sustainability

MDPI

Review

Trace Metal Contamination in Community Garden Soils across the United States

Maeve Malone and Kabindra M. Shakya *

Department of Geography and the Environment, Villanova University, Villanova, PA 19085, USA
* Correspondence: kabindra.shakya@villanova.edu

Abstract: Community gardens are often seen as a means for producing sustainable food resources in urban communities. However, the presence of trace metals and metalloids such as lead, arsenic, and cadmium in urban soils poses a health risk to gardeners who participate in urban community gardens. They are exposed to these contaminates through multiple exposure pathways such as inhalation and ingestion directly through soil or through crops grown in the soil. Hot spots of soil contamination are higher in areas of cities with greater minority populations and lower incomes. This paper reviews the state of heavy metal contamination in community garden soils across the United States. This paper outlines the major sources of heavy metals in urban soils, exposure pathways, the ways to reduce heavy metal levels in garden soils, the means to slow down the uptake of heavy metals, and limit the exposure of these contaminates. The application of biochar and compost, implementing raised beds, and maintaining a natural pH are all examples of ways to mitigate heavy metal contaminants.

Keywords: lead; arsenic; cadmium; zinc; community garden; soil pollution; heavy metal; environmental justice

check for updates

Citation: Malone, M.; Shakya, K.M. Trace Metal Contamination in Community Garden Soils across the United States. *Sustainability* **2024**, *16*, 1831. https://doi.org/10.3390/su16051831

Academic Editor: Grigorios L. Kyriakopoulos

Received: 5 January 2024
Revised: 7 February 2024
Accepted: 16 February 2024
Published: 23 February 2024

1. Introduction

Community gardens in urban environments have been increasing in popularity across the United States in recent decades [1–5]. There are multiple potential reasons for this uptick in interest in shared community cultivation. Cities, especially in environmental justice areas, are often the areas where there is a lack of access to nutritious and fresh food due to fresh produce not being available in these neighborhoods [1]. Fast food chains and convenience stores tend to dominate these areas and stifle out any potential competition from local grocery stores that carry fresh produce [6]. Urban gardens provide easy access to nutritious food for families as well as for the whole community. Since the food production is local, it also helps to reduce environmental footprints related to food transport and packaging. Local food production can be more resilient to other natural and man-made events, including road closures and transportation- and food-production-related issues; thus, community gardens contribute to food security in a region. During the COVID-19 pandemic, food insecurity increased by almost 4% nationwide due to high unemployment and disruptions in the food supply chain. This made it more difficult for fresh and perishable produce to make its way into urban areas [7]. Urban gardening provides affordable alternatives to the unhealthy fast food that dominates urban families' meal options. A lot of social capital can also be gained through community gardening. Unlike suburban gardens, where a small plot of land is tended to by an individual or a few individuals, community gardens can host hundreds of people who are all working together toward a common goal: successful cultivation. This leads to an increase in the connectedness of the community as well as better mental health [2]. Local food production is also a more sustainable option. It can greatly reduce environmental and carbon footprints associated with the transport of produce and can help create a sustainable environment. Community gardens are increasing in popularity in urban areas because they provide organic produce, give time to working together with families to produce their own food, and help reduce mental stress. Community gardens are especially important in environmental justice areas because community gardens provide a venue for building the community, increasing awareness of health and environmental issues, and improving access to healthy and organic produce. The availability of resources from governmental and non-governmental organizations such as the Farm Philly Program of the City of Philadelphia and Pennsylvania Horticultural Society community garden programs in cities such as Philadelphia also help promote community garden activities in urban areas.

However, the increasing popularity of community gardens leads to an increase in the number of gardeners who are unaware of healthy gardening practices. A survey of 121 urban community gardeners in Kansas, Indiana, and Washington in the United States found that most informants did not express high levels of concern regarding soil contamination [3]. However, when trace metal contamination was specified, a majority of gardeners out of the 472 surveyed nationwide expressed interest in testing their soil for trace metals [4]. Community gardens are often established in abandoned housing or parking lots, which have historically high levels of trace metal contamination [1,5,8,9]. Most American cities do not have space for their citizens to grow gardens. Therefore, urban community gardens can be located on or near contaminated plots of land, such as brownfields or superfund sites [10]. These sites have elevated levels of contamination compared to surrounding areas and are not safe for public use unless they are cleaned up. Brownfields and abandoned industrial sites, which were used as sites for community gardens in urban areas, were mostly contaminated with asbestos, creosote, metals and metalloids (lead, mercury, arsenic, etc.), volatile organic compounds (VOCs), pesticides, and polycyclic aromatic hydrocarbons (PAHs), and superfund locations were mostly contaminated with metals and metalloids, PAHs, petroleum products, polychlorinated biphenyls (PCBs), and pesticides [10]. Many of these contaminated sites in urban areas are a result of past industrialization. Cities also have many potential sources of trace metal contamination, such as old chipping lead paint, gasoline, runoff from nearby roads, fertilizer, municipal solid waste disposal, nearby mining, and nearby smelting [11–15]. The lack of consideration towards soil quality could lead to community members ingesting unhealthy levels of trace metals through inhalation or ingestion [16].

Soil contamination disproportionately affects African Americans because of their high participation in community gardens [10]. African American gardeners are more concerned about soil contamination compared to other races, and they are also the most at risk [4]. The most polluted parts of urban areas tend to be the older areas that are closest to pollution sources, such as industrial areas or highly trafficked roads. This causes city centers to have higher amounts of pollution compared to the outskirts of cities [3,15,17,18]. These areas also have high poverty rates and high concentrations of people of color [19]. The United States Environmental Protection Agency (US EPA) has no specific standards for contamination within urban community gardens. The contaminants in soil that they do have thresholds for, such as lead, are not intended for gardeners but are instead created to protect children's health in outdoor play areas [10]. The US EPA has a lead level standard of 400 ppm by weight for children's play areas, which is the standard that many studies reviewed and used for their threshold. In 2014, they suggested a lead level recommendation of 100 ppm for gardening, citing the increased exposure pathway for gardeners, but this standard has not been officially recognized or implemented by the US EPA. In January 2024, the US EPA lowered the screening level for lead in soil at residential properties from 400 ppm to 200 ppm, and at residential properties with multiple lead sources to 100 ppm. States like California and countries like Finland have lower lead thresholds in soil, which are closer to the recommendation of 100 ppm (Table 1). The lack of consistent standards makes remediation very difficult.

As more people participate in community gardening, it is important for people to be aware of the risks of trace metal contamination, exposure pathways, and mitigation approaches. While the US EPA has online resources informing urban gardeners about soil contamination and how to mitigate the risks, they may not be enough to help protect urban community gardeners. These gardeners need to be educated on what standards are safe for them while they are gardening instead of what standards are safe for children on playgrounds. Existing standards on trace metal concentrations in soils need to be updated and specialized to urban environments, and new standards need to be created. The US EPA recently updated screening level guidance for lead in soil of residential areas where children live and play. Informing the public regarding dangerous and natural background concentrations of trace metals is also essential for proper testing, regular monitoring, and minimizing risks, and this article also addresses these topics. In this paper, we selected and reviewed published manuscripts in the United States concerning trace metal and metalloid contamination (Pb, As, Cd, and Zn) in urban community gardens. Studies on trace metal contamination in community gardens have mainly focused on quantifying lead contamination, mapping contamination in the region, assessing the relationship with land uses and local contaminant sources, analyzing variations in geographical regions, comparing concentrations to the available public health guidelines, measuring the speciation and mobility of metals and metalloids, and examining the influence of garden characteristics such as raised beds [1,11,13–15,17,20–25]. This paper presents the plant uptake of trace metals, various exposure pathways to trace metals in community gardens, environmental justice issues, the effect of soil pH and plant nutrients on trace metals, and various soil remediation applications.

2. Method

An integrative review of manuscripts published on trace metal contamination across the United States was carried out. The relevant literature was searched for in two databases: Web of Science and PubMed. The key phrase “community garden” was searched, and the results were increasingly specified by using the word “contamination” and then “USA”. These two keywords narrowed the results down from 13,971 to 87 articles in the Web of Science database and down from 3719 to 42 on the PubMed database (Figure 1). The phrase “urban garden” was also searched, which yielded 8852 results on Web of Science and 1824 results on PubMed. The results were refined using the words “metals” and then “USA”, which took the number of articles down to 111 and 47. The keyword “USA” was chosen to eliminate studies from outside of the United States, but there was no limitation put on the age of the articles.

After refining the results through search queries, the titles and the abstracts of the articles were read to see if the articles were relevant to trace metal and metalloid contamination. Articles solely focusing on the contaminant uptake by plants and by humans, soil not in community gardens, soil remediation studies, and studies performed outside of the United States were excluded from the literature review. After screening the articles, 40 relevant articles from Web of Science and 27 articles from PubMed remained. Duplicates of the articles that appeared in the second database search were then removed, which left a total of 52 articles for review. The initial search using the terms “community garden” and “urban garden” resulted in thousands of results. Therefore, the total number of articles published on soil contamination is expected to be greater than 52 articles. Expanding to various other terms besides the terms “contamination” and “metals” and including other databases may likely increase the number of published articles on this topic. In this article, we mainly included the articles that resulted from the queries shown in Figure 1.

