HEAVY METAL SOIL CONCENTRATIONS IN THE URBAN TOLEDO, OHIO AREA: LEGACY OF HUMAN ACTIVITIES

Karen R. Burris

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Committee:

John Farver, Advisor

Jeffrey Snyder

Margaret Yacobucci

ABSTRACT

John Farver, Advisor

Urban environments have a history of anthropogenic input of heavy metals to soils. Toledo, Ohio is an urban setting that has been altered through heavy industry and transportation dating back to the 1800s. Heavy metal contamination in soil has been shown to cause serious health effects in humans, such as brain damage, birth defects, cancer, and even death.

A total of 137 Toledo soil samples were collected in collaboration with local Toledo schools, the Manos Community Garden, and a previous study completed by Stewart et al (2014). Stewart's study samples and the local Toledo schools' soil samples were collected by K-12 students through a hands-on citizen science project. The samples were analyzed to determine the concentrations of a series of heavy metals, including arsenic, cadmium, chromium, lead, nickel, and zinc. The results revealed multiple samples with elevated levels of all six focus metals greater than the Ohio EPA's soil background levels of the region. Two of these elements, arsenic and lead, had concentrations higher than the USEPA screening level for soils of this region in 73% and 7% of samples, respectively. Locations with elevated heavy metals concentrations in soils were mostly residential yards with older houses and within areas of high transportation. Therefore, the elevated levels of heavy metals were likely deposited from a legacy of human activities. Heavy metal predictive concentration maps of the Toledo, Ohio area were created to show possible areas of concern. The predictive maps showed a higher concentration of most elements in the Old West End area of Toledo.

The findings were presented to the collaborating schools and in public forums to educate citizens about elevated heavy metal soil contamination in their area. They were given possible reasons for the contamination, explaining the harmful side effects of human activities on the soils. The health risks associated with the contamination were presented along with how to prevent health issues and how to take precautions around heavy metals.

Dedicated to my loving parents Rodney and Bonnie Burris, for never giving up on me and always pushing me to succeed.

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INTRODUCTION

In urban environments, the effects of pollution and contamination on the residents can be detrimental to their health and wellbeing. Exposure to heavy metals can be hazardous to human health due to their toxicity even at low concentrations (Idodo-Umeh and Ogbeibu, 2010). Heavy metals in urban environments can come from a variety of anthropogenic sources including factories, coal burning power plants, battery manufacturing, dredged soil sludge, smelting, metal works, waste material, previously contaminated water ways and soil, lead based paint, farm fertilizer, and automobile emissions (Olawoyin et al., 2012; ATSDR, 2007; Pradeepkumar, 1991; Wu et al., 2013). The heavy metals released by human activities can enter the water supply, be released into the air, and be deposited in the soil. Heavy metals are also found naturally in the soil and water from normal earth processes. However, the concentrations of heavy metals in these natural sources are generally below levels deemed detrimental to human health.

Elevated concentrations of heavy metals in some soils can simply represent higher natural background levels of the elements in the soil. Soil is the result of weathering of rocks. Rocks contain a variety of different elements depending on where and how the rocks were formed. Therefore, different geographic locations will have different background levels of heavy metals in the soil. The background levels of many regions have been extensively researched to determine how much of each element is found naturally in the soil. Establishing the background level is the starting point for conducting soil investigations. The results of two different studies will be used to provide background levels for this project: the Ohio Environmental Protection Agency (2015) and Cox-Colvin & Associates (1996).

The Ohio EPA (2015) established the background metal concentrations in soils in Lucas County, Ohio for seven different elements. It used property reconnaissance, the Lucas County

Soil Survey, and 11 sample locations to determine the background levels for Lucas County for soils with more or less than 50% sand. The seven elements established did not include the element zinc. For this study, zinc's background level was taken from the Cox-Colvin & Associates (1996) study. Cox-Colvin's study sampled soil that was considered to be unaffected by industrial contamination in multiple sites across all of Ohio. Cox-Colvin & Associates used 64 samples to statistically generate Ohio specific background levels for 20 different metals. For both of these studies, background levels of metals in soils were found to vary significantly between soils even in proximity of one meter to one another. Considering the background levels reported for Ohio in the studies referenced, arsenic concentrations is over its respective screening level could be a result of the pre-existing background level and not anthropogenic activity.

Another major reason for elevated concentrations of heavy metals in soils is human activity. In urban areas, there is a greater density of humans than in rural areas. Therefore, any adverse human activity would be more magnified. For example, urban settings have more daily commuters and more vehicles on the roads. Most cars and buses run on fossil fuels and release emissions into the air that are then deposited on the soils of the surrounding area. The greater the density of people in an area, the greater the deposition of fossil fuel derived elements onto the soil. The heavy metals naturally contained in fossil fuels include arsenic, chromium, nickel, and zinc (Moreno et al., 2007). In addition, prior to being banned in the U.S. in the 1990s, lead was added to gasoline (Filippelli et al., 2005). The ban was enacted in 1996 for on-road vehicles, but 4-5 million tons of Pb in the form of tetraethyllead (TEL) had already been added to gasoline in the previous decades (Mielke, 1994). The lead deposited from car exhaust can remain in the soil for thousands of years (Rooney et al., 1999; ATSDR, 2007). Any locations that were high in population prior to the 1990s will likely have elevated levels of lead in their soils due to TEL in

the gasoline. The other heavy metal elements (arsenic, chromium, nickel, and zinc) are still present in car exhaust and deposited on the soil, again resulting in higher concentrations of these elements in the urban soils. Areas that have a high population density also tend to be high in industry and factories, which can further contribute to elevated concentrations of heavy metals. During manufacturing, factories using metals or other chemicals tend to release emissions into the air that then settle and accumulate on the local soil.

Toledo, Ohio

Toledo is an urban area with a history of heavy industry and transportation dating back to the 1800s. As Toledo is at a crossroads between multiple current and past major metropolises, including Detroit, Chicago, Indianapolis, Columbus, and Cleveland, it has served as a major transportation hub. There are two major interstate highways running through the heart of Toledo: I-75 and I-80/I-90. The combination of industrial and transportation-related outputs may account for the elevated levels of heavy metal contamination in Toledo-area urban soils. The contaminated soils can be brought into the home by foot traffic or wind, creating household dust containing harmful levels of heavy metals.

Increased volumes of traffic are a byproduct of a rise in population density. The Toledo area population grew from 100,000 to 380,000, almost quadrupling, from 1900 to 1950 (Toledo Population, 2019). The increased population from 1900 to 1950 also brought a need for more housing during a time period that coincided with the extensive use of lead-based paints. When these older houses are torn down, soil lead contamination can occur. Residual lead paint is deposited into the nearby soils and any debris that is burned on site will leave residual lead in the soils as well. Additionally, normal weathering of a lead painted house will deposit lead around

the perimeter. This perimeter is called the drip zone and is defined as the one-meter distance from the exterior of a house or other Pb painted structures. Drip zones have been shown to contain highly elevated levels of lead contamination (Merkley, 2019; Pettinelli, 2007). Due to the coincidence of Toledo's population and housing boom in the early twentieth century with use of lead-based paints, and its ongoing existence at the nexus of many metropolises, Toledo provides an ideal site to examine the contamination levels caused by urban living that can be extrapolated to other similar urban settings worldwide.

Beyond lead, there are several other heavy metals that could be potentially harmful. Arsenic (As), Cadmium (Cd), chromium (Cr), lead (Pb), nickel (Ni), and zinc (Zn) are a few of the heavy metals found in soils in Toledo, Ohio. These will be the focus metals for this study because they represent the range of sources and pathways of the other heavy metals. Previous studies have also found As, Cd, Cr, Pb, Ni, and Zn to be at elevated concentrations or above background levels in similar urban environments (Murray et al., 2004). A brief description of the sources, pathways and accumulation, and health effects of the focus heavy metals is provided below.

Arsenic

Arsenic is a heavy metal that occurs naturally in soils and can become elevated due to anthropogenic activities (Reimann and Caritat, 1998). Natural sources of higher concentrations of As are primarily from igneous and sedimentary rock deposits, which then weather into soils with high As concentrations (Mandal and Suzuki, 2002; Stevens et al., 2018). Anthropogenic sources of arsenic in the soils can come from the burning of fossil fuels, the smelting of metal, the manufacturing of arsenic containing products including pesticides, insecticides, herbicides,

wood sealers and preservatives, additives to feed, fertilizer, and waste (Enterline et al., 1995; Foy et al., 1992; Liu et al., 2009; Nriagu and Azcue, 1994; Yang et al., 2015).

Arsenic can be found in plants at elevated concentrations. Bioaccumulation causes arsenic to pass up through the food chain from primary producers to secondary producers and higher trophic levels (Idodo-Umeh and Ogbeibu, 2010; Gal et al., 2005). Plants can take up arsenic from water or soil through their roots and retain it within their biomass. When the plant is eaten by another organism, the arsenic is transferred to this new organism. The result of up-trophic accumulation is elevated As levels in foodstuffs consumed by humans. Any plants that are grown in soil containing As will retain the arsenic with the highest concentrations stored in the root system (Roychowdhury et al., 2005). Research has found that the vegetation that accumulates the most As are mustard, rice, amaranth, and spinach (Kar et al., 2013). The bioaccumulation of As presents a potential threat to urban or home gardeners. Home gardeners generally do not test their soil for heavy metal contaminants and, as such, are unaware of any contamination and cannot know if the vegetation they grow is safe to consume or not. Gardens pose a special threat to children who might be exposed to or play in the soil. Children spend much more time engaging in hand-to-mouth activity, subsequently ingesting soil and dust particles that could contain arsenic (Liu et al., 2016) as well as other heavy metals.

The US Agency for Toxic Substances and Disease Registry has named arsenic as one of the top priorities in terms of harmful pollutants (ATSDR, 2007). This heavy metal is a carcinogen that is known to cause cancer of the skin, liver, lung, kidney, and bladder (Alain et al., 1993; ATSDR, 2007; Mazumder et al., 2005; Tseng, 1977). In addition, As may cause other health issues such as skin lesions, intestinal or metabolic disorders, birth complications, and cardiovascular diseases (Ahmad et al. 2001; Done and Peart, 1971; Jain and Ali, 2000). Children

are prone to more permanent damage than adults; their faster metabolism, smaller body mass, and undeveloped brains put them at a higher risk (Carrizales et al., 2006; Zhang et al., 2013; Asadullah and Chaudhury, 2008). In addition, children may suffer from intellectual damage such as long-term memory issues, impaired verbal IQ and comprehension, and overall reduced intellectual function (Asadullah and Chaudhury, 2008; Calderon et al., 2001).

Cadmium

Cadmium is a heavy metal that occurs naturally in soils and can become elevated due to anthropogenic activities (Alloway, 2013). Natural sources of higher concentrations of Cd are primarily from sedimentary rock deposits, which then weather into soils with high Cd concentrations (Greenwood and Earnshaw, 1997; Kabata-Pendias and Pendias, 2001). Anthropogenic sources of cadmium in the soils can come from fertilizers, production of metal, production of batteries, combustion of oil, and sewage sludge (Alloway, 2013).

Cadmium is a heavy metal that geoaccumulates and bioaccumulates. Geoaccumulation refers to the properties of an element that allow it to become soluble in water and transported through a water system (Wu, 2013). Cadmium from the atmosphere that is deposited does not remain in the soil where it was deposited, and can be transported by runoff and streams leading to contamination of other water and soil. After transportation, the amount of cadmium at its final site of deposition would be at a much higher concentration than it originally was due to geoaccumulation (Opfer, 2011). Bioaccumulation means that cadmium passes through the food chain going from primary producers to secondary producers and so forth up trophic levels (Ido-Umeh, 2010; Gall, 2015). Plant life can accumulate cadmium through uptake from soil or water. The plant stores the cadmium until it is eaten by another organism or the plant dies and

decomposes. The result of up-trophic accumulation is elevated Cd levels in foodstuffs consumed by humans. Zhang (2013) looked specifically at the accumulation of cadmium in lettuce and determined that lettuce accumulates Cd at greater proportions compared to other vegetation. This property makes leafy vegetables the predominant source of high health risk contamination levels of cadmium as opposed to other food sources (Zhang, 2013). Cadmium does not have an adverse effect on plant health; therefore plants can continue to thrive even if they have elevated levels of cadmium (Hashemi, 2002). The bioaccumulation of Cd presents a potential threat to urban home gardeners who cannot visibly see if the vegetation they grow is safe to consume or not.

As cadmium accumulates in the body it can cause damage to the lungs, kidneys, and bones and has carcinogenic properties (Olawoyin, 2012; Nordberg, 2009; Pan, 2010). Due to bioaccumulation, Cd is especially malicious to the liver, which attempts to filter out the foreign compound (Chakraborty, 2013; Bertin, 2006). However, since humans have no way of expelling cadmium out of the liver, as more and more cadmium from foods are digested, the concentration of Cd in the liver increases leading to severe damage (Chakraborty, 2013).

Chromium and Nickel

Chromium and nickel are heavy metals that have similar chemical behavior in soils. Cr and Ni are found naturally in soils at higher concentrations than most other heavy metals as they exist in all rock types (Alloway, 2013). However, in more recent years the anthropogenic input of chromium and nickel has increased dramatically (Alloway, 2013). The production of specialty steels, particularly stainless steel, as well as fertilizer, batteries, and the combustion of coal and petroleum all release these heavy metals into the air or deposit them onto soils (Alloway, 2013). Another major anthropogenic input is the use of sewage sludge from municipal wastewater

treatment facilities as a fertilizer on agricultural fields. This practice reintegrates these heavy metals back into the environment.

There are two forms of chromium that could be found in soils, the hexavalent (Cr VI) and trivalent forms (Cr III). The trivalent form is the type of chromium that is found naturally in soils from weathering of all rock types and is more likely the form found in residential yards (USEPA, 2000). The hexavalent is sourced back to direct contact with manufacturing, production, industry and therefore less likely to be found in residential soils (USEPA, 2000).

Nickel is an essential element for plant growth, but very low concentrations are required for optimal growth (Alloway, 2013). Compared to other heavy metals, nickel bioaccumulates more efficiently in plant matter (Correia et al., 2018). Conversely, chromium is not essential for plant growth. Chromium tends to be less bioavailable than nickel, but still is absorbed by plants, particularly leafy greens such as cabbage (Alloway, 2013). High nickel and chromium concentrations in the soil damage leaves, stunt the growth of plants, and result in poorly developed root systems (Pratt, 1966).

Chromium and nickel health risks range from irritations to potential fatalities. The hexavalent Cr (VI) form of chromium is a strong oxidizing agent and is much more toxic than the minerals containing the Cr (III) form, which is found naturally in soils (USEPA, 2000). USEPA screening values for Cr (VI) are 23 mg/kg and 12000 ppm for Cr (III). Exposure to Cr (VI) is generally occupational. The hexavalent form can cause skin lesions, ulceration and perforation of the nasal septum, eardrum perforation, decreased spermatogenesis, and lung carcinoma (Yoshinaga et al., 2018). The inhalation of Cr via dust can lead to many pulmonary issues such as asthma, pulmonary fibrosis, and lung cancer (Buzea et al., 2007). Nickel similarly

causes pulmonary issues such as chronic bronchitis, reduced lung function, and cancer of the lung and nasal sinus (ATSDR, 2005).

Lead

Lead is a heavy metal that occurs naturally in soils at a minimal amount from the weathering of all rock types (National Academies of Sciences et al., 2017). Lead can become greatly elevated in soils due to human activity (Alloway, 2013). Lead is a relatively immobile element, so once it is deposited on soils it tends not to move or be carried away (Alloway, 2013). It also binds strongly to organics and iron oxides. Urban, agricultural, and mining areas generally have higher concentrations of lead because of transportation, farming, and industry (Rooney et al., 1999).

Two main sources of lead in urban areas are lead-based paint and leaded gasoline, both of which were banned in the US by the 1990s (Filippelli et al., 2005). Older houses can be a source if they are still painted with lead-based paint or if soils surrounding the dwellings are contaminated due to poor removal of older paint (Lanphear et al., 1998). However, Lanphear showed that lead paint is not the most significant source of lead poisoning, for children in particular (1998). Rather, a substantial source of lead poisoning in children stems from the use of lead in gasoline (Mielke et al., 1999). The lead in emissions from automobiles settles onto the soil where it bonds tightly to sediments; once it is deposited in the topsoil, it can remain there for thousands of years (Rooney et al., 1999; ATSDR, 2007). Consequently, the soils with the greatest lead contamination tend to be located in historically high-volume traffic areas (Stewart et al., 2014; Filippelli et al., 2005; Mielke et al., 2013; Mielke and Reagan, 1998).

Lead contaminated soil can enter the body by inhalation from the air or ingestion into the body from a variety of pathways (Duggan et al., 1985). Being a major transportation and shipping hub, and having several historic neighborhoods, Toledo has both a history of high traffic volume and many old or demolished lead-painted houses and hence is likely to have elevated lead levels, as reported in Stewart et al. (2014) and Merkley et al. (2019). The Merkley et al. (2019) study focused on soil in and around community gardens. This study found that the lead levels in Toledo's community gardens were mostly due to demolished structures that were painted with lead-based paint and high-volume traffic areas.

Children are the most at risk for lead poisoning because they are more likely to engage in hand-to-mouth activities, consequently ingesting contaminated soil (Clark et al., 2006; Lanphear et al., 1998). The contaminated soil can originate from a playground, backyard, or household dust (Duggan et al., 1985). The Ohio 2016 State Health Assessment found that across the state of Ohio, 6% of children had elevated blood lead levels compared to the US average of 4.2% (Ohio Department of Health, 2016). Lucas County alone had over 5% of young children with confirmed elevated blood lead levels of 5 ug/dL or greater (Ohio Department of Health, 2016). In congruence, the 2019 Ohio State Health Assessment Summary Report declared the city of Toledo to be at a 10, out of a scale of 10, for lead exposure risk, well above the nation's risk average of 5.5 (Ohio Department of Health, 2019).

Plants do accumulate some amount of lead from soils. However, as the concentration of lead in the soil increases, the rate of absorption into plant matter does not increase. There is no correlation between the amount of lead in the soil and the amount taken up by plants (Menzies et al., 2007).

The inhalation or ingestion of lead can cause many health concerns. For the general population, the greatest system at risk is the nervous system, which can be greatly harmed (RAIS, 2009; Gump et al., 2005; ATSDR, 2007). Other negative effects include brain damage, anemia, kidney failure, rise in blood pressure, ankle and wrist fragility, and even death (RAIS, 2009; Gump et al., 2005; ATSDR, 2007).

Lead is especially harmful to young children, who engage in hand-to-mouth activities and have lower body masses; about 50% of ingested lead is absorbed into a child's bloodstream while only 10% of lead is absorbed into an adult's bloodstream (Lanphear et al., 1998). Since children are still in development, the most detrimental effect of lead poisoning is brain damage leading to learning impairments (ATSDR, 2000).

Zinc

Zinc is a heavy metal that can also be found naturally in soils formed from parent rocks of all types but is also present due to anthropogenic sources. Anthropogenic sources of zinc include fertilizers, the use of sewage or animal sludge for soil amendments, brass production, and any galvanized metal such as fencing or building frames; all are potential sources for elevated levels of zinc in soils (Alloway, 2013).

Zinc is an essential nutrient for plants and animals. When zinc comes in contact with other elements in soil, an immediate chemical reaction occurs. This reaction causes zinc to absorb into solid phases, which makes the zinc unavailable to be taken up by plants (Alloway, 2013). This change actually causes a major deficiency of zinc in plant matter, causing harm to the growth of plants. To fix this, artificial fertilizer, sewage sludge, or manure can be applied to agricultural fields. However, since zinc immediately reacts with the soil, zinc has to be added

repetitively to the soil. This could in turn be toxic to the roots and stocks of plants and also toxic to humans because of the oversaturation of solidified zinc in the soil.

A higher concentration of zinc in soil is rarer than finding soils that are deficient. High industry is one of the causes in these rare cases, as manufactured (galvanized) metals or burned fossil fuels can contaminate the surrounding soil. Another cause is from excessive fertilizer use.

The primary risk in regard to zinc for humans is deficiency. Deficiency of zinc can cause a variety of adverse effects such as severe immune dysfunctions, hyperammonemia, neurosensory disorders, and decreased muscle mass, growth retardation, delayed sexual and skeletal maturation and behavioral effects (Alloway, 2013; Prasad, 2008). Although the more rare case, there is still the possibility of zinc being at too high of a concentration and causing health issues in humans. Zinc toxicity could cause problems such as immunosuppression, harmful effects towards the lymphocyte function, and negative effects on the immune-regulatory system (Plum et al., 2010).

EDUCATIONAL OUTREACH

One reason that the health issues of heavy metal contamination are still a concern in urban settings is a general lack of public awareness of how and where the toxins come from and move through and accumulate in the environment (Popoola et al., 2019). Since heavy metal poisoning most strongly affects children, both school children and, in turn, their parents should be the main target for education about the potential health risks associated with contaminated soil. Some ways to accomplish this task include collaborating with local urban schools, analyzing soil that the public views to be of the greatest concern, and holding informative outreach sessions in schools and public forums.

Collaborating with local classrooms can provide an opportunity for the students to become the science investigators. This citizen science approach involves scientific research conducted by a non-professional or amateur individual. Previous research by Stewart et al. (2014) and by Senabre et al. (2018) have shown citizen science to be an effective form of sample collection and in turn, hands-on education.

In this study, students at focus schools in the Toledo area were asked to choose locations they wanted to test for heavy metals in the soil (see Appendix B). The children gained permission from their parents to collect the soil sample themselves (see Appendix B). By participating in this research project, the students were able to experience a hands-on-approach to inquiry-based learning about the environment and the effects that human activities have on the health of the environment. They were also informed of the possible risks associated with contaminated soil and how to avoid, or at least minimize, these risks (see Appendix A). The children's parents were informed of heavy metal risks through the informational letter and

permission slip pertaining to their child's involvement in this study (see Appendix B). After soil analysis, follow-up presentations (see Appendix C) were provided of quantified contamination levels of the soil, along with predictive maps of the Toledo-Ottawa Hills area (see Appendix C), and a reiteration of the hazards of heavy metals and precautions to be taken (see Appendix D).

The citizen science approach taken by this study educated both parents and children on the potential hazards of contaminated soil. Children were encouraged to adopt best practices to minimize their exposure and uptake of heavy metals, like washing their hands before eating and after playing outdoors. Students and parents were informed about safer gardening procedures. The teachers involved in the students' classrooms were also better educated on the potential risks of contamination in soils and can now continue to educate future students on how to avoid exposure and lessen health risks. This study also benefits the general public of Toledo by providing an analytical report of the concentration of heavy metals in their local soils.

