# Trace Metal Contamination in New York City Garden Soils

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**Abstract:** Urban gardening, urban agriculture, and urban farming provide healthy food and promote environmental, social, cultural, and educational benefits. However, urban soil is a natural sink for contaminants derived mainly from historical anthropogenic activities. This article reports a summary of trace metal concentrations (Cr, Co, Ni, Cu, Zn, As, Cd, and Pb) of 1,652 garden soil samples from 904 gardens in New York City. Based on the Soil Cleanup Objective (SCO) criteria developed by New York State Department of Environmental Conservation (6 NYCRR Part 375), many of the soils analyzed exceeded the limits for Pb, Cr, As, and Cd levels. Higher percentages of home gardens are contaminated than community gardens. When accounting for Pb and As levels, about 21% of the community garden samples and 71% of the home garden samples exceed respective SCO limits. Among all home and community garden samples, less than 3% meet the criteria for unrestricted use when all trace metals are considered. There are controversies on the appropriateness of SCO criteria for urban gardening situations. Consistent soil trace metal guidelines pertaining to gardening need to be developed. Expanded soil screening, greater public awareness, and education are urgently needed to ensure safe and successful urban agriculture.

**Key Words:** Urban, soil, trace metal, contamination

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About 80% of the population in the United States lives in urban areas. Traditionally, gardening included growing ornamental plants and participating in recreational activities, but more and more people are becoming interested in harvesting produce in gardens. Recent surveys showed that 35% of all households in America, or 42 million households, are growing food at home or in a community garden—up 17% in 5 years. The largest increases in participation were seen among younger households—up 63% to 13 million since 2008. There are 2 million more households community gardening—up 200% since 2008 (National Gardening Association, 2014).

Gardening provides many benefits that are currently appreciated in society. Vegetables and fruits produced in gardens in low-income areas can be important and affordable sources of nutrition. In large cities, particularly in "food deserts" where access to healthy and safe food is limited, urban agriculture may enhance dietary needs (Alaimo et al., 2008; Armstrong, 2000; McCormack et al., 2010). Current food systems for urban areas in the United States generally rely on long supply lines dependent on fossil fuels. Food produced locally can be useful supplements for helping municipalities build safe, secure, and sustainable food systems (Blair et al., 1991).

In addition to providing healthy and nutritious food, urban agriculture also promotes urban environmental sustainability, social equity and justice, and opportunities for outdoor education. Eating food grown locally saves energy and reduces greenhouse gas emissions caused by production and transport. Planting in previously abandoned lands not only reclaims unused space but also sequesters carbon dioxide, reduces air-borne dust, improves air quality, and mitigates the urban "heat island" effect. Gardens provide spaces for numerous social and community-building interactions (Kuo et al., 1998; Wakefield et al., 2007). Gardening may also enhance psychological well-being (Kaplan, 1973; Fabrigoule et al., 1995; Simons et al., 2006). Many schools have their own gardens to teach concepts of modern and sustainable urban living, such as food and nutrition, farming and agriculture, waste recycling, and conservation.

A significant percentage of urban land surfaces are impervious (Nowak and Greenfield, 2012). Most human exposure to urban soil occurs in parks, green spaces, and landscapes used for recreational purposes. Limited studies have documented metal contamination of soils in many of the world's largest cities, including London (Kelly and Thornton, 1996), Hong Kong (Chen et al., 1997; Lee et al., 2006), Berlin (Birke and Rauch, 2000), Oslo (Tijhuis et al., 2002), Stockholm (Linde et al., 2001), Beijing (Chen et al., 2005; Zheng et al., 2008), Hangzhou (Wuzhong et al., 2004), Grugliasco (Poggio et al., 2009), Bangkok (Wilcke et al., 1998), and several other European cities (e.g., Biasioli et al., 2007). Mielke et al. (1983) were the first to discuss the extensive Pb and other metal contamination of urban soils in the United States. The USEPA (1998) conducted a literature survey and found that soils in many cities around the country were highly contaminated with Pb, including New Orleans, Boston, and Baltimore. These cities are characterized by historical industrial activities that have concentrated much of the pollutants in urban soil during the past few centuries. Mitchell et al. (2014) conducted the first study of metal contamination of community garden soils in New York City.

Metal contaminants can enter the human body through several different pathways. For example, fine soil particles are one of the sources of air particulates that can lead to air quality problems both outdoors and indoors. Mielke and Reagan (1998) showed that soil lead is at least equal to or more important than lead-based paint as a pathway for human lead exposure, especially after lead abatement campaigns have greatly limited the exposure to leaded paint. According to Lanphear et al. (1998), the levels of lead in household dust and soil that are associated with elevated blood lead levels among US children remain poorly defined. Their results showed that lead-contaminated house dust is the major source of lead exposure for children. Weitzman et al. (1993) demonstrated that lead-contaminated soil increased the lead load of urban children, and that abatement of lead-contaminated soil around homes results in a decline in blood lead levels. As the urban gardening population involved in food production increases, there is concern that metals in soil can be transferred into produce

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and subsequently pose health risks on consumption. Gardening also increases the chances of ingestion and inhalation of contaminated soil dusts. In many cases, children are encouraged to participate in such activities, even though they are the most susceptible to contaminants.