The literature review involved two researchers who read about half of these articles and determined whether the information was applicable to the literature review. Our main focus was to include articles that measured trace metal contaminants in community gardens within the United States. After reading all of the articles, we removed 18 articles, leaving only 34 relevant articles. The main criteria for elimination were not including the measurement of trace metals in the soils of community gardens. Even if the main purpose of the review article was not to focus on urban soil contamination in community gardens, if data were taken from urban gardens, the article was included because the data were still relevant to the review. We also included literature review articles because they contained relevant information and data. We also included additional relevant articles and website resources that provided useful information for this review but did not result from the above search criteria.

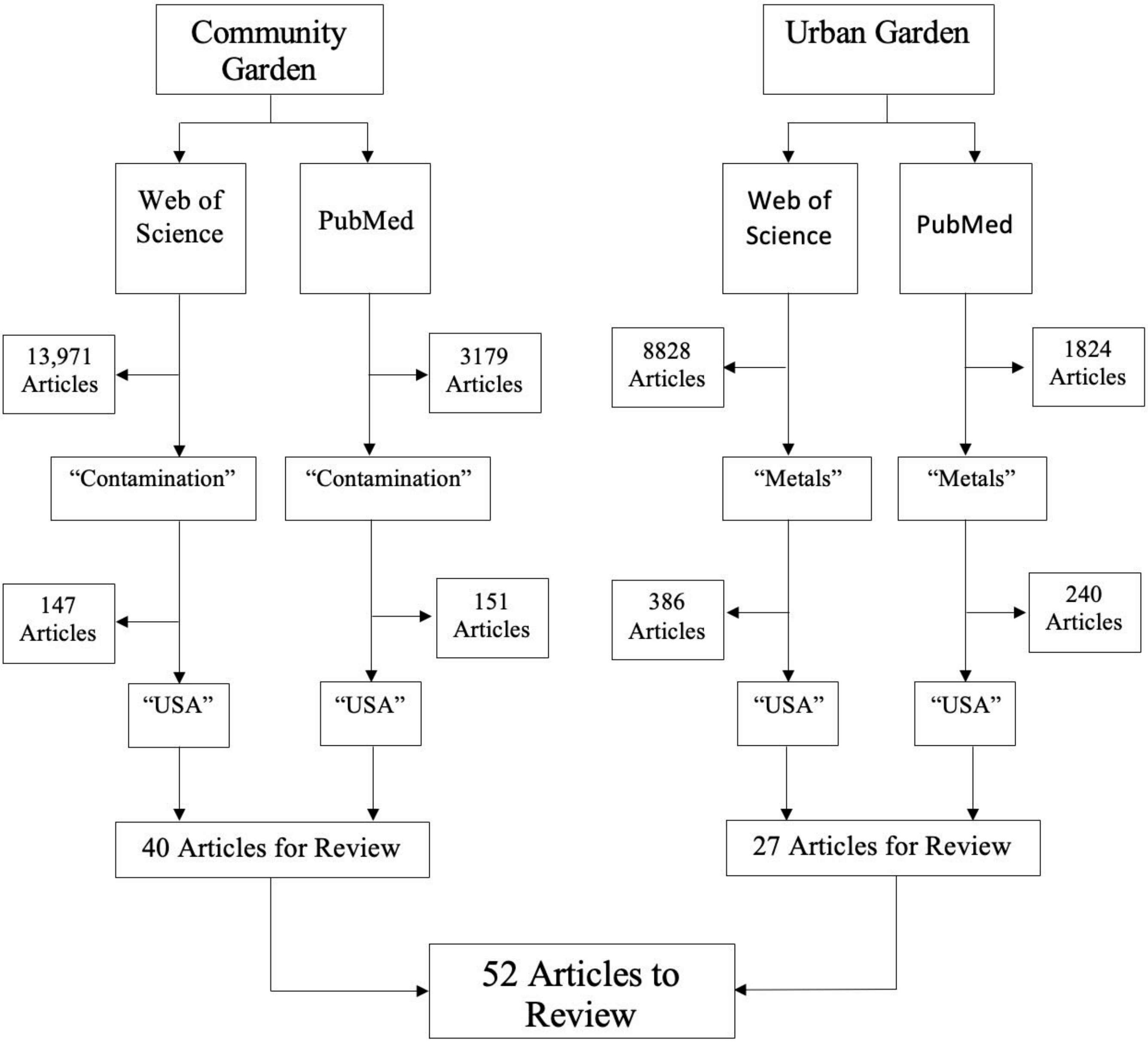

Figure 1. The number of articles retrieved from Web of Science and PubMed databases using the terms "community garden" and "urban garden". The keywords used for filtering are shown in quotes.

3. Soil Contamination in Urban Community Gardens

3.1. Lead (Pb)

Lead is a non-essential element and is not known to be required for plants. Most of the papers published on trace metal contamination within urban community gardens include or solely focus on lead contamination. This is likely because there are multiple sources of lead soil contamination in urban environments, such as waste incineration, coal and oil combustion, the historic use of leaded gasoline, paints containing lead and other metals, and the demolition of old housing [5]. Thus, lead is likely to be the main concern for environmental contaminants in urban gardens. Lead is mainly present in fine particle sizes [22]. The acute health effects of lead include nausea, headaches, poor appetite, weight loss, renal dysfunction, fatigue, and sleeplessness, and the chronic health effects of lead include intellectual disability, birth defects, brain damage, and kidney damage [26]. The US EPA has set soil guidelines that safe lead levels should not exceed 400 ppm for children's play areas or 1200 ppm for all other areas of a yard, which was recently decreased to 200 ppm. In 2013, the US EPA Technical Review Workgroups Lead Committee created a recommendation of 100 ppm for urban gardeners; however, none of the studies used in this literature review used this recommendation as a standard [15]. These regulations are important so that the public can quantifiably determine the health of their soil. However, the US national standard of lead is high compared to other areas of the world, which has prompted some states to set their own standards (Table 1). For example, the California Office of Environmental Health Hazard Assessment uses a guideline of 80 ppm [15]. Lead levels in Oakland, California, were lower than the US EPA recommended level of 400 ppm but higher than the California Human Health Screening Level of 80 ppm [14]. A shared standard based on scientific evidence on the risks to human health should be established so that people will be able to discern unsafe amounts of lead in their soil from safe and naturally occurring lead [10].

Table 1. The safe level of lead set by various agencies and countries.

Location	Residential Area Lead Standard (ppm)
Finland (Europe) *	60
California	80
World Health Organization	85
Canada	140
USEPA	200
Connecticut	400
New York	400

* The Finnish standard values represent a good approximation of the mean values of different national systems in Europe, and they have been applied in an international context [27]. This is not the complete list of standards, but it is compiled to show the variation in safety standards across different nations and US States.

If urban soils in old industrial cities were analyzed using California lead guidelines, 55–77% of the soils in Schwarz's study would be found to contain unsafe lead levels [15]. The 400 ppm standard for the presence of lead in residential soil was set in 1994 by the US EPA with the intention of limiting the exposure of children to lead and keeping their blood lead levels below 10 μg/dL. When the Center for Disease Control and Prevention (CDC) updated the action level for blood lead levels in children from 10 μg/dL to 5 μg/dL in 2012, the US EPA did not update their soil standard for lead and has done it only recently in January 2024. This standard is also not directly relevant to gardeners in urban areas because they are exposed to different pathways and amounts of lead than the average child in a residential area. The CDC has further updated the reference value for blood lead levels in children from 5 μg/dL to 3.5 μg/dL in 2021.

Lead occurs naturally in uncontaminated surface soils in the United States at 22 ppm [28]. However, uncontaminated soil and contaminated soil can exist close to each other, which can cause lead levels to vary across a single garden. Furthermore, the resuspension of lead-containing dust/soil particles can spread lead from contaminated sites to uncontaminated sites across a city. The lead levels in soil across cities such as Baltimore and New York City have stark rural-to-urban lead gradients. In Chicago, Illinois, lead levels were five times greater in metropolitan area soil samples compared to rural forest soils [15]. Cities such as Baltimore have seen lead contamination in soil even two decades after a ban on lead-based fuel and lead paints [15]. Soil samples taken from community gardens in Philadelphia and Pittsburgh, with legacies of industrialization, had higher concentrations of lead than samples taken from suburban locations [21]. There was lead contamination in the soils of Philadelphia due to nearly 150 years of the operation of industrial facilities producing paint and other lead-bearing products [29]. Summary of four trace metal and metalloids (Pb, As, Cd, and Zn) across community gardens in the US are given in Table 2.

Within cities, high levels of variation can occur between neighborhoods, backyards, or garden beds. Lead hot spots generally exist in lower-income areas and along roof drip lines, by driveways or roadsides, and wherever lead-based paint chips are present [30,31]. This is due to lead having a high spatial variability across sites, especially within residential areas due to high activity [22]. Lead concentrations were below 200 ppm and above 600 ppm within the same 10 × 10-foot garden plot in a community garden [22]. The disparity between lead concentrations within a small area highlights the need for thorough testing in community gardens and widespread remediation tactics. Applying a combination of compost and biochar can reduce the availability of lead, and applying a cover and using no-till agricultural practices will reduce lead mobilization [8,12,22,32]. However, the presence of dissolved organic carbon and other soil characteristics may affect the results, and this application may increase the bioaccessibility of arsenic. Therefore, monitoring for soil contamination should still be continued.

