Contaminated Commons: The Paradox of Soil Justice and Contamination in Seattle Community Gardens

Vedika Bhat

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Committee:

Yona Sipos

Meilani Lanier-Kamaha'o

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Department of Environmental and Occupational Health Sciences

University of Washington

Abstract

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Vedika Bhat

Chair of the Supervisory Committee:

Yona Sipos

Department of Environmental and Occupational Health Sciences

Many urban community gardens across the United States occupy previously industrial land, commonly termed "brownfields". This shared characteristic underscores a critical tension within urban agriculture, where spaces of substantial social, health, and environmental benefits may also expose gardeners to environmental risks, particularly in the form of soil contamination. In Seattle and King County, lead and arsenic contamination are of high concern because of land-use patterns and absence of known safe exposure levels for these heavy metals. This convergent parallel mixed methods study integrates community gardener perspectives and behaviors around soil contamination and mitigation with GIS spatial analysis of lead and arsenic soil contamination to identify pathways for community-led action and remediation. Findings demonstrate that gardeners perceive and mitigate contamination risk collectively, with community labor serving as the primary form of agency and safe gardening practices centered on regenerative soil stewardship rather than individual-level behavioral interventions. Gardeners also understand soil contamination as spatially uneven across the region, a perception supported by the first regional-scale soil contamination maps, focused on Seattle community gardens. Spatial analysis further suggested that lead and arsenic may follow distinct contamination pathways not fully reflected in focus-group discussions. Conversely, focus-group participants identified municipal compost as a potential

contamination source not tested for or represented in spatial datasets. These findings suggest that addressing soil contamination in urban community gardens requires approaches that both include and move beyond individual behavior change to strengthen community capacity, institutional accountability, and transparent, nuanced, contaminant-specific risk communication. Although grounded in Seattle, this research has broader relevance for the paradox present in urban community agriculture, where community gardens simultaneously function as sites of environmental justice and exposure.

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To my family, I recognize the cumulative hours and energy you have invested in my success and education. I'm sure the majority of those hours have been spent on my monologues of uncertainty - thank you for listening.

Lastly, thank you to all the community gardeners and farmers who participated in events and group discussions for this research. I hope this work clears a bit of the path forward.

"All flourishing is mutual."

Robin Wall Kimmerer, *Braiding Sweetgrass*

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1. Introduction

1.1 Background and Context

Urbanization is reshaping global population patterns at an unprecedented scale. As of 2025, nearly half of the world's 8.2 billion people reside in urban areas, with cities expected to accommodate approximately two-thirds of global population growth by 2050[1]. As urban populations expand, so too do concerns about access to nutritious food and environments that support physical and mental well-being[2]. Urban community gardens (UCGs) have emerged as critical interventions within this context, offering multifunctional and transformative benefits that extend beyond food production. Participation in community gardening has been associated with increased physical activity, improved dietary intake, and enhanced social connectedness, while also reducing perceived stress and anxiety among participants[2,3]. These spaces may also play a role in modifying key risk factors associated with non-communicable and chronic diseases, including cancer, by promoting healthier lifestyles and fostering supportive community environments[3]. As such, UCGs represent an increasingly important component of urban public health.

Urban Community Gardening in Seattle

The community gardening movement in Seattle, Washington is rooted in a long-standing tradition of civic engagement and urban land stewardship, most notably exemplified by the municipal P-Patch program. Established in the early 1970s, the P-Patch program originated as a grassroots initiative to provide residents with access to land and educate children about food production during the "Boeing Bust", a period of rapid disinvestment and food insecurity for city residents[4,5]. The term "P-Patch" itself derives from the Picardo Farm, the original community gardening site, and has since become synonymous with community gardening in Seattle. Today, the P-Patch network encompasses 90 gardens serving 3,500 households, primarily supporting low-income and historically underserved communities in an effort to advance racial equity and environmental stewardship[4].

As community gardening was growing in Seattle, there was a similar resurgence across the country. Following earlier waves of "victory gardens" during World Wars I and II, the 1970s saw renewed interest in urban gardening driven by economic recession, rising food costs, and grassroots activism in response to urban disinvestment[6]. In cities such as New York, community gardens often emerged through informal occupation of vacant lots, particularly in neighborhoods affected by fiscal crisis and abandonment[7]. These gardens frequently functioned as sites of resistance and self-determination, created and maintained by residents in the absence of formal institutional support. Thus, UCGs are a form of the commons, a term describing shared management of natural resources that is neither public nor private[7–9].

Given this, Seattle P-Patches developed with relatively strong municipal backing, which has shaped both its structure and longevity. Nevertheless, many UCGs across the United States occupy abandoned, previously industrial land, commonly termed "brownfields"[10]. The historical uses of these sites introduce potential environmental exposures, particularly from legacy soil contaminants that remain on-site. These shared characteristics of urban soils underscore a critical tension within urban agriculture, where spaces that provide substantial social, health, and environmental benefits may also expose gardeners to environmental risks. What happens when sites for flourishing also have histories of contamination? Understanding this paradox has become increasingly important for environmental justice and urban agriculture research.

<u>Soil Contamination in Seattle</u>

In 1994, the Washington State Department of Ecology (DOE) released a report on a soil contamination assessment used to determine the background levels of elements and chemicals[11]. These efforts established estimates of "background" concentrations, which are defined as levels of substances present in the environment that are not attributable to contamination from a specific site or release[11]. Background concentrations may reflect natural geologic conditions or broader regional influences, and provide an important benchmark to identify site-related contamination.

In Washington, the environmental cleanup framework is further governed by the Model Toxic Control Act (MTCA) of 1989[12]. This legislation considers background concentrations alongside cleanup levels, which are regulatory thresholds used to determine whether remediation is necessary[12]. Cleanup levels represent a threshold for the concentrations of hazardous substances in environmental media (e.g. soil or groundwater) below which conditions are considered protective of human health and the environment under specified exposure conditions[13]. These thresholds are informed by a compendium of technical information and assumptions about land use and exposure pathways from the DOE Cleanup Levels and Risk Calculation information service[13]. Calculated cleanup levels aide in determining actions needed to protect human and environmental health at sites being cleaned by MTCA[13].

Soil contamination represents a persistent and unevenly distributed environmental health risk in Seattle[14]. Historical industrial activities have left a legacy of contamination that continues to shape present-day exposure pathways. One of the most significant sources of regional contamination is the former American Smelting and Refining Company (ASARCO) copper smelter in nearby Tacoma, which emitted plumes of arsenic and lead across an approximate 1,000 square-mile-wide geographic area between 1890 and 1985 [15–17]. In response to widespread contamination concerns, the DOE developed the Dirt Alert program, to provide residential soil testing and a publicly accessible modeled contamination map to identify potential risks[16].

The Dirt Alert program is supported through the 2009 ASARCO Bankruptcy Settlement, which allocated $94.6 million for soil testing and remediation within areas determined to have been affected by the smelter emissions based on atmospheric deposition modeling and environmental sampling[18]. Importantly, these funds are specifically designated for lead and arsenic contamination, reflecting both the contaminants most strongly linked to ASARCO operation and those reflecting clear regulatory mandates. As a result, lead and arsenic are among the most extensively monitored soil contaminants in the region, while other urban soil contaminants are less routinely assessed and may receive comparatively limited policy attention or remediation resources despite their potential relevance to urban agriculture and/or impact on human and environmental health.

The ASARCO Smelter represents only one of several historical contamination pathways affecting Seattle soils. While regional arsenic and lead depositions have received substantial attention due to dedicated settlement funding and public health messaging, urban soil and sediment contamination in Seattle is shaped by a range of land-use histories. One prominent example is the Lower Duwamish Waterway, where decades of industrial activity have contributed to extensive environmental contamination[19] and disproportionate health burdens in surrounding communities, particularly South Park and Georgetown[20]. The river sediments have been designated a Superfund site, essentially meaning that under the Comprehensive Environmental Response, Compensation, and Liability Act of 1980, industrial polluters and the federal government are liable to remediate the space and protect public health[21]. ZIP code 98108, including the South Park and Georgetown neighborhoods that rest by the river, have life expectancies 8 years shorter than the county average, 47% higher rates of heart disease, more than two times higher hospitalization rates for childhood asthma, and even higher rates of lung cancer, diabetes, and death from stroke compared to the rest of King County[20].

Beyond major industrial sites, additional contamination risks are associated with active spills, hazardous waste facilities, radioactive and nuclear waste, former landfills, historic orchards, and previous and current industrial sites[22]. These land uses have deposited a wide range of contaminants of concern to environmental and human health, including PAHS, petroleum products, surfactants, pesticides/herbicides, phenols, sodium, and nitrates, just to name a few[10,22]. Collectively, these contaminants and their pathways highlight that urban soil in Seattle is shaped by multiple overlapping historical and contemporary land uses.

<u>Soil contamination in community gardens</u>

These contamination patterns have direct implications for community gardening. Research has demonstrated that urban garden soils can contain elevated levels of heavy metals such as lead and arsenic, often exceeding recommended thresholds for safe exposure[14,23,24]. In Seattle and comparable urban contexts, these contaminants originate from historical industrial emissions, leaded gasoline residues, and past land uses[14,25]. Despite this evidence, there remains a notable gap in policy protections specific to urban agriculture[10,26].

Existing regulatory frameworks typically apply residential soil exposure standards to UCGs, which may not adequately account for the frequency, duration, and pathways of exposure associated with gardening activities, including direct soil contact, ingestion, and consumption of contaminated produce[10,27–29]. As a result, community gardeners face unrecognized or insufficiently mitigated risks for their land-use interaction[14,28,29].

In recognition of these policy gaps, the EPA released interim guidelines for gardening in urban areas in 2011[10]. These guidelines emphasize individual level protections (e.g. wearing gloves, washing hands and produce) as well as structural interventions (e.g. choosing where to garden based on nearby urban infrastructure, gardening in raised beds). While these recommendations provide practical strategies for reducing exposure, they do not establish regulatory requirements or dedicated protections for UCGs.

Among these contaminants, lead is of particular concern due to its persistence in the soil and well documented adverse health effects. Recent research suggests that there is a strong link between soil lead concentrations and blood lead levels in children[30,31]. The Center for Disease Control (CDC) and World Health Organization claim that there are no safe levels of exposure to lead, and childhood exposure can have severe long-term health effects, including neurodevelopmental damage, decreased growth, learning disabilities, and impaired hearing[25]. In UCG contexts, this is of particular concern because the children of community gardeners have been shown to eat more garden produce than adults living with gardeners, and children have increased hand-to -mouth behaviors that alter and increase their exposure in UCGs[32].

In response to growing awareness of soil contamination, local organizations have initiated efforts to expand soil testing and education. The King Conservation District (KCD) launched a soil testing program in 2024 in partnership with the DOE, inspired by the DOE Dirt Alert initiative, offering free lead and arsenic testing for community agriculture sites. Concurrently, nonprofit organizations such as Sustainable Seattle (S2) have developed soil health and environmental justice programs that engage community members in conversations about contamination, risk, and mitigation[33]. These efforts align with broader state-level initiatives, such as the Washington Environmental Health Disparities (WA EHD) Map, which visualizes cumulative environmental burdens and social vulnerabilities to inform equitable policy and resource allocation[34].

1.2 Study Innovation and Significance

Despite these advancements, critical gaps remain in both data accessibility and community engagement. Notably, results from the new KCD soil contamination testing program have yet to be spatially mapped or analyzed. Mapping such data is essential for identifying geographic patterns of contamination, highlighting disparities across neighborhoods, and supporting targeted interventions[35]. Geographic Information Systems (GIS) provide a powerful tool for visualizing environmental health risks in relation to demographic and socioeconomic factors, thereby advancing environmental justice goals[35,36]. Without spatial analysis, important patterns of inequity may remain obscured, limiting the effectiveness of policy and intervention strategies.

At the same time, quantitative data alone cannot fully capture the lived experiences, perceptions, and priorities of community gardeners. Qualitative approaches, including community-based events and participatory engagement efforts such as those facilitated by S2, are essential for understanding how individuals interpret and respond to environmental risks[37,38]. Mixed methods research, which integrates quantitative spatial analysis with qualitative insights, is particularly well-suited to environmental justice contexts, where issues of power, perception, and lived experience intersect with measurable environmental hazards[39]. Furthermore, in the context of limited technological solutions for soil remediation and mitigation, community perspectives play a crucial role in identifying feasible, culturally appropriate, and locally relevant strategies for reducing exposure[37,38].

The purpose of this study is to investigate soil contamination in Seattle UCGs through a mixed methods and GIS-based approach. Specifically, this research aims to (1) spatially analyze soil contamination data from community garden sites, including previously unmapped datasets such as those from KCD, and (2) integrate qualitative insights from community engagement efforts to better understand perceptions of risk, knowledge and action gaps, and priorities for intervention. By combining these approaches, the study seeks to illuminate both the spatial distribution of contamination and the social dimensions of environmental health risk.

1.3 Guiding Frameworks, Models, and Theories

Socio-Ecological Model

The Socio-Ecological Model (SEM) was developed in the 1970s by American psychologist Urie Bronfenbrenner[40,41]. It was used to visualize the relationship of environmental systems beyond the individual in the process of human development. Over the development of this theory, the CDC adapted the model to create the SEM for Violence Prevention[42]. Visually, the model presents multiple concentric circles representing scaled social systems. Beyond the individual, the closest and most direct environment is the interpersonal, comprised of families, friends, and social networks. Following, in order of highest individual impact and least systemic influence, is the organizational environment (organization, social institutions), community (relationships between organizations), and finally, public policy (Figure 1.1).

Figure 1.1: The Socio-Ecological Model can frame impacts of agricultural safety and health interventions at multiple levels, from the individual to public policy[42].

This model is widely used in health settings to determine the impact of a public health challenge, program, or intervention. This model is easily adaptable to a wide breadth of public health contexts, such as agricultural health and safety research[40]. Therefore, this study employs the adapted SEM framework[42].

Environmental Health Literacy Model

The Environmental Health Literacy Model (EHLM) is an emergent and interdisciplinary model that outlines how individuals understand environmental exposures and further engages their skills to advocate or protect themselves[43] (Figure 1.2). The National Institute of Environmental Health Sciences has advanced the development and application of this model, now commonly applied to environmental education initiatives, particularly where environmental justice and contamination are concerned[44].

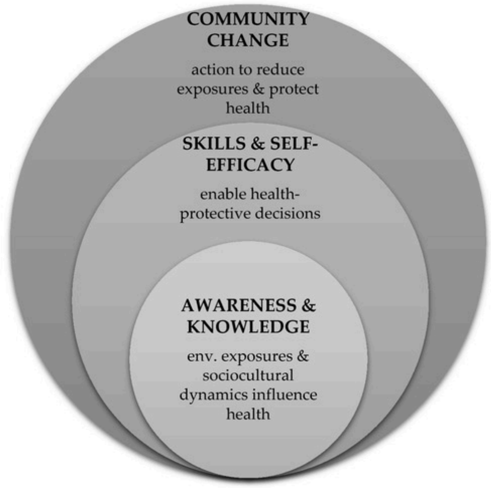

Figure 1.2: Environmental Health Literacy starts from individual awareness and results in community change[45].

The EHLM retains a layered structure, framing how individual knowledge leads to community change. The center comprises an individual's awareness and knowledge of an environmental health issue. The next layer is the individual's skills and ability to employ health protective decisions. Finally, the individual must take actions to reduce their exposure to said environmental health concern in order to demonstrate environmental health literacy.

This model is not employed consistently yet across the handful of environmental health literacy studies that currently exist. However, all those studies qualitatively explore knowledge and capacity of participants regarding a contamination concern, similar to the goals of this project. For example, one study explores EHL of PBB contamination in Michigan, while another explores both COVID-19 and PFAS drinking water contamination in North Carolina[45–47].

The qualitative goal of this project was to explore how community gardeners in Seattle understand, communicate, and manage their soil contamination risk within their community gardens. The notion of safety in a particular environment, both natural and social, was addressed in this objective. UCGs in Seattle are generally governed by the City's Department of Neighborhoods, meaning safety and health within these spaces is affected by all scales of the SEM. Organic certification and P-Patch program policy governs soil safety and contamination as much as community norms and individual behaviors. Regarding the latter, individual behaviors are affected by an individual's environmental health literacy. Thus, classifying awareness, self-efficacy, and action aided in characterizing how individuals experience this soil contamination in their urban community gardens. The SEM and EHLM guided coding by situating gardener perceptions and practices within multiple, interacting environments, allocating responsibility for upstream and downstream actors and supports. Each layer of the SEM and EHLM related to a question in the focus group guide (Appendix 1) and represented a code category in the a priori codebook (Appendix 2), and the use of process and values coding helped in analyzing the relationship between the data and theory.

