A MIXED METHOD APPROACH TO CHARACTERIZE AND INFORM COMMUNITY GARDENS

A Dissertation

by

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ABSTRACT

Background: Community gardens provide an opportunity to strengthen local food systems, promote sustainability in the food supply chain, and compensate for inequitable access to retail outlets of fresh produce. However, urban environments present a number of unique challenges and potential risks that should be considered when planning and developing local agricultural production operations. Therefore, research is needed to characterize existing community gardens in urban areas to inform the development of effective, sustainable, and suitable risk mitigation strategies.

Methods: A mixed methods approach was used to characterize existing community gardens in Houston, Texas. First, ground and garden bed soils collected from community garden sites in Houston, Texas were screened for trace and heavy metals using X-ray fluorescence spectrometry to determine whether soilborne metal concentrations were within acceptable ranges, as defined by available federal regulatory standards. Next, a geographic information system-mediated weighted overlay analysis was performed to investigate the suitability of existing community garden sites based on physical site characteristics, risk factors, and need for improved food access. Finally, a survey of Houston, Texas community gardeners was conducted to better understand their risk-based knowledge and perceptions, current gardening practices, and willingness to implement risk mitigation measures.

Results: Existing community garden sites had moderate site suitability scores for urban agricultural development overall with low suitability scores for impervious surface and soil quality. Ground and garden bed soil collected from community gardens located in Houston, Texas were found to have excess concentrations of arsenic compared to federal health screening limits. Community gardeners had few concerns with regard to risk, favored the location, quality of resources, and social atmosphere of their respective gardens, and were willing to use diverse strategies to reduce potential hazards related to garden soil contamination.

Discussion: The information provided here provides insight into community gardening in Houston, Texas. Opportunities for outreach and engagement related to potential risks associated with urban gardening were identified. This growing community serves an essential function in expanding access to healthy food items and could benefit from university partnerships that facilitate access to soil testing and remediation strategies.

CONTRIBUTORS AND FUNDING SOURCES

Contributors

This work was supervised by a dissertation committee consisting of Dr. Jennifer A. Horney of the Program in Epidemiology of the University of Delaware and, at Texas A&M University, Dr. Galen D. Newman of the Department of Landscape Architecture and Urban Planning, Dr. Thomas J. McDonald of the Department of Environmental and Occupational Health, and Dr. Xiahui Xu of the Department of Epidemiology and Biostatistics.

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NOMENCLATURE

ATSDR	Agency for Toxic Substances and Disease Registry
CDC	U.S. Centers for Disease Control and Prevention
EPA	U.S. Environmental Protection Agency
FEMA	Federal Emergency Management Agency
GIS	Geographic Information System
IARC	International Agency for Research on Cancer
IOM	Intitute of Medicine
mg/kg	Miligrams per kilogram
NRCS	Natural Resources Conservation Service
ppm	Parts per million
TCEQ	Texas Commission on Environmental Quality
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
WHO	World Health Organization

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CHAPTER I

INTRODUCTION

Overview of Community Gardening

The U.S. Department of Agriculture's (USDA) Economic Research Service (ERS) estimates that 37.2 million people living in 14.3 million households lack sufficient resources to acquire with certainty enough food for all of their members (USDA ERS, 2018). Relative to the national rate of food insecure households (11.1%), food insecurity disproportionately affects socially vulnerable populations, including households with children, minority households, and those living in poverty (USDA ERS, 2018). Local food systems have emerged as an important strategy for addressing the complex problem of food insecurity.

Community-level agricultural production has garnered support from government agencies at all levels, as reflected by an increasing number of programs and policies developed to strengthen production in local food systems (Low et al., 2015). For example, at the Federal level, the USDA-Natural Resources Conservation Service (NRCS) provides financial support through the Texas Urban and Rural Conservation Project for local-level agricultural efforts that aim to establish community gardens and high tunnels for food production, rainwater harvesting systems, and pollinator habitats (USDA-NRCS, 2019a). Over $262,000 in funding was distributed through this program to support 32 projects in the 2019 grant cycle (USDA-NRCS, 2019b). A 2011-2012 survey of community garden organizations in the U.S. (N=445) indicated that around half of respondents received support from local governments in the form of access to gardening materials and equipment (50%) and expedited authorization to use public land (47%) (Lawson & Drake, 2013).

According to the National Garden Association, food garden participation among U.S. households increased by approximately 17% from 2008 (36 million households) to 2013 (42 million households) (National Gardening Association, 2014). Interest in gardens in the U.S. is growing, as indicated by a significant increase ($p=0.0001$) in Google searches for the plural and singular forms of the "community garden" and "gardening" from 2004 through 2014 (Andrew et al., 2016). Community gardens have the potential to provide a multitude of benefits, including increasing the production of and access to food, community building, neighborhood revitalization, and socializing, general and garden knowledge-building, and improved nutrition (Lawson & Drake, 2013). However, community garden soils are not routinely tested for potential hazards (Hunter et al., 2019; Ramirez-Andreotta et al., 2019), and gardener knowledge of exposure reduction strategies and interventions is often limited (Wong et al., 2018). Researchers seeking to better understand how best to support local gardeners have reported a need for information and guidance pertaining to soil testing and remediation strategies (Kim et al., 2014; Harms, Presley, Hettiarachchi, & Thien, 2013).

Garden Soil Contamination

The distribution and concentration of soilborne contaminants are affected by environmental conditions, historic land uses, and many other factors (ATSDR, 2007; Smith, Cannon, Woodruff, Solano, Kilburn, & Fey, 2013). Although parks are a frequent setting of community gardens, available evidence suggests that around 10% of community gardens may be located on land previously used as an industrial site (Hunter et al., 2019; Ramirez-Andreotta et al., 2019). A 2017 survey of 395 community garden leaders in Atlanta, GA revealed that 85% of garden sites were located within 9 feet of a roadway or street (Hunter et al., 2019). An assessment of six existing community gardens by researchers from the Duke University Superfund Research Center identified runoff due to impervious surfaces such as transportation infrastructure and parking lots as among the most frequent contaminant sources (Clark, Luukinen, & Kastleman, 2018). In soil samples collected from community gardens in Los Angeles County, CA, metal concentrations including lead, arsenic, and cadmium were associated with proximity to roads (Clarke, Luukinen, & Bain, 2015). Probabilistic predictive exposure modeling by Spielthoff et al. (2016) suggests that ingestion of soil and dust is the dominant exposure route among childhood visitors to community gardens, while the consumption of contaminated produce is the greatest source of lead exposure among adult gardeners. Extrapolation of cumulative exposures from all pathways indicates that around 10% of adult and 40% of child visitors to a New York City garden could exceed the U.S. Food and Drug Administration's respective provisional tolerable total intakes for lead of 75 and 6 μg/day (Spielthoff et al., 2016). This is notable because children are rarely prohibited from entering community garden sites (Hunter et al., 2019).

Ingestion of contaminated crops is a recognized route of exposure to soilborne contaminants among community gardeners, but fewer are aware of the potential for direct soil ingestion during routine gardening activities (Kim et al., 2014). Concern for contaminant uptake in produce grown in community gardens is justified as internalization of contaminants such as arsenic and other hazardous agents from soil has been demonstrated (ATSDR, 2007, 2016; WHO, 2001, Warren et al., 2003; Hettick, Cañas-Carrell, French, & Klein, 2015; Vithanage, Dabrowska, Mukherjee, Sandhi, & Bhattacharya, 2012). Dermal contact with contaminated dust or soil is also a well-known exposure route among community gardeners, while inhalation of particulate-bound contaminants tends to be overlooked (Kim et al., 2014). Inhalation of particulate-bound contaminants such as arsenic may result in mechanical filtering in the nasopharynx region, capture in and cleared from the pulmonary mucosal lining, or deposition in the interior lining of the lungs leading to absorption into the body (Yip & Dart, 2001).

Soil is considered to be among the important sources of population exposure to lead, where it is typically strongly bound to fine organic matter at the superficial depth of 1 to 2 inches (ATSDR, 2007; Mielke & Reagan, 1998). The rate of lead absorption in humans differs by route of exposure, with the greatest uptake occurring in the gastrointestinal tract after ingestion, followed by inhalation, and lastly dermal contact (ATSDR, 2007; Centeno et al., 2002; IARC, 2006). Though naturally present in the environment, the vast majority of lead in soil and dust is attributed to anthropogenic activities with leaded gasoline and paint being the greatest contributing sources, although these uses have been effectively banned in the U.S. since 1976 and 1988, respectively (ATSDR, 2007; IARC, 2006; Mielke et al., 2011). Lead exposure has been associated with a wide range of adverse health effects in humans, including gastrointestinal disturbances, decreased neurological functioning, and heart and kidney disease (IARC, 2006). Susceptibility to the potential neurodevelopmental harms of ingested lead is also greater among young children (ATSDR, 2007; Canfield et al., 2003; Centeno et al., 2002), who are also predisposed to lead consumption from floor dust due to frequent contact with household flooring coupled with excess hand-to-mouth behavior (Maton, Angle, Stanek, Reese, & Kuehnemann, 2000).

The metalloid arsenic is both ubiquitous and may result from both natural (e.g., volcanic eruptions, wildfires, and low-temperature volatilization) and anthropogenic processes and activities (e.g., application of arsenic-containing pesticides in agricultural production, chromated copper arsenate-treated wood, combustion of tobacco and coal, and copper or lead smelting operations) (ATSDR, 2007, 2016; WHO, 2001). Arsenic and inorganic arsenic compounds are classified as carcinogenic to humans (Group 1) by IARC (IARC, 2012). Acute and chronic exposures to certain forms of arsenic, most critically those classified as inorganic arsenicals, have been shown capable of inducing functional impairment and/or catalyzing disease development in nearly all organ systems in the human body (ATSDR, 2007, 2016; WHO, 2001). Dermal absorption contributes a minority of total daily arsenic intake relative to ingestion and inhalation routes of exposure (ATSDR, 2007, 2016; WHO, 2001). The majority of total and inorganic arsenic exposures among U.S. residents are due to the consumption of contaminated foods (Kurzius-Spencer et al., 2014; Xue, Zartarian, Wang, Liu, & Georgopoulos, 2010). Although fish and shellfish constitute the greatest sources of total foodborne arsenic exposures each day (ATSDR, 2007), plant-derived foods are the dominant dietary contributors of arsenic in its highly toxic, inorganic state (ATSDR, 2007, National

Research Council, 2013; Xue et al., 2010). Prenatal exposure to arsenic has been associated with preterm birth, low birthweight (Yang et al., 2003), and elevated risk of stillbirth (Cherry, Shaikh, McDonald, & Chowdhury, 2008). Adverse neurodevelopmental and neurocognitive effects including impaired executive functioning and memory have been associated previously with chronic exposure to low levels of arsenic (O'Bryant, Edwards, Menon, Gong, & Barber, 2011). These effects, coupled with accelerated amyloid accumulation secondary to long-term exposure in animal models (Niño et al., 2018), have led many to posit potential associations between arsenic and Alzheimer's disease, which elicits similar effects in early stages (O'Bryant et al., 2011; Niño et al., 2018; Dani, 2010; Gharibzadeh & Hoseini, 2008).

Chromium is a trace element that is native component of rocks and soils and occurs naturally in fresh plant- and animal-derived foods at concentrations that are usually between <10 and 1,300 ug/kg (ATSDR, 2012). The Institute of Medicine (IOM) recommends a daily intake of 20 to 45 ug of chromium(III) to sustain normal fat, protein, and glucose metabolism (IOM, 2001). However, chromium(VI) compounds are classified by IARC as carcinogenic to humans (Group 1) (IARC, 1990). Although the majority of chromium is excreted from in urine within one week of exposure, fractions may persist in human cells for a number of years (ATSDR, 2012). Irritation of the respiratory tract and respiratory problems have been observed following occupational chromium exposures and repeated exposure to chromium-containing compounds may induce an allergic response (ATSDR, 2012).

Risk Reduction Strategies

Existing research suggests that community gardeners are often unconcerned about potential adverse health effects resulting from exposure to soilborne contaminants (Kim et al., 2014). A 2015 survey of community gardeners (N=93) in St. Louis, MO indicated that 68.8% had no concerns about garden soil contamination and over half (57.8%) had no knowledge of how to decrease exposure to potential soil contaminants (Wong et al., 2018). Recognizing that community garden organizations often struggle to obtain sufficient funds for basic supplies such as soil, water, compost, and other gardening materials (Lawson & Drake, 2013), low-cost risk reduction approaches are needed to achieve widespread use.

As previously reviewed by others (EPA, 2000; Smith et al., 2013), conventional soil remediation strategies geared toward stabilization include excavation and dumping, soil washing, electrokinetics, and vitrification and asphalt capping. Although effective in improving soil conditions within a given area, implementation of these strategies may be limited by their high costs, environmental disruption, and concerns regarding downstream disposal of contaminated soil (ATSDR, 2007, 2016). Soil amendments may be more appropriate interventions to address issues concerning ingestion of arsenic-bearing soils, as well as those resulting from runoff and leaching from contaminated sites (ATSDR, 2007, 2016; Hettick et al., 2015; Paltseva et al., 2018). Novel broad-acting clay-based enterosorbents that have been shown to be effective in binding common garden soil contaminants (e.g., benzo[a]pyrene, aldicarb, aflatoxin B1) (Wang, Hearon, Johnson, & Phillips, 2019; Wang, Hearon, & Phillips, 2019; Zu et al., 2018;

Wang, Maki, Deng, Tian, & Phillips, 2017) and may be useful for the remediation of contaminated soils in community garden settings.

Another approach to remediating soil contamination in community gardens may be phytoaccumulation, which refers to the general uptake and storage of contaminants in plants and encompasses phytoextraction, wherein contaminants are concentrated in the aboveground components and phytostabilization where contaminants are immobilized in (absorption), on (adsorption), or around (precipitation) the roots (EPA, 2000) Phytoremediation technologies leverage plants to degrade, contain, or remove contaminants from soil, sediment, and groundwater (EPA, 2000) and are a sustainable, environmentally-friendly, and cost-effective approach to reducing arsenic and arsenic-containing compounds from soils (ATSDR, 2007, 2016; WHO, 2001; EPA, 2000; Vithanage et al., 2012). The ability of plants to resist the toxic effects and to hyperaccumulate arsenic was first described by Ma et al. (2001), who discovered that *Pteris vittata*, commonly known as the Chinese ladder brake fern, was capable of transporting arsenic in soil through its roots and to its fronds, with a storage capacity of approximately 1,442-7526 mg As/kg. Since this discovery, a number of other plant species have been investigated and shown to be effective in reducing this metalloid and its compounds from soil (EPA, 2000).

Significance

Houston, Texas is a large metropolitan city with a diverse population of over 2,325,500 individuals (U.S. Census Bureau, 2020). From 2010 to 2018, the population living in Houston grew by 11.1%, which compares to a national population growth rate over the same period of only 6.0% (U.S. Census Bureau, 2020). The population living in Houston is rich in diversity, with 44.8% of all people being of Hispanic or Latino ethnicity and a racial distribution of 57.6% White, 22.5% Black or African American, and 6.9% Asian (U.S. Census Bureau, 2020). The poverty rate in Houston, Texas is 20.4%, which is greater than that of both Texas (14.6%) and the United States (11.8%) (U.S. Census Bureau, 2020). In Harris County, Texas, approximately 16.3% of all people and 23.2% of the population under 18 years of age were challenged by food insecurity in 2017 (Houston Health Department, 2019). In addition, approximately 17.4% of census tracts in Houston, Texas are classified by the USDA as being low income with low access to a large grocery store, supermarket, or supercenter within 1-mile of a substantial proportion of residents (USDA, 2017). When defined at distance of 0.5-mile, half of all Houston, Texas census tracts are classified as being low income with low access to food (USDA, 2017).

Development within the City of Houston boundary is not regulated by zoning restrictions (Turner, 2020). As a result, residential properties may be located adjacent to industrial facilities and potential point sources of hazardous releases. Excess exposure to ambient air toxics among Houston's minority residents has been documented (Collins, Gineski, Chakraborty, Montgomery, & Hernandez, 2015; Chakraborty, Collins, Gineski, Montgomery, & Hernandez, 2014). Patterns of environmental exposure-associated diseases and conditions have also been observed in Houston. For example, the Texas Department of State Health Services (DSHS) recently identified census tract-level clusters of cancers affecting the liver, lung and bronchus, esophagus, and larynx in Houston, Texas (Texas DSHS, 2019).

The City of Houston's support for local agricultural initiatives is evidenced by their aptly-named Urban Garden Program, which currently facilitates 11 community gardens located in city parks (Houston Parks and Recreation Department, 2019). However, given Houston's inequitable access to retailers of fresh produce (USDA ERS, 2017), unique lack of zoning (Turner, 2020), disparate hazardous environmental exposures (Collins et al., 2015; Chakraborty, 2015) and adverse health outcomes (Texas DSHS, 2019), it is important that factors affecting agricultural productivity and environmental risk are weighed against societal need during all phases of community garden development.

Although gardening for food production has become more prevalent, as indicated by the 17% increase in food garden participation among U.S. households from 2008 to 2013 (National Gardening Association, 2014), this potential solution to food insecurity is challenged by inconsistent knowledge of potential risks from associated exposures (Kim et al., 2014). However, community gardeners tend to underestimate the risk of hazardous exposures related to gardening (Hunter et al., 2019; Kim et al., 2014; Wong et al., 2018), community garden soils are seldom tested for potential hazards on a routine basis (Hunter et al., 2019; Ramirez-Andreotta et al., 2019), and gardener knowledge of exposure reduction strategies and interventions is frequently limited (Wong et al., 2018). Researchers seeking to better understand the needs of local gardeners have reported a need for information and guidance pertaining to soil testing and remediation strategies (Kim et al., 2014; Harms, Presley, Hettiarachchi, & Thien, 2013).

Overview of Study Design

A weighted overlay suitability analysis was conducted using GIS to evaluate the suitability of existing community gardens sites and identify locations in the City of Houston, Texas that are highly suitable for the development of community gardens. The suitability criteria included 1) Land use group; 2) Land cover class; 3) Soil quality; 4) Terrain slope gradient; 5) Impervious surface; 6) Tree canopy coverage; 7) Road density; 8) TRI facility proximity; 9) Flood zone; 10) ToxPi Pollution Hazard Score; and 11) Food access index. The weighted overlay was used to generate suitability scores for existing community garden sites in Houston, Texas.

Soil samples were collected from the grounds and garden beds of existing community garden sites in Houston, Texas. Lyophilized, prepared soil samples were screened using XRF to derive estimated concentrations of trace and heavy metals. Approximate concentrations were compared to existing regulatory standards to determine the need for further testing.

A cross-sectional survey of individuals affiliated with community gardens located in Houston, Texas was conducted in the spring of 2020. The questionnaire instrument included 17 questions within the domains of participant demographics, community garden characteristics, and garden risk knowledge and perceptions. Descriptive statistics were used to better understand the study population.

Specific Aims and Objectives

Aim 1: Characterize existing community garden sites in Houston, Texas and rank the suitability of identified sites based on estimated probability of contamination.

Objective 1.1: Compile a library of spatial data identifying existing community gardens.

Objective 1.2: Apply GIS suitability analysis to characterize, evaluate, and score existing community gardens.

Rationale: Site suitability analysis of existing community garden sites provides a quantitative approach to integrate multidimensional measures with which to inform risk reduction strategies at existing locations and optimize future developments.