OBJECTIVES

The objectives of this study are to:

1. Determine the concentrations of a series of metals, including the heavy metals arsenic, chromium, lead, nickel, and zinc, in residential soils in the Toledo, Ohio area.

2. Produce heavy metal predictive maps of the Toledo, Ohio area to show possible areas of concern.

3. Educate the public about elevated heavy metal soil contamination in their area, including potential causes of the contamination and the health risks associated with the contamination.

4. Promote hands-on science education in local Toledo schools by conducting citizen science research with K-12 students.

METHODS

Participant Selection

Four Toledo-area schools collaborated with this project: Ottawa Hills Elementary, Horizon Science Academy Schools, Madison Avenue School of Arts, and Imagine Hill Academy. These schools were chosen to provide a wide spatial variety of soil sampling locations. The four schools' locations are shown in Figure 1, with the students' sampling locations shown in Figure 2. Ottawa Hills Elementary was chosen to connect this study to a previous study completed by Stewart et al. (2014). Imagine Hill Academy was chosen in part because the school manages gardens on its grounds. Horizon Science Academy and Madison Avenue School of Arts were chosen for their closer proximity to inner city Toledo in order to collect more spatially diverse samples and to fill in areas not sampled by Stewart et al. (2014). The collaborating class levels ranged from second to tenth grade. Ottawa Hills involved three fourth grade classes; Imagine Hill involved one third grade class; Madison Avenue School of Arts had four second grade classes; and Horizon Science Academy involved two seventh grade, one eighth grade, one ninth grade, and three tenth grade classes. The educational study reached approximately 360 students and their families. A total of 120 soil samples were collected by the students. Some of the samples were not included because they lacked location type, were from a poor location type (such as an indoor house plant), had no address, had no permission slip returned with the sample, or the sample was of a different soil type than what was on the label. For example, soil samples that were labeled as front yard yet contained potting soil pearls were discarded. A total of 100 viable soil samples were analyzed in this project, as described in Appendix E.

Sample Collection

The collection of soil samples from the Toledo area was conducted with the collaboration of local schools and community gardens. At the schools, the students were first given an interactive presentation (Appendix A). The presentation guided the students to describe all they knew about: what contamination is, where contamination comes from, what heavy metals are, how heavy metals affect the human body, and how they can get into the human body. If the students could not come up with answers to these questions, they were given guiding questions and illustrations to help them. The presentation was modified for lower level grades with accordance to the Ohio Learning Standards (2018) to provide a simpler explanation of what heavy metals are and how they can be harmful. The presentation then outlined how the students were to select a sample site, how to collect soil samples, how to describe the location where they collected the sample, from whom to get permission for taking the soil sample, and how to prevent themselves from being harmed by soil contamination. The students were then given sample collection materials including a ziptop HDPE baggie, a plastic spoon for digging, measuring and collecting soil, and an instruction sheet reiterating how they should collect the soil sample. The students were also given a letter for their parents describing the soil project, how their child can participate in it, and explaining that there will be a follow up school visit to discuss the results of the project. Along with the letter, a permission slip to be signed by the parent was included stating that their child was allowed to participate in the project (Appendix B).

During the initial school presentation, students were asked to describe good and poor soil slope location types. Good location types included their front or backyard, the school playground, a local playground by their house, a family garden, or a family farm. The poor

location types included a potted house plant, in the middle of a road, or any areas for which they did not ask the land owner for permission to take their soil. The students were given a time frame in which they had to collect the soil sample and bring both the sample and the permission slip back. During that time, the participating students chose a location where they were interested in the contamination level of the soil. They wrote the address of their sampling location and the type of location, such as the front yard, on the baggie. Following their detailed instruction sheet, the students then dug 5 cm below the soil horizon, or until they dug past any mulch, grass, or stones. They used the 5 cm mark drawn on their plastic spoon for measuring guidance. They then scooped approximately four spoonfuls of soil into their labeled soil sample baggie, making sure they securely sealed their bag when finished. They were then instructed to dispose of their plastic spoon and wash their hands after soil collection.

This collection method follows a citizen science model wherein the school children actively participated in the sample collection. The described sample collection method follows all proper soil collection procedures as outlined by the USEPA Method 5035 (2014). This strategy for including the students in the sampling has been successfully employed in a previous study of blood lead levels in Toledo, OH area children by Stewart et al. (2014).

Soil samples from the Stewart et al. (2014) study were also incorporated into this study. All of the 29 samples were collected by students from the front yard of their homes. The instructions and tools for soil sampling given to the students as part of the Stewart et al. (2014) study were similar to this study. The soil sample descriptions and locations are listed in Appendix E.

Community Gardens

Community gardens grow vegetables and other crops that are distributed to members of the community. Most of the Toledo area community gardens have private owners or are private organizations, and often donate their garden's produce to community members. The regulations for community garden soil tend to be minimal or non-existent compared to those of commercial farms. These gardens are in urban locations, which tend to have higher levels of heavy metals, therefore the soil should be analyzed before consumption of any produce.

Soil samples were collected with the collaboration of the Manos Community Garden in Toledo (Figure 1). In order to assure sampling consistency, plastic spoons and plastic ziptop bags were also used for sample collection in the garden. Prior to sampling, any loose covering such as mulch or gravel was scraped away in order to minimize the amount of larger or organic materials collected that cannot be digested in analyzation. Four spoonfuls of soil were collected at six different locations throughout garden beds and walkways. The plastic spoons were disposed of after each sample was taken. The bags were labeled according to sample depth, walkway or bed number, and GPS location. The samples taken included eight from different unlined, raised beds and two from walkways. The raised beds appeared to be filled with a mixture of potting soil and fill dirt and then covered with mulch. The garden's directors were not positive as to where the fill soil had come from, as they contracted out the construction of the garden.

Due to the garden area being on a slope, the height of the beds varied from 10 cm to over 70 cm. The four beds chosen for sample collection were selected because they were not located next to each other and had different raised bed heights above ground. The heights of the raised beds were measured starting from the ground and measuring up the side of the wood boxes on

the tallest and shortest sides. The depths of the bed samples were originally to be 10 cm and 20 cm below the soil horizon in order to reach past any windborne contamination from the surrounding ground soil. However, digging through a raised bed that was not lined, had dense plantings of vegetables growing in it, and only using a spoon was very challenging. Therefore, the deeper 20 cm samples were collected by digging as far down as the soil would allow. The first bed sampled had a height above ground of 35.5 cm to 69.25 cm. The second bed had a height of 13 cm to 28 cm. Only one sample was collected at 10 cm below the soil horizon because after 10 cm the hard ground soil had been struck, making it too hard to dig through. The third bed was 29 cm high all the way around. The samples were collected at 10 cm and 16 cm. The fourth bed was 18 cm all the way around. Samples were collected at 10 cm and 16 cm. Two samples were collected from the garden's pathways after digging aside the mulch and gravel to get to underlying soil. Due to the variance in soil depth, two of the samples were deemed un-useable, leaving a total of 8 samples from the Manos Community Gardens. Descriptions and GPS locations of soil samples are presented in Appendix E with pictures in Figure 3.

Sample Processing

The sample analysis for all soils followed USEPA Method 3051A for microwave-assisted digestion of sediments, sludges, and soils followed by analysis using Method 6010C for inductively coupled plasma-optical emissions spectrometry (USEPA, 2007a; USEPA, 2007b). All soil samples were stored in a refrigerator until they were dried. Samples were dried in acid-washed ceramic crucibles in a drying oven at 60°C for at least 48 hours and maintained a constant weight. After drying, the samples were homogenized using an acid-washed mortar and pestle. As much as possible, the large and non-soil particles, such as stones, mulch, glass, sticks, etc., were removed.

Following the USEPA Method 3051A for microwave digestion protocol, an approximately 0.5 g aliquot of a dried soil sample was weighed using an analytical balance accurate to ± 0.0001 g then transferred to a MARS Xpress Teflon vessel (2007a). Each alternate digestion run included either an acid blank or SRM Montana I Soil 2710a sediment standard. Only 16 vessels could be run at a time: 15 soil samples and one control. The rotation of 9 mL and 10 mL of concentrated trace metals grade nitric acid were added along with 3 mL of concentrated trace metals grade HCl. The samples were then left loosely covered with plastic wrap overnight to allow any reactions with organic matter to take place.

The following day the vessels were capped and the weight of the vessel was recorded. The samples were then placed in the turntable inserted in the CEM-MARS Xpress microwave digestion system. They were then digested according to USEPA Method 3051A by ramping the samples up to a temperature of 175ºC in five minutes, followed by a hold at 175ºC for an additional 5 minutes (2007a). The vessels were allowed to cool for approximately one hour. With the caps still on the vessels, the vessels were re-weighed and the weights were recorded. If the vessels had >1% weight loss after the digestion, they were discarded. The vessel caps were then loosened slightly to release any remaining pressure. The digested samples were then gravity filtered through Watson #40 qualitative filter paper. The filtered samples were then brought up to a volume of 50 mL or 100 mL, with Milli-Q ultrapure water (18.2 M□-cm). The samples were transferred to polypropylene Nalgene bottles that were labeled with the sample code, the date bottled, and the initials of the researcher. They were then placed in a refrigerator at 4ºC until analysis with the inductively coupled plasma-optical emissions spectrometer (ICP-OES). Between each digestion the Xpress vessels were run through the CEM-MARS Xpress microwave with acid blanks of 10 mL of concentrated trace metals grade nitric acid and 3 mL of

concentrated trace metals grade HCl. This procedure was done in order to clean out any residue left behind in the vessels.

The digested samples were analyzed following the USEPA Method 6010C (2007b). A ThermoElement iCap6500 inductively coupled plasma-optical emissions spectrometry (ICP-OES) was used in the BGSU Geochemistry laboratory. Each sample was analyzed for a suite of twenty metals, including Al, As, Ba, Ca, Cd, Co, Cr, Cu, Fe, K, Mg, Mn, Mo, Na, Ni, Pb, Se, Sr, Ti, and Zn. Multiple wavelengths were monitored for each element, where the reported concentrations are based on the wavelength recommended in USEPA Method 6010C (2007b). The selected wavelengths (in nm) were Aluminum 308.215, Arsenic 189.043, Barium 455.403, Cadmium 226.502, Calcium 317.933, Chromium 267.716, Cobalt 228.616, Copper 324.754, Iron 259.940, Lead 220.353, Magnesium 279.079, Manganese 257.610, Molybdenum 202.030, Nickel 231.604, Potassium 766.491, Selenium 196.026, Sodium 588.995, Strontium 407.771, Titanium 334.941, Zinc 213.856. Arsenic 189.043 was chosen due to a strong interference for the Arsenic 193.696 wavelength due to Aluminum.

Precision of the ICP-OES analysis was calculated (minimum detection limits) based on blanks and standards prepared using SPEX CertiPrep AA/ICP-AES Plasma Grade standard solutions. Reliability of the sediment digestion method was evaluated using method (acid) blanks and standard reference material (SRM 2710a Montana I Soil). Reaction vessels were randomized for each microwave digestion run and one out of every sixteen contained a method (acid) blank or reference material to ensure no contamination between sediment samples. Potential instrument drift during analysis was monitored by running a quality control sample after every ten unknown samples. The accuracy of the ICP-OES analysis was checked using SPEX CertiPrep Multi-

element solution 2 certified standard, which was randomly included in each set of thirty unknowns. The mean minimum detection limits are noted in Appendix E.

The concentrations of the elements measured in the digested samples were converted to the concentration in dry soil as outlined in the USEPA 3051A Method (2007a). The sample number and converted metals concentration data, in ppm, are shown in Appendix E along with the sample type, collection date, and sample location.

Geospatial Analysis of Element Concentrations

Predictive metallic soil concentration maps were created using ArcGIS geospatial tools (ESRI, 2018). First, the metals concentration data were compiled in Excel, then converted into CSV (comma-delimited) files (MS-DOS) and imported into ESRI's ArcGIS (ESRI, 2018). The data are displayed as points using the eastings and northings associated with each sampling locality and projecting them to NAD 1983 zone 17N. Five focus elements (As, Cr, Pb, Ni, and Zn) in each location were interpolated using Empirical Bayesian kriging with parameters set to standard with a power of 2. Maps of predictive element concentrations were created, accounting for error of spatial variance between sample locations. The border extent of the interpolation was confined to be the city limits of both Toledo and Ottawa Hills combined. The expressed values were then adjusted to compare them to the corresponding Ohio EPA screening levels for each element, along with standard deviations, and background levels.

The ESRI ArcGIS software was used to identify hot spots and cold spots within the Toledo and Ottawa Hills city limits (ESRI, 2018). The tool Hot Spot Analysis (Getis-Ord Gi*) shows "statistically significant spatial clusters of high values (hot spots) and low values (cold spots)" as the sample points relate to one another (ESRI, 2018). A hot spot would be described as

an area of points that are both close together spatially and close together in high value. For the maps in this study, a hot spot would show the areas of high heavy metal concentration by mapping points that have similarly high values in the same area. Similarly, a cold spot would show areas of relatively lower heavy metal concentrations, as shown by their lower numerical values in ppm. The Hot Spot Analysis tool also gives 90%, 95%, and 99% confidence levels for each classification of hot, cold, or not significantly related. The confidence levels are based upon Gi_Bin fields: +/-3 bin field shows 99% confidence in statistical significance, the +/-2 bin field shows 95% confidence, and the +/-1 bin field shows 90% confidence. Some points are deemed not significantly related. These points are either too different in numerical value, too far apart from one another spatially, or both.

The heavy metal concentrations were compared to screening levels designated by the United States Environmental Protection Agency (USEPA, 2019). A screening level is used as a comparison of the element's concentration in the environment to show whether the actual concentration is high enough that it may cause health issues for humans. If the concentration of a soil sample is found at an equal or higher value than that of a screening level, then the soil is not considered to be safe. The USEPA screening levels were created to assess the risk to humans of certain elements in the environment. The screening levels were calculated through extensive research and testing using several factors such as chemical toxicity values, exposure assumptions, and slope factors. Several different screening levels are created for each element depending on the environment being tested. The screening levels being used for this study are classified as the noncancerous child hazard index = 0.1. These screening levels were created as an index to gauge whether the concentrations in the soil would be hazardous but not cancerous for children. It was chosen over the other screening levels because these levels are potentially

hazardous for humans, but especially dangerous for children, who are more susceptible to negative health effects.

RESULTS

Full results, including concentrations (in ppm) of all twenty elements analyzed using the ICP-OES for each sample, are presented in Appendix E. Summary statistics for all elements along with the percentage of samples exceeding the screening level are listed in Table 1. The Results and Discussion sections will focus on the six elements (arsenic, cadmium, chromium, lead, nickel, and zinc) with concentrations possibly elevated due to anthropogenic inputs and which represent a range of geochemical properties and toxicities that could impact the community.

Arsenic

Arsenic concentrations are presented in Figure 4 showing the frequencies of 120 soil samples that were above detection limits, showing a right tailed distribution. For arsenic, a sample measured at 219.001 ppm was deemed an outlier in the dataset since it was several standard deviations away from the nearest data point, and was not included in the figures, as were samples below detection limits.

A map was created to show the predictive values of arsenic in the Toledo/Ottawa Hills city limits (Figure 5). The results show a higher predictive concentration area forming around the northwest (east of Ottawa Hills) section of the map. The hot spot analysis shows multiple hot spots in and around the northwest (Ottawa Hills) of the mapping area, within a 99% and 90% confidence interval (Figure 6).

The overall arsenic concentrations of the soil samples had a mean value of 7.810 ppm, a median of 6.019 ppm, a standard deviation of 6.262 ppm, and a range of 2.422-44.632 ppm. The

USEPA screening level for arsenic is 3.5 ppm (2019). Of the 137 samples, 100 (73%) were over the USEPA screening level for arsenic.

Cadmium

A histogram plot of cadmium concentrations is presented in Figure 7 showing the frequencies of 137 soil samples. The histogram shows the majority of the chromium sample concentrations skewed to the left.

A map was created to show the predictive values of cadmium in the Toledo/Ottawa Hills city limits (Figure 5). The results show a higher predictive concentration area forming around the middle (Old West End) and southwest (south of Ottawa Hills) section of the map. The hot spot analysis shows multiple hot spots around the middle (Old West End) and cold spots around the western part (Ottawa Hills) of the mapping area), with a 99%, 95%, and 90% confidence interval (Figure 6).

The overall cadmium concentrations of the soil samples had a mean value of 1.840 ppm, a median of 1.658 ppm, a standard deviation of 0.896 ppm, and a range of 1.710-6.064 ppm. The USEPA screening level for cadmium is 7.1 ppm (2019). Of the 137 samples, 0 were over the USEPA screening level for cadmium.

Chromium

A histogram plot of chromium concentrations is presented in Figure 7 showing the frequencies of 137 soil samples. The histogram shows the majority of the chromium sample concentrations skewed to the left.

A map was created to show the predictive values of chromium in the Toledo/Ottawa Hills city limits (Figure 8). The chromium map shows a higher predictive concentration area in the central northern (DeVeaux) and southern (Maumee) area of the map The hot spot analysis shows multiple hot spots around the middle of the map (DeVeaux and The Old West End), with a 95%, and 90% confidence interval (Figure 9).

The overall chromium concentrations of the soil samples had a mean value of 19.445 ppm, a median of 16.620 ppm, a standard deviation of 13.268 ppm, and a range of 4.059-98.662 ppm. The USEPA screening level for chromium insoluble salts is 12000 ppm (2019). Of the 137 samples, 0 were over the USEPA screening level for chromium.

Lead

A histogram plot of lead concentrations is presented in Figure 10 showing the frequencies of 137 soil samples. The histogram shows a right tailed distribution.

A map was created to show the predictive values of lead in the Toledo/Ottawa Hills city limits (Figure 11). The lead map shows a higher predictive concentration area in the central (The Old West End) and western area (Ottawa Hills) of the map. The hot spot analysis shows multiple hot spots around the middle of the map (The Old West End), with a 99% and 95% confidence interval (Figure 12). The hot spot analysis shows multiple cold spots in the western area of the map (Ottawa Hills) with 90% and 95% confidence intervals.

The overall lead concentrations of the soil samples had a mean value of 133.145 ppm, a median of 41.665 ppm, a standard deviation of 247.718 ppm, and a range of 3.692-1903.409 ppm. The USEPA screening level for lead is 400 ppm (2019). Of the 137 samples, 17 (7 %) were over the USEPA screening level for lead.

Nickel

A histogram plot of nickel concentrations is presented in Figure 13 showing the frequencies of 137 soil samples. The histogram shows a right tailed distribution.

A map was created to show the predictive values of nickel in the Toledo/Ottawa Hills city limits (Figure 14). The nickel map shows a higher predictive concentration area in the central (The Old West End) and southwestern (Maumee) area of the map. The hot spot analysis shows multiple hot spots around the middle of the map (The Old West End), with a 99% and 95% confidence interval (Figure 15). The hot spot analysis shows multiple hot spots around the central (Old West End) are of the map with a 99%, 95%, and 90% confidence interval (Figure 1223). The map shows cold spots in the western area of the map (Ottawa Hills area) with 99%, 95%, and 90% confidence intervals.

The overall nickel concentrations of the soil samples had a mean value of 11.524 ppm, a median of 10.071 ppm, a standard deviation of 6.582 ppm, and a range of 2.792-39.140 ppm. The USEPA screening level for nickel is 150 ppm (2019). Of the 137 samples, 0 were over the USEPA screening level for nickel.

Zinc

A histogram plot of zinc concentrations is presented in Figure 16 showing the frequencies of 137 soil samples. The histogram shows a right tailed distribution.

A map was created to show the predictive values of zinc in the Toledo/Ottawa Hills city limits (Figure 17). The zinc map shows multiple risk areas forming around the northern (Deveaux), central (The Old Went End), and southern (Maumee) regions of the map. The hot

spot analysis shows multiple hot spots around the central region of the map (The Old West End), with a 99%, 95%, and 90% confidence interval (Figure 18). The hot spot analysis shows multiple cold spots in the midwestern area of the map (Ottawa Hills area) with 99%, 95%, and 90% confidence intervals.

The overall zinc concentrations of the soil samples had a mean value of 127.480 ppm, a median of 74.298 ppm, a standard deviation of 132.927 ppm, and a range of 6.932-762.147 ppm. The USEPA screening level for zinc is 2300 ppm (2019). Of the 137 samples, 0 were over the USEPA screening level for zinc.

DISCUSSION

This study's soil concentrations were compared to screening levels and background levels of the area. Several elements were found to be over these levels (Table 1). Here, I focus on discussing the focus elements for the study: arsenic, cadmium, chromium, lead, nickel, and zinc.

Arsenic

The Ohio EPA (2015) reported that in Northwest Ohio, soils containing less than 50% sand have an arsenic background upper limit of 9.7 ppm. The arsenic concentrations of soils from this study ranged from 2.422 ppm to 44.632 ppm. The USEPA screening level for arsenic is 3.5 ppm (2019), resulting in 16% of the samples over both the USEPA screening level and the background level. These samples are spread across the mapped area and are not concentrated in one area. They are all from personal properties, with samples taken from yards and gardens. These soil sample locations may be considered elevated due to anthropogenic activities such as burning fossil fuels, application of herbicides and insecticides, or use of fertilizer.

A significant number of Toledo area arsenic concentrations are at hazardous levels according to the USEPA safety recommendations. At these concentrations, there will be significant health issues to the residing population, especially children. However, the remediation of soil to a concentration level below the background is not a feasible task. Therefore, in order to prevent future health issues, precaution needs to be taken around the interaction of the soil. Produce should not be consumed if they are planted directly in the soil. After outdoor activities, all exposed skin should be washed thoroughly, especially before eating. With these precautions, risks to human health can be prevented or at least lessened.

Cadmium

There is no background level reported for cadmium from the Ohio EPA for Lucas County. Cox-Colvin & Associates (1996) found Ohio soils to have background levels of cadmium with a geometric mean of 0.507 ppm. The cadmium concentrations of soils from this study ranged from 1.710 ppm to 6.064 ppm. For cadmium 100% of the samples are over the background level. The USEPA screening level for cadmium is 7.1 ppm (2019), resulting in 0% of the samples over both the USEPA screening level and the background level. With all samples being higher than the background level, these soil sample should be considered elevated due to anthropogenic activities. Possible sources such as metal production, burning fossil fuels, or application of fertilizers.

The remediation of all soil to a concentration level below the background is not a feasible task. The concentrations from this study are below screening level for human health risks. Precaution still needs to be taken around the interaction of the soil. Produce should not be consumed if they are planted directly in the soil. After outdoor activities, all exposed skin should be washed thoroughly, especially before eating.