This study is a mixed methods inquiry, an emergent research design in health research that integrates qualitative and quantitative methodologies to multifaceted and complex inquiries. UCGs represent spaces of environmental stewardship and resilience, while also existing within broader contexts of environmental injustice and health disparities. Therefore, understanding contamination in UCGs is not a qualitative or quantitative inquiry alone; it requires attention to measurable environmental indicators as well as the lived experience and priorities of community members. Thus, a community-engaged and mixed methodology was deemed appropriate for this research study.

2 Methods

Study setting

This research focuses on urban growers and urban growing spaces of community gardens in Seattle, Washington. The qualitative aspect of the study took place from August 2025 to May 2026 across a variety of community-based settings, including gardens and community events within the city. The quantitative aspect of the study included soil lead and arsenic test results from February 2024 to January 2026 for community agriculture sites within King County, concentrated in the Seattle area. This study integrates qualitative methods (2.1) and quantitative methods (2.2), resulting in a mixed methods analysis. This research was conducted via the University of Washington, in partnership with Sustainable Seattle (S2) and King Conservation District (KCD), operating in an academic-community-government nexus.

2.1 Qualitative methods to collect community gardener perspectives and behaviors

Aim 1: to explore how community gardeners in Seattle understand, communicate, and mitigate their soil contamination risk within their urban community gardens (UCGs).

Focus groups discussions (FGDs) with Seattle community gardeners and farmers were conducted in November 2025 in partnership with S2. Since soil safety policies in urban gardening spaces are nonexistent[14], many safety recommendations rely on the individual behaviors of gardeners, such as wearing gloves, washing produce and hands, and gardening in raised beds[10]. This requires some basic understanding or perception of soil contamination risk paired with knowledge around soil risk management practices. The FGD method was an effective qualitative method to investigate what gardeners think of soil contamination, why they think that way, and what safety behaviors they do or do not adopt[48].

FGDs are particularly useful when current knowledge of subjects are complex or developing; FGDs also lend themselves well to mixed-methods inquiries as a source of elaboration[49]. Furthermore, regulatory guidance on exposure to contaminants in urban gardens is largely nonexistent or ambiguous where present[14,38]. FGDs reproduce the familiar and interpersonal nature in which these soil contamination-related conversations and decisions happen day-to-day at UCGs[48].

Content analysis was used to analyze FGD qualitative data due to the open-ended nature of discussion questions and the brief written responses provided on participant sticky notes[50]. Directed content analysis was specifically selected because this study was theoretically informed by the SEM and EHLM[50]. Both the FGD guide (Appendix 1) and an a priori codebook (Appendix 2) were developed using concepts from these frameworks.

On November 5th, 2025, the University of Washington Human Subjects Division determined that this activity is human subjects research and qualifies for exempt status (IRB ID: STUDY00024264).

<u>Recruitment</u>

The study subjects were purposively sampled key informants recruited to participate in a group discussion on topics related to community gardening. Community garden contact information was obtained from the KCD Community Agriculture Map[51]. Those garden sites that fell within the U.S. Census Bureau 2020 TIGER FGDB borders for the City of Seattle were selected, and the associated email and contact information of community garden leaders (e.g. staff, community garden coordinators) obtained from the map data. Community garden leaders were recruited via an email to attend an S2 community event, during which they were invited to participate in FGDs. During this time, VB was an intern for the Soil Health and Justice Initiative hosted by S2, as well as the primary investigator for this research study. The participant recruitment email invitations included RSVP information and a digital flyer with information about the FGDs so that these contacts could further recruit community gardeners from the sites they served. Participants included garden/farm managers, garden/farm staff, or outstanding community gardeners, as recognized and defined by community garden leadership. Participant recruitment occurred solely through this email list, including individual and group follow-up invitations, to keep sampling non-biased and reproducible. For grant compliance and in alignment with S2 practices, the community event was also listed publicly on the S2 website and shared with S2 partners.

Study subjects

For subjects to participate in an FGD, they had to meet the inclusion criteria to be enrolled in the study. Individuals had to be 18 years of age or older. They had to describe their role in the urban gardening community in Seattle as either a community gardener, farm/garden manager, or farm/garden staff. They had to have participated in farming/gardening related tasks at a community or urban garden located in Seattle in the past 12 months, and intended to continue to do so in the next 12 months. Those who could not comfortably hold an in-depth conversation in English had to have a translator to participate in live discussion.

Participants were compensated for their time through an honorarium coordinated by S2 and supported by a grant from the Puget Soundkeeper Alliance and the Rose Foundation for Communities and the Environment. Support for The Sustainable Seattle Soil Health and Justice Initiative was provided by the Puget Sound Stewardship and Mitigation Fund, a grantmaking fund enabled by Puget Soundkeeper Alliance's Clean Water Act enforcement program, which protects the health of Puget Sound and its residents by enforcing federal water quality laws against serious violators. The Fund's goal is to mitigate past pollution runoff by supporting community-based efforts to protect or improve the water quality of Puget Sound. The Rose Foundation for Communities and the Environment administers the Fund to enable community-based watershed stewardship in close nexus with the specifics of the enabling settlements.

Data collection

A semi-structured focus group guide was developed to elicit participant experiences, knowledge, and perceptions related to soil contamination risk and gardening practices. Guide questions were iteratively refined through pilot engagement at five community outreach events conducted during VB's internship with S2, allowing for assessment of clarity, relevance, and participant interpretation prior to formal data collection. Question phrasing was reviewed for neutrality, rigor, asset-based framing, and approachability for non-academic audiences. Questions were rooted in the guiding EHLM and SEM

(Section 1.1) to (1) directly surface participants' knowledge and uncertainty around soil health, (2) explore gardening behaviors and self-efficacy, and (3) explore challenges and supports on gardens/farms in reference to the qualitative aim of the study (Appendix 1).

Four semi-structured FGDs were conducted at Estelita's Social Justice Library in Beacon Hill on November 16, 2025, and lasted ~90 minutes. FGDs were part of a larger S2 community event, where participants were invited to debrief their small discussions as a large group over a catered meal. Participants were assigned anonymous identifiers during the FGD using a group and participant ID. Other than VB, FGD facilitators were S2 staff or board members, who received a 1.5 hour training session on the discussion guide and protocol. Because S2 has had frequent previous programming at many community gardening sites in the city, group facilitators were seen as trusted community-based organizers.

At the start of each FGD, participants completed a demographic survey capturing age group, race, ethnicity, gender, and five-digit ZIP code to contextualize participant perspectives and support integration with spatial analyses. Survey responses were linked to participant IDs, and no direct identifiers were retained for analysis.

<u>Data logistics and storage</u>

All study data were primary and self-reported. The final analytic dataset consisted of demographic summaries, geographic indicators, and analytic materials including codebooks and memos. Qualitative data sources included facilitator notes, participant-generated materials (e.g., card sorting outputs), and images documenting event artifacts. Facilitators maintained handwritten memos and post-session debrief notes to document analytic reflections and enhance methodological rigor.

Demographic survey responses were exported into spreadsheet format and linked to participants using non-identifiable participant IDs. These data were used exclusively to contextualize findings and describe participant characteristics and were not discussed during group sessions, unless the participant brought up relevant aspects of their demographics while engaging in conversation. Screening data, including names and emails, were collected solely for consent verification, participation tracking, and study communication. Direct identifiers were removed following transcription and data verification, with no key file. Five-digit ZIP codes were retained only as aggregated geographic indicators to assess spatial representation and support integration with contamination mapping analyses.

All data was digitized and archived by S2 in compliance with grant requirements and S2 internal policies.

Coding description overview

The coding team comprised VB, YS (thesis chair), and NS (MS candidate). Team members held distinct roles throughout the analytic process. This study used a hybrid inductive-deductive approach within a directed content analysis framework. An a priori codebook was developed by VB in December 2025, informed by the SEM and EHLM, guiding research questions, and relevant literature (Appendix 2). The codebook was piloted on 6 of 22 transcripts (27% of the dataset) by VB and YS. Following independent coding, the coders met for a one-hour consensus meeting to compare code applications, discuss analytic memos, clarify definitions, and refine inclusion/exclusion criteria on February 18th, 2026. Based on this discussion, VB revised the codebook by removing unused deductive codes, clarifying definitions, and incorporating inductively generated and in vivo codes that emerged from the data.

Using the revised codebook, VB held a one-hour training meeting with NS to familiarize her with the study, codebook, and coding software Dedoose, Version 10.1.4. VB and NS independently coded the full dataset. Coding occurred at the phrase level, with text segments ranging from a single word to a complete sentence that captured a discrete analytic concept. Given the brevity of note-text entries, all text was treated as relevant to the research question; in some cases, an entire note-text entry was coded as a single unit. Multiple codes were applied when passages reflected more than one construct. Throughout coding, coders documented analytic and reflexive memos to capture interpretive decisions and emerging themes. Following the completion of independent coding, the coders met for 30 minutes on March 4th, 2026 to resolve discrepancies and harmonize codes. Final codebook revisions were made through consensus. Because few discrepancies required reconciliation and no substantial new themes or codes emerged during later stages of coding, VB determined that coding was complete.

Late-stage analysis

Late-stage analysis occurred in three phases: pattern identification, theme consolidation, and theoretical integration[50]. VB used analytic tools in Dedoose to generate code frequency tables, code-document tables, and code co-occurrence matrices. Frequency tables were used to examine how often codes appear and how widely they were distributed across the 22 transcripts. Distribution across transcripts was prioritized over raw frequency in order to identify patterns that recur across participants rather than isolated repetition within a single case. Co-occurrence matrices were used to examine how constructs clustered together, such as how definitions of risk intersect with particular socio-ecological levels or environmental health literacy dimensions. Based on quantity and depth of data, a pattern was considered analytically meaningful if it appeared in at least three transcripts, demonstrated consistent relational pairing with another construct across cases, or revealed a theoretically important tension when compared to expectations derived from the guiding frameworks (Section 1.1). Outlier or minority perspectives were retained when they illuminated uncertainty, inequity, or value conflict regarding the research question.

Theme consolidation occurred by grouping conceptually related codes and reviewing their excerpts collectively. For each proposed theme, VB drafted a thematic memo that articulated a clear thematic sentence, defined boundaries of inclusion and exclusion, summarized variation within the theme, and explained how participant reasoning or value frameworks shape the responses captured within it. Negative or disconfirming cases were examined to refine theme boundaries and prevent overgeneralization. A theme was retained only if it demonstrated internal coherence across excerpts, clear distinction from other themes, and direct relevance to the research question. YS and MLK (thesis committee member and S2 ED) reviewed thematic memos and supporting excerpts to assess whether interpretations were grounded in the data and analytically defensible.

In the final phase, themes were mapped onto the concentric structure of the SEM and the EHL framework in a final joint display (Chapter 4). This integrative approach made relation, expansion, and variance to guiding theory clear and interpretable.

2.2 Quantitative methods for mapping soil contamination

Aim 2: The second aim of this study is to identify spatial trends in lead and arsenic soil contamination across UCGs in Seattle.

The application software Environmental Systems Research Institute (ESRI) Aeronautical Reconnaissance Coverage Geographic Information System (ArcGIS) Pro platform, Version 3.6.0 was used to spatially map and analyze soil contamination results. Data containing the lead and arsenic concentrations of soil samples from King County community agriculture sites were provided by KCD. These community agriculture sites include gardens and farms outside concentrated urban settings within the county, thus the distinction of this terminology with UCGs, which refers to sites more specifically located in Seattle. The KCD free soil contaminant testing program began in February 2024 and is ongoing, so a snapshot of sample results exported on January 15th, 2026 was analyzed for the purposes of this research project. While soil testing efforts have existed prior to this research, this study is the first spatialization of soil contamination in this region.

This spatialization is particularly important as mapping tools can support distributive justice for communities disproportionately affected by poor environmental health conditions[52]. Distributive justice refers to the equitable distribution of environmental burdens, benefits, and services across communities[53]. Within environmental justice scholarship, distributive injustice occurs when certain communities disproportionately bear environmental hazards while receiving fewer environmental benefits or protective investments[53]. Mapping contamination patterns can help identify whether soil contamination burdens are distributed equitably across communities, making spatial analyses particularly relevant for examining environmental justice concerns within Seattle community gardens.

Data inclusion and confidentiality

Soil testing samples dated from February 11th, 2024 to November 20th, 2026. The dataset was snapshot on January 15th, 2026. Samples were collected using the KCD soil collection protocol in either the early spring or late fall, to ensure soil was not saturated and increase accuracy of the results. All samples submitted to the program were processed through A&L Western Laboratories, using EPA Method 3050B/6010C. Resulting metal concentrations were reported in ppm (parts per million).

Soil testing results were included on the map if the associated community garden had a publicly available, verifiable contact and address. The KCD Community Agriculture Map was used as a formal list of existing community agriculture sites in the county; this map was created by Jacob Tracy, AmeriCorps Community Agriculture Specialist and released on April 1st, 2025. For data confidentiality, mapped soil contamination results were aggregated to the 5-digit ZIP code level after analysis, and results were only ranked and mapped if there were 2 or more gardens located within that ZIP code. KCD retains a point map with disaggregated data, as well as raw sample data. Results for the entire King County region were mapped to contextualize contamination trends and recognize that hypothesized soil contamination trends operate on a regional scale that is environmentally meaningful, extending beyond restricted city limits.

Definition of key analysis variables and statistical methods

Lead and arsenic contamination

To test this hypothesis, aggregated lead and arsenic soil contamination data was reclassified into deciles, creating a Lead Contamination (LC) rank and Arsenic Contamination (AC) rank. Both Washington Department of Ecology (DOE) background and Model Toxics Control Act Method A cleanup levels for lead and arsenic were mapped to acknowledge the existing elevated levels of soil lead and arsenic contamination in Seattle, so as not to overemphasize background levels[13]. Inferential statistics were performed to understand if lead and arsenic contamination concentrations were significantly correlated using Pearson's *r*.

Environmental health disparities

South Seattle has the highest ranked census tracts for overall environmental health disparity within the Washington State Environmental Health Disparities (WA EHD) Map [34]. The WA EHD map and index is a cumulative impact screening tool publicly released by the DOE in 2019[52]. It compares census tracts across Washington State using a set of environmental exposure indicators, environmental effects indicators, sensitive population characteristics, and socioeconomic vulnerability measures (Figure 2.1)[34]. These indicators include factors such as air pollution exposure (e.g., $PM_{2.5}$ and ozone), proximity to hazardous waste sites and heavy traffic corridors, housing-related lead exposure risk, cardiovascular disease mortality, poverty, race and ethnicity, housing affordability, language isolation, and educational attainment[34].

The map was developed through a participatory process including communities across Washington State[52]. These variables are combined into a decile-based Environmental Health Disparities ranking that reflects the relative burden of environmental hazards and social vulnerability experienced by each census tract across the state. Higher-ranked tracts therefore represent communities facing greater cumulative environmental health risks due to the interaction of pollution exposures and structural inequities. This index uses additive interactions rather than multiplicative because they are better to assess the public health significance and subgroup priority of interaction, which is particularly important for a study, such as this, on environmental exposures and vulnerabilities across communities[54]. The EHD ranking from WA EHD Map Version 3.0 was used in this study as an indicator for environmental health disparities, as it represents the most current mapped indicators that are meaningful and significant to both Washington State residents and government.

Soil contamination is not included in the ranking of environmental health disparities. Therefore, to test similarity between soil contamination patterns and other mapped environmental health disparities, the residual of ranking was mapped. The WA EHD map contains census tract rankings for environmental exposures, environmental effects, sensitive populations, and socioeconomic factors. These themes use a combination of additive and multiplicative methods to calculate the final environmental health disparity score (Figure 2.1). Of interest to this study was to test if soil lead and arsenic contamination aligns with other currently mapped pollution burdens, as well as mapped environmental health disparities. Each garden in this study had their average lead and arsenic concentrations ranked into deciles, similar to the decile ranking of pollution burden and environmental health disparities scores from the WA EHD map. A Spearman (ρ) correlation was found between LC ranking and Pollution Burden and EHD rankings, and similar with AC rankings, to determine if contamination is higher in high Pollution Burden and EHD census tracts. These results were the first assessment of spatial soil contamination patterns in relation to known spatial EHD indicators in King County. In addition, gardens were spatially joined to the census tract they reside in, and a residual of pollution burden and environmental health disparity rankings was obtained from both lead and arsenic rankings. Those residuals that were close to 0 indicated that contamination ranking and rankings from the WA EHD map are similar for a census tract. Positive residuals indicated that soil metal contamination was higher than expected from EHD rankings, and negative residuals indicated that soil metal contamination was less than expected from EHD rankings. This study hypothesized that heavy metal contamination would be similar to other mapped pollution and environmental burdens, therefore predicted to see near zero residuals for contaminants.