Aim 2: Quantify the concentrations of trace and heavy metals in soil samples collected garden beds and grounds of existing community garden sites in Houston, Texas.

Objective 2.1: Collect soil samples from existing community garden sites located in Houston, Texas.

Objective 2.2: Analyze soil samples using x-ray fluorescence to quantify selected heavy and trace metals

Objective 2.3: Compare the results of soil analysis with pertinent federal, state, and local regulatory and recommended contaminant limits

Rationale: Soil screening can facilitate the identification of community garden sites with elevated concentrations of trace and heavy metals, which would thereby indicate a need to implement risk mitigation measures.

Aim 3: Ascertain community gardener knowledge of potential soil-borne chemical hazards and their perceived acceptability of novel soil remediation technologies, including clay-based sorbents.

Objective 3.1: Develop a questionnaire instrument to characterize current community gardening practices and characterize community gardeners and gardens in Houston, Texas.

Objective 3.2: Collect survey responses from community gardeners in Houston, Texas.

Objective 3.3: Interpret survey responses to develop recommendations for soil remediation strategies.

Rationale: Risk mitigation and outreach and engagement activities aimed at promoting healthier urban gardening should be informed by the needs and preferences of the end-users. Thus, baseline information is needed to characterize the knowledge, preferences, and current practices of community gardeners.

CHAPTER II

COMMUNITY GARDEN SITE SUITABILITY ANALYSIS

Introduction

Urban areas are increasingly populous, with 55% of the global population living in an urban area in 2018 and a projected 68% of people expected to live in urban areas by 2050 (United Nations, 2019). In the United States, 82% of residents lived in an urban area in 2018 (United Nations, 2019). According to the Food and Agriculture Organization of the United Nations (2017), an increase of nearly 45% over 2013 food production will be needed to meet worldwide demand by 2050, with global food security expected to become more challenging. Although the availability of affordable foods has been increased by industrialization in the food supply chain, the sustainability of large-scale food production operations and practices remains a significant challenge. For example, a lack of agricultural diversity due to practices such as monocropping render long-term food security vulnerable to plant disease outbreaks (National Academies of Sciences, Engineering, and Medicine. 2019). The availability of suitable groundwater and soil is limited and a likely threat to food production in the United States and worldwide (Rockström et al., 2017). Drought, flooding, and other natural disasters present both present and emerging challenges to food production that are expected to become increasingly disruptive (National Academies of Sciences, Engineering, and Medicine, 2019). In response to these challenges and others, local food production has garnered increasing attention as a potentially more sustainable approach to strengthening local food supply chains, including those located in urban areas.

Government agencies at all levels have supported community-level agricultural production in Texas. The U.S. Department of Agriculture's Natural Resources Conservation Service (USDA-NRCS) provides financial support through the Texas Urban and Rural Conservation Project supplied over $262,000 to agricultural initiatives including community gardens in 2019 (USDA-NRCS, 2019a). Local governments have initiated programs to support community garden development such as the City of Houston's Urban Garden Program. This growing program currently has 11 community gardens located in city parks (Houston Parks and Recreation Department, 2019).

City planners must attenuate the needs of growing populations with a finite supply of land and physical resources while preparing for future threats and challenges associated with climate change (Kim & Newman, 2019). The distribution and concentration of soilborne contaminants are affected by environmental conditions, historic land uses, and many other factors (Agency for Toxic Substances and Disease Registry [ATSDR], 2007; 2016; Smith et al., 2013). Community garden affiliates have previously identified heavy metal contamination of soils as a primary hazard related to gardening, followed by pesticides and other organic chemicals (Hunter et al., 2019; Kim et al., 2014; Wong et al., 2018). However, irregular garden soil testing (Hunter et al., 2019; Ramirez-Andreotta et al., 2019) is problematic, especially for environmentally-stable contaminants like heavy metals, which tend to persist and accumulate in soil (ATSDR, 2007; 2016).

Geospatial analysis has been applied to inform land use planning, including urban agriculture siting. Balmer et al. (2005) conducted a suitability analysis to identify publicly-owned vacant land in Portland, Oregon that could be utilized for urban agriculture. In Seattle, Washington, Horst (2008) inventoried public lands, school grounds, and parks that would be appropriate for conversion into community gardens. Mendes, Balmer, Kaethler, & Rhoads (2008) leveraged suitability modeling to inform planning for urban agriculture-related sustainability initiatives in Vancouver, British Columbia. A similar approach has also been applied to inventory vacant and underutilized land that was both publicly-owned and suitable for agricultural production in Oakland, California (McClintock, Cooper, & Khandeshi, 2013). Eanes and Ventura (2015) identified 1,065 acres of vacant land parcels in Madison, Wisconsin, accounting for approximately 1.3% of the total land area, with potential to be converted into community gardens. Rogers and Hiner (2016) developed spatial models to optimize urban agriculture siting as green infrastructure in Austin, Texas. In Boston, Massachusetts, Saha and Eckelman (2017) found 7.4% of the city's land base to be suitable for gardening. Mack, Tong, and Credit (2017) evaluated the socioeconomic, land use, and demographic characteristics of existing garden locations in Maricopa County, Arizona and developed a spatial optimization model to guide need-based garden siting. However, expanding access to food is seldom included as a criterion in GIS-based suitability modeling for urban agriculture.

Community gardens may have additional benefits for urban planning and landscape beyond expanding access to food. For example, Gittleman, Farmer, Kremer, and McPhearson (2017) observed community gardens in New York City benefited stormwater mitigation by providing pervious surface for drainage and estimated that 12 million gallons of stormwater was sequestered by raised garden beds amended with compost. In urban areas, however, flooding of community garden sites may also introduce mobilized contaminants from other sources into the soil and growing produce. In Houston, Texas, sea level rise is expected to expand floodplain boundaries in both existing and projected urban areas in Houston, Texas (Kim & Newman, 2019). This is especially challenging in highly urbanized and densely populated areas, where available land parcels are often small and non-uniformly shaped, which makes site selection for agricultural production complex. The City of Houston's Urban Garden Program has supported the development of 11 community gardens located in city parks (Houston Parks and Recreation Department, 2019). However, parks in Houston, and in other cities, also serve to mitigate stormwater as designated areas of pervious surface. For example, as a result of widespread flooding due to Hurricane Harvey, 121 of 349 parks in Harris County, Texas were flooded, of which almost 85% shared a sub-watershed with a petroleum storage tank, municipal solid waste, or superfund site (Karaye, Stone, Casillas, Newman & Horney., 2019). Thus, it is imperative that flood risk be considered in tandem with land use when planning for urban agricultural development.

Soil contamination is affected by a multitude of factors, including historic land usage, physical site attributes, and climatological patterns (ATSDR, 2007; 2016; Smith et al., 2013). Hunter et al. (2019) and Ramirez-Andreotta et al. (2019) similarly observed that around 10% of community gardens sites in their respective studies had previously been used for industrial land uses. Heavy metals are typically the most common soil contaminants of concern identified by community gardeners and garden leaders followed by pesticides and other organic chemicals (Hunter et al., 2019; Kim et al., 2014; Wong et al., 2018). Although some environmental contaminants are readily degraded in the environment by physical, chemical, and/or microbial agents, heavy metals such as arsenic and lead are not easily metabolized or altered and thus tend to persist and accumulate in concentration once introduced (ATSDR, 2007; 2016). Thus, site and proximate land usage are important factors in evaluating the risk of community garden contamination.

From an operational perspective, access to roads is important for transporting gardening supplies and materials (Pramanik, 2016). However, due to deposition from vehicular emissions, soils adjacent to major roadways with high traffic volume tend to have the greatest levels of metal contamination (Mielke, Laidlaw, & Gonzales, 2011). Proximity to roads was observed to be associated with elevated concentrations of arsenic, cadmium, and lead in soil samples collected from community gardens in Los Angeles County, CA (Clarke, Jenerette, & Bain, 2015). Proximity to pre-1978 buildings and runoff from roads, parking lots, and other impervious surfaces have previously been identified as important contributors to contamination of community garden soils (Clark, Luukinen, & Kastleman, 2018). Leaders of Atlanta, GA community gardens were interviewed in 2017, and 85% (N=395) indicated having a garden site within 9 feet of a roadway or street, near pre-1978 housing (13.4%, 63) or of unknown proximity to these types of potential contamination sources (37.5%) (Hunter et al., 2019). Although ground soil located near transportation infrastructure has a higher risk of heavy metal contamination, proximity to roads and bus stops is typically incorporated in land use suitability models as a favorable attribute as it facilitates the transport of human and physical resources necessary for operational sustainability (Eanes & Ventura, 2015).

There are also a number of site-specific factors that are frequently included in urban agricultural land use suitability models as they can affect the operational viability and sustainability of an urban agricultural operations. For example, Richardson and Moskal (2015) discovered that potential food crop production in Seattle, Washington was reduced by between 19% and 35% due to tree shading. Prior models have addressed this issue by prioritizing areas with low tree canopy coverage, with ideal maximum coverage rates typically ranging from 0% (Richardson & Moskal, 2015) to 25% (Balmer et al., 2005). Slope is also an important factor because it can serve as an indicator of erosion vulnerability and/or runoff (Yalew, van Griensven, Mul, & van der Zaag, 2016). Prior models have selected acceptable slope percentages for urban agriculture of below 10% (Balmer et al., 2005) and 20% (Eanes & Ventura, 2015). Soil quality is critical for conventional agricultural production (Juhos, Szabó, & Ladányi, 2016) and has been incorporated through the use of the U.S. Department of Agriculture's nationwide inventory of prime farmland (Rogers & Hiner, 2016). Conventional agricultural production also requires pervious surface for planting. Balmer et al. (2005) limited potential sites for small scale agriculture to those with a maximum impervious surface of 15%, while Eanes and Ventura (2015) considered only pervious surface.

The City of Houston, Texas is home to a diverse population of over 2,325,500 people, of whom 44.8% are of Hispanic or Latino ethnicity and 57.6%, 22.5%, and 6.9% are of White, Black or African American, and Asian racial origin, respectively (U.S. Census Bureau, 2020). Houston's population grew by 11.1% between 2010 and 2018, a rate that is nearly double that of the national rate (6.0%) but lower than that of Texas (14.1%) over the same period (U.S. Census Bureau, 2020). The poverty rate among Houston residents is higher than the rates of poverty at state and national levels (14.6% and 11.8%, respectively) (U.S. Census Bureau, 2020). According to the U.S. Department of Agriculture's Food Research Atlas (2017), 17.4% of census tracts in Houston, Texas are low income and have a substantial population (33% of the total population or at least 500 people) that do not have access to a large grocery store, supermarket, or supercenter within 1 mile of their home. When reduced to a radius of 0.5 mile, 50.1% of all census tracts in Houston are classified as both low income and low food access (USDA, 2017).

The City of Houston is unique from most other major urban metropolitan areas in that development is not subject to comprehensive zoning regulations (Turner, 2020), meaning that residential properties may be located adjacent or in close proximity to potential point sources of pollution such as Toxic Release Inventory (TRI) facilities. Collins, Gineski, Chakraborty, Montgomery, and Hernandez (2015) applied GIS to investigate the associations between hazardous air pollutant exposure-associated cancer risk and socioeconomic status in Houston, Texas. Mean cancer risk, which was extrapolated from the U.S. EPA's National Air Toxics Assessment, was observed to be strongly associated with Hispanic or Latino ethnicity and Black or African American race (Collins et al., 2015). Chakraborty, Collins, Gineski, Montgomery, and Hernandez (2014) similarly found that neighborhoods in Houston with relatively higher proportions of Hispanic residents were more likely to have chronic exposure to hazardous ambient air pollutants and acute hazardous chemical releases, and neighborhoods with high percentages of Black or African American residents overall had excess cancer risks due to chronic pollution exposures. Bodenreider, Wright, Barr, Xu, and Wilson (2019) observed that census tracts with high rates of poverty tended to have disproportionately high numbers of TRI facilities, and the frequency of major air pollution sources with a census tract was observed to be associated with both high poverty rate and higher percentage of persons of color. Disparate patterns of diseases and conditions associated with environmental exposures have also been observed in Houston. A recent epidemiologic investigation conducted by the Texas Department of State Health Services (DSHS) involving ten census tracts in northeast Houston confirmed excess rates of liver cancer in six census tracts, lung and bronchus cancers in two census tracts, and cancers of the esophagus and larynx in one census tract each (Texas DSHS, 2019).

In the present study, Geographic Information System (GIS) analysis was used to characterize, compare, and assess the suitability of existing community garden sites located in Houston, Texas. The purpose of the present study was to integrate key physical attributes and indicators of risk with societal need to quantitatively evaluate the suitability of existing community garden sites located in Houston, Texas. Input variables were informed by prior suitability analyses for urban agriculture and selected to represent the physical site characteristics contributing to garden site suitability, the potential risks presented by natural and anthropogenic hazards, and the area-based need for increased food access.

Methods

A weighted suitability analysis was conducted using GIS to evaluate the suitability of existing community gardens sites and identify locations in the City of Houston, Texas that are highly suitable for the development of urban gardens. Suitability criteria were informed by prior GIS models for agricultural production (summarized in Table 1). The garden suitability map was created by overlaying weighted raster layers for eleven variables: 1) Land use group; 2) Land cover class; 3) Soil quality; 4) Terrain slope gradient; 5) Impervious surface; 6) Tree canopy coverage; 7) Road density; 8) TRI facility proximity; 9) Flood zone; 10) ToxPi Pollution Hazard Score; and 11) Food access index.

The final suitability output was generated by overlaying raster maps corresponding with each of the suitability criteria. With the exception of food access index, which was assigned a weight of 10%, each criterion comprised 9% of the cumulative model weight of 100%. Weighted overlay analyses enable the integration of diverse datasets by reclassifying multiple raster layers to a uniform scale of measurement (Mutke, Kier, Braun, Schultz, & Barthlott, 2001). In the present study, each suitability criterion was received in raster format or rasterized and then reclassified to a scale of 1 to 5, corresponding with least and most suitable, respectively.

Table 1. Community garden site suitability criteria

Variable	Rating Scale	Criteria	Dataset / Source	Model Variable Precedent(s)
Site Suitability Criteria				
Land Use Group	1	Industrial / Transportation and utilities	COH Land Use / City of Houston GIS	Balmer et al., 2005; Eanes & Ventura, 2015; Mack et al., 2017; Rogers & Hines, 2016
	2	Commercial / Office		
	3	Agricultural production / Undeveloped		
	4	Public and institutional / Single family residential / Multifamily residential		
	5	Parks and open space		
Land Cover Class	1	Water (open water, perennial ice/snow); Barren (rock/sand/clay); Wetlands (woody wetlands, emergent herbaceous wetlands)	NLCD 2016 Land Cover (CONUS) / U.S. Geological Survey	Balmer et al., 2005; Eanes & Ventura, 2015; Rogers & Hines, 2016
	2	Developed, high intensity		
	3	Planted/cultivated (pasture/hay, cultivated crops); Developed, medium intensity; Forest (deciduous forest, evergreen forest, mixed forest); Shrubland (dwarf shrub, shrub/scrub)		
	4	Developed, low intensity		
	5	Developed, open space; Herbaceous (grasslands/herbaceous, sedge/herbaceous, lichens, moss)		

Table 1 Continued

Variable	Rating Scale	Criteria	Dataset / Source	Model Variable Precedent(s)
Soil Quality	1	Not prime farmland	Soil Survey Geographic Database – Farmland Class / Natural Resources Conservation Service	Rogers & Hines, 2016
	2	Prime farmland if drained		
	3	Farmland of statewide importance		
	5	Prime farmland		
Slope Percent	1	20% or higher	Soil Survey Geographic Database – Slope Gradient Dominant Class / Natural Resources Conservation Service	Balmer et al., 2005; Eanes & Ventura, 2015; Mendes et al. 2008; McClintock et al., 2013
	2	15 to < 20 %		
	3	10 to < 15%		
	4	5 to < 10 %		
	5	< 5%		
Impervious Surface	1	20% or higher	NLCD 2016 Percent Developed Imperviousness (CONUS) / U.S. Geological Survey	Balmer et al., 2005; Eanes & Ventura, 2015; Mendes et al. 2008;
	2	15 to < 20 %		
	3	10 to < 15%		
	4	5 to < 10 %		
	5	< 5%		
Tree Canopy Coverage	1	20% or higher	NLCD 2016 USFS Tree Canopy Cover (CONUS), U.S. Forest Service	Balmer et al., 2005; Mendes et al. 2008; Grewal & Grewal, 2012; Richardson & Moskal, 2015
	2	15 to < 20 %		
	3	10 to < 15%		
	4	5 to < 10 %		
	5	< 5%		

Table 1 Continued

Variable	Rating Scale	Criteria	Dataset / Source	Model Variable Precedent(s)
Risk Suitability Criteria				
Road Density	1	0.00 to < 6.87	ESRI Feature Layer based on 2014 Census Tiger data / ESRI	Balmer et al., 2005
	2	6.87 to < 13.73		
	3	13.73 to < 20.60		
	4	20.60 to < 27.46		
	5	27.46 to 34.33		
TRI Facility Proximity	1	Parcels located < 0.5 miles away from a TRI facility address	Toxic Release Inventory Point Addresses / U.S. Environmental Protection Agency	
	2	Parcels located 0.5 to < 1.0 miles away from a TRI facility address		
	3	Parcels located 1.0 to < 1.5 miles away from a TRI facility address		
	4	Parcels located 1.5 to < 2.0 miles away from a TRI facility address		
	5	Parcels located at least 2.0 miles away from a TRI facility address		
Flood Zone	1	0.2% chance of flood	National Flood Hazard Layer / Federal Emergency Management Agency	Balmer et al., 2005; Eanes & Ventura, 2015;
	2	Reduced flood hazard zone		
	3	0.1% chance of flood		
	5	Not in a flood zone		

Table 1 Continued

Variable	Rating Scale	Criteria	Dataset / Source	Model Variable Precedent(s)
ToxPi Pollution Hazard Score	1	0.8 to 1.0	HGB EnviroScreen ToxPi Pollution Hazard Score / Texas A&M Superfund Research Center	Bhandari, Lewis, Craft, Marvel, Reif, & Chiu, 2020
	2	0.6 to < 0.8		
	3	0.4 to < 0.6		
	4	0.2 to < 0.4		
	5	Less than 0.2		
Need Suitability Criteria				
Food Access Index	1	Not low income and low access	Food Research Atlas / U.S. Department of Agriculture	Mack et al., 2017; Ackerman et al., 2014
	3	Low income and low food access at 1 mile		
	5	Low income and low food access at ½ mile		
Contextual Attributes				
Census Tract Boundaries	Not scored	Shapefile containing the boundaries of census tracts located in the City of Houston	2010 Census Tract Boundaries / U.S. Census Bureau	
Parcel Boundaries	Not scored	Shapefile containing the boundaries of land parcels located in the City of Houston	2019 Land Parcels / Texas Natural Resources Information System	
City of Houston Boundary	Not scored	Shapefile containing the boundary of the City of Houston	City of Houston Boundary / Harris County Appraisal District	
Community Garden Sites	Not scored	Address points for community gardens located in Houston, Texas	Urban Harvest	

Data Sources

Shapefiles containing parcel polygons within the City of Houston were obtained from the Harris County Appraisal District (HCAD) Public Data GIS data file, which was last updated in April 2020 (HCAD, 2020). Land parcel data for Fort Bend, Harris, and Montgomery Counties, Texas, was obtained from the Texas Natural Resources Information System (TNRIS, 2019), and 2010 census tract polygons were obtained from the U.S. Census Bureau (2019). Address points of existing community garden sites in Houston, Texas were obtained from the public membership list of Urban Harvest (2020) and are shown in Figure 1.