Table 2. Lead levels across urban community gardens in the US.

Location	Pb (ppm)	As (ppm)	Cd (ppm)	Zn (ppm)	Number of Gardens	Number of Samples	Type of Site
Aspen, CO, USA [33]	172 (9.2–808)	–	2.5 (0.2–14.2)	120 (8.4–484)	65	>195	Former mine dump sites
Baltimore, MD, USA [23]	104.5 (7.4–130.4)	3.7 (0.2–13.5)	1.4	139.7 (39.7–542)	104	616	Urban
Boston, MA, USA [34]	130 (117–170) [a]	30–39 [b]	–	–	3 (88 plots)		Traffic, industrial
Cleveland, OH, USA [35]	224 (14–1241)	15 (7–58)	1.2 (0.5–2.5)	197 (83–543)	–	65	Vacant lots
Detroit, MI, USA [30]	151 (17–882)	–	–	–	2	80	Urban/residential
New Orleans, LA, USA [36]	38.4 (1.4–9540)	3 (0.7–61.7)	0.318 (0.248–8.8)	91.5 (17.8–7330)	27	appx. 600	Urban/Suburban; backyards and community gardens
New York City, NY, USA [1]	102 (11–2455)	5.7 (<5.3–93.2)	<0.4 (<0.4–3.1)	138 (21–2317)	54	564	Urban/residential
New York City, NY, USA [24]	600 (3–8912)	12 (0.9–7.6)	1.6 (0.1–11)	327 (35–2352)	905	1652	Urban/residential
Oakland, CA, USA [14]	47–326	–	–	–	3	6	Urban/residential
Philadelphia, PA, USA [21]	47.6–351.4	0.9–9.6	0.1–1.4	177.4–936	11	78	Urban
Philadelphia, PA, USA [21]	10.3–185.5	0.77–3.22	0.2–0.5	39.2–158.5	5	24	Suburban
Pittsburgh, PA, USA [21]	83.1–232.9	1.9–11.4	0.2–1.3	110.9–237.9	5	20	Urban
Roxbury and Dorchester, MA, USA [11]	950 (80–3680)	–	–	–	141	692	Backyard

Boston, MA: [a] compost soil; [b] CCA-bordered garden plots.

3.2. Arsenic (As)

Arsenic accounts for 1.5–2 ppm of the continental crust, making it the twentieth most abundant element on Earth. Arsenic can cause brain damage, cardiovascular and respiratory disorders, conjunctivitis, dermatitis, and skin cancer. Zinc can cause ataxia, depression, gastrointestinal irritation, hematuria, icterus, impotence, kidney and liver failure, lethargy, macular degeneration, prostate cancer, seizures, and vomiting [37]. Past mining activities caused arsenic contamination in neighboring communities in Nevada County in California [16]. It can substitute for sulfur in soils, and the majority of arsenic found in soils is found in its inorganic form [38]. California has elevated levels of arsenic in its soils compared to the rest of the United States, with a median background level of 5 ppm [25]. Arsenic is another common contaminant often found in urban gardens and, along with lead, is the most common contaminant cited as a source of toxins [5]. The natural source of arsenic is bedrock, while anthropogenic sources include mining and smelters [39]. Pesticides used in gardens are a common source of arsenic. Similar to most trace metal contamination, it is transported mainly through deposition from air or leaching from source materials [25]. Garden timbers and creosote railroad tires used to construct raised beds were also common sources of arsenic leaching. In addition to these sources, fertilizers, lime, composts, or sewage sludge may also contribute to arsenic pollution in urban soils [39]. Phosphate-based fertilizers can be especially problematic in terms of arsenic. The continued application of coal and wood ashes can also increase arsenic levels in the soil [39].

The three gardens chosen differed in age, but all were located in urban areas, had at least 27 plots, and were bordered by materials with high contents of PAHs and arsenic, such as creosote railroad tires or chromated copper arsenate (CAA)-treated lumber. CAA was historically used as a wood preservative. During sampling, the levels of PAHs and arsenic in the soil rose closer to the border [34]. Clarke [25] also reported finding correlations between CAA-treated wood and its effect on arsenic levels in soil. In this study, 30% of gardens not lined with CAA-treated wood were above California's background arsenic levels of 5 mg/kg, while 68% of plots containing treated wood exceeded it [25]. From soil, plants can uptake arsenic as arsenate or arsenous acid, which may cause increased arsenic levels in crop plants [39].

Arsenic is found to be more available in soils that have an organic matter content of less than 20 percent; therefore, raising the organic matter level would help reduce arsenic levels [25]. While phosphate-based soil amendments are common solutions to reducing lead in soils, they have been found to increase the mobility of arsenic in the soil, which results in greater plant uptake. Triple Super Phosphate (a phosphate-based fertilizer), manure compost, and raised-bed treatments all increased the extractability of arsenic in soils by 101%, 56%, and 114% while reducing the extractability of lead [32]. The increased arsenic solubilization and extractability from phosphate amendment and raised-bed treatments show that these remediation strategies may not be feasible for soils contaminated with both lead and arsenic. There is no single solution for dealing with trace metal and metalloid soil contamination, so solutions should be determined on a case-by-case basis.

3.3. Cadmium (Cd)

Cadmium, along with lead and arsenic, is among the top 10 hazardous substances in terms of public health and is also one of the most detected metals in community garden soils [4,8,13]. The health effects of cadmium include renal dysfunction, bone damage, coughing, emphysema, headache, hypertension, lung and prostate cancer, lymphocytosis, microcytic hypochromic anemia, testicular atrophy, and vomiting [26,37]. Cadmium is currently used in tires as a stabilizer and is present in vehicle exhaust, which explains why cadmium levels decrease with distance from roads in cultivated soils. Exchangeable concentrations of both cadmium and arsenic were found to increase with age and proximity to roads in a study of community garden soils in Los Angeles, CA [25]. In garden settings, it has been historically used in mineral phosphorus fertilizers and is present in treated wood that is used for raised beds. The application of sewage sludge and atmospheric deposition can increase cadmium levels in the soil. These practices increase cadmium concentrations in gardens over time [25]. Atmospheric deposition and phosphate fertilizers may be one of the main causes of increased cadmium levels in modern soil [40]. Cadmium is bioavailable in soil and is readily taken by food crops [8]. Therefore, even small concentrations may be of concern as the uptake rate is likely greater. Cadmium has high toxicity and a high residence time. The bioavailability of cadmium in soil also lasts for a long time [40]. The bioavailability of cadmium can be higher than lead and arsenic [25]. In comparison to arsenic and lead, cadmium has high bioavailability in crops [25]. Thus, cadmium in garden soils can be of great concern. The ingestion of food crops grown in contaminated soils is the most common exposure pathway of cadmium. The dietary intake of cadmium may constitute as high as 90% of cadmium exposure in the general population [40]. A case of 'itai-itai' disease, a bone disease with fractures and severe pain, in the early 1950s in Japan caused by the consumption of rice grown in cadmium-contaminated soil brought attention to the toxicity of cadmium from food crops [40]. Toxicity and mortality may occur from a total lifetime intake of 2–10 g of Cd or severe poisoning from a daily intake of 300 µg/day of Cd [40].

Cadmium concentrations in crops may increase with increasing total soil cadmium concentrations, decreasing soil pH, zinc deficiency, and decreasing %organic matter at a constant total Cd; therefore, soil liming, organic amendment, and zinc fertilization may help reduce cadmium uptake in plants [40]. Gardeners can attempt to mitigate cadmium contamination by using biochar or adding zinc to the soil [8]. Background cadmium levels in the soil are 0.6 mg/kg, and the recommended cadmium intake is 70 µg per day [41]. Urban garden soil can exceed the background level [5,25].

3.4. Zinc (Zn)

Zinc, unlike some other trace metals, is relatively nontoxic to humans and is necessary for plant nourishment [42]. It is also beneficial to reduce cadmium uptake by plants, limiting its toxic exposure to humans [8]. Elevated levels of Zinc in the soil can occur from atmospheric deposition, zinc smelters, zinc mines, and the application of fertilizers and sewage sludge [43]. Zinc concentrations are increased in soils with decreased soil pH [43]. Both cadmium and zinc have high leachability compared to that of other trace metals in soils, but their mobility can be decreased by increasing soil pH [17]. Increased soil cation exchange capacity (CEC) can decrease zinc toxicity [43]. When comparing produce grown in urban areas to nonurban areas, zinc concentrations were higher for every type of produce sampled except for sweet potatoes [23]. Zinc is often found in soils by roadsides, which is likely due to the use of zinc in tires and pesticides [1]. In comparison to other trace elements such as Pb, As, and Cd, zinc deficiency and low bioavailability in soils can also be a concern [43]. The concern of toxicity from crops related to high Zn in the soil is low because the phytotoxic effects limit excessive zinc transfer to the food chain [43].

Zinc is an indicator metal, which means that when it is present, it is likely that other trace metals, such as cadmium, will also be present. Instead of gardeners paying for multiple trace metal tests, they can only pay for a zinc test, which is more affordable than a lead or other trace metal test (USD 10–USD 15 per sample) [1].