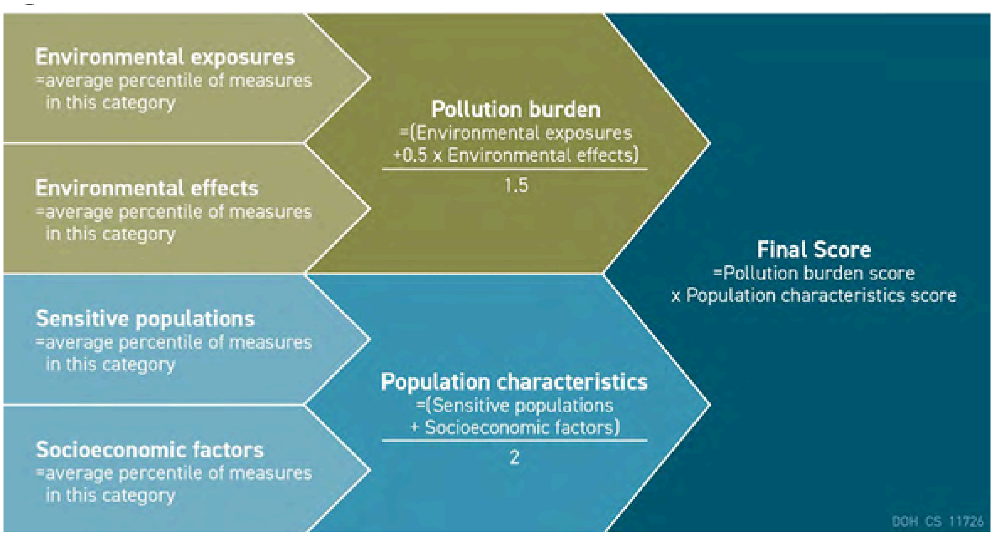

Figure 2.1: The themes used to calculate the intermediate Pollution Burden and Population Characteristic scores and final Environmental Health Disparity score for the WA EHD Map[34]. This study found residuals between lead and arsenic soil contamination and Pollution Burden

and final Environmental Health Disparity scores.

A complication of GIS and choropleth mapping is the Modifiable Area Unit Problem, where results can be mapped and aggregated to different area units (e.g. ZIP codes, census tracts, state boundaries) to show different results and trends[55]. Due to the data confidentiality agreements this study has with KCD, is it important to keep this Modifiable Area Unit Problem in mind. Soil sample results are point-based, and heavy metal contamination has been shown to vary from spot to spot within gardens greatly[56]. Therefore aggregation of a handful of results to the ZIP level is an overstatement, and it is encouraged by the research team to remember that the polygons displayed on the map do not represent or depict all soil within that polygon.

<u>Hypothesis testing</u>

The hypothesis for soil lead and arsenic maps were that South Seattle ZIP codes would have the highest mean concentrations of lead and arsenic, and that metals would have positive co-contamination. This hypothesis is grounded in the evidence of legacy industrial contamination[16,20,57], disparate environmental and human health outcomes by neighborhood[20,52], and previous soil contamination research in Seattle UCGs[14]. Based on theories of distributive injustice, as well as regional industrial histories, it was also hypothesized that soil lead and arsenic contamination would align with other mapped regional cumulative pollution burden and environmental health disparities.

2. 3 Methods for integration

Aim 3: The final aim of this study was to explore how community gardener perspectives and behaviors around soil contamination risk relate to the spatial distribution of soil lead and arsenic contamination in UCGs.

This study used a convergent parallel mixed-methods study design, which involved merging the results from the quantitative and qualitative data so that a comparison could be made, and a more complete understanding emerged than that provided by the quantitative and qualitative results alone (Figure 2.2). In achieving this aim, data was merged in a joint display matrix, aligning themes from FGDs with geographic contamination rankings and statistical analyses.

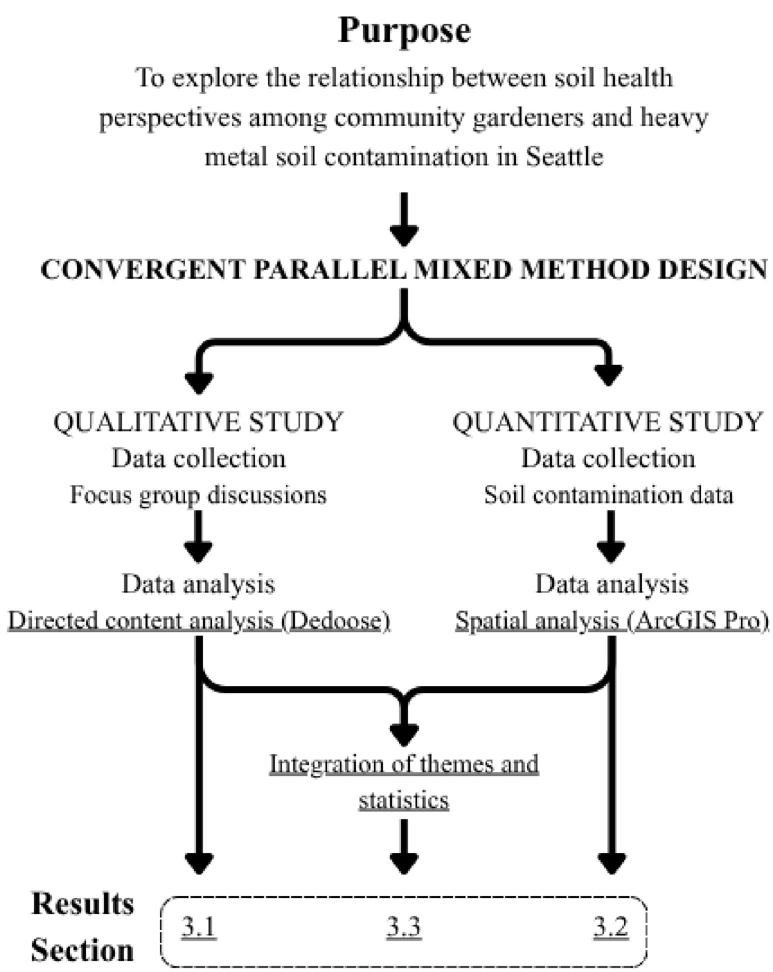

Figure 2.2: Thesis methods overview visually displays the convergent parallel mixed methods design used to address research inquiries.

Findings from Section 2.1 were compared to statistical and spatial results from Section 2.2 to identify patterns of convergence, divergence, and expansion. Convergence was defined as agreement or alignment between qualitative and quantitative results. Divergence was defined as disagreement or misalignment between qualitative and quantitative results. Finally, expansion was defined as results where qualitative findings revealed dynamics not captured in quantitative analyses, or vice versa.

These comparisons supported interpretation of whether soil contamination risk is primarily experienced as a known and managed exposure, an uncertain exposure, or an unrecognized exposure across community gardening contexts. This aim is exploratory in nature, acknowledging that the contamination maps do not fully represent soil contamination risk, and that mismatch does not indicate causality. The aim of this integration is to provide a community-based and quantitative-backed understanding of soil contamination risk in UCGs.

3. Results

This section presents findings from the qualitative (Section 3.1) and quantitative (Section 3.2) components of the study, culminating in the presentation of points of integration (Section 3.3) for community gardener perspectives and behaviors around soil contamination and spatialized heavy metal soil contamination in community gardens.

3.1 Community Gardener Understanding, Perspective, and Behaviors Regarding Soil Contamination in Community Gardens

Participant Demographics:

A total of 22 Seattle-based gardeners and farmers participated in four focus group discussions (FGDs) (Table 3.1), representing a diverse range of racial, age, and geographic backgrounds. Half of participants (50%) identified as White, while the remaining participants identified as Asian (22.7%), Black or African American, American Indian or Alaska Native, multiracial (13.6%), or preferred not to disclose (Table 3.1).

Participants ranged in age from 18 to 89 years, with half (50%) between 30 and 49 years old, reflecting both younger and older adult perspectives. Slightly more than half (54.5%) of participants identified as women.

Table 3.1: Participant Demographics for Focus Group Discussions Held in November 2026 with S2 ($n = 22$)

Characteristic	n **(%)**
Race	
American Indian or Alaska Native	1 (4.5%)
Asian	5 (22.7%)
Black or African American	1 (4.5%)
Multiracial	3 (13.6%)
American Indian or Alaska Native + Black or African American	
Asian + Native Hawaiian or Other Pacific Islander + White	
Asian + White	
White	11 (50.0%)
Prefer not to answer	1 (4.5%)
Age Group	
18–29	3 (13.6%)
30–49	11 (50.0%)
50–69	7 (31.8%)
70–89	1 (4.5%)
Gender	
Man	6 (27.3%)
Nonbinary	3 (13.6%)
Woman	12 (54.5%)
Other	1 (4.5%)

Participants reported primarily spending their time gardening or farming at sites across 11 ZIP codes spanning Seattle, representing approximately 44% of ZIP codes within or intersecting city boundaries. Although some ZIP codes extend beyond municipal limits, participant locations covered a substantial portion of the land area of Seattle, indicating broad geographic representation as can be seen in Figure 3.1. City boundary data were derived from the 2020 Decennial Census via ArcGIS Living Atlas (CITE).

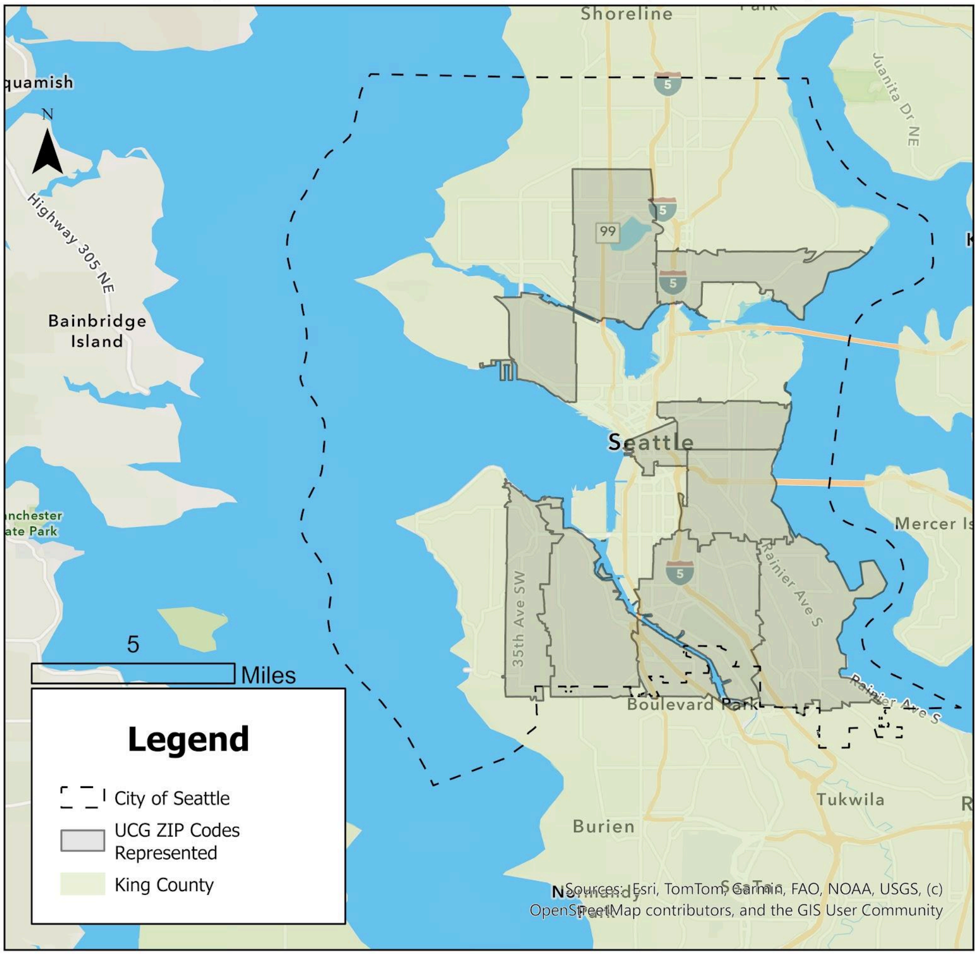

Figure 3.1: This map represents the distribution of ZIP codes where focus group discussion participants, composed of urban community gardeners and farmers, reported spending the majority of their time gardening.

Overview:

FGDs were centered around eliciting community gardener understanding, perspectives, and behaviors related to soil contamination, and health, within UCGs. Results suggest that gardeners have awareness and a sense of agency regarding soil contamination in their gardens, and have identified barriers to further literacy and health-protective decision-making on the policy and societal level. Behavioral trends also give insight into how individual recommendations are engaged with by key informants in the Seattle farming and gardening community.

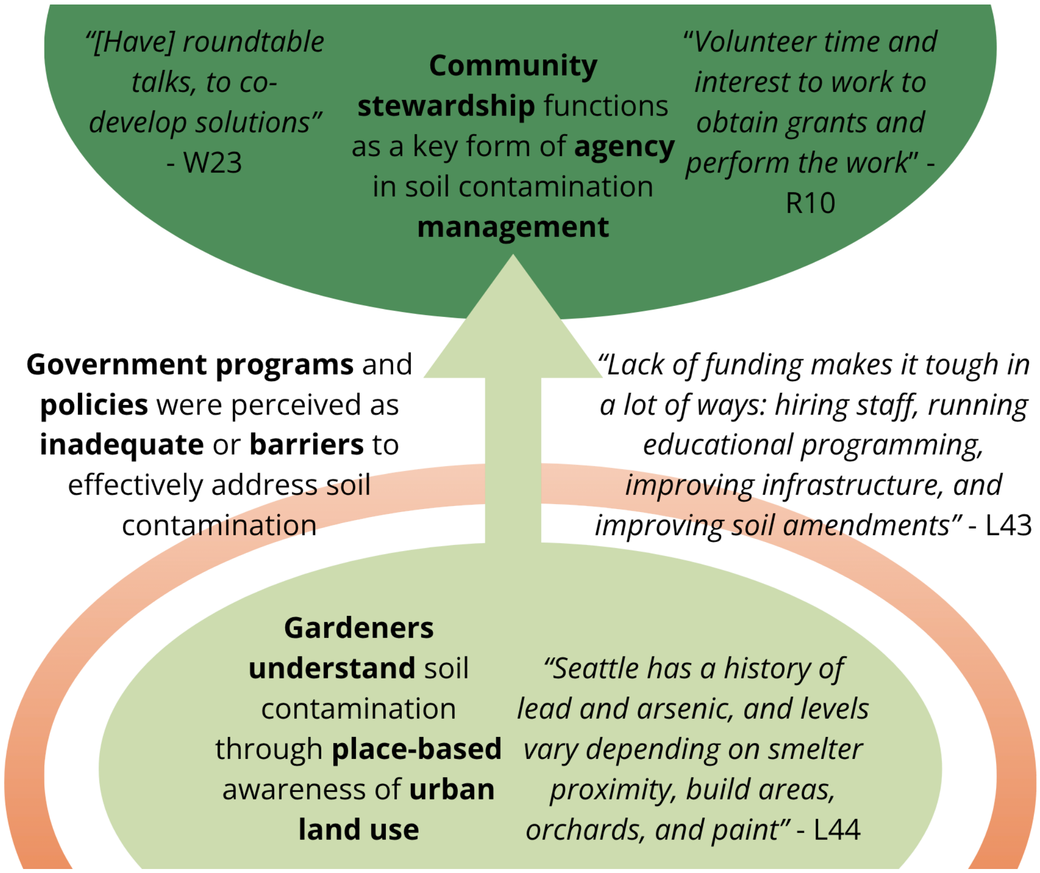

Figure 3.2: Thematic display of three major qualitative findings: (1) gardeners understand soil contamination through place-based awareness of urban land use, (2) government programs and policies were perceived as inadequate or barriers to effectively address soil contamination, and (3) community stewardship functions as a key form of agency in soil contamination management. Colors and visual structure distinguish thematic categories, while participant quotations provide examples of perspectives represented within each theme.