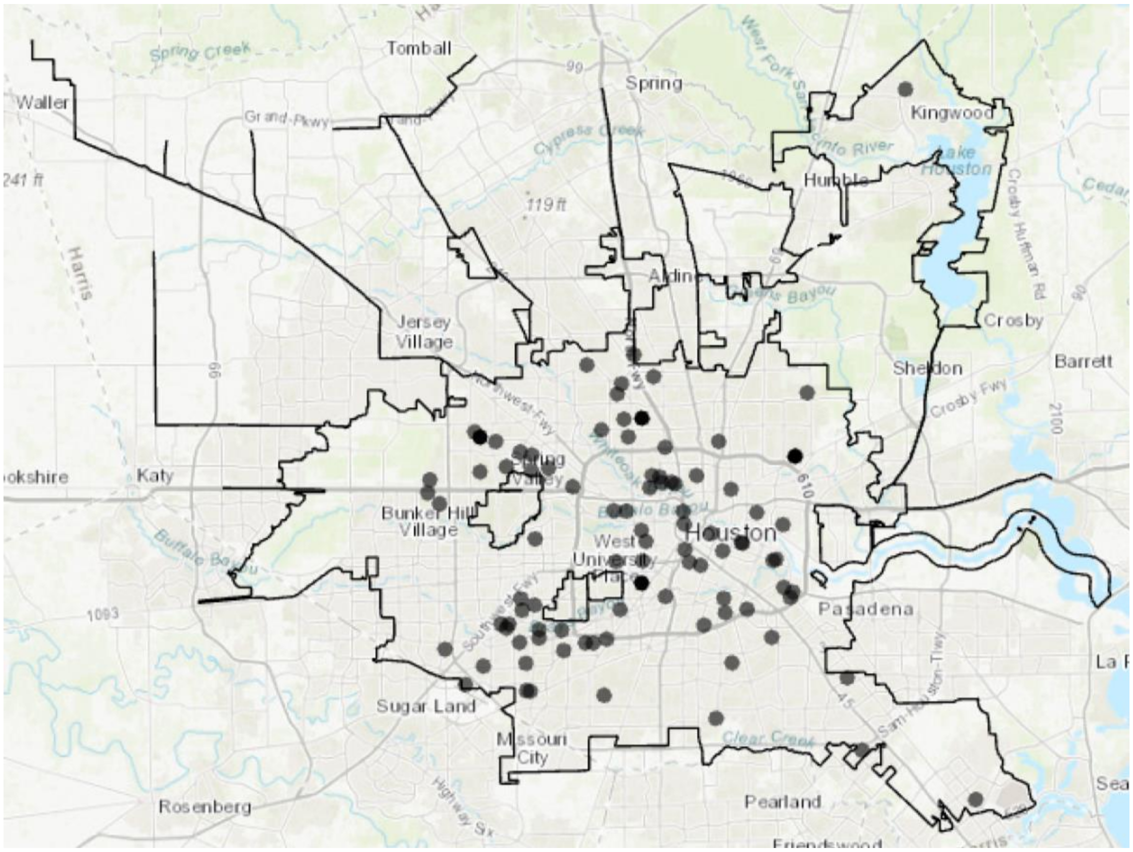

Figure 1. Community garden sites in Houston, TX

Census tracts with low income and low supermarket access were identified from the Food Research Atlas of the U.S. Department of Agriculture (USDA, 2017). The Food Research Atlas classified low income census tracts as those having a poverty rate of 20% or higher or with median family income of 80% or less than of the associated state or metropolitan county levels (USDA, 2017). Census tracts in which 33% of the population or 500 or more individuals reside more than 1.0 mile and 0.5 mile, respectively, from a supercenter, large grocery store, or supermarket were defined as low access (USDA, 2017).

Raster layers from the 2016 National Land Cover Database were obtained for percent developed imperviousness (U.S. Geological Survey, 2019), land cover class (U.S. Geological Survey, 2019), and tree canopy cover (U.S. Forest Service, 2019). Farmland classification, which was applied as an index for soil quality, and terrain slope gradient were supplied by the Natural Resources Conservation Service's Soil Survey Geographic Database (NRCS, 2019). Land use group designations were obtained from the City of Houston Open GIS (City of Houston, 2020). To account for potential contaminants that may be introduced from point- and non-point sources of pollution, address points of Toxic Release Inventory facilities located in Houston, Texas, were obtained from the U.S. Environmental Protection Agency (2020) and the Houston-Galveston Bay (HGB) EnviroScreen tool of the Texas A&M Superfund Research Center was leveraged to derive census-tract level ToxPi Pollution Hazard Scores (Texas A&M Superfund Research Center, 2020; Bhandari et al., 2020). Road density calculated from 2014 Census Tiger shapefiles was obtained from the ESRI Living Atlas feature service (ESRI, 2019).

Data Analysis

ArcGIS Pro 2.5.0 software (Environmental Systems Research Institute, Inc.) was used for data cleaning and analysis. Each shapefile was received in or projected to the GCS_WGS_1984 coordinate system prior to analysis. The spatial dataset representing known garden sites was reviewed to ensure that all garden address points were matched with a land parcel. Once verified, community garden address points were spatially joined with the matching parcel. Weighted overlay was selected for analysis because it enables a quantitative approach to evaluating and comparing the suitability of a specific area based on the relative importance of specific spatial attributes (Mutke et al., 2001). Suitability criteria data obtained in polygon or feature form were clipped to the City of Houston boundary followed by conversion to raster form. Each raster dataset was reclassified to a uniform scale of 1 to 5, with 1 being the least suitable and 5 being the most suitable for gardening. Using the ArcGIS Weighted Overlay tool, which multiplies each raster by a defined weight out of a total model weight of 100% (Marinoni, 2004). The weighted score for each raster is then summed to generate a cumulative suitability score for a given area. In the present model, all suitability criteria were weighted at 9% except for food access index, which was weighted at 10% of the composite model. The defined areas of interest were comprised of community garden address parcels.

Results

The City of Houston is the fourth most populous cities in the United States (U.S. Census Bureau, 2019). Houston is rich in culture, having a more diverse ethnic and racial distribution than the State of Texas or nation (U.S. Census Bureau, 2020). There were 144 garden sites indexed in the Urban Harvest membership listing, of which 91 were unique addresses located within the City of Houston boundary (Figure 1). Of the 91 sites that qualified for inclusion, 62 were classified as school gardens, 12 as neighborhood gardens, 9 as allotment gardens, 7 as donation gardens, and 1 as a market garden.

Site Suitability Analysis

The individual layers that were incorporated in the site suitability analysis are depicted in Figure 2 with enlarged images provided in Appendix 1. The community garden site suitability map for Houston, Texas is shown in Figure 3.

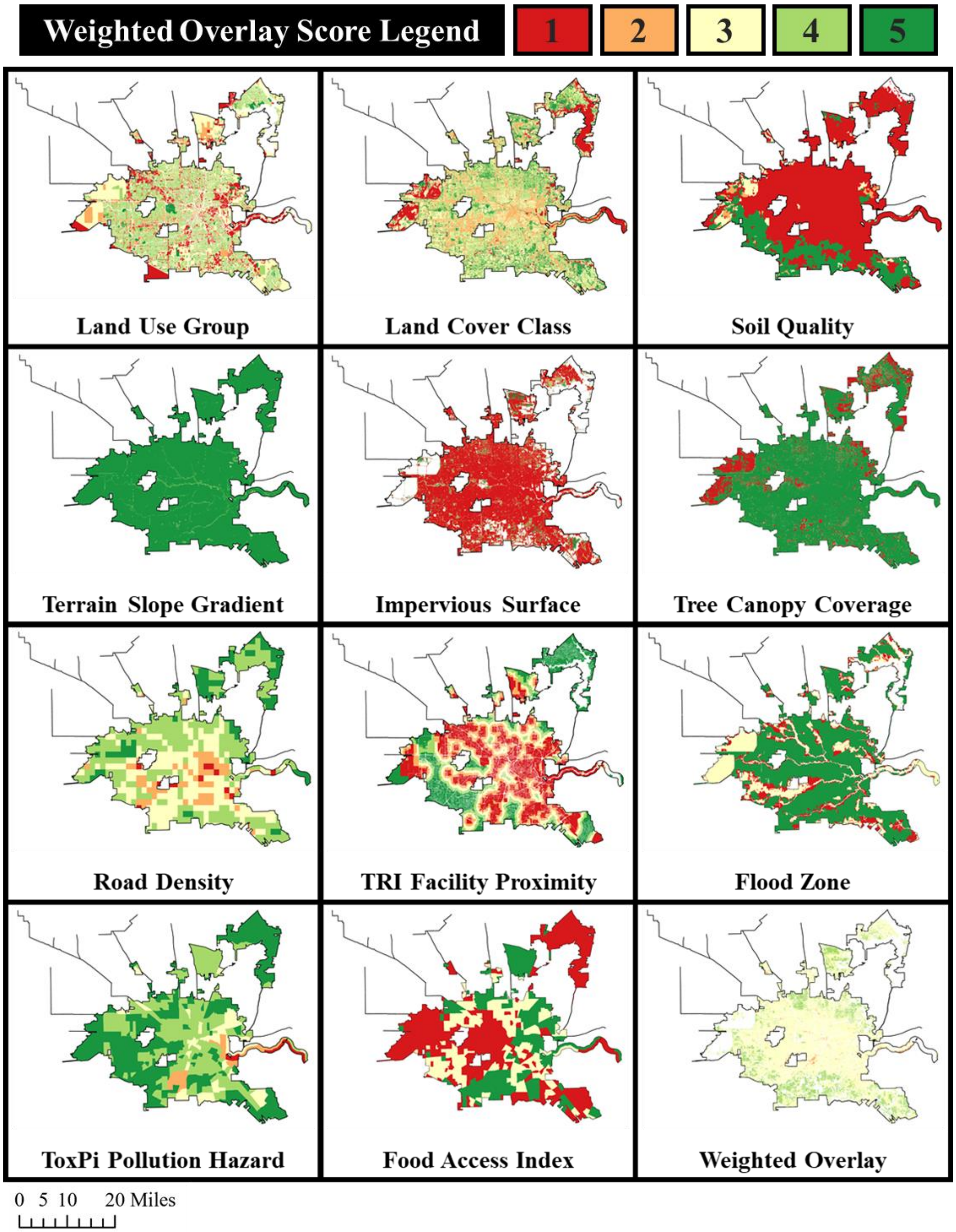

Figure 2. Raster layers used in weighted overlay analysis and suitability score layer product

In total, there were 84 community garden address parcels for which complete spatial data were available. The mean suitability score was 3.15 with a standard deviation of 0.27, corresponding with a moderate suitability score on a scale of 1 (least suitable) to 5 (most suitable). Scores ranged from 3.0 to 4.0, indicating that none of the garden sites evaluated were deemed to be of very low, low, or very high suitability for agricultural production. Over three-quarters (76.2%) of all sites received a score of between 3.0 to 3.2, representing the lowest suitability tier of all gardens scored. The highest suitability tier included 6.0% of all gardens that scored between 3.8 to 4.0.

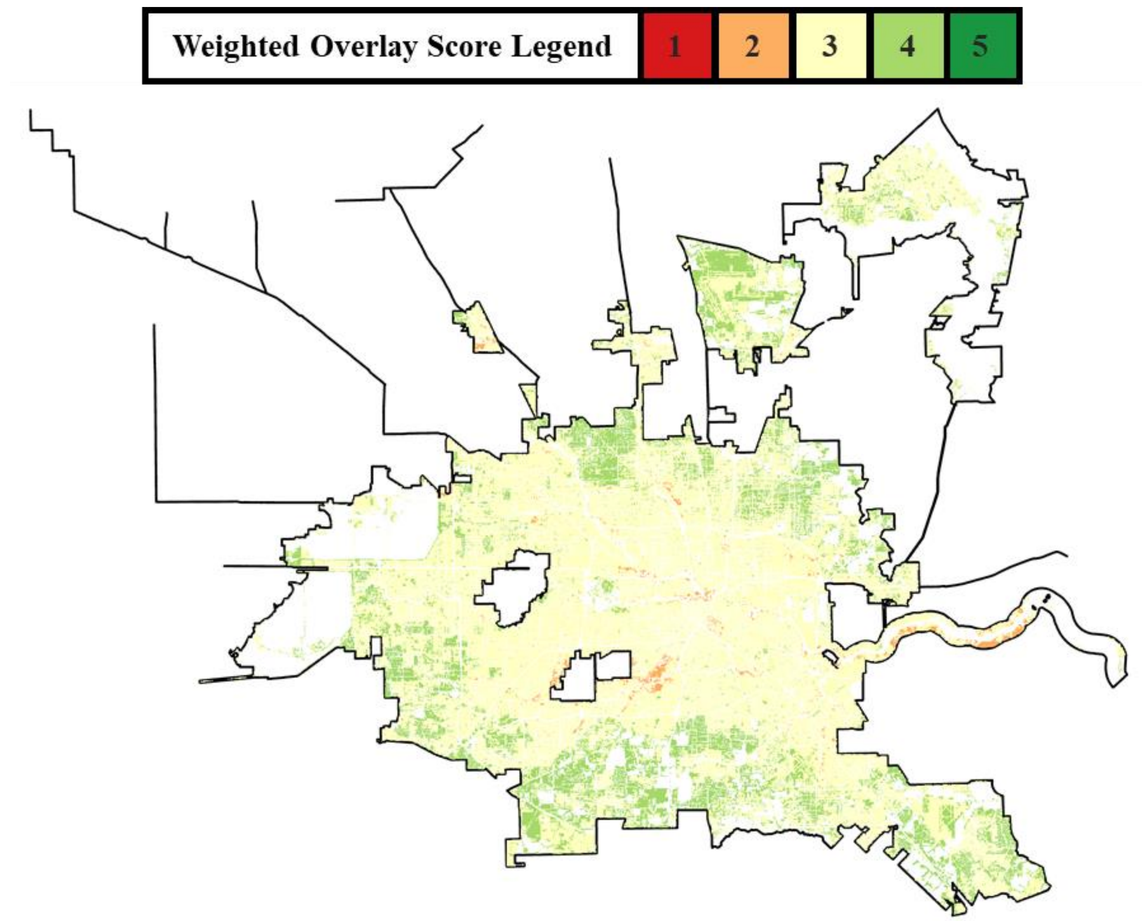

Figure 3. Community garden site suitability map, Houston, TX

The criterion-specific suitability score distributions for the 84 community gardens included are shown in Table 2. The average of the mean scores for the six site-based suitability factors of land use group, land cover class, soil quality, terrain slope gradient, impervious surface, and tree canopy coverage was 3.24, which indicates better than moderate suitability for urban gardening. Overall, the criterion having the highest mean score, corresponding to the most suitable for urban agricultural development, was terrain slope gradient (mean = 5.00) followed by tree canopy (mean = 4.94). This indicates that the existing community garden sites are primarily located on land parcels with dominant slope percentages and tree canopy coverages of less than 5% and thus are deemed highly suitable for urban gardening according to these factors. Mean scores for land use group and land cover class indicated moderate suitability for urban agriculture at 3.48 and 3.12, respectively. In contrast, the mean scores for soil quality (mean = 1.58) and impervious surface (mean = 1.29) were below 2.0, representing very low to low suitability for urban gardening.

Table 2. Distribution of community garden scores by suitability criterion

Criterion	N	Mean	Standard Deviation	Minimum	Maximum
Land Use Group	84	3.48	0.92	1	4
Land Cover Class	84	3.12	0.57	1	5
Soil Quality	84	1.58	1.38	1	5
Terrain Slope Gradient	84	5.00	0.00	4	5
Impervious Surface	84	1.29	0.38	1	5
Tree Canopy Coverage	84	4.94	0.21	1	5
Road Density	84	3.04	0.84	1	5
TRI Facility Proximity	84	2.60	1.38	1	5
Flood Zone	84	4.34	1.22	1	5
ToxPi Pollution Hazard Score	84	4.44	0.63	2	5
Food Access Index	84	2.25	1.43	1	5

The average of the mean scores for the four risk-based suitability factors of road density, TRI facility proximity, flood zone index, and ToxPi Pollution Hazard Score was 3.61, indicating moderate to high suitability of existing community garden sites for these criteria, on average. However, existing sites were found to be more suitable in terms of flood zone index (mean = 4.34) and ToxPi Pollution Hazard score (mean = 4.44), moderately suitable as defined by road density (mean = 3.04), and less suitable when assessed by TRI facility proximity (mean = 2.60). This indicates that, while most community garden sites are located in minimal flood risk zones with favorable cumulative pollution hazard risk and acceptable road density, proximity to TRI facilities would not be considered ideal.

The need-based criterion included in the present model was derived from the USDA Food Research Atlas (2017). Based on this criterion, existing community garden sites have less than moderate suitability for addressing low food access in low income communities overall.

The mean suitability score for ToxPi Pollution Hazard Score, which is an indicator of proximity to point sources of pollution (Bhandari et al., 2020), was 4.44 with a minimum of 2 and a maximum of 5. This indicates that, overall, existing community gardens are located in areas with low hazard risk from point sources of pollution such as leaking petroleum storage tanks. However, some gardens were situated in locations that would not be considered ideal if this score were viewed alone. The mean score for flood zone index was 4.34 with a standard deviation of 1.22, a minimum score of 1 and a maximum score of 5. This shows that, while the existing gardens are largely located in areas classified as minimal risk for flooding, some are presently located within the bounds of the 100- or 500-year floodplain, as defined by the Federal Emergency Management Agency (FEMA, 2020).

Discussion

Recognizing the risk from current and future anthropogenic and natural disasters in tandem with continuing hazardous emissions, the need to invest in environmental exposure research is both clear and urgent. Although gardening for food production has become more prevalent, as indicated by the 17% increase in food garden participation among U.S. households between 2008 and 2013 (National Gardening Association, 2014), this potential solution to food insecurity is challenged by inconsistent knowledge of potential risks from gardening-related soilborne heavy metal and organic chemical exposures among community gardeners (Kim et al., 2014). Overall, existing garden sites in Houston, Texas were found to be of moderate to high suitability based on the site-, risk-, and need-based criteria that were included. Recognition that existing community garden siting was more suitable according to the risk-based and site-based criteria than the need-based criterion suggests a need to better incorporate social factors in future land use planning. However, the available data does not indicate how and where the produce grown at each garden is distributed.

In the present study, the majority of community gardening organizations indexed were classified as school gardens. However, a 2011-2012 survey of 445 community gardening organizations across the U.S. reported that 43.8% of respondents were neighborhood gardens while only 3.0% were school-based gardens (Lawson & Drake, 2013). This difference highlights the need to better understand, accommodate, and assist the unique gardening communities that exist at local, state, and national levels. In the present study, mean scores for soil quality and impervious surface were consistent with very low to low suitability for urban gardening. However, these concerns may not be directly applicable to raised garden beds, which are recommended for urban gardens (U.S. EPA, 2014).