Chromium

The Ohio EPA reported that in Northwest Ohio, with soils generally containing less than 50% sand, the background upper limit is 22.20 ppm of chromium (2015). The concentrations obtained in this study ranged from 4.059 ppm to 98.662 ppm. Resulting with 27% of the samples over the Ohio EPA background level. The USEPA screening level for chromium insoluble salts is 12000 ppm (2019). No soil samples were over both the background and the screening levels.

The elemental detection methods used in this study cannot distinguish between Cr (III) and Cr (VI). Chromium (VI) is rare to find in residential soils, and most of the soil samples used in this study were taken from residential soils. Chromium (III) is likely the type being seen in this studies results. If any Cr (VI) was deposited in the soils, it most likely was deposited long enough ago that the Cr (VI) has already oxidized to the Cr (III) form.

The elevated chromium levels in the samples is not high enough to recommend remediation of the soil. Precaution should still be taken as some chromium concentrations are above background levels and chromium can cause serious health issues in humans.

Lead

The Ohio EPA reported that in Northwest Ohio, with soils generally containing less than 50% sand, the background upper limit for lead is 17 ppm (2015). The concentrations from this study ranged from 3.692 ppm to 1903.409 ppm. Of the 137 samples, 72% were over background soil levels. The USEPA screening level for lead is 400 ppm (2015). Of the soil samples 7% were over both the screening level and the background levels.

All samples over the lead USEPA action levels were taken from residential yards that were scattered throughout the studied area as shown in Figure 11. Their close proximity to highways might indicate that the higher lead levels result from vehicle emissions prior to the 1970s, when lead remained in gasoline. These higher lead concentrations could also be from the paint of the homes since they were mostly built before the 1970s, when lead was still used in paint. The high lead levels in the samples may also have been from the application of pesticides, herbicides, or fertilizers, which may contain lead.

Exposure to lead over recommended levels can cause various severe health problems. The soil from the sampling localities over the USEPA screening levels will contribute to these health problems now and in the future. The high concentration of lead in Toledo has already been reported in well over 1,000 children in the last three years alone (Toledo Blade, 2019). Estimates bring that number closer to 3,500 children who will suffer from permanent learning disabilities and other effects of lead poisoning (Toledo Blade, 2019). This problem will persist without intervention.

Remediation of the soil is a necessary but an extensive undertaking. The Stewart et al. (2014) study showed the highest risk of elevated blood lead level in children was located in the center of Toledo. This is the same region of predicted elevated concentrations (Figure 11) from this study. As this is the most densely populated portion of the city, it is a difficult location to remediate. This problem permeates throughout the entire region of heavily trafficked and populated areas. Toledo has two options in regard to lead contamination: constant and continuing health issues for the most prone citizens or expensive and laborious soil remediation in the heart of the city.

Nickel

The Ohio EPA reported that in Northwest Ohio, with soils generally containing less than 50% sand, the background upper limit for nickel is 22.45 ppm (OEPA, 2015). The nickel concentrations in soils analyzed in this study ranged from 2.792 ppm to 39.140 ppm. Of the 137 samples, 7% exceeded the Ohio EPA background level of 22.45 ppm. The USEPA screening level for nickel is 150 ppm (2019). No soil samples were over both the background and the screening levels.

The levels of nickel in the area are most likely the result of anthropogenic processes, being higher than the background soil levels. The elevated nickel levels in the samples is not high enough, however, to recommend remediation of the soil. Precaution should still be taken as nickel can cause serious health issues in humans.

Zinc

There is no background level reported for zinc from the Ohio EPA for Lucas County. Cox-Colvin & Associates found Ohio soils to have background levels of zinc with a geometric mean of 42.7 ppm (1996). The zinc concentrations from this study ranged from 6.932 ppm to 762.147 ppm. Of the 137 samples, 73% had zinc concentrations above background soil levels of 42.7 ppm. The USEPA screening level for zinc is 2300 ppm (2019). No soil samples were over both the background and the screening levels.

The levels of zinc in the area is most likely the result of anthropogenic processes, being higher than the background soil levels. The elevated zinc levels in the samples is not high enough however to recommend remediation of the soil. Zinc deficiency in soils is more common than zinc toxicity in soils (Alloway, 2013). However, to be deficient the concentrations should be lower than 0.50 ppm (Alloway, 2013). No samples from this study were found to be at or below deficient levels. The lowest sample concentration was at 6.932 ppm, over 13 times the amount of deficiency. Precaution should still be taken as zinc can cause health issues in humans.

Correlations Across Metals

Comparing the spatially predictive maps, a mix of common and unique sources can be inferred. Several metals show increased concentrations in The Old West End region of Toledo. This area received its neighborhood name for being a large area of residential homes dating back

from the 1870s to the 1920s. Because of the similar age and geographical concentrations, while multiple sources may be behind these concentrations, all are most likely from anthropogenic sources.

Similar Urban Areas

The soils analyzed in this study are compared in Table 2 to the Detroit residential average surface and subsurface soils taken in accordance with 1983 USEPA methods (Murray et al., 2004). Specific soil collection depth standards were not described in the Detroit study, therefore both surface and subsurface measurements are used for comparison. Detroit is geographically close to Toledo, but is larger in size, industry, population, and transportation. The arsenic concentration levels were significantly higher in Toledo soils than in Detroit. The arsenic, cadmium, and zinc concentrations were higher in Toledo than in Detroit. The chromium, lead, and nickel concentrations levels were similar in both surface and subsurface categories. The majority of metals are similar in concentration levels. The similarity in concentrations and the close proximity of these two Rust Belt cities make the sources of their pollution likely to be similar.

Follow-Up Presentations

After sample analysis and spatial mapping, several presentations were given to the public in the spring of 2016 in order to share the results and further educate the public. These presentations were held at Imagine Hill Academy, Glass City Academy, Toledo-Lucas County Public Library, Reynolds Corner Branch Library, and West Toledo Branch Library. An interactive PowerPoint presentation was delivered (Appendix C). A question and answer session was held at the conclusion of the presentation. An educational pamphlet about lead and its

hazards was also distributed to the audience (Appendix D). The pamphlet only discussed lead because lead, and in particular the main source of lead poisoning, is generally the most widely misunderstood of all heavy metal toxins.

SUMMARY

In an urban environment such as Toledo, Ohio, the effects of pollution and contamination on its citizens can be detrimental to their health. The soils in Toledo, Ohio are located in an area that is highly probable to have elevated concentrations of heavy metals due to the abundant amount of industry and transportation. Analysis of soil samples in this study showed many elements are indeed at elevated concentrations above background and screening levels in the city of Toledo. The residents of the area are potentially unaware of lurking danger. The educational outreach of this study was aimed at both children and parents to get the word out about soil contamination and its threat to humans. As outlined in the Stewart et al. (2014) study, health issues are already prevalent as a result of heavy metal contamination of soils. Educating the general public on this health concern and potential solutions can help prevent cognitive and developmental issues in future generations by providing residents with the knowledge to protect themselves and the children of the community.

In order to prevent further health issues, remediation of the soil contamination should be pursued. Remediation of soils should be implemented at many of the sampling locations. Remediation of soil is the process of purifying soil of contaminants. Remediation can be handled several different ways, however all are extensive and costly. Unfortunately, there are also no current government subsidies for soil remediation on private land. As a result, most private lands are untested and unlikely to be remediated. Despite this economic barrier, remediation is the only solution. The two most common types of remediation include soil section removal and bioremediation with plant life (Hettiarachchi and Pierzynski, 2004; Chon et al., 2011).

Future extensions of this study would include widening the spatial soil sampling, collecting soil samples from more community gardens, and collecting more samples from areas of high concern. High concern areas might include abandoned buildings, factories, demolition zones, or areas that have been newly reclaimed into public use such as recreational areas or parks. More intensive statistical analysis could be performed to determine precise predicted patterns of heavy metal concentrations in the Toledo area. Widening the area of educational outreach should also be implemented in order to educate a larger audience about the health risks associated with heavy metal contamination in soils. The alarming concentrations found in this study merit further investigation, analysis, and education in this and surrounding areas.

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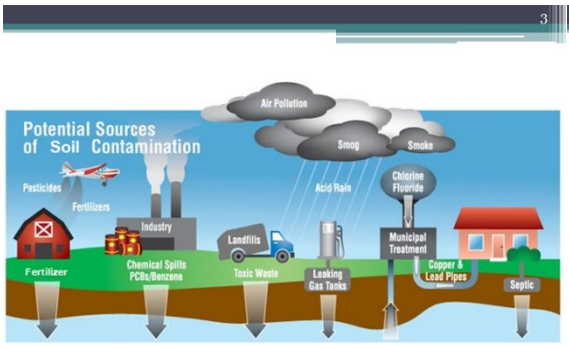
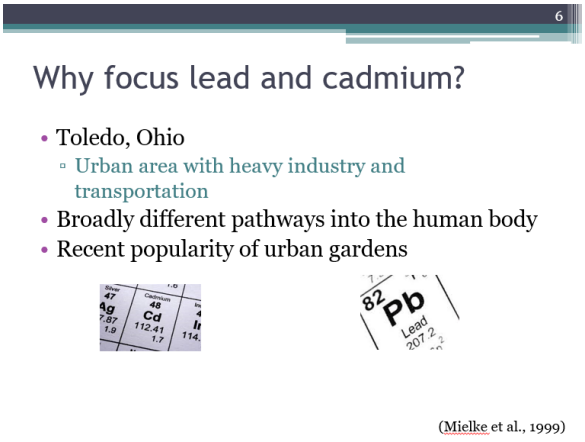
APPENDIX A. INTRODUCTION PRESENTATION

Presentation given to local Toledo student participants prior to sample collection. Directed towards school age students who were to collect soil samples for the study.





(Mielke et al., 1999)

7

Lead

Where does lead come from?

- Lead banned in paint 1925, Gas 1989
- Leaded gas more significant source for lead poisoning
  - Emission particles settle on soil, bond tightly, remain for thousands of years

(Lanphear et al., 1998 ; Mielke et al., 2011; Rooney et al., 1997; ASTDR, 2007)

8

Lead

How does lead affect human health?

- General population
  - damages nervous system
  - brain damage
  - anemia
  - liver complications
  - kidney failure
  - high blood pressure
  - ankle and wrist fragility
  - death
- Children
  - more at risk- more likely to engage in hand-to-mouth activities ingesting contaminated soil
    - playground, backyard, or household dust
  - children absorb 40% more lead into bloodstream
  - children are still in development-brain damage leading to learning impairments

(ASTDR, 2000; Clark et al., 2006; Lanphear et al., 1998; Duggan, 1985; RAIS, 2009; Gump et al., 2005; ASTDR, 2007)

11

How do we know if the soil is contaminated?!

12

13

How do you collect soil samples?

- Have clean tools and containers
- Pick a good location
- Write the location on your container
- Clear away plants
- Close the container
- Wash your hands!

14

Tools and Containers will be provided for you

Tool for digging (and measuring!): Plastic Spoon

Container: Plastic Bag

15

Choose a location (make sure to get permission!)

- **After getting permission**
- **Write the type of place (garden, yard, playground) and the address on the baggie**

16

Measure 5 cm below the soil then take 4 spoonfuls into your baggie

Measure

Dig Soil

Put soil in baggie

17

Then WASH your hands!!

Bring the baggie to your teacher along with your permission slip signed by your parents

18

How can you avoid getting sick?

- Wash your hands before eating, or touching your mouth
- Grow your vegetables in safe soil
- Wash your fruits and vegetables

APPENDIX B. CONSENT LETTER

Correspondence sent home with students. Permission Slip, collection instructions, and follow-up letter sent to parents or guardians of students invited to participate in the study.

BGSU
BOWLING GREEN STATE UNIVERSITY

To: Parents & Guardians

As a geology Graduate student with a Bachelors in Education at BGSU, I am conducting an outreach program for local area schools. I will be involving students in a soil research project to test the safety of local soils.

The program will include a safety session of the risks and health issues of contaminated soils, followed by safe soil collection instructions. The students will then be allowed to take a soil sample at their own desired location, accompanied by an adult. The soil sample will then be analyzed for any contaminants by BGSU. The condition of the soil will be presented at a public forum where students, teachers, parents, and guardians are welcome to listen to the results of the program as well as be informed of how to avoid health risks of contaminated soil.

For the privacy of the student, student names, identifiers, or addresses will be completely confidential and will not be produced for in any part of the study.

If you have any questions, you can contact me through my email or contact your student's classroom teacher.

Karen Burris
burrisk@bgsu.edu
Graduate Student
Bowling Green State University
Geology Department

Please detach and return the following permission slip to the classroom teacher.

Soil Collection Permission Form Please Complete and Return to your Child's Teacher	
Student Name:	
	I **DO** give permission to you to include my child to participate in the research and soil collection.
	I **DO NOT** give permission to include my child to participate in the research and soil collection.
Parent's/Guardian's Signature:	Date:

Soil Collection Instructions

1. Choose a location to take your sample.

    -Make sure you have permission to take the soil!

    -Possible locations could be: your back or front yard, your vegetable garden, a playground, or somewhere at your school (again make sure you have permission!)

2. Write the type of location and the location's address on the outside of your plastic collection baggie. (ex. My garden 523 Oak St. Toledo)

3. Using the measuring line on the plastic spoon in your collection baggie, measure 5 centimeters below the soil. Then take 4 spoonfuls of soil and poor them into your plastic baggie.

4. Throw away the spoon and WASH YOUR HANDS.

5. Bring the baggie with the soil back to your classroom teacher.

BGSU.
BOWLING GREEN STATE UNIVERSITY

To: Parents & Guardians

As a geology Graduate student with a Bachelor in Education at BGSU, I am conducting an outreach program for local area schools. I will be involving students in a soil research project to test the safety of local soils.

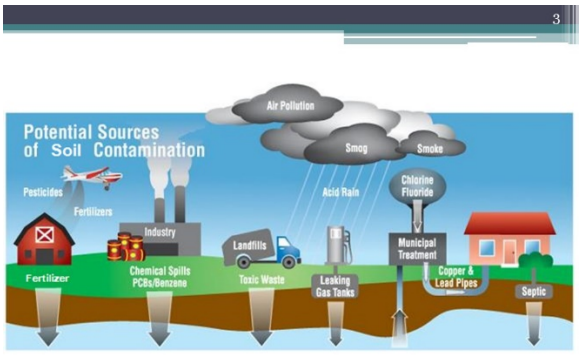
I have recently visited your student's school and would like to include you in the results of the study. The condition of the soil will be presented at a public forum where students, teachers, parents, and guardians are welcome to listen to the results of the program as well as be informed of how to avoid health risks of contaminated soil. The talk will be held in the fall, and your school will be contacted before hand as to the time and location it will be held.

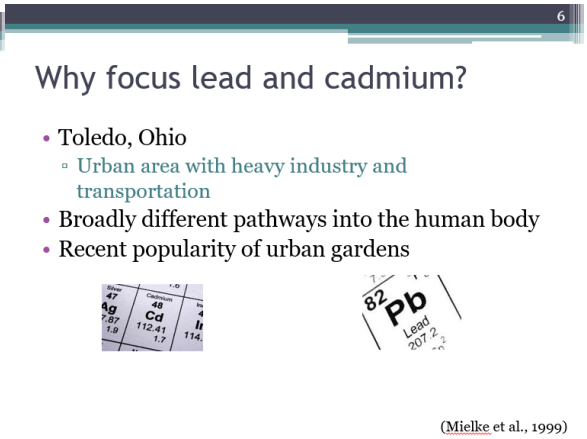
If you have any questions, you can contact me through my email or contact your student's classroom teacher.

Karen Burris
burrisk@bgsu.edu
Graduate Student
Bowling Green State University
Geology Department

APPENDIX C. FOLLOW-UP PRESENTATION

Follow-up presentation given after sample collection. Informative conclusion of analytical research along with reiteration of why the study was conducted given to schools and public forums.





7

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(Lanphear et al., 1998 ; Mielke et al., 2011; Rooney et al., 1997; ASTDR, 2007)

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  - ankle and wrist fragility
  - death
- Children
  - more at risk- more likely to engage in hand-to-mouth activities ingesting contaminated soil
    - playground, backyard, or household dust
  - children absorb 40% more lead into bloodstream
  - children are still in development-brain damage leading to learning impairments

(ASTDR, 2000; Clark et al., 2006; Lanphear et al., 1998; Duggan, 1985; RAIS, 2009; Gump et al., 2005; ASTDR, 2007)

11

How do we know if the soil is contaminated?!

12

Soil Sampling

Conducted by Horizon's 7^{th} -11^{th} grade science classes in the Spring and Fall of 2015

13

How do you collect soil samples?

- Have clean tools and containers
- Pick a good location
- Write the location on your container
- Clear away plants
- Close the container
- Wash your hands!

14

Tools and Containers will be provided for you

Tool for digging (and measuring!): Plastic Spoon

Container: Plastic Bag

15

Choose a location (make sure to get permission from Ms. Valentine!)

- **After getting permission**
- **Write the type of place you are taking a soil sample (garden, yard, playground)**

16

Measure 5 cm below the soil
Then take 4 spoonfuls into your baggie

Measure

Dig Soil

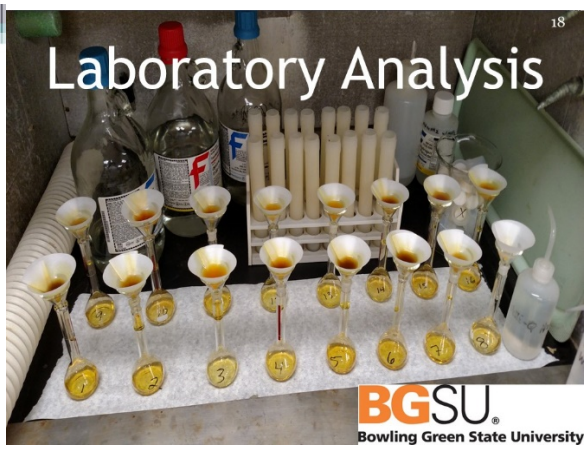
Put soil in baggie and close tightly

17

Then WASH your hands!!

18

Laboratory Analysis



19

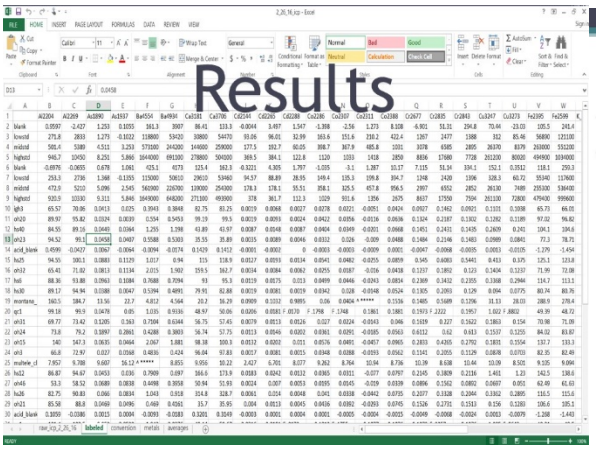
Analysis Process

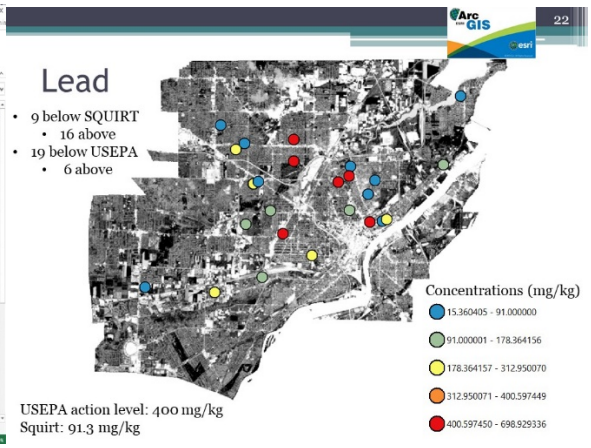
Dry Soil → Homogenize Soil → Add soil to acid

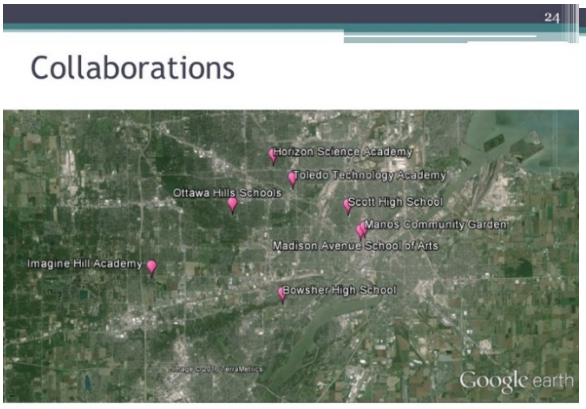
20

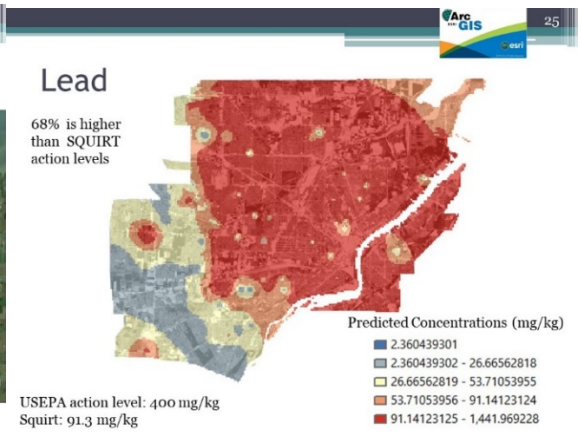
Analysis Process continued

Heat up and pressurize acid/soil mixture → Filter out soil → Run liquid through machine to determine heavy metal concentrations


Results


22
Lead
• 9 below SQUIRT
• 16 above
• 19 below USEPA
• 6 above
Concentrations (mg/kg)
15.360405 - 91.000000
91.000001 - 178.364156
178.364157 - 312.950070
312.950071 - 400.597449
400.597450 - 698.929336
USEPA action level: 400 mg/kg
Squirt: 91.3 mg/kg


24
Collaborations
Horizon Science Academy
Toledo Technology Academy
Ottawa Hills Schools
Scott High School
Manos Community Garden
Madison Avenue School of Arts
Imagine Hill Academy
Bowsher High School
Google earth


25
Lead
68% is higher than SQUIRT action levels
Predicted Concentrations (mg/kg)
2.360439301
2.360439302 - 26.66562818
26.66562819 - 53.71053955
53.71053956 - 91.14123124
91.14123125 - 1,441.969228
USEPA action level: 400 mg/kg
Squirt: 91.3 mg/kg


27
How can you avoid soil contamination risks?
• Wash your hands before eating, or touching your mouth
• Wash your hands after any outdoor activities
• Grow your vegetables in safe soil
• Wash your fruits and vegetables
• Get your soil tested!
Hill Laboratories
TRIED, TESTED AND TRUSTED
www.hill-laboratories.com