3.1.1 Gardeners understand soil contamination through place-based and spatial awareness of urban land use.

All participants (*n*=22) identified point or non-point sources of contamination that they understood as contributing to soil contamination in their gardens. Rather than describing contamination as isolated or site-specific, gardeners frequently referenced geographic patterns, regional histories, and past land uses as explanations for why contamination occurs in particular areas throughout the city. These responses reflect a place-based understanding of soil contamination in Seattle.

About half of participants (*n*=11) connected contamination patterns to historical land use and industrial activity. For instance, one gardener referenced legacy pollution sources, noting that "Seattle has a history of lead and arsenic, and levels vary depending on smelter proximity, build areas, orchards, and paint" (L44). Another participant described contamination as the result of long-term accumulation, stating that they had "heard our soil/land has been contaminated for centuries of industrialization and it's 'not safe'" (L45). These responses reflect an understanding of contamination as historically produced rather than solely the result of present-day conditions.

There were 27% (*n*=6) of participants who described urban soils as inherently more likely to contain contaminants compared to non-urban areas. For example, one participant explained that "the soil in our urban areas have elevated levels of heavy metals" (W22), suggesting an expectation that contamination is a defining feature of urban environments. Others described spatial variation within Seattle, identifying specific neighborhoods or zones as more heavily impacted. One participant noted that "South Seattle has a lot of different types of industrial contaminants in the soil" (R13), while another referenced "generally higher levels of heavy metals in Seattle urban soils, especially near industrial zones and red lined neighborhoods" (L43). These responses illustrate how participants form spatial hypotheses about the distribution of contaminants across the city.

In one focus group, participants extended these place-based understandings to discussions of remediation, emphasizing the persistent and non-degradable nature of many contaminants. Rather than viewing remediation as elimination, participants described it as the redistribution of contaminated materials across space. As one participant explained, "We know we have high levels of lead and heavy metals, but we don't want to bag it up and send it to the Columbia River," adding that "we know what happens in that landfill" (W22). This perspective reflects concern about shifting contamination burdens to other locations. Participants described a "moral obligation to keep [contaminated soil] on the land" (W22) until more responsible solutions are available, while also acknowledging the challenge of "disposing of contaminated plants and soil in a morally responsible way (send our "dirty" materials to pollute another community)" (W22).

Although participants did not consistently use explicit environmental justice terminology, their references to redlining, industrial zoning, and uneven neighborhood-level contamination suggest an awareness of spatial inequities. These place-based understandings demonstrate how gardeners situate soil contamination within broader urban histories, land use patterns, and distributions of environmental risk.

3.1.2. Government programs and policies were perceived as inadequate and, in some cases, as barriers that may contribute to or fail to effectively address soil contamination in community gardens.

When discussing challenges related to managing soil health and contamination, a majority of 64% (n=14) of participants identified gaps at the policy or societal level. These concerns were consistently framed as a lack of resources and institutional support rather than a call for increased regulation. Participants described a perceived "lack of systemic support from the city/local government" (F33), emphasizing that existing structures do not provide sufficient material or financial assistance to address contamination.

Half of participants (n=11) specifically identified funding as a key barrier. Gardeners described the need for financial support for physical materials, such as "raised garden materials + compost" (F32), as well as compensation for labor, including "city or state funding for full or part-time farm/garden stewards" (R16). One participant summarized the breadth of this gap, explaining that the "lack of funding makes it tough in a lot of ways: hiring staff, running educational programming, improving infrastructure, and improving soil amendments" (L43). Within this context, addressing soil contamination becomes an added burden layered onto already resource-intensive garden management, positioning soil contamination mitigation as inaccessible without systemic support.

A smaller subset of participants (18%, *n*=4) emphasized the need for more accessible, professional, and non-regulatory soil testing. Participants expressed interest in support from trusted institutions, such as "universities and/or community biology labs to assist with testing/microplastics/cost/technical support" (R16). Although these responses did not explicitly reference government programs, they point to a gap in awareness or accessibility of existing public soil testing services. As such, limited visibility and uptake of these programs function as an additional barrier to addressing contamination.

Concerns about institutional systems extended beyond funding and testing to include distrust in municipal composting programs. While some participants discussed contamination as a consequence of urban land use, a similar proportion (18%, *n*=4) raised the possibility that soil amendments themselves could introduce contaminants. Participants questioned the integrity of compost inputs, expressing concern about "source material contamination (not trusting that the compost brought to us is clean)" (W22) and asking, "How do they separate and keep that clean?" (L41). One participant reported testing free city compost and finding "higher levels [of lead and arsenic] in the compost than in the [garden] itself" (L43). Another described refusing city-provided compost and instead using those beds for non-food crops to reduce potential exposure.

These accounts complicate the assumption that composting is an unambiguous solution to soil contamination. Instead, gardeners described how recommended mitigation strategies may themselves introduce new risks. These findings suggest that participants view government-linked programs not only as insufficiently supportive but, in some cases, as potential contributors to contamination concerns.

3.1.3. Community stewardship functions as a key form of agency in managing soil contamination.

64% (n=14) of participants described responses to soil contamination as collective rather than individual efforts. Rather than emphasizing personal behavior alone, gardeners framed contamination management as requiring shared labor, coordinated knowledge exchange, and pooled resources across garden communities. In this framing, community gardeners and farmers were active agents who worked collaboratively to navigate contamination challenges through stewardship, experimentation, and mutual support.

Participants described several forms of collective action. Some emphasized informal spaces for collaboration, such as "roundtable talks, to co-develop solutions" (W23) to soil health challenges with other community gardens. Others imagined citizen science projects that could pilot phytoremediation strategies together, including "gardener networks to trial different crops on remediating soil" (L43). These responses suggest that gardeners viewed collaborative learning and citizen science as important tools to take next steps in addressing local soil contamination.

Collective agency also included the practical work of securing resources. Participants noted that addressing contamination often required grant writing, coordination, and administrative labor in addition to day-to-day gardening. As one participant explained, gardeners may "volunteer time and interest to work to obtain grants and perform the work" (R10). Others pointed to the need for shared funding, technical assistance, and partnerships with universities, extension programs, and other organizations. In this sense, community stewardship extended to include the labor of engaging with better resourced systems to allocate the resources needed for remediation and long-term soil management.

These responses show that participants conceptualized soil contamination as a problem best addressed through collective stewardship, shared labor, and collaborative knowledge production. Community networks were not only sources of support; they were also the means through which gardeners exercised agency in the face of contamination-related constraints and lack of systemic support.

3.1.4 Community gardeners selectively adopt safe gardening practices in response to soil contamination.

Materials around soil contamination in this region emphasize individual safe gardening practices gardeners can take to protect themselves, since there are no protective policies for urban gardeners regarding exposures to contaminants in the garden. KCD, DOE, and other common handout materials for urban gardeners list urban gardening best practices and recommendations from the aforementioned 2011 EPA Interim Guidelines[10].

To manage conciseness, these recommendations were adapted into 11 cards for this study, which participants discussed and sorted into four categories based on frequency and likelihood of them completing the listed behavior: 1) I don't do this, and won't, 2) I want to do this, but don't, 3) I sometimes do this, or 4) I always do this. Participants were encouraged to discuss and record notes about their engagement with these recommendations (Table 3.2).

Table 3.2: Seattle Community Gardener and Farmer Adoption of Recommended Safe Gardening Behaviors for Contaminated Soil Based on 2011 EPA Interim Guidelines ($n = 22$)

Behavior	Mean Score	Median Score	I always do this (%)	I don't do this, and won't (%)
I add compost or organic matter to improve the soil	3.86	4	85.7	0
I cover soil with mulch, landscaping material, groundcover, cover crop, etc. to protect it	3.71	4	71.4	0
I wash all produce I consume from the garden/farm thoroughly before consuming	3.29	3	33.3	0
I garden in raised beds or containers	3.25	3	30.0	0
I wear gloves and/or wash my hands after gardening	3.24	4	52.4	14.3
I avoid tracking soil into my home (shoes/tools/clothes)	3.10	3	47.6	9.5
I discard outer leaves of leafy greens from my garden/farm before consuming	2.95	3	42.9	23.8
I choose crops based on soil conditions	2.85	3	25.0	10.0
I check or test my soil (for nutrients or contaminants)	2.60	3	20.0	15.0
I keep soil moist while working to reduce dust	2.45	3	30.0	40.0
I choose where to garden based on nearby roads, railways, or older buildings	2.40	2.5	25.0	35.0

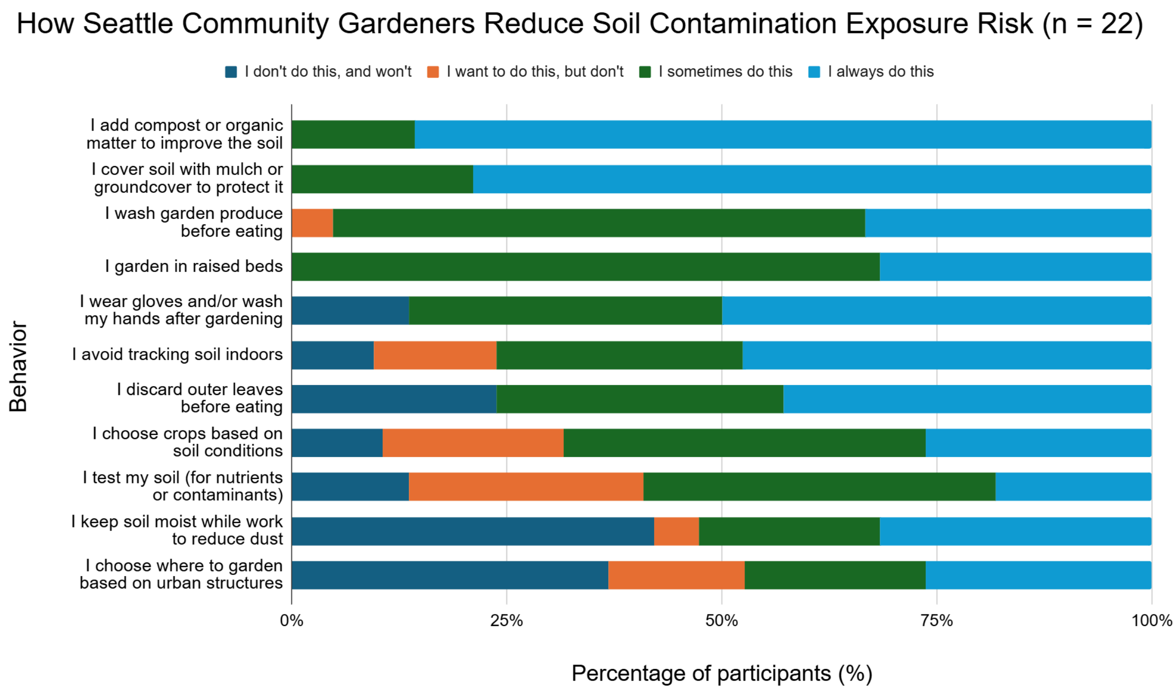

Figure 3.3: Horizontal stacked bar chart of how community gardener focus group participants reduce their soil contamination risks while gardening. These behaviors are slightly adapted from the EPA Interim Guidelines for Safe Gardening Practices released in 2011. Results show that the most consistently reported behaviors were those that aligned with regenerative soil management practices. Individual exposure mitigation behaviors were less uniformly adopted, followed by contamination-specific behaviors.

Table 3.2 and Figure 3.3 illustrate that community gardener engagement with recommended safe gardening behaviors reflected a combination of routine protective practices, partial adoption, and selective use of contamination-management strategies. Overall, the most consistently reported behaviors were those that aligned with everyday garden maintenance and soil care. For example, 85.7% of participants reported that they always add compost or organic matter to improve soil, and 71.4% reported that they always cover soil with mulch, landscaping material, groundcover, or cover crops to protect it. These behaviors suggest that participants often manage contamination risk through general soil amending and regenerative practices rather than through contamination-specific protective behaviors alone.

Behaviors related to personal exposure reduction were also common, though less uniformly adopted. Just over half of participants (52.4%) said they always wear gloves and/or wash their hands after gardening, and 47.6% reported always avoiding tracking soil into their home through shoes, tools, or clothing. Fewer participants reported consistently washing produce thoroughly before eating it (33.3%) or discarding outer leaves of leafy greens (42.9%). These patterns suggest that gardeners were more likely to adopt practices that were familiar, visible, or embedded in everyday garden routines and regenerative soil management than those tied more directly to food exposure pathways.

Other contamination-specific behaviors were reported less consistently. Only 30% of participants said they always garden in raised beds or containers, and 25% reported always choosing crops based on soil conditions. Similarly, 20% said they always test their soil for nutrients or contaminants, and 25% reported choosing where to garden based on nearby roads, railways, or older buildings. These lower frequencies indicate that while participants understood contamination as relevant to spatial conditions and crop decisions, these considerations did not always translate into practice.

Some practices reflected substantial uncertainty or lower uptake. Forty percent of participants reported that they never keep soil moist while working to reduce dust, and 35% said they never choose where to garden based on nearby roads, railways, or older buildings. Fourteen percent of gardeners reported that they never wear gloves or wash their hands after gardening, despite knowing about soil contamination concerns. 23.8% of participants said they never discard outer leaves of leafy greens before consumption. Ultimately, these findings show that participants did not engage uniformly with recommended safe gardening behaviors, and that while some behaviors were less accessible to adopt (e.g. choosing where to garden), other more accessible behaviors were perhaps less familiar or less clearly understood as contamination-related.

In context with earlier themes, these results suggest that community gardeners understand soil contamination through spatial, historical, and institutional lenses, but their management practices are shaped by the limits of available resources, knowledge, infrastructure, and possibly habits. Participants appeared to draw most readily on practices already embedded in gardening culture, while contamination-specific behaviors such as soil testing, site selection, prevention and food preparation were more selectively used.

Qualitative results suggest that safe gardening in contaminated soils is not generally perceived or managed at the individual level; both conversation and current behavior revolve around systemic health protection in UCGs. The most salient safety behaviors for gardeners were related to regenerative soil management: soil amending and covering. Future action for soil contamination mitigation, despite uncertainty, was elicited at the community level, whereas the greatest barriers occurred at the policy level. This conceptual community understanding of soil contamination risk as a larger ecological, community, and governmental responsibility is a significant result of this study.

3.2 Mapping Lead and Arsenic Soil Contamination

To contextualize soil contaminant concentrations in UCGs, results were evaluated relative to background and cleanup thresholds established by MTCA for lead and arsenic (Section 1.1). Consistent with the ASARCO cleanup, MTCA Method A residential cleanup thresholds are used in this research. For lead, the determined local/regional background concentration is 24 ppm, and residential cleanup concentration is 250 ppm. For arsenic, the local/regional background level is 7 ppm and the residential cleanup level is 20 ppm. Throughout this analysis, lead and arsenic concentrations were compared against their respective background concentrations and residential cleanup levels to characterize the extent and distribution of contamination across sampled community garden sites. When sample results are above a background concentration and below the cleanup level the concentration is considered elevated.

Data confidentiality

33 gardens with soil contamination data qualified for spatial GIS analysis, spanning 21 ZIP codes of King County, WA. Qualification meant that more than 2 community gardens were present in the mapped ZIP code, according to the Community Agriculture Map made by KCD in 2025[58] (Figure 3.4). While this strategy protects the confidentiality of results, maps generated from a limited number of sampled gardens

may visually overemphasize the extent of contamination and give the impression of broader contamination patterns than are supported by the underlying point data. If multiple tested gardens were in the same ZIP, results were averaged and the mean result was ranked. A record of the number of gardens tested within each of the 21 ZIP codes can be referred to in Appendix 4. Without garden population or land area data, these averages were not weighted. Thus, descriptive statistics were reported at the ZIP code scale, and the proportion of ZIP codes exceeding regional cleanup standards was calculated using ZIP level values.