The present suitability analysis is limited by a number of important factors. The USDA Food Research Atlas provided classification of low income and low food access census tracts, which served to represent need in the present garden site suitability model. Although need is an essential consideration in land use planning, the Food Research Atlas was last updated in January 2017 (USDA, 2019) and would not capture food retail outlets that have opened or closed in the interim period. However, prior suitability studies have used this data resource (Mack et al., 2017; Ackerman et al., 2014), and the 2017 edition is the most recent available. Selection of evaluation criteria was informed by prior suitability analyses of community gardens in the United States and studies of community gardener site needs and preferences. However, the criteria included are not comprehensive. For example, ambient temperature, an important factor in the viability of agricultural production (Saha & Eckelman, 2017), was not included in the present analysis due to the limited study area included. In addition, suitability criteria were reclassified to a uniform scale according to prior site suitability analyses for urban agriculture (summarized in Table 1). The utility of future spatial analyses developed to inform community garden site selection may be improved by reclassifying each factor to a regional scale (Newman, Smith, & Brody, 2017).

Food insecurity is a significant and growing global issue, particularly in urban and rapidly urbanizing areas. Although community gardening is a promising approach to expand access to fresh, nutritious produce, the potential benefits and sustainability of such endeavors must be carefully considered against the potential threats to viability and exposure risks imparted by the surrounding site and environmental conditions. Soil quality was found to be a key driver of unsuitability among the community garden sites evaluated. Given that residential exposure to environmental hazards disproportionately affects socioeconomically disadvantaged populations (Collins et al., 2015; Chakraborty et al., 2015), who also face excess rates of food insecurity (USDA ERS, 2019), concerted efforts to address threats to local food supply systems in environmental justice communities are needed.

CHAPTER III

COMMUNITY GARDEN SOIL SCREENING

Introduction

The Centers for Disease Control and Prevention (CDC) defines community gardens as "collaborative projects on shared open spaces where participants share in the maintenance and products of the garden, including healthful and affordable fresh fruits and vegetables" (CDC, 2010). Community gardens are an emerging solution to food insecurity in the U.S. and have been shown to enhance vegetable intake among both adults and children (Carney et al., 2012). According to the National Garden Association, food garden participation among U.S. households increased by approximately 17% from 2008 (36 million households) to 2013 (42 million households) (National Gardening Association, 2014). Although community gardens have the potential to provide a multitude of benefits, including increasing the production of and access to food, community building, neighborhood revitalization, and socializing, general and garden knowledge-building, and improved nutrition (Lawson & Drake, 2013), available evidence suggests that community gardeners tend to underestimate the risk of hazardous exposures related to gardening (Hunter et al., 2019; Kim, Poulsen, Margulies, Dix, Palmer, & Nachman, 2014; Wong, Gable, & Rivera-Núñez, 2018) and are often unfamiliar with exposure reduction strategies and interventions (Wong et al., 2018).

Heavy metals are among the most common soil contaminants of concern among community gardeners (Kim et al., 2014; Wong et al., 2018; Hunter et al., 2019).

Ingestion of contaminated crops is largely a known route of exposure to soilborne contaminants among community gardeners; fewer are aware of the potential for direct soil ingestion during routine gardening activities (Kim et al., 2014). The potential for soilborne contaminants to be transferred to produce has been document, as has the internalization and uptake of certain metals into produce items (ATSDR, 2007, 2016; WHO, 2001, Warren et al., 2003; U.S. EPA, 2000; Hettick, Cañas-Carrell, French, & Klein, 2015; Vithanage, Dabrowska, Mukherjee, Sandhi, & Bhattacharya, 2012). Dermal contact with contaminated dust or soil is the most widely recognized exposure route among community gardeners, while inhalation of particulate-bound contaminants tends to be overlooked (Kim et al., 2014). Inhalation of particulate-bound contaminants such as arsenic may result in mechanical filtering in the nasopharynx region, capture in and cleared from the pulmonary mucosal lining, or deposition in the interior lining of the lungs leading to absorption into the body (Yip & Dart, 2001).

Lead, arsenic, and chromium are contaminants of interest in garden soils because these elements are both naturally-occurring in the environment and produced from anthropogenic activities. Soil is considered to be among the important sources of population exposure to lead, where it is typically strongly bound to fine organic matter at the superficial depth of 1 to 2 inches (ATSDR, 2007; Mielke & Reagan, 1998). The rate of lead absorption in humans differs by route of exposure, with the greatest uptake occurring in the gastrointestinal tract after ingestion, followed by inhalation, and lastly dermal contact (ATSDR, 2007; Centeno et al., 2002; IARC, 2007). Though naturally present in the environment, the vast majority of lead in soil and dust is attributed to anthropogenic activities with leaded gasoline and paint being the greatest contributing sources, although these uses have been effectively banned in the U.S. since 1976 and 1988, respectively (ATSDR, 2007; IARC, 2006; Mielke, Laidlaw, & Gonzales, 2011). Inorganic lead compounds are classified as being probable carcinogens to humans (Group 2A) by IARC (2006). Children are vulnerable to adverse neurodevelopmental outcomes secondary to lead exposure (ATSDR, 2007; Canfield et al., 2003; Centeno et al., 2002) and are predisposed to having excess exposure to lead in dust due to higher frequencies of contact with household flooring and hand-to-mouth contact (Maton, Angle, Stanek, Reese, & Kuehnemann, 2000). A study of New York City community gardeners and child visitors found that adults were most likely to be exposed to soilborne lead as a result of contaminated produce consumption, while children were most likely to be exposed as a result of soil and dust ingestion (Spielthoff et al., 2016).

The presence and concentration of garden contaminants are affected by a number of site-specific factors such as historical land use, proximity to roadways and older buildings, and extent of impervious surface and greenspace (Agency for Toxic Substances and Disease Registry, 2007; Clark, Luukinen, & Kastleman, 2018; Smith, Cannon, Woodruff, Solano, Kilburn, & Fey, 2013). It is difficult to determine the extent to which the soil in community garden sites is contaminated, if at all, because soil testing is not typically performed at community garden sites on a a routine basis (Hunter et al., 2019; Ramirez-Andreotta, Tapper, Clough, Carrera, & Sandhaus, 2019). To support and inform evidence-based strategies to mitigate potential risks associated with urban community gardening, ground and garden bed soil was collected from community garden sites located in Houston, Texas and screened for trace and heavy metals.

Methods

Sample Collection and Preparation

The setting of this study consisted of community garden sites in Houston, Texas that are not affiliated with primary or secondary schools. Eligible sampling sites were identified from publicly-available membership listing of Urban Harvest (2020). Selected community garden sites were approached in the spring of 2020 for soil sampling. A composite sample of ground soil was collected from the perimeter adjacent to and surrounding garden bed locations. When accessible, a composite sample of soil was also collected from the garden beds. For each composite sample, six surface soil plugs were collected using a new, single-use Terra Core Soil Sampler (En Novative Technologies, Inc.) and inserted into a sterile polyethylene bag. Once complete, the plastic bag was sealed, double-bagged, and then transferred into a cooler containing frozen ice packs for transport to the Texas A&M University School of Public Health (SPH) laboratory.

Upon arrival at the SPH laboratory, samples were immediately placed in -80 °C storage until frozen and then lyophilized for a period of 36 to 48 hours. Subsequent to freeze-drying, particle size uniformity was achieved by grinding each sample with a clean, dry mortar and pestle and then passing each sample through a clean, dry 60-mesh sieve in accordance with U.S. EPA Method 6200 (U.S. EPA, 2007). To achieve homogenization, each soil sample was transferred onto a clean sheet of butcher paper and rolled as described in U.S. EPA (2007). Single-use, double open-ended XRF sample cups (polyethylene, 31.0 mm internal diameter) were labeled and sealed on one end with Mylar film (2.5 µm). Each sample cup was then filled with a prepared soil sample, compacted and flattened by tamping, and sealed with Mylar film in preparation for analysis.

Sample Analysis

A Niton™ XL3t XRF Analyzer (Thermo Scientific™, Boston, MA) with a high-performance semiconductor detector, X-ray tube (Au anode 50 kV maximum, 200 µA maximum) excitation source, and 50 kV voltage was used in accordance with manufacturer instructions to evaluate the presence and approximate concentration of selected trace and heavy metals in prepared soil samples. To minimize potential interference from device positioning and inconsistent distance between the device probe window and sample (EPA, 2007), the XRF device was placed in a stationary test stand (Thermo Scientific) with the device probe window positioned in direct contact with the Mylar interface of the prepared, flattened soil sample. Internal device calibration was performed in advance of sample analysis in accordance with the instrument manufacturer's instructions. Standard reference materials (SRM) comprised of 2709a San Joaquin soil (National Institute of Standards and Technology, 2010) and TILL-4 soil (Natural Resources Canada, 1995) were used to evaluate the analytical device's accuracy and the stability and consistency of analysis. Samples of these reference materials and a blank sample of silicon dioxide prepared in XRF sample cups were procured from Thermo Scientific and analyzed at the start and end of each working day and between each sample set of 20.

Data Analysis

The Standard Thermo Scientific™ Niton Data Transfer (NDT™) PC software suite was used to facilitate data transfer. Concentrations reported represent the average of triplicate readings of each sample and are appropriately interpreted as estimates. Results were compared to the U.S. EPA's Soil Screening Levels, the U.S. Geological Survey's 2013 Geochemical and Mineralogical Data for Soils of the Conterminous United States (Smith et al., 2013), and the Texas Commission on Environmental Quality's (TCEQ) Texas-Specific Soil Background Levels, which are based on a 1975 soil assessment produced by the U.S. Geological Survey (TCEQ, n.d.).

Results

Composite soil samples were collected from the grounds of 24 community garden sites located in Houston, Texas. Garden beds used for plant-based food production were accessible at 22 of the community garden sites from which ground soil was collected. The distributions of arsenic, cadmium, chromium, copper, lead, and zinc in soil samples collected from the garden beds and grounds of community garden sites in Houston, Texas are shown in Figure 4.

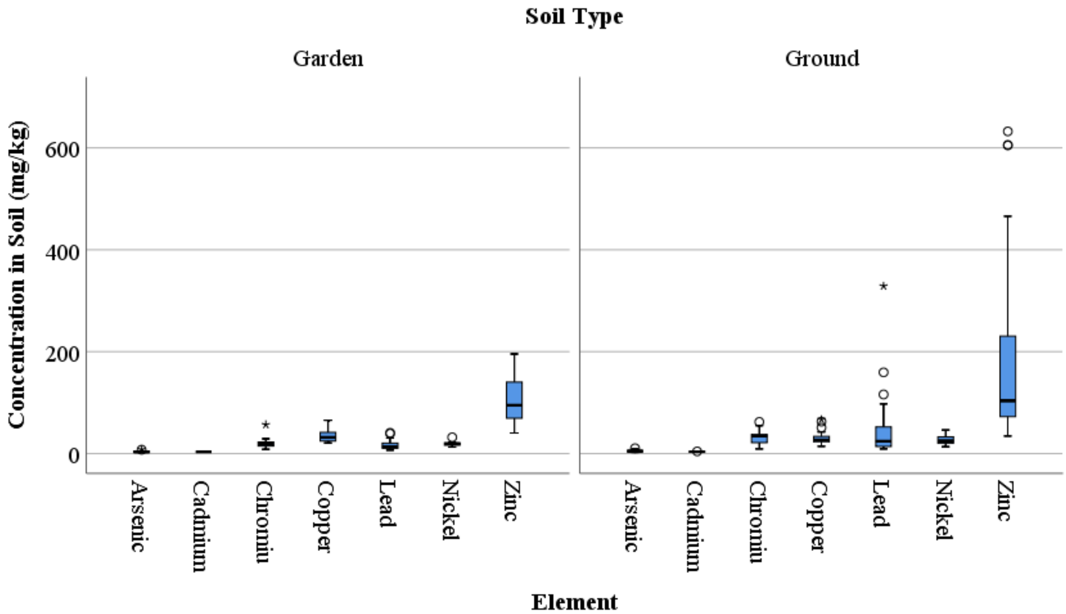

Figure 4. Box plot depicting selected metal concentrations in community garden bed and ground soils, Houston, TX

Overall, the estimated concentrations in the ground soil sample were below the estimated levels in the garden bed soil sample for all elements except calcium, manganese, potassium, strontium, and sulfur. Chromium, copper, lead, and zinc were present at detectable levels in each of the 24 ground soil samples that were collected with overall mean concentrations of 32.6 mg Cr/kg, 31.3 mg Cu/kg, 52.4 mg Pb/kg, and 186.6 mg Zn/kg, respectively. Arsenic and nickel were each detected in 22 ground soil samples, and cadmium was found to be present in only seven ground soil samples. Surface soil samples collected for U.S. Geological Survey (N=4,841) from conterminous U.S. contained an average of 6.4 ∓ 16.7 SD mg As/kg (range: <0.6 to 830 mg As/kg) for arsenic, 36 ∓ 89 SD mg Cr/kg (range: <1 to 4,120 mg Cr/kg) for chromium, and 25.8 ∓ 185 SD mg Pb/kg (range: <0.5 to 12,400 mg Pb/kg) for lead (Smith et al., 2013).

Compared to soil collected from garden beds (N=22), the overall mean concentrations in ground soil was 67.9% higher for lead, 43.3% higher for zinc, 23.9% higher for nickel, and 22.9% higher for arsenic. The average level of copper in ground soil was 9.1% lower than the overall mean observed in garden bed soil.

Table 3. Elemental concentrations in garden bed and ground soil collected from community gardens in Houston, TX

	Garden Soil (N=22)			Ground Soil (N=24)		
	N > LOD*	Mean (mg/kg)	Standard deviation	N > LOD*	Mean (mg/kg)	Standard deviation
As	21	4.1	1.4	22	5.3	1.9
Ba	15	127.6	71.4	23	195.4	54.7
Cd	1	3.5	0.0	7	3.6	0.3
Cr	19	20.5	10.1	24	32.6	12.6
Cu	22	34.2	10.9	24	31.3	12.7
Fe	22	6168.8	1841.5	24	10163.8	4979.3
Mn	22	233.5	51.0	24	237.0	87.9
Ni	10	20.4	4.8	22	26.9	7.8
Pb	22	16.8	9.3	24	52.4	68.3
V	22	37.6	7.5	24	56.6	17.4
Zn	22	105.8	43.6	24	186.6	186.6

*Represents the number of samples that were used to calculate the mean and standard deviation as samples having concentrations below the limit of detection (LOD) were excluded from analysis

Copper, lead, and zinc were present at detectable levels in each of the 22 garden bed soil samples collected. The estimated mean and maximum concentrations of copper were 34.2 mg/kg and 65.2 mg/kg, respectively. The average estimated concentration of lead was 16.8 mg/kg with the highest level observed being 40.6 mg/kg. With respect to zinc, the mean concentration was estimated to be 105.8 mg/kg and the maximum was 195.6 mg/kg. With a singular exception, arsenic was present at detectable levels in garden bed soil samples collected from all sites (N=21, mean: 4.1 mg/kg, maximum: 7.8 mg/kg). Nickel was measured at a detectable level in soil samples collected from ten garden beds (mean: 20.4 mg/kg, maximum: 31.9 mg/kg), while cadmium was detected in garden bed soil collected from only one site at a level of 3.5 mg/kg. The mean and maximum concentrations of chromium were 20.5 mg/kg and 56.7 mg/kg among the 21 garden bed soil samples with detectable levels.

Table 4. Reference concentrations for soil metals in Houston, TX, and the U.S.

Element	U.S. EPA Soil Screening Level* (U.S. EPA, 2019)	USA Soil Background Mean Soil Concentration (Smith et al., 2013)	Texas Soil Background Mean Soil Concentration (TCEQ, n.d.)	Houston Background Mean Soil Concentration (Chu, 2019)
	mg/kg			
As	0.4	6.4	5.9	2.9
Ba	5,500.0	518.0	300.0	120.9
Cd	70.0	0.3	-	0.3
Co	-	8.9	7.0	3.1
Cr	230.0	36.0	30.0	11.5
Cu	-	17.9	15.0	58.2
Fe	-	2.1	15,000.0	6,403.1
Mn	-	612.0	300.0	220.6
Ni	1,600.0	17.7	10.0	8.0
Pb	-	25.8	15.0	60.2
V	550.0	60.0	50.0	11.7
Zn	23,000.0	66.0	30.0	279.8

*U.S. EPA Generic Soil Screening Levels (SSLs) for residential scenario and ingestion-dermal exposure

Reference concentrations for soil metals are shown in Table 4. Only one element, arsenic, was estimated to be present in garden bed and ground soils at a concentration above the U.S. EPA's Soil Screening Level, which serves as a risk-based reference for human health. However, the U.S. EPA’s Soil Screening Level for arsenic (0.4 mg/kg) is below the average background level for surface soils in Texas (6.4 mg/kg) and in the U.S. (5.9 mg/kg). The estimated mean concentration of arsenic in the garden bed soil samples was 4.1 mg/kg while the ground soil samples were estimated to have 5.3 mg/kg of arsenic. The estimated mean concentration of lead in the garden bed soil samples was 16.8 mg/kg, which is below the U.S. EPA’s Soil Screening Level of 400 mg/kg, similar to the average background concentration in the U.S. of 25.1 mg/kg of lead in soil, but slightly above the Texas-Specific Soil Background Level of 15.0 mg/kg. Notably, ground soil collected from one garden had an estimated lead concentration of 328.7 mg/kg, which is above the average background level for Texas and the U.S. but below the U.S. EPA’s Soil Screening Level.

Discussion

The concentration of lead in ground soil collected from community garden sites in Houston, Texas was in excess of the background levels reported from state and federal agencies. However, the levels observed in the present study were comparable to more recent data reported in the scientific literature, which indicates a need for additional, fine-scale soil screening. It is important to note that these values represent estimated concentrations are intended only for characterization and screening.

When available, the long-term reliability of soil assessment data is further challenged by contaminant mobilization and transfer due to disaster events, which are expected to increase in both frequency and intensity due to climate change (National Research Council, 2006). For example, Mielke, Gonzales, and Powell (2017) observed significant reductions ($p<0.05$) in soil lead levels in the samples collected after Hurricane Katrina compared to the samples collected before the storm. Potential changes in the distribution of contaminants from disaster events are important because few community gardens test soil for heavy metal contamination more than once a year (Hunter et al., 2019).

Community gardens are an essential component of the local food system in Houston, Texas. However, the variability in soil metal concentrations between existing community garden sites in Houston, Texas highlights the need for site-specific soil testing. All proposed community garden sites should also be tested in advance of development to ensure that local soil conditions do not present excess risk of produce contamination. With the exception of arsenic, the mean concentration of metals in ground and garden soils collected from Houston, Texas community gardens did not exceed the U.S. EPA's SSLs for residential locations and ingestion-dermal exposure (U.S. EPA, 2019). Importantly, the analytical method used in the present study provides only an estimate. Thus, confirmatory soil testing is advised even for the sites that were screened.

This study has several important limitations. Due to access limitations, the community gardens evaluated represent only a sample of the existing sites in Houston, Texas. For example, community gardens located on school property were not considered, and planned sampling at additional community gardens was prohibited along with all other field work due to the ongoing outbreak of coronavirus disease 2019 (COVID-19). However, the sample of gardens tested included gardens from neighborhoods across the City of Houston, and the concentrations of metals observed in ground soil samples were consistent with another recent soil survey in Houston (Chu, 2019;). In addition, the sampling design employed in this study does not capture concentration gradients across the garden site. Furthermore, the method used in laboratory analysis provides only an estimate of analyte concentration and has reduced sensitivity to detect low analyte levels relative to traditional approaches such as inductively coupled plasma-mass spectroscopy (ICP-MS). Results obtained are adequate to begin community engagement and research translation efforts related to potential exposures to metals in garden soils, however.