New York City is one of the largest metropolitan areas in the United States, with a population of about 9 million. The past few years have seen rapid increase in the interest levels and participation in gardening. One of the largest gardeners' associations in the country, GreenThumb, currently oversees more than 600 community gardens. Despite this encouraging trend, very little soil metal contamination data are available to the public. A recent article by Mitchell et al. (2014) reported metal contamination in about 50 community gardens. The prime objective of this study was to assess the magnitude of soil trace metal contamination in home and community gardens where food has been grown or was intended to be grown.

## SAMPLES AND METHODS

Soil samples were sent to the Environmental Sciences Analytical Center at Brooklyn College of The City University of New York by gardeners from all five boroughs of New York City to screen for trace metal contamination. Since 2009, the laboratory has received about 3,000 garden soil samples from New York City. This study only reports the 1,652 samples from 904 garden addresses that can be mapped. Among the 1,652 samples, trace metal results are available for 475 samples, whereas only Pb concentrations are available for the others.

Gardeners were instructed to collect soil from the surface down to depths of 14 to 20 cm (6–8 inches) and from 5 to 10 locations spread within each garden. The 6- to 8-inch guideline was used because the majority of vegetable crop roots are concentrated in the top 6 inches of the soil. A small percentage of gardeners only concerned with surface contamination collected soil from

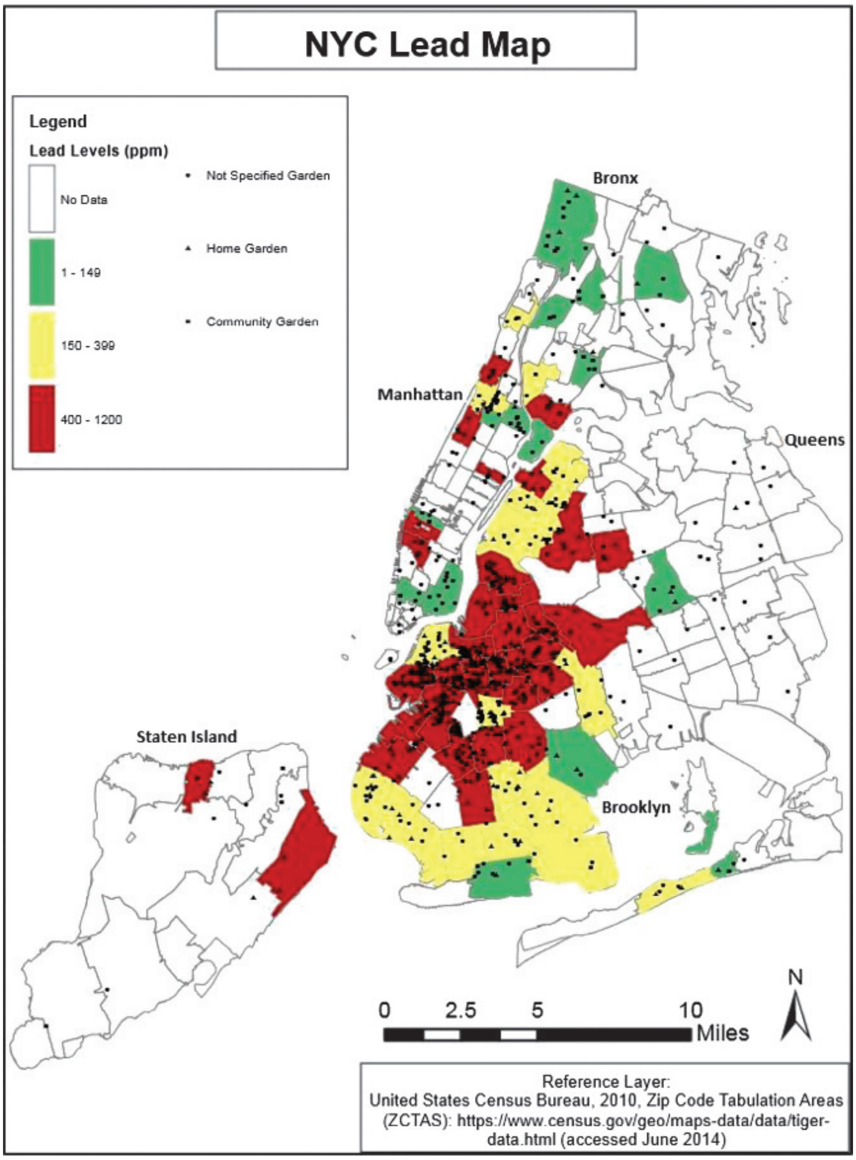


**FIG. 1.** Distribution of gardens where the soil samples were collected for this study. This map includes 904 identifiable street addresses for the gardens, and each dot on the map represents a garden. Each polygon on the map represents a zip code. Each zip code is color coded based on median Pb concentration, except for the zip codes with fewer than five samples.