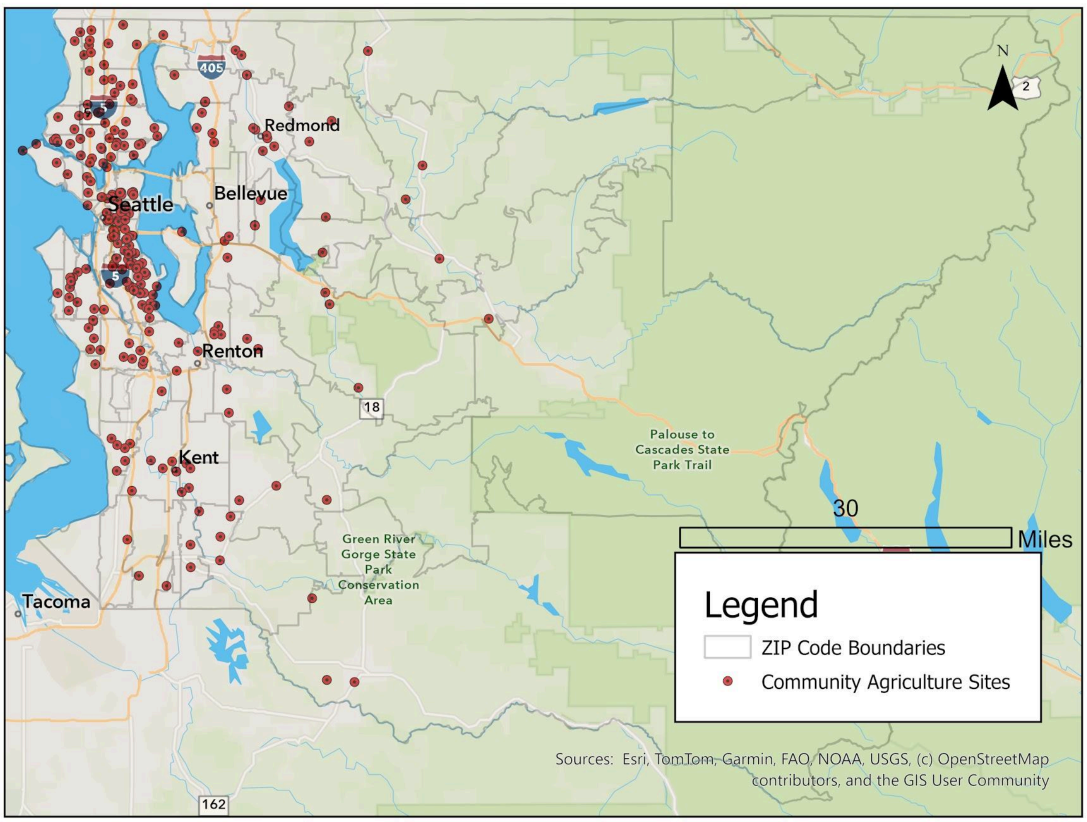

Figure 3.4: Community agriculture sites in King County, WA, as mapped by King Conservation District in 2025[58].

3.2.1 Lead soil contamination in Seattle community gardens

Across the 130 soil lead samples in the study area, concentrations ranged from 3.65 ppm to 1201.37 ppm, with a median of 24.28 ppm. Across the 21 ZIP codes, 7 (33.33%) had elevated mean concentrations of lead, with 2 ZIP codes (9.52%) exceeding the MTCA residential cleanup threshold of 250ppm[11]. It is necessary to reiterate that data is aggregated at the ZIP code level, and that the following maps do not represent soil contamination across the entire ZIP code, but rather, community garden soil samples within ZIP codes.

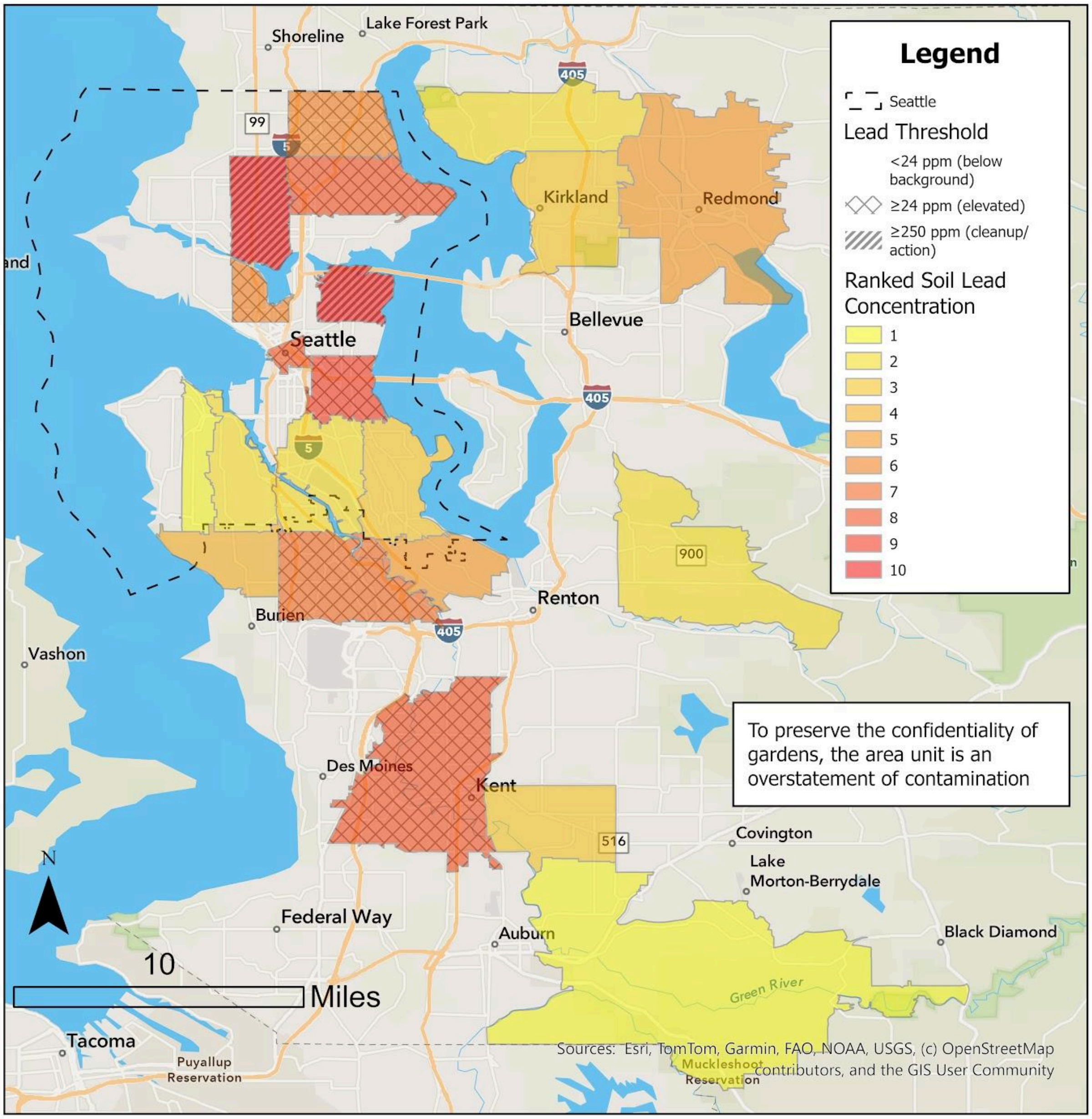

Figure 3.5: Soil lead contamination of community agriculture sites across King County, WA, ranked by ZIP code. Between one (1) and three (3) gardens were sampled per ZIP code. Texture overlays across ZIP codes represent whether the average lead concentrations across gardens in that ZIP are below or elevated compared to background soil lead concentrations (24 ppm) for the region, or in exceedance of the residential cleanup thresholds (>250 ppm).

Figure 3.5 illustrates the spatial distribution of mean lead concentrations across the study area by ZIP code. The map reveals a distinct urban concentration of elevated soil lead levels, with the highest lead concentrations clustered around residential areas of Central and North Seattle. The Lower Duwamish Waterway has low rankings of mean lead concentration. Another elevated cluster appears in South King County. Conversely, those ZIP codes to the east of Lake Washington, with less urban and industrial land-use history, consistently exhibit lower concentrations of lead.

3.2.2 Arsenic soil contamination in Seattle community gardens

Across the 128 soil arsenic samples in the study area, concentrations ranged from 0.08 ppm to 15.45 ppm, with a median of 4.93 ppm. Across the 21 ZIP codes, 2 (9.52%) had elevated mean concentrations of lead, with no ZIP codes exceeding the MTCA residential cleanup level of 20 ppm[11]. It is necessary to reiterate that data is aggregated at the ZIP code level, and that the following maps do not represent soil contamination across the entire ZIP code, but rather, community garden soil samples within ZIP codes.

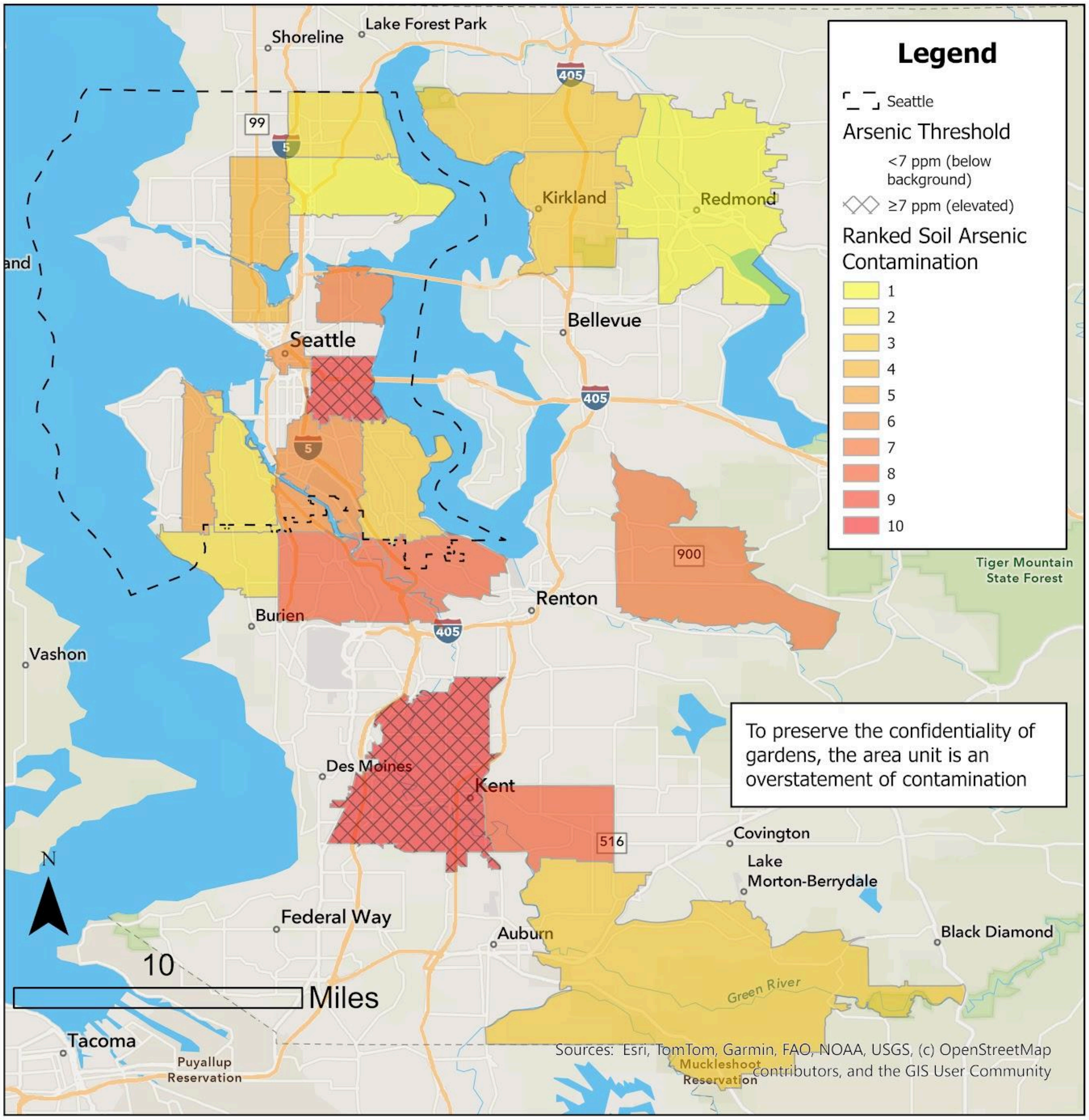

Figure 3.6: Soil arsenic contamination of community agriculture sites across King County, WA, ranked by ZIP code. Between one (1) and three (3) gardens were sampled per ZIP code. Texture overlays across ZIP codes represent whether the average arsenic concentrations across gardens in that ZIP are below or elevated compared to background soil arsenic concentrations (7 ppm) for the region. All ZIP codes were below the residential cleanup threshold for arsenic (>20 ppm)

Figure 3.6 illustrates a different spatial distribution of mean arsenic compared to mean lead concentrations across the study area. Though there are not as many exceedances of thresholds, and most mean arsenic rankings fall below background levels for the region, the map shows clustering of higher arsenic concentrations in the Lower Duwamish Waterway and South King County. A cluster of low ranking ZIP codes is visible in North Seattle and North King County, as well as West Seattle.

3.2.3 Lead and arsenic co-contamination: moderately positive correlation

A Spearman's rank correlation analysis revealed a significant, moderate positive association between the two metals *($\rho = 0.45, p = 0.009$)*. A linear regression model indicated that ranked lead concentrations explain about 70% of the variance in ranked soil arsenic concentrations *($R^2 = 0.74$)* (Figure 3.7), confirming that these metals tend to co-occur across the study area. This moderate relationship suggests that while lead and arsenic share common sources, they are also influenced by different local factors or accumulation rates in urban soils.

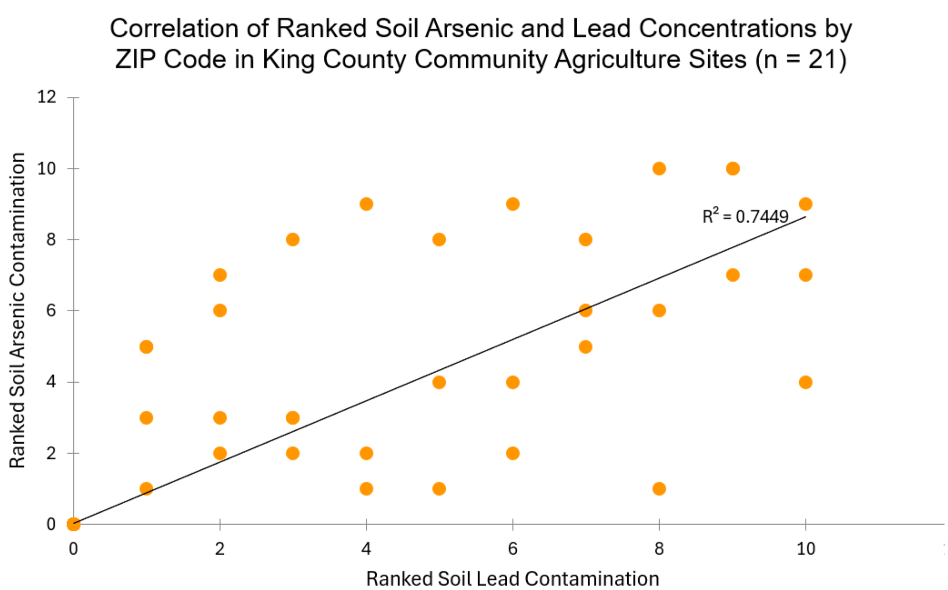

Figure 3.7: Relationship between decile-ranked soil lead and arsenic concentrations in community agriculture sites across King County, Washington. Each point represents a ZIP code containing one or more sampled sites. Lead and arsenic concentrations were aggregated and ranked by decile prior to analysis. The scatter plot demonstrates a moderate positive correlation between lead and arsenic contamination.

3.2.4 Soil lead and arsenic contamination and pollution burden: spatializing results with other Environmental Health Disparities (EHD)

Given the observed variation in lead and arsenic patterns, these metals were analyzed as individual variables rather than as a combined index. This approach allowed for a more granular comparison of each metal against spatialized environmental health indicators, as sourced from the WA EHD Map[34]. Since the EHD ranks are reported by census tract, each garden's ranked lead and arsenic results were joined to the tract level. For mapping visualization, and data confidentiality, census tracts results were joined to the ZIP code they intersected with.

Table 3.3 presents the results of these inferential analyses at the tract level, including Spearman's rank correlation coefficients (ρ) and their associated significance levels (p), which illustrate the spatial relationship between heavy metal burdens and existing environmental disparities in the region. This preserved the data specificity required for correlation analyses. Relationships were considered statistically significant at $p < 0.05$.