28
Acknowledgements
BGSU
Bowling Green State University
• BGSU Geology Department
• Dr. Peter V. Gorsevski
• Dr. Jeff Miner
• Dr. John Farver
• Lauren Stewart
• Imagine Hill Academy
• Madison Avenue School of Arts
• Horizon Science Academy
• Ottawa Hills Elementary
Hill Academy

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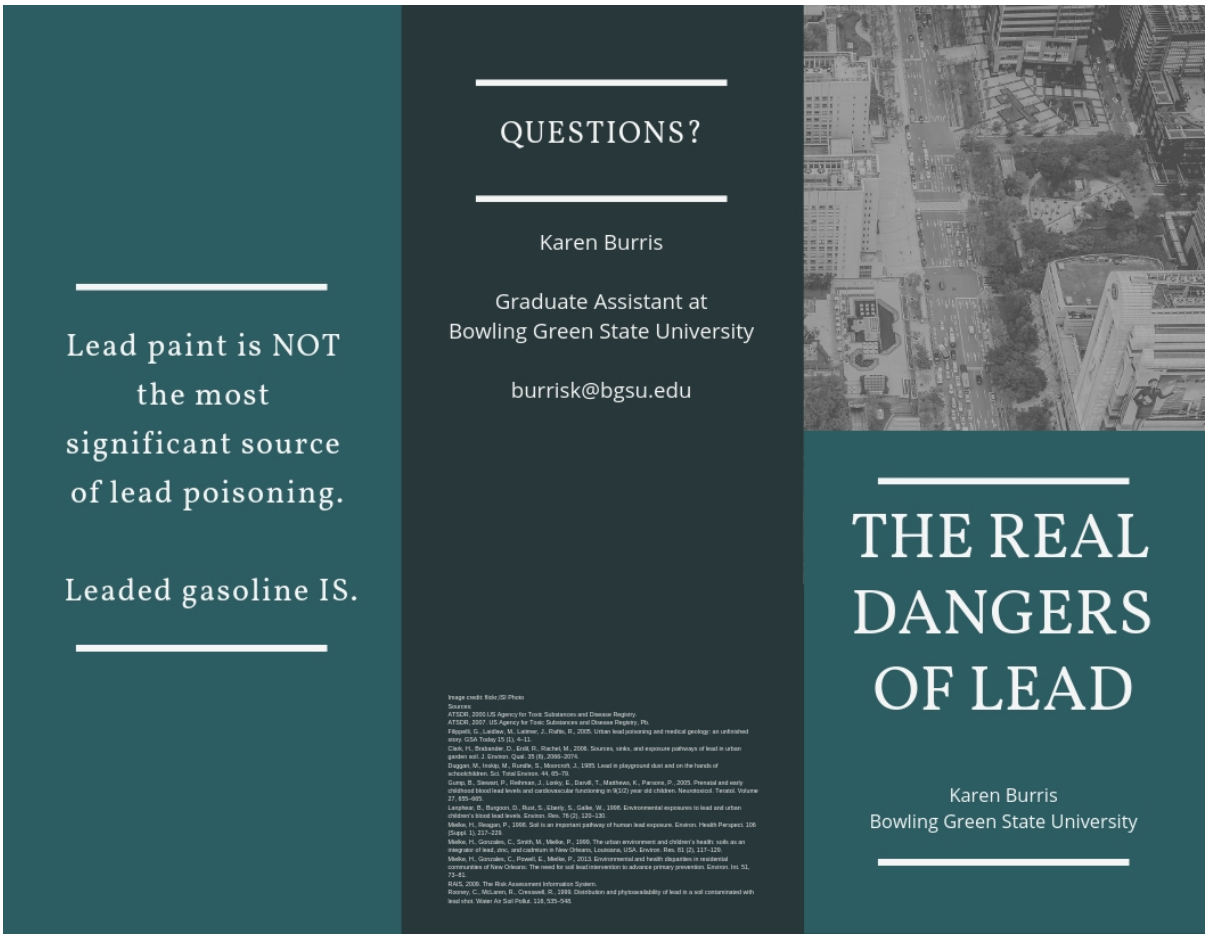
APPENDIX D. BROCHURE

Brochure of lead poisoning dangers. Informative pamphlet of sources and health hazards of lead poisioning, which was distributed at the follow-up presentations.



THE TRUTH ABOUT LEAD

Children are the most at risk for lead poisoning because they are more likely to engage in hand-to-mouth activities, consequently ingesting contaminated soil. The contaminated soil can originate from a playground, backyard, or household dust. In addition, a child's body digests lead differently than adults with 50% of ingested lead being absorbed into a child's bloodstream while only 10% of lead is absorbed into an adult's bloodstream. Since children are still in development, the most detrimental effect of lead poisoning is brain damage leading to learning impairments.

Negative health effects include brain damage, learning disabilities, nervous system damage, anemia, kidney failure, the rise of blood pressure, ankle and wrist fragility, and even death.

LEADED GASOLINE

Two main sources of lead in urban areas are lead based paint and leaded gasoline, both of which were banned prior to the 1980s, over 30 years ago. Older houses can be a source if they are still painted with lead based paint or if soils surrounding dwellings are contaminated by poor removal of older paint. However, studies showed that lead paint is not the most significant source of lead poisoning, for children in particular. Rather, the most concerning source of lead contamination is from the use of lead in gasoline. The lead in emissions from automobiles settles onto the soil where it bonds tightly to sediments and once it is deposited in the topsoil it can remain there for thousands of years. The soils with the greatest lead contamination tend to be located in historically high volume traffic areas where leaded gasoline was burning in motor vehicles.

APPENDIX E. DATA

Complete data set of soil samples and analytical results. Sample organizations, locations, descriptions, and concentrations of heavy metals in ppm. Samples below detection limits are labeled “bdl”. Includes samples collected as part of Stewart et al. (2014) study.

sample name	organization	type of soil	notes about sample	Al	As	Ba	Ca	Cd	Co	Cr
e98	Toledo Early College	yard	Stewart (2014)	7509.193	2.613	58.525	18202.1	1.664	3.619	70.176
hs1	Horizon Science Academy	yard	backyard	6427.882	7.096	89.235	50222.1	2.027	3.707	10.562
hs11	Horizon Science Academy	garden		5886.427	4.363	30.451	7938.3	0.940	2.632	7.915
hs12	Horizon Science Academy	garden		15601.943	8.026	142.217	31041.9	6.064	6.766	37.970
hs13	Horizon Science Academy	yard	backyard	11390.678	7.427	75.805	4539.6	3.088	3.998	14.570
hs14	Horizon Science Academy	school		6560.899	2.661	28.006	9885.7	0.985	2.700	7.154
hs16	Horizon Science Academy	yard	backyard	10128.205	6.982	78.718	7227.8	1.913	4.487	15.710
hs17	Horizon Science Academy	yard	by curb	10168.344	23.549	74.700	17318.1	2.999	5.476	28.986
hs18	Horizon Science Academy	yard	backyard, by fence	6745.310	bdl	31.947	10520.2	0.986	2.843	8.161
hs19	Horizon Science Academy	school	front of school	8628.019	5.362	114.589	32260.9	2.039	4.145	21.237
hs2	Horizon Science Academy	yard	backyard	9409.932	6.890	112.608	18224.3	2.071	4.801	18.435
hs20	Horizon Science Academy	school	front of school	3522.750	bdl	28.777	6162.1	0.620	1.625	5.269
hs21	Horizon Science Academy	school	front of school	7163.615	2.906	32.365	9950.2	1.015	2.886	8.181
hs23	Horizon Science Academy	school	front of school	6159.560	bdl	29.645	10341.5	0.897	2.315	7.525
hs24	Horizon Science Academy	school	front of school	3600.917	bdl	16.992	6347.2	0.529	1.336	4.059
hs25	Horizon Science Academy	yard	side of fence	17695.985	18.184	185.927	21529.6	5.067	9.809	98.662
hs26	Horizon Science Academy	garden	backyard garden	16444.444	11.637	202.924	63333.3	4.074	8.655	40.195
hs27	Horizon Science Academy	yard		7584.646	bdl	31.063	3984.3	0.984	2.756	7.894
hs28	Horizon Science Academy	yard	backyard	14115.523	9.785	131.617	18259.5	3.762	6.479	38.666
hs3	Horizon Science Academy	yard	backyard	5798.528	3.132	78.152	4992.0	1.223	2.854	13.892
hs30	Horizon Science Academy	garden		16609.824	4.875	99.018	14910.1	2.335	6.710	23.318
hs31	Horizon Science Academy	yard	backyard	8284.080	7.703	93.956	18671.1	2.631	5.491	18.723
hs33	Horizon Science Academy	yard		8988.049	5.437	462.578	17594.0	3.468	7.357	51.910
hs34	Horizon Science Academy	yard		6717.633	7.546	50.417	21346.3	1.469	3.237	16.620
hs35	Horizon Science Academy	yard	backyard	12359.354	9.286	205.567	10595.7	3.037	7.027	20.966
hs37	Horizon Science Academy	yard	backyard	10413.476	5.590	88.448	3643.8	2.230	4.431	23.248
hs38	Horizon Science Academy	yard	house	7595.412	6.775	200.752	14013.1	2.843	4.250	22.436

sample name	organization	type of soil	notes about sample	Al	As	Ba	Ca	Cd	Co	Cr
hs39	Horizon Science Academy	yard	house	11427.732	7.775	124.951	32197.4	3.036	6.835	20.740
hs4	Horizon Science Academy	yard	backyard	10248.102	6.795	150.713	15312.0	2.629	6.054	20.394
hs40	Horizon Science Academy	yard	backyard	8145.017	4.854	120.549	4240.1	2.059	3.879	13.189
hs42	Horizon Science Academy	yard	backyard	17561.338	7.212	137.565	37286.2	3.123	11.171	25.093
hs43	Horizon Science Academy	yard	Frontyard	9171.810	4.579	54.350	16549.9	1.652	4.639	18.077
hs45	Horizon Science Academy	Frontyard		6851.487	3.348	79.663	46907.6	1.733	3.742	32.805
hs46	Horizon Science Academy	garden		5380.519	5.316	40.502	4806.4	1.026	2.014	8.888
hs47	Horizon Science Academy	yard	front yard	9450.217	5.082	64.991	10041.6	2.154	4.780	24.504
hs5	Horizon Science Academy	garden		7584.503	4.793	49.901	10723.5	1.581	3.904	11.890
hs6	Horizon Science Academy	garden		17058.710	17.458	145.883	18157.3	4.747	9.649	44.468
hs7	Horizon Science Academy	garden		10323.575	9.611	80.942	8660.4	2.542	5.287	22.217
hs8	Horizon Science Academy	garden		10842.126	10.293	87.259	9446.5	2.708	5.614	23.114
hs9	Horizon Science Academy	school	football field	7022.692	2.621	29.519	8834.1	0.939	2.758	7.394
ihg1	Imagine Hill Avenue Environmental School	garden	raisedbed unlined	5176.611	3.522	35.482	7396.7	0.888	2.485	6.935
ihg2	Imagine Hill Avenue Environmental School	garden	raised bed unlined	10905.504	7.595	66.561	14900.4	1.795	4.557	15.052
ihg3	Imagine Hill Avenue Environmental School	garden	raised bed unlined	6500.394	2.819	38.821	8076.7	1.045	2.701	8.606
ihp1	Imagine Hill Avenue Environmental School	school	playground	6507.489	2.577	15.707	1236.1	0.681	1.653	5.602
ihp3	Imagine Hill Avenue Environmental School	school	playground	5550.324	7.661	17.471	1065.3	0.765	2.168	5.719
ihp5	Imagine Hill Avenue Environmental School	school	playground	6135.332	bdl	61.393	18198.9	1.184	2.091	5.800
iht1	Imagine Hill Avenue Environmental School	school	behind school in tree covered area	6298.392	3.117	21.809	2360.5	0.874	1.836	6.035
ma1	Madison Avenue Art Academy	yard	front yard	7573.076	5.071	130.642	6377.0	2.287	4.285	14.466

sample name	Cu	Fe	K	Mg	Mn	Mo	Na	Ni	Pb	Se	Sr	Ti	Zn
e98	23.766	10882.52	1744.53	6731.18	388.233	0.677	178.79	9.967	29.185	bdl	55.622	222.76	74.298
hs1	11.112	14539.49	1391.20	3525.78	527.515	2.336	256.90	8.081	13.140	bdl	45.936	143.46	50.859
hs11	39.543	6531.46	1198.06	4120.50	121.983	0.534	361.79	6.312	5.590	bdl	14.187	118.82	27.374
hs12	278.028	27172.94	2981.82	11864.32	339.392	2.231	225.66	30.754	295.123	bdl	59.349	398.42	472.737
hs13	25.294	11223.95	1220.73	1499.43	137.969	0.701	168.64	9.966	121.410	bdl	24.233	255.97	216.749
hs14	4.415	6314.54	652.74	3525.82	95.861	bdl	155.52	5.203	15.609	bdl	110.367	212.46	22.054
hs16	44.034	12209.07	2112.43	3398.42	231.065	0.828	196.94	12.791	62.939	bdl	21.065	145.86	176.627
hs17	22.968	18101.78	2749.61	7608.36	351.877	1.238	189.24	17.899	126.645	bdl	49.487	196.88	125.677
hs18	4.796	6669.89	905.05	4103.65	104.796	0.425	173.25	5.898	18.874	bdl	94.218	238.83	25.914
hs19	22.000	12415.46	1584.54	10888.89	168.986	1.237	261.06	16.010	34.908	bdl	119.324	259.81	86.551
hs2	33.617	11050.03	1870.08	6211.29	252.520	0.971	166.58	11.398	214.587	bdl	55.727	162.27	199.835
hs20	4.796	4268.27	425.35	2292.69	52.955	0.453	93.66	4.314	11.621	bdl	20.307	108.33	18.328
hs21	5.056	6777.47	848.53	3931.13	94.666	bdl	149.26	5.474	22.990	bdl	134.813	235.47	33.141
hs23	4.611	5831.56	645.96	3987.07	88.646	0.338	133.71	5.084	16.226	bdl	117.885	218.31	25.555
hs24	2.643	3323.69	372.86	2591.74	53.261	bdl	90.77	2.792	11.578	bdl	48.434	134.12	13.931
hs25	80.975	24168.26	2760.99	9512.43	534.990	2.294	309.56	39.140	360.803	bdl	76.061	399.04	478.776
hs26	69.376	24152.05	3510.72	13904.48	579.727	5.867	2469.79	26.784	85.419	bdl	226.511	424.17	214.035
hs27	5.177	6456.69	556.89	1667.13	80.886	0.492	173.43	5.059	16.319	bdl	15.295	220.67	23.406
hs28	31.902	16855.41	2580.28	9021.47	349.040	1.387	235.23	16.683	310.659	bdl	42.599	300.02	475.204
hs3	13.584	6908.31	1183.37	2109.19	123.111	bdl	349.74	6.673	264.718	bdl	17.959	122.81	158.015
hs30	18.072	15586.65	2941.61	6759.96	313.068	1.427	245.97	17.349	100.593	bdl	58.443	429.84	83.763
hs31	30.848	15321.26	1826.69	7372.74	284.461	1.277	226.69	18.513	134.166	bdl	49.857	182.25	177.102
hs33	52.880	14253.53	1948.47	6564.46	381.955	0.509	241.18	15.027	1903.409	bdl	66.546	239.03	762.147
hs34	10.445	8901.91	1247.62	8568.31	186.100	1.092	120.00	8.737	144.142	bdl	32.466	207.11	106.573
hs35	38.563	18886.51	2958.93	4483.16	407.826	1.032	153.26	18.162	540.977	bdl	36.967	243.53	234.573
hs37	14.386	11906.58	1589.78	2123.85	189.223	0.747	129.69	11.715	333.078	bdl	17.429	249.04	225.976
hs38	109.002	13377.02	1684.66	4139.36	207.594	1.976	#VALUE!	14.109	302.140	bdl	44.111	167.02	484.194
hs39	25.108	16482.57	3296.12	11051.70	400.118	1.116	181.08	17.803	390.325	bdl	49.315	244.61	368.586
hs4	32.485	13969.64	2464.36	4973.15	320.867	1.352	229.40	18.645	317.071	bdl	51.157	199.41	448.528
hs40	26.417	10403.82	1112.99	1683.91	163.418	0.398	146.31	9.519	240.004	bdl	28.347	240.40	230.257
hs42	23.606	21672.86	5167.29	13594.80	568.401	1.729	270.07	23.513	185.632	3.736	60.372	261.52	136.952
hs43	20.904	11676.29	1796.54	7543.30	174.537	1.433	1133.59	12.383	116.444	bdl	42.863	255.03	96.914
hs45	25.359	10606.66	3612.37	13630.10	461.887	1.211	300.57	11.316	31.012	bdl	204.648	141.62	96.721
hs46	5.538	6281.95	486.25	1228.70	112.897	0.629	98.37	4.251	24.235	bdl	21.379	190.26	48.402
hs47	24.107	11670.13	1785.38	3274.14	223.503	1.474	411.86	13.187	49.650	bdl	39.033	210.84	107.217
hs5	16.584	9705.48	1389.60	4227.12	212.295	0.721	106.74	10.160	61.830	bdl	26.962	147.95	91.579
hs6	68.049	22883.16	2687.46	7719.43	524.705	1.938	354.97	29.994	282.503	bdl	65.549	398.37	436.737
hs7	35.410	12268.88	1825.89	4004.24	276.579	1.030	230.26	14.802	137.808	bdl	32.097	253.18	214.850
hs8	37.547	13338.64	1810.27	4455.50	281.306	0.956	233.72	15.349	197.730	bdl	34.402	260.20	237.906
hs9	4.617	6338.03	705.20	3155.32	90.473	0.782	186.07	5.282	15.747	bdl	122.379	272.10	22.633
ihg1	10.297	5887.05	626.12	2626.22	134.803	bdl	121.43	5.418	10.008	bdl	23.189	137.50	35.342
ihg2	18.090	11850.46	1404.81	5350.17	247.978	0.533	361.22	10.219	20.458	bdl	44.526	332.61	56.737
ihg3	11.672	6569.40	802.64	2720.82	161.080	0.335	166.80	5.747	11.534	bdl	24.970	215.00	42.153
ihp1	2.470	4236.53	470.14	606.30	47.598	bdl	66.04	3.346	7.333	bdl	7.751	184.69	17.584
ihp3	1.727	5098.10	378.07	681.38	53.473	bdl	73.86	3.973	5.896	bdl	7.563	211.60	13.508
ihp5	13.948	5208.13	688.30	1902.74	115.052	0.690	112.92	4.656	10.831	bdl	105.800	202.21	101.539
iht1	4.010	4763.75	525.71	664.58	75.213	bdl	77.45	3.683	12.617	bdl	12.170	203.30	23.000
ma1	28.485	10896.80	1425.73	2801.75	223.603	0.885	439.55	11.086	415.490	bdl	28.346	227.88	286.339

sample name	organization	type of soil	notes about sample	Al	As	Ba	Ca	Cd	Co	Cr
ma10	Madison Avenue Art Academy	yard	frontyard	10484.347	5.040	103.071	9686.0	1.723	4.794	17.307
ma12	Madison Avenue Art Academy	yard	backyard	9033.248	5.145	120.720	10142.5	1.761	5.027	15.822
ma2	Madison Avenue Art Academy	garden		8804.391	4.450	86.412	31348.9	1.711	5.637	28.273
ma4	Madison Avenue Art Academy	yard		10925.926	6.803	96.725	13243.7	2.086	6.491	18.460
mg1	Manos Community Garden	garden	bed 1-10cm deep, raised beds	5901.123	bdl	65.846	24975.4	1.221	2.738	11.641
mg10	Manos Community Garden	garden	walkway between beds	5786.640	bdl	80.219	35324.0	1.276	2.841	12.423
mg2	Manos Community Garden	garden	Bed 1-14 cm deep, raised beds	6418.042	2.683	66.195	24715.0	1.287	2.909	13.699
mg3	Manos Community Garden	garden	Bed 2 -10 cm deep, raised beds	6500.992	bdl	63.175	27361.1	1.359	3.323	14.921
mg5	Manos Community Garden	garden	Bed 3 -10 cm deep, raised beds	7455.551	3.516	69.597	23073.9	1.521	3.734	13.967
mg6	Manos Community Garden	garden	Bed 3- 16 cm deep, raised beds	6398.974	3.650	61.839	24704.0	1.302	3.118	16.476
mg7	Manos Community Garden	garden	Bed 4- 10 cm deep, raised beds	5626.471	2.422	66.980	26803.9	1.255	2.853	12.147
mg8	Manos Community Garden	garden	Bed 4-16 cm deep, raised beds	6850.527	3.220	57.424	19608.4	1.332	3.290	12.711
o11	Ottawa Hills Elementary	yard	Stewart (2014)	9824.425	3.902	43.465	2089.3	1.658	3.024	17.577
o15	Ottawa Hills Elementary	yard	Stewart (2014)	10473.247	6.529	52.579	4520.0	2.086	4.732	28.627
o19	Ottawa Hills Elementary	yard	Stewart (2014)	11350.679	5.376	52.918	18852.1	2.028	5.625	15.956
o20	Ottawa Hills Elementary	yard	Stewart (2014)	7950.679	9.195	55.506	10715.0	1.243	3.326	13.630
o24	Ottawa Hills Elementary	yard	Stewart (2014)	5114.605	bdl	45.994	10541.8	0.720	1.856	7.871
o25	Ottawa Hills Elementary	yard	Stewart (2014)	6776.379	8.348	46.499	11152.5	1.565	3.053	14.034
o26	Ottawa Hills Elementary	yard	Stewart (2014)	7258.793	outlier	36.520	6570.1	1.248	2.682	39.163
o35	Ottawa Hills Elementary	yard	Stewart (2014)	5149.225	bdl	19.619	5208.5	0.880	2.277	7.920
o51	Ottawa Hills Elementary	yard	Stewart (2014)	8425.350	3.363	52.566	11895.4	1.691	3.733	19.168
o6	Ottawa Hills Elementary	yard	Stewart (2014)	12959.302	44.632	65.388	9996.1	2.403	6.667	21.589
oh1	Ottawa Hills Elementary	yard	backyard	5321.937	3.058	47.597	18716.0	1.083	2.469	12.175