CHAPTER IV

COMMUNITY GARDEN SURVEY

Introduction

Community gardens are an emerging solution to food insecurity in the U.S., which affects an estimated 37.2 million individuals in the U.S. each year (U.S. Department of Agriculture, Economic Research Service [USDA ERS], 2017). The Centers for Disease Control and Prevention (CDC) defines community gardens as "collaborative projects on shared open spaces where participants share in the maintenance and products of the garden, including healthful and affordable fresh fruits and vegetables" (CDC, 2010). Community gardens have the potential to provide a multitude of benefits, including increasing the production of and access to food, community building, neighborhood revitalization, and socializing, general and garden knowledge-building, and improved nutrition (Carney et al., 2012; Lawson & Drake, 2013). A survey conducted by the National Garden Association found that 42 million households participated in food gardening in 2013, an increase of approximately 17% over 2008 (National Gardening Association, 2014). The number of Google searches for "community garden" and "gardening" increased significantly (p=0.0001) in the U.S. from 2004 through 2014 (Andrew et al., 2016), highlighting greater interest in community gardens among the general public. Interest in and support for community gardens has also grown among governmental agencies.

A national survey of 445 community gardening organizations found that 50% of respondents received access to gardening materials and equipment from their respective local governments, and 47% benefited from expedited authorization to use public land for gardening (Lawson & Drake, 2013). Most respondents were affiliated with small organizations representing one garden (39%) or large organizations affiliated with four to thirty gardens (30%), while organizations of medium (two to three gardens) and very large (thirty-one or more gardens) size comprised 19% and 12%, respectively. Neighborhood gardens composed around 44% of the sample, with the remaining classifications being reported by below 10% of respondents. Nearly half (48%) of the gardens represented were located on public land, 24% on private land, and 18% on land belonging to the organization. Respondent organizations (N=338) reported playing a role in the establishment of 2,660 community gardens from 2007 through 2011, only 19% of which were initiated by an external organization or agency (Lawson & Drake, 2013). Other forms of government support for local food production include programs like the City of Houston's Urban Garden Program, which presently supports 11 community gardens in city parks (Houston Parks and Recreation Department, 2019).

Community gardeners tend to underestimate the risk of hazardous exposures related to gardening (Hunter et al., 2019; Kim et al., 2014; Wong et al., 2018), in part because community garden soils are seldom tested for potential hazards (Hunter et al., 2019; Ramirez-Andreotta et al., 2019) so gardener knowledge of exposure reduction strategies and interventions is frequently limited (Wong et al., 2018). Heavy metals are usually the most common soil contaminants of concern among community gardeners

(Kim et al., 2014; Wong et al., 2018; Hunter et al., 2019). Cooper et al. (2020) evaluated metal uptake in vegetables grown in-ground at and collected from community and background gardens in San Diego, California. Edible strawberry and swiss chard tissues were found to be respectively contaminated with lead (0.84 ± 0.404 mg/kg dry weight) and arsenic (0.80 + 0.073 mg/kg dry weight). Community gardeners have a range of understanding with regard to potential exposures that may occur as a result of gardening activities. For example, community gardeners surveyed by Kim et al. (2014) were aware of the potential for exposure to soilborne contaminants from direct ingestion and dermal contact but few knew that inhalation of contaminants bound to particulate matter also presented a potential exposure risk. According to Spielthoff et al. (2016), the dominant route of lead exposure among adult gardeners was consumption of contaminated produce ngestion of soil and dust is the dominant exposure route among childhood visitors to community gardens (Spielthoff et al., 2016), while the consumption of contaminated produce is the greatest source of lead exposure among adult gardeners. Estimates suggest that 10% of adult and 40% of child visitors could have exceeded the U.S. Food and Drug Administration's lead intake limits (75 and 6 μg/day, respectively) based on cumulative exposures (Spielthoff et al., 2016).

Efforts to extrapolate the extent of garden contamination are difficult because soil testing can be infrequent and irregular (Hunter et al., 2019; Ramirez-Andreotta, Tapper, Clough, Carrera, & Sandhaus, 2019). Site-specific factors like the percentage of impervious surface coverage and greenspace, proximity to transportation infrastructure and pre-1978 buildings, and historical land use can affect the chemical composition of soils (Agency for Toxic Substances and Disease Registry [ATSDR], 2007; Clark, Luukinen, & Kastleman, 2018; Smith, Cannon, Woodruff, Solano, Kilburn, & Fey, 2013). Organic chemicals (e.g., organophosphate pesticides, polycyclic aromatic hydrocarbons, polychlorinated biphenyls) are also persistent environmental contaminants that are relevant to community garden soils; however, awareness of these potential hazards among community gardeners is low compared to metals (Hunter et al., 2019; Kim et al., 2014; Wong et al., 2018). Pesticide application in community gardens is seldom reported by gardeners (Blaine, Grewal, Dawes, & Snider, 2010; Hunter et al., 2019; Wong et al., 2018). An online survey of 500 community gardeners conducted in 2017 revealed that only 11% reported using conventional chemical treatments involving pesticides, while most identified practices as natural (53.6%) or USDA Certified Organic (32.4%) (Hunter et al., 2019). Nearly three-quarters (73%) of Baltimore, MD gardeners surveyed (N=70) deliberately avoided the use of commercial pesticide and fertilizer formulations (Kim et al., 2014). Cleveland, OH community gardeners surveyed in 2009 (N=124) revealed that 67% of gardens used no chemicals and identified as organic and only 6% reported the application of pesticides (Blaine et al., 2010). Regardless of present pesticide use, legacy pesticides may be introduced from atmospheric deposition in Houston, Texas (Clark, Yoon, Shesley, & Usenko, 2016) or present at sites as a result of historic land usage (Ziter, Graves, & Turner, 2017).

Recognizing that community garden organizations often struggle to obtain sufficient funds for soil, water, compost, and other gardening materials (Lawson & Drake, 2013), low-cost risk reduction approaches are needed to achieve widespread use.

Behavioral interventions may be cost-effective and efficacious in reducing the risk of gardening-related exposure to soilborne contaminants. For example, water washing of produce is universally recommended to consumers by the U.S. Food and Drug Administration (FDA, 2018) and has been shown to reduce arsenic and lead contamination in vegetables grown in contaminated soils (Paltseva et al., 2018). However, some have suggested that the efficacy of water washing for root vegetables compared to fruiting and leafy vegetables is reduced as a result of internalization and accumulation of metals (Spliethoff et al., 2016). Conventional soil remediation strategies geared toward stabilization include excavation and dumping, soil washing, electrokinetics, and vitrification and asphalt capping (U.S. EPA, 2000; Smith et al., 2013). Although effective in improving soil conditions within a given area, implementation of these strategies may be limited by cost, environmental disruption, and concerns regarding downstream disposal of contaminated soil (ATSDR, 2007, 2016).

There is relatively widespread interest and investment in developing novel and optimizing traditional remediation techniques and technologies to improve both efficacy and sustainability. Among these are phytoremediation and targeted soil amendments. Phytoremediation technologies leverage plants to degrade, contain, or remove contaminants from soil, sediment, and groundwater (U.S. EPA, 2000). Phytoaccumulation refers to the general uptake and storage of contaminants in plants and encompasses phytoextraction, wherein contaminants are concentrated in the aboveground components, phytostabilization, which refers to plant-mediated immobilization of contaminants in (absorption), on (adsorption), or around (precipitation) the roots, (U.S. EPA, 2000). Soil amendments refer to waste residual products (e.g., animal manures, composted agricultural byproducts, wood ash, fertilizers) that can be used for in situ, meaning in-place, remediation of soils. For example, novel broad-acting clay-based enterosorbents that have been shown to be effective in binding common garden soil contaminants (e.g., benzo[a]pyrene, aldicarb, aflatoxin B1) (Wang, Hearon, Johnson, & Phillips, 2019; Wang, Hearon, & Phillips, 2019; Wang, Maki, Deng, Tian, & Phillips, 2017) may be useful for the remediation of contaminated soils. Raised garden beds have been shown to be effective in reducing metal uptake and contamination in vegetables grown in community gardens (Cooper et al., 2019). Although researchers seeking to better understand the needs of local gardeners have reported a need for information and guidance pertaining to soil testing and acceptability of remediation strategies (Kim et al., 2014; Harms, Presley, Hettiarachchi, & Thien, 2013), little is known about the acceptability of emerging technologies to reduce the risk associated with potential hazardous exposures from community gardens.

Rationale

Community gardens provide a multitude of benefits to communities, including expanding access to fresh, nutritious foods and promoting sustainability in local food supply chains. However, available evidence suggests that community gardeners and garden organizers tend to underestimate the risk of potential garden contamination and are often unsure of how to access soil testing services. These knowledge gaps are of particular concern in urban areas where community gardens are more frequently in close proximity with potential sources of hazardous contaminants such as transportation infrastructure and industrial facilities. Community gardens located in the City of Houston, Texas are further challenged by a lack of zoning, which has meant that development has been mostly unchecked and industrial land uses may be intermingled with residential and other types of land uses, such as parks (Turner, 2020); however, little is known about the knowledge, practices, and perceptions of risk of community gardeners in this area. Therefore, research is needed to characterize this population, identify risk-related knowledge gaps, and develop strategies and interventions that are both effective in reducing risk and perceived as being acceptable for implementation in community garden settings.

The purpose of this study was to address these research needs by surveying community garden affiliates at community garden sites located in Houston, Texas. Specific items of interest included current gardening practices, perceptions and knowledge of garden-related risks, and acceptance of interventions to reduce gardening-related risks. The questionnaire instrument included questions about participant demographics, community garden characteristics, and garden risk knowledge and perceptions. Results from this study aim to provide a baseline characterization of current community garden and gardener attributes in Houston, Texas to inform the development interventions to reduce the risk of soilborne chemical contaminants and guide the design of outreach and educational activities to improve community garden safety.

Methods

Recruitment

The study protocol, questionnaire instrument (shown in Appendix 2), information sheet (Appendix 3), and recruitment e-mail (Appendix 4) were reviewed and approved by the Texas A&M University Institutional Review Board prior to data collection and determined to be exempt (IRB # IRB2019-1204M).

Contact information for 38 existing community gardens was obtained from publicly-available online membership listings and community garden websites. Based on prior experience with requirements for accessing public schools located in Houston, Texas, school-affiliated community gardens were excluded from this study. The recruitment email shown in Appendix 4 was distributed to each of the 38 community gardens for which contact information was available once per week for three weeks, for a total of three separate recruitment attempts. The study information sheet, shown in Appendix 3, was included as an attachment in each recruitment email and provides a brief background about the study's purpose and process. The Information Sheet also contains instructions to contact the study's principal investigator and/or the Texas A&M Institutional Review Board in the event that questions or concerns emerge regarding the survey. The recruitment email also contained a link to the online survey, which was disseminated on the Qualtrics survey platform. The Information Sheet was again provided upon clicking the link, and potential participants were asked to respond to two questions to confirm that they are 18 years of age or older and affiliated with a community garden in Houston, Texas. Participants who are confirmed to be eligible to participate were presented a final question that requested their consent to participate. Individuals who indicated that they are not 18 years of age or older, who were not affiliated with a community garden in Houston, Texas, and/or declined to consent to participate were be directed to a thank you page and did not advance to the survey. Those who were eligible and consent to participate will advance to the survey. The period required to complete the survey was estimated to be 15 minutes.

Questionnaire Instrument

Participants were permitted to skip any question that they did not wish to answer and to exit the survey at any point. Additionally, participants are provided the option to select "prefer not to respond" for any survey question and to end the survey at any point. The questionnaire instrument, shown in Appendix 2, was comprised of 17 questions within the domains of participant demographics, community garden characteristics, and garden risk knowledge and perceptions. Specifically, there were 6 questions about respondent demographic and household attributes, including age, gender, race and ethnicity, educational attainment, household size and household income. There were 4 questions about community garden characteristics, 2 questions designed to ascertain knowledge and perceptions about garden-associated risk, and 5 questions to discern willingness to use risk reduction measures such as garden soil testing, remediating soil, changing gardening practices, and produce washing.

Data Analysis

Survey data collection was achieved using the Qualitrics survey platform. Following the four-week data collection period, the web-based survey response period was ended. Data was exported from Qualtrics and imported into IBM SPSS Statistics (Version 26) software for analysis, which included the calculation of response frequencies.

Results

There were 25 individuals who initiated the informed consent and screening portion of the survey. Of these, two indicated that they were under the age of 18 and thus were ineligible to advance to the survey. A third individual indicated that they were not affiliated with a community garden in Houston, Texas and was therefore ineligible to participate. Each of the 22 individuals who were eligible conceded to participate in the survey; however, two of these individuals closed the survey without submitting a response to any of the questionnaire instrument items. Thus, the response frequencies presented herein are derived from a total study population of 20 individuals.

Participant Demographics

Respondent demographic distributions are summarized in Table 5. Of the 18 individuals who entered a response for gender, half were male and half were female. Nearly half (45.0%) of all respondents were 65 years of age or older, 35.0% were 55 to 64 years of age, and 15.0% were aged 26 to 24 years. Half of all respondents were White, 30.0% were Black or African American, and 20.0% did not provide a response for race. None of the individuals surveyed reported being of Hispanic, Latino, or Spanish ethnicity. Of the 18 study subjects that provided a response, all reported having at least an associate's degree-level educational attainment, with 45.0% of the study population having completed a bachelor's degree and 10% having completed a master's degree.

With regard to household size, most respondents reported living in a 2-person household (N=11), followed by living alone (n=3) and in a 3-person household (N=2). Two additional people reported living in a household with four or more people. Respondents were next asked to indicate whether their household income was above or below the federal poverty line for their stated household size. Of the 17 individuals who submitted a response, 16 indicated a household income above and 1 indicated a household income below the respective federal poverty limit for their household size.

Table 5. Demographic distribution of survey respondents (N=20).

Variable	N (%)
Gender	
Male	9 (45.0%)
Female	9 (45.0%)
Prefer not to answer	1 (5.0%)
Response missing	1 (5.0%)
Age in years	
18 to 25	0 (0.0%)
26 to 34	3 (15.0%)
35 to 54	0 (0.00%)
55 to 64	7 (35.0%)
65 or more	9 (45.0%)
Prefer not to answer	0 (0.0%)
Response missing	1 (5.0%)
Ethnicity	
Hispanic, Latino, or Spanish	0 (0.0%)
Not Hispanic Latino, or Spanish	17 (85.0%)
Prefer not to answer	2 (10.0%)
Response missing	1 (5.0%)
Race	
White	10 (50.0%)
Black or African American	6 (30.0%)
Other	1 (5.0%)
Prefer not to answer	2 (10%)
Response missing	1 (5.0%)

Table 5 Continued

Variable	N (%)
Household size	
1	3 (15.0%)
2	11 (55.0%)
3	2 (10.0%)
4	1 (5.0%)
20	1 (5.0%)
Response missing	2 (10.0%)
Household income	
Above poverty limit for household size	16 (80.0%)
Below poverty limit for household size	1 (5.0%)
Prefer not to respond	1 (5.0%)
Response missing	2 (10.0%)
Educational attainment	
Associate's degree	7 (35.0%)
Bachelor's degree	9 (45.0%)
Master's degree	2 (10.0%)
Prefer not to answer	1 (5.0%)
Response missing	1 (5.0%)

Community Garden Characteristics

Survey respondents were next asked about the operational characteristics of their respective gardens. Specific items of interest included produce types grown and types of soil amendments applied to garden beds. All respondents indicated growing root and leafy vegetables, and all but one respondent reported growing herbs (Table 6). Fruits were less commonly grown, with 70% of respondents indicating growing fruit commodities. The three respondents who selected other wrote in the following descriptions: 1) peppers, squash, okra; 2) flowers; and 3) beans and peas. Response frequencies by soil amendment type are also displayed in Table 6. The most common type reported was compost (90.0%), followed by top soil (75.0%). Manure use was reported by 40% of respondents, while only 20.0% indicated use of Miracle-Gro and general pesticides, respectively. Of the five respondents who selected "Other," four wrote in the description MicorLife fertilizer and one entered "Mulch and organic ant control like orange oil and molasses."

Table 6. Produce type grown in community garden and garden amendments reported by community garden affiliates (N=20)

Variable	N (%)
Produce type grown	
Root vegetables	20 (100.0%)
Leafy vegetables	20 (100.0%)
Fruits	14 (70.0%)
Herbs	19 (95.0%)
Other	3 (15.0%)
Unknown	0 (0.00%)
Prefer not to answer	1 (5.0%)
Amendment type used	
Compost	18 (90.0%)
Top soil	15 (75.0%)
Manure	8 (40.0%)
Miracle-Gro	4 (20.0%)
Pesticides	4 (20.0%)
Lime	0 (0.0%)
Nothing	0 (0.0%)
Other	5 (25.0%)
Unknown	1 (5.0%)
Prefer not to answer	1 (5.0%)

Participants were asked to rate certain attributes about their community garden as being excellent, good, average, poor, or terrible (Table 7). Overall, respondents were pleased with the ease of access to their respective gardens, with 90% rating their garden location as being excellent or good. Quality of garden resources (e.g., soil and water) was also highly rated overall, with 90.0% selecting excellent or good though one person assigning a rating of poor. Knowledge of community garden staff and volunteers was rated well, with three-quarters of respondents selecting excellent or good and 20.0% assigning a rating of average. With regard to social atmosphere, 35.0% selected excellent, 35.0% selected good, and 25.0% selected average.

Table 7. Survey respondent (N=20) rankings of community garden attributes

Variable	Excellent N (%)	Good N (%)	Average N (%)	Poor N (%)	Terrible N (%)	No response* N (%)
Garden location (ease of access)	11 (55.0%)	7 (35.0%)	1 (5.0%)	0 (0.0%)	0 (0.0%)	1 (5.0%)
Quality of garden resources such as soil and water	7 (35.0%)	11 (55.0%)	1 (5.0%)	1 (5.0%)	0 (0.0%)	0 (0.0%)
Knowledge of community garden staff and volunteers	4 (20.0%)	11 (55.0%)	4 (20.0%)	0 (0.0%)	0 (0.0%)	1 (5.0%)
Social atmosphere	7 (35.0%)	7 (35.0%)	5 (25.0%)	0 (0.0%)	0 (0.0%)	1 (5.0%)

*Includes “Prefer not to respond” and missing responses

Participants were asked to indicate whether their knowledge and level of care had improved as a result of working in the garden (data not shown). Of the 20 individuals who responded, 17 individuals agreed or strongly agreed that they knew more about the environment as a result of working in the garden, 1 was neutral, 1 somewhat disagreed, and 1 preferred not to answer. With regard to level of care for the environment, 15 of 20 respondents agreed or strongly agreed that they cared more as a result of working in the garden, 3 were neutral, 1 somewhat disagreed, and 1 person preferred not to respond.