Table 3.3: Spearman Correlations Between Community Agriculture Soil Lead and Arsenic Rankings and WA Environmental Health Disparities Map Metrics (Pollution Burden and Environmental Heath Disparity Rankings) by ZIP code in King County, WA ($n = 21$)

Compared Variables (ranked)	Spearman's ρ	p	Interpretation
Lead and Pollution Burden	0.150	0.404	Weak positive
Arsenic and Pollution Burden	0.502	0.002**	Moderate positive
Lead and EHD	-0.162	0.368	Weak negative
Arsenic and EHD	0.325	0.065†	Moderate positive

** $p < 0.01$
† $p < 0.10$

Spearman's rank correlation analysis revealed varied relationships between soil metal concentrations and regional environmental health indicators (Table 3.3). Arsenic levels exhibited the most consistent associations with environmental burdens; specifically, there was a significant, moderately positive correlation between arsenic concentrations and the overall pollution burden *($\rho = 0.50, p = 0.003$)*. The association between arsenic and the cumulative environmental burden was also positive, though it reached only marginal statistical significance $(\rho = 0.32, p = 0.065)$. In contrast, lead concentrations did not show statistically significant associations with either the pollution burden $(\rho = 0.15, p = 0.403)$ or the cumulative burden $(\rho = -0.16, p = 0.368)$. These results suggest that in the study area, soil arsenic concentrations in community gardens align more closely with mapped environmental health disparities than lead concentrations.

Arsenic concentrations showed a significant positive correlation with overall pollution burdens, indicating a spatial alignment between soil arsenic contamination and areas identified as having higher pollution burdens. In contrast, lead concentrations did not show statistically significant associations with these disparities. These results indicate that arsenic and lead exhibit different patterns of spatial distribution relative to existing environmental health disparities.

To isolate geographic areas where soil contamination levels deviate from broader environmental health disparities, residual maps were generated for lead and arsenic (Figure 3.8). Residual values were derived by subtracting the pollution burden rank from the mean soil metal concentration rank. Positive residuals (mapped in green) identify ZIP codes where soil contamination exceeds levels predicted by regional pollution burden rankings, while negative residuals (mapped in purple) signify areas where contamination is lower than predicted. This visualization allows for the identification of potential discrepancy zones, where local soil health issues may be masked or underestimated by regional-scale pollution indices.

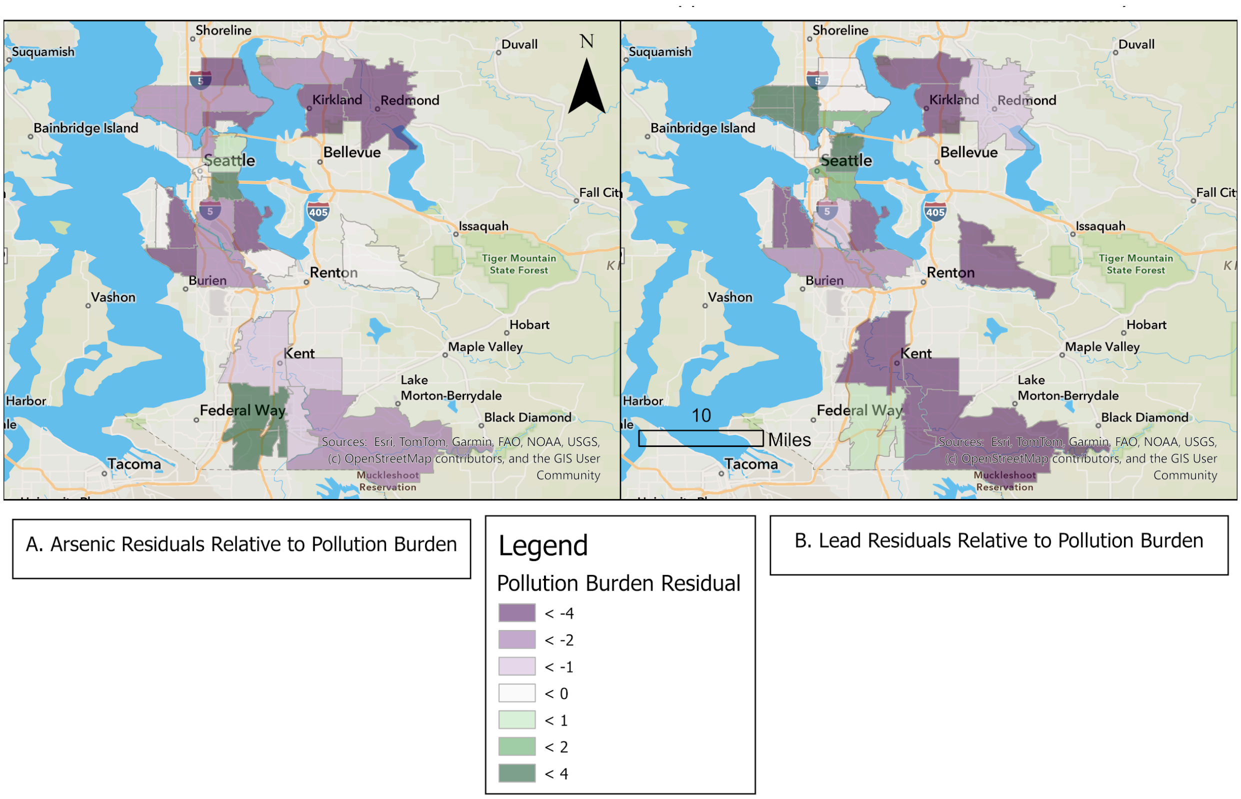

Figure 3.8: Residuals of soil arsenic (A) and lead (B) contamination relative to mapped pollution burden in community agriculture sites of King County, WA. Residuals were calculated by subtracting the WA Environmental Health Disparities Map pollution burden decile from the census-tract contaminant decile ranking. Positive values indicate contamination levels higher than expected relative to pollution burden, while negative values indicate lower-than-expected contamination. Residuals range from −4 to 4, highlighting differences in the spatial relationships between arsenic, lead, and pollution burden.

Arsenic showed the clearest spatial concordance with pollution burden, as seen by the less extreme residuals in Figure 3.8 (less difference with other mapped pollution burdens). Lead did not show significant residual association with pollution burden, suggesting a weaker link to regional burden patterns.

Soil arsenic contamination displayed a moderately positive association ($p = 0.065$) with ranked EHD (Table 3.3), whereas lead did not display a significant association. To further test the inquiry that soil arsenic contamination was spatially associated with other environmental health disparities, a residual map was produced comparing arsenic contamination and EHD rankings (Figure 3.9).

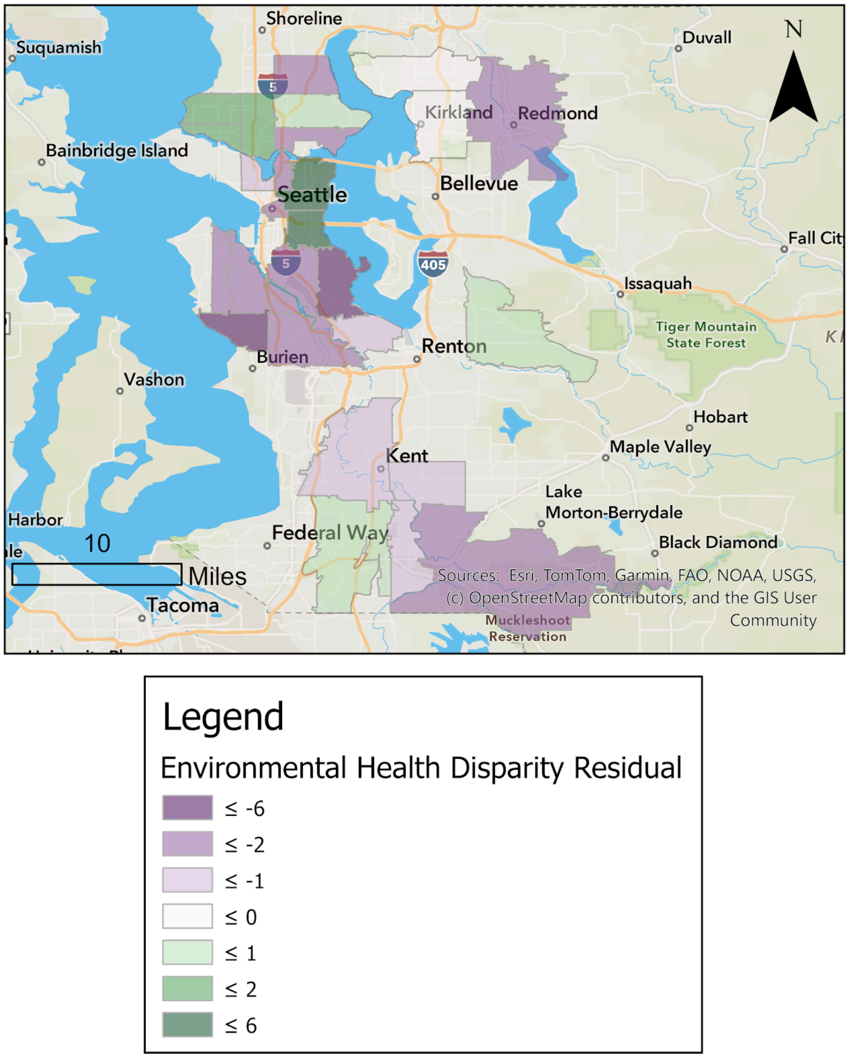

Figure 3.9: Residuals of soil arsenic contamination relative to mapped cumulative environmental health disparities in community agriculture sites of King County, WA. Residuals were calculated by subtracting the WA Environmental Health Disparities Map overall environmental health disparity decile from the census-tract arsenic contaminant decile ranking. Positive values indicate contamination levels higher than expected relative to environmental health disparity ranking, while negative values indicate lower-than-expected contamination. Residuals range from −6 to 6, highlighting differences in the spatial relationships between soil arsenic and currently mapped environmental health disparities.

Arsenic showed a marginal relationship with EHD, weaker but consistent with the pollution burden result. Residual mapping showed that arsenic aligned more closely with tract-level pollution burden and, to a lesser extent, with environmental health disparities. Lead did not show a significant residual relationship with pollution burden, indicating that lead contamination may be driven by more localized factors. Structural environmental inequality may shape arsenic contamination patterns more strongly than lead contamination patterns in community garden soils. However, lead contamination is prevalent in higher concentrations in community gardens and is the contaminant of greater concern in UCGs. These maps suggest that different contaminants follow different spatial pathways within Seattle UCGs.

3.3 Distributive Injustice, Nuance, and Compost in the Contaminated Commons: Integrated Synthesis of Findings

This study utilized a convergent parallel design to examine soil contamination in Seattle community gardens through both spatial and community perspectives. Integration of the quantitative and qualitative findings identified areas of convergence, divergence, and expansion (Table 3.4). Convergence refers to instances where both data strands supported a similar conclusion, strengthening confidence in the interpretation through corroboration across methods. Divergence refers to instances where findings differed between qualitative and quantitative data, suggesting complexity, alternative explanations, or limitations in one or both forms of evidence. Expansion refers to insights generated by one method that extended understanding beyond what could be captured by the other method alone.

The joint display in Table 3.4 highlights where spatialized environmental health data and community discussion informed one another. Convergence was most evident in the framing of soil contamination as a form of distributive environmental injustice, with both spatial patterns and participant perspectives indicating that contamination is unevenly distributed across Seattle and shaped by historical land-use and industrial legacies. Divergence occurred where quantitative analyses identified contaminant-specific spatial patterns that were not reflected in focus group discussions, suggesting that community understandings of contamination may not always align with measured differences between contaminants. Expansion emerged through community discussions of compost as a potential contamination source, an issue that could not be evaluated through quantitative analysis because compost was not tested.

Table 3.4: Joint display of qualitative and quantitative integration points across areas of convergence, divergence, and expansion between community gardener discussions and spatial soil contamination data.

Integration Point	Qualitative Finding	Quantitative Finding	Interpretation
Convergence	3.1.1	3.2.1 3.2.2 3.2.4	3.3.1: Soil contamination is understood and mapped to be unequally spatially distributed across Seattle. Urban land-use and industrial legacy contamination contribute to current trends.
Divergence	-	3.2.3	3.3.2: Lead and arsenic showed different spatial trends and contamination pathways. There is nuance in *how* contaminants are spatially related.
Expansion	3.1.2 3.1.4	-	3.3.3: This study did not test compost. Compost may warrant further investigation as a potential source of contamination, particularly because amending soil with compost was the most salient safety behavior.

These integration points provide a more comprehensive understanding of soil contamination in Seattle community gardens than either data source could provide independently. Interpretations are further discussed in the subsequent subsections.

3.3.1 Soil contamination is distributed unevenly, sometimes correlating with currently mapped pollution burden and environmental health disparity indicators.

The findings of section 3.21 and 3.2.2 (Figures 3.5 and 3.6) illustrate that gardens distributed across King County have varying concentrations of lead and arsenic. These two metals are examples of the range of contaminants that could be affecting these urban and previously industrial soils, which gardeners have a place-based understanding about (Section 3.1.1).

Arsenic specifically correlated strongly with mapped pollution burden *(ρ=0.5)* and marginally with environmental health disparity indicators *(ρ=0.3)* from the WA EHD map. These indicators are based on environmental exposures (e.g. PM 2.5 concentration, ozone concentration), environmental effects (e.g. proximity to superfund sites, water quality), socioeconomic factors (e.g. people of color, population living in poverty), and sensitive populations (e.g. air quality related respiratory disease, death from cardiovascular disease). These arsenic concentrations correlating with these regional patterns of disparity is corroborated by gardener understanding of contamination burdens faced by UCGs.

3.3.2 Lead and arsenic, not "lead-arsenic"; differing spatial patterns

While there was significant correlation between lead and arsenic, after running the analyses in section 3.2.3 it was clear that these two metals have different contamination patterns, explaining why the correlation was moderately positive instead of significantly positive. This spatial pattern difference was not illuminated by discussion with community gardeners. In fact, in conversation, gardeners were not specific about which contaminant, and often grouped both metals together, talking about "lead and arsenic" or "lead-arsenic" contamination. This discrepancy suggests that awareness of these distinct spatial trends is lacking, and therefore shapes expectations, communication, and perception of what the soil contamination risk is for UCGs.

3.3.3 Compost was identified as a reservoir of potential concern and further testing for soil contamination in UCGs.

Section 3.1.2 reported that some community gardeners are not only concerned about historical industrial contamination or ongoing contamination expected through urbanization, but also contamination via provided soil amendments. This concern could not be explored with the quantitative data because compost was not tested for lead and arsenic through the KCD soil contaminant testing program. This concern becomes all the more significant looking at results of section 3.1.4, which show that composting is the most adhered to safety behavior of the gardeners.

3.4 Limitations

This study has several limitations. First, the spatial analysis was subject to the Modifiable Area Unit Problem, which may be particularly relevant for lead results after looking at spatial results. Lead contamination may be more hyperlocal than arsenic, requiring a smaller scale spatial analysis to more accurately capture exposure variability and environmental risk patterns.

Additionally, greater availability and coverage of UCG soil contamination data could strengthen future analyses. Limited sampling density and uneven spatial distribution of contaminant testing may have constrained or biased the ability to fully characterize contamination patterns across UCGs.

This study also did not explore in depth when, why, or under what circumstances participants adopted specific safe gardening behaviors. Thus, uptake of safe gardening behaviors remain descriptive in this study, limiting insights on actions and solutions to improve individual risk mitigation measures.

Finally, FGDs were not audio-recorded. As a result, qualitative analysis relied primarily on participant sticky notes and facilitator field notes, which may have limited the depth and completeness of captured discussion. Some nuance, detail, or conversational context may therefore not have been fully represented in the qualitative findings.

4. Discussion

This study examined soil contamination in Seattle community gardens through a convergent parallel mixed methods design. The integration of spatial analysis of soil lead and arsenic concentrations with community gardener perspectives to achieve a more complete understanding of the intersection between soil contamination and justice. These results positioned UCGs as both sites of unevenly distributed environmental exposure and spaces of collective stewardship within the Seattle urban landscape. Soil sampling confirms that contaminants such as lead and arsenic are present across the study area, while the interpretation of gardeners situate these risks within broader histories of industrialization and urban development. However, the distribution of contamination does not always align neatly across contaminant types or with broader mapped pollution burdens. These points of convergence and divergence between lived experience and spatial contamination patterns underscore the importance of accessible, nuanced, place-based environmental health knowledge in understanding exposure pathways present in UCGs.