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**TABLE 1.** Descriptive Statistics of Trace Metal Concentrations in Garden Soil Samples Collected in New York City

| | Cr | Co | Ni | Cu | Zn | As | Cd | Pb |
|---|---|---|---|---|---|---|---|---|
| Overall New York City (*n* = 1,652 for Pb; *n* = 475 for other metals) | | | | | | | | |
| Median | 49 | 9 | 28 | 77 | 248 | 10 | 1.2 | 355 |
| Mean | 55 | 9 | 32 | 110 | 327 | 12 | 1.6 | 600 |
| S.D. | 29 | 4 | 24 | 123 | 258 | 7.5 | 1.5 | 767 |
| Maximum | 262 | 28 | 333 | 1,286 | 2,352 | 76 | 11 | 8,912 |
| Minimum | 4 | 2 | 2 | 5 | 35 | 0.9 | 0.1 | 3 |
| Unrestricted use std | 30 | — | 30 | 50 | 109 | 13 | 2.5 | 63 |
| *% exceeding limit* | *85* | — | *44* | *75* | *88* | *32* | *24* | *92* |
| USEPA SSL | 120,000 | — | 1,600 | — | 23,000 | 0.4 | 70 | 400 |
| NYS Background† | 14 | — | 17 | 14 | 65 | 5 | 0.5 | 19 |
| Home garden samples (*n* = 197) | | | | | | | | |
| Median | 53 | 9 | 30 | 89 | 300 | 12 | 1.8 | 632 |
| Residential std | 36 | — | 310 | 270 | 10,000 | 16 | 2.5 | 400 |
| *% exceeding limit* | *86* | — | *0* | *8* | *0* | *28* | *36* | *68* |
| Community garden samples (*n* =106) | | | | | | | | |
| Median | 39 | 8 | 21 | 55 | 169 | 7.6 | 1.1 | 140 |
| Restricted Res. std | 180 | — | 310 | 270 | 10,000 | 16 | 4.3 | 400 |
| *% exceeding limit* | *0* | — | *1* | *0* | *0* | *9* | *2* | *10* |

New York State Department of Environmental Protection SCO standards are used for comparison. (All numbers are in mg Pb kg-1 except for those in *italic,* which signify the percentage of samples exceeding limits).

†New York State Department of Environmental Conservation. NYS rural background ranges are the minimum to 95th percentile of levels in "source-distant" rural soils in NYS reported in the NYSDOH/NYSDEC Rural Soil Background Survey. A report on the survey is available at: http://www.dec.ny.gov/docs/remediation_hudson_pdf/appendixde.pdf.

the top 1 to 2 inches. The collected soil from various locations and depths within a garden parcel was thoroughly mixed, with stones and plant fragments removed, and about 200 to 300 g was packed into plastic bags and sent to the laboratory. Repeated tillage of garden soils causes the mixed depth to have nearly uniform metal concentrations at any one point in a garden, although Pb and other elements can vary widely across a garden because of source variation.

For the majority of the samples, Pb concentrations were obtained using a portable X-ray fluorescence (XRF) scanner (Innov-X Delta Classic) (modified EPA method 6200). The scans were performed directly on plastic bags containing air-dried soil sent in by gardeners, without processing. In general, each sample was scanned three times, with samples remixed between scans. For each scan, the total exposure time was 90 seconds. Mean concentrations from the three scans were then recorded.

For 475 of the samples, testing of all metals was requested. On receiving the samples, they were first dried to constant weight at 105°C, disaggregated using a mortar and pestle, and sieved less than 2 mm. For part of the samples, the fine fraction was acid digested using a microwave oven following EPA Method 3051, and about one third of the samples were digested in 7-mL Teflon vessels on a hotplate. The digested samples were then analyzed for Cr, Co, Ni, Cu, Zn, As, Cd, and Pb using Dynamic Reaction Cell Inductively Coupled Plasma Mass Spectrometry (ICP-MS) (Perkin Elmer, Elan DRCe) at Brooklyn College (EPA Method 6020).

Reference standards SRM-2702, SRM-2586, SRM-2587, and SRM-2702a were used for external quality control (http://www.nist.gov/srm/). Each batch digestion of up to 25 samples always included at least three of these reference standards. In the later stages of the study, an intralaboratory consistency standard (a large volume unknown prepared from the mixing of all reference material digests) was also analyzed with ICP-MS for every six soil samples. This consistency standard was also used to monitor and correct for drifts during the run. Ge was used as an internal standard for instrumental drift correction in all

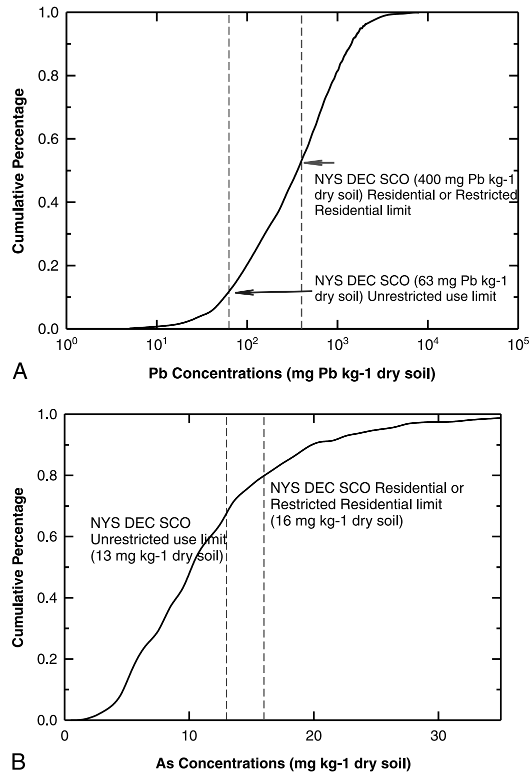


**FIG. 2.** Concentration distribution curves for selected metals: A, Pb; B, As. These metals are of the most concern based on the SCO criteria developed by the New York State Department of Environmental Conservation. The respective SCO criteria are also plotted for comparison.

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analyses. A comparison between the external correction method and the internal correction method with Ge did not show significant or systematic differences.

For the majority of samples for which ICP-MS results were obtained, XRF screening was also performed and Pb concentrations were recorded. There is good agreement between the two sets of Pb concentration data, with correlation coefficient at 0.94.

For statistical analyses, mean, median, S.D., maximum, and minimum values were calculated. Multivariate correlations were used for some trace metals.

## RESULTS AND DISCUSSION

### Sample Characteristics

A total of 1,652 garden soil samples from the five boroughs of New York City were submitted from 904 gardens. About 35% ($n$ = 315) of the gardens were identified as home gardens, 11% ($n$ = 95) were community gardens, and the rest were unidentified.

The spatial distribution of these gardens is shown in Fig. 1. These represent 904 gardens with street addresses that could be mapped. In some cases, multiple samples were obtained from different locations or depths within the same property. Because samples were submitted randomly by gardeners instead of collected systematically (e.g., targeted sampling from each grid on the map), the spatial distributions of samples are not uniform. Brooklyn, in particular northern Brooklyn, contributed the largest number of samples. This is followed by Manhattan and the Bronx. Although the data set is not ideal in the sense that samples were not collected evenly from all parts of the city, it nonetheless provides an overall assessment of the distribution and status of garden soil contamination in New York City. It should be noted that the Mitchell et al. (2014) study focused on community gardens.

### Summary of Concentrations

Table 1 lists descriptive statistics of metal concentrations for all 1,652 garden soil samples. The concentrations differ by three orders of magnitude, with Pb being the highest at a median value of 355 mg Pb $kg^{-1}$, whereas Cd the lowest at 1.2 mg Cd $kg^{-1}$. For each metal, concentrations also show several orders of magnitude variation among samples, especially for Pb. The concentration distribution curves for Pb and As are shown in Fig. 2. It should be noted that the mean Pb concentration at 600 mg Pb $kg^{-1}$, almost twice the median value, is skewed by some samples with extremely high values of up to 8,912 mg Pb $kg^{-1}$.

The data indicate that community garden soils have significantly lower metal concentrations than home garden samples, especially for Pb, Cu, and Zn (Table 1). The median for Pb (140 mg Pb $kg^{-1}$) for community gardens is one fourth that of home gardens, whereas Zn and Cu are nearly 50% lower. Community gardens have likely been more actively cultivated, and in many cases, organic materials were added to topsoil across time. Tillage and new soil would have at least diluted the levels of trace metal contaminants in garden soil.

Among the five boroughs, samples from Brooklyn soils contain the highest contaminant concentrations, whereas Bronx soils contain the least. Median Pb concentration in Brooklyn is twice that of the Bronx (Fig. 3). In Fig. 1, zip codes are color coded according to Pb concentrations. Although gardeners from Northern Brooklyn contributed the largest number of samples, they are also located in the areas with the highest metal concentrations. The geographical pattern of Pb contamination is consistent with findings from many other cities. Old industrial or urban centers are often the most polluted, and the degree of contamination tends to decrease toward more recently developed urban or suburban areas.

Lead concentrations have been correlated by proximity to urban centers with industrial activities as well as to major roads with residue of leaded gasoline (e.g., Yan et al., 2013). Although this pattern may occur on large scales, heterogeneities are present at small scales. For example, soils that have been cultivated are less likely to contain high levels of metal contaminants because new materials (compost, mulch, or externally sourced topsoil) may have been added in the past, and cultivation may have mixed the most-contaminated topsoil with “cleaner” soil in the

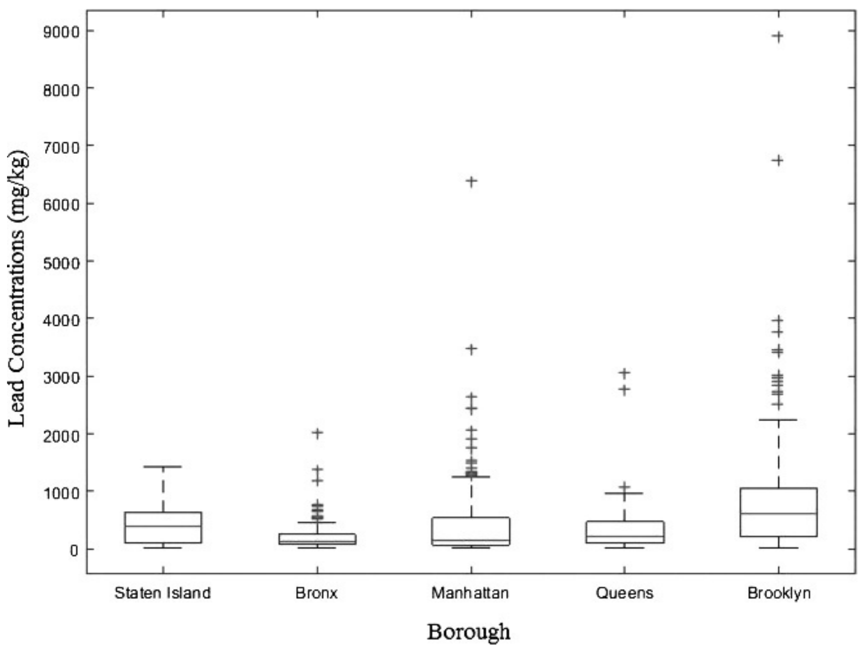


**FIG. 3.** Box plots of garden soil Pb concentrations for five boroughs in New York City. The box plot displays values of the median, the first and third quartiles, the minimum and maximum, and any outliers.

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subsurface. The addition of amendments changes soil element levels and fertility, and as a result, localized soil conditions are highly variable and affected by land use history.

## New York State Soil Cleanup Objectives Criteria and USEPA Soil Screening Levels

Currently, there are no specific guideline values that regulate residential or community garden contaminant levels for growing edible produce (USEPA, 2011). The New York State Department of Environmental Conservation developed guidelines for land use after Brownfield redevelopment. These Soil Cleanup Objectives (SCO) were developed based on rural soil conditions, which are generally quite distinct from conditions of urban soil. There are questions regarding the practicality and appropriateness of these guidelines for urban gardening situations because of the widespread contamination of urban soils. Nevertheless, these SCO values are currently the only available consistent recommendations that can be used to assess the garden soils in New York City. The SCO include several categories where uses for gardens are referenced (New York State Department of Environmental Conservation, Brownfield and Superfund Regulation, 6 NYCRR Part 375). Home gardens (single-family houses) are permissible under the "Residential" category, whereas community gardens may be classified under

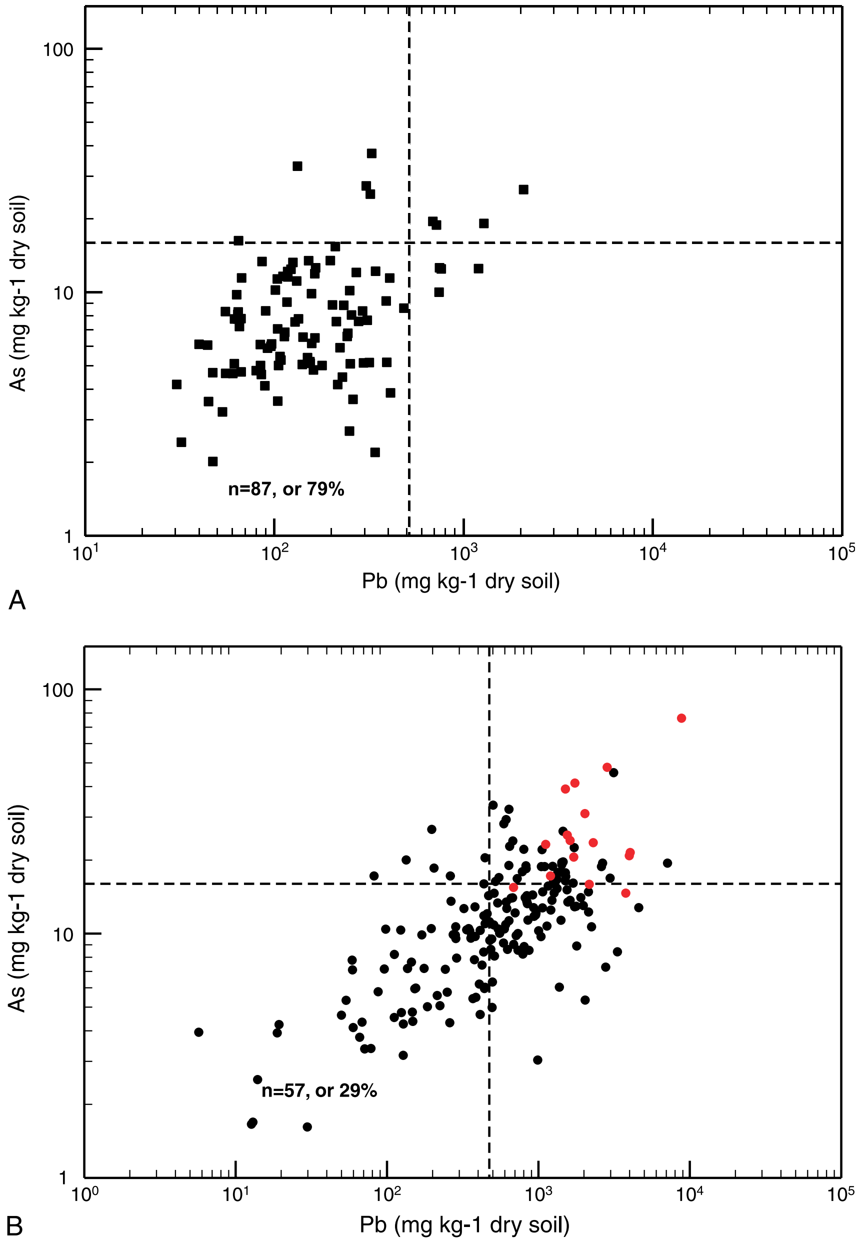


**FIG. 4.** Comparison of soil Pb and As concentrations to the NYS SCO criteria. The data points are color coded based on whether any of the other metals analyzed exceed SCO criteria. If none of the other metals exceed its respective SCO standard, the color is black; otherwise, the symbol is red. A, Community garden samples where the "Restricted Residential" standards are shown in dashed lines. B, Home garden samples compared with the "Residential" standards are shown in dashed lines. The *n* = and % in the lower left quadrant refer to the number/proportion of samples below the respective standards.

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**TABLE 2.** Comparison of Mean Heavy Metal Concentrations in Urban Soils in Selected Major Cities Around the World

| | No. Samples | Cr | Ni | Cu | Zn | As | Cd | Pb | Type of Samples | References |
|---|---|---|---|---|---|---|---|---|---|---|
| New York City | 1,652 | 55 | 32 | 110 | 327 | 12 | 1.6 | 600 | Garden soil | This study |
| Bangkok | 30 | 25 | 23 | 27 | 38 | — | 0.15 | 29 | Topsoil | Wilcke et al. (1998) |
| Hong Kong | 236 | 17 | 4 | 10 | 78 | — | 0.33 | 71 | Urban | Lee et al. (2006) |
| Beijing | ~770 | 34 | 27 | 21 | 62 | 7.8 | 0.12 | 27 | Top soil, mean | Chen et al. (2005) |
| Berlin | 2,182 | 25 | 8 | 31 | 129 | 3.9 | 0.35 | 77 | 0–20 cm | Birke and Rauch (2000) |
| Damascus | 51 | 51 | 35 | 30 | 84 | — | — | 10 | Topsoil, agriculture | Moller et al. (2005) |
| Galway | 166 | — | 22 | 27 | 85 | 8 | — | 58 | Topsoil | Zhang (2006) |
| Torino | 123 | 129 | 153 | 71 | 147 | — | — | 94 | 1–10 cm | Biasioli et al. (2007) |
| Oslo | ~300 | 29 | 24 | 24 | 130 | 4.5 | 0.34 | 34 | Topsoil | Tijhuis et al. (2002) |
| London-Richmond | 214 | — | — | 30 | 108 | — | <0.2 | 158 | Topsoil | Kelly and Thornton (1996) |
| London-Wolverhampton | 295 | — | — | 62 | 231 | — | 0.80 | 106 | Topsoil | Kelly and Thornton (1996) |
| Connecticut | 174 | 14 | 12 | 40 | 163 | 4.2 | <0.5 | 176 | Community gardens | Stilwell et al. (2008) |
| Zagleb | 331 | — | 49 | 18 | 70 | — | 0.5 | 23 | Agricultural soil | Romic and Romic (2003) |
| Baltimore | 422 | — | 2.8 | 17 | 92 | — | 0.56 | 100 | Vegetable garden soil | Mielke et al. (1983) |

the "Restricted Residential" category with approval. The "Unrestricted" category was developed to be the most conservatively protective of human health, ecological resources, and groundwater for all land uses and accounted for rural soil background concentrations.

Comparisons with the SCO values are summarized in Table 1 and illustrated in Fig. 2 for Pb and As. For home gardens, the percentages of samples that exceed the "Residential" criteria are Pb (68%), Cd (36%), Cr (86%), As (28%), and Cu (8%). For community gardens, the metals that exceed the "Restricted Residential" thresholds are Pb (10%), As (9%), and Cd (2%). For nearly all the metals, the majority of samples tested exceeded the SCO standard for Unrestricted use. Figure 4 illustrates the variations of Pb and As concentrations of home gardens and community gardens in comparison with their respective SCO standards. About 79% of the samples met the Restricted Residential use standard for community gardens compared with 29% of the home garden samples. In all, only 13 of 475 samples with trace metal results, or less than 3%, meet the NYS DEC criteria for Unrestricted use.

The USEPA Soil Screening Levels (SSL) are generally higher than the NYS SCO criteria, except for As. Like the SCO criteria, the SSL were not developed specifically for urban situations or for urban farming. Federal soil standards (Section 403 of the USEPA's Toxic Substances Control Act) defines soil as a hazard in play areas if bare soil contains 400 mg Pb $kg^{-1}$ or more or if average lead concentrations exceed 1,200 mg Pb $kg^{-1}$ in all parts of the yard, which are not bare soil play areas. If the 1,200-mg Pb $kg^{-1}$ standard is used, only 3% of the community garden samples and 28% of the home garden samples in this study exceed this limit.

## Comparison With Other Cities

Ajmone-Marsan and Biasioli (2010) compared trace metal concentrations in topsoil of major cities in Europe and Asia, where survey data have been more frequently published in peer-reviewed journals. Samples from New York City contain the highest mean concentrations of Pb (600 mg $kg^{-1}$), Cu (110 mg $kg^{-1}$), Cd (1.6 mg $kg^{-1}$), As (12 mg $kg^{-1}$), and Zn (327 mg $kg^{-1}$) when compared with the other cities listed in Table 2. The second highest levels of these metals are found in Connecticut community gardens (Pb, 176 mg $kg^{-1}$), London-Wolverampton (Cu, 62 mg $kg^{-1}$; Cd, 0.8 mg $kg^{-1}$; Zn, 262 mg $kg^{-1}$), and Beijing (As, 7.8 mg $kg^{-1}$). In contrast, Ni and Cr levels in New York City garden soils are above average among all the cities referenced but are lower than Torino (Biasioli et al., 2007).

There have been a limited number of studies focusing specifically on trace metals in a range of home garden soils, and most of these have focused on lead (e.g., Mielke et al., 1983; Stilwell et al., 2008; Romic and Romic, 2003; Finster et al., 2004). In a study in Baltimore (Mielke et al., 1983), soil samples collected from 422 vegetable gardens located within a 30-mile radius from downtown Baltimore were analyzed for lead. The median lead concentration was 100 mg Pb $kg^{-1}$, and about 20% of the samples exceeded the 400-mg $kg^{-1}$ guideline. Samples with elevated lead levels clustered toward the city center. Finster et al. (2004) analyzed 87 soil samples in 17 gardens in Chicago, IL, and reported that soil lead averaged 800 mg Pb $kg^{-1}$. Only one fourth of the samples contained less than 400 mg Pb $kg^{-1}$ of Pb, whereas half of the samples were between 400 and 1,200 mg Pb $kg^{-1}$.

## Fine Soil Particles and Associated High Lead Concentrations

One of the soil samples (a sandy loam) with high Pb concentration (Pb, 1,808 mg Pb $kg^{-1}$) was sieved to seven size fractions, and the Pb concentrations of these fractions are compared in Fig. 5.

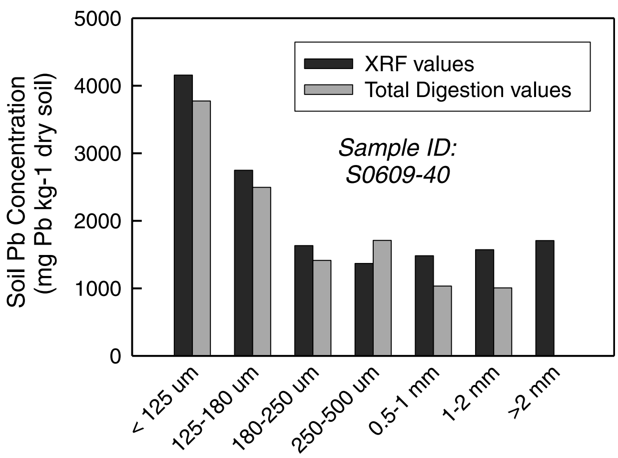


**FIG. 5.** Soil Pb concentrations of different size fractions of the same garden soil sample. The Pb concentrations were measured by both the acid digestion method (as described in this study) and a portable XRF scanner (Innov-X).


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**TABLE 3.** Correlation Matrix of Garden Soil Heavy Metals in New York City

| | Co | Ni | Cu | Zn | As | Cd | Pb |
|---|---|---|---|---|---|---|---|
| Cr | 0.70† | 0.66† | 0.51† | 0.45 | 0.42 | 0.15 | 0.09 |
| Co | | 0.60† | 0.49 | 0.41 | 0.43 | 0.12 | 0.09 |
| Ni | | | 0.33 | 0.31 | 0.25 | 0.11 | 0.07 |
| Cu | | | | 0.54† | 0.37 | 0.03 | 0.14 |
| Zn | | | | | 0.32 | 0.20 | 0.49 |
| As | | | | | | 0.21 | 0.23 |
| Cd | | | | | | | 0.21 |

†Correlation coefficients larger than 0.5.

There is an inverse correlation between particle size and the concentration of Pb. This is indeed true for other metals (data not shown here). The less than 125-μm fraction contains twice the Pb concentration of fractions larger than 180 μm. In a study of urban soils from Nanjing, China, Wang et al. (2006) found that both Pb and Cu were concentrated in clay-sized fractions (<2 μm) and medium-coarse sand fractions but were depleted in the fraction of 25 to 250 μm (coarse silt to fine sand). Madrid et al. (2008) also found enrichment of Cu, Zn, and Pb in finer fractions of soils from the City of Sevilla. The exact causes of such enrichment in fine particles may vary in different situations but may be explained by the origin of these metal contaminants.

## Multivariate Correlations and Potential Sources

The high Cr and Ni concentrations found in New York City soils can be partly attributed to the influence of serpentinite bedrock in Staten Island, which may have influenced glacial deposits over a larger area (Gasser et al., 1994; Oze et al., 2004). This is substantiated by correlation between the two metals with correlation coefficient at 0.66 (Table 3). This is strong evidence that they are lithogenic in origin, which renders them relatively immobile and difficult to be leached with chemical extractants (Cheng et al., 2011). Biasioli et al. (2007) also found similar correlations for soils from three European cities.

The correlation coefficients between Pb and other metals ranged from 0.1 to 0.49. It is commonly recognized that the sources of anthropogenic Pb in soils are leaded gasoline, which was prevalent for decades in the 20th century, and leaded paints that were still in use until the late 1970s. Some older houses still contain leaded paint and have been accountable for many children's high blood lead levels. Renovation of houses can generate significant amounts of fine lead-rich dust, which may be subsequently deposited on soil. Cd and As are the least correlated with all other metals, which likely suggests that they came from different sources, such as arsenic-bearing pesticides and pressure-treated wood.

Another important source of trace metals could be refuse incineration during the 20th Century. Between 1908 and 1993, approximately 0.11 billion tons of refuse were combusted and 34 million tons of combusted residue were disposed of in local landfills. Refuse incinerators were operated without air pollution control and emitted 1 million tons of particles (a total of 120 mg for each square centimeter of land in NYC) (Walsh et al., 2001; Walsh, 2002). Trace metal and radionuclide data from sediment cores in Central Park Lake provided a record of atmospheric pollutant deposition in New York City through the 20th Century, which suggested that leaded gasoline was not the dominant source of atmospheric Pb for New York City (Chillrud et al., 1999).

## IMPLICATIONS AND CONCLUSIONS

This study reveals that a large proportion of the home garden soil samples and some community garden soil samples do not meet the New York State SCO criteria for gardens. There are questions regarding the degree to which these SCO criteria, developed largely on rural conditions where historical anthropogenic deposition of contamination is minimal, are appropriate and practical for urban situations. Given that these guidelines are not health-based recommendations, the development of new guidelines will likely have to take into consideration background concentrations in the region as well as soil and produce ingestion criteria. However, applying different standards may also raise ethical issues, which may need to be further investigated.

To ensure gardener safety and health, both the benefits and the risks associated with urban gardening activities should be widely shared with the public. Education around best management practices is essential before cultivating edible food in the urban environment. It is also highly recommended that soils are tested before planting. Trace metal exposure can be greatly reduced by following some simple best management practices, such as washing vegetables and hands thoroughly. Different plants have different potentials to uptake metals; therefore, it is important to know and educate the public about the appropriate vegetables and fruits to grow. There should be strong land-use rules regarding gardening and changing vegetation with the aim of limiting movement of high-Pb urban soils into homes where it may cause adverse health effects to young children. In terms of soil remediation, there is also a lack of information as to what methods are available and how to make them more effective. At a minimum, some public "translation" of existing research results needs to be done. More studies are needed to accurately assess the metal exposure and health risks that urban gardeners are exposed to.

## ACKNOWLEDGMENTS

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