Garden Risk Knowledge and Perceptions

The next section of the questionnaire instrument was dedicated to learning about gardener knowledge and perceptions related to gardening-related risks. The first two questions were open-ended and asked about concerns for potential gardening-related health hazards. When asked to describe any health concerns related to gardening, 12 individuals reported having no concerns, one expressed concern about hazards presented by fire ants, hornets, and bees, and an additional response was entered expressing concern for cancer clusters that have been reported in Houston, Texas. The next question was more general and asked respondents to describe soil contaminants that urban gardeners in general should be concerned about. Of the 13 responses that were submitted, nine indicated no known soil contaminants of concern, two included expressions of general concern. Additional responses included “rats eating veggies and bedding plants,” and “I’m not aware of any soil contaminants, however, the above clusters of cancer in Kashmere Gardens area is a major concern.”

The final section of the survey sought to determine what testing or remediation strategies community gardeners would be willing to take if they suspected or were to confirm their garden soil to be contaminated. Survey respondents were asked if they would be willing to test garden soil if it were suspected of being contaminated with metals such as lead, chromium, or arsenic and with organic chemicals such as pesticides.

With regard to metals, 80.0% of participants would test, 5.0% might test, 10.0% would not test, and 5.0% did not respond. When asked about organic chemicals, 80.0% indicated that they would test, 15.0% selected that they would not test, and 5.0% did not respond. Subsequently, respondents were provided an open-ended opportunity to describe any additional steps that they would be willing to take if they discovered their soil to be contaminated. Four respondents reiterated a willingness to test soil if contamination were suspected, one stated, "No specific concerns," and another, "We have raised beds."

Next, respondents were asked about their willingness to implement physical remediation measures if they were to confirm their garden soil to be contaminated. At least half of all respondents expressed willingness to add natural soil amendment such as compost or minerals (60.0%), add fertilizers, clays, or other sorbent materials that bind contaminants (55.0%), initiate phytoremediation by planting certain non-edible plants (55.0%), or initiate mycoremediation by adding fungus or fungal metabolites capable of degrading, removing, and/or stabilizing contaminants in soil (50.0%). Removing and replacing contaminated soil was a less popular option, with 35.0% selecting "Yes," 35.0% selecting "Maybe," and 15.0% selecting "No." When asked if there were other risk reduction measures that they would be willing to consider if soil contamination in their garden were confirmed, seven respondents entered optional open-ended text, one of which was "N/A" and another stating "not aware of others." Understandably, the remaining responses indicated a number of important factors and uncertainties that would need to be considered in addressing soil contamination. These included "I would want information on the contaminates and go from there," and "We would have to work with the owner and see what she is willing to do to reduce the risk." Others considered the level of investment that would be required to remediate contaminated soil, on stating that they were "Willing to try other measures as long as it does not require strenuous labor," and another that "depending on the health and safety risks, we would pursue all mitigation steps needed including completely starting over with new soil if necessary." A final response brought emphasis to the dire reality that may result from such a discovery, responding that "If our soil was contaminated, we would not continue our business."

Respondents were next asked about their willingness to implement behavioral changes to mitigate risk if soil contamination were confirmed in the garden that they are affiliated with. The majority (85.0%, respectively) of community garden affiliates indicated that they would be willing to grow produce in raised beds or containers, wash produce with water before consuming it, or wash hands immediately after gardening if their garden soil was confirmed to be contaminated. Three-quarters of all respondents indicated that they would be willing to stop eating produce grown in contaminated soil. Although 85.0% of respondents would be willing wash hands after gardening, only 70% would be willing to wear gloves while gardening. Even less popular was peeling produce before consuming (65.0% willing), washing produce with vinegar, detergent, or other treatment solution before consuming (55.0% willing), and ceasing to grow certain crop types like root vegetables (50.0%).

Table 8. Willingness to use testing and risk reduction strategies among Houston, TX community gardeners (N=20)

Variable	Yes N (%)	Maybe N (%)	No N (%)	Prefer not to respond N(%)	Response missing N(%)
If you suspected that your garden soil was contaminated, would you be willing to test the garden soil for:					
Metals such as lead, chromium, or arsenic	16 (80.0%)	1 (5.0%)	2 (10.0%)	0 (0.0%)	1 (5.0%)
Organic chemicals such as pesticides	16 (80.0%)	0 (0.0%)	3 (15.0%)	0 (0.0%)	1 (5.0%)
If you confirmed that your garden soil was contaminated, would you be willing to:					
Install a barrier over contaminated soil such as a plastic cover	6 (30.0%)	7 (35.0%)	3 (15.0%)	3 (15.0%)	1 (5.0%)
Add natural soil amendments such as compost or minerals	12 (60.0%)	2 (10.0%)	1 (5.0%)	3 (15.0%)	2 (10.0%)
Add fertilizers, clays, or other sorbent materials that bind contaminants	11 (55.0%)	5 (25.0%)	0 (0.0%)	2 (10.0%)	2 (10.0%)
Remove and replace contaminated soil	7 (35.0%)	7 (35.0%)	3 (15.0%)	2 (10.0%)	1 (5.0%)
Plant certain types of plants that can degrade, remove, and/or stabilize contaminants in soil	11 (55.0%)	5 (25.0%)	0 (0.0%)	2 (10.0%)	2 (10.0%)
Add fungus or fungal metabolites that can degrade, remove, and/or stabilize contaminants in soil	10 (50.0%)	5 (25.0%)	1 (5.0%)	2 (10.0%)	2 (10.0%)

Table 8 Continued

Variable	Yes N (%)	Maybe N (%)	No N (%)	Prefer not to respond N (%)	Response missing N (%)
If you confirmed that your garden soil was contaminated, would you be willing to:					
Stop eating produce grown in contaminated areas	15 (75.0%)	0 (0.0%)	1 (5.0%)	1 (5.0%)	3 (15.0%)
Grow produce in raised beds or containers	17 (85.0%)	1 (5.0%)	1 (5.0%)	0 (0.0%)	2 (10.0%)
Stop growing certain crops such as root vegetables	10 (50.0%)	6 (30.0%)	0 (0.0%)	1 (5.0%)	2 (10.0%)
Wear gloves while gardening	14 (70.0%)	3 (15.0%)	1 (5.0%)	0 (0.0%)	2 (10.0%)
Wash hands immediately after gardening	17 (85.0%)	0 (0.0%)	1 (5.0%)	0 (0.0%)	2 (10.0%)
Wash produce with water before consuming	17 (85.0%)	0 (0.0%)	1 (5.0%)	1 (5.0%)	2 (10.0%)
Wash produce with vinegar, detergent, or other treatment solution before consuming	11 (55.0%)	7 (35.0%)	0 (0.0%)	1 (5.0%)	1 (5.0%)
Peel produce before consuming	13 (65.0%)	3 (15.0%)	1 (5.0%)	1 (5.0%)	2 (10.0%)

Discussion

The aim of this study was to build understanding and awareness of the community gardening community in Houston, Texas, to guide community outreach and educational activities aimed at improving community garden safety, and to inform current and future research seeking to reduce garden-associated exposures through the use of soil amendments and other approaches. In the present study, 95% of all respondents reported growing herbs and all indicated growing root and leafy vegetables. Most gardeners also grew fruit, but less commonly than vegetables. Compost, top soil, and, to a lesser extent, manure were common soil amendments used to supplement community garden beds in Houston. Consistent with prior studies of community gardeners in urban areas, the respondents in the present study largely viewed their respective gardens positively with respect to location, quality of resources, and social atmosphere.

The demographic distribution of the study population is not representative of the larger Houston community. In the present study, there were 20 respondents, of whom none were Hispanic or Latino and comprised racially of 50% White and 30% Black or African American individuals, all of whom have completed at least an associate's degree or higher. In contrast, Houston has a population of 2,325,500 people, of whom 44.8% are of Hispanic or Latino ethnicity with a racial distribution of 57.6% White, 22.5% Black or African American, and 6.9% Asian (U.S. Census Bureau, 2020). The demographic composition of community gardeners varies across studies. A survey of 2017 ACGA Conference attendees (N=500) reported that respondents were largely white (87.3%), not Hispanic or Latino (98.0%), male (73.6%), between the 36 to 55 years of age (50.1%), with an income ranging from $50,000 to $99,9999 (73.9%), and more than a high-school level or equivalent level of education (97.9%) (Hunter et al., 2019). A Cleveland, Ohio survey indicated that community gardeners (N=124) tended to be older, ranging from 14 to 85 years with a mean age of 55 (Blaine, Grewal, Dawes, & Snider, 2010). Although the Houston gardening community has not been well-characterized, this disparity could well be attributed to the limited sample size of 20 in the present study.

The present study indicates both an opportunity to provide educational and outreach services to community gardeners in Houston Texas, as well as interest to learn among the gardening community that such services would seek to serve. Community gardeners would be willing to seek soil testing if they suspected their soil to be contaminated. Although willingness to use certain physical interventions and behavioral changes to reduce exposure to potential soilborne hazards differed, the survey respondents were largely willing to use common interventions that are known to be effective in reducing risk. These included growing produce in raised beds or containers, washing produce with water before consuming it, washing hands immediately after gardening, and peeling produce before consuming. Several respondents expressed interest in learning more about potential risks and remediation strategies to reduce risk, highlighting a wealth of opportunities for community and university partnerships. Concerns expressed by gardeners with respect to soil contamination were minimal, and no specific contaminant type (e.g., metals, pesticides, microbial pathogens) was stated by any respondent. This is in agreement with prior studies. For example, a 2015 survey of community gardeners (N=93) in St. Louis, MO indicated that 68.8% had no concerns about garden soil contamination and over half (57.8%) had no knowledge of how to decrease exposure to potential soil contaminants (Wong et al., 2018).

Findings from this survey may be used to direct the development of new practices and technologies to address potential garden contamination and to identify opportunities for outreach and engagement with community gardeners. Although limited in scope, the information from this study can be used to tailor programming activities to the gardening community of Houston, Texas. For example, it may be useful to know that community gardeners were more commonly willing to wash hands immediately after gardening than to wear gloves while gardening. In addition, the results of this study could be used to apply for additional funding to conduct larger studies and interventions to reduce garden-related contaminant exposure risks, to publish research articles highlighting the need for continued work, and to inform policy related to healthy gardening. However, there are a number of substantial limitations, most importantly the sample size of this study. The information presented here is descriptive alone as the sample size does not permit meaningful statistical interpretation. In addition, school-based gardens were excluded from the present study. Although a national survey of community garden organizations (N=445) conducted from 2007 to 2011 indicated that only 3% of respondents were affiliated with schools (Lawson & Drake, 2013), this may not be true for the City of Houston's community garden population. Future efforts are planned to build upon this work to include a larger sample size, likely to include additional areas of study.

CHAPTER V

CONCLUSIONS

Community garden soils were found to have elevated concentrations of arsenic and had heterogenous elemental concentrations. Notably, the information derived from soil screening indicates that existing community garden beds in Houston, Texas would not be expected to present elevated risk due to heavy metal contamination. However, all of the garden beds sampled were raised beds, which have been shown to be effective in reducing contamination risk. In addition, the weighted overlay analysis conducted in Chapter 2 identified soil quality and impervious surface percentage as the greatest weaknesses among existing community gardens. Thus, it appears that community gardeners have are actively engaged in finding strategies to overcome these and other challenges inherent to urban agricultural production.

The information presented also highlights a need for ongoing risk reduction in existing community garden sites and for evidence-based planning for future community garden developments in Houston. Specifically, some of the soil samples collected from the grounds adjacent to raised community garden beds had elevated concentrations of soilborne hazards, including lead. The suitability analysis indicated that existing gardens are not optimally placed for flood risk reduction, which suggests that some gardens have greater risk of contamination due to soil transfer from flood events.

The survey revealed that gardeners are actively engaged and interested in reducing risk associated with potential garden-related exposures. Strategies to reduce risk should be informed by the end-user preferences and needs, both of which may be better understood by the information gathered. In addition, the survey highlighted opportunities to engage community gardeners in education and outreach with regard to soil testing and risk mitigation strategies.

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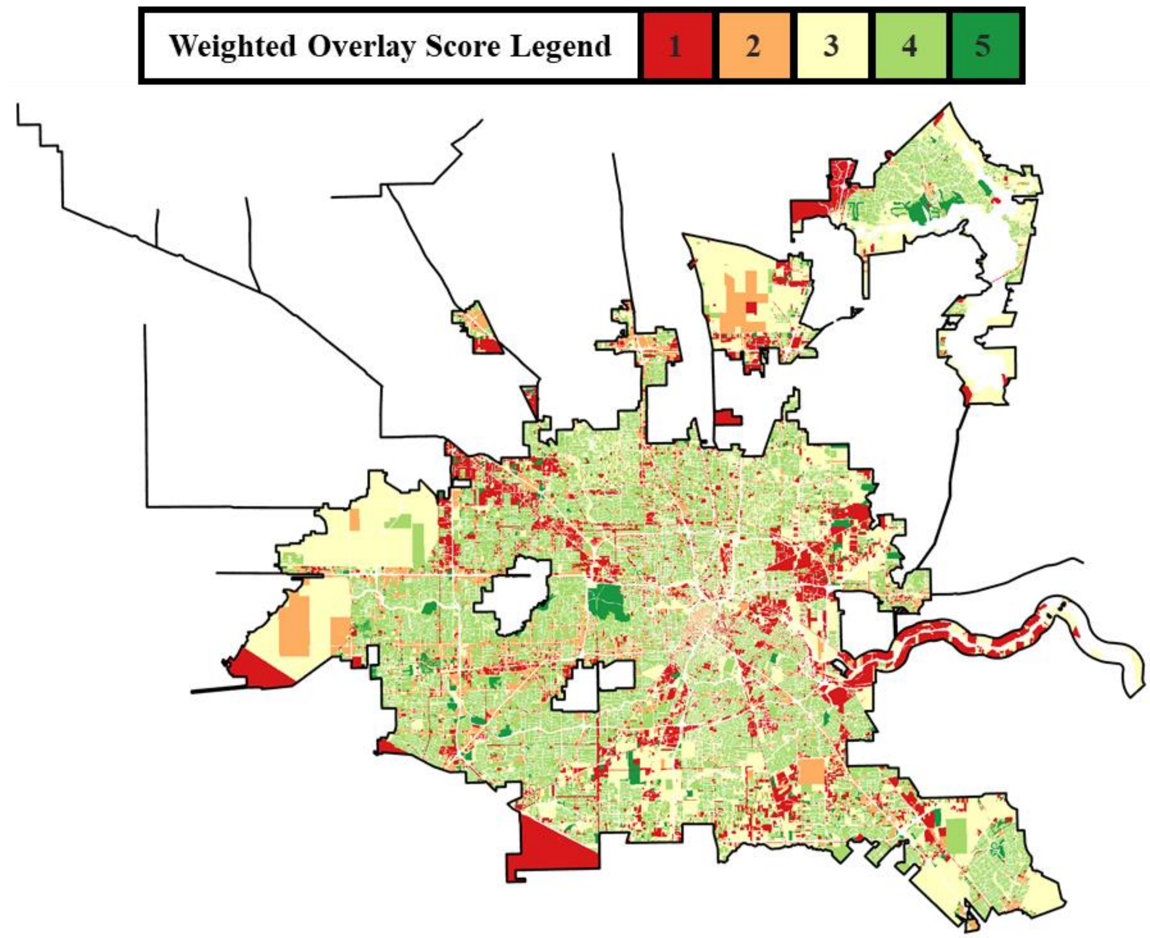
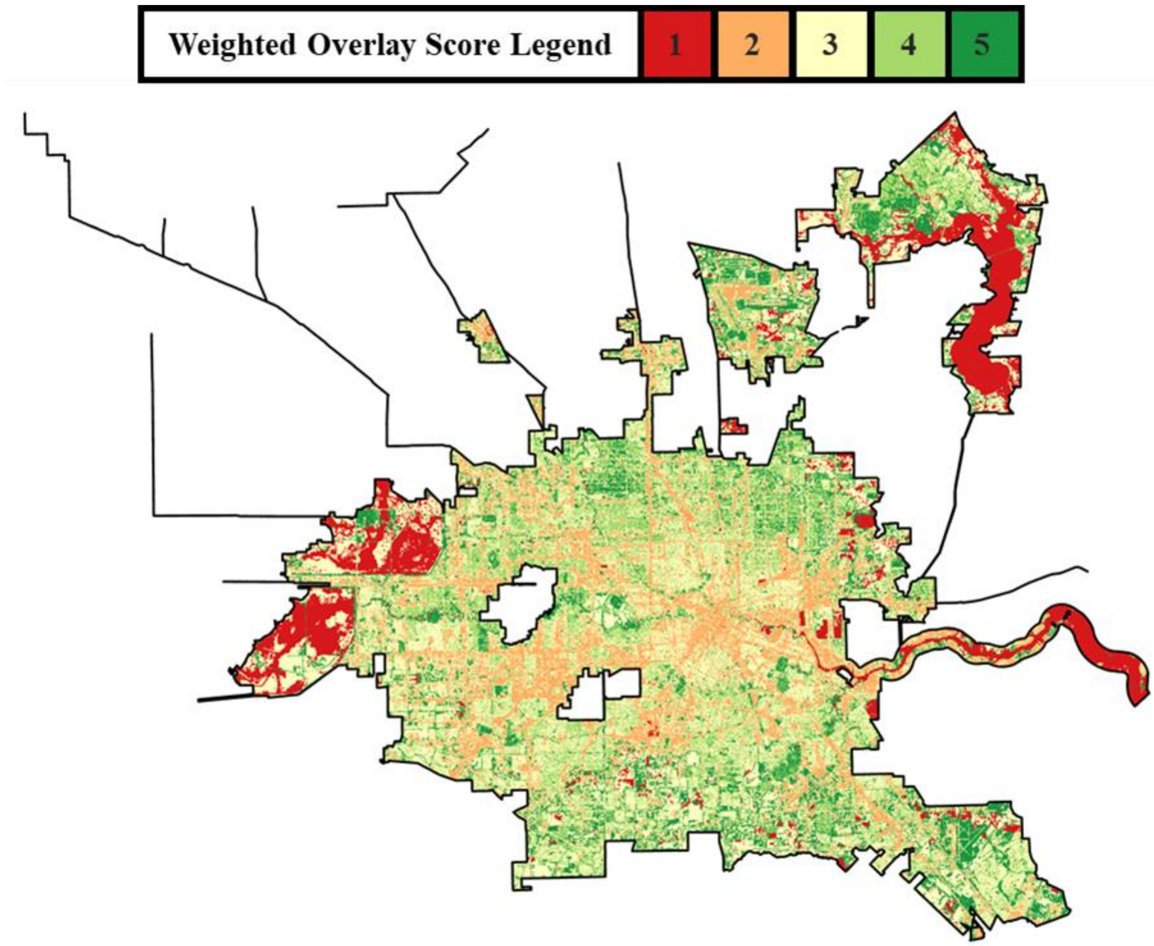
APPENDIX 1