4. Plant Uptake of Trace Metals

In addition to the inhalation of soil dust, another major concern surrounding trace metal contamination in urban community garden settings is plant uptake. The phytoavailability of trace metals, like lead, is dependent on many factors, such as solubility in the soil, plant nutrient status in the soil, the physiology of each plant species, and heat or moisture stress [20,23,28,34]. Produce grown in contaminated soil can uptake available forms of metals through their root system [20,23,28,34]. This process can transport trace metals from garden soil, where only gardeners and people near the garden can be exposed, to people's homes and their kitchen tables. There is some awareness among gardeners that growing crops in contaminated soil is the greatest risk associated with community gardening in an urban area [5]. Research shows that urban-grown crops and rural-grown crops have similar levels of trace metal uptake [23]. In one study, there was little to no association between the levels of lead in contaminated garden soil and the lead levels in plant tissue [23].

Although fruit trees are not commonly grown in community gardens, previous studies have shown that fruit trees grown in contaminated soil can also uptake trace metals. Metals are taken up by fruit trees because they are essential nutrients for growth. Fruits usually contain nontoxic metals such as copper, magnesium, and zinc. Only in the leaves of the tree were there toxic trace metals and metalloids, such as lead and arsenic [6]. Leafy vegetables and root vegetables have higher amounts of trace metal uptake compared to fruits and nightshade vegetables (eggplant, tomato, potato, etc.) [5]. Some plants do not uptake trace metals due to their physiological structure. Root vegetables and leafy plants might see trace metals as nutrients, and others do not [10]. Multiple studies have supported this link between plant species and trace metal uptake. The highest levels of lead were found in root vegetables across urban and nonurban areas [23]. Because 95% of lead is absorbed in the roots of vegetables, vegetables like carrots, turnips, beets, and radishes are more susceptible to contamination [17]. In one study [32], a majority of onions were found to have a lead content that was above the European Union's lead standard for roots and crops after being grown in untreated soil with 80–92% lead bioaccessibility. The arsenic content in the soils was 93%, leading to half of the onions uptaking >0.1 mg/kg [32]. The addition of soil treatments, such as organic matter, and remediation efforts, such as raised beds and peeling vegetables, will help reduce the uptake of trace metals in vegetables.

High levels of trace metals were also found in the leaves of plants than in any other area [33], with high concentrations of metals being found in leafy vegetables such as lettuce or cabbage, which might be due to strong transpiration throughout the leaves as they are the main part of the plant used for photosynthesis. Root vegetables are speculated to have high concentrations of metals because lead, cadmium, and arsenic are not nutrients like copper and zinc, so they are stored in the root of the vegetable [44]. Trace metals, such as lead, concentrate in the xylem or core of vegetables. Since root vegetables have a larger xylem compared to fruits or nightshade vegetables, there is an increased amount of stored toxic trace metals [28].

There are also studies that suggest that high levels of metals in soils may not be indicative of high levels of metals in produce grown in that soil [20,23]. However, lead in chicken eggs was associated with lead in garden soil, suggesting that contact between chickens and high lead-content soil should be prevented [20]. Plant uptake is dependent on the bioavailable forms of trace metals; therefore, speciation of trace metals, not only the total concentration of trace metals, will be needed to assess health risks [17]. Plant uptake of trace metals also depends on plant species, time, and soil conditions. Therefore, not all produce from gardens contaminated with trace metals may always pose a risk [17]. The conversion of bioavailable forms of trace metals, such as free ions or weakly sorbed forms, to precipitations or more stable compounds will immobilize these metals and thus lower plant uptake and prevent groundwater pollution [17].

5. Exposure

5.1. Exposure Pathways

The most common exposure pathways for trace metals in urban garden settings are the inhalation of dust particles, dermal exposure, the ingestion of soil, the ingestion of crops grown in contaminated soil, and the ingestion of contaminated groundwater or irrigation water. Soil in urban gardens can often become mobilized by drying out into dust and being picked up by the wind, which is then carried into the lungs of gardeners. This happens most often during the summer months when the climate is warmer and drier, and many people are outside. Inhalation as an exposure pathway is the most likely to increase blood lead levels and makes up three-fourths of lead exposure in toddlers [28]. A lot of contaminated dust is tracked into homes on clothes and shoes, expanding the exposure area. The inhalation of dust from outdoor gardening can expose gardeners or their families to trace metals if they track dust into the home, and incidental ingestion of dirt on produce is also a concern in urban environments [3,14,15,18]. Standard methods of household cleaning and sweeping up this dust are ineffective at reducing children's blood lead levels [15,18]. Since soil dust makes up such a large percentage of dust in urban homes (20–80%) and there is no effective way of getting rid of it, measures should be taken to prevent the dust from entering the home in the first place by removing shoes and outer layers of clothing [30]. Windblown soil and dust can be rescued at the garden site by encapsulating the soil with unamended sediment at around a 15 cm thickness [9]. The continued placement of this layer would protect nearby residents and gardeners from inhaling contaminated soil.

When 70 gardeners from 15 different community gardeners in Baltimore, Maryland, were surveyed, 63% of gardeners mentioned that dermal contact was an important exposure pathway of contaminants, while inhalation was only mentioned by 39% of gardeners [3]. It is also important to note that these gardeners come from a higher income and educational background than the surrounding population. This might indicate that less educated gardeners or gardeners with a lower income might not be as aware of dermal contact as a risk. While dermal exposure is a pathway for trace metal contamination to make its way to people, the damage is often minimal. Dermal exposure to lead from soils is considered negligible, and the absorption rate of all metals in soils was found to be between 0.1 and 1%. To prevent dermal exposure, gardeners should wear gloves while gardening and wash their hands after gardening [45].

Crops grown in contaminated soil are susceptible to varying amounts of trace metal uptake. These metals can make their way into humans when ingested [16,20,28,34]. In urban community gardens, this might seem like a larger concern because of the high levels of contamination in the soil. However, the difference in the trace metal concentrations of plants grown in urban and nonurban environments is negligible. This shows that this is an exposure pathway for all people consuming crops, not just urban gardeners [23]. Additionally, not all trace metals present in the soil are available for uptake. Only about 10% of most trace metals are bioavailable for plants to uptake [17]. Both urban and nonurban gardeners should be aware of this exposure pathway and should attempt to limit trace metal uptake of plants in their soil. This can be carried out by applying a 10% volume-to-weight ratio of biochar and compost to limit the availability of trace metals, mainly lead, and avoiding growing too many root crops or leafy crops, as they tend to uptake more trace metals than fruits or nightshade vegetables [5,17,33].

The amount of trace metals present in irrigation water and groundwater across all cities and towns largely relates to pollution from the surrounding geographic area. Urban waters can experience poorer water quality than suburban or rural areas because of high amounts of pollution and centralized water sources [46]. In Baltimore City, one study found that 80% of irrigation water was detected as containing barium and copper, and all rain barrels, a popular way for urban residents to collect irrigation water, had lead concentrations over the US EPA drinking water action level (15 ppb) [23]. People with wells use groundwater for everything from cooking to showering. Groundwater can become contaminated with trace metals when it encounters soil, which poses a risk to people who rely on it [10].

Although urban community gardens have elevated amounts of trace metals present in the soil, this does not necessarily mean that they are at a greater risk of trace metal exposure through the crops grown there. It may depend on the selection of crops and gardening practices. Cheng et al., 2011 [17], estimated that 92% of vegetables grown in urban areas present minimal risk to the average consumer. Root vegetables, the largest harbors of toxic trace metals, are not commonly grown in New York City urban community gardens, and urban gardeners consume fewer plants than suburban gardeners due to space limitations [20]. Although Lupolt et al. (2021) found that leafy vegetables grown in Baltimore, Maryland, had higher trace metal levels compared to those grown in a nonurban setting, a large majority of them were below the World Health Organization's recommendations for lead levels (85 ppm) in leafy vegetables [20]. The median levels of metals in urban plants compared to the median levels in nonurban plants showed no significant difference [23]. There have also been instances of the inadequate washing of crop material when testing for trace metals. If the plant is not thoroughly cleaned, metals present in the soil on the outside of the plant will be measured as part of the plant tissue [28]. The uptake of toxic metals by plants is a threat to the health of gardeners; however, not all urban gardeners are at elevated risk, and it may depend on the proximity of the garden's location to past industrial sites and other emission sources (Table 2).

5.2. Exposure to Children

Lead is a known neurotoxin that can negatively affect a child's neurological development, overall growth, and even academic achievement [13,22]. Approximately 412,000 avoidable deaths can be linked back to lead contamination [47]. The US EPA set the maximum contaminant level for lead in soils at 400 ppm for bare residential soils where children are likely to play [15,30,32].

The negative impacts of lead are most worrisome among children because they are more sensitive than adults to the effects of lead. Children absorb 50% of ingested lead while adults absorb under 5%; children have an air and chloric intake two to three times greater than adults, and children have high rates of hand-to-mouth activity, which can be major pathways of lead ingestion [14–16]. An estimated 72–91% of lead exposure in children is due to incidental soil ingestion [3]. The children of community gardeners eat more produce than adults living with gardeners and are encouraged to participate in gardening activities [20,24]. There are also benefits to children being involved in community gardens. It is great for children's education and community involvement; however, these benefits should be properly weighed against the risks of community gardens that have contaminated soil [4]. There are multiple ways to protect children from soil-based lead exposure, such as limiting the amount of time children spend at community gardens that have contaminated soil, peeling and/or washing produce harvested from gardens, and decreasing and controlling the amount of dust (20–80% of dust in urban homes is soil dust) in and around the house by cleaning often and removing gloves and shoes before entering the house [3,22,30].