sample name	organization	type of soil	notes about sample	Al	As	Ba	Ca	Cd	Co	Cr
oh10	Ottawa Hills Elementary	garden		5570.141	7.445	34.346	5141.1	1.078	2.978	12.716
oh11	Ottawa Hills Elementary	yard	backyard	8845.129	5.898	71.785	6672.4	1.712	4.623	20.167
oh12	Ottawa Hills Elementary	garden		4804.525	2.500	50.437	12125.4	1.042	2.401	8.801
oh13	Ottawa Hills Elementary	yard		8308.824	6.521	70.511	27767.0	1.471	3.831	11.823
oh14	Ottawa Hills Elementary	garden		10522.359	9.042	132.311	34131.4	2.137	5.441	23.763
oh15	Ottawa Hills Elementary	yard		14225.901	6.602	204.090	10253.2	2.775	6.183	28.169
oh16	Ottawa Hills Elementary	yard	backyard	9388.247	4.393	46.445	10452.8	1.455	3.950	13.160
oh18	Ottawa Hills Elementary	yard	backyard	10759.494	6.611	55.433	5066.2	1.733	4.654	20.915
oh19	Ottawa Hills Elementary	yard	backyard	7500.988	4.287	148.657	40892.9	1.442	4.504	12.782
oh2	Ottawa Hills Elementary	yard	backyard	4310.378	bdl	39.156	14141.6	0.883	2.241	8.846
oh20	Ottawa Hills Elementary	garden	garden	8761.045	bdl	55.645	9615.2	1.433	3.888	12.193
oh21	Ottawa Hills Elementary	yard	by river soil	10520.542	4.079	56.851	3988.8	1.835	4.697	17.072
oh23	Ottawa Hills Elementary	yard	frontyard	9390.798	4.335	55.598	3505.1	1.323	3.377	14.001
oh24	Ottawa Hills Elementary	yard	backyard	7881.289	20.213	44.780	6167.2	2.088	4.007	64.317
oh25	Ottawa Hills Elementary	yard	frontyard	9816.550	3.864	46.546	5224.4	1.542	3.864	13.700
oh26	Ottawa Hills Elementary	garden		7535.862	4.294	70.662	13961.5	1.425	3.920	11.780
oh27	Ottawa Hills Elementary	garden		8758.061	3.117	35.333	2580.6	1.348	4.006	11.921
oh28	Ottawa Hills Elementary	garden		10571.485	23.967	77.536	24283.2	2.215	5.478	28.436
oh29	Ottawa Hills Elementary	yard	backyard	8689.109	5.267	54.693	7111.9	1.426	3.594	18.178
oh3	Ottawa Hills Elementary	garden	flower bed in backyard	6611.842	2.457	46.314	9800.7	1.219	3.589	11.068
oh30	Ottawa Hills Elementary	garden		10945.160	8.834	62.634	14419.0	1.940	5.431	24.863
oh31	Ottawa Hills Elementary	yard	backyard	7654.746	13.038	74.946	6109.3	1.680	3.144	16.821
oh32	Ottawa Hills Elementary	yard	frontyard	6657.027	8.974	203.489	16358.2	1.195	2.593	12.223
oh33	Ottawa Hills Elementary	yard	side yard along fence line	4256.109	bdl	20.841	7303.0	1.046	2.248	7.028
oh34	Ottawa Hills Elementary	yard	front yard	9241.393	4.532	38.767	1949.0	1.537	3.560	30.480
oh35	Ottawa Hills Elementary	yard	backyard	7405.202	3.107	34.008	4276.4	1.062	2.789	9.242
oh36	Ottawa Hills Elementary	yard	backyard	10691.145	14.746	42.392	1412.7	1.217	3.004	13.685

sample name	Cu	Fe	K	Mg	Mn	Mo	Na	Ni	Pb	Se	Sr	Ti	Zn
ma10	22.485	11429.42	1739.52	4401.46	186.749	0.679	540.17	13.113	237.547	bdl	37.192	309.71	158.890
ma12	28.033	11112.21	1445.68	3859.09	217.099	0.940	253.81	14.101	235.801	bdl	35.078	219.67	158.223
ma2	39.597	10591.38	2960.84	7404.07	457.971	1.454	505.93	12.035	22.508	bdl	117.682	230.02	198.378
ma4	19.727	13888.89	2265.11	5990.25	398.441	0.936	207.99	16.160	178.285	bdl	30.175	249.90	191.345
mg1	66.279	7053.38	1915.50	7043.53	218.042	0.650	117.20	7.652	17.067	bdl	168.111	154.13	77.950
mg10	24.327	7447.66	1855.43	12103.69	193.819	0.638	143.57	7.358	92.742	bdl	233.400	128.41	104.985
mg2	66.283	7590.41	2187.50	6988.01	255.012	0.619	123.03	8.579	16.903	bdl	132.567	156.35	68.956
mg3	72.192	8502.98	1808.53	8203.37	229.663	0.655	133.73	9.573	24.464	bdl	165.675	162.20	61.052
mg5	19.557	9834.06	1966.22	7147.37	239.234	0.869	244.37	10.431	15.271	bdl	130.126	166.26	50.533
mg6	30.367	8747.04	1860.10	8251.78	244.870	0.967	312.35	8.268	14.799	bdl	116.575	135.73	47.553
mg7	49.480	7581.37	1579.41	8706.86	217.549	0.510	118.53	8.941	14.725	bdl	129.902	135.49	60.078
mg8	51.699	8653.35	1706.42	6156.83	202.246	0.735	113.00	9.779	14.858	bdl	80.302	160.60	48.807
o11	11.061	7838.47	674.01	1185.72	78.209	0.371	125.48	6.340	55.638	bdl	13.188	233.52	51.619
o15	15.163	13590.88	2273.52	2511.11	276.222	0.657	144.49	11.937	193.548	bdl	33.977	245.12	73.942
o19	16.625	13988.90	2091.07	8320.26	285.058	1.129	177.44	14.636	5.529	3.501	32.485	299.22	30.496
o20	9.511	8302.43	1315.24	3742.11	207.704	0.392	108.30	8.134	16.947	bdl	38.922	210.00	45.202
o24	18.611	4442.13	717.75	2493.84	141.504	bdl	125.21	3.940	6.317	bdl	38.028	165.85	37.308
o25	38.609	8913.38	1113.34	5140.24	146.346	0.668	135.85	8.252	45.488	bdl	19.767	142.34	68.336
o26	14.060	8253.09	1193.75	2091.77	111.515	0.776	101.00	6.642	63.618	bdl	37.070	153.76	41.452
o35	3.109	5714.56	479.24	1890.19	91.085	bdl	114.21	4.132	3.692	bdl	15.171	223.26	14.970
o51	23.698	8996.89	1260.69	3909.41	292.963	0.719	161.63	11.625	51.030	bdl	45.237	230.56	74.670
o6	18.450	16887.60	3405.04	5079.46	372.287	1.318	623.84	17.810	31.085	bdl	45.329	224.22	50.407
oh1	14.188	6609.69	1341.50	4902.18	146.686	0.342	191.64	5.470	13.390	bdl	101.823	151.95	43.913
oh10	9.992	7449.06	1530.56	1725.90	176.078	0.470	77.86	7.034	13.323	bdl	28.762	163.73	29.976
oh11	58.562	10759.13	1185.88	2439.12	282.344	0.704	81.24	10.654	53.101	bdl	29.319	179.57	82.401
oh12	8.275	6590.59	660.15	2947.01	171.363	0.417	161.74	7.214	10.776	bdl	35.295	218.00	32.139
oh13	13.700	9202.79	1693.30	15116.10	178.560	0.813	800.70	8.901	26.335	bdl	446.401	214.98	54.567
oh14	36.941	12411.95	1909.58	8330.04	252.869	3.166	449.54	15.374	11.516	bdl	122.596	323.51	70.954
oh15	19.367	14926.97	3001.95	5425.51	300.584	0.750	215.77	15.316	1399.221	bdl	61.334	251.31	454.333
oh16	10.626	10211.95	1450.87	4474.95	149.326	0.636	130.73	10.376	5.462	bdl	22.524	204.05	32.447
oh18	126.485	10749.76	1758.52	2599.81	212.269	1.032	142.16	11.616	43.048	bdl	25.180	281.11	88.481
oh19	10.036	9774.79	1886.80	17046.62	224.812	0.356	176.81	9.759	5.847	bdl	#VALUE!	190.30	32.122
oh2	10.854	5369.54	975.75	4221.14	119.108	0.475	261.40	4.821	10.407	bdl	68.274	132.01	33.734
oh20	13.646	9408.99	1513.84	3472.41	243.177	0.540	142.25	8.679	7.363	bdl	42.460	235.81	29.560
oh21	17.471	11487.83	1943.56	2396.29	260.471	0.748	165.64	12.655	24.282	bdl	26.895	201.04	81.252
oh23	11.009	7845.58	934.14	1462.28	110.190	0.385	119.96	7.553	30.460	bdl	17.575	248.03	42.259
oh24	16.663	9400.48	1360.11	2772.92	174.985	0.845	129.95	11.125	49.622	bdl	16.365	230.46	58.670
oh25	9.719	10228.34	1492.97	3105.00	162.685	0.742	99.32	8.528	25.722	bdl	15.418	191.55	44.614
oh26	10.729	9107.88	1090.59	4828.06	334.152	0.619	105.23	10.071	20.927	bdl	35.272	129.20	45.117
oh27	7.837	9986.32	1444.21	1686.54	154.778	0.352	120.87	9.136	17.305	bdl	12.566	271.15	27.047
oh28	30.255	14247.58	4358.32	6221.08	329.840	1.661	661.66	15.088	41.665	bdl	81.036	294.25	119.241
oh29	16.713	9141.58	1507.92	2935.64	151.188	0.881	106.63	9.069	304.752	bdl	21.941	227.72	121.881
oh3	9.269	8532.31	1238.39	4582.04	211.397	0.503	122.39	8.408	9.752	bdl	47.068	208.01	30.147
oh30	16.117	13854.70	2484.57	8017.99	286.193	0.829	98.82	14.019	31.864	bdl	38.529	174.80	53.465
oh31	20.141	8161.72	926.02	1646.69	173.511	0.472	110.04	9.982	119.473	bdl	32.816	179.31	129.593
oh32	14.662	7505.30	658.18	7342.39	135.724	0.829	89.43	6.256	40.091	bdl	34.914	187.68	51.774
oh33	3.412	7339.20	435.29	2468.23	103.324	bdl	85.85	3.675	4.428	bdl	19.795	254.55	13.675
oh34	7.528	9326.98	1044.54	1433.38	160.124	0.486	159.17	7.742	25.073	bdl	16.845	189.09	29.839
oh35	5.807	7509.43	1143.54	1413.54	95.761	0.685	110.88	5.926	12.408	bdl	17.560	200.02	28.311
oh36	7.069	9275.48	1608.68	1380.52	53.780	0.668	144.75	7.618	47.830	bdl	9.935	229.33	82.427

sample name	organization	type of soil	notes about sample	Al	As	Ba	Ca	Cd	Co	Cr
oh37	Ottawa Hills Elementary	yard	backyard	8698.050	5.791	41.974	13220.4	1.379	3.762	10.833
oh38	Ottawa Hills Elementary	yard	Frontyard	9359.073	21.120	48.890	4084.0	1.535	3.610	16.419
oh39	Ottawa Hills Elementary	yard	backyard	5305.633	bdl	21.594	2455.1	0.799	2.217	5.813
oh4	Ottawa Hills Elementary	garden		9165.350	16.505	54.741	2879.3	1.383	4.050	20.792
oh41	Ottawa Hills Elementary	yard		6133.920	bdl	23.920	1736.1	0.880	2.463	8.749
oh42	Ottawa Hills Elementary	yard	front yard	11157.230	5.987	91.526	5977.4	2.123	4.973	20.696
oh43	Ottawa Hills Elementary	yard	backyard	9851.232	4.404	58.818	4131.0	1.852	3.951	28.729
oh44	Ottawa Hills Elementary	yard	front yard	6598.859	8.099	43.726	3124.5	1.511	2.804	62.357
oh46	Ottawa Hills Elementary	garden		5670.319	6.912	46.275	5440.2	1.016	2.221	9.283
oh47	Ottawa Hills Elementary	yard	front yard	8151.318	6.710	64.640	9937.0	1.515	3.955	17.552
oh48	Ottawa Hills Elementary	yard	under a swingset	11226.190	26.766	43.829	2039.7	1.726	5.159	22.083
oh49	Ottawa Hills Elementary	garden	flower bed	11029.688	4.218	65.577	4707.8	2.142	5.505	21.749
oh5	Ottawa Hills Elementary	yard	backyard	7154.520	3.923	26.464	1161.9	1.264	3.106	20.121
oh50	Ottawa Hills Elementary	yard	by creek	11789.577	7.011	82.271	10314.7	2.478	6.529	18.555
oh51	Ottawa Hills Elementary	yard	front yard	6900.219	4.731	60.515	23742.8	1.451	3.528	13.188
oh52	Ottawa Hills Elementary	yard	backyard	9427.474	3.093	101.134	11821.3	1.652	4.918	14.486
oh53	Ottawa Hills Elementary	yard	backyard	9848.246	6.050	42.669	4527.0	3.350	4.789	33.484
oh6	Ottawa Hills Elementary	yard	backyard	6543.840	30.140	48.677	7142.9	1.304	2.702	22.978
oh7	Ottawa Hills Elementary	yard	backyard	25414.365	8.544	131.650	21586.4	3.749	10.438	34.096
oh8	Ottawa Hills Elementary	garden		9976.572	6.345	67.903	11118.7	1.855	4.803	27.411
oh9	Ottawa Hills Elementary	yard	backyard	7693.220	4.408	30.757	2972.9	1.403	3.558	13.263
s101	Scott High School	yard	Stewart (2014)	10394.610	7.180	119.249	9205.0	2.089	6.285	18.624
S105	Scott High School	yard	Stewart (2014)	6926.588	18.695	40.491	10644.7	1.541	3.956	22.442
s110	Scott High School	yard	Stewart (2014)	9287.760	12.479	75.616	5844.0	1.518	3.332	14.779
s27	Scott High School	yard	Stewart (2014)	6960.504	9.445	115.341	9166.2	2.900	4.560	18.928
s32	Scott High School	yard	Stewart (2014)	13369.162	9.850	126.050	5763.1	2.599	6.605	22.298
s40	Scott High School	yard	Stewart (2014)	10011.558	7.243	78.443	18273.9	2.254	5.991	15.912

sample name	organization	type of soil	notes about sample	Al	As	Ba	Ca	Cd	Co	Cr
s53	Scott High School	yard	Stewart (2014)	11492.308	8.731	127.538	10690.4	2.846	6.365	22.962
s56	Scott High School	yard	by fence, Stewart (2014)	14224.971	10.002	124.952	19530.3	3.092	9.074	22.584
s58	Scott High School	yard	by metal fence, Stewart (2014)	7051.257	4.265	252.028	4395.4	1.781	3.810	13.863
s60	Scott High School	yard	Stewart (2014)	11145.571	5.728	70.954	9321.6	1.793	5.282	15.798
s68	Scott High School	yard	Stewart (2014)	10324.840	7.781	88.874	20676.9	2.645	5.660	25.092
s71	Scott High School	yard	Stewart (2014)	11101.891	5.944	107.217	3514.1	1.949	5.712	19.278
s73	Scott High School	yard	by fence, Stewart (2014)	9052.561	5.666	92.230	14168.7	1.914	4.904	17.958
s80	Scott High School	yard	Stewart (2014)	9088.252	5.552	110.481	2922.3	1.929	6.215	17.144
s83	Scott High School	yard	Stewart (2014)	17271.658	17.640	312.819	79459.0	3.587	8.938	52.626
s87	Scott High School	yard	Stewart (2014)	5154.475	2.651	31.971	28263.9	1.076	2.990	11.162
s90	Scott High School	yard	Stewart (2014)	9124.710	14.679	120.159	14614.6	2.324	5.751	21.495
s93	Scott High School	yard	Stewart (2014)	8762.241	13.533	62.946	30826.5	1.782	5.151	21.191

sample name	Cu	Fe	K	Mg	Mn	Mo	Na	Ni	Pb	Se	Sr	Ti	Zn
oh37	8.489	9775.46	1337.40	4817.81	154.678	0.532	108.39	8.410	12.310	bdl	30.510	185.62	26.137
oh38	11.390	9806.95	1233.59	1955.60	166.409	0.705	108.30	9.035	64.170	bdl	15.492	251.45	83.909
oh39	4.235	4982.02	355.17	1203.76	47.443	bdl	170.12	3.516	6.053	bdl	17.419	181.18	6.932
oh4	21.493	9383.64	1365.07	1691.03	123.963	0.385	123.07	9.650	93.076	bdl	16.100	168.61	70.249
oh41	5.142	5546.43	539.59	910.95	99.413	bdl	82.71	4.555	14.585	bdl	9.707	238.42	25.846
oh42	61.687	10474.37	1441.85	2234.12	208.493	0.976	267.41	10.080	696.634	bdl	31.121	258.42	240.819
oh43	25.241	9862.07	1515.27	1895.57	178.424	0.729	164.04	10.345	66.837	bdl	17.970	222.17	91.241
oh44	13.451	8864.07	788.12	1254.75	152.947	0.618	132.60	8.213	42.414	bdl	16.264	173.67	47.357
oh46	6.972	6803.78	522.41	1571.71	118.426	0.478	102.69	5.060	24.582	bdl	22.689	208.76	50.687
oh47	20.789	8810.51	1758.17	2643.64	250.295	0.826	167.95	9.150	156.533	bdl	48.888	231.90	158.697
oh48	10.595	12555.56	1352.38	1931.94	138.056	1.071	114.70	10.952	24.921	bdl	16.290	227.58	26.845
oh49	17.381	12805.34	1833.90	2498.12	282.319	1.146	142.24	14.215	38.566	bdl	20.462	160.09	135.569
oh5	10.384	8895.86	974.61	1176.82	115.392	0.597	80.18	6.880	21.943	bdl	9.787	171.64	38.700
oh50	18.505	14818.09	2194.69	5325.47	522.222	1.013	154.87	15.497	31.947	bdl	35.831	200.20	81.111
oh51	27.579	9358.97	1514.61	7376.27	197.575	0.745	115.68	9.938	20.513	bdl	86.514	160.01	52.425
oh52	33.814	11081.65	1307.20	3658.02	333.718	bdl	235.16	11.028	12.219	bdl	56.196	229.39	47.224
oh53	15.786	11044.54	1285.38	2558.14	233.938	0.788	255.81	10.150	74.340	3.528	16.791	249.70	147.379
oh6	14.021	7774.00	692.74	1906.65	182.181	bdl	69.39	6.009	58.012	bdl	31.822	174.23	53.912
oh7	25.552	25789.27	6339.78	11195.74	601.618	2.092	228.69	27.802	42.463	bdl	52.762	282.75	230.268
oh8	14.155	11415.46	1772.75	3939.87	250.293	0.703	216.13	10.387	29.461	bdl	53.885	226.47	48.750
oh9	6.385	8760.62	1104.37	1575.61	189.978	bdl	116.09	7.492	22.119	3.558	11.998	211.31	36.944
s101	27.247	13657.36	2004.81	5368.62	336.189	1.319	269.87	16.092	763.908	bdl	27.844	253.22	287.969
S105	10.574	8817.04	1407.57	4644.35	292.126	0.475	230.89	9.034	44.922	bdl	32.408	236.97	38.094
s110	8.459	11075.04	2002.10	2113.81	116.288	0.955	207.75	8.316	22.838	bdl	59.605	224.46	59.958
s27	34.688	11829.80	909.18	3976.34	151.650	0.763	249.00	13.299	490.174	bdl	42.301	239.84	428.163
s32	181.415	15880.40	2036.35	3087.75	227.282	1.505	174.67	18.468	220.833	bdl	25.601	257.38	292.750
s40	20.632	14536.70	2022.73	7410.90	279.137	1.637	345.98	14.872	85.398	bdl	46.985	244.46	100.790
s53	34.346	18030.77	2030.77	4644.23	269.231	0.885	230.58	18.519	637.885	bdl	38.365	290.77	373.269
s56	54.194	17935.83	2745.46	8741.79	417.279	1.430	487.82	22.468	300.348	bdl	36.287	255.32	367.511
s58	21.720	8608.75	1067.68	1818.72	125.074	0.742	219.57	9.331	973.580	bdl	21.581	203.84	441.916
s60	17.717	11465.40	1765.85	4045.36	276.798	0.911	182.30	12.124	63.268	bdl	33.349	251.21	287.265
s68	45.166	14619.72	2129.94	9470.92	306.555	1.089	194.51	18.382	257.343	bdl	56.098	258.32	255.981
s71	21.305	12429.56	1954.84	2066.77	324.199	0.810	172.00	12.659	144.732	bdl	26.689	314.94	123.640
s73	16.121	11416.87	1699.68	6626.36	239.859	0.990	185.30	12.141	196.820	bdl	30.213	226.15	218.054
s80	21.508	11733.88	1410.87	1729.40	376.193	1.052	145.26	11.884	153.926	bdl	21.235	213.52	113.871
s83	55.449	24853.00	2996.86	14623.68	333.791	4.077	805.57	36.946	47.668	4.312	314.387	540.38	190.631
s87	10.484	7273.27	1114.01	9471.80	162.507	0.379	#VALUE!	19.932	21.666	bdl	44.369	212.28	48.057
s90	28.679	12902.79	1719.40	6870.64	211.851	0.755	294.15	15.105	349.148	bdl	134.314	273.24	274.400
s93	21.759	12124.95	2271.84	13934.59	234.822	1.156	380.34	35.155	108.461	bdl	47.082	242.85	95.417

APPENDIX F. FIGURES

Figure 1. Locations of the four Toledo schools and community garden. School points depict the locations of the schools that collaborated with this project. Community Garden point depicts the location of the collected soil samples at the garden.

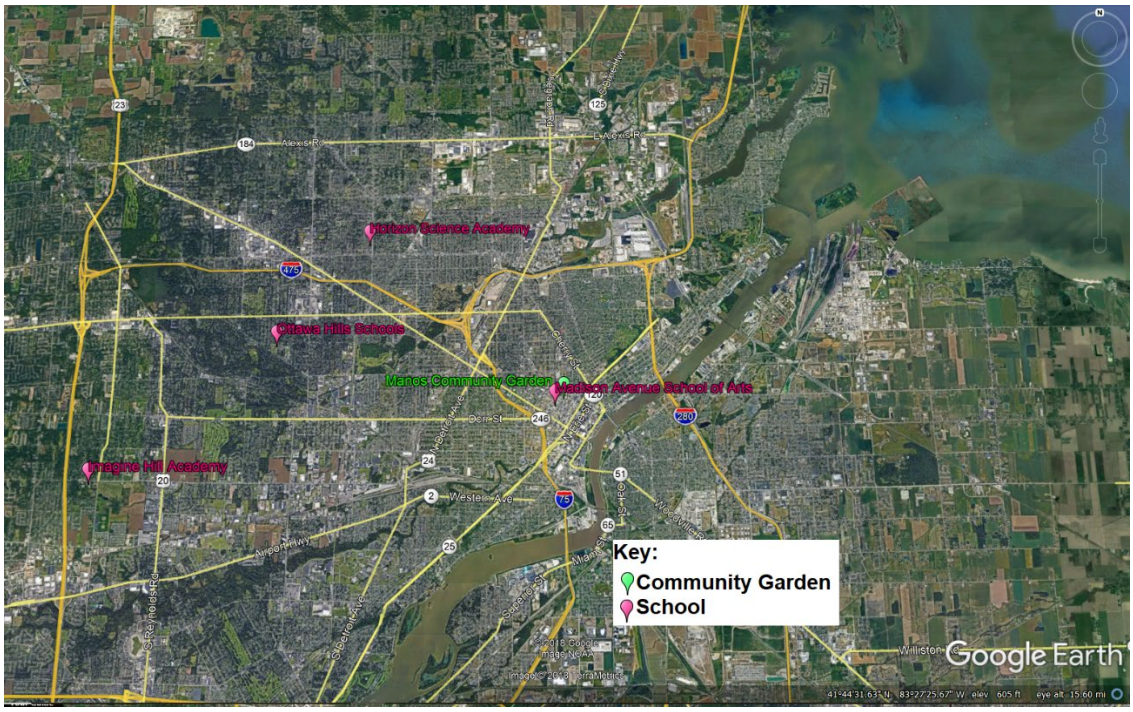


Figure 2. Soil sample locations analyzed for heavy metals. Locations are differentiated between those collected in this study and those from Stewart et al. (2014).

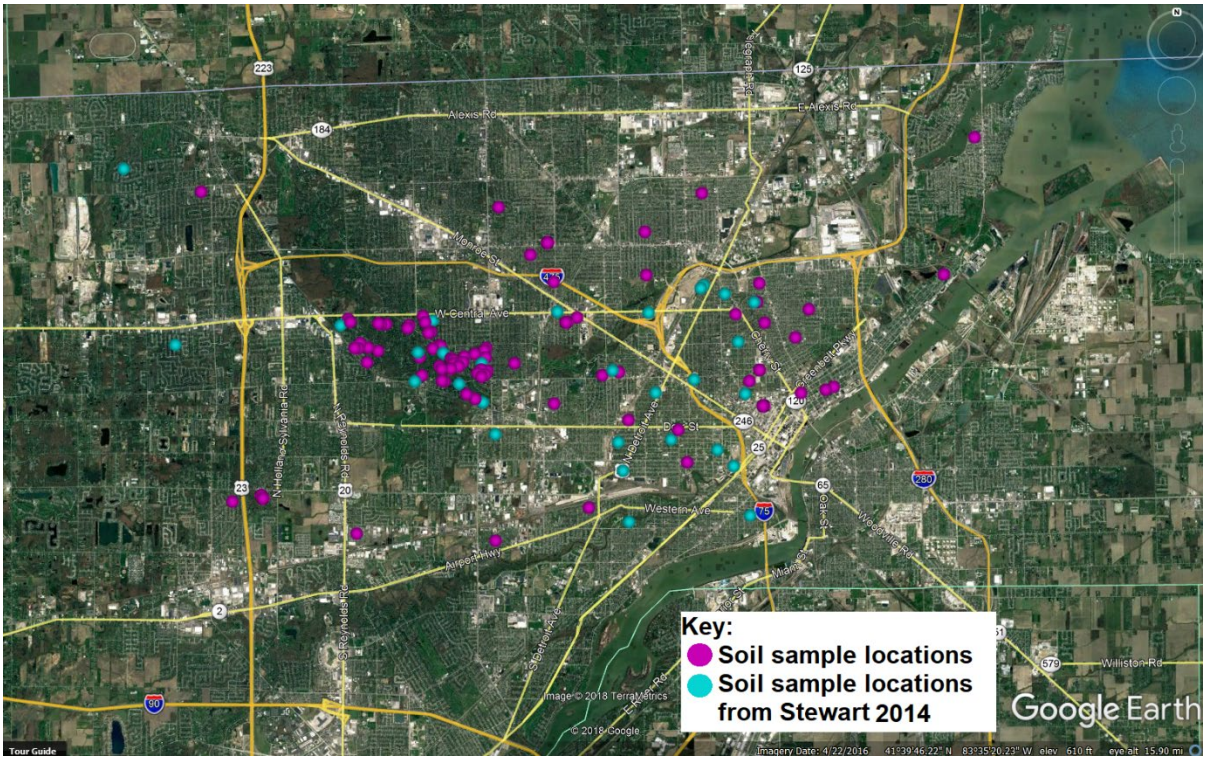


Figure 3. Soil sample locations at the Manos Community Garden. Photographs are shown with each individual sample site with its label.

Figure 4. Histogram of arsenic ppm concentrations in 120 samples. For arsenic the USEPA screening level is 3.5 ppm, and the Ohio EPA background upper limit is 9.7 ppm (2019 and 2015).

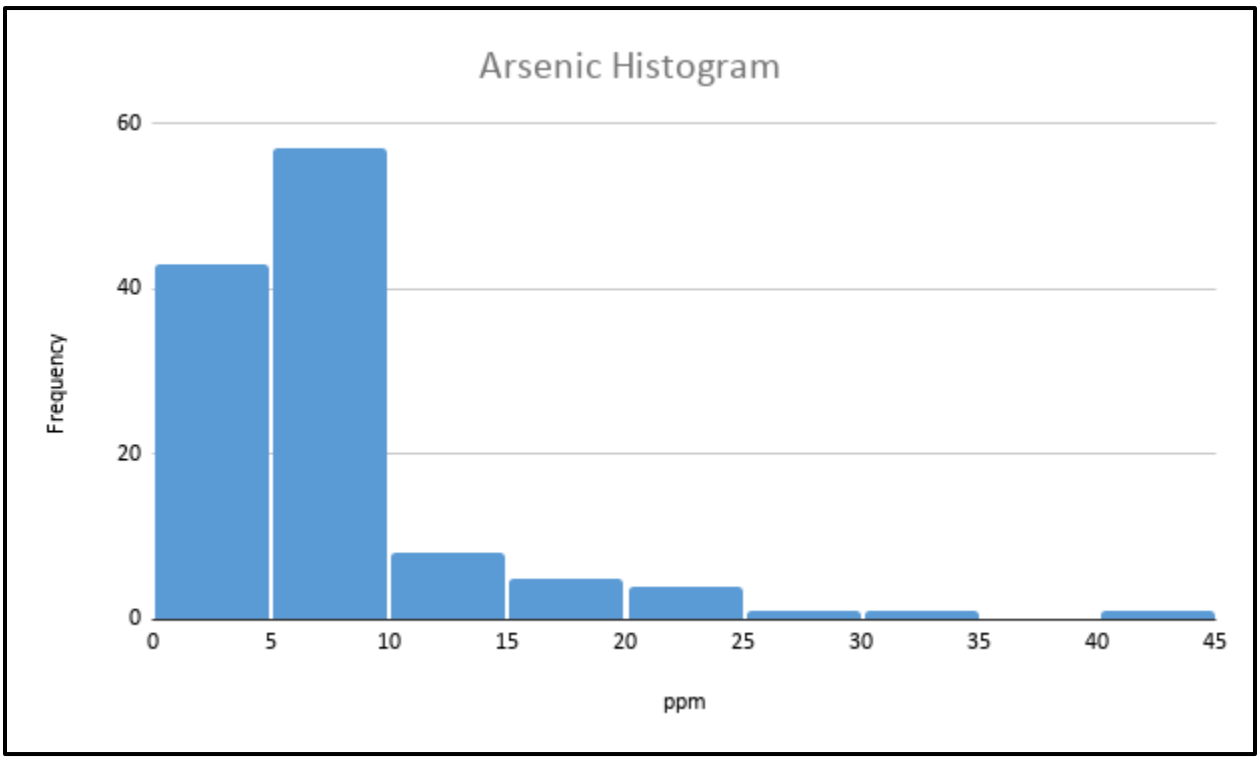


Figure 5. Spatially predictive arsenic concentrations. Map shows interpolation using Empirical Bayesian kriging with parameters set using standard deviation of the samples of 8.874 ppm, the USEPA screening level of 3.5 ppm, and the Ohio EPA background upper limit of 9.7 ppm (2019 and 2015). Specific parameters are shown below map. Map shows the extent of the Toledo and Ottawa Hills city limits and is overlain with the labeled sample collection locations.

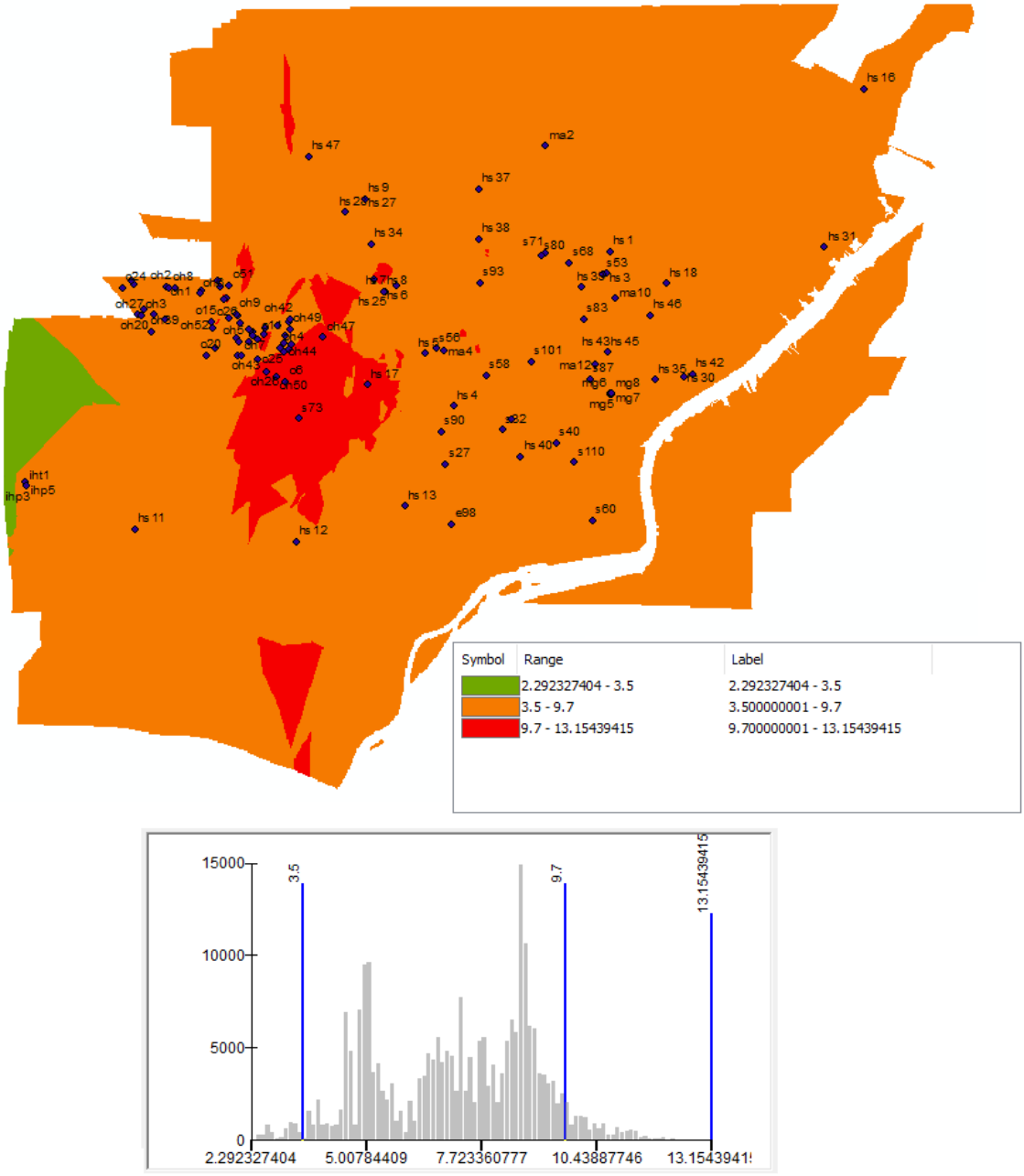


Figure 6. Hot Spot Analysis of arsenic soil concentration values. Each point displays clusters of samples with similar concentrations, with tones defining the reliability of each area.

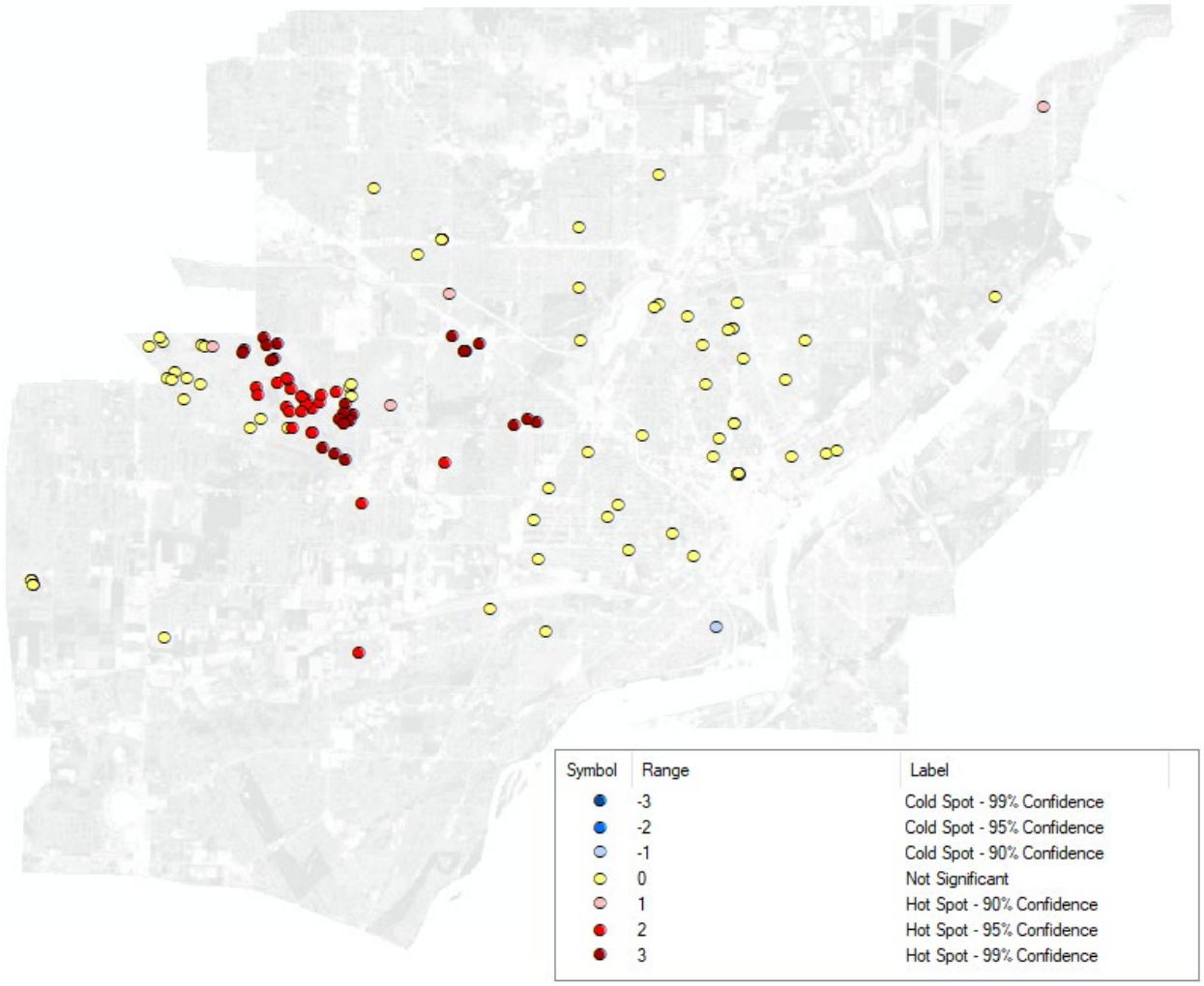


Figure 7. Histogram of frequency of cadmium ppm in 137 samples. For cadmium the USEPA screening level is 7.1 ppm and the Cox-Colvin & Associates background level is 0.507 ppm (2019 and 1996).

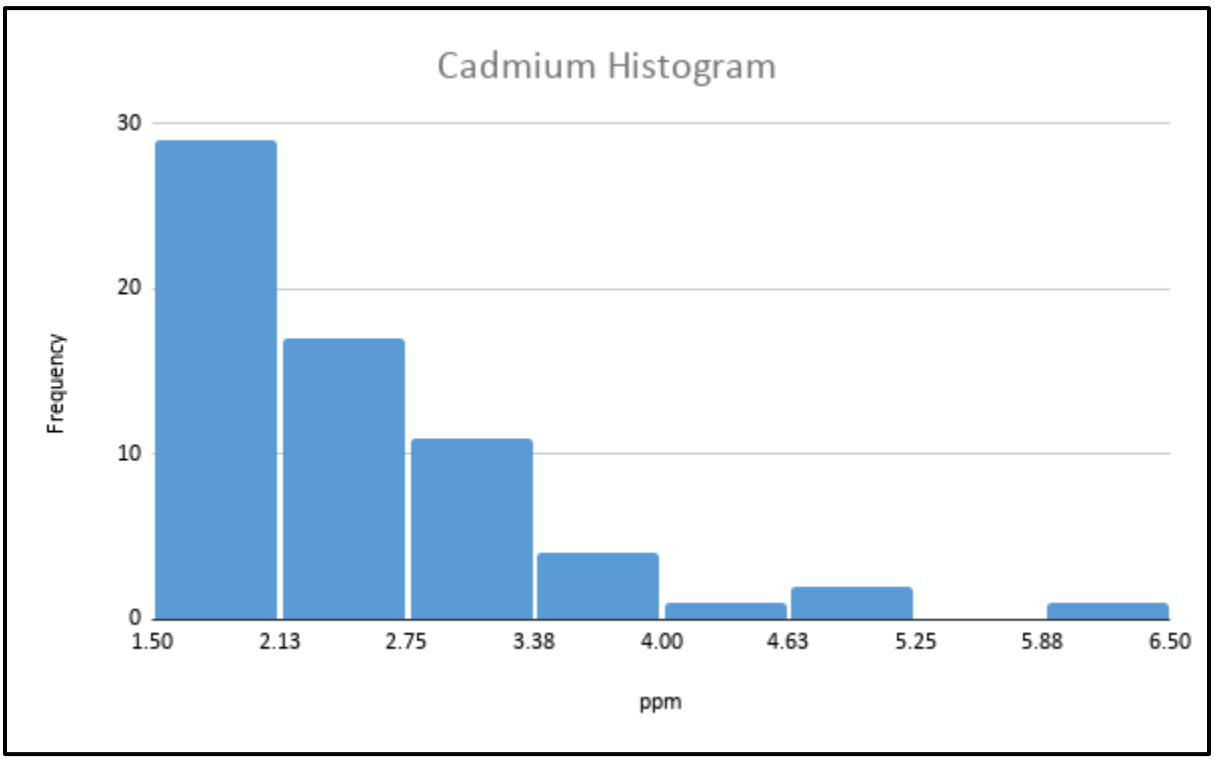


Figure 8. Spatially predictive cadmium concentrations. Map shows interpolation using Empirical Bayesian kriging with parameters set using standard deviation of the samples of 0.896 ppm and the Cox-Colvin & Associates background level of 0.507 ppm (1996). Specific parameters are shown below map. Map shows the extent of the Toledo and Ottawa Hills city limits and is overlain with the labeled sample collection locations.

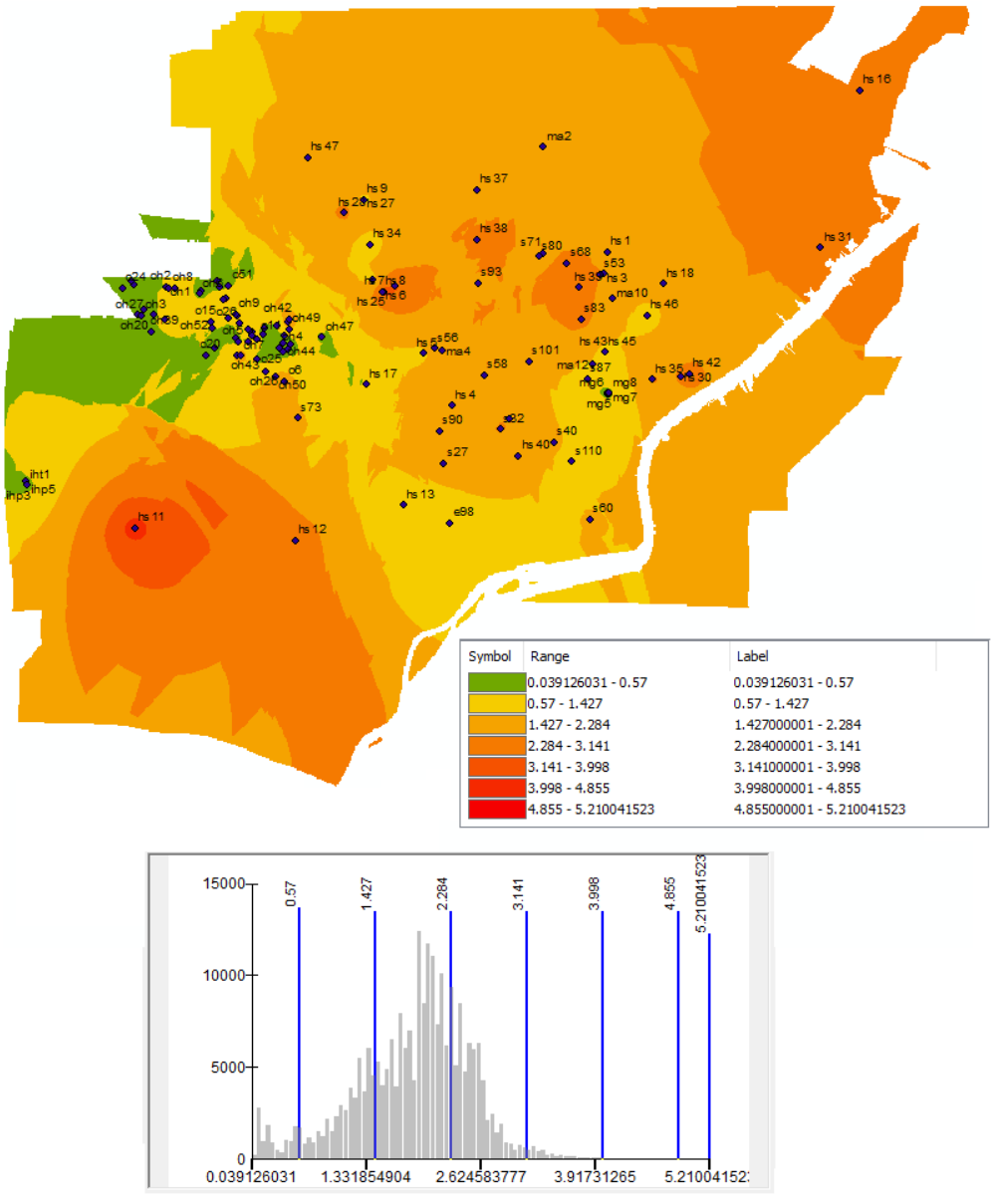


Figure 9. Hot Spot Analysis of cadmium soil concentration values. Each point displays clusters of samples with similar concentrations, with tones defining the reliability of each area.

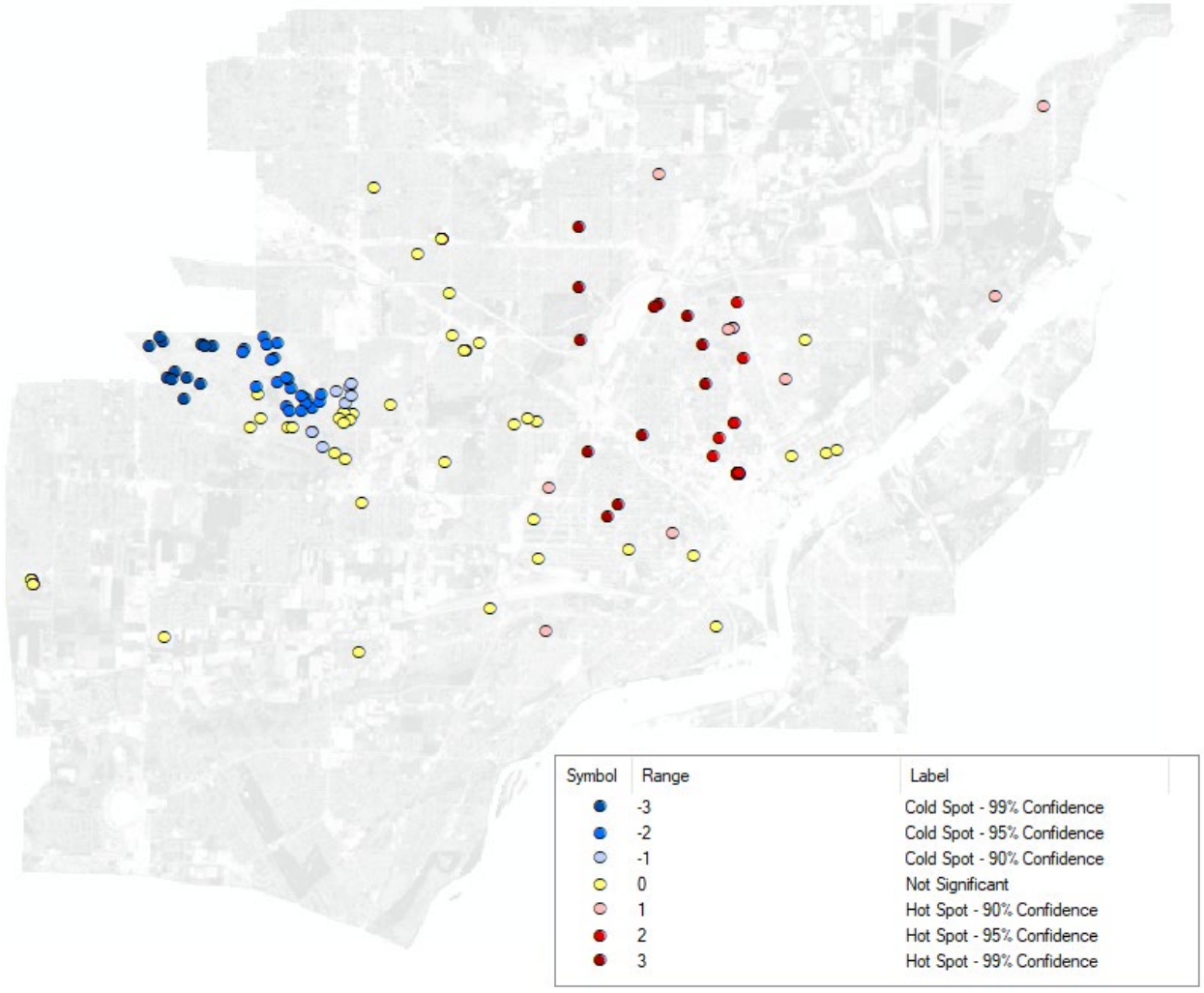


Figure 10. Histogram of frequency of chromium ppm in 137 samples. For chromium the USEPA screening level is 12000 ppm and the Ohio EPA background upper limit is 22.20 ppm (2019 and 2015).

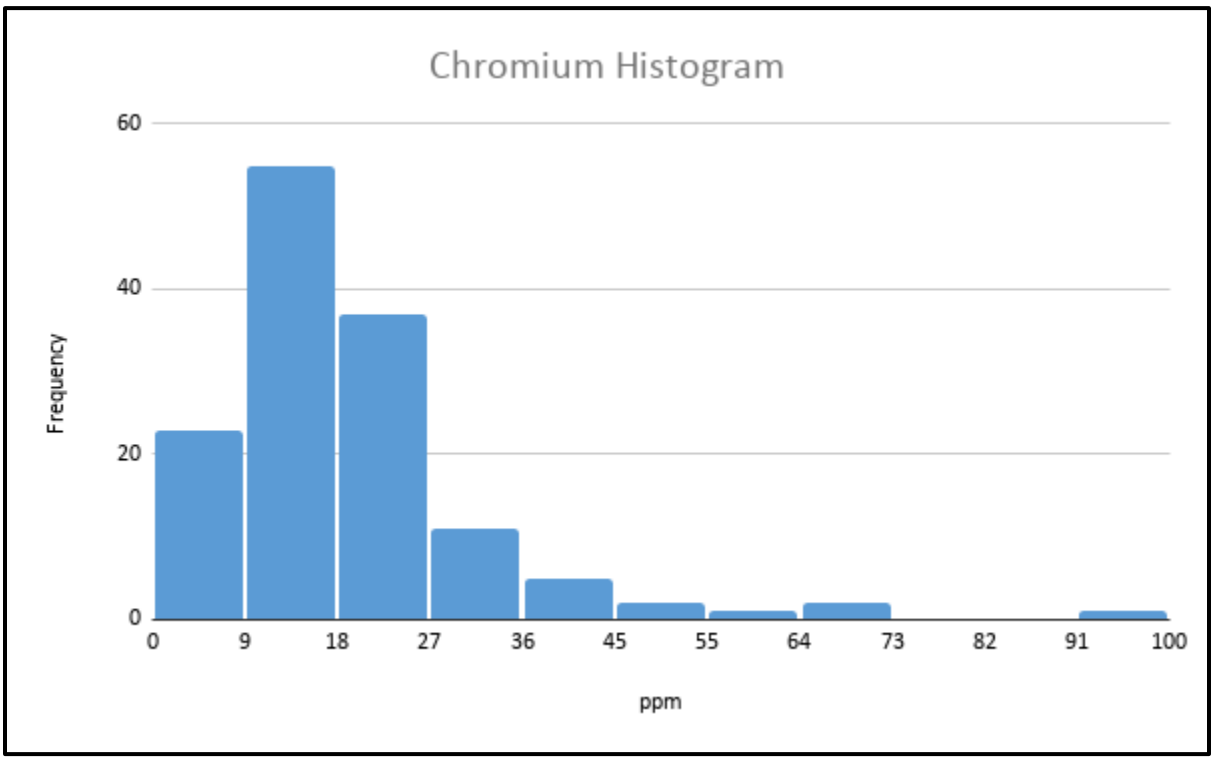
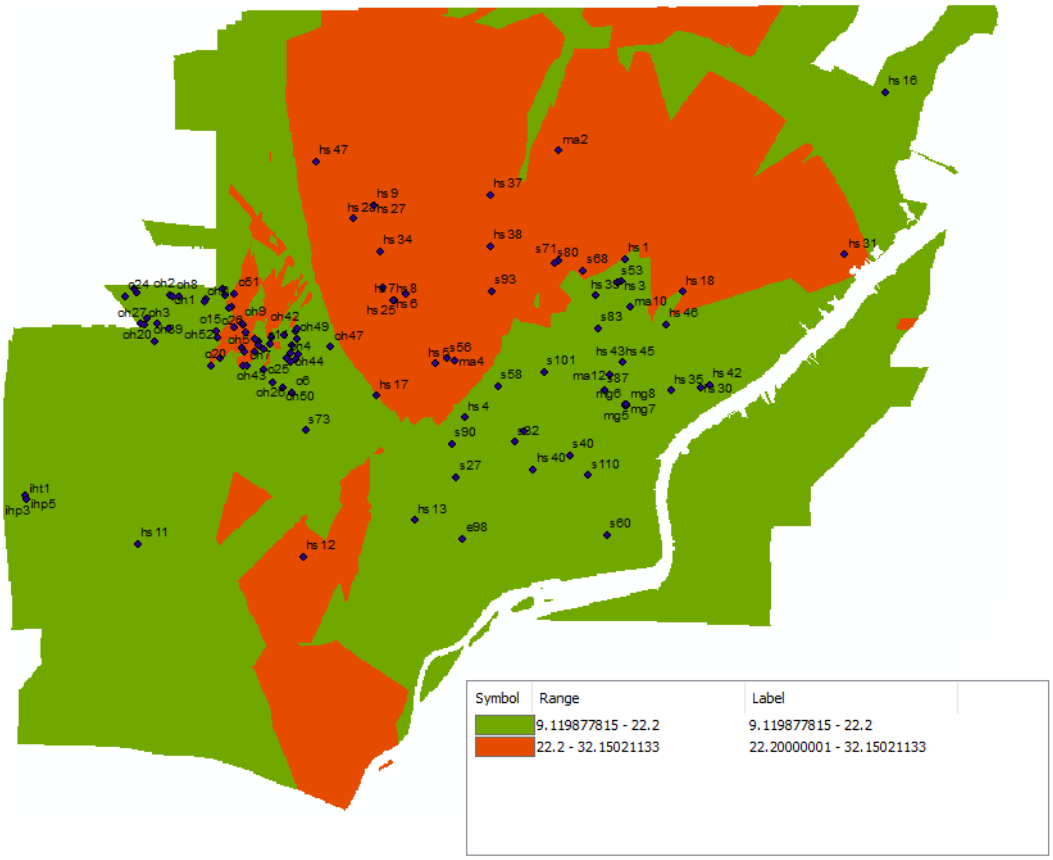


Figure 11. Spatially predictive chromium concentrations. Map shows interpolation using Empirical Bayesian kriging with parameters set using standard deviation of the samples of 15.892 ppm, the USEPA screening level of 12000 ppm (outside of predictive values shown), and the Ohio EPA background upper limit of 22.20 ppm (2019 and 2015). Specific parameters are shown below map. Map shows the extent of the Toledo and Ottawa Hills city limits and is overlain with the labeled sample collection locations.



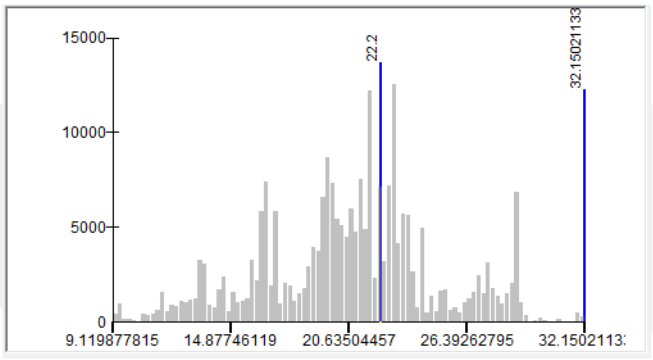


Figure 12. Hot Spot Analysis of chromium soil concentration values. Each point displays clusters of samples with similar concentrations, with tones defining the reliability of each area.

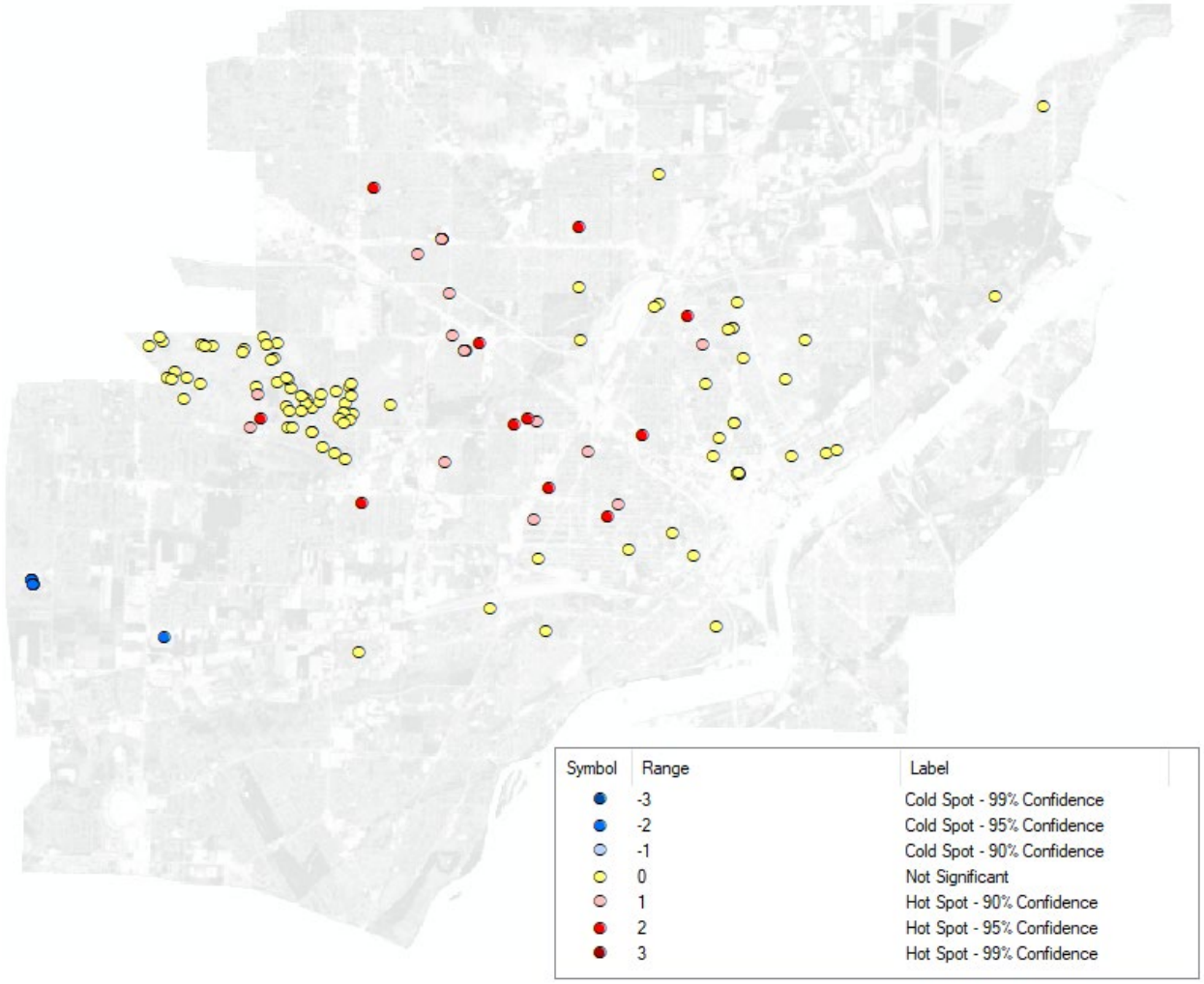


Figure 13. Histogram of frequency of lead ppm in 137 samples. For lead the USEPA screening level is 400 ppm and the Ohio EPA background upper limit is 17 ppm (2019 and 2015).

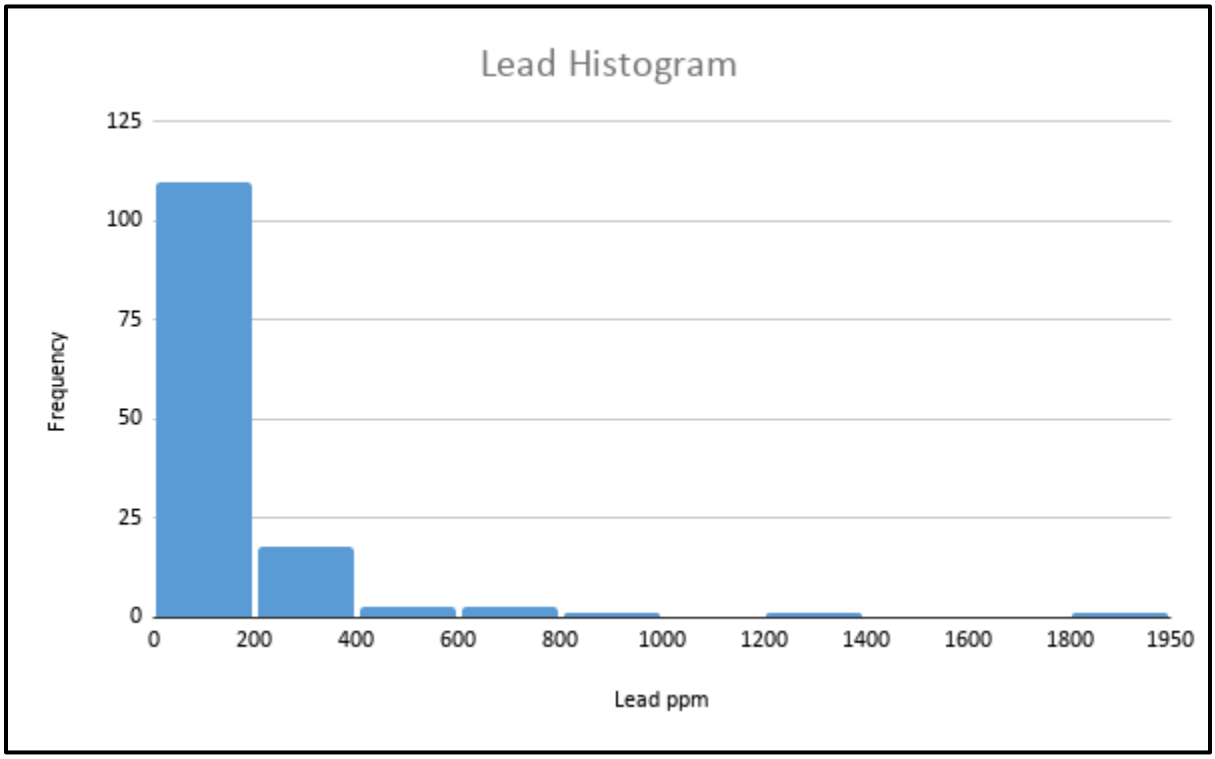


Figure 14. Spatially predictive lead concentrations. Map shows interpolation using Empirical Bayesian kriging with parameters set using standard deviation of the samples of 297.254 ppm, the USEPA screening level of 400 ppm, and the Ohio EPA background upper limit of 17 ppm (2019 and 2015). Specific parameters are shown below map. Map shows the extent of the Toledo and Ottawa Hills city limits and is overlain with the labeled sample collection locations.

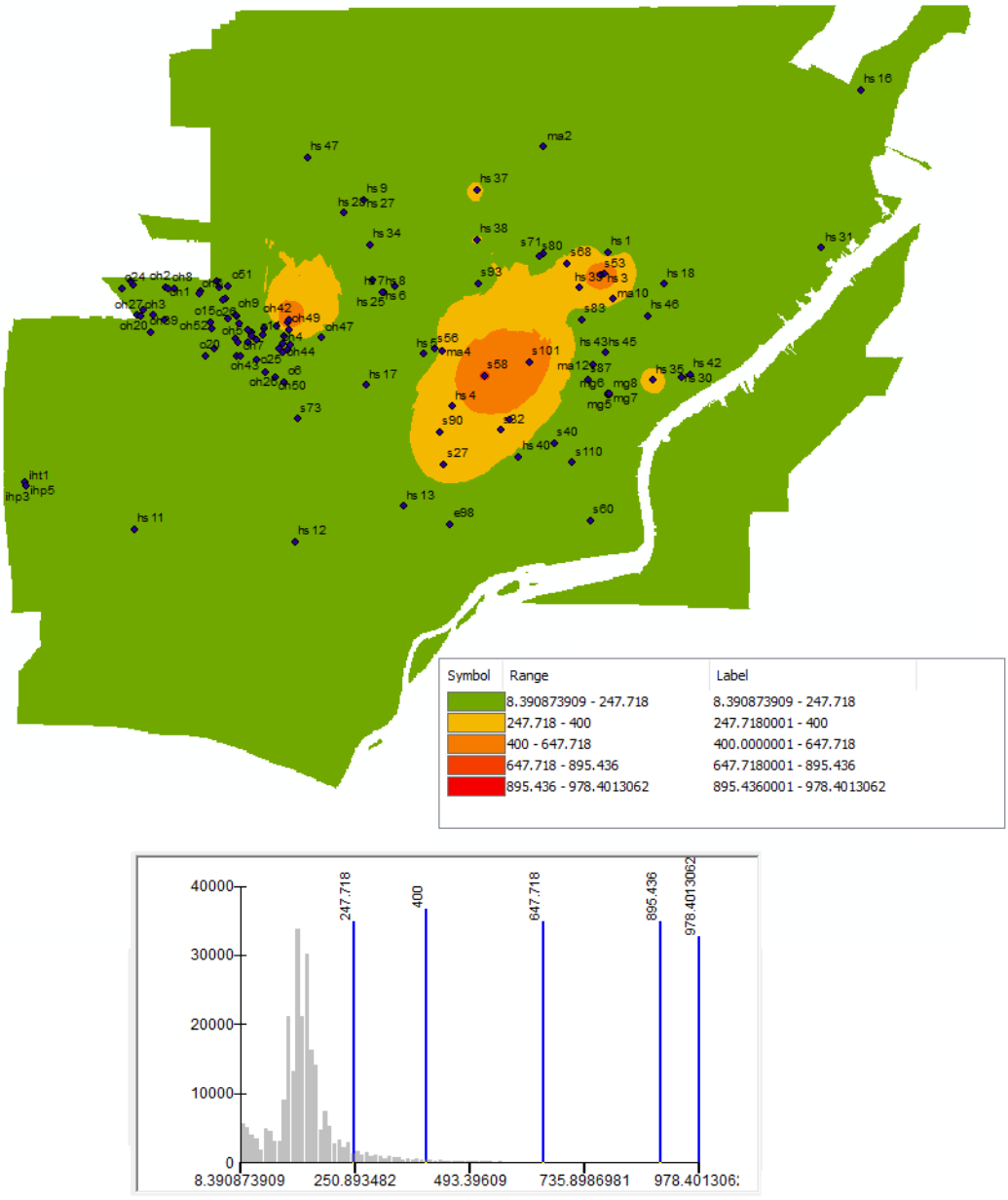


Figure 15. Hot Spot Analysis of lead soil concentration values. Each point displays clusters of samples with similar concentrations, with tones defining the reliability of each area.

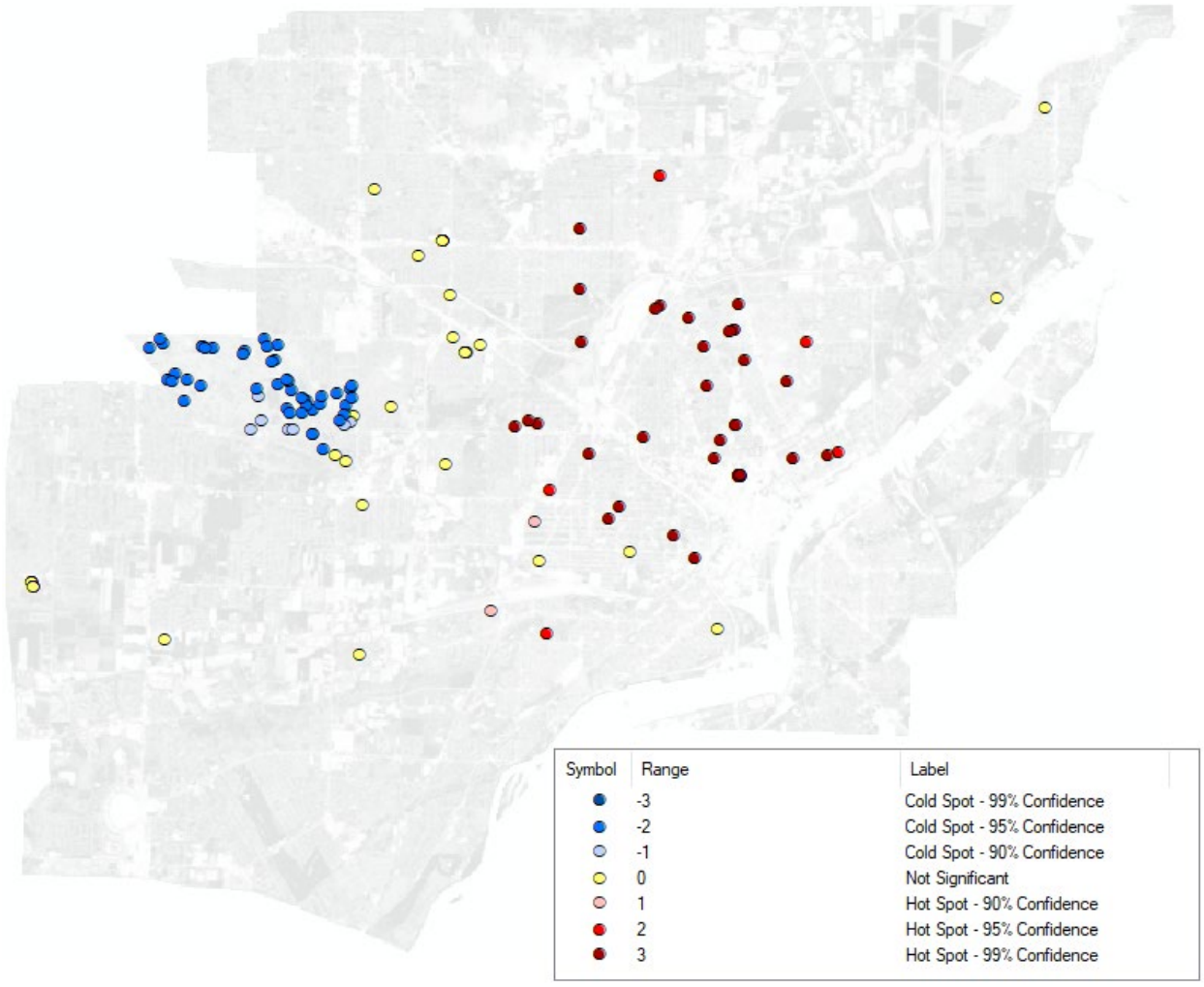


Figure 16. Histogram of frequency of nickel ppm in 137 samples. For nickel the USEPA screening level is 150 ppm and Ohio EPA background upper limit is 22.45 ppm (2019 and 2015).

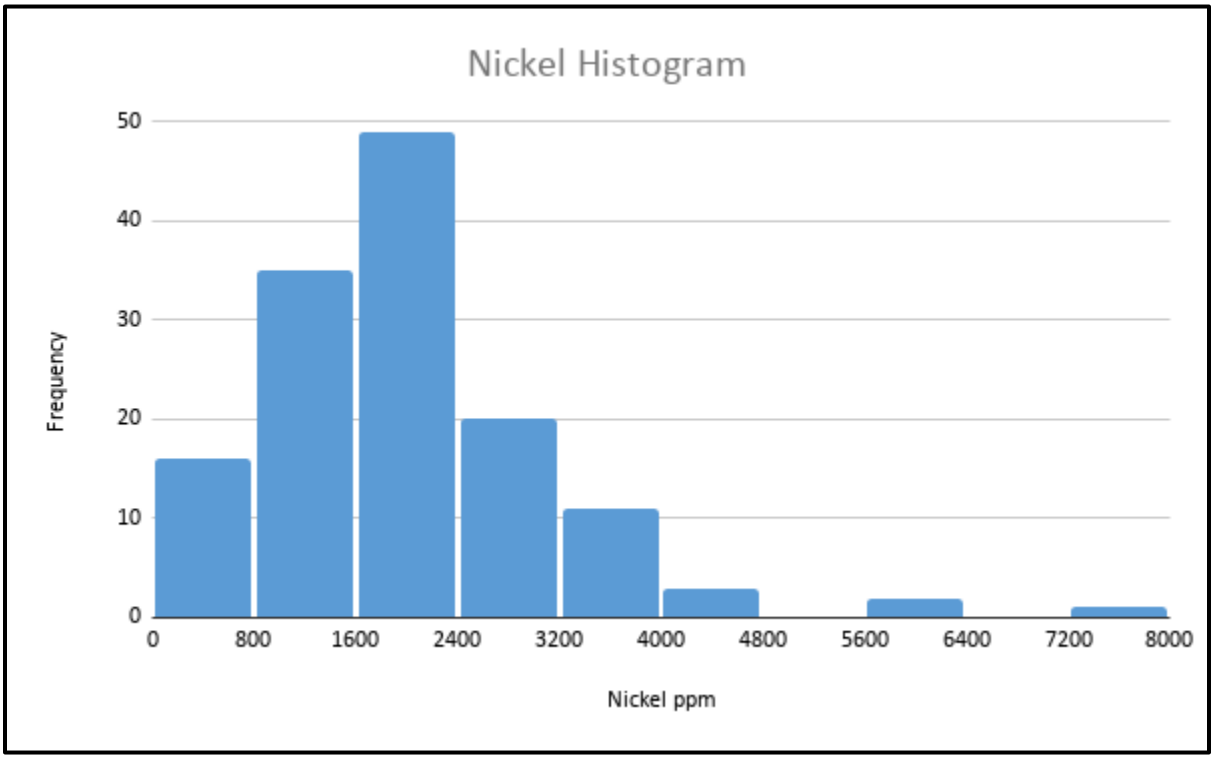
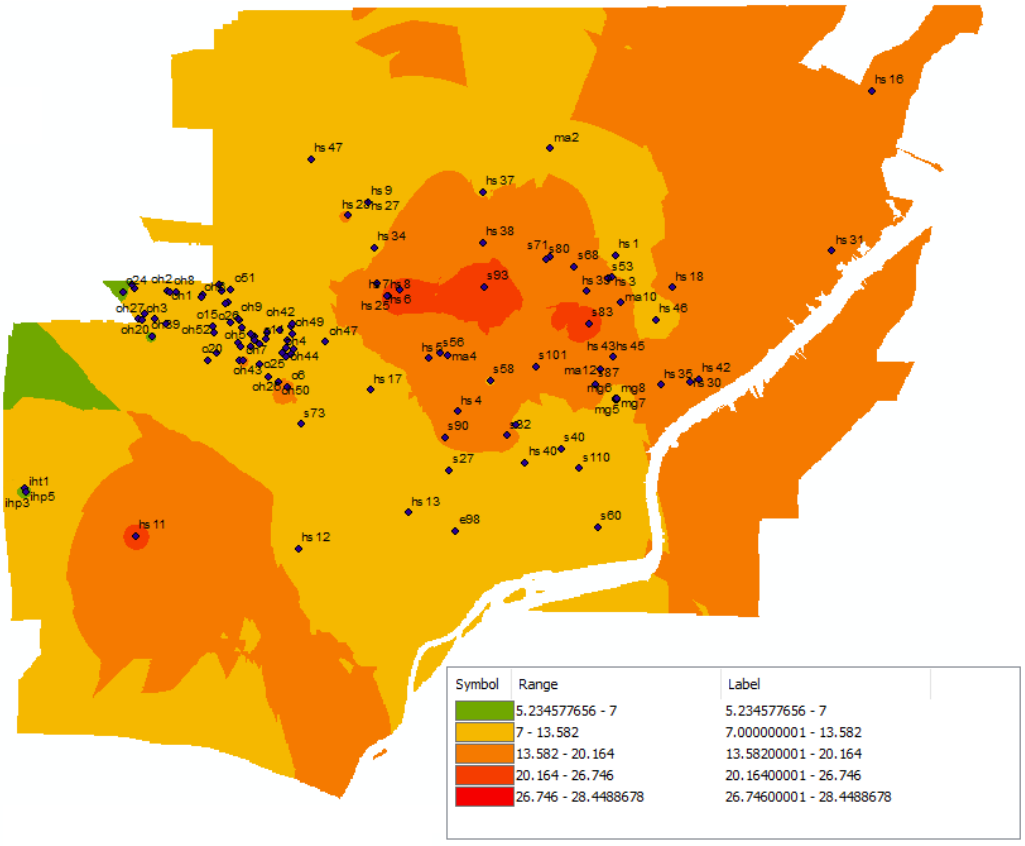


Figure 17. Spatially predictive nickel concentrations. Map shows interpolation using Empirical Bayesian kriging with parameters set using standard deviation of the samples of 7.885 ppm, the USEPA screening level of 150 ppm (outside of predictive values shown, and Ohio EPA background upper limit of 22.45 ppm (2019 and 2015). Specific parameters are shown below map. Map shows the extent of the Toledo and Ottawa Hills city limits and is overlain with the labeled sample collection locations.



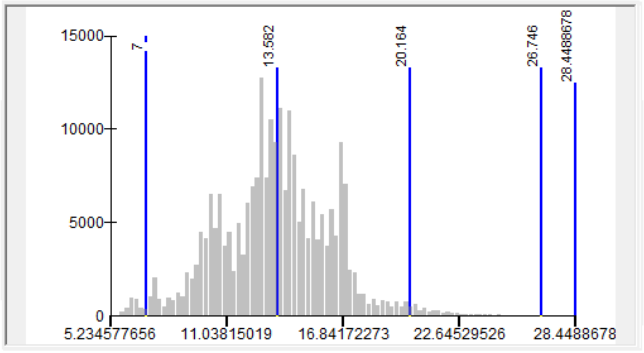


Figure 18. Hot Spot Analysis of nickel soil concentration values. Each point displays clusters of samples with similar concentrations, with tones defining the reliability of each area.

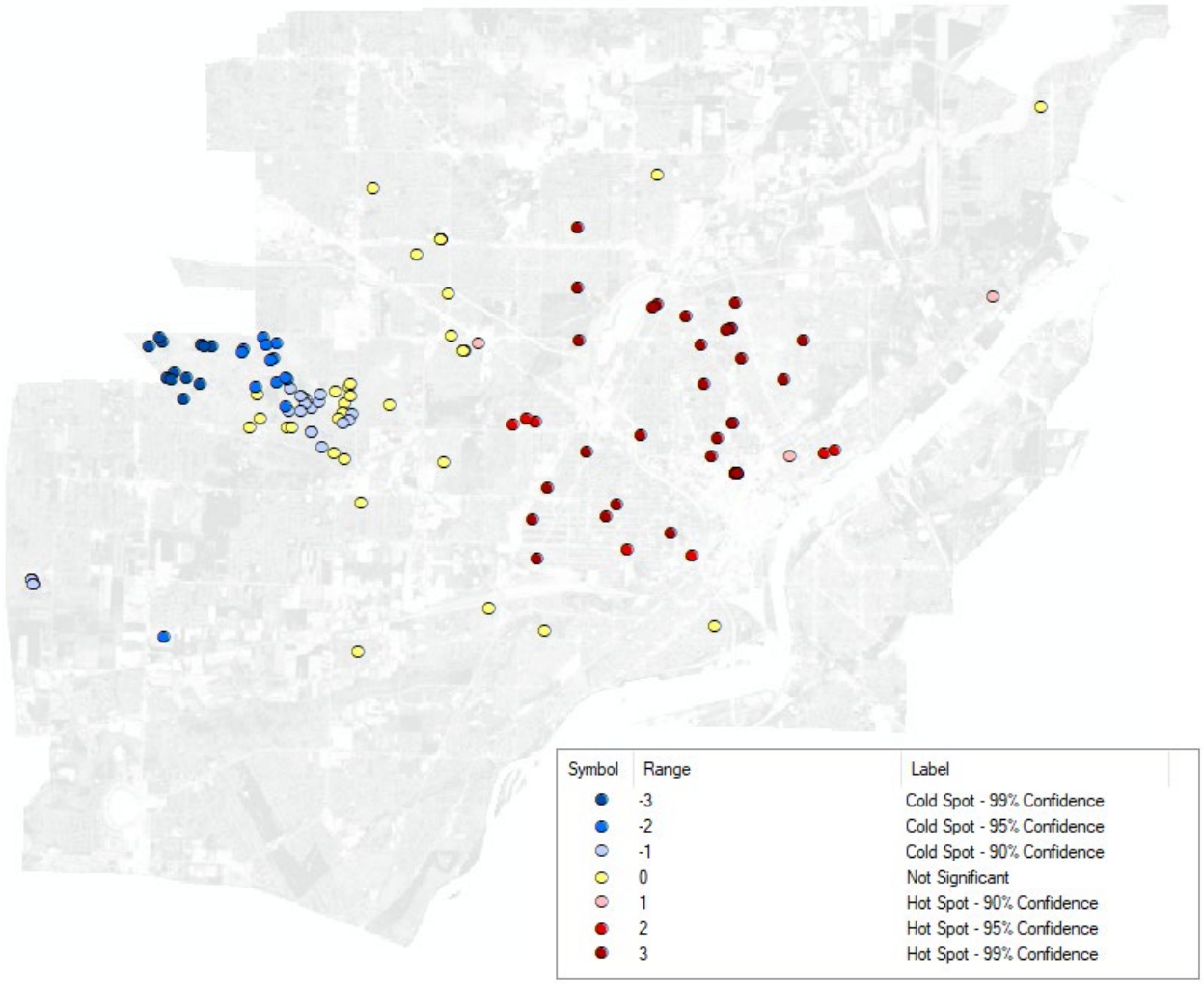


Figure 19. Histogram of frequency of zinc ppm in 137 samples. For zinc the USEPA screening level is 2300 ppm and Cox-Colvin & Associates background level is 42.7 ppm (2019 and 1996).

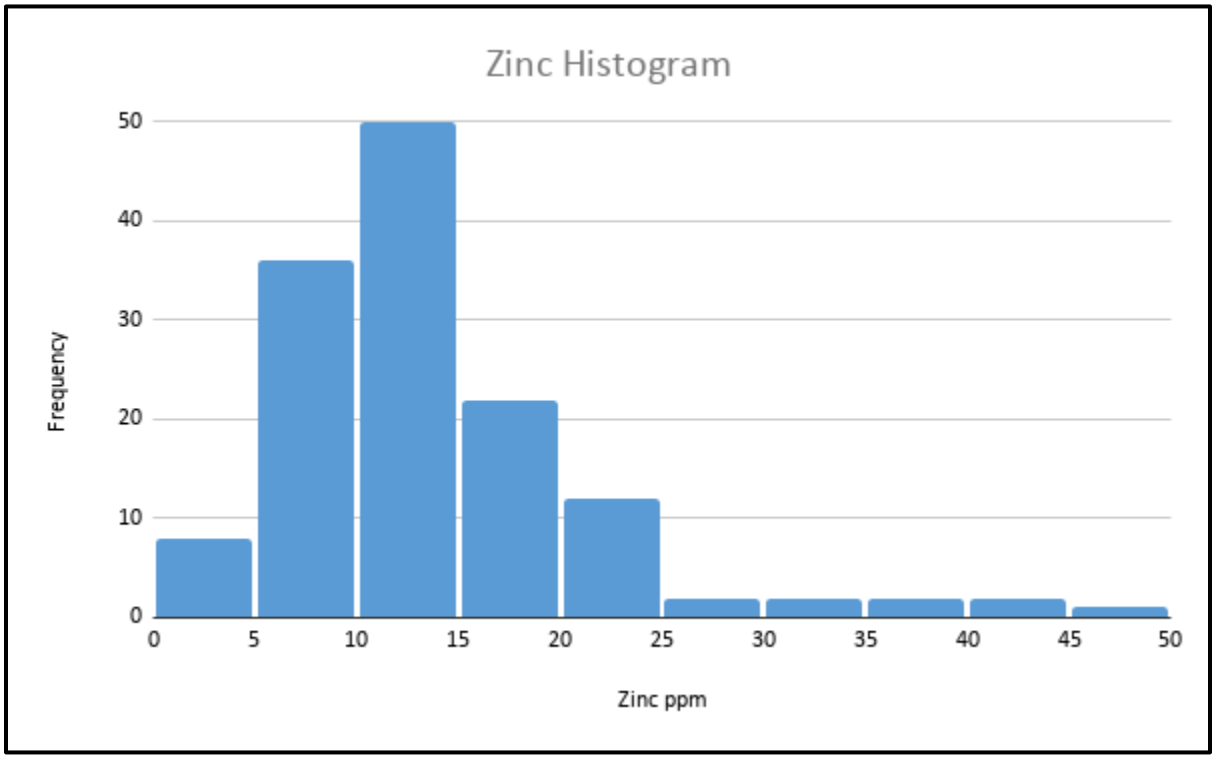


Figure 20. Spatially predictive zinc concentrations. Map shows interpolation using Empirical Bayesian kriging with parameters set using standard deviation of the samples of 159.493 ppm, the USEPA screening level of 2300 ppm (outside of predictive values shown), and Cox-Colvin & Associates background level of 42.7 ppm (2019 and 1996). Specific parameters are shown below map. Map shows the extent of the Toledo and Ottawa Hills city limits and is overlain with the labeled sample collection locations.

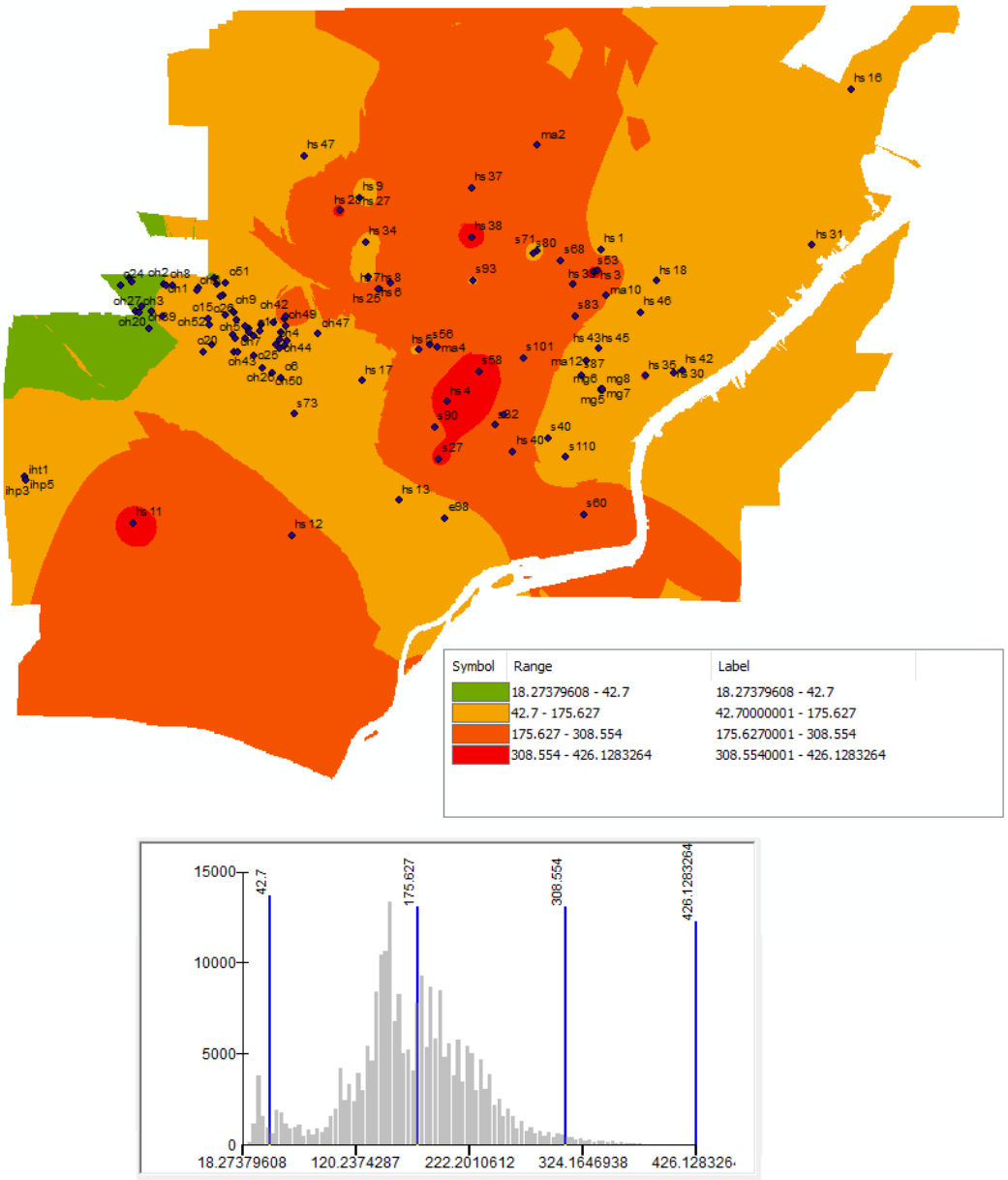