The implications of this research hold local and general weight across the academic-community-government nexus. Community gardens function as part of the urban commons, where land, labor, and knowledge are shared across participants. The points of convergence and divergence give stakeholders a substantive grounding in the state of the commons and an outline of what it might look like to move environmental justice initiatives forward.

4.1 Individual awareness-to-action gap in soil contamination risk mitigation

Participants demonstrated universal awareness of soil contamination sources and spatial distribution patterns, reflecting a strong foundation of general environmental health literacy. Gardeners identified industrial legacies and urban land use as key drivers of contamination, and these perceptions were supported by spatial clustering observed in the lead and arsenic maps. In this sense, awareness was not a limiting factor in understanding soil contamination risk.

However, this awareness did not consistently translate into the adoption of individual protective behaviors, such as wearing gloves and washing or removing outer leaves of garden produce. Habitual engagement with recommended safe gardening practices was uneven, with the highest uptake observed among general soil management practices such as composting and mulching. In contrast, behaviors more directly tied to contamination mitigation, such as soil testing, site selection, and PPE practices were less consistently adopted. This pattern suggests that gardeners primarily mitigate risk through practices already embedded in gardening culture, rather than through contamination-specific interventions.

When considered alongside the collective-action framing of solutions expressed in focus groups, these findings suggest that promoting safer gardening practices is not solely a matter of providing information. Rather, it requires understanding the cultural norms, motivations, and structural conditions that influence behavior. Because gardening practices are often shaped by culture, experience, and community expectations and norms, future research should explore how demographic and cultural factors affect risk perception and responses to soil contamination. Differences in resources and organizational capacity may further influence the feasibility of interventions across garden settings (e.g. P-Patches vs. neighborhood gardens). Given these considerations, interventions that are highly visible, familiar, and easily integrated into existing gardening routines may be particularly effective. Normalizing these practices through both physical infrastructure (e.g. sinks and soap with signage that supports handwashing) and community expectations (e.g. all volunteers encouraged to wear provided gloves before their shift) may support risk reduction in this interim period while broader structural and policy-level actions are developed and implemented.

4.2 Agency exists at the community level; policy is a barrier to further environmental health literacy and risk mitigation

While individual-level action was variable, participants consistently emphasized community-level stewardship as the primary mechanism for addressing soil contamination. Gardeners described collaborative approaches, including knowledge sharing, informal experimentation, and collective resource mobilization, as essential to managing contaminated soils. These findings position community networks as key sites of agency, where gardeners actively navigate contamination despite limited institutional support.

At the same time, participants identified significant gaps in government programs and policies, particularly related to funding, technical assistance, and accessible soil testing. Rather than calling for increased regulation, gardeners expressed a need for material and infrastructural support. Notably, some of the resources participants requested already exist, suggesting that perceived inadequacies reflect both limitations in current programming and promotions, resulting in limited awareness, accessibility, or communication surrounding available services. For example, participants calling for expanded soil testing were not always aware of the free lead and arsenic testing and infrastructure support offered through KCD. These findings suggest that the challenge is not solely the absence of programs, but also the extent to which programs are visible, trusted, and responsive to community concerns. These insights offer pathways for effective communication and transparency between governmental programs and UCGs.

These dynamics reflect classic challenges in managing the commons, where individual action alone is insufficient to address shared environmental risks[8]. Instead, effective management requires coordinated resources, transparency, and accountability from all levels of community and institution. In this study, the burden of soil contamination management appears to be shifted onto community gardeners, who had to navigate environmental risk and systemic limitations at the community level.

4.3 Spatial nuance of lead and arsenic contamination pathways

Quantitative findings revealed that while lead and arsenic were moderately correlated, they exhibited distinct spatial patterns, partially supporting the hypothesis that lead and arsenic contamination would be positively correlated (partial due to strength of correlation). Lead concentrations were more variable and did not significantly align with broader environmental health disparity indicators, but arsenic showed a significant association with pollution burden and a marginal relationship with cumulative environmental health disparities. This partially supported the hypothesis that both lead and arsenic contamination patterns would correlate with other mapped pollution burdens and environmental health disparities in the region.

Arsenic and lead deposition from the ASARCO Tacoma Smelter occurred at a regional scale, affecting large portions of the Puget Sound region through atmospheric deposition[16]. Resulting soil arsenic contamination aligns with census-tract-level pollution burden and disparity indices, reflecting broad patterns of historical industrial pollution. In contrast, although lead was also emitted by the smelter, it is additionally associated with diffuse, hyperlocal sources such as deteriorating lead-based paint from old housing and and historical leaded gasoline emissions from vehicles, leading to high variability and heterogeneity across short distances[25,59,60]. Consequently, lead contamination may be strongly influenced by site-specific land-use histories that are not captured by aggregated environmental health indicators. This scale mismatch suggests that regional monitoring frameworks may be sufficient for identifying broad arsenic exposure patterns but may overlook localized lead hotspots, underscoring the need for site-specific assessment alongside regional environmental health monitoring.

This divergence was not reflected in participant narratives, where gardeners frequently grouped contaminants together as “lead and arsenic”. While this combined framing may be effective for raising general awareness of soil contamination, it may also obscure important differences in contaminant sources, pathways, spatial distributions, and health risks. Linking to the barrier role of policy and programming discussed in Section 4.2, this pattern may reflect the influence of regional messaging associated with the Tacoma ASARCO Smelter, which has historically linked lead and arsenic as co-occurring contaminants of concern. Because lead and arsenic are among the most frequently monitored and communicated soil contaminants in the Puget Sound region, participants may have internalized them as a single contamination issue rather than two contaminants with distinct environmental behaviors and risk profiles. This finding suggests that communication strategies that emphasize contaminants collectively may increase awareness, but may also limit more nuanced forms of environmental health literacy needed to understand contaminant-specific risks and management approaches in UCGs.

These findings highlight the need for contaminant and pathway-specific approaches to soil assessment and risk communication. While aggregated indicators are useful for broad awareness, they may mask localized variability and reduce the precision of both scientific analysis and community action and response. For example, if air borne pollutants are main drivers of arsenic deposition[61], and closely align with regional pollution burdens, a future inquiry may look into which other soil contaminants follow that pathway. Further testing and future mapping of these soil contaminants is required to gain a better understanding of contamination trends across the region. This may possibly include a zonal aggregation that is smaller than ZIP-level, to control for the Modifiable Area Unit Problem.

4.4 Compost: critical and underexamined source of contamination

One of the most significant points of expansion from the qualitative data was the identification of compost as a potential source of contamination. This concern is particularly important given that amending soil with compost was the most consistently adopted practice among FGD participants, many of whom represented key leadership roles and modeled best practices at their UCGs. Compost amendment is not only a core principle of regenerative gardening and farming, but also a widely promoted strategy for urban soil contamination mitigation. Outreach materials from the EPA, DOE, and KCD recommend incorporating compost into UCG soils to reduce exposure risk by diluting contaminant concentrations, particularly for heavy metals like lead that are of high concern in urban gardening contexts but are not readily bioavailable to plants[62]. This stands true in the context of these study results, which identified lead exceedances above background and cleanup levels in UCGs. The strong institutional and community emphasis on compost amendment warrants further investigation. Given the high uptake of this practice among gardeners, compost itself may represent a potential pathway for contaminant introduction if source materials are not consistently monitored or regulated.

This concern is not without precedent. Previous studies conducted around municipal solid waste contamination arrive at a similar conclusion: safely using municipal solid waste compost must consider the composition process, and possible contaminants like microplastics, heavy metals, and pesticides[14,63].

The possibility of contaminant introduction through compost also raises broader questions and tensions in urban soil health guidance; the same amendment promoted to mitigate contaminant exposure may also serve as a potential pathway for contaminant introduction under certain waste management and sourcing conditions. Because the soil dataset used in this study did not include any compost testing, compost-specific contamination patterns were beyond the scope of this study.

This finding points to a critical gap in current soil contamination outreach materials in this region, which tend to focus on legacy pollution while overlooking contemporary inputs. Ensuring the safety and transparency of compost systems represents a tangible opportunity for intervention, with implications for both exposure reduction and trust in municipal programs. This issue requires proactive municipal inquiry and involvement.

4.5 Implications for soil health and justice in Seattle

These findings suggest that addressing soil contamination in UCGs requires a dual approach: inquire further into individual behavior-focused interventions, while prioritizing increasing community capacity and institutional accountability. While individual actions can reduce exposure, participants consistently identified barriers operating a policy and programmatic levels, indicating that responsibility for safer gardening cannot solely rest with individual gardeners.

At the research level, future studies should examine safety behavior motivations through demographic and cultural lenses to better understand the mechanisms underlying the awareness-to-action gap. While this study provides an initial quantitative assessment of safety practices among garden leaders, it also highlights the need for qualitative inquiry into how language, culture, race, education, and other social determinants influence responses to contamination and safety information. Understanding these dynamics could help community organizations and government partners design risk communication and intervention strategies that are more responsive to and effective for diverse gardening communities. More broadly, such research would deepen understanding of how environmental health literacy translates into practice in UCGs.

At the policy and programmatic level, the findings point to several opportunities for action by community and government partners. Participants frequently identified barriers related to testing and remediation resources; however, they did not call for increased regulation of UCGs. Instead, organizations operating in technical assistance and capacity building roles may be well positioned to support risk mitigation and reduction efforts. In particular, KCD, in partnership with the City of Seattle Department of Neighborhoods and community-based organizations such as S2, could expand outreach regarding soil testing programs, strengthen contamination-related education resources, and improve clarity of pathways for gardens to technical assistance. Given that many Seattle UCGs operate within the P-Patch system, coordination between KCD and the Seattle Department of Neighborhoods may be particularly important for implementing garden-scale interventions and ensuring that contamination concerns are addressed consistently across sites. Next steps at this level include:

- Expand assessment of contaminants relevant to Seattle urban agriculture. A recent study of Seattle UCG produce points to cadmium being a contaminant of concern[64], while emerging urban contaminants such as microplastics remain uncharacterized in these soils[65]. Future efforts should evaluate whether the current emphasis on arsenic reflects its relative contribution to risk compared to other established and emerging contaminants.
- Expand access to free soil contamination testing and outreach programs for community gardeners. Testing programs should include evaluation of compost and improve source labeling to distinguish between soil amendments and native soil.
- Develop contaminant-specific risk communication strategies that distinguish between lead, arsenic, and other emerging contaminants. Communication materials should reflect differences in contaminant sources, exposure pathways, health risks, and recommended mitigation practices.
- Support community-based stewardship through sustained funding, technical assistance, and partnerships between community gardeners, community-based organizations, universities, extension programs, conservation districts, and local governments.

- Explore the viability of proactive municipal support and technical assistance when sample results exceed applicable MTCA cleanup thresholds, particularly through government-funded testing. Current pathways for liability, remediation, and technical assistance in urban community gardens remain unclear, which may discourage participation in testing programs and leave gardeners uncertain about appropriate next steps when elevated or cleanup contaminant concentrations are identified.
- Continue developing publicly accessible spatial visualization tools that provide gardeners with local context for soil contamination patterns. Future analyses should incorporate temporal trends, explore alternative area units of analysis, and compare contamination patterns with other environmental health indicators to identify broader spatial inequities.

At the community level, participants emphasized the importance of collective action and knowledge sharing. Future efforts could focus on sustaining conversations around soil contamination and strengthening networks among garden leaders to facilitate the exchange of practical knowledge and resources. One potential opportunity is the development of citizen science phytoremediation trials across participating gardens. Leveraging the free lead and arsenic testing program through KCD, gardeners - possibly in collaboration with academic and government researchers - could collaboratively evaluate phytoremediation strategies across different crops, seasons, and locations while generating locally relevant evidence. Garden leaders may also consider strengthening partnerships with KCD and S2 to explore the feasibility of plant tissue sampling, expanded contaminant testing panels, or other community-led monitoring initiatives.

This study highlights that urban soil contamination is not fully captured by existing environmental health indicators. While lead and arsenic had positive instances of co-contamination, arsenic aligned with regional patterns of pollution burden, whereas lead did not significantly correlate and expanded beyond established, currently mapped patterns. Furthermore, potential compost contamination pathways and other contaminants of concern were not captured in existing spatial datasets. Additionally, compost-related risks were not reflected in spatial datasets. These findings suggest that urban soils are not adequately represented by current environmental health indicators and warrant more direct assessment within environmental monitoring and environmental justice frameworks. Expanding soil-focused monitoring efforts could improve understanding of contamination exposure pathways and support more equitable allocation of testing, remediation, and educational resources across Seattle community gardens.

4.6 Beyond Seattle, but still in the city: relevance to urban agriculture

Although this study is grounded in Seattle, its findings have broader relevance for urban agriculture in other cities. Community gardens often emerge in response to food access inequities and function as spaces of resilience and collective care [6]. However, they are frequently situated on land with complex environmental histories[10].

This research demonstrates that soil contamination and exposure in these spaces is socially structured. Soil health and contamination is a basic indicator of the conditions in which food is grown, and community convenes. Therefore, soil health and contamination are both social determinants of health, shaped by historical land use, contemporary infrastructure, and community-led management. It can be easy to feel helpless in the face of this environmental justice paradox, which is why members across the academic-community-government nexus must be seated at the table and mobilize their resources to comprehensively approach soil safety, integrating scientific assessment with community knowledge and priorities.

5. Conclusion

This study examined soil contamination in Seattle UCGs through a convergent parallel mixed methods approach, integrating spatial analysis of lead and arsenic concentrations with community gardener perspectives. The findings demonstrate that UCGs occupy an environmental justice paradox: they are spaces that promote food access, stewardship, wellbeing, and community resilience, while also growing on soil shaped by legacy and ongoing threats of contamination. Gardeners demonstrated strong awareness of contamination sources. While this awareness did not always translate to consistent individual protective behaviors, gardeners primarily navigated contamination collectively through community knowledge sharing and coordinated efforts. At the community level, UCGs face real barriers related to testing access, institutional transparency and support, and uncertainty around contamination pathways.

This research further highlights that urban soil contamination is spatially and socially complex, and not fully captured through currently mapped environmental health indicators. Lead and arsenic displayed slightly distinct spatial patterns, suggesting that contamination pathways operate on different geographic scales and require contaminant-specific assessment and communications strategies. Additionally, the identification of compost as a potential contaminant source points to important gaps in current outreach and monitoring frameworks, and the need for more research. Soil contamination is an environmental and human health justice issue, particularly at community food production sites. The findings suggest that communities are already prepared to organize, steward, and mobilize their labor toward healthier and more just community gardens, but require greater institutional support, transparency, and shared accountability to do so sustainably.

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Appendix 1- Focus Group Discussion Guide

Questions

Goal I: Surface participants' existing ideas, knowledge, and questions about soil contamination and health.

Facilitator Notes: During the quiet time, you can set up a large poster board split into two columns labelled "What we know" and "What we wonder". Groups do not need to answer questions brought up in this activity, though participants may have answers to share.

- What we know/What we wonder (10 minutes)
  - 3-4 minutes: Sticky Note Activity
    - *Take your sticky note pad and write one thing you've heard or think might be true about soil health or contamination in Seattle urban gardens/farms.*
    - *On another note, write one thing you wonder or are curious about regarding soil health or contamination in Seattle urban gardens/farms.*
    - *If you're not sure, think about where you first learned about soil and how confident you feel in that information.*
  - 5-7 minutes: Poster Activity
    - Post on poster, participants explain their knowledge (probes).
    - Participants pose their questions, we discuss (probes).

Facilitator probes:

Know

- Can you tell us more about where you heard that/how you know?
- What makes you confident or unsure about that information?
- Do others have similar or different understandings?

Wonder

- What/who are reliable sources of information about soil contamination that you trust?
- What do others know or wonder about this question?

Facilitator transition:

Now that we've shared what we know and wonder, let's talk about what we actually do when we garden.

Goal II: Explore gardening behaviors and self-efficacy across participants.

Facilitator Notes: Instruct participants to group in 2-3 people. Pass out Likert Scale Quadrants to each group. Instruct participants to open their envelopes labels with their Participant ID.

These envelopes contain a personal set of 13 gardening behavior cards. The guiding question is: What kinds of things do you pay attention to while gardening in your community garden? Do any of those relate to health and safety?

Within your group, please discuss each card and how often you do that activity. Share why, if the behavior is something particularly notable to you, and feel free to ask each other questions. The quadrant *sheet I've set before you has 4 categories: I always do this, I sometimes do this, I want to do this but don't, and I don't plan to/won't do this. While discussing each card, place it in the quadrant that best fits your practice. There are no right or wrong answers, this is all about what you actually do day-to-day in the field.*

If you have notes or caveats about your card placement, feel free to write them on the front or back of that card. For example, only doing an activity in the summer, during harvest, or if there are kids present. Also, please write other gardening behaviors if you get time on the blank cards at the end of your set. You will have about 10 minutes to discuss with each other, before we share-out.