Children who live in or near major cities have higher blood lead levels than children living in more rural areas [8,11,18,22,28]. Although the CDC recently lowered the acceptable amount of blood lead levels to 3.5 µg/dL, the number of children living in urban areas with lead blood levels above 10 µg/dL is estimated to be 16% [35]. The blood lead levels of children are closely associated with city-side and soil lead levels [18]. The Centers for Disease Control, the World Health Organization, and the Mayo Clinic all state that there is no safe blood lead level for children or adults. Even low levels of lead found in the body have adverse effects on development and academic achievement.

6. Environmental Justice

Soil contamination is a worry that is largely unique to communities of color in urban areas. Historic practices such as redlining negatively affected people of color in urban environments, and the effects are still seen today. In Oakland, California, redlining in the first half of the 20th century and highway construction and deindustrialization in the second half disproportionally affected African American, Southeast Asian, and Latino communities. They were forced to live in the North, East, and West flatlands of Oakland, while more affluent rich white people got to live in the hills. The hills have much lower levels of lead in their soil and have the resources to not have to rely on community gardens for fresh produce [14]. The same trend is seen on the East Coast in cities like Boston, Massachusetts. While only 24.2% of Boston is Black or African American, the areas in the city with the highest blood lead levels of children are 45% for Black or African American in Dorchester, Massachusetts, and 53% for Black or African American in Roxbury, Massachusetts [11]. Minorities have disproportionately high rates of exposure to soil pollutants and trace metals in their communities, which may explain why Black gardeners across the country are more concerned than their White counterparts about soil contamination [4].

Community gardens in urban areas may be built in brownfields because they are typically large and unoccupied areas of land, which can be hard to come by in a city. Brownfields are largely found in large industrial areas and are disproportionately located near communities of color [48]. These properties are often contaminated by pollutants from previous activities that occurred on the site, and extensive remediation is often required to properly convert these sites into gardens that are fit to grow food and for daily human activities. Historical redlining in urban areas across the United States or lack of local government funding in minority communities could have led to increased exposure to Black and Brown communities.

The median household income from urban garden cold spots of lead levels to hot spots of lead levels decreased from USD 75,692 to USD 38,757 in Baltimore, Maryland [31]. From cold spots to hot spots, there was a 74.9% increase in African Americans living in those areas, a 14.2% increase in unemployment, and a 29.1% increase in people depending on Maryland's Supplemental Nutrient Assistance Program [31]. A survey of 472 gardeners across the country showed that there is a link between the intention to test soils for contamination and higher incomes [4]. Soil testing in gardens is most needed in urban community spaces; however, due to costs, these tests are not performed, and consequently, the health of the gardeners can potentially suffer. The cost of clean topsoil is also high (approximately USD 4000 to replace contaminated topsoil with 15 cm of clean topsoil), so this effective remediation tactic cannot be implemented in urban communities that need it the most [9].

The lack of regulations relating to trace metals in urban soils puts minority populations and people living in poverty at greater risk of exposure. Trace metals and metalloids such as lead, arsenic, cadmium, and zinc are commonly found in contaminated garden soils and have lasting health effects. Gardens along roof drip lines, roadsides, or near areas where lead-based paint chips, smelters, mines, current and past industries, brownfields, or superfund sites are present can lead to increased trace metal contamination in urban areas [21,30,31]. Agencies in the United States have a history of overlooking communities of color in contaminated environments [10]. Concern regarding trace metal contamination is on the rise, especially within the Black community, as more and more studies have been carried out on the topic [4,5]. Many urban gardeners recognize that there is a lack of scientific consensus about what levels of trace metal contamination are considered safe [3].

Often, when the community garden is being led by a site manager or scientific group, the gardeners in the community may feel like they are being talked down to regarding their exposure to contamination rather than participating in an open dialogue on what can be done to reduce exposure. It is common in marginalized communities for people to be told about the risks that they will experience rather than their experiences, which could be used to properly quantify their risk [3]. Black gardeners are shown to be more concerned about soil contamination, and low-income gardeners have mentioned a need for more access to information about soil contamination, so the need for education exists [4]. A majority of community gardeners receive their information on the potential risks of gardening, such as soil contamination, from fellow gardeners, the internet, social media, non-profits, and community garden training events. However, even with these resources, less than half of the 472 participants in one study were concerned about exposure to heavy metal contaminates in the soil [4]. Physical hazards such as the theft of crops and pests were mentioned more often than chemical contaminants in a study group of 20 gardeners [4]. Expanded information and disclosure of garden site history and further emphasis on the potential hazards of trace metal contamination in soils can help encourage testing in urban areas.

7. Soil Remediation

7.1. Raised Bed

The practice of gardening in raised beds is several decades old and is a popular way for many gardeners to try and curb contamination within their garden soil. They have been proven to have fewer trace metals present and can reduce the amount of toxicants entering the soil compared to garden beds on the ground [1,11].

While effective, raised garden beds are not guaranteed to have safe concentrations of metals when they are initially put in place or over time [5,25]. There may still be contamination in raised beds from wind-transported particles from nearby sources and the wood that the bed is made from [25]. In a study focusing on Philadelphia community gardens, raised beds were effective in lowering the concentrations of lead and arsenic but not zinc, copper, vanadium, and nickel [21]. The wood used on railways was historically treated with copper chromate arsenate, which can diffuse arsenic, copper, and chromium into the soil if in contact. Unfortunately, a lack of public awareness causes these old railway sleepers to be a popular choice for the walls of raised garden beds [5]. Some communities also might not have the resources to construct raised beds and might resort to easily accessible, chemically treated wood. In multiple studies, gardeners falsely believed that the use of raised beds eliminates soil contamination; therefore, testing and other remediation measures were not considered necessary [3,4]. These misconceptions highlight the need for more education within gardening communities.

7.2. Replacement of Topsoil

The removal and replacement of garden topsoil is an effective way of removing trace metal contaminants [10,11,24]. The undisturbed soil in urban areas has high concentrations of trace metals, so removal and replacement are necessary to maintain human and crop health [17]. The topsoil is the most important layer to replace because it is the layer most likely to become airborne and make its way into the lungs of gardeners and nearby homes.

7.3. pH, Compost, and Biochar

Soil pH, fertilizers, nutrients, compost, and biochar also play a role in the trace element distribution in garden soils [49–53]. Certain fertilizers that contain different plant nutrients can have the same effect on soil. For example, fertilizers containing ammonium decrease the negative charge of the soil, which increases lead availability, while fertilizers containing phosphates increase the negative charge and decrease lead availability [12,51]. Maintaining a neutral pH will ensure that the availability of all trace metals will stay low, which will decrease plant uptake [17]. High pH levels can facilitate the formation of metal carbonates and increase net negative charge, leading to the formation of metal–organic complexes [50]. Neutral-to-slightly basic pH will prevent the mobility of carbonate-bound metals [17], decrease the availability of cationic metals, such as lead, and increase the availability of anionic elements, such as arsenic [12]. A high soil pH can also reduce the leachability of cadmium zinc, immobilizing it in the soil [17]. Soil pH can greatly influence the solubility of metals such as metal oxide, hydroxide, and carbonate (MCO_3) [52]:

$$MCO_3\ (s) + 2H^+ \leftrightarrow M^{2+} + CO_2\ (g) + H_2O$$

In a lab experiment, applying the proper amount of lime led to increased soil pH and reduced heavy metal extractability, thus decreasing heavy metal toxicity [49]. In addition to liming, the addition of biochar can increase soil pH and immobilize metals in the soil [50]. The proper combination and application of biochar and compost can eliminate the need for potentially hazardous fertilizers and decrease the amount of trace metals already present in garden soils [8]. The addition of a 10% volume-to-weight ratio of an amendment that is equal parts biochar and compost can nourish the soil as well as prevent trace metals from becoming highly available [12]. Organic materials, which are found in much higher levels in cultivated soil than in uncultivated soil, increase cadmium concentrations and decrease lead concentrations [25].

Many urban gardeners rely on compost as a tool to help decrease the amount of lead in contaminated urban gardens [1,8,9,11,28,32]. While compost successfully reduces the amount of lead in soil, some studies have shown that applying compost to a garden will increase the plant uptake of lead and other trace metals [12,53]. When compared to biochar, compost is more decomposable and contains more humic substances, which are reactive and form complexes with metal ions and minerals [12]. Lead enrichment in compost could be from source materials containing broken down urban soil materials such as plant waste or leaves with soil adhered to them [1,8,9,11,28,32]. One study found that while compost did decrease the amount of available lead in soil by 8%, the tissue of radishes grown in the soil with compost had a 19% increase in lead content [12]. Compost increased the accumulation of trace metals such as lead, copper, cadmium, and chromium in spinach and dill plants [53]. Using compost that is made from food waste or using compost production methods that minimize the incorporation of urban soil could reduce the amount of lead present [1,8,9,11,28,32].

