased. Alternatively, the number of Anglos/Whites decreased as pollution levels increased.

Lower socioeconomic status has also been associated with increased exposure to pollutants. Those of lower socioeconomic status may be exposed to conditions that increase their risk of developing health problems due to exposure to heavy metals. Such conditions include poor diet and insufficient quantities of food (Mahaffey, 1990), as well as living in high density and low-quality housing (Adler & Newman, 2002). Diawara et al. (2006) found that lower income communities in Pueblo, Co, which were predominately African American and Hispanic, were more likely to be living near areas contaminated with cadmium and lead than other groups. In Southern California, Morello-Frosch et al. (2001) found lifetime cancer risk negatively correlated with median household income.

While specific patterns have emerged showing disparities in exposure to environmental toxins, the findings of some location-based studies indicate that every city is different and therefore should be assessed based on its own unique mix of demographic and socioeconomic factors. For example, Downey et al. (2008) examined the role ethnicity plays in exposure to hazardous pollutants on a nationwide scale and found unexpected results: every ethnic group was the most exposed group in at least some of 329 cities studied. African Americans and Hispanics had the greatest risk of exposure to environmental toxins in 32% and 22% of the cities analyzed, respectively. The least “burdened” groups nationwide, Asians and Whites were the most exposed groups in 11% and 4% of the cities, respectively. This finding exemplifies that exposure rates by distinct racial, ethnic, and socioeconomic groups should be verified on a case by case

basis, rather than assuming that exposure levels follow these significant, but not universal, trends.

Strategies to Reduce Metals Levels in Gardens

Regardless of a gardener's ethnicity, race, or household income, certain garden types have shown the potential for limiting amounts of heavy metals in soils. In one of only a few studies that tested soils from community gardens, Preer Sekhon, Weeks, and Stephens (1980) found that community gardens in Washington, D.C. had slightly lower levels of lead than backyard gardens. On the other hand, Stilwell, Rathier, and Musante (2008) found significantly higher levels of lead in produce grown in Connecticut community gardens than in store-bought produce, although levels were not significantly different for arsenic, cadmium, chromium, or nickel.

Clark et al. (2008) found that raised beds tend to have lower lead levels than gardens where crops are sown directly into the existing soil. In their study, 118 existing in-ground gardens and 23 newly constructed raised beds were monitored over four years. The mean soil lead level for all gardens was 950 ppm, with raised beds averaging only 336 ppm. The mean lead concentration in the raised beds more than doubled over the four years of the study, indicating that active sources of lead contamination were nearby, although significant variation occurred from year to year (Clark et al.). Overall, raised beds may be effective at limiting lead concentrations in garden soils, but they do not eliminate re-contamination from airborne particulates. Raised beds require an initial investment of time and money to build and fill with soil, limiting their use as a gardening strategy to those with the resources to create them.

Research Questions

This study was designed to inventory a diversity of heavy metals in garden soils throughout a heterogeneous urban area, identify sources of contamination, assess whether nationwide patterns in exposure to environmental toxins are applicable to heavy metal exposure by vegetable gardeners in San Francisco, and identify gardening strategies that can reduce exposure. The primary questions considered included:

General

- On average, are metal levels below published guidelines for human health?
- Are certain heavy metals more likely to be found together than others?

Land Use

- Does proximity to high-traffic roads affect levels of heavy metals?
- Is there a relationship between the age of homes and metal levels?
- Does land use designation predict heavy metal concentrations?
- Are gardens in neighborhoods with a history of known industrial contamination more likely to have higher levels of heavy metals?

Ethnicity, Race, and Income

- Do gardens in low-income neighborhoods have elevated metal levels?
- Do predominantly White/Anglo neighborhoods have lower levels of metals than communities of color?

Garden Management

- Are community gardens and school gardens safer than backyard gardens?
- Do raised beds have lower metal levels than in-ground gardens?

Methods

Study Area

San Francisco prides itself on being a hub of the locavore movement, with many residents and restaurants purchasing meats, dairy, and produce grown within a 100-mile radius rather than ingredients obtained from further afar. In 2011, urban agriculture proponents worked with local politicians to approve zoning ordinance modifications that permit agriculture throughout San Francisco and allow growers to sell their products at their farm or garden site (San Francisco Planning Code Amendment, Urban Agriculture, 2011). Land is at a premium in this 121.7 km² city, yet there are more than 75 school gardens, 51 official community gardens, and an untold number of unofficial community and backyard gardens (San Francisco Garden Resource Organization, 2011). Both the abundance of existing gardens and the likely increase in urban farms in the near future due to 2011 zoning changes singled out San Francisco as an ideal location for studying the presence and distribution of heavy metals in urban gardens.

The study area for this project consisted of five contiguous zip codes in the south and east of San Francisco: 94107, 94110, 94114, 94124, and 94134 (Figure 1). The zip codes were chosen for their unique mixture of racial/ethnic and economic demographics.

Figure 1. Study area zip codes in San Francisco, CA.

As of 2000, the most recent year that census data for income are available at this resolution, three of the zip codes had an annual median household income below the citywide average of \$55,221 (U.S. Census Bureau, 2000d) (Table 2). Four of the five zip codes had a majority population representing a different racial or ethnic group (U.S. Census Bureau, 2000c), with the fifth zip code (94114) having a much higher median household income (Table 2).

Table 2. *Study Area Demographics*

Zip Code	Dominant Racial or Ethnic Group ^a	% Population of Dominant Ethnic Group ^a	2000 Median Household Income ^b	Median Income, Reported by Participants
94107	White/Anglo	62.40%	\$61,362	\$75,000
94110	Hispanic	46.10%	\$53,795	\$70,000
94114	White/Anglo	82.90%	\$75,727	\$100,000
94124	African American	48.00%	\$37,146	\$75,000
94134	Asian	51.50%	\$54,342	\$60,000
^a U.S. Census (2000c)				
^b U.S. Census (2000d)				

Study Design

Recruitment and community engagement. To be eligible to participate in this project, a gardener had to have tended a garden during 2010-growing season that was located within the study area, and have eaten produce from that garden. Eligible gardeners had to complete an anonymous survey outlining their gardening habits (Appendix B). During the summer of 2010, gardeners were recruited at a variety of public venues such as farmers' markets, garden supply stores, and garden-related events.

Literature about the project was translated into Spanish, Vietnamese, Chinese, and Tagalog, with Spanish and Chinese interpreters attending some recruitment events. Information about the project was distributed via email to coordinators of community gardens, school gardens, and private gardening organizations, with articles appearing in neighborhood papers also contributing to the recruitment effort. A free educational meeting was held in each of the five target zip codes to provide a forum for gardeners to learn about issues specific to the presence of heavy metals in gardens.

Surveys and informed consent. Eligible participants were asked to read an Informed Consent document (Appendix A) and complete a one-page anonymous survey (Appendix B). The survey asked for approximate garden location using cross streets, types of crops grown for food, ethnicity and/or race, and household income. The survey was pilot tested with 15 low- to moderate-income gardeners of different ethnic and racial groups to improve usability. To maintain anonymity, the completed surveys collected at recruitment events were kept separate from the gardener's contact information.

In advance of the soil sampling visits, participating gardeners were provided with a copy of the Agreement to Participate in Research Consent Form (Appendix C). During the site visit, the gardener and researcher each signed two copies of the Consent Form prior to collecting a soil sample. Each party kept a copy of the form.

Approval from San José State University's Human Subjects Institutional Review Board was secured before data collection commenced (Protocol #S1002050). The surveys and informed consent documents were translated into Spanish, Vietnamese, Chinese, and Tagalog. The Department of World Languages and Literatures at San José State University verified all but the Tagalog translations. Dr. Pia Arboleda, an assistant professor of Filipino and Philippine Literature at the University of Hawaii, verified the Tagalog translations.

Participating Gardeners

Of the 191 eligible gardeners recruited to participate, 20 gardeners from each zip code were selected using a random number generating script in Microsoft Excel® 2008 for Mac (v. 12.3.1). When notified of their selection status, all

gardeners were provided with an electronic version of an informational pamphlet on heavy metals and gardening (Appendix D). Those not selected to participate also received information on how to conduct soil testing on their own. If a selected gardener did not schedule a soil-sampling visit within two weeks, they were contacted again in an attempt to secure their participation. If no contact was made within three weeks, the gardener was dropped from the project and another gardener was offered a chance to participate. Each selected gardener was eligible for one free soil test at his or her garden. Multiple plots in a community garden were tested only if several gardeners had signed up for the study and two or more were selected.

Certain zip codes had many more interested gardeners than others (Table 3).

Table 3. *Breakdown of Gardeners*

Zip Code	Interested Gardeners	Gardens Tested	Gardens Included in Statistical Analyses
94107	25	20	18
94110	76	20	17
94114	33	20	20
94124	29	20	17
94134	28	20	19
	<i>N</i> = 191	<i>N</i> = 100	<i>N</i> = 91

While word of the study passed easily through email and list serves in the 94110 neighborhood, extra outreach efforts were conducted in the zip codes with fewer initial recruits. This included posting fliers in laundromats and libraries, engaging with neighborhood groups, and contacting churches and local newspapers.

While 20 gardens were tested in each zip code, 9 gardens were excluded from the statistical analyses as explained in the Soil Sampling Protocol section below.

Garden Visits

Garden sites were fully documented on a data collection form (Appendix E) as part of each site visit. Documentation included a hand-drawn map identifying the location of raised beds, in-ground garden plots, planters, nearby buildings, and specific soil sampling sites. Gardeners were asked questions related to the history of the garden site and their use of compost, pesticides, and fertilizers. Participants completed the one-page survey (Appendix B) again, this time including their name so their demographic information could be coupled with soil test results.

Soil Sampling Protocols

A variety of methods have been used in previous studies for collecting garden soil samples. Clark et al. (2006) collected four samples at each garden site, two between 0 and 10 cm and two between 30 and 40 cm. Finster et al. (2004) collected composite samples consisting of four subsamples collected from the top 7.6 cm. Douay et al. (2007) collected samples from the top 25 cm, with between 15 and 20 subsamples used to create each composite sample. Both Sipter et al. (2008) and Zheng et al. (2007) collected soil from around plant roots at depths from 0 to 20 cm. At each garden in San Francisco, three subsamples were taken from either raised beds or in-ground gardens. For each subsample, a hole between 8 and 12 cm in depth was dug, and a slice of soil was taken along the entire depth of the hole. This was done in order to capture changes in metal

levels throughout the soil profile. The three subsamples were mixed together to create a single composite sample.

When choosing subsample locations, a few factors were considered. First, each subsample needed to be close to food crops (or where food crops were recently grown), but far enough away from existing plants to minimize injury to existing root systems. To ensure consistency, each composite sample was composed of subsamples taken from areas with similar soil origin, garden type (e.g., raised bed or in-ground garden), or proximity to a structure. Of the 100 vegetable gardens sampled, nine gardens were ultimately excluded from the statistical analyses because their subsamples were collected from a mixture of raised bed and in-ground sources, limiting their utility in comparisons between garden types. These nine gardens, however, are included in the maps.

Specific criteria were developed to distinguish raised beds from in-ground gardens. Raised beds were considered areas where garden soil was at least partially separated from the existing soil by a barrier and the soil surface was above the surrounding grade. This included stand-alone containers such as planters and pots, as well as raised beds that were built on top of the existing soil. Retaining walls were used to create gardens in that much of the study area had hills. These gardens were considered in-ground gardens if their average slope approximated the surrounding natural grade.

When collecting each subsample, mulch and debris on the soil surface was first moved aside. Using a clean, stainless steel trowel, subsamples were collected and placed in a paper bag inside of a Ziploc bag. All bags were labeled with the date and site location code (Custo et al., 2005). The trowel was rinsed and wiped clean between

gardens. Gardeners were asked to refrain from watering for a day before the soil sampling, so the soil would be fairly dry. Soil samples that were overly moist were air dried in a cool location. Once dry, the samples were crushed until they could be sifted through a 2 mm brass sieve. The sample was then placed back into the bag, mixed, and run through the sieve again. A sample of approximately 100 g was separated out for testing by making diagonal passes through the mounded, sifted soil with a beaker.

Soil Testing Protocols

MACS Laboratory Inc. (MACS Lab), an Environmental Laboratory Accreditation Program (ELAP) laboratory formerly of Hayward, CA, conducted the soil analyses. Accreditation by ELAP permits a lab to conduct certain analyses of “Inorganic Chemistry & Toxic Chemical Elements of Hazardous Waste” for government agencies in California (California Environmental Laboratory Improvement Act, 1988). The soils were digested using EPA SW 846 Method 3050B: Acid Digestion for Sediments, Sludges, and Soils (Finster et al., 2004), and analyzed using NIOSH Method 7300 (Elements by ICP) (National Institute for Occupational Safety and Health, 2003) on a Thermo Jerrell Ash ICAP 61E Trace Analyzer. The laboratory determined pH using a Corning 430 pH meter. Even though all samples were tested for mercury, Method 3050B is not an EPA approved method for this metal, and thus mercury was excluded from this study.

Soil Test Results

MACS Lab provided the test results as individual soil analysis reports. Each participant was provided with a copy of the report for their garden, a letter explaining the initial findings of the study (Appendix F), a copy of the table of safe levels (Table 1), and

an updated version of the pamphlet on heavy metals (Appendix D). All of the 191 eligible gardeners were contacted with the link to the project website that summarized the initial findings, explained how to collect soil samples for testing, listed government published thresholds, and included garden-related information on heavy metals. The website can be accessed at <https://sites.google.com/site/healthygardeners/>.

Statistical Analyses

PASW® Statistics (ver. 18.0.3) was used for inferential statistical analyses. Alpha was set at 0.05 and the sample size was 91 for most statistical tests, unless otherwise noted (Table 4). For example, community and school gardens were excluded from all analyses with ethnicity, race, and income, because gardeners with a diversity of backgrounds often shared the same garden. Also, only backyard gardens were included in tests involving home age, because they were the only gardens directly associated with an adjacent building. Additionally, when examining the relationship between zoning designation and heavy metal levels, so few gardens existed in industrial, mixed-use, and commercial zones that these zones were excluded from these tests.

Table 4. *Summary of Methods*

Variable	Test	n	Transforms	Data Sources and Notes
Safe Levels and Relationships	Chi-Square	$N = 91$		Safe = CHHSL Unsafe = in-between Hazardous = CA Toxic Waste
Vehicle Traffic: Distance and Longitude	Pearson's Correlation Mann-Whitney Regression	$N = 91$	$\ln(\text{As} + 1)$ $\ln(\text{Pb})$	Distance and longitude determined using ArcGIS
Home Age	Regression Mann-Whitney	$n = 65$	$\ln(\text{As} + 1)$ $\ln(\text{Pb})$	San Francisco Assessor-Recorder; Backyard gardens only.
Zoning Designation	ANOVA	Residential = 68 Public = 12	(1/Pb)	San Francisco Enterprise GIS
Known Contamination / Zip Codes	ANOVA with a Priori Comparisons	94107 = 18 94110 = 17 94114 = 20 94124 = 17 94134 = 19	$\ln(\text{Cd} + 1)$ $\ln(\text{Pb})$	Comparisons based on DTSC citing 94107, 94124 and 94134 with multiple industrial contamination sites.
Income	Regression	$n = 48$ Reported Income	$\ln(\text{As} + 1)$ $\ln(\text{Pb})$	San Francisco Enterprise GIS (base map), American Fact Finder (census data);
Race/Ethnicity	ANOVAs	Asian = 10 African Amer. = 4 Hispanic = 6 White/Anglo = 45 Non-White = 22 White/Anglo = 43		TIGER (census boundaries); Backyard gardens only.
Backyard, Community and School Gardens	ANOVA Descriptive	Backyard = 65 Community = 22 School = 4	$\ln(\text{As} + 1)$ $\ln(\text{Cd} + 1)$ (1/Pb)	Community gardens had shared plots, not all were official community gardens.
In-Ground and Raised Bed Gardens	ANOVA Regression	In-Ground = 66 Raised Beds = 25 $n = 66$	$\ln(\text{As} + 1)$ $\ln(\text{Cd} + 1)$ $\ln(\text{As} + 1)$ $\ln(\text{Pb})$	pH with in-ground gardens.

Preparation of Data

Of the 100 San Francisco gardens tested, three metals had at least one sample that was below the laboratory's limit of quantification (LOQ). In a review of the methods used for datasets that include values above zero but below the LOQ, Finkelstein and Verma (2001) found that instead of simply excluding these data points, many researchers replaced these undetectable values with values derived using the Limit of Detection (LOD). The LOD is based on the method of analysis and the substance being tested for.

Croghan and Egeghy (2003) found that replacing undetectable values with 0 did not result in significant differences between the actual and derived means in normally distributed datasets if the replacements occurred in 5% or less of the data points. In the San Francisco study, cadmium and vanadium had 3% and 1% of soil samples below the LOQ, respectively, allowing for the undetectable cadmium values to be replaced with 0. Vanadium was ultimately excluded from the statistics, so no replacements were made.

At or below a 25% replacement rate, Croghan and Egeghy (2003) found no significant difference in the means when substituting undetectable values with values calculated by dividing the LOD by the square root of 2 [$\text{LOD} / (\sqrt{2})$]. In the San Francisco study, 26% of gardens had arsenic levels below the LOQ. It was assumed that a 1% increase over this replacement rate would not substantially increase the error rate, thus the substitution was made for the 24 samples with undetectable arsenic levels. The arsenic LOD of 0.0056 ppm was acquired from the National Institute for Occupational Safety and Health's Manual of Analytical Methods (2003) for Method 7300, with the resulting replacement value calculated as follows: $[(0.0056) / (\sqrt{2})] = 0.00396$ ppm.

Statistical Tests

Significant relationships between metals with a skewness $< |2.0|$ were tested using Pearson Product Moment Correlation. Pearson's was also used to identify significant relationships between metal levels and distance to roadways (Aelion et al., 2009; Hafen & Brinkmann, 1996) and pH (Madejon et al., 2009). The Chi-Square Goodness of Fit test was used to determine if the differences between observed and expected levels of metals were significant. For this test, gardens were placed into three categories based on their observed concentration: (a) *safe* (below the CHHSL), (b) *hazardous* (above the TTLC), and (c) *unsafe* (between *safe* and *hazardous*).

Regressions were used to identify relationships between metal levels and continuous variables including longitude, home age, and income. To conduct the regressions, variables were transformed until they had a skewness of $< |2.0|$ and Kurtosis of $< |3.0|$. To achieve this, arsenic and lead were natural log transformed as $\ln(\text{As} + 1)$ and $\ln(\text{Pb})$. For the regressions, if $p < \alpha$ (0.05), a significant relationship was assumed. Of equal importance is the predictive power of the model as seen through the r^2 -value. As r^2 approached 1, indicating that more of the data points conform to the model, the relationship between variables increased in predictive power. For example, if a significant relationship between two variables was observed (i.e., $p < 0.05$), but the r^2 -value was close to zero, the regression was determined to be only weakly predictive.

Analysis of Variance (ANOVA) was conducted to identify differences in mean metal levels between categorical variables such as zoning designation, zip code, ethnicity and race, backyard and community gardens, and raised bed and in-ground gardens. If the

p -value for Levene's Test of Homogeneity of Variances for a variable was < 0.05 , it was transformed until $p > 0.05$. Variables were transformed as listed in Table 4. If the means of different metals varied significantly with an independent variable with greater than two levels, a priori comparisons were conducted. A priori comparisons were employed when looking at areas of known contamination, with the two groupings formed being (a) zip codes with one or more California Department of Toxic Substances Control's (DTSC) hazardous waste sites within its boundaries, and (b) zip codes without a DTSC site.

Additional t -tests were conducted to determine if significant differences existed between two independent variables between populations. If Levene's Test of Homogeneity of Variances resulted in $p < 0.05$, the non-parametric Mann-Whitney U test was used rather than the t -test. Mann-Whitney was used for identifying differences in metal levels between two distinct groupings for distance to high traffic roads (within and beyond 750 meters from high traffic roadways) and home age (homes built within the past 75 years and homes built earlier than that).

Spatial Analyses

Maps were created with ESRI® ArcGIS™ (ver. 9.3.1) to illustrate heavy metal concentrations by zip code, ethnicity and/or race, and income. Metal levels for each garden were symbolized by a colored symbol signifying the assumed safety of the soil: (a) green, or safe (below the CHHSL); (b) yellow, or potentially unsafe (between levels); or (c) red, or hazardous (above the TTLC). This color scheme was designed for easy interpretation, using the commonly recognized colors used in traffic lights. "Distance joins" in ArcGIS were used to calculate distance to nearest high traffic roads, and "spatial

joins” integrated census tract boundaries with garden locations. The longitude of each garden site was determined using the “field calculator.” After these spatial analyses were conducted, exact locations of some of the gardens were slightly altered in the maps to ensure that participants’ identities remained confidential.

Data Sources

Shapefiles were acquired from the San Francisco Enterprise GIS Program (City and County of San Francisco, 2009) to create base maps of the study area. Features used from this source include zip code boundaries, roads, and zoning designations. Census tract and block group boundaries for the 2000 and 2010 U.S. Census were retrieved from the Topologically Integrated Geographic Encoding and Referencing (TIGER) portal (U.S. Census Bureau, 2011b). Census tract and block group demographics and income data was downloaded from the American FactFinder (U.S. Census Bureau, 2000a, b, 2011a). The ages of the homes associated with the backyard gardens in this study were acquired from the San Francisco Assessor-Recorder’s online parcel search (City and County of San Francisco, 2011a).

To determine the locations of DTSC hazardous waste sites, reports by zip code were generated using the DTSC EnviroStor (2011a) online database. The DTSC sites include both sites that are permitted to manage hazardous waste and those where hazardous waste cleanup efforts are planned or have already taken place. These sites include Federal Superfund, State Response, Voluntary Cleanup, School Cleanup, Corrective Action, and Tiered Permit sites.

Challenges

The terms ‘race’ and ‘ethnicity’ are used through this document and are based on definitions set forth by the U.S. Office of Management and Budget (1997). Specific racial categories under these guidelines include American Indian or Alaska Native, Asian, African American or Black, Native Hawaiian or other Pacific Islander, and White. In the 2010 Census, ethnicity is divided into two categories, “Hispanic or Latino” and “Not Hispanic or Latino,” with persons of Hispanic or Latino origin also being classified into one of the race categories (Humes, Jones & Ramirez, 2011). In order to quantify those of Hispanic decent for this project, the percent of Hispanics/Latinos of the total population from the “Hispanic or Latino (of any race)” breakdown from the Census Summary Files was used. Population percentages for race were pulled from the “Race alone or in combination with one or more other races” breakdown. Some duplication within these figures is acknowledged, since race and ethnicity are two separate categories in the census.

Participants in the study were asked to self-report their race and/or ethnicity. Due to the small sample size for certain groups, participants in certain categories were lumped together to enhance analyses for race and ethnicity variables. Specifically, Native Hawaiians and other Pacific Islanders were added to the Asian race category, and American Indians or Alaska Natives were included in the Hispanic or Latino ethnicity category. This oversimplification was not intended to exclude or diminish the relevancy of any particular group, but rather to help increase the robustness of the analysis. To

better identify patterns related to race and/or ethnicity, additionally studies with much larger and varied sample populations should be conducted.

Of the 174 gardeners registered for the study and who self-identified their race and/or ethnicity, 63% listed an Anglo-American or European ancestry. In contrast, White/Anglo residents comprised only 45% of the overall population in the study area in 2010 (U.S. Census Bureau, 2011a). Language and culture may have posed a barrier in outreaching to communities of color, especially those gardeners with little or no English language skills. Gardening may also be more prevalent among Whites/Anglos in San Francisco than among people of color, but this could not be confirmed. Thus, all findings are limited to only the population of gardeners that participated in this study.

Of the 65 participating backyard gardeners, 17 did not want to disclose or did not know, in the case of shared households, their household income. Many gardeners also chose not to provide their ethnicity and/or race. If not self-reported, ethnicity or race was estimated through direct interactions with the gardener, yet household income was considered missing data.

Results

Safe Levels

More than half of San Francisco gardens exceeded the California Human Health Screening Level (CHHSL) for arsenic (As), cadmium (Cd), or lead (Pb) (As: 73.6%; Cd: 83.5%; Pb: 61.5%). The observed mean for each of these three metals was greater than its CHHSL (Table 5).

Table 5. *Heavy Metal Concentrations and pH in San Francisco Gardens*

	Range ^a	Mean	Median	Std. Deviation	CHHSL ^b
As	< LOQ - 23.8	4.56	2.92	5.25	0.07
Ba	11.7 - 509	170.24	128	117.49	5,200
Cd	< LOQ - 8.14	2.71	2.39	1.47	1.7
Co	0.62 - 96.2	11.49	7.45	12.92	660
Cr	2.57 - 585	64.22	42.5	80.98	100,000
Cu	1.56 - 2630	75.8	43.7	271.83	3,000
Ni	1.59 - 1760	102.26	32	246.69	1,600
Pb	6.55 - 2040	357.48	124	466.75	80
V	< LOQ - 73.8	21.98	20.6	11.51	530
Zn	33.3 - 707	218.43	153	162.02	23,000
pH	5.32 - 8.44	6.92	6.97	0.46	-

^a < LOQ indicates that some gardens were below the Limit of Quantification.
^b California Human Health Screening Levels (Cal/EPA, 2010)

Nine gardens exceeded both the Total Threshold Limit Concentration (TTLC) for lead and the CHHSLs for arsenic and cadmium. The TTLC defines what is considered hazardous waste in California. One garden exceeded the TTLC for copper, but did not

exceed the CHHSL, which is 500 ppm higher than the hazardous waste level in the case of copper. The single garden with a concentration of nickel greater than the CHHSL (1,600 ppm) also exceeded the CHHSLs for arsenic, cadmium, and lead.

Antimony (Sb), beryllium (Be), molybdenum (Mo), selenium (Se), silver (Ag), and thallium (Tl) had six or fewer gardens with observed concentrations above the laboratory's Limit of Quantification (LOQ). These metals were excluded from all inferential statistics other than to identify metals that were correlated. Copper (Cu), nickel (Ni), and vanadium (V) were also excluded in this fashion, in that one garden or fewer exceeded the CHHSL for these metals.

Relationships Between Metals

Barium, cobalt, chromium, and zinc were correlated with lead (Pearson's Correlation, Ba: $r = 0.850, p < 0.001$; Co: $r = 0.786, p < 0.001$; Cr: $r = 0.713, p < 0.001$; Zn: $r = 0.894, p < 0.001$). Lead was chosen for the statistical analyses because it could not be separated from the other correlated metals. Correlations between arsenic and lead ($r = 0.659, p < 0.001$) and cadmium and lead ($r = 0.635, p < 0.001$) were weaker than the correlations of other metals with lead, although still significant. All further inferential statistics were limited to arsenic, cadmium, and lead in that they were prevalent in most gardens, were the only metals with study means greater than their CHHSL, and were correlated with the less common metals.

Arsenic and cadmium concentrations were more likely than expected to be above the CHHSL if a garden also had a lead level above the CHHSL (Chi-square, As: $df = 2, g = 23.260, p < 0.001$; Cd: $g = 17.733, p < 0.001$) (Table 6; Table 7; Table 8).

Table 6. *Summary of Findings*

Factor	Statistical Test	Independent Variable	Dependent Variables <i>p</i> -values, (<i>r</i> -values) [†] & [<i>r</i> ² -values] ^{††}		
			<u>As</u>	<u>Cd</u>	<u>Pb</u>
Safe Levels & Relationships	Chi-Square	Pb (safe, unsafe, hazardous)	safe/unsafe < 0.001 [*]	safe/unsafe < 0.001 [*]	-
		Cd (safe, unsafe)	safe/unsafe < 0.001 [*]	-	-
Vehicular Traffic	Pearson's Correlation	Distance to Roads	0.280 (-0.114)	0.201 (-0.123)	0.153 (-0.151)
	Mann-Whitney	> 750 m vs. < 750 m	0.040 [*]	0.150	0.008 [*]
	Regression	Longitude	0.024 [*] [0.056]	0.319 [0.011]	0.009 [*] [0.075]
Home Age	Regression	Age of Home	0.313 [0.016]	0.011 [*] [0.099]	< 0.001 [*] [0.289]
	Mann-Whitney	> 75 years vs. < 75 years	0.085 ^{**}	0.018 [*]	> 0.001 [*]
Zoning Designation	ANOVA	Residential vs. Public	0.065 ^{**}	0.540	0.636
Zip Codes	ANOVA	Zip Codes	0.088 ^{**}	0.007 [*]	0.018 [*]
	Planned Comparisons	94107+94124+94134 vs. 94110+94114	-	0.099 ^{**}	0.009 [*]
Income	Regression	Reported Income	0.023 [*] [0.107]	0.075 ^{**} [0.075]	0.058 ^{**} [0.076]
Race/Ethnicity	ANOVA	All Categories	0.177	0.272	0.539
		Non-White vs. White/Anglo	0.114	0.564	0.306
Backyard & Community Gardens	ANOVA	Backyard vs. Community Gardens	< 0.001 [*]	0.006 [*]	0.037 [*]
In-Ground & Raised Beds	ANOVA	In-Ground vs. Raised Beds	< 0.001 [*]	< 0.001 [*]	0.038 [*]
	Pearson's Correlation	pH (In-Ground)	0.073 ^{**} (-0.222)	0.781 (0.035)	0.847 (-0.024)

[†] *r*-values have a strong relationship at ≥ 0.6 . ^{††} *r*²-values are increasingly robust towards 1.

^{*} Significant at $p < 0.05$. ^{**} Significant at $p < 0.1$.

Table 7. *Relationship Between Safe and Unsafe Levels of Arsenic and Lead*

			Lead Levels		
			Safe	Unsafe	Hazardous
Arsenic Levels ($p < 0.001$)	Safe	Observed	19	5	0
		Expected	9.2	12.4	2.4
	Unsafe	Observed	16	42	9
		Expected	25.8	34.6	6.6
	Total	Observed	35	47	9

Table 8. *Relationship Between Safe and Unsafe Levels of Cadmium and Lead*

			Lead Levels		
			Safe	Unsafe	Hazardous
Cadmium Levels ($p < 0.001$)	Safe	Observed	13	2	0
		Expected	5.8	7.7	1.5
	Unsafe	Observed	22	45	9
		Expected	29.2	39.3	7.5
	Total	Observed	35	47	9

The arsenic level of a garden was also more likely than expected to be above the CHHSL if the cadmium level was also above the CHHSL (Chi-square, $g = 20.397$, $p < 0.001$) (Table 6; Table 9).

Table 9. *Relationship Between Safe and Unsafe Levels of Arsenic and Cadmium*

			Cadmium Levels	
			Safe	Unsafe
Arsenic Levels ($p < 0.001$)	Safe	Observed	11	13
		Expected	4	20
	Unsafe	Observed	4	63
		Expected	11	56
	Total		Observed	15

Vehicular Traffic

No significant relationships were identified between the levels of each metal and the distance from a garden to the nearest freeway, highway, or four-lane road (Pearson's Correlation, As: $r = -0.114$, $p = 0.280$; Cd: $r = -0.123$, $p = 0.245$; Pb: $r = -0.151$, $p = 0.153$) (Table 6; Figure 2). A significant difference was found between mean lead levels for gardens located within 750 m ($n = 78$) and further than 750 m ($n = 13$) of a major roadway (Mann-Whitney, $U = 274.5$, $p = 0.008$).

Figure 2. Plot showing the inconclusive relationship between lead levels and distance in meters to nearest high traffic roadway.

Very weak, yet significant, negative linear relationships were observed between West-East longitude and levels of both arsenic and lead (Regression, As: $r^2 = 0.056$, $p = 0.024$; Pb: $r^2 = 0.075$, $p = 0.009$) (Table 6; Figure 3; Figure 4). Slightly higher concentrations of arsenic and lead were found in gardens to the west of the study area than in those to the east. No clear relationship was found between cadmium and longitude (Linear Regression, $r^2 = 0.011$, $p = 0.319$).

Figure 3. Decrease in arsenic levels in gardens with longitude from west to east. The vertical line represents the approximate location of U.S. Highway 101. Dashed lines are 95% confidence limits, and the dotted line is the natural log of (CHHSL + 1).

Figure 4. Decrease in lead levels in gardens with longitude from west to east. The vertical line represents the approximate location of U.S. Highway 101. Dashed lines are 95% confidence limits, and the dotted line is the natural log of the CHHSL.

Age of Home

Weak, but significant, positive linear relationships were detected between the ages of homes associated with backyard gardens ($n = 65$) and levels of both cadmium and lead (Regression, Cd: $r^2 = 0.099$, $p = 0.011$; Pb: $r^2 = 0.289$, $p < 0.001$) (Table 6; Figure 5; Figure 6).

Figure 5. Increase in cadmium levels in backyard gardens with home age. Dashed lines are 95% confidence limits, and the dotted line is the CHHSL.

Figure 6. Increase in lead levels in backyard gardens with home age. Dashed lines are 95% confidence limits, and the dotted line is the natural log of the CHHSL.

Older homes had slightly more cadmium and lead in their garden soils than newer homes. A significant difference was found between mean levels of these metals for homes built within the last 75 years ($n = 25$) and those built later ($n = 40$) (Mann-Whitney, Cd: $U = 318.5$, $p = 0.018$; Pb: $U = 177.0$, $p < 0.001$). Arsenic levels tended to increase with home age as well, though the findings were not significant and less robust (Regression, $r^2 = 0.016$, $p = 0.313$).

Zoning Designations

Metal concentrations did not significantly differ between residential ($n = 68$) and publicly ($n = 12$) zoned areas. A trend was found for arsenic, with levels higher in gardens located in residential zones (ANOVA, $p = 0.065$) (Table 6).

Known Contamination/Zip Codes

The highest mean levels for nine of the 10 most commonly found metals in the study were found in either 94107 or 94114 (Table 10). Vanadium was highest in 94110. These three zip codes comprise the northernmost portion of the study area.

Table 10. *Mean Concentrations of the 10 Most Common Metals by Zip Code*

	94107	94110	94114	94124	94134
As	3.77	4.32	7.43	3.46	3.48
Ba	194.69	204.95	225.01	118.02	105.08
Cd	3.48	2.77	3.04	1.95	2.25
Co	23.86	9.73	9.87	6.67	7.38
Cr	143.14	51.99	50.73	35.89	39.97
Cu	55.37	54.95	59.72	34.20	33.96
Ni	368.06	44.95	46.10	30.62	24.95
Pb	493.28	446.22	527.41	129.40	174.61
V	14.14	27.23	24.64	20.47	23.28
Zn	265.56	249.12	282.39	149.84	140.35
	$n = 18$	$n = 17$	$n = 20$	$n = 17$	$n = 19$

Note: Highest mean level for each metal is shown in bold.

Nine gardens had soils exceeding the TTLC for lead ($> 1,000$ ppm). All nine of these gardens were located in the three contiguous zip codes in the north of the study area (Figure 7). Four of the gardens were located in 94107, three in 94114, and two in 94110.

Figure 7. Lead levels in vegetable gardens of San Francisco, CA. Nine gardens had soils that exceeded California's TTLC, the hazardous waste threshold for lead (> 1,000 ppm).

Overall, 83% of the gardens had levels above the CHHSL for cadmium (1.7 ppm), with the southernmost zip code (94134) having the lowest percentage of its gardens (21%) above the CHHSL (Figure 8). Only one garden, in 94107, had a nickel concentration above the CHHSL. The only garden that exceeded the TTLC hazardous waste level for copper was located in 94110.

Concentrations of cadmium and lead were significantly different between the five study area zip codes (ANOVA, Cd: $p = 0.007$; Pb: $p = 0.018$) (Table 6; Figure 9; Figure 10). Contrasts for the a priori comparison for cadmium and lead by zip code were based on the presence/absence of hazardous waste sites as identified by the Department of Toxic Substances Control (DTSC, 2011a). Surprisingly, the zip codes with DTSC sites (94107 + 94124 + 94134) had significantly lower levels of lead than the other zip codes (94110 + 94114) (ANOVA, Pb: $p = 0.009$) (Table 6). Mean cadmium levels were highest in 94107, and resulted in a significant contrast between 94107 and 94124 + 94134 (ANOVA, Cd: $p = 0.002$). Mean arsenic concentrations were highest in 94114, but overall were not found in significantly different concentrations throughout the five zip code area (ANOVA, $p = 0.088$) (Table 6; Figure 11). 94134 had only two DTSC sites within its boundary, but an additional five sites were located within 120 m of its boundaries and were added to the total DTSC sites for the zip code due to their close proximity.

Figure 8. Cadmium levels in vegetable gardens of San Francisco, CA. A majority of gardens had levels above the CHHSL for cadmium

Figure 9. Mean cadmium levels and the number of sites with known contamination by zip code. Cadmium levels were significantly different between zip codes, with the highest mean concentration observed in 94107. Error bars are 95% confidence limits and the dotted line is the CHHSL.

Figure 10. Mean lead levels and the number of sites with known contamination by zip code. Lead levels were significantly different between zip codes, with the highest mean concentration observed in 94114. Error bars are 95% confidence limits and the dotted line is the CHHSL.

Figure 11. Mean arsenic levels and the number of sites with known contamination by zip code. Mean arsenic concentrations were not significantly different across all zip codes, with the highest mean concentration observed in 94114. Error bars are 95% confidence limits and the dotted line is the CHHSL.

Household Income

Reported income weakly predicted metal concentrations of backyard gardens ($n = 48$). Mean arsenic concentrations differed significantly with income, with levels slightly decreasing as gardener income increased (Regression, $r^2 = 0.107$, $p = 0.023$) (Table 6; Figure 12).

Figure 12. Reported household income of participating gardeners weakly predicted arsenic levels. Arsenic levels were slightly lower in gardens of higher income gardeners. Error bars are 95% confidence limits and dotted line the natural log of (CHHSL + 1).

Cadmium and lead concentrations tended to be slightly higher in gardens of lower income gardeners, although not significantly so (Regression, Cd: $r^2 = 0.075$, $p = 0.067$; Pb: $r^2 = 0.076$, $p = 0.058$) (Table 6). Many gardeners did not report their income, so metal levels were mapped with income from the 2000 Census (2000b). Six of the nine gardens with hazardous levels of lead ($> 1,000$ ppm) were situated in block groups with a median household income above the San Francisco average of \$55,221 (Figure 13).

Figure 13. Lead levels and median household income by block group, 2000. Six of the nine gardens with hazardous levels of lead (> 1,000 ppm) were in block groups with a median household income above the San Francisco average of \$55,221.

Race/Ethnicity

Metal concentrations did not differ significantly between backyard gardeners ($n = 65$) for self-reported race and/or ethnicity (ANOVA, As: $p = 0.177$; Cd: $p = 0.272$; Pb: $p = 0.539$) (Table 6). Additionally, no significant difference was found when these gardeners were lumped into categories of “White” and “non-White” (ANOVA, As: $p = 0.114$; Cd: $p = 0.564$; Pb: $p = 0.306$). Descriptive statistics showed that the raw means of arsenic, cadmium, and lead were slightly higher among White/Anglo gardeners than non-White gardeners.

The ethnicity and/or race reported by each gardener was not necessarily representative of the local neighborhood, thus lead concentrations were mapped with 2000 Census (2000a) race/ethnicity figures. Seven of the nine gardens with lead levels above the TTLC for hazardous waste were located in White/Anglo dominated block groups (Figure 14).

Figure 14. Lead levels and race/ethnicity by block group, 2000. Seven of the nine gardens with hazardous lead concentrations were located in White/Anglo dominated block groups.

Backyard, Community, and School Gardens

Backyard gardens ($n = 65$) had significantly higher concentrations of arsenic, cadmium, and lead than community gardens ($n = 22$) (ANOVA, As: $p < 0.001$; Cd: $p = 0.006$; Pb: $p = 0.037$) (Table 6; Figure 15; Figure 16; Figure 17).

Figure 15. Mean arsenic concentrations in community and backyard gardens. Community gardens had significantly lower concentrations of arsenic than backyard gardens. Error bars are 95% confidence limits and the dotted line is the CHHSL.

Figure 16. Mean cadmium levels in community and backyard gardens. Community gardens had significantly lower concentrations of cadmium than backyard gardens. Error bars are 95% confidence limits and the dotted line is the CHHSL.

Figure 17. Mean lead levels in community and backyard gardens. Community gardens had significantly lower concentrations of lead than backyard gardens. Error bars are 95% confidence limits and the dotted line is the CHHSL.

For both backyard and community gardens, the means for all three metals were above the CHHSL. The highest single observations for each of the 10 most commonly found metals were observed in backyard gardens with in-ground beds (Table 10).

Of the four school gardens tested, two had levels below the CHHSL for arsenic, cadmium, and lead. Of the two remaining school gardens, both had unsafe levels of arsenic and cadmium, with one also having a hazardous level of lead. The later was the only school garden with an in-ground garden (Table 11).

Table 11. *Heavy Metal Concentrations in School Gardens*

School Location	As (ppm) ^a	Cd (ppm)	Pb (ppm)	Garden Type	Land Use History
94114	12.7	6.04	1130	In-Ground	Former parking lot.
94124	1.78	1.94	27.7	Raised Bed	Prior contamination at site; near active Superfund site.
94114	< LOQ	1.64	40.4	Raised Bed	Former site of tree; long-term history unknown.
94134	< LOQ	1.01	9.56	Raised Bed	In complex of WWII barracks; long term history unknown.

^a < LOQ indicates a value below the Limit of Quantification.

Raised Beds and In-Ground Gardens

For the 10 most commonly found metals (Table 5), in-ground gardens ($n = 66$) had the highest single observation in the study. In-ground gardens also had a higher mean than raised beds ($n = 25$) for each of these 10 metals (Table 12). Concentrations of arsenic, cadmium, and lead were significantly lower in raised bed gardens than in-ground gardens (ANOVA, As: $p < 0.001$; Cd: $p < 0.001$; Pb: $p = 0.038$) (Table 6; Figure 18; Figure 19; Figure 20).

Table 12. *Heavy Metal Concentrations in Raised Bed and In-Ground Gardens*

	Mean		Lowest Observation		Highest Observation	
	In-Ground (<i>n</i> = 66)	Raised Beds (<i>n</i> = 25)	In-Ground ^a	Raised Beds ^a	In-Ground	Raised Beds
As	5.58	1.87	< LOQ	< LOQ	23.8	11.8
Ba	189.45	119.52	11.70	41.6	509	420
Cd	3.05	1.78	< LOQ	< LOQ	8.14	3.52
Co	13.09	7.27	0.62	1.36	96.2	33.6
Cr	74.3	37.62	2.57	5.95	585	138
Cu	88.74	41.61	1.56	13.7	2630	122
Ni	124.12	44.54	1.59	5.75	1760	235
Pb	419.84	192.85	15.9	6.55	2040	1330
V	23.97	16.74	< LOQ	5.25	73.8	46.1
Zn	242.05	156.06	33.3	35.9	707	550
^a < LOQ indicates a value below the Limit of Quantification.

Figure 18. Mean arsenic levels in in-ground and raised bed gardens. Concentrations of arsenic were significantly higher in in-ground gardens than in raised beds. Error bars are 95% confidence limits and the dotted line is the CHHSL.

Figure 19. Mean cadmium levels in in-ground and raised bed gardens. Concentrations of cadmium were significantly higher in in-ground gardens than in raised beds. Error bars are 95% confidence limits and the dotted line is the CHHSL.

Figure 20. Mean lead concentrations in in-ground and raised bed gardens. Levels of lead were significantly higher in in-ground gardens than in raised beds. Error bars are 95% confidence limits and the dotted line is the CHHSL.

None of the metal levels significantly differed with soil pH for raised bed gardens or across all gardens together. An extremely weak negative correlation was found with pH and arsenic levels for in-ground gardens, with arsenic levels only slightly decreasing with higher soil pH (Pearson's Correlation, $n = 66$, $r = -0.222$, $p = 0.073$).

Discussion

Exposure to Heavy Metals by San Francisco Gardeners

Fifty three percent of the gardens tested in San Francisco were above the California Human Health Screening Level (CHHSL) of 80 ppm for all three metals of most concern: arsenic, cadmium, and lead. With a mean lead level of 357 ppm, San Francisco gardens recorded lower average levels than gardens in Chicago (800 ppm) (Finster et al., 2004) and the Boston area (950 ppm) (Clark et al., 2008). Even though San Francisco gardens had substantially lower lead levels than those found in these East Coast garden studies, the fact that more than half of the San Francisco gardens had concentrations of one or more heavy metal in excess of what is deemed safe for human health highlights this as an emerging public health concern.

The concentrations that are considered safe for human contact should be of primary interest in discussions of issues related to heavy metal exposure. Lack of agreement between government agencies on what exposure rates are actually safe has left this central issue unresolved. For example, only 38% of San Francisco gardens had lead levels “below thresholds of concern for risks to human health” as defined by Cal/EPA’s CHHSLs (Cal/EPA, 2005, p. 5). The number of “safe” gardens rises to 67%, when assessing safety under the higher thresholds of EPA’s Land Application of Biosolids for Home Vegetable Gardens. The authors of both the Chicago and Boston area studies used 400 ppm, the EPA’s Regional Screening Level (RSL) for residential soil, as their baseline for determining safety (Clark et al., 2008; Finster et al., 2004; EPA, 2011b). Using the RSL for lead, 71% of San Francisco gardens would be considered safe for children to

play in. A third of the gardens tested fall within the 320 ppm difference between the CHHSL and the RSL for lead, leaving the safety of these gardens uncertain.

Turning to arsenic and cadmium levels as another example, not a single San Francisco garden would be considered unsafe using either the EPA's Biosolids guidelines or the RSLs. Alternatively, 74% and 84% of San Francisco gardens were above the CHHSLs for these two metals, respectively. While the Biosolids guidelines are the only ones that specifically address metal levels for gardens and include the consumption of produce as part of its risk calculations, the CHHSLs are arguably a better gauge of what is safe. The CHHSLs are based on more recent public health and scientific findings, and are updated as needed. For example, Cal/EPA (2009) lowered the CHHSL for lead from 150 ppm to 80 ppm based on newly revised thresholds for blood lead levels. In contrast, the Biosolids level has remained unchanged at 300 ppm since its publication in 1993. In another indication that the CHHSLs are the most appropriate levels, the California Department of Toxic Substances Control (DTSC, 2011b) recommends the EPA adopt the CHHSL for arsenic (0.07 ppm) in replacement of the existing RSL (39 ppm).

The results of the San Francisco study showed that there is a strong likelihood that if a garden has an unsafe level of arsenic, cadmium, or lead, it will have an unsafe level of all three metals. This indicates a substantial likelihood for most San Francisco gardeners to be exposed to multiple heavy metals. While estimations of risk for multiple contaminants do exist, the CHHSLs, Biosolids guidelines, and RSLs only consider exposure to a single contaminant. Currently, the EPA is developing a cumulative risk assessment protocol for multiple sources of exposure (Callahan & Sexton, 2007). Sexton

and Hattis (2007) have suggested that such a model should include biological, chemical, physical, and social factors—all stressors that have been previously linked to illness and poor health. Individuals with low socioeconomic status are likely to be exposed to many such stressors, notably living in housing that is in disrepair, overcrowding, and lack of adequate health care (Adler & Newman, 2002). For individuals with known exposure to multiple environmental toxins and other physical and social stressors, conservatively reducing exposure is suggested until a reliable cumulative risk assessment model is published and actual risk can be calculated.

It is vital to minimize direct and indirect exposure to garden soils with unsafe levels of heavy metals so any toxic exposure effects do not outweigh the overall benefits of gardening, including access to fresh, home-grown produce. To ensure that exposed residential soils are safe, including garden soils, soil testing should be conducted every few years to monitor changes in heavy metal concentrations. This is especially important if individuals that come into frequent contact with the soil are at high risk for negative health effects due to age, health, exposure to multiple contaminants, insufficient income, or low quantity and quality of food.

Legacy of Leaded Gasoline

Results showed no significant linear relationship between metal levels and distance from high traffic roads, but gardens located within 750 m of such roadways had significantly higher lead levels than gardens farther away. These findings indicate that airborne vehicle emissions were a likely contributor of lead to San Francisco gardens, but that the mechanisms of dispersal were not consistent and other contributors to overall

lead levels have also existed. The lack of a spike in lead levels near or directly downwind (to the east) from Highway 101 supports the notion that vehicle emissions are neither the primary nor the only contributor to current lead levels (Figure 4).

Researchers worldwide have reported finding negative correlations between lead levels in soil and proximity to freeways or other high traffic roads (Manta et al., 2002; Markus & McBratney, 1996). However, the results of some studies suggest the influence of leaded gasoline is less than expected (Clark et al., 2006; Hafen & Brinkmann, 1996). The inconsistent distribution of lead concentrations in San Francisco gardens shows that even gardens located close to each other can have radically divergent concentrations (Figure 7). In a soils project conducted in West Oakland, CA, just across San Francisco Bay, McClintock (2011) similarly found that lead levels can vary significantly from parcel to parcel within a neighborhood. Together, the San Francisco and Oakland findings indicating that a common, single point source is likely not the most influential contributor of lead.

Legacy of Lead-Based Paint

Particulates from paint, however, are likely the primary source of lead, and possibly cadmium, in San Francisco garden soils. Lead concentrations were significantly higher in the backyard gardens of older homes where lead paint had likely been present for many years. Cadmium levels also increased with home age, although the r^2 value was very low and only accounted for about 10% of the variability in cadmium levels.

Some researchers have confirmed that airborne particulates and dust derived from lead-based paint are a major source of lead in garden soils (Clark et al., 2008; Finster et

al., 2004), with active construction on homes with lead-based paint significantly increasing the amount of lead-containing dust in the air (Mucha et al., 2009). In fact, the San Francisco garden with the highest concentration of lead was adjacent to a Victorian home being sanded for exterior repainting. The contractor for the work appeared to have taken only minimal precautions to contain the paint, with paint chips visible on the garden's surface. The EPA (Lead; Renovation, Repair, and Painting Program, 73 Fed. Reg., 2008) recognizes that lead-containing paint and dust generated through construction is a serious hazard, and as of 2010 requires contractors working with lead-based paint to become trained and certified in lead-safe work practices. Paint containing > 0.06% lead was banned in most residential applications in the U.S. in 1978, with lead paint banned seven years earlier in public housing projects. While lead was added to improve the durability of paint, cadmium is still used as a pigment in some bright colors including Cadmium Red and Cadmium Orange. Only seven of the 65 homes in this study were built after the ban on lead-based paint.

A pair of neighboring gardens in the 94107 zip code was scrutinized in detail to determine if metal levels were affected by construction on structures with lead-based paint. These adjacent gardens both had in-ground gardens. The homes associated with each of these gardens were both built more than 110 years ago and likely painted with lead-based paint numerous times over the years. One garden had a safe level of lead, with building permit records showing only window and door replacements in the past 25 years. The second garden exceeded the TTLC hazardous waste threshold for lead and had more than double the amount of cadmium as the first garden. As reported by the

gardener in the second home, substantial construction had occurred over the past 20 years including building an addition, remodeling, and re-painting on multiple occasions. This example illustrates that the number of times that a house has been sanded, re-painted or otherwise disturbed by construction may increase the accumulation of airborne particulates of lead, and possibly cadmium, in backyard soils.

Place, People, and Socioeconomics

Zoning designations are a static snapshot of a city's planning goals at one moment in time, thus it is not surprising that they would be poor predictors of heavy metal contamination in San Francisco gardens. Current zoning of an area by itself usually does not, and often cannot, reflect both the land use history and changing demographics of a particular neighborhood.

In San Francisco, current waves of gentrification, and ensuing emigration, have resulted in drastically shifting demographics in recent years. Maps depicting the dominant racial and ethnic groups for the study area in 2000 (Figure 14) and 2010 (Figure 21) illustrate how San Francisco has changed in only a decade. For example, White/Anglo populations have become more prevalent in many census tracts that had been predominantly Hispanic/Latino. Changes in income are assumed to have accompanied this shifting demographic, but cannot be confirmed until the 2010 Census data for income has been released at this resolution.

Figure 21. Lead levels and race/ethnicity by census tract, 2010. All gardens with hazardous waste levels of lead were located in predominately White/Anglo census tracts using race/ethnicity data from the 2010 Census (U.S. Census Bureau, 2011a).

Health risks due to exposure to environmental toxins have been shown to exist between different racial, ethnic, and socioeconomic groups. In maps of the San Francisco Bay Area generated by Pastor et al. (2005), communities of color living in the southeast section of San Francisco have a higher than average risk of cancer due to exposure to airborne environmental toxins. In Southern California, Morello-Frosch et al. (2001) found lower income residents and minority communities, especially Hispanics, to be at most risk for exposure to environmental toxins. Inconsistent with such findings on disparities in exposure to environmental toxins, the racial and ethnic minorities and low-income communities in this study were not the most at-risk groups for exposure to heavy metals when garden soil is the pathway of exposure.

In cosmopolitan cities such as San Francisco, rapid and dramatic demographic shifts are frequently documented. To determine if such changes have altered patterns of exposure to heavy metals by gardeners of different racial and ethnic groups, demographic shifts in San Francisco over the past decade were mapped with the metal concentrations of each garden. In 2000, two of the nine gardens with hazardous lead levels were located in census tracts that were predominately Hispanic/Latino (Figure 14). As of 2010, widespread gentrification resulted in all nine gardens with hazardous lead levels being located in areas dominated by Whites/Anglos (Figure 21).

Changes such as these radically alter the “riskscape” over time, rendering studies that use data from a static point in time potentially irrelevant not long after they have been conducted. Some of the landmark research in the environmental justice field has been confounded in just this way. Morello-Frosch et al. (2001) and Pastor et al. (2005)

looked at inequalities in exposure to environmental toxins by different racial and ethnic groups using air quality data and population numbers only from a single year. While their findings are very informative, repeating the same study with updated data over time would be even further enlightening, albeit time-consuming.

As Downey et al. (2008) concluded in their nationwide study of exposure to airborne environmental toxins, even though African Americans and Hispanics have the greatest risk of exposure in cities nationwide, all ethnic groups, including Asians and Whites/Anglos, are the most exposed groups in some cities. Along with the results of the San Francisco study, findings such as these show that inconsistencies in patterns of exposure exist. Rather than basing predictions on the presence or absence of contaminants on broad generalizations, this exemplifies the need to conduct garden soil testing in every neighborhood, regardless of its demographic and socioeconomic profile.

Place, People, and Pollution

Not changing as quickly as where residents of different groups prefer to live, is the location of sites that have been contaminated with hazardous waste. The DTSC EnviroStor website lists 29 sites within the study area that are either permitted to manage hazardous waste or where a cleanup of such waste is planned or has already taken place (DTSC, 2011a). Nineteen of the DTSC sites are located in zip codes with predominantly African American/Black or Asian residents, with the remainder of sites located in predominantly White/Anglo zip codes (Figure 9). The majority African American/Black Bayview Hunters Point neighborhood has the most DTSC sites ($n = 17$), including the only active Superfund site in San Francisco. This neighborhood also had the lowest

median household income of the five study area zip codes (Table 2). No DTSC sites were found in the highest income zip code, which was predominantly White/Anglo.

Surprisingly, two specific census blocks, each with a DTSC site, went from being mostly populated with Hispanics/Latinos or African Americans/Blacks in 2000, to being mostly White/Anglo by 2010. It is unclear why these White/Anglo residents, presumed to have higher than average incomes, would choose to move into an area that is in close proximity to a site containing hazardous waste. This behavior contradicts what many environmental and public health researchers have found previously. For instance, Pastor et al. (2005) reported that Whites/Anglos in California were the only racial or ethnic group that continually decreased in population as the risk for cancer from exposure to environmental toxins increased. The divergence from this statewide pattern in two San Francisco census blocks is relatively insignificant when looking at California in general, but it is a reminder that big-picture trends may not be applicable at the local level. Thus, reiterating that each garden site should be assessed for safety based on facts, rather than the race, ethnicity, or socioeconomic status of its gardener.

Heavy Metals and Industrial Pollutants

The number of DTSC sites located in communities of color in San Francisco reflects common findings that non-Whites are often the most exposed to environmental toxins; however, the soil test results tell a different story. The analysis of San Francisco garden soils showed that residents in neighborhoods with hazardous waste sites were at less risk for exposure to heavy metals than residents in neighborhoods that did not have any severely contaminated parcels. The lowest mean levels of nine of the 10 most

common heavy metals found in this study, including arsenic, cadmium, and lead, were located in two of the zip codes with DTSC sites (Table 10). In contrast, the zip code with the highest observed levels of arsenic, barium, copper, lead, and zinc, had no DTSC sites.

The DTSC sites located within the study area had hazardous levels of a variety of substances, including metals, organic compounds, and even radioactive waste. Metals found at some of these sites included arsenic, chromium, lead, nickel, mercury, and zinc. Other pollutants of concern included benzene, cyanide, methane, tetrachloroethylene (PCE), acetone, volatile organic compounds (VOCs), polychlorinated biphenyls (PCBs), and polycyclic aromatic hydrocarbons (PAHs) (DTSC, 2011a). Further testing of soils for non-metallic compounds should be conducted to identify any differences in patterns of exposure from what was found for heavy metals.

Sorting the Sources: San Francisco's "Painted Ladies" and Others

Why are the socioeconomic and demographic communities that are usually least exposed to environmental toxins nationwide the most exposed in San Francisco? Since proximity to hazardous waste sites does not appear to significantly contribute to heavy metal contamination in garden soils, what other factors might be at play? Perhaps an increased awareness of residents in neighborhoods with known contamination results in local residents taking action to ensure their soil is safe? More likely is a surprising culprit: the array of colorful and ornate Victorian-era homes. With most built over 100 years ago, the iconic Victorians are the oldest and often highest priced dwellings in the city. Homes of this age have a legacy of lead-based paint of 70 years or longer.

The increase in cadmium and lead in garden soils with home age, along with the highest mean metal levels being found in the higher income and mostly White/Anglo neighborhoods, implicate Victorians as a primary pathway of exposure to these metals for gardeners. The Victorians are concentrated in the predominantly White/Anglo neighborhoods of 94114 and 94107, as well as in the Hispanic/Latino Mission District which has become predominately White/Anglo since 2000. A clear decrease in cadmium and lead levels appears in homes that were built beginning in the mid-1930s. This includes gardens in the mostly African American/Black and Asian neighborhoods, which had the lowest mean levels of nine of the 10 most common metals found in the study.

One final pathway of heavy metals deposition into San Francisco gardens is the actions of individual homeowners. Researching the history of a specific garden site may uncover clues as to why current concentrations are what they are. Take, for example, a detailed analysis of two gardens in the 94107 located within 100 m of each other. Both were backyard gardens associated with a Victorian-era home, but with different lead concentrations. One of the gardens was above the TTLC hazardous threshold for lead, while the other was nearly 1,000 ppm lower. The first garden had previously been home to a cooper, while the second garden had no known relationship to industry.

Even a partial history of a parcel can provide a gardener with the incentive to test their soil. Of the nine gardens with a hazardous level of lead, four were at homes that underwent recent construction, two had been covered by concrete or asphalt at some point, and one was the former cooperage mentioned above. One of the nine gardens was the oldest home in the study, built circa 1890. The final garden, a community garden

plot, was directly adjacent to a home that was built after the ban on lead paint. The history of the plot was not known, and so the reason for the extremely high lead concentration remains unclear. Due to the high variability in the actions of homeowners and/or tenants, trying to predict contamination levels of individual gardens is ill advised, with actual soil testing the best method for assessing the health and safety of soil.

Backyard and Community Gardens

The backyard gardens tested for this study came in a striking variety, with many quite exceptional in design and ingenuity. Some crops shared space with chickens, bees, fish ponds, or murals. Many were terraced to take advantage of the sunny slopes of San Francisco's steep hillsides. There were herbs growing in pots on stairwells, broccoli growing in re-purposed plastic furniture, professionally built raised beds, yards with so much shade that few crops could grow, and small sidewalk strips planted with crops ranging from taro to tomatoes. While this diversity made every garden visit distinctive, it also yielded few commonalities between backyard gardens. The one constant was the presence of one, but usually more, houses in close proximity to the growing area. While the presence of lead-based paint is a significant factor in cadmium and lead levels, the use of backyard spaces by homeowners and tenants can leave a lasting legacy in the existing soil. From burying and burning household waste to the application of pesticides and fertilizers, many backyards have a sordid history of contamination, perhaps more so than their community garden counterparts. Of the community gardens surveyed, approximately half appear to have never been developed. Furthermore, all city-sanctioned community gardens prohibit the use of synthetic pesticides (City and County

of San Francisco, 2006). A majority of the participating community gardeners did not know the source of the soil used in their raised beds, most of which were constructed by the City and County. Additionally, most community gardeners did not know if the city had previously tested their garden plot. The only participating community garden that had been tested by local officials was on a recently remediated brownfield.

The designation of “community garden” obviously does not guarantee uncontaminated soil. For example, the mean levels of arsenic, cadmium, and lead for community gardens were above the CHHSLs. Seven of the 15 community gardens tested were built on sites that were a former or existing parking lot, classified as a brownfield, located within 100 m of a freeway, and/or had been an informal neighborhood dump site. Outside of this study, Stilwell et al. (2008) found that produce grown in four Connecticut community gardens had significantly higher average levels of lead than store-bought produce, although lower levels of arsenic and cadmium.

Overall, San Francisco community gardens are significantly safer than backyard gardens. Unfortunately, of the 40 community gardens managed by a government agency in San Francisco, only eight do not have a waiting list (San Francisco Garden Resource Organization). Nineteen of these gardens have an active waiting list, with multiple gardens listing wait times of up to three years. One popular garden, tucked away in a quiet little alley of the busy Mission District, estimates the wait to be 18 years or more.

School Gardens

As part of this study, only four gardens at a school or after-school program were tested. Using the CHHSLs, two were considered safe, one unsafe, with an elementary

school garden recording a lead level over the hazardous waste threshold. Not one of the school gardens included in this study had conducted soil testing previously, yet all four allowed access to the garden and the produce grown on-site by young children. One school garden coordinator was told to test the soil by the Recreation and Parks department who had built the garden's raised beds, but provided no instructions or resources to do so. Two of the garden coordinators, including the coordinator from the garden with a hazardous lead level, believed that testing was not a priority since their soil was purchased from a garden supply store.

Lanphear et al. (1998) estimated that 18% of children exposed to residential soil with a lead concentration at the hazardous waste level of 1,000 ppm had a blood lead level greater than 10 $\mu\text{g}/\text{dl}$. The Centers for Disease Control and Prevention (2000) defines this as an "elevated blood lead level" for children under six years old. Contact with soil at school gardens is a definite pathway of exposure for young children. The lack of testing of school garden soils, especially at the two public school gardens, is a significant oversight by the local school district that should be rectified.

Raised Bed and In-Ground Gardens

Raised beds had a lower mean than in-ground gardens for each of the 10 metals most commonly found in this study (Table 12). The lower levels of heavy metals in raised beds may be a direct result of using imported soil as fill rather than using the existing soil. Using fill, however, is not a guarantee of clean soil. Municipal compost used to fill the raised beds in the Boston area study by Clark et al. (2008) had a beginning mean lead concentration of 150 ± 40 ppm. This level is above the CHHSL (80 ppm) yet

below both the EPA's 300 ppm Biosolids level (Table 1) and the mean lead level found across all gardens in this study (357 ppm).

Clark et al. (2008) found that raised beds had lower overall lead levels than in-ground gardens in their Boston study. A look at a pair of garden plots within the same San Francisco community garden demonstrates that such differences between raised bed and in-ground gardens may also hold true for the San Francisco area. The first plot was a raised bed garden, had safe levels of cadmium and lead, and was located in the center of the community garden. The second plot was an in-ground garden with a hazardous level of lead, an unsafe cadmium level, and was located approximately one meter from a house at the edge of the community garden. The house was built after the ban on lead-based paint, so it is unclear how the soil at the second plot became contaminated, but the difference of over 1300 ppm in soil lead between the two plots exemplifies the potential benefits of raised bed gardening.

All soils are subject to atmospheric deposition of environmental toxins, with those in residential settings also potentially exposed to lead from lead-based paint. Naturally existing levels of heavy metals contribute to existing concentrations found in soil as well, especially for in-ground gardens. Several San Francisco neighborhoods included in this study have unique geologic profiles that may have influenced the observed metal levels. For instance, two of the study area zip codes are known to have serpentine soils, which are associated with high levels of chromium and nickel (Bonifacio, Falsone & Piazza, 2010). Not surprisingly, the highest mean chromium and nickel levels in the study area were found in these two zip codes. The six highest nickel observations study-wide were

also observed in in-ground gardens in these same zip codes. Determining natural background levels for each neighborhood was beyond the scope of this project, but national and some regional background levels have been published. Of note, one estimate of the nationwide mean background level for arsenic is 5.2 ppm (Andersen, 1998), which is much higher than the CHHSL of 0.07 ppm for arsenic. Twenty-five of the 27 gardens that exceeded the national average for arsenic were in-ground gardens.

For prospective gardeners looking to install a garden, purchasing soil and compost may be a better option than using existing soil. However, commercially sold soils and compost are not guaranteed to be free of contaminants, since they are not highly regulated. The EPA Biosolids guidelines (Standards for the Use or Disposal of Sewage Sludge, 40 C.F.R. § 503.13, 1997) apply only to compost that is made with some amount of reclaimed biosolids; otherwise, no laws technically govern the amount of metals found in soil and compost used in landscaping applications. Local nurseries can be asked if any of their products have been tested and if the test results are available.

The San Francisco Public Utilities Commission tested seven commonly available brands of commercial compost as well as compost created using biosolids from Bay-Area wastewater-treatment plants. Using its own laboratory, the agency found that all products were below the CHHSL for 13 of 15 heavy metals (Miller, 2010). One of the compost products was over the CHHSL for cadmium. Additionally, five products exceeded the CHHSL for arsenic, with three registering levels below the laboratory's limit of quantification of 3.75 ppm, yet potentially above the CHHSL of 0.07 ppm.

Whereas the use of raised beds, planters, or pots can potentially limit heavy metal concentrations, not all gardeners have the time and money to create raised beds.

Regardless of the type of garden utilized, a thorough assessment should be conducted of each garden site to identify potential sources of contamination, in addition to periodically conducting comprehensive soil testing to monitor changes in metal levels over time.

Conclusions

Urban gardening is growing in popularity. It is an integral component of the push to localize food systems while improving food security in neighborhoods where healthy food is not readily available. In San Francisco alone, gardens have sprouted up in the most unlikely places, including an unused freeway off-ramp and in dumpsters repurposed as orchards. Gardeners that participated in the study included octogenarians with a farming background, tech-savvy twenty somethings growing their own food for the first time, and apartment dwellers that beautified courtyards and stairwells with dwarf fruit trees. Regardless of where a garden is located, who the gardener is, or what growing techniques they use, urban gardening not only brings fresh produce to the table, but also empowers city residents to be directly involved in the production of their own food.

Gardeners need clean and healthy soil, just as their crops do, to grow and thrive. Unfortunately, many San Francisco vegetable gardens have heavy metal concentrations higher than Cal/EPA's Human Health Screening Levels, with exposure to multiple metals likely in gardens with unsafe levels of arsenic, cadmium, or lead. Government agencies do not agree on what levels of certain metals are safe for garden soil, and safe levels have not been determined for those with exposure to multiple contaminants. This leaves the gardening public unsure of whether or not their garden is safe to work in and eat from.

Some gardens in this study had indisputably high levels of lead. This does not mean that urban grown produce is necessarily less healthy than produce available in stores or at farmers' markets. Produce often has a label indicating where it was grown, although these labels do not offer specific information about the farm's soil or what

agricultural products have been applied to the fields. Limiting direct and indirect ingestion of soil itself is a logical and necessary step in reducing heavy metal exposure. By testing garden soil regularly, gardeners will know if they are growing produce in soil that is relatively safe, and they can take action if not.

Situating a vegetable garden away from high traffic areas may keep lead and arsenic levels lower than for gardens established in an area near many large roadways. A glance at a map of most U.S. cities, however, will likely reveal that expressways, highways, freeways, and other thoroughfares are ubiquitous in urban areas, with many urban dwellers living close to at least one heavily used roadway. Additionally, many individuals do not have much choice in where their home and garden is located, with household income, real estate prices, rents, and cultural factors, such as race and/or ethnicity, potentially influencing where one puts down roots. Increased mobility is assumed for those with greater financial resources, with past research showing that lower income communities often live in areas with greater exposure to environmental toxins than those with higher incomes (Diawara et al., 2006; Morello-Frosch et al., 2001), presumably not by choice.

In San Francisco, however, such trends in exposure do not hold true with regard to garden soil contamination. Cadmium and lead concentrations were greatest in higher income and predominately White/Anglo neighborhoods. The San Francisco Victorians, with successive layers of lead-based paint accumulating for the past 100 years or longer, appear to be a chief contributor of cadmium and lead to San Francisco garden soils.

Thus, those gardeners with the financial means to live in these ornate, high priced homes have inadvertently increased their risk for exposure to lead and cadmium.

In San Francisco, community gardens and gardens with raised beds have lower metal levels than backyard and in-ground gardens, respectively. There is no guarantee, however, that soils in these gardens are within safe thresholds for human health, or will remain so over time. Soil testing every few years will allow gardeners to stay informed of the health and safety of their garden. Along with soil testing, construction of raised beds requires a financial investment, which may not be possible for all low-income gardeners, including fixed-income seniors. For those without the means to construct raised beds, community gardens are a viable option in those cities with a community gardening program, although popular gardens can have a years-long waiting list.

It is good practice for all gardeners to limit their exposure to heavy metals through garden soils, with high-risk individuals needing to be more vigilant in reducing exposure. Such individuals include children under six years old, pregnant women, those with weakened immune systems, and people with known exposure to multiple contaminants. By taking a few simple steps in their gardens and kitchens, gardeners and their families can effectively manage and reduce their exposure to heavy metals (Figure 22).

- **Wash and scrub produce** before eating and soak leafy greens like kale and collards in a vinegar and water solution, or in slightly soapy water. Lightly scrub and then rinse.
- **Peel all roots** (e.g., carrots and radish) and discard the outer two or three layers of cabbage and brussel sprouts before eating.
- **Grow fruits and above-ground vegetables** instead of root crops. They usually have fewer metals in their tissues and on their surface.
- **Add compost** yearly at the rate of 1 part compost for every 3 parts existing soil.
- **Adjust your soil pH** to be between 6.5 and 7.0. Ask your local nursery about which amendments are right for your soil.
- **Limit the amount of soil children "eat"** by keeping their hands out of their mouths and having them wash their hands frequently.
- **Keep garden tools and work shoes outside** so soil is not brought inside the home.
- **Mulch all bare soil** with wood chips or a similar covering. Rather than digging in soil, provide a covered sandbox for children to play in.
- **Eat a healthy diet** with lots of fruits, vegetables, and foods rich in iron, such as beans and greens.
- **Test your soil for heavy metals.** Contact the University of Massachusetts, Amherst for inexpensive soil testing (www.umass.edu/soiltest/) or get a referral from the local lead prevention program for an independent certified Environmental Laboratory. In California, ask for the “CAM17” metals test.

Figure 22. Ten simple steps gardeners can take to reduce their exposure to heavy metals.

Recommendations Based on Findings

Urban Gardeners

- Test garden soil when first starting a garden to assess the safety of your soil.

For community gardens, inquire about previous soil test results. Re-test every few years to ensure safe levels are maintained.

- Use raised beds for growing vegetables whenever possible.
- Join a community garden if available in your area.
- Investigate the history of the site where your garden is located. Use this knowledge to inform decisions about your garden, such as what contaminants to test for.
- Assess garden sites for active sources of contamination, including chipping paint on a nearby house or other structure.
- Urban garden soil can have unsafe levels of one or more heavy metals.
Minimize exposure to metals and environmental toxins in general, and take extra precautions for individuals with multiple exposure pathways.

Municipalities

- Fund public health educational programs to educate gardeners of the need for soil testing. For example, the San Francisco Department of Public Health (2011b) created a document on managing lead in gardens that promotes using Cal/EPA's CHHSL as a baseline safe level for lead.

- Encourage government agencies to develop a set of guidelines stating what levels of heavy metals and other contaminants are safe for both residential and agricultural soils.
- Provide subsidized soil testing so all gardeners can manage their own risk of exposure.
- Provide no-cost soil testing for school gardens every other year, especially for those gardens that serve children under six years old.
- Strictly enforce the EPA’s 2010 “Renovation, Repair & Painting Program” for lead abatement (EPA, Lead; Renovation, Repair, and Painting Program, 73 Fed. Reg., 2008).

Further Research

- Explore models for identifying potentially unsafe gardens based on a minimum number of soil tests conducted in an area.
- Explore risk by demographic group based on the types of crops grown and consumed.
- Conduct soil testing for persistent organic pollutants and other contaminants of concern. If found in quantities that may be unsafe, analyze landscape features to detect patterns and sources of contamination.
- Develop a website with garden-related research that would be accessible by backyard gardeners with little or no science background.

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Appendix A

Informed Consent

Informed Consent

Race, Ethnicity, and Exposure to Heavy Metals by Urban Gardeners: A Research Project Sponsored by San José State University, the California Environmental Protection Agency's Environmental Justice Small Grants Program, and the Garden Club of America.

Your participation in this project is voluntary. By completing this survey, you are consenting to participate in this research.

The purpose of this research is to see if there are heavy metals in the garden soils of the following San Francisco neighborhoods: Bayview/ Hunter's Point (94124), the Mission District (94110), Potrero Hill (94107), Noe Valley/Castro (94114), and Portola/Visitation Valley (94134). The research is also designed to see if the amounts of heavy metals in garden soil differs between these neighborhoods. This survey will provide information on what crops different ethnic groups grow in San Francisco, which is important information in determining if heavy metals exist in the foods that we eat from our gardens.

If you would like to have your garden soil tested for heavy metals, please provide your contact information on the sign up sheet after completing the survey. Twenty gardeners from each neighborhood will be randomly chosen to have their soil tested, and will be contacted within two months to schedule the testing.

We appreciate your participation. If you have any questions or concerns, please feel free to contact either Jennifer Gorospe, graduate student, by email (SFgardeners@gmail.com) or Dr. Rachel O'Malley, faculty advisor, by leaving a message at (408) 924.5450. You may also reach either of us by mail at:

San Jose State University
Department of Environmental Studies
One Washington Square
San Jose, CA 95192-0115

Appendix B

Gardener Survey

A Survey of Gardeners from the 94107, 94110, 94114, 94124, and 94134 Zip Codes
*A Research Project Sponsored by San Jose State University and the
California Environmental Protection Agency's Environmental Justice Small Grants Program and
the Garden Club of America*

Thank you for your participation. Through this survey, I hope to determine the levels of lead and other metals in garden soils in San Francisco, and see if the levels of heavy metals we consume by eating the vegetables we grow ourselves is safe. Please fill out the survey to the best of your ability and please ask if you have any questions. You may choose to not answer any of the questions.

Your First Name: _____ Home zip code: _____

Your race/ethnicity (one or more): _____

Garden location (nearest intersection): _____X_____

Is your garden at your home? ☐ Yes ☐ No Household Income: _____

Is there a pregnant woman or child under 5 years old living at your home? ☐ Yes ☐ No

What kind of garden do you have? (mark one or more): ☐ Raised Beds ☐ In Ground
☐ Outdoor Planters ☐ Indoor Planters ☐ Other: _____

What vegetables, fruits, herbs, beans and grains do you grow and eat from your garden?

Season	Name of crops you eat from your garden
Example	cherry tomato, chayote, collards, lettuce, and bok choy
Spring	
Summer	
Fall	
Winter	

Thank you for your participation! Please submit form in person.

=====

For more information on the survey, contact
Jennifer Gorospe via email at sfgardeners@gmail.com or by mail at
c/o San Jose State University; Department of Environmental Studies
One Washington Square; San Jose, CA 95192-0115
Forms submitted via email or US Post will not be accepted.

Appendix C

Agreement to Participate in Research Consent Form

Consent Form

Agreement to Participate in Research

Responsible Investigator: Jennifer Gorospe (Graduate Student)

Title of Protocol: Race, Ethnicity, and Exposure to Heavy Metals by Urban Gardeners

1. You are invited to participate in a research study investigating levels of heavy metals in gardens in five San Francisco neighborhoods: Bayview/Hunter's Point, Visitation Valley/Portola, Potrero Hill, Noe Valley/Castro, and the Mission. This study is designed to identify any differences that may exist among these areas in
 - a) the amounts of heavy metals in home garden soils or
 - b) exposure risks for different groups of people based on the foods they eat from their gardens.
2. To participate in this study, you are requested to
 - a) complete a one-page survey and
 - b) allow Ms. Jennifer Gorospe and one assistant to sample the soil in your garden for heavy metals if requested. Soil sampling requires collecting 2 cups of soil or less from 4 to 6 small holes (about 4 inches deep). If you wish to participate in the study, researchers will carefully avoid damaging any plants in your garden during soil collection in any way; however, we cannot take responsibility for any perceived loss of plant productivity as a result of participation in the study.
3. There is no monetary compensation for participation in this research. For participating in this study, you will receive an educational pamphlet on potential health risks associated with heavy metal exposure, plus guidelines for how to reduce exposure to heavy metals in urban gardens. You will also be invited to attend a community meeting to explore these issues in more depth. If you have your soil tested, you will receive the soil test results and a basic explanation of the results within two months of the sample date. Soil test results are useful to decide what types of crops to grow and whether soil amendments could be help your garden grow better. The testing of garden soil is valued at \$85.
4. Heavy metals may be found in your garden, or they may be absent. If elevated metal levels are encountered, participants in this study will be encouraged to follow the precautions recommended in the educational materials provided and to contact the Childhood Lead Prevention program at (415) 252-3956. Participants can use soil data to determine what, if any, action to take to limit exposure. Although most heavy metals that humans consume are not absorbed into our blood, children under the age of 5, and developing fetuses can be at risk.

Initials _____

Households with pregnant mothers or small children will be encouraged to take extra precautions. There is a risk that metal levels in some gardens could be higher than study participants are comfortable with, which could cause some distress, such as the desire to stop eating food from your garden.

5. The results of the approximately 100 soil tests taken through this study will also be used to create a generalized map of heavy metals in garden soils in these four neighborhoods of San Francisco. Survey answers and soil test results will not be associated with your name or address, but will be given a unique identification number. The exact location of your garden will not be identifiable on any map we generate, with the location being shown as the nearest cross street or along a gradient.

6. This study may be published in an academic journal, and the heavy metal map will be made available to the public, to advocacy organizations and to local government. Study results may or may not result in the allocation of resources, such as subsidized soil testing, to areas where high levels of heavy metals may be more likely to be found.

7. Questions about this research may be addressed to Jennifer Gorospe, graduate student, at SFgardeners@gmail.com or at [REDACTED] Complaints about the research may be presented to Dr. Lynne Trulio, Chair, Department of Environmental Studies, at (408) 924-5450. Questions about a research subjects' rights, or research-related injury may be presented to Pamela Stacks, Ph.D., Associate Vice President, Graduate Studies and Research, at (408) 924-2427.

8. No service of any kind, to which you are otherwise entitled, will be lost or jeopardized if you choose not to participate in the study.

9. Your consent is being given voluntarily. You may refuse to participate in the entire study or in any part of the study. You have the right to not answer questions you do not wish to answer. If you decide to participate in the study, you are free to withdraw at any time without any negative effect on your relations with San Jose State University.

10. At the time that you sign this consent form, you will receive a copy of it for your records, signed and dated by the investigator.

The signature of a subject on this document indicates agreement to participate in the study.

The signature of a researcher on this document indicates agreement to include the above named subject in the research and attestation that the subject has been fully informed of his or her rights.

Participant's Signature

Date

Investigator's Signature

Date

Appendix D

Educational Pamphlet

Gardening

... without heavy metals

Metals & Your Health

Lead, Iron, Cadmium and Nickel are some of the elements we call heavy metals. Though we require certain heavy metals such as Iron and Zinc for good health, all metals can be toxic if we are exposed to them at high levels. Being "*exposed*" refers to when these metals get into our body, mostly by eating, drinking, or breathing particles that are too small to see. If we are exposed to too much of one metal, it can cause damage to our kidneys, nerves, lungs, bones, or other parts of our body. **Like most adults in this country, it is unlikely that you will be exposed to unhealthy levels of heavy metals from eating your garden produce, but you may want to consider taking a few simple steps to keep your family safe.**

How Do Heavy Metals Get Into Gardens?

All heavy metals occur naturally on earth, and you should expect to find some metals in your garden soil. In cities and industrial areas, particles of heavy metals are released into the air by vehicle and train exhaust, power plants, certain businesses and houses with lead-based paint and then land back on the ground.

Your Child & Heavy Metals

Pregnant women and children are at the most risk of getting sick from exposure. Kids under 6 and unborn babies grow so fast that their bodies absorb metals at a higher rate than adults. It is important to know the amount of heavy metals in your garden and to take action to reduce your family's exposure.

Inform Yourself!

- **Have your soil tested.** (See www.umass.edu/soiltest/.)
- **Learn how eat safely from your garden** (see other side).
- **Take extra precautions if children or pregnant women live in your home**, such as contacting your local Lead Prevention Program.

Garden Crops & Heavy Metals

After heavy metals are released into the air, they eventually settle back down to the ground. These tiny particles can coat the leaves of our crops and become part of the soil. Once in the soil, the metals can be absorbed through the roots of our crops where they can stay in the roots, or travel up the plant into it's stem, leaves, or fruits. A few crops known to absorb metals include:

- **Lead:** Napa Cabbage, Onions, Lettuce, Turnip Greens, Cilantro
- **Cadmium:** Lettuce, Spinach, Turnip Greens, Carrots, Leeks
- **Zinc:** Spinach, Chard
- **Arsenic:** Mustard Greens, Apples

In a nutshell....

The U.S. Environmental Protection Agency (U.S. EPA) and many Public Health agencies have published what they consider to be "safe levels" of certain metals in soil. Unfortunately, these organizations do not always agree on what is safe, and "safe levels" specifically for gardens where food is grown can be higher than what is considered safe by other agencies. For example, the U.S. EPA states that up to 300 *ppm* (or 300 parts out of a million) of Lead is a safe level for compost that will be added to a home vegetable garden. The California EPA says that to be below the "level of concern for human health" soil should have less than 80 ppm of Lead. Since there is no simple answer as to what is considered "safe," you can use the table on page 3 to help you decide what levels you feel are safe for your garden. Then, by educating yourself and adopting a few common-sense actions, you can continue to safely enjoy gardening and eating fresh, healthy produce.

Eating Safely From Your Garden

Most people are only exposed to a very small quantity of heavy metals by eating produce from their garden. However, since the risk of health problems is higher for children under 6 and pregnant women with unborn children, be extra careful in avoiding exposure by following all of these recommendations and contacting your local Department of Public Health's Lead Prevention Program.

- **Wash and scrub produce** before eating and soak leafy vegetables like kale and collards for 3 minutes in 1 cup of vinegar to 3 cups of water or in slightly soapy water. Lightly scrub and then rinse to remove any small particles.
- **Peel all roots** (i.e., carrots and radish) and discard the outer 2 or 3 layers of cabbage and brussel sprouts and before eating.
- **Grow fruits and above-ground vegetables** instead of root crops. They usually have less metals in their tissues and on their surface.
- **Add compost** to the soil every year. Add 1 part compost for every 3 parts existing soil.
- **Adjust your pH** to be between 6.5 and 7.0. Ask a nursery which soil ammendments are right for your soil.
- **Limit the amount of soil children "eat"** by keeping their hands out of their mouth and having them wash their hands frequently.
- **Keep all garden tools and work shoes outside** so you don't bring soil into the house and **mulch all bare soil** with wood chips or similar. A covered sandbox is a great alternative for kids to dig in.
- **Eat a healthy diet** including lots of fruits, vegetables, and foods rich in Iron, such as beans and greens. A diet low in certain vitamins and minerals can result in our bodies absorbing more metals than it would normally.
- **Know your soil by testing it for heavy metals.** For \$10 + shipping, you can have your soil tested through University of Massachusetts, Amherst (see *below*). You can also contact your local Department of Public Health for a referral to a certified Environmental Laboratory. This will cost more but likely be more accurate. In California, you should ask for the "CAM17" metals testing.

What Levels Are Safe for My Garden?

Recommended Limits of Heavy Metals for Soil in Parts per Million (ppm)

	Land Application of Biosolids for Home Vegetable Gardens †	Human Health Screening Level (HHSI)	Regional Screening Level for Superfund Sites, Residential Soil	Total Threshold Limit Concentration for Hazardous Toxic Waste
Agency & Online Access	U.S. EPA Clean Water Act Title 40, Section 503.13 http://ecfr.gpoaccess.gov	California Office of Environmental Health Hazard Assessment http://oehha.ca.gov/risk/ chhsltable.html	U.S. EPA Region 9 www.epa.gov/region9/ superfund/prg	California Department of Toxic Substances Control CA Code of Regulations, Title 22, Section 66261.24; www.dtsc.ca.gov/laws regspolicies/title22/index.cfm
Antimony		30	31	500
Arsenic	41	0.07	39	500
Barium	-	5,200	15,000	10,000
Beryllium	-	16	160	75
Cadmium	39	1.7	70	100
Chromium (III)	-	100,000	120,000	2,500
Cobalt	-	660	23	8,000
Copper	1,500	3,000	3,100	2,500
Lead	300	80	400	1,000
Mercury	17	18	23	20
Molybdenum	-	380	390	3,500
Nickel	420	1,600	1,500	2,000
Selenium	100	380	390	100
Silver	-	380	390	500
Thallium	-	5	0.78	700
Vanadium	-	530	390	2,400
Zinc	2,800	23,000	23,000	5,000
	For compost made from sewage sludge. Current as of 11/2010. Considers ingesting soil & eating produce.	“Below level of concern for human health.” Current as of 11/2009. Considers ingesting soil.	Safe for children under 6 to play in at cleaned-up Superfund sites. Updated 5/2010. Considers ingesting soil.	Soil above this level may be unsafe. Updated 3/2009.

† When these levels were first being discussed in 1984, existing research on some metals indicated that they were not hazardous enough to consider.

Soil Testing

Taking a Soil Sample

Having your soil tested is the best way to know how healthy your soil is. For each area you want to test, take **3 to 5 subsamples** and mix them together to form a **composite sample**. Each composite sample should be taken from a specific area (i.e., one raised bed). To get started, you need a clean trowel, ruler, Ziploc bag, and fairly dry soil.

- To take a subsample, dig a 10" hole and take a "slice" of soil from top to bottom with your trowel. Place the soil in the Ziploc bag.
- Repeat 3 or 4 times, taking each subsample from within the same area. Label the bag as sample 1.
- Use a new bag for each composite sample, making sure to label them.
- Allow the samples to air-dry & mix thoroughly. Send 1 cup of the soil to the lab with your order form.

Managing Heavy Metals

The **table of safe levels** lists the amounts of metals government agencies say are safe for soil and gardens. Use the table and your soil test results to decide if you feel your garden is safe. Reducing exposure is your first priority if your garden has high levels of heavy metals, so consider taking these precautions, especially if you have young children:

- High lead levels often result from lead-based paint. Fix flaking paint, talk to neighbors with flaking paint, and **contact your local Lead Prevention Program** as a resource. If reported, **landlords may be required to remove or pave-over soil with high levels of lead**.
- Identify the source of the metals and take steps to reduce exposure.
- Add organic compost and/or new soil to dilute existing soil.
- Install raised beds with new soil.
- Do not put garden green waste into your home compost bin.
- Do not grow root crops or other foods that absorb metals until you retest the soil and know it is safe.
- Retest your soil often so you can monitor changes in your levels.
- For severe contamination, contact an environmental engineering firm.

Resources

U.S. EPA

Lead in Paint Dust and Soil
www.epa.gov/lead/

National Lead Information Center
(800) 424-LEAD

Soil and Plant Testing Laboratory
Univ. of Massachusetts, Amherst
www.umass.edu/soiltest/
(413) 545-2311

This pamphlet was created by Jennifer Gorospe of San José State University with City Slicker Farms & Arc Ecology, with support from California Environmental Protection Agency's Environmental Justice Small Grants Program & the Garden Club of America. Photos by Zoey Kroll, Jennifer Gorospe, Erin Wilson and Cristina Ibarra.

For more information contact
SFgardenders@gmail.com.

Appendix E

Data Collection Form

Name: _____	Address/ZIP: _____
Date of Visit: _____	Scheduled Appt: _____
Signed Copies of consent form provided: ☐ Gardener ☐ Project Copy	
☐ Community Grdn ☐ Backyard Grdn ☐ School Grdn ☐ Other: _____	
Map of Garden showing X-streets, structures and sample locations.	
Key: Raised beds (R), In Ground (G), Planters (P), Mulch (M), and Fruit Trees (F)	
Crops Observed: _____	
Types of mulch observed: _____	
*How long have you been gardening at this location? _____	
*Where did the soil come from? _____	
*Do you use any fertilizers, herbicides, or fungicides?	
Yes / No	Brands: _____
*Do you add compost to the soil, and if you do, where does it come from?	
Yes / No	Origin of compost: _____
*Do you know of any previous land use for this site besides residential?	
Yes / No	Type of Land Use: _____

Appendix F

Results Letter to Participants

Date

Dear San Francisco Garden Study Participant,

This letter provides preliminary information about the soil sample taken from your garden this past fall. In this packet, you will find:

- Your soil test results (*Analysis Report*);
- Information on the SFPUC Biosolids Compost program;
- Summary graphs that show average levels for the gardens tested; and
- An updated copy of the pamphlet on heavy metals and gardens with a table showing "safe" levels for each metal.

Information in this packet represents results from my research at San José State University only; it does not reflect the views or opinions of the California EPA or other project sponsors. As part of this project, all individual soil test results and specific garden locations have been kept completely confidential, and shared directly with study participants only on an individual basis.

Your Results

Your soil was tested professionally for 17 metals and pH, using very accurate methods (see adjacent box). These test results should be more accurate than numbers you might get from a less expensive soil test, however, accuracy for mercury may be lower than for other metals in the study, because it is extremely volatile (can rapidly change into a gas), making it hard to measure.

Your *Analysis Report* lists each metal that was tested, followed by its concentration in parts per million (ppm). Concentrations that were too small to measure simply show a "less than" symbol (<) before the lowest concentration that the lab could detect.

Testing Info

MACS Lab

www.macslab.com

510.786.9751

ELAP Certified

Testing Methods

CAM17 Metals

EPA Methods 3050B
& 7300 (ICP-AES)

Cost

\$100-150/sample

*It's easy to take
action to reduce the
amount of metals
we are exposed to
through gardening.*

Average Levels

Across the entire study, **raised bed gardens had lower concentrations than in-ground gardens** for all of the 10 commonly found metals (see last page of this letter). Seven of the metals were found in only very few of the gardens.

All metals occur naturally on the earth, and you should expect to find some metals in your soil. Naturally existing levels, called background levels, can vary widely, even across the Bay Area. For some metals, such as arsenic, background levels may be higher than the "safe" levels explained on the next page.

"Safe" Levels

Different government agencies consider different concentrations of metals in the soil to be "safe" (see enclosed pamphlet).

- For example, for 7 of the metals tested, levels that are considered hazardous waste by the California Department of Toxic Substances Control are below the limit that the U.S. EPA considers to be safe for children under six to play in.
- Similarly, levels of lead, arsenic and cadmium considered safe by the U.S. EPA for compost used in vegetable gardens are higher than levels the California Office of Environmental Health Hazard Assessment considers safe for human health.
- Furthermore, all standards cited here consider the risk to children from directly eating soil, however only the *Land Application of Biosolids* standard considers human health risk due to eating garden produce.

A sandbox that can be covered when not in use is a great alternative area for kids to dig.

Children are at greatest risk from exposure to metals in soils. Many agencies - including San Francisco's Department of Public Health – state that there is no safe level of lead in our bodies. The amount of metals we are exposed to from eating produce, however, is far less than that of eating soil.

SFPUC Biosolids Compost

Many study participants expressed concern over potential contaminants in compost that was given away by the San Francisco Public Utilities Commission (SFPUC) before March, 2010. The compost was made from decomposed biosolids from various wastewater treatment plants of Central California, including San Francisco's Southeast and Oceanside plants. Although no test results are publically

San Francisco Public Utilities Commission's Biosolids Compost Program

Memo, including test results, can be requested at (415) 554-3289, or downloaded from

http://sfwater.org/detail.cfm/MC_ID/14/MSC_ID/127/MTO_ID/759/C_ID/5112/ListID/1

available for metals or organic compounds on the batches of compost that were given away, and no independent tests have been conducted, the SFPUC's in-house certified lab tested the compost for metals and organic pollutants in July 2010. The SFPUC memo shows that all chemical concentrations met the U.S. EPA requirements for compost that is used on home gardens. While biosolids are a plentiful source of

fertilizer for gardens, future programs should provide lab test results, compost manufacturing process information, and details on appropriate application rates.

Gardening for your Health

Eating from a home garden provides fresh and nutritious food at a reasonable cost. We all can take these simple **actions** to minimize the amount of metals we are exposed to.

1. **Wash and scrub produce** before eating and soak leafy vegetables like kale and collards for 3 minutes in 1 cup of vinegar to 3 cups of water or in soapy water. Lightly scrub and rinse well.
2. **Peel root crops** and discard the top few layers of cabbage, brussel sprouts, and similar crops.
3. **Grow fruits and above-ground vegetables** instead of root crops, since they usually have less metals in their tissues and on their surface.
4. **Add compost** to your garden every year. Add 1 part compost for every 3 parts soil.
5. **Adjust your pH** to be between 6.5 and 7.0. Ask a nursery which products are right for your soil.
6. **Limit the amount of soil children "eat"** by keeping their hands clean and out of their mouth,
7. **Keep garden tools and work shoes outside** and **mulch all bare soil** with wood chips or similar.
8. **Eat a healthy diet**, including a lot of fresh fruits and vegetables and foods rich in iron such as beans and greens. Poor diets can result in our bodies absorbing more metals than they would normally.

Reducing Metals in Soil

If your garden has levels of metals that you feel are unsafe for you and your family, taking action to reduce exposure is your first priority. The eight steps listed above will help limit your exposure. You may want to take extra precautions, however, especially if you have children. Our local Childhood Lead Prevention Program offers education, need-based financial assistance for homeowners, and other services to help manage lead in and around the home, including lead in soil. However, soil with high levels of lead may be considered a hazard that a landlord may be required to remove or pave over with concrete, if reported to a government agency.

*SF Department of Public Health Childhood Lead Prevention Program, (415) 252-3800
www.sfdph.org/dph/EH/CEHP*

*San Francisco Health Code, Article 11, Section 581(b) (10):
Homeowners must provide housing free of lead hazards where children live or visit often.*

In some cases, gardeners may be able to reduce the concentration of metals in their garden. Depending on where your levels start off, it may take years for the soil to get to a level that you feel is safe. If you decide to try the remediation strategies listed below, you should retest your soil yearly until repeat results show the soil to be at levels you consider safe.

- If your lead level is high, it is likely that nearby homes are releasing dust from lead-based paint that is drifting into your garden. **Fix any flaking paint** on your home, talk to your neighbors if they have flaking paint, and contact the Lead Prevention Program if it is appropriate.
- Try to **identify the source** of your contamination and take steps to reduce or eliminate exposure.
- **Add compost** and/or soil from a nursery to dilute the existing soil.
- Create **raised garden beds** using non-pressure treated wood, and fill with 'new' soil or compost that is organic or has been tested by the supplier for heavy metals. Test your soil every few years to ensure that you have reduced or eliminated the source of the metals.
- **Place all garden green waste in your green bin.** Do not add it to your home compost bin.
- **Avoid growing roots crops** or other vegetables that are known to accumulate metals until you retest your soil and know that it is safe.
- **Test your soil regularly.** If you cannot afford certified soil testing from a private independent lab such as the lab used for this study, the University of Massachusetts, Amherst, provides basic household soil testing for \$10 per sample (see enclosed pamphlet for more information).
- If your contamination is extensive, you may want to contact an environmental engineering firm to professionally assess the situation.

Please feel free to contact me if you have questions about your test results.

Thank you for your participation,

Jennifer Gorospe

Project Info

*Researcher: Jennifer Gorospe,
M.S. Candidate, San José State
University, sfgardeners@gmail.com*

*Funders: California Environmental
Protection Agency's Environmental
Justice Small Grants Program & The
Garden Club of America*

Heavy Metals in In-Ground and Raised Bed Gardens of San Francisco

Metals that were undetectable in over 94% of the gardens were not graphed, including antimony, beryllium, mercury, molybdenum, selenium, silver, & thallium. 9 of the gardens are not included because their soil samples were taken from both garden types and mixed. The HHSLs can be found at <http://oehha.ca.gov/risk/chhsltable.html>. Created by Jennifer Gorospe, M.S. Candidate, San José State University, 2011.

Appendix G

Select Data for 94107

ID	As ^a	Ba	Cd	Co	Cr	Cu	Ni	Pb	V ^a	Zn	pH	Garden Bed Type	Garden Type	Home Age (yrs)
07a	3.7	406	8.14	96.2	297	84.5	1760	745	< LOQ	512	6.9	In Ground	Backyard	104
07b	6.39	282	6.48	49.4	314	62.9	892	937	11	459	6.92	In Ground	Backyard	102
07c	4.49	326	6.8	46.5	585	88.8	916	753	10.6	430	7.09	In Ground	Backyard	110
07d	7.28	344	5.36	47.2	312	57.5	838	1120	11	505	7.72	In Ground	Backyard	102
07e	2.78	94.1	2.5	13.4	52	40.9	150	37.2	21.1	83.6	7.01	In Ground	Backyard	26
07f	< LOQ	85.3	2.39	25	126	45.3	472	135	11.9	134	7.29	In Ground	Backyard	82
07g	3.24	94.1	2.32	6.67	35.7	45.2	32.8	62.3	16.1	96.1	6.54	In Ground	Backyard	29
07h	9.86	439	5.98	37.8	289	94.4	657	1750	14.8	650	6.83	In Ground	Backyard	104
07i	1.93	141	2.47	12.1	63.2	44.3	139	163	19.2	209	6.96	In Ground	Backyard	103
07j	< LOQ	78.5	3.19	9.77	36.1	17.1	26.1	16.5	26.2	59.1	7.7	In Ground	Backyard	102
07k	11	242	2.48	4.58	35.1	60.1	23.7	1400	13.2	290	6.57	In Ground	Comm.	
07l	11.8	420	3.52	33.6	126	122	219	1260	15.3	550	7.7	Raised Bed	Backyard	110
07m	< LOQ	131	1.94	14.4	138	45.1	235	273	11.6	182	6.5	Raised Bed	Backyard	110
07n	< LOQ	129	1.73	3.86	17.2	63.1	18.7	64.2	11.9	200	6.75	Raised Bed	Backyard	106
07p	< LOQ	89.2	1.76	5.74	24.5	42.8	36.4	35	12.7	108	7.4	Raised Bed	Backyard	17
07q	< LOQ	53.8	1.16	4.59	24.1	22.5	20.2	29.3	13.3	73.2	7.4	Raised Bed	Comm.	
07r	2.22	64.6	1.94	10.6	53	25.9	137	44.8	12	120	7.63	Raised Bed	Comm.	
07s	3.17	84.8	2.49	8.09	48.7	34.3	52.1	53.8	22.7	119	7.08	Raised Bed	Comm.	

^a < LOQ indicates a value below the Limit of Quantification.

Appendix H

Select Data for 94110

ID	As ^a	Ba	Cd	Co	Cr	Cu	Ni	Pb	V	Zn	pH	Garden Bed Type	Garden Type	Home Age (yrs)
10a	3.59	306	3.18	12.2	48.3	72.1	46.5	876	30.7	306	6.64	In Ground	Backyard	99
10b	7.6	479	5.13	9.02	61.6	132	32.1	1330	27	603	6.62	In Ground	Backyard	102
10c	12	228	3.37	9.12	48.7	64.7	32	637	27.6	387	7.21	In Ground	Backyard	110
10d	21.9	363	3.91	10.4	76.4	2630	71.3	2000	36.4	567	7.27	In Ground	Backyard	98
10e	2.92	374	2.29	6.19	52.1	41	20.8	560	23.8	305	6.49	In Ground	Backyard	104
10f	3.2	235	1.98	7.06	37.4	53.4	32.2	838	15.5	385	7	In Ground	Backyard	97
10g	3.1	369	5.87	31.3	102	77.5	61.6	445	73.8	385	7	In Ground	Backyard	110
10h	2.3	135	2.08	6.77	41.3	32.2	25	298	23.3	153	6.89	In Ground	Backyard	102
10i	5.91	58.4	1.43	5.43	33.4	25.8	17.8	30.9	15.9	63.5	7.25	In Ground	Backyard	55
10j	<LOQ	102	2.25	10.8	49.5	34.6	42.4	68.7	31.1	114	7.01	In Ground	Comm.	
10k	<LOQ	118	3.21	18.4	141	33.3	212	49.7	33	92.8	7.08	In Ground	Comm.	
10l	<LOQ	32.2	1.24	4.68	24.8	11.5	18.7	16.6	13.3	47.8	7.76	In Ground	Comm.	
10m	2.37	97.5	2.2	7.45	38	51.7	44.3	89.8	18.1	176	7.33	In Ground	Comm.	
10n	<LOQ	114	1.76	5.06	19.8	55.3	16.4	45.8	15.6	149	7.41	In Ground	Comm.	
10p	2.49	128	2.33	5.92	24.9	70.3	20.9	112	18.6	175	7.14	In Ground	Comm.	
10q	3.32	102	1.9	5.34	32.5	46.6	31.8	64.3	13.1	145	6.73	Raised Bed	Comm.	
10r	2.64	243	2.97	10.2	52.1	47.7	38.4	124	46.1	181	5.58	Raised Bed	Comm.	

^a < LOQ indicates a value below the Limit of Quantification.

Appendix I

Select Data for 94114

ID	As ^a	Ba	Cd	Co	Cr	Cu	Ni	Pb	V	Zn	pH	Garden Bed Type	Garden Type	Home Age (yrs)
14a	5.58	220	3.14	14	61.3	59.2	41	283	36.3	217	6.74	In Ground	Backyard	100
14b	5.99	245	3.58	11.8	39.8	55.1	40.2	624	22.1	268	6.75	In Ground	Backyard	80
14c	17	223	2.44	5.68	32.5	59	20.4	723	17.8	254	6.48	In Ground	Backyard	115
14d	3.65	152	2.03	6.25	27.6	43.7	18.3	347	17.5	215	7.44	In Ground	Backyard	104
14e	10	279	2.76	10.8	48.3	68	50.2	218	26.5	193	7.15	In Ground	Backyard	103
14f	4.73	130	1.85	6.31	27.4	43.3	20.6	307	21.8	155	7.87	In Ground	Backyard	103
14g	4.5	208	2.53	9.22	62.7	41.9	24.7	378	30	235	6.57	In Ground	Backyard	55
14h	23.8	509	6.13	14.5	65.4	98.9	54.9	2040	34.2	707	6.87	In Ground	Backyard	85
14i	5.77	197	2.63	8.83	59.3	44.3	64.3	502	21.4	302	6.85	In Ground	Backyard	120
14j	14.6	298	5.03	17.6	80.5	109	91.2	540	34.6	450	7.23	In Ground	Backyard	82
14k	6.98	135	3.22	12.2	42.5	35.8	72.9	97.3	22.4	148	6.91	In Ground	Backyard	3
14l	14.2	348	4.95	8.48	52.3	76	28.5	899	23.8	373	6.46	In Ground	Backyard	108
14m	1.56	82.6	1.68	9.38	54.8	42.3	134	97.9	9.93	113	7.2	In Ground	Backyard	120
14n	2.88	135	2.93	12.6	64.8	35.6	79.6	59.8	27.4	115	7.09	In Ground	Comm.	
14p	12.7	427	6.04	19.6	128	104	66.9	1130	52.8	629	6.68	In Ground	School	
14q	3.43	122	1.7	6.07	18.6	58.1	17.4	27.8	17.8	118	7.04	Raised Bed	Backyard	103
14r	11.3	345	2.39	6.89	37.7	77.8	23.5	1330	20.2	544	7.03	Raised Bed	Backyard	121
14s	<LOQ	75.7	1.51	5.02	25.5	50.8	23	34.9	15.2	95.7	6.38	Raised Bed	Backyard	112
14t	<LOQ	302	2.65	6.44	56.2	58.7	22.4	869	25.6	422	7.1	Raised Bed	Backyard	106
14u	<LOQ	66.8	1.61	5.77	29.3	32.8	27.9	40.4	15.5	94	7	Raised Bed	School	

^a < LOQ indicates a value below the Limit of Quantification.

Appendix J

Select Data for 94124

ID	As ^a	Ba	Cd ^a	Co	Cr	Cu	Ni	Pb	V	Zn	pH	Garden Bed Type	Garden Type	Home Age (yrs)
24a	2.57	217	2.81	8.29	46.9	51.6	31	109	43.3	161	8.44	In Ground	Backyard	69
24b	<LOQ	87.4	1.83	5.64	36	23.3	36.1	178	16.7	146	6.87	In Ground	Backyard	64
24c	2.84	95	1.99	6.98	42.6	48.4	40.8	71.9	18.4	153	6.15	In Ground	Backyard	55
24d	2.82	137	3.16	14	47.3	26.2	36.3	70.6	48.5	101	5.94	In Ground	Backyard	65
24e	17.2	124	2.06	4.22	57.3	66.9	14	272	13.3	307	6.78	In Ground	Backyard	102
24f	6.39	161	2.54	9.44	30.5	50.1	29.9	106	19.4	143	7.48	In Ground	Backyard	11
24g	3.67	138	2.03	5.66	37.6	32.3	18.1	159	22.5	209	7.26	In Ground	Backyard	69
24h	8.18	133	2.67	6.33	48.7	43.5	23.7	92.2	23.7	141	6.45	In Ground	Backyard	68
24i	<LOQ	11.7	<LOQ	0.619	2.57	1.56	1.59	45	1.54	33.3	6.73	In Ground	Backyard	86
24j	3.07	102	2.42	9.01	40.3	23.7	35.2	91.1	26.3	164	6.81	In Ground	Backyard	63
24k	5.98	348	3.49	8.66	53.1	60.6	33.4	670	28.5	463	7.08	In Ground	Backyard	80
24l	2.2	76.8	1.85	6.84	31.1	41.2	32	33.9	15.8	97.6	6.44	In Ground	Comm.	
24m	2.1	112	1.5	5.93	36.1	27.7	42.6	177	14.1	156	6.97	In Ground	Comm.	
24n	<LOQ	108	2.83	12.5	63.5	29.3	116	76.4	23.9	135	7.03	In Ground	Comm.	
24p	<LOQ	41.7	<LOQ	1.65	5.95	19.6	5.75	6.55	6.16	48.1	7.19	Raised Bed	Backyard	21
24q	<LOQ	43	<LOQ	1.36	6.13	13.7	5.86	13.4	5.25	35.9	7.19	Raised Bed	Comm.	
24r	1.78	70.7	1.94	6.31	24.4	21.7	18.3	27.7	20.6	53.3	7.03	Raised Bed	School	

^a < LOQ indicates a value below the Limit of Quantification.

Appendix K

Select Data for 94134

ID	As ^a	Ba	Cd	Co	Cr	Cu	Ni	Pb	V	Zn	pH	Garden Bed Type	Garden Type	Home Age (yrs)
34a	2.5	114	2.39	5	38	33.1	22.1	122	23.5	153	6.81	In Ground	Backyard	57
34b	4.26	180	3.45	7.98	26	55.2	29.9	188	18.4	241	6.98	In Ground	Backyard	99
34c	21.3	105	2.89	11.1	63.6	36.3	28.3	150	37.2	201	5.32	In Ground	Backyard	62
34d	4.17	105	2.43	7.69	42.1	33.7	34.2	972	22.8	119	6.43	In Ground	Backyard	69
34e	1.88	38.2	1.87	4.47	39	12.6	16.5	26.2	19.9	85.6	6.7	In Ground	Backyard	47
34f	3.84	114	1.96	5.37	38.7	31.5	15.5	244	19.9	145	6.44	In Ground	Backyard	24
34g	2.22	70.7	2.07	5.69	40.3	31.6	17.3	15.9	24.5	49.8	5.99	In Ground	Backyard	55
34h	6.78	81.5	1.9	6.17	84	35.4	33.2	120	21.6	145	6.39	In Ground	Backyard	72
34i	3.83	241	4	16.6	45.9	58.2	31.9	358	38.7	261	7.24	In Ground	Backyard	59
34j	<LOQ	200	4	16.7	73.2	48.8	55.5	482	48.9	354	6.82	In Ground	Backyard	98
34k	1.83	76.9	2.09	5.18	34.7	32.2	19.6	72.3	18.5	126	6.57	In Ground	Backyard	60
34l	8.82	164	2.55	9.86	51.2	31.2	33.4	134	33	150	6.86	In Ground	Backyard	77
34m	<LOQ	87.5	1.83	6.73	43	43.7	29.8	53.8	22.8	95.8	6.99	In Ground	Comm.	
34n	<LOQ	52.8	1.52	6.52	35.1	14.9	18.5	27.1	20.7	58.4	7.01	In Ground	Comm.	
34p	2.29	98.3	1.81	6.86	35.7	60.2	24.9	71.7	21.1	152	6.63	Raised Bed	Backyard	60
34q	<LOQ	70.3	1.35	4.21	9.79	23.9	10	33.4	10.4	84.7	7.01	Raised Bed	Comm.	
34r	2.42	85.1	2.17	6.75	34.5	31.2	30.6	209	21.6	79.8	6.79	Raised Bed	Comm.	
34s	<LOQ	70.6	1.4	4.53	10.8	14.1	10.6	28.7	11.7	129	6.75	Raised Bed	Comm.	
34t	<LOQ	41.6	1.01	2.72	13.8	17.5	12.2	9.56	7.05	36.6	7.2	Raised Bed	School	

^a < LOQ indicates a value below the Limit of Quantification.