Give a 5- and 1-minute reminder to wrap up discussion. As they are wrapping up, gather all cards in a quadrant across small groups into the respectively labeled envelope. E.g. "Raven - I always do this" will contain all IDed cards placed in that quadrant across the 2-3 small groups. There will be 4 envelopes. You can do this during the 5-minute debrief/prompting/probing, as no specific notes have to be taken besides emergent themes or observations that stand out to you.

- What kinds of things do you pay attention to while gardening in your community garden? Do any of those relate to health and safety?
  (15 minutes: 10 minutes to sort cards & discuss with buddy; 5 minutes to debrief)
    - Buddy up and sort these cards with behaviors/activities with a partner into - I always do this, I sometimes do this, I want to do this, I won't do this
    - Don't have to agree, feel free to place cards in separate quadrants, and add practices that aren't provided
    - Write what you honestly, actually do in the field

Facilitator Prompts:

- What's something your partner does/you hear that you haven't thought of before?
- Are any of these practices shared or supported by your garden or other programs? Do they do anything you haven't listed?

Facilitator transition:

We've talked about different strategies people employ when working with garden soils. Now let's look at what helps or makes it harder to garden the way you'd like.

Goal III: Explore challenges and supports across Seattle urban gardens/farms

We're going to explore challenges to gardening or farming in Seattle, and what supports or solutions would help.

On one sticky note, write a challenge.

On another, write a support or solution (if you have one). It's ok if it's not perfect, we will discuss.

Think about anything that affects how you grow - logistics, land, water, knowledge, soil, space, time, community, policy - anything that matters to you.

You will have 4 minutes to individually write. You can write multiple challenges or solutions, just make sure they're on separate sticky notes. As you wrap up, post your notes on the poster, and maybe start clustering your sticky notes next to others with similar ideas.

For Facilitator: During quiet time, split the poster into "Challenges" and "Ways we overcome".

Take 2 minutes to rapidly cluster challenges and solutions approximately. Think of broad categories. After clustering, move to voting:

Everyone gets two markings/dot stickers.

Place your marking/dot next to the barriers that are most important to you right now. You can put both on one barrier or split them.

- Barriers and Supports : What makes it challenging to garden/farm the way you want here? What helps you overcome those challenges? Who/what structures are responsible for helping you overcome?
  (15 minutes)
  - One sticky note for each, 4 minutes writing down.
  - People vote for what they agree with 2 markings/dot stickers (2 mins).
- Choose the top-voted barrier:
  - Why is this barrier so important to us?
  - If this barrier were removed, what would it take? What would help? Think about what structures influence this, or what would make this easier in the next few seasons.
  - Facilitator notes solution ideas and participant contributions in their notes, likely will be in conversational form with 1-2 main contributions per person speaking. Invite individuals to speak/facilitate group conversation if needed.

Goal IV: Gardener's spatial hypothesis of contamination

Facilitator Notes: *We're interested in what gardeners and urban farmers notice about soil quality in their neighborhood. Think about places, activities, or features in the area in which you grow around Seattle. We'll be collecting all of your ideas to create a map that shows what those who actually steward the soil expect about soil quality compared to those modelling soil conditions. There are no wrong answers, we want to hear your observations and thoughts.*

What kinds of land-uses, activities, or things in the area do you think have affected how clean or healthy the soil is today? For example industrial zones, traffic, older buildings, or vacant lots. Talk about how you think these indicators will affect soil quality.

We'll come up with at least 5 items in order of importance.

For Facilitator: Write their indicators on a poster in list format. Try to write this list in order of importance, likely in the order mentioned in conversation. Mark/tally indicators if they're brought up multiple times. Participants may bring up items they associate with soil health (e.g. redlining), actual sources of contaminants (e.g. lead from housing), or more general indicators. For general indicators, probe where in the city they think it would affect soil and/or what affect this indicator has (positive or negative?). If there is hesitancy/lull, probe for social, historic, or neighborhood patterns. (10 minutes)

Probe: Can you tell us where in the city you have seen/think this would affect the soil?

Probe: Are there any social, historic, or neighborhood patterns you think matter for soil health?

Facilitator transition:

Before we close, let's reflect on what stands out from today's discussion.

Goal V: Group synthesis and reflection

Facilitator prompts (5 minutes)

- What surprised you or stood out to you in today's conversation?

(Allow participants to share 2–3 highlights; facilitator summarizes themes neutrally.)

- Synthesis/Reflection (Segue to wrap-up)
  Name converging or diverging themes…

This completed the set of questions for our research today. I'd like to open things up for any remaining questions, comments, or contributions before we turn to open share-out

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Group Reflection: Each facilitator leads one question. Based on timing we can prioritize what to reflect:
- Every group share a thought/fact or a question your group had. Let us know if your question was answered through conversation or not.
- Every group: Are there any practices that you'd like to try but haven't? What would make that easier?
- Top challenge identified and ways to overcome

Facilitators talk about themes they notice. Open the floor

Wrap up
Thank you again for participating. We will be sharing back key themes from this group in a moment. Your comments will be used to inform programming that S2 does in 2026 and also support Vedika in her MPH research. S2 will be updating the SHJI webpage with events and opportunities to be involved as well as new information as it becomes available.

Vedika's research is anticipated to wrap up in June 2026 and results of this focus group will be shared out through S2. If you do not want your voice or perspectives included please let me know now so that we can make note of that. Because all of the data is anonymous we cannot remove your comments after today.

Thank everyone for participating!

Appendix 2 - A priori codebook

A priori codes

ID	Parent ID	Code	Definition	Notes/Examples
1		SEM Level	Identification of the level of the Socio-Ecological Model at which the issue primarily operates. Code the highest level referenced unless the participant describes interaction across levels.	Double-coding is appropriate when multiple levels are discussed.
2	1	Individual	References to participant's personal knowledge, skills, beliefs, and/or behaviors relating to gardening, soil, or environmental exposure.	"I" Fear of contamination, knowing to wear gloves
3	1	Interpersonal	Interpersonal or social relationships that influence gardening practices/experience, knowledge, risk perceptions, or access to resources.	"Friends", "fellow gardeners" Learning from other gardeners, language barriers
4	1	Organizational	Structures, policies, norms, or resources within a garden program or managing organization that shape participant experiences.	"P-Patch" Garden rules, access to compost, tool libraries
5	1	Community	Broader neighborhood or community-level conditions that influence environmental exposure, access, or gardening experience.	Zoning, historic land-use, redlining
6	1	Policy	Government policy, regulation, programs, or governance processes affecting land use, environmental safety, or garden operations.	Testing programs, land tenure, funding rules
7	1	Built environment	Human-made physical infrastructure that shapes environmental exposure or gardening conditions.	
8	1	Natural environment	Naturally occurring environmental conditions shaping gardening practices.	Climate, weather, conditions typical of this bioregion
9		Content area	Identification of the primary environmental, material, or operational topic being discussed.	
10	9	Soil contamination	Comments referring to pollutants and contaminants within the garden soil, natural soil, and/or amended soil	Heavy metals, plastics, pesticides
11	9	Soil fertility or health	Discussion of biological functions, nutrients, and productivity of the soil.	
12	9	Soil texture	Referring to the texture and physical structure of soil	Sandy, loam, dense, hard
13	9	Soil testing	Formal assessment of soil for contaminants or nutrients	KCD lead and arsenic testing

				Exclude guessing without testing ("Uncertainty")
14	9	Water access	Availability, affordability, reliability, or infrastructure related to irrigation .	Cost of water
15	9	Runoff	Natural hydrography of garden plot	Flooding
16	9	Land access	Ability to obtain space for gardening, regardless of legal ownership	Gardening space, development
17	9	Land tenure	Legal ownership, stability, or long-term security of land for gardening	Garden waitlists, tenant rights
18	9	Dust	Concern over airborne particles and inhalation exposure.	
19	9	Traffic	Pollution exposure related to nearby transportation sources	Cars, planes
20	9	Food	Decision or behaviors related to growing, preparing, or consuming garden produce in response to environmental conditions	Avoiding root crops
21	9	Pests	Organisms that damage crops or create health concerns	Rats, insects, pests, wildlife
22	9	Tools	Physical materials or infrastructure used to support gardening activities	Raised beds, fencing
23	9	Labor	Physical, mental, and emotional capacity to complete a task/perform labor	Aging gardeners
24	9	Time	Constraints related to availability of time	
25	9	Funding	Financial resources affecting participation or safety practices	Grants, salary, desire for more money
26		EHL Level	Identification of how environmentally literate the participant is on a subject	
27	25	Knowledge	Access to information or education exposure	Conflicting information
28	25	Aware	Awareness that environmental exposures and/or sociocultural dynamics that influence health, without necessarily understanding mechanisms	"I know that_"
28 9	25	Understand	Demonstrated comprehension of causal pathways, exposure routes, or health implications	Knowing contamination sources. "Lead can accumulate in root vegetables"
30	25	Skill	Practical ability to implement protective or adaptive gardening behaviors	Can include individual level - mulching - up to community level - communication,

31	25	Self-efficacy	Confidence in their ability to address or reduce risk	Feeling able to protect oneself
32	25	Agency	Collective or individual action taken to address environmental conditions	Advocacy, past or planned action
33	25	Trust	Confidence or skepticism toward institutions or data sources.	Compost source, educational or extension program, friends
34		Orientation	Describe how participants engage or communicate on environmental content	
35	33	Positive orientation	Comments on how gardeners are engaging with the issue positively	
36	33	Negative orientation	Comments on how gardeners are engaging with the issue negatively	
37	33	Barrier	Structural, financial, information, or logistical constraints that limit action	Cost, lack of access. Clear need not indicated
38	33	Support	Existing resources or assets that enable safer and desired participation	Free compost, community events
39	33	Need	Explicitly stated desired resources	May be similar to barriers, but look for an explicitly labeled need: "I/we need _"
40		EJ	References linking environmental conditions to inequity, systemic disadvantage, or disparate exposure.	Redlining, gentrification, racialized exposure
41		Historical	Mentions of past land use or legacy contamination shaping present risk	Smelters, landfills, past construction zones
42		Uncertainty	Expressions of ambiguity, confusion, or incomplete knowledge.	"I don't know if_", "I'm unsure that_". Often double coded with EHL codes

Appendix 3 - Final codebook

ID	Parent ID	Code	Definition	Notes/Examples
1		SEM Level	Identification of the level of the Socio-Ecological Model at which the issue primarily operates. Code the highest level referenced unless the participant describes interaction across levels.	Double-coding is appropriate when multiple levels are discussed.
2	1	Individual	References to participant's personal knowledge, skills, beliefs, and/or behaviors relating to gardening, soil, or environmental exposure. Intrapersonal factors.	"I" Fear of contamination, knowing to wear gloves
3	1	Interpersonal	Interpersonal or social relationships that influence gardening practices/experience, knowledge, risk perceptions, or access to resources.	"Friends", "fellow gardeners" Learning from other gardeners, language barriers
4	1	Community	Formal and informal structures, norms, governance processes, and resource distributions within a defined garden system, neighborhood, or managing organization that shape participant experience and environmental health practices.	"P-Patch". Garden rules, access to compost, norms around "organic" practices.
5	1	Policy/Societal	Formal governmental policies, regulations, funding mechanisms, and governance structures shaping land use, environmental safety, or urban gardening systems.	Testing programs, land tenure policies, zoning laws
6	1	Built environment	Human-made physical infrastructure that shapes environmental exposure or gardening conditions.	Smelters, landfills, past construction zones Zoning, historic land-use, redlining
7	1	Natural environment	Biophysical and ecological conditions not primarily produced by human-built infrastructure that influence gardening practices or exposure pathways.	Climate, weather, conditions typical of this bioregion
8		Content	This category captures the primary environmental, material, infrastructural, or operational topic under discussion. Code the dominant subject matter of the statement.	
9	8	Soil contamination	References to the presence, sources, distribution, or management of pollutants in garden soils, including native or amended soils.	Plastics, pesticides
10	9	Lead	Specifically lead contamination, its sources, health effects, or mitigation strategies.	Child code
11	9	Arsenic	Specifically arsenic contamination, its sources, health	Child code

			effects, or mitigation strategies.	
12	9	Heavy metals	References to cadmium, mercury, or heavy metals discussed more generally without naming lead or arsenic.	Child code
13	9	Compost	This subcode applies when compost is discussed as a potential contamination source or vector.	Child code. Concerns around municipal compost quality
14	8	Mitigation	Descriptions or questions about actionable strategies to reduce exposure	Raised beds, questions about how one can protect themselves from soil contamination, safety
15	8	Soil fertility or health	Discussion of biological functions, nutrients, and productivity of the soil.	
16	8	Soil testing	Formal assessment of soil for contaminants or nutrients conducted by institutions, agencies, or testing programs.	KCD lead and arsenic testing Exclude guessing without testing ("Uncertainty")
~~17~~	~~8~~	Water access	Comments about water access or contamination pathways via water.	Cost of water, irrigation, hydrography
18	8	Land tenure	Legal ownership, stability, or long-term security of land for gardening	Garden waitlists, tenant rights
19	8	Traffic	Pollution exposure related to nearby transportation sources	Cars, planes
20	8	Food	Decision or behaviors related to growing, preparing, or consuming garden produce in response to environmental conditions	Avoiding root crops
21	8	Pests	Organisms that damage crops or create health concerns	Rats, insects, pests, wildlife
22	8	Tools	Physical materials or infrastructure used to support gardening activities	Raised beds, fencing, irrigation systems, signage, PPE
23	8	Labor	Physical, cognitive, and emotional capacity required to engage in gardening activities.	Aging gardeners
24	8	Time	Constraints related to availability of time	
25	8	Funding	Financial resources affecting participation or safety practices	Grants, salary, desire for more money
26		EHL Level	Identification of how environmentally literate the participant is on a subject	
27	26	Knowledg e	Access to information or education exposure	Conflicting information
28	26	Aware	Awareness that environmental exposures and/or	"I know that_"

			sociocultural dynamics that influence health, without necessarily understanding mechanisms	
29	26	Understan d	Demonstrated comprehension of causal pathways, exposure routes, or health implications	Knowing contamination sources. “Lead can accumulate in root vegetables”
30	26	Skill	Practical ability to implement protective or adaptive gardening behaviors	Can include individual level - mulching - up to community level - communication,
31	26	Self-effica cy	Confidence in their ability to address or reduce risk	Feeling able to protect oneself
32	26	Agency	Collective or individual action taken to address environmental conditions	Advocacy, past or planned action
33	26	Trust	Confidence or skepticism toward institutions or data sources.	Compost source, educational or extension program, friends
34	26	Uncertaint y	Expressions of ambiguity, confusion, or incomplete knowledge.	“I don’t know if_”, “I’m unsure that_”.
35		Orientation	Describe how participants engage or communicate on environmental content	
36	35	Barrier	Structural, financial, resource, information, or logistical constraints that limit action.	Cost, lack of access. “I/we need_”
37	35	Support	Existing resources or assets that enable safer and desired participation	Free compost, community events
38	35	Idea	Future support that would help overcome a barrier, challenge, or build on an existing support.	
39	35	Risk perception	How risky participants judge a situation to be, including explanation for that perception	“I don’t see it as a big problem” “How big of a problem is this?”
40	35	Equity/incl usivity	Mentions of unequal access, race/class impacts, language barriers, or culturally specific gardening practices.	
41	35	Emotions	Emotions motivating or inhibiting action	Fear, anger, resignation, pride, “I’m worried that_”
42		Historical	Comments referring to historical acts affecting current conditions or exposures.	Redlining, zoning, smelter plume.
43	42	Tacoma smelter	Comments referring to the Tacoma ASARCO smelter plume as a source of contamination affecting current conditions or exposure.	

Appendix 4 - Quantitative Data Overview Table

Table A4: Number of Community Agriculture Sites Tested for Soil Lead and Arsenic by ZIP Code in King County, WA ($n = 21$)

ZIP Code	Number of Gardens Tested
98030	2
98032	3
98033	1
98034	1
98052	1
98059	1
98092	1
98103	1
98104	1
98106	2
98108	3
98109	3
98112	1
98115	3
98118	2
98126	1
98144	2
98146	1
98168	1
98178	1