A better alternative to applying only compost to contaminated garden soil is to apply a mix of compost and biochar (a charcoal-like substance that is rich in carbon). It is low-cost, environmentally friendly, and is created through the pyrolysis of manure and straw in a low-oxygen environment. Biochar reduces the availability of lead in the soil and plant availability, and compost introduces nitrogen and other nutrients, which are depleted with the introduction of biochar [12]. Biochar is believed to be effective in reducing trace metals in soils because of its large surface area, very microporous structure, active organic functional groups, and hydroxide and carbonate phases that cause trace metals to precipitate. Furthermore, it generally has a high pH and cation exchange capacity (CEC). After biochar was applied to native soil, lead availability was reduced by 20%, and the bioaccumulation of lead in plants was reduced by 11% [12]. The ideal ratio of compost to biochar was found to be 5–10% v/w of contaminated soil [53]. In a laboratory experiment, biochar-amended soils helped to increase soil pH and reduce metal bioavailability, thus increasing heavy metal (such as Cd and Pb) immobilization [50]. Application of proper amounts of lime can increase soil pH, reduce heavy metal extractability, thus decreasing heavy metal toxicity [49]. In addition to liming, the addition of biochar can increase soil pH and immobilize metals in the soil [50].

7.4. Limitations

While using the above recommendations, it is important to understand that a solution needs to be optimized based on various factors such as the properties of the soil, the contaminant of concern, crops to be grown, contamination sources, and the transportation pathways of the contaminant. The use of raised beds may not always be helpful if the source of the contaminant travels through air deposition. It is important to provide the proper amount of lime. The addition of calcium nitrate and calcium chloride may have varying results on soil pH and metal bioavailability [49]. Although biochar and the combination of biochar and compost can help reduce lead bioavailability, biochar may not be easily accessible [12]. Biochar is relatively expensive and may not be readily or freely available like compost [12]. Addition of compost and phosphate-based fertilizers need to be carefully assessed for not introducing trace metal contaminants. The above-mentioned remediations are not complete. There are many other methods, such as soil washing and soil mobilization and immobilization techniques, which can be used for heavy metal removal from soil. Additionally, phytoremediation is one of the most effective techniques for heavy metal removal from soils, which has not been discussed in this paper.

8. Conclusions

8.1. Benefits of Community Gardens

Community gardens in urban communities can have numerous benefits for nearby populations. Community gardeners in Salt Lake City, Utah, had a lower body mass index than their neighbors and family who did not participate in community gardening activities [5]. This is likely due to gardeners performing physical activity in the gardens and having more healthy food options at their disposal. Along with physical health, many studies show that the mental health of urban gardeners can be improved through gardening. Community gardens also provide access to fresh produce that might not be available nearby or might be expensive [54]. Gardens also reduce reliance on long, fossil fuel-powered supply lines stretching from rural farms to local supermarkets [17]. One question that many researchers have sought to answer is whether the benefits of urban community gardens outweigh the risks, and most concluded that they did [4].

8.2. Risks and Misconceptions

There is a risk of trace metal exposure while gardening in an urban setting; however, it is important to quantify the level of risk and specify the types of risk that gardeners face. In most of the surveys included in this literature review, the common misconceptions that gardeners believe were outlined. For example, one group of gardeners believed that growing fruits and vegetables in contaminated soil is the greatest risk associated with community gardening, even though it has been shown to be a less significant exposure pathway when compared to inhalation and ingestion [5]. The same risks were echoed by urban gardeners from Kansas, Indiana, and Washington, with 70% of the 121 participants surveyed describing the ingestion of crops as a pathway of contamination. Only 39% mentioned inhalation as a pathway [3]. Many gardeners also believe that if they are planting in a raised garden bed and have test results indicating that their soil is safe, they have nothing to be concerned about. However, trace metals like lead can still enter the soil of raised beds due to wind transportation. For example, in Dorchester, Massachusetts, the lead levels in urban raised beds were found to have increased by 185 ppm over 4 years [3]. It is important to regularly administer tests for metal contamination in urban garden soils and communicate the quantified risks relating to trace metal contaminants. Community garden users should also be educated about the various exposure pathways, not only the ingestion pathway. They need to be educated about the available practices that can help reduce exposure to trace metal contamination. These can include behavioral practices such as using gloves, changing clothes to minimize bringing contaminants inside houses, leaving shoes outdoors, and washing vegetables.

8.3. Useful Practices

Community garden practitioners should be aware of the potential sources of environmental contaminants in community gardens and the available management practices (Figure 2). These can often be cleared by testing the soil. Gardeners should be educated on the proper selection of crops to limit their exposure. It is important to take precautions to limit the amount of soil dust that transfers from community gardens to inside homes. The US EPA, state agencies, and universities have several useful resources available online, such as general guides to community gardening in urban environments and information on brownfields. The proper washing of produce, use of mulch on the top of the soil, adding organic matter, and maintaining a neutral pH can also limit the uptake of trace metals by plants [8]. The use of raised beds and the application of biochar and compost can also be helpful for selected trace metal contaminants, and CCA wood should be avoided for use in raised beds. Crops should be planted away from the road to minimize deposition [25]. Researchers have shown that various methods can be effective in reducing the mobility or plant uptake of trace elements ([17] and references therein).

8.4. Recommendations

Comparison between studies from across the United States has been made difficult by the multiple trace metal threshold standards that are used. Many studies compare their lead levels to the 400 ppm standard set by the US EPA for residential soils, while other studies use state guidelines, such as California, which has an 80 ppm threshold. However, no study used the US EPA Technical Review Workgroups Lead Committee's recommendation of 100 ppm for urban gardeners, which reveals the need for greater dissemination of this recommendation so that gardeners can be properly informed. Consistent, clear, and scientifically backed standards should be created and shared widely by the US EPA to educate state authorities and gardeners.

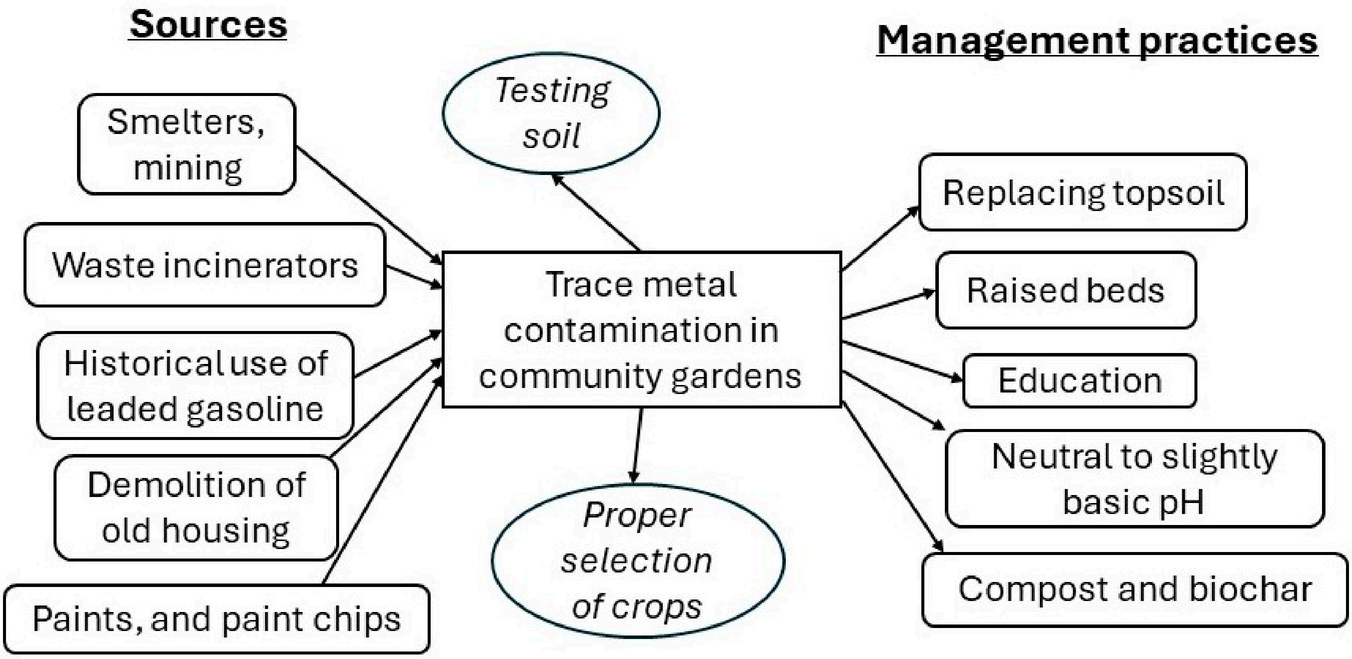

Figure 2. Potential sources of trace metal contaminants and management practices to reduce trace metal contaminants in community garden soils.

As mentioned earlier, there is no safe lead level in the blood, as any amount of lead will have adverse effects on a person. Establishment of safe stringent lead level in soil would lead to increased intervention from local governments or environmental groups because intervention would be required to make it safe for people to garden. However, lowering the standard level for lead or other heavy metals might make some areas inaccessible to gardening due to the high costs of remediation at the contaminated site. Not all gardeners are open to testing their soil for chemical contamination, such as PCBs, due to liability and cost concerns as well as sample representativeness and interpretation of the results. The presence of heavy metals in the soil might lead to a mandatory and expensive cleanup and lead to stigma for the owner of the garden/property [4]. Providing resources not only for testing, but also for remediation, further education on how to interpret soil test results, and clear guidance on how to proceed if garden soil is contaminated are needed if proper cleanup efforts are to be made.

The US EPA should create new trace metal standards for soil where community gardeners are intentionally interacting with the soil and make a greater effort to educate gardeners. They should consider the multiple different exposure pathways that go along with community gardening (inhalation, direct ingestion, dermal contact, and plant uptake). The time of year, time spent gardening each week, and specific types of activities performed in the garden should also be taken into account when creating these standards. Site-specific assessments should be given on a biannual basis in each community garden to ensure that proper remediation practices are taking place to limit the amount of trace metal increases. Along with the soil, the produce grown in gardens should be tested for trace metals to obtain an idea of their availability in the soil. It is more important to test the soil before converting abandoned and empty lots into community gardens.

Many universities and independent labs across the United States offer trace metal testing for residential soils. Table S1 outlines many trace metal testing sites across multiple states at varying price ranges. This is by no means a comprehensive list of all soil testing sites in the country, but it provides options and accurate pricing so that gardeners can see if soil testing is financially feasible for them. The environmental agencies of many states also provide resources on their website for local labs that will test residential soil for contamination. Universities often have handheld portable XRFs that can be used to survey the contamination of trace metals in soils at on-site locations. By collaborating more closely with universities, this can be carried out at no cost to the communities [22].

Several laboratory studies have been conducted on the effectiveness of various methods to reduce the availability of metal concentrations, exposure to trace metal concentrations, and the uptake of metals by plants. Future studies should focus on testing the effectiveness of the methods in situ in community garden settings. It is important to develop cost-effective methods and easily accessible methods to analyze metal contamination in community gardens so that community garden communities can benefit. We have compiled an example list of available testing locations in Table S1. Developing inexpensive remedial solutions is a challenge. However, the best soil management strategy for reducing metal contamination, exposure, and plant uptake can be developed in collaboration with community garden organizations and local non-profit organizations. Future studies can examine the effectiveness of various intervention methods that improve education on soil contamination among garden users.

In addition to the management practices outlined in Figure 2, several practices can help reduce exposure to trace metals:

- Minimizing the time spent for children at community gardens that are known to have trace metal contaminants.
- Using gloves and washing hands after gardening.
- Leaving gardening clothes and shoes outdoors.
- Education about potential trace metal contaminants.
- Washing produce.
- Selecting produce that will have less metal uptake.
- Collaborating with the local universities and organizations for regular soil testing.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su16051831/s1, Table S1: Trace metal soil testing sites across the United States.

Author Contributions: Conceptualization, K.M.S.; methodology, M.M. and K.M.S.; writing—original draft preparation, M.M.; writing—review and editing, M.M. and K.M.S.; supervision, K.M.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Acknowledgments: We appreciate the support from the Center for Research and Fellowships at Villanova University for Maeve Malone.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Mitchell, R.G.; Spliethoff, H.M.; Ribaudo, L.N.; Lopp, D.M.; Shayler, H.A.; Marquez-Bravo, L.G.; Lambert, V.T.; Ferenz, G.S.; Russell-Anelli, J.M.; Stone, E.B.; et al. Lead (Pb) and other metals in New York City community garden soils: Factors influencing contaminant distributions. *Environ. Pollut.* **2014**, *187*, 162–169. [CrossRef]
2. Siewell, N.; Aguirre, S.; Thomas, M. Building Sustainable Neighborhoods through Community Gardens: Enhancing Residents' Well-being through University—Community Engagement Initiative. *Metrop. Univ.* **2015**, *18*, 173–190.
3. Kim, B.F.; Poulsen, M.N.; Margulies, J.D.; Dix, K.L.; Palmer, A.M.; Nachman, K.E. Urban Community Gardeners' Knowledge and Perceptions of Soil Contaminant Risks. *PLoS ONE* **2014**, *9*, e87913. [CrossRef]
4. Hunter, C.M.; Williamson, D.H.Z.; Gribble, M.O.; Bradshaw, H.; Pearson, M.; Saikawa, E.; Ryan, P.B.; Kegler, M. Perspectives on Heavy Metal Soil Testing Among Community Gardeners in the United States: A Mixed Methods Approach. *Int. J. Environ. Res. Public Health* **2019**, *16*, 2350. [CrossRef]

5. Al-Delaimy, W.K.; Webb, M. Community Gardens as Environmental Health Interventions: Benefits Versus Potential Risks. *Curr. Environ. Health Rep.* **2017**, *4*, 252–265. [CrossRef] [PubMed]
6. Cooper, A.M.; Felix, D.; Alcantara, F.; Zaslavsky, I.; Work, A.; Watson, P.L.; Pezzoli, K.; Yu, Q.; Zhu, D.; Scavo, A.J.; et al. Monitoring and mitigation of toxic heavy metals and arsenic accumulation in food crops: A case study of an urban community garden. *Plant Direct* **2020**, *4*, e00198. [CrossRef] [PubMed]
7. Parekh, N.; Ali, S.H.; O'Connor, J.; Tozan, Y.; Jones, A.M.; Capasso, A.; Foreman, J.; DiClemente, R.J. Food insecurity among households with children during the COVID-19 pandemic: Results from a study among social media users across the United States. *Nutr. J.* **2021**, *20*, 73. [CrossRef] [PubMed]
8. Kaiser, M.L.; Williams, M.L.; Basta, N.; Hand, M.; Huber, S. When Vacant Lots Become Urban Gardens: Characterizing the Perceived and Actual Food Safety Concerns of Urban Agriculture in Ohio. *J. Food Prot.* **2015**, *78*, 2070–2080. [CrossRef] [PubMed]
9. Walsh, D.; Glass, K.; Morris, S.; Zhang, H.; McRae, I.; Anderson, N.; Alfieri, A.; Egendorf, S.P.; Holberton, S.; Owrang, S.; et al. Sediment exchange to mitigate pollutant exposure in urban soil. *J. Environ. Manag.* **2018**, *214*, 354–361. [CrossRef]
10. Malone, M. Seeking justice, eating toxics: Overlooked contaminants in urban community gardens. *Agric. Hum. Values* **2022**, *39*, 165–184. [CrossRef]
11. Clark, H.F.; Hausladen, D.M.; Brabander, D.J. Urban gardens: Lead exposure; recontamination mechanisms, and implications for remediation design. *Environ. Res.* **2008**, *107*, 312–319. [CrossRef]
12. Geiger, T.; Norton, U. Effects of Garden Amendments on Soil Available Lead and Plant Uptake in a Contaminated Calcareous Soil. *Appl. Sci.* **2021**, *11*, 5777. [CrossRef]
13. Goswami, O.; Rouff, A.A. Soil Lead Concentration and Speciation in Community Farms of Newark. New Jersey, USA. *Soil Syst.* **2020**, *5*, 2. [CrossRef]
14. McClintock, N. Assessing soil lead contamination at multiple scales in Oakland, California: Implications for urban agriculture and environmental justice. *Appl. Geogr.* **2012**, *35*, 460–473. [CrossRef]
15. Schwarz, K.; Pouyat, R.; Yesilonis, I. Legacies of Lead in Charm City's Soil: Lessons from the Baltimore Ecosystem Study. *Int. J. Environ. Res. Public Health* **2016**, *13*, 209. [CrossRef] [PubMed]
16. Manjón, I.; Ramírez-Andreotta, M.D.; Sáez, A.E.; Root, R.A.; Hild, J.; Janes, M.K.; Alexander-Ozinskas, A. Ingestion and inhalation of metal(loid)s through preschool gardening: An exposure and risk assessment in legacy mining communities. *Sci. Total Environ.* **2020**, *718*, 134639. [CrossRef] [PubMed]
17. Cheng, Z.; Lee, L.; Dayan, S.; Grinshtein, M.; Shaw, R. Speciation of heavy metals in garden soils: Evidences from selective and sequential chemical leaching. *J. Soils Sediments* **2011**, *11*, 628–638. [CrossRef]
18. Mielke, H.W. Nature and extent of metal-contaminated soils in urban environments (keynote talk). *Environ. Geochem. Health* **2016**, *38*, 987–999. [CrossRef]
19. Glaeser, E.L.; Kahn, M.E.; Rappaport, J. Why do the poor live in cities? The role of public transportation. *J. Urban Econ.* **2008**, *63*, 1–24. [CrossRef]
20. Spliethoff, H.M.; Mitchell, R.G.; Shayler, H.; Marquez-Bravo, L.G.; Russell-Anelli, J.; Ferenz, G.; McBride, M. Estimated lead (Pb) exposures for a population of urban community gardeners. *Environ. Geochem. Health* **2016**, *38*, 955–971. [CrossRef]
21. Bassetti, O.G.; McDonough, R.A.; Shakya, K.M. Soil contamination in community gardens of Philadelphia and Pittsburgh, Pennsylvania. *Environ. Monit. Assess.* **2023**, *195*, 782. [CrossRef]
22. Latimer, J.C.; Van Halen, D.; Speer, J.; Krull, S.; Weaver, P.; Pettit, J.; Foxx, H. Soil Lead Testing at a High Spatial Resolution in an Urban Community Garden: A Case Study in Relic Lead in Terre Haute. Indiana. *J. Environ. Health* **2016**, *79*, 28–35.
23. Lupolt, S.N.; Santo, R.E.; Kim, B.F.; Green, C.; Codling, E.; Rule, A.M.; Chen, R.; Scheckel, K.G.; Strauss, M.; Cocke, A.; et al. The Safe Urban Harvests Study: A Community-Driven Cross-Sectional Assessment of Metals in Soil, Irrigation Water, and Produce from Urban Farms and Gardens in Baltimore, Maryland. *Environ. Health Perspect.* **2021**, *129*, 117004. [CrossRef]
24. Cheng, Z.; Paltseva, A.; Li, I.; Morin, T.; Huot, H.; Egendorf, S.; Su, Z.; Yolanda, R.; Singh, K.; Lee, L.; et al. Trace Metal Contamination in New York City Garden Soils. *Soil Sci.* **2015**, *180*, 167–174. [CrossRef]
25. Clarke, L.W.; Jenerette, G.D.; Bain, D.J. Urban legacies and soil management affect the concentration and speciation of trace metals in Los Angeles community garden soils. *Environ. Pollut.* **2015**, *197*, 1–12. [CrossRef]
26. Jaishankar, M.; Tseten, T.; Anbalagan, N.; Mathew, B.B.; Beeregowda, K.N. Toxicity, mechanism and health effects of some heavy metals. *Interdiscip. Toxicol.* **2014**, *7*, 60–72. [CrossRef]
27. Tóth, G.; Hermann, T.; Silva, M.R.D.; Montanarella, L. Heavy metals in agricultural soils of the European Union with implications for food safety. *Environ. Int.* **2016**, *88*, 299–309. [CrossRef] [PubMed]
28. Brown, S.L.; Chaney, R.L.; Hettiarachchi, G.M. Lead in Urban Soils: A Real or Perceived Concern for Urban Agriculture? *J. Environ. Qual.* **2016**, *45*, 26–36. [CrossRef] [PubMed]
29. Tuccillo, M.E.; Blue, J.; Koplos, J.; Kelly, J.; Wilkin, R.T. Complexities in attributing lead contamination to specific sources in an industrial area of Philadelphia, PA. *Heliyon* **2023**, *9*, e15666. [CrossRef] [PubMed]
30. Bugdalski, L.; Lemke, L.D.; McElmurry, S.P. Spatial Variation of Soil Lead in an Urban Community Garden: Implications for Risk-Based Sampling: Spatial Variation of Soil Lead in an Urban Community Garden. *Risk Anal.* **2014**, *34*, 17–27. [CrossRef] [PubMed]

31. Hall, J.; Shargo, I.; Khanjar, N.; Howard, J.; Schmidt, L.; Deng, A.; Edwards, C.; Berman, I.; Galarraga, J.; Wilson, S. Proximity of Urban Farms to Hazards With and Without Heavy Metal Contamination in Baltimore, Maryland. *Environ. Justice* **2021**, *14*, 56–69. [CrossRef]
32. Paltseva, A.A.; Cheng, Z.; Egendorf, S.P.; Groffman, P.M. Remediation of an urban garden with elevated levels of soil contamination. *Sci. Total Environ.* **2020**, *722*, 137965. [CrossRef]
33. Boon, D.Y.; Soltanpour, P.N. Lead, Cadmium, and Zinc Contamination of Aspen Garden Soils and Vegetation. *J. Environ. Qual.* **1992**, *21*, 82–86. [CrossRef]
34. Heiger-Bernays, W.; Fraser, A.; Burns, V.; Diskin, K.; Pierotti, D.; Merchant-Borna, K.; McClean, M.; Brabander, D.; Hynes, H.P. Characterization and Low-Cost Remediation of Soils Contaminated by Timbers in Community Gardens. *Int. J. Soil Sediment Water* **2009**, *2*, 5.
35. Minca, K.K.; Basta, N.T. Comparison of plant nutrient and environmental soil tests to predict Pb in urban soils. *Sci. Total Environ.* **2013**, *445–446*, 57–63. [CrossRef]
36. Moller, K.; Hartwell, J.; Simon-Friedt, B.; Wilson, M.; Wickliffe, J. Soil Contaminant Concentrations at Urban Agricultural Sites in New Orleans, Louisiana: A Comparison of Two Analytical Methods. *J. Agric. Food Syst. Community Dev.* **2018**, *8*, 139–149. [CrossRef]
37. Li, C.; Zhou, K.; Qin, W.; Tian, C.; Qi, M.; Yan, X.; Han, W. A Review on Heavy Metals Contamination in Soil: Effects, Sources, and Remediation Techniques. *Soil Sediment Contam. Int. J.* **2019**, *28*, 380–394. [CrossRef]
38. Parsania, S.; Mohammadi, P.; Soudi, M.R. Biotransformation and removal of arsenic oxyanions by Alishewanella agri PMS5 in biofilm and planktonic states. *Chemosphere* **2021**, *284*, 131336. [CrossRef] [PubMed]
39. Walter, W.W. Arsenic. In *Heavy Metals in Soils: Trace Metals and Metalloids in Soils and Their Bioavailability*, 3rd ed.; Alloway, B.J., Ed.; Springer: Berlin/Heidelberg, Germany, 2010.
40. Smolders, E.; Mertens, J. Cadmium. In *Heavy Metals in Soils: Trace Metals and Metalloids in Soils and Their Bioavailability*, 3rd ed.; Alloway, B.J., Ed.; Springer: Berlin/Heidelberg, Germany, 2010.
41. Preer, J.; Abdi, A.; Sekhon, H.; Murchison, G. Metals in Urban Gardens—Effect of Lime and Sludge. *J. Environ. Sci. Health Part-Environ. Sci. Eng. Toxic Hazard. Subst. Control* **1995**, *30*, 2041–2056. [CrossRef]
42. McIvor, K.; Cogger, C.; Brown, S. Effects of Biosolids Based Soil Products on Soil Physical and Chemical Properties in Urban Gardens. *Compost Sci. Util.* **2012**, *20*, 199–206. [CrossRef]
43. Mertens, J.; Smolders, E. Zinc. In *Heavy Metals in Soils: Trace Metals and Metalloids in Soils and Their Bioavailability*; Alloway, B.J., Ed.; Springer: Berlin/Heidelberg, Germany, 2010.
44. Zhou, H.; Yang, W.-T.; Zhou, X.; Liu, L.; Gu, J.-F.; Wang, W.-L.; Zou, J.-L.; Tian, T.; Peng, P.-Q.; Liao, B.-H. Accumulation of Heavy Metals in Vegetable Species Planted in Contaminated Soils and the Health Risk Assessment. *Int. J. Environ. Res. Public Health* **2016**, *13*, 289. [CrossRef]
45. U.S. Environmental Protection Agency. *Assessing Dermal Exposure from Soil*; U.S. Environmental Protection Agency: Washington, DC, USA, 2015.
46. U.S. Environmental Protection Agency. *Why Urban Waters?* U.S. Environmental Protection Agency: Washington, DC, USA, 2013.
47. Lanphear, B.P.; Rauch, S.; Auinger, P.; Allen, R.W.; Hornung, R.W. Low-level lead exposure and mortality in US adults: A population-based cohort study. *Lancet Public Health* **2018**, *3*, e177–e184. [CrossRef]
48. Smollin, L.; Lubitow, A. Environmental Justice and Interventions to Prevent Environmental Injustice in the United States. *Encycl. Environ. Health Second Ed. Ref. Module Earth Syst. Environ. Sci.* **2019**, 561–568. [CrossRef]
49. Li, L.; Mao, K.; Ippolito, J.A.; Xing, W.; Chen, X.; Zhu, W.; Cheng, Y. Calcium amendments affect heavy metal bioavailability in acidic and calcareous soils. *Int. J. Environ. Sci. Technol.* **2022**, *19*, 10067–10076. [CrossRef]
50. Xu, Y.; Seshadri, B.; Sarkar, B.; Wang, H.; Rumpel, C.; Sparks, D.; Farrell, M.; Hall, T.; Yang, X.; Bolan, N. Biochar modulates heavy metal toxicity and improves microbial carbon use efficiency in soil. *Sci. Total Environ.* **2018**, *621*, 148–159. [CrossRef] [PubMed]
51. Paltseva, A.A.; Deeb, M.; Di Iorio, E.; Circelli, L.; Cheng, Z.; Colombo, C. Prediction of bioaccessible lead in urban and suburban soils with Vis-NIR diffuse reflectance spectroscopy. *Sci. Total Environ.* **2022**, *809*, 151107. [CrossRef] [PubMed]
52. Young, S.D. Chemistry of Heavy Metals and Metalloids in soils. In *Heavy Metals in Soils: Trace Metals and Metalloids in Soils and Their Bioavailability*, 3rd ed.; Alloway, B.J., Ed.; Springer: Berlin/Heidelberg, Germany, 2010.
53. Medyńska-Juraszek, A.; Bednik, M.; Chohura, P. Assessing the influence of compost and Biochar Amendments on the Mobility and Uptake of Heavy Metals by Green Leafy vegetables. *Int. J. Environ. Res. Public Health* **2020**, *17*, 7861. [CrossRef] [PubMed]
54. Wong, R.; Gable, L.; Rivera-Nunez, Z. Perceived Benefits of Participation and Risks of Soil Contamination in St Louis Urban Community Gardens. *J. Community Health* **2018**, *43*, 604–610. [CrossRef]