SITE SUITABILITY ANALYSIS LAYERS

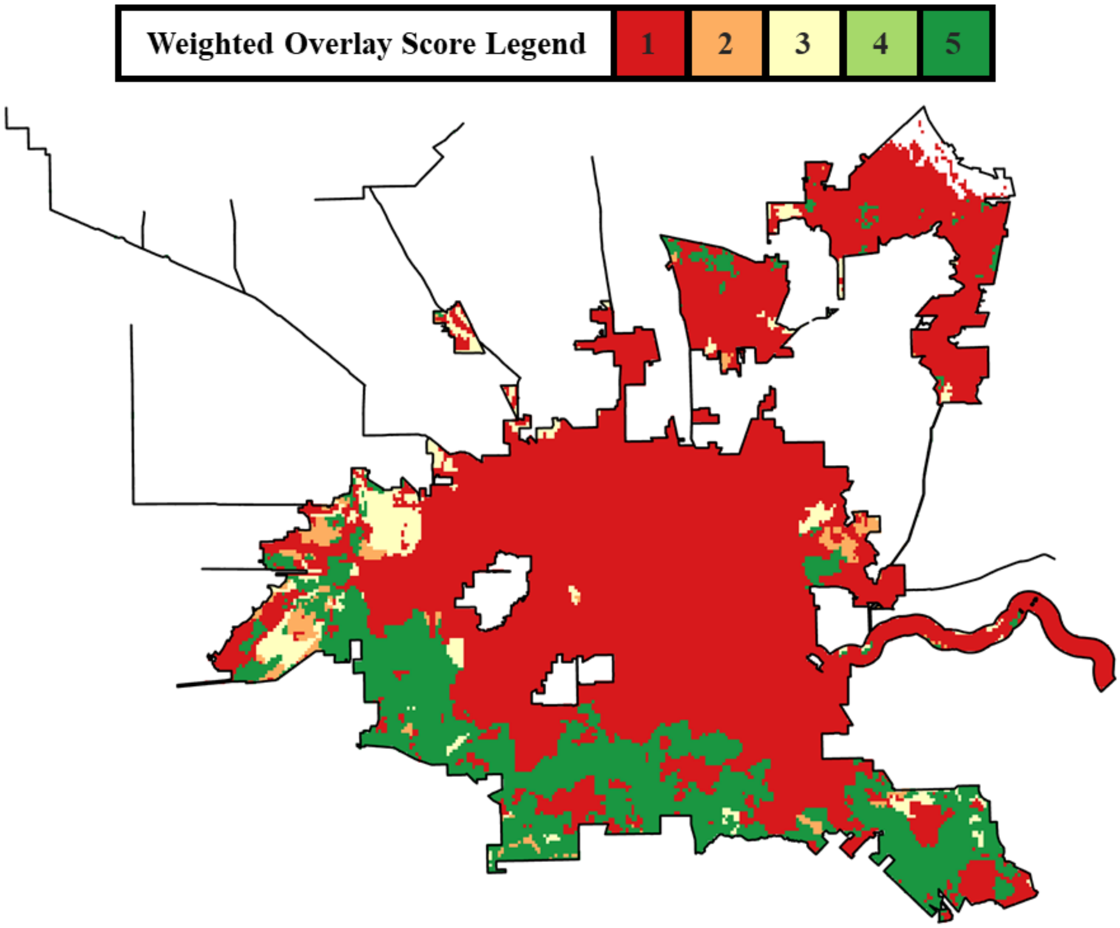
Land Use Group Suitability Layer



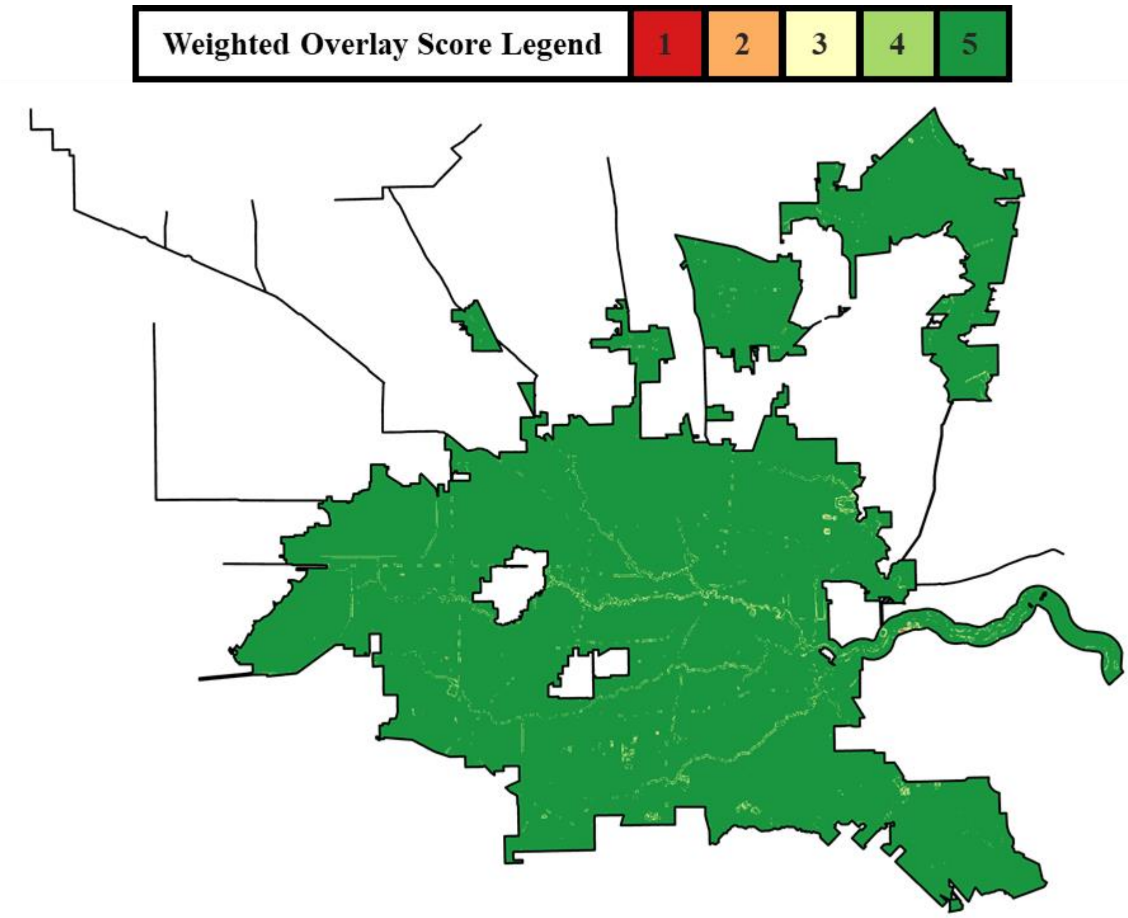
Land Cover Class Suitability Layer



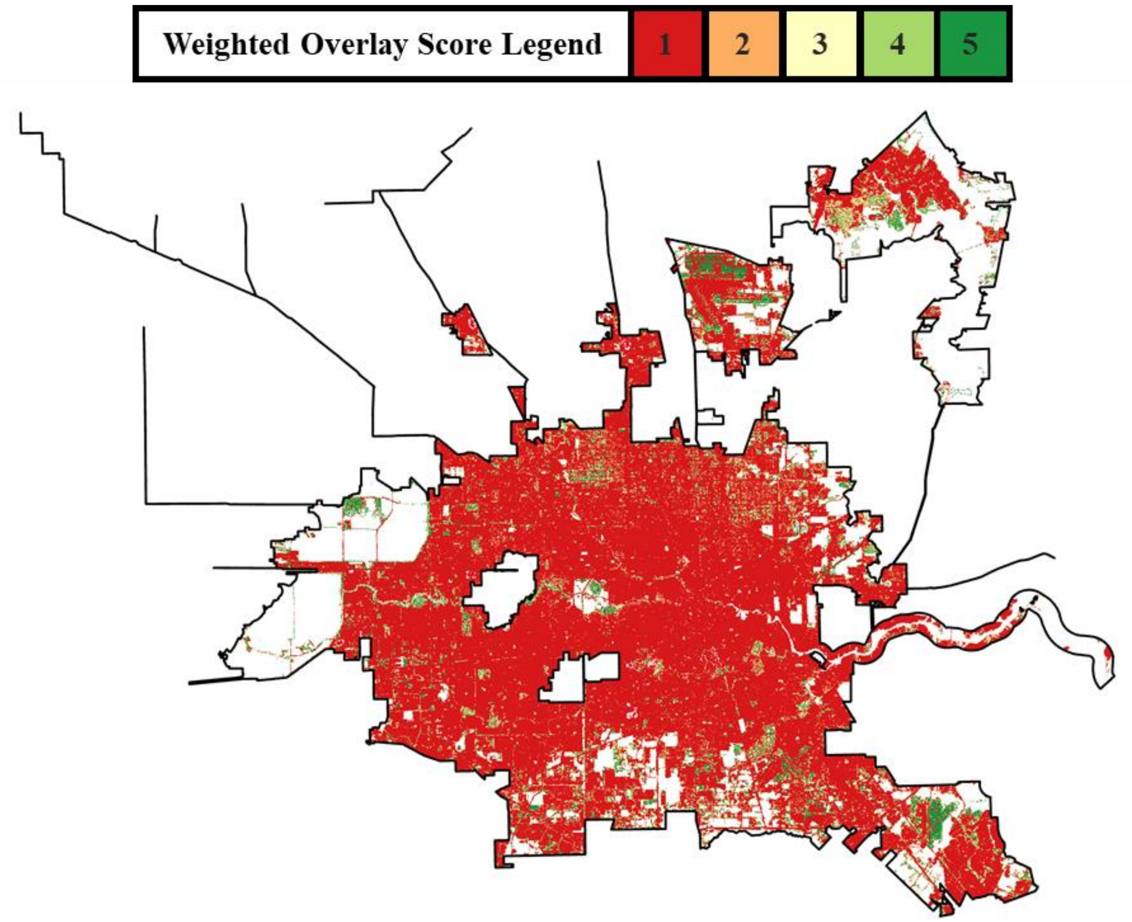
Soil Quality Suitability Layer



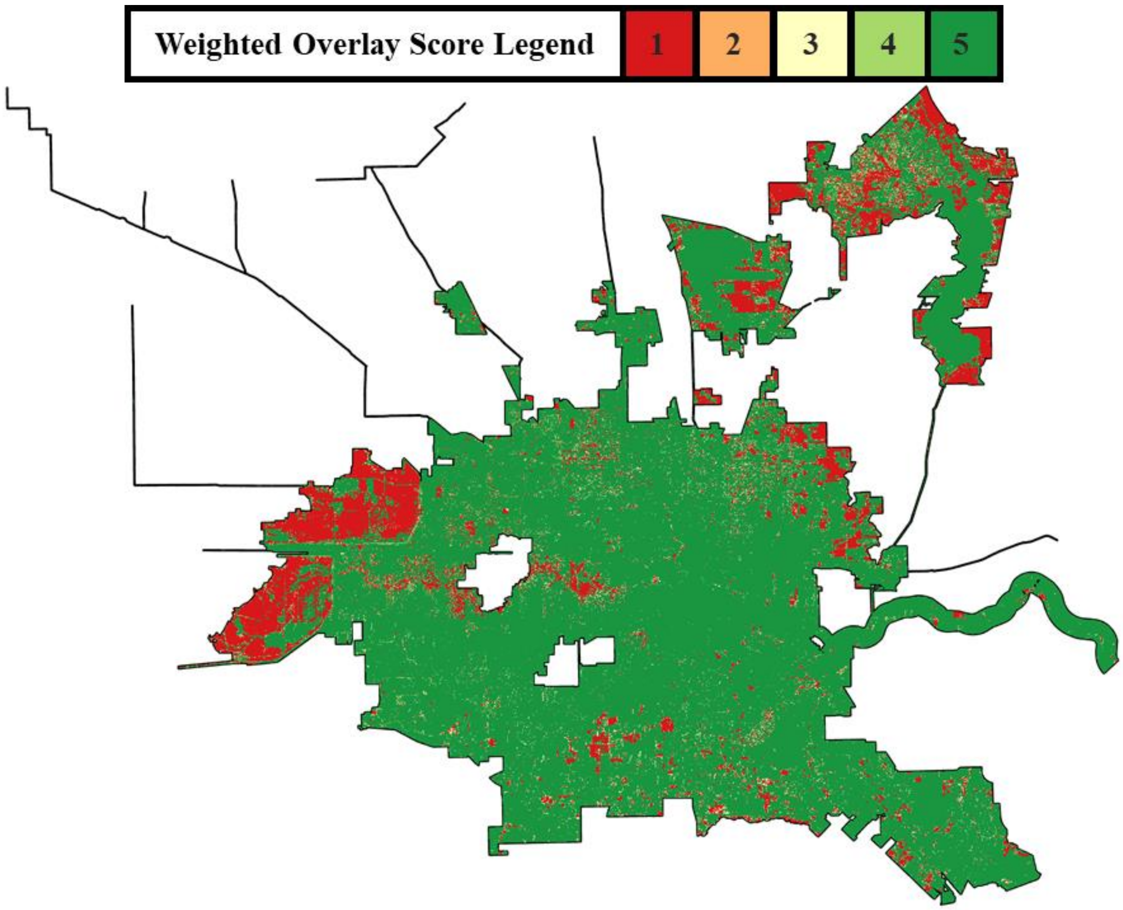
Terrain Slope Gradient Suitability Layer



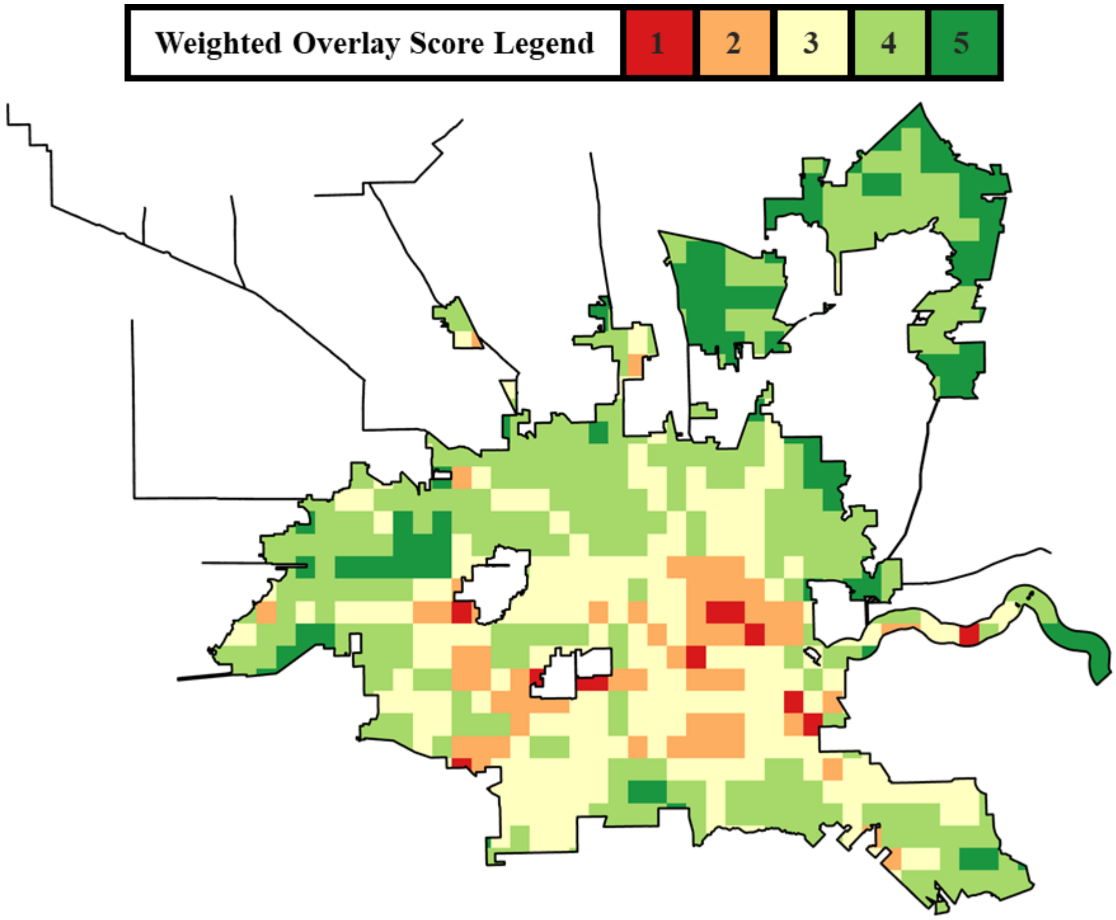
Impervious Surface Suitability Layer



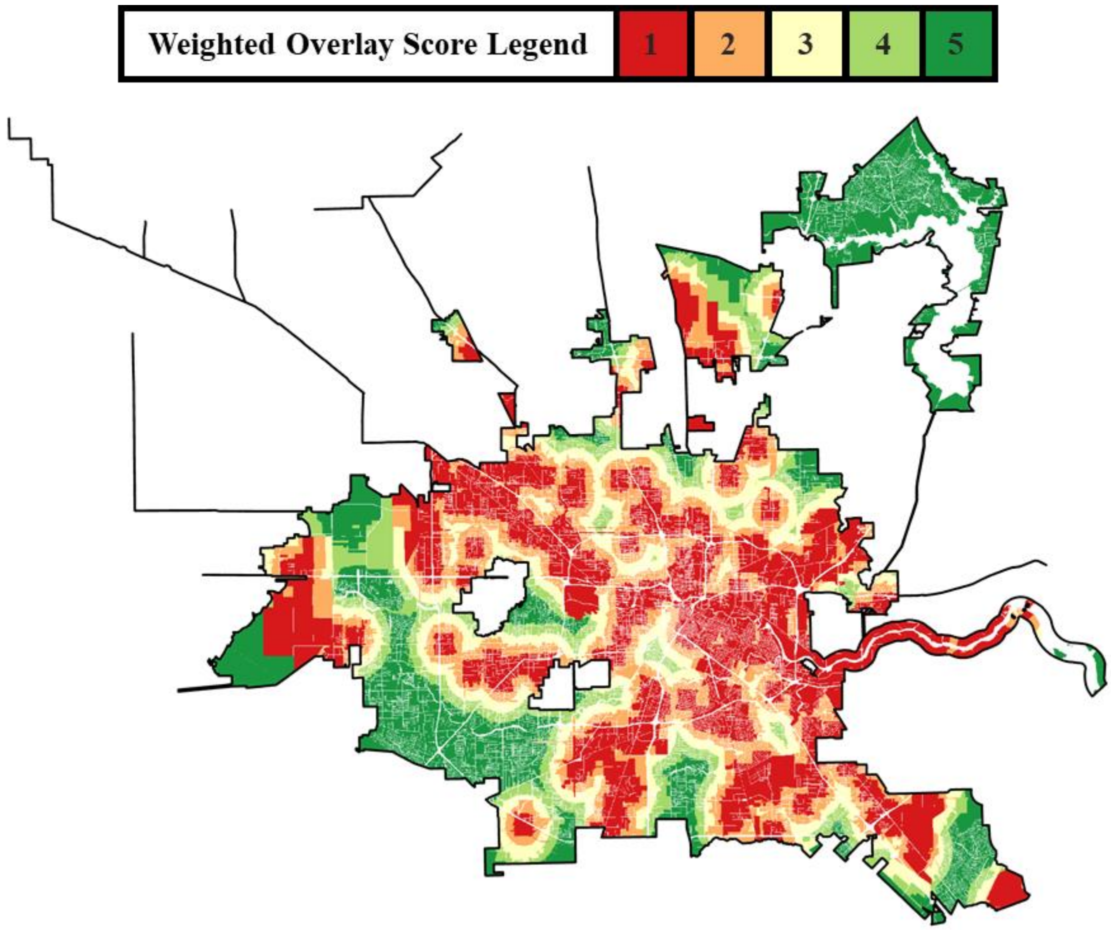
Tree Canopy Coverage Suitability Layer



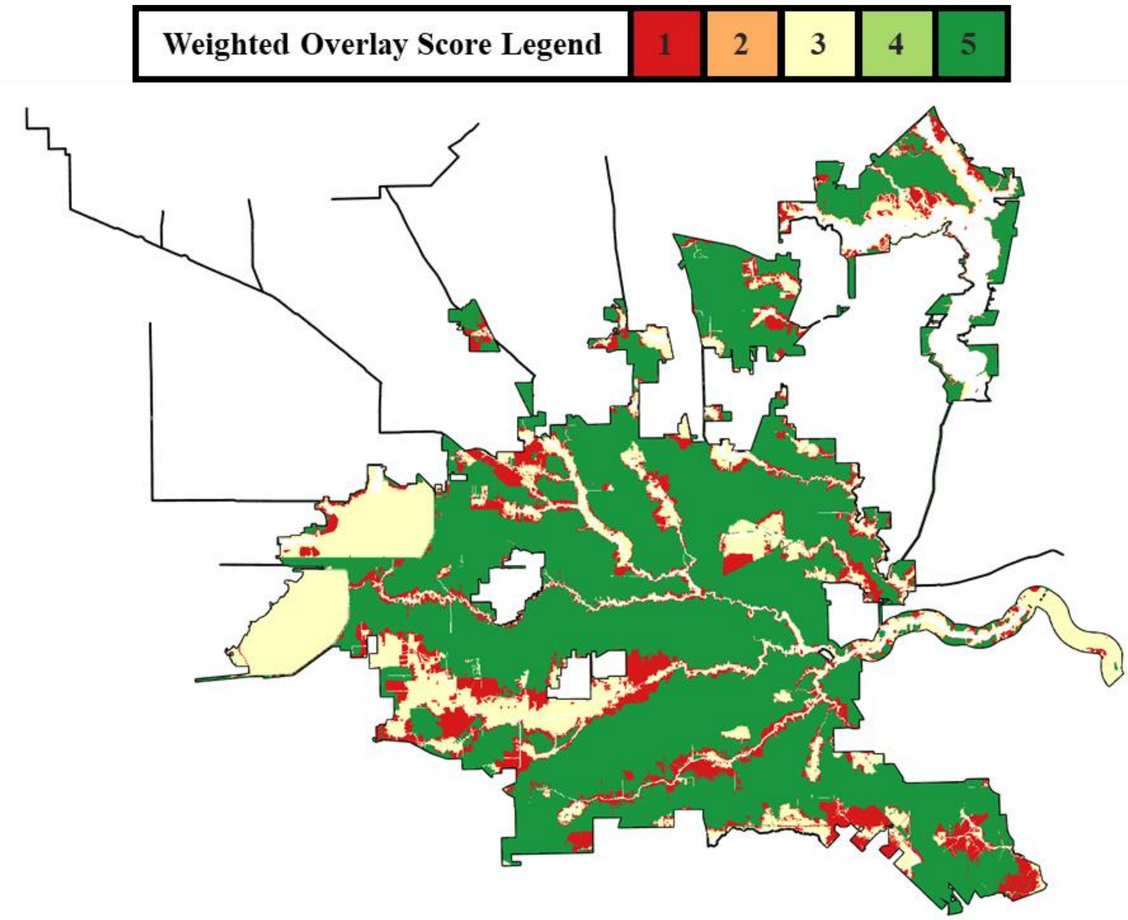
Road Density Suitability Layer



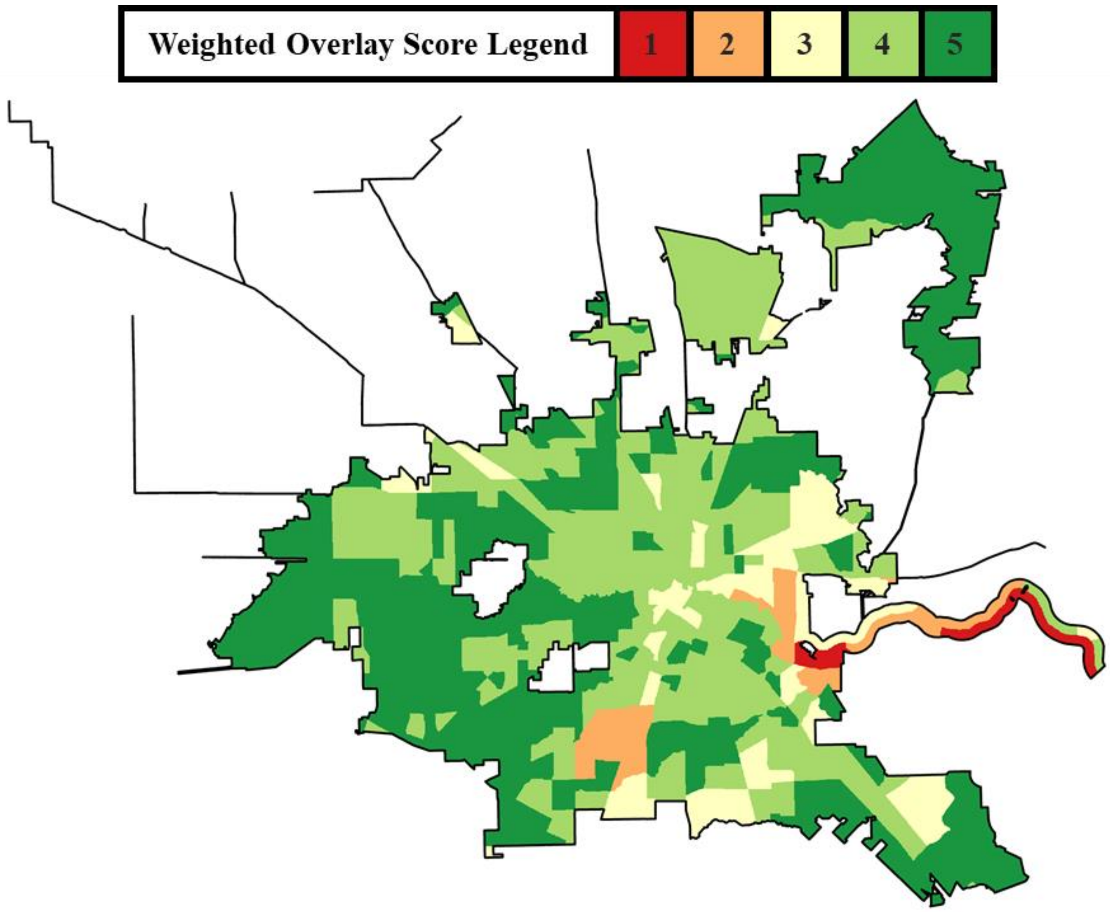
TRI Facility Proximity Suitability Layer



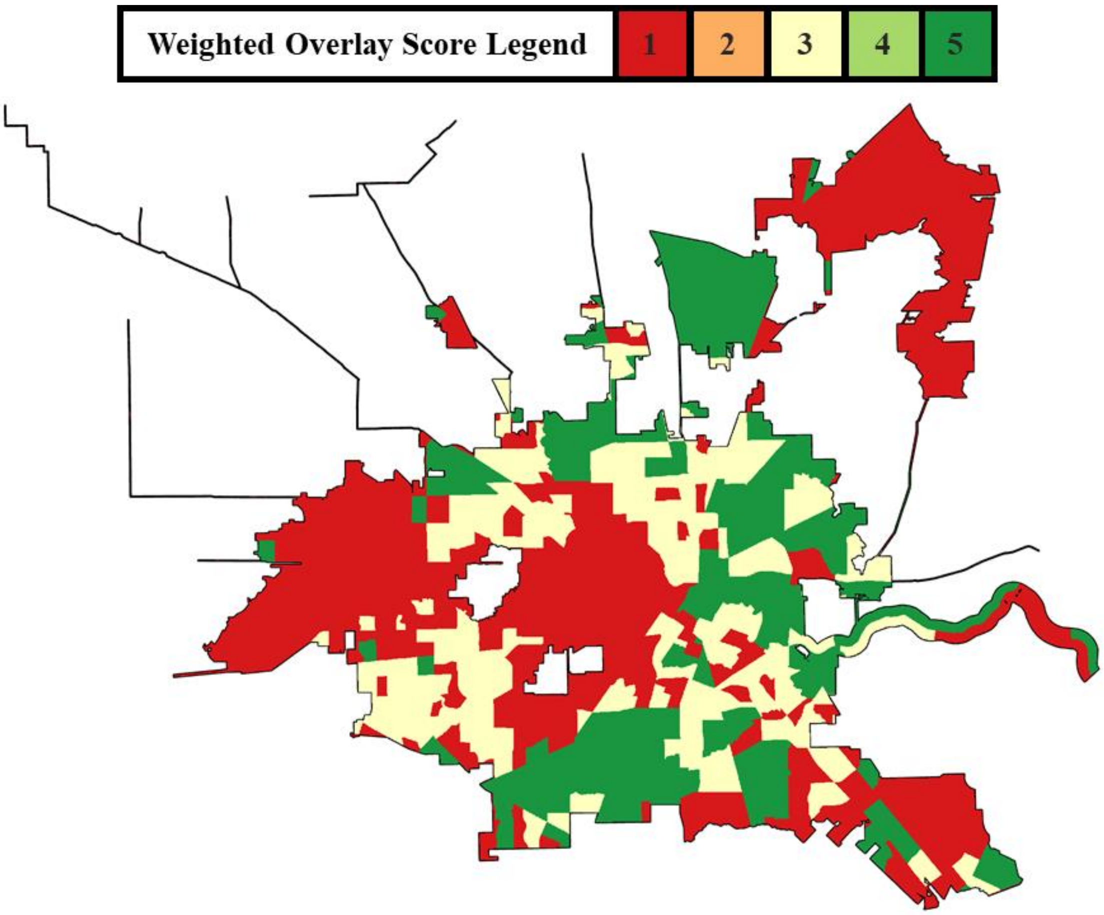
Flood Zone Suitability Layer



ToxPi Pollution Hazard Score Suitability Layer



Food Access Index Suitability Layer



APPENDIX 2

COMMUNITY GARDEN SURVEY INSTRUMENT

COMMUNITY GARDENER KNOWLEDGE AND RISK PERCEPTIONS SURVEY

1. Garden ID Number: _____ **2. Interviewer Initials:** _____	**3. Date / Time of Interview:** _ _ / _ _ / _ _ _ _ ___ : ___ AM/PM *M M D D Y Y YY*	*Key:* *D/K = Don't know*

PARTICIPANT DEMOGRAPHICS

4. Sex: □ Male □ Female □ D/K □ Refuse

5. How old are you in years? □ 18-25 □ 26-34 □ 35-54 □ 55-64 □ 65 or older □ Refuse

6. What is your race / ethnicity? Select all that apply:

- □ White (non-Hispanic)
- □ African, Black, or African American
- □ Asian, Asian American, or Pacific Islander
- □ Native American/American Indian
- □ Native American/American Indian
- □ Hispanic or Latino
- □ Other (write in): _____________
- □ Refuse

7. What is the highest level of education you have completed?

- □ Less than High School
- □ High School / GED
- □ Some College
- □ Associate Degree
- □ Undergraduate Degree
- □ Graduate Degree
- □ Other (write in): _____________
- □ Refuse

8. How many people currently live in your household?

□ 1 □ 2 □ 3 □ 4 □ 5 □ 6 □ 7 □ 8 □ Other (write in): _________

9. Is your total annual household income above or below the reference value for household size?

□ Above reference value □ Below reference value □ Refuse

Household Size (People in Household)	*Reference Value (USD)*	*Household Size (People in Household)*	*Reference Value (USD)*
1	*$12,490*	*6*	*$34,590*
2	*$16,910*	*7*	*$39,010*
3	*$21,330*	*8*	*$43,430*
4	*$25,750*	*>8*	*Add $4,420 for each additional person*
5	*$30,170*		

COMMUNITY GARDEN CHARACTERISTICS

10. Which of the following produce types are grown in {this garden}? Select all that apply:

□ Root vegetables □ Leafy vegetables □ Fruits □ Herbs □ Flowers □ Other: _________ □ D/K

11. Which of the following are applied in {this garden}? Select all that apply:

□ Compost □ Lime □ Miracle-Gro □ Manure □ Pesticides □ Top Soil □ Nothing

□ Other: ______________________________________ □ D/K

12. Please rate the following aspects of working at {this garden}:

12.1 The location of the garden(s) (distance from your home)	□ Excellent □ Good □ Fair □ Poor
12.2 The quality of the garden resources (soil, water, etc.)	□ Excellent □ Good □ Fair □ Poor
12.3 The knowledge of staff/volunteers	□ Excellent □ Good □ Fair □ Poor
12.4 The social atmosphere at the garden	□ Excellent □ Good □ Fair □ Poor

13. Please indicate how much you agree or disagree with following statements.

13.1 Because I work in {this garden}, I know more about the environment

□ Strongly agree □ Agree □ Disagree □ Strongly disagree □ D/K

13.2 Because I work in {this garden}, I care more about the environment

□ Strongly agree □ Agree □ Disagree □ Strongly disagree □ D/K

IRB NUMBER: IRB2019-1204M
IRB APPROVAL DATE: 02/20/2020

COMMUNITY GARDENER KNOWLEDGE AND RISK PERCEPTIONS SURVEY

GARDEN RISK KNOWLEDGE AND PERCEPTIONS	
14. Do you have any concerns about hazards to your health from your work in the garden? Describe:	
15. What soil contaminants are you aware of that urban gardeners should be concerned about in general? Describe:	
WILLINGNESS TO USE GARDEN RISK REDUCTION MEASURES	
If you suspected that your garden soil was contaminated, would you be willing to…?	
16. Test garden soil for:	
16.1 Metals such as lead, chromium or arsenic	☐ Yes ☐ No ☐ Maybe ☐ D/K
16.2 Organic chemicals including certain pesticides	☐ Yes ☐ No ☐ Maybe ☐ D/K
16.3 Other contaminants (describe):	
If you confirmed that your garden soil was contaminated, would you be willing to…?	
17. Remediate (clean up) soil by:	
17.1 Installing a barrier over contaminated soil, such as a plastic cover	☐ Yes ☐ No ☐ Maybe ☐ D/K
17.2 Adding natural soil amendments (e.g., compost, minerals)	☐ Yes ☐ No ☐ Maybe ☐ D/K
17.3 Adding fertilizers, clays or other sorbents that could improve the soil by binding to contaminants	☐ Yes ☐ No ☐ Maybe ☐ D/K
17.4 Removing and replacing contaminated soil	☐ Yes ☐ No ☐ Maybe ☐ D/K
17.5 Phytoremediation (i.e., the use of living plants to degrade, remove, and/or stabilize contaminants)	☐ Yes ☐ No ☐ Maybe ☐ D/K
17.6 Mycoremediation (i.e., the use of living fungi and/or fungal metabolites to degrade, remove, and/or stabilize contaminants)	☐ Yes ☐ No ☐ Maybe ☐ D/K
18. Change gardening practices by:	
18.1 Stop eating produce in contaminated areas	☐ Yes ☐ No ☐ Maybe ☐ D/K
18.2 Grow produce in raised beds or containers	☐ Yes ☐ No ☐ Maybe ☐ D/K
18.3 Only growing certain crops (e.g., NOT root vegetables)	☐ Yes ☐ No ☐ Maybe ☐ D/K
18.4 Wearing gloves while gardening	☐ Yes ☐ No ☐ Maybe ☐ D/K
18.5 Washing hands after gardening	☐ Yes ☐ No ☐ Maybe ☐ D/K
19. Remove surface contaminants on produce before eating by:	
19.1 Washing produce with water	☐ Yes ☐ No ☐ Maybe ☐ D/K
19.2 Washing produce with other solution (e.g., vinegar, detergent)	☐ Yes ☐ No ☐ Maybe ☐ D/K
19.3 Peeling produce	☐ Yes ☐ No ☐ Maybe ☐ D/K
20. Other risk reduction measure (Describe):	

IRB NUMBER: IRB2019-1204M
IRB APPROVAL DATE: 02/20/2020

APPENDIX 3

SURVEY INFORMATION SHEET

(Adapted from IRB Template Version 5/01/2018)

TEXAS A&M UNIVERSITY HUMAN RESEARCH PROTECTION PROGRAM
INFORMED CONSENT DOCUMENT

Title of Research Study: Assessment of Community Gardener Perceptions and Practices in Houston, TX

Investigator: Galen Newman, PhD

Why am I being asked to take part in this research study

You are invited to participate in this study because we are trying to learn more about community gardens and gardeners in Houston, Texas. You were selected as a possible participant because you were identified as a contact for a community garden in Houston, Texas. You must be 18 years of age or older to participate.

Why is this research being done?

We are gathering information to better understand community gardening and gardeners in Houston, Texas. Specifically, we want to learn about the concerns, perceptions, and knowledge of community gardeners.

How long will the research last?

The survey usually lasts around 15 minutes.

What happens if I say "Yes, I want to be in this research"?

If you agree to participate, you will be directed to the online survey form.

What happens if I do not want to be in this research?

Your participation in this study is voluntary. You can decide not to participate in this research and it will not be held against you. You can skip any question that you do not wish to answer and can end the survey at any time if you decide not to participate.

Is there any way being in this study could harm me?

We don't expect that you would be harmed from the questions that would be asked, but you can skip any question that makes you feel uncomfortable or stop the survey at any time.

What happens to the information collected for the research?

The information we collect may be used in research reports, presentations, and future studies. We will not collect any information that would link you with your survey responses.

(5/01/2018)

INFORMATION SHEET

Who can I talk to?

Please feel free to ask questions regarding this study. You may contact Galen Newman, the principal investigator of this study, later if you have additional questions or concerns at (979) 862-4320 or gnewman@arch.tamu.edu.

You may also contact the Human Research Protection Program at Texas A&M University (which is a group of people who review the research to protect your rights) by phone at 1-979-458-4067, toll free at 1-855-795-8636, or by email at irb@tamu.edu for:

- additional help with any questions about the research
- voicing concerns or complaints about the research
- obtaining answers to questions about your rights as a research participant
- concerns in the event the research staff could not be reached
- the desire to talk to someone other than the research staff

APPENDIX 4

SURVEY RECRUITMENT E-MAIL MESSAGE TEMPLATE

Dear [INSERT NAME],

My name is [INSERT NAME], and I am a student at the Texas A&M University School of Public Health. I am writing to invite you to participate in a research study about community gardens and gardeners in Houston, Texas. Individuals who are at least 18 years of age and affiliated with a community garden in Houston, Texas are eligible to participate. Your contact information was obtained from the public membership listing of a community garden association.

If you decide to participate in this study, you will click the link below to complete an online survey. The survey typically takes arounds 15 minutes to complete, and no information that could be used to identify you would be collected. Findings from this survey may be used to direct the development of new practices and technologies to address potential garden contamination and to identify opportunities for outreach and engagement with community gardeners. In addition, the results of this study could be used to apply for additional funding to conduct larger studies and interventions to reduce garden-related contaminant exposure risks, to publish research articles highlighting the need for continued work, and to inform policy related to healthy gardening.

Remember, this is completely voluntary. You can choose to be in the study or not. If you have any questions about the study, please contact me at [INSERT E-MAIL ADDRESS].

The survey is available at: [INSERT SURVEY LINK]

Thank you very much.

Sincerely,

[INSERT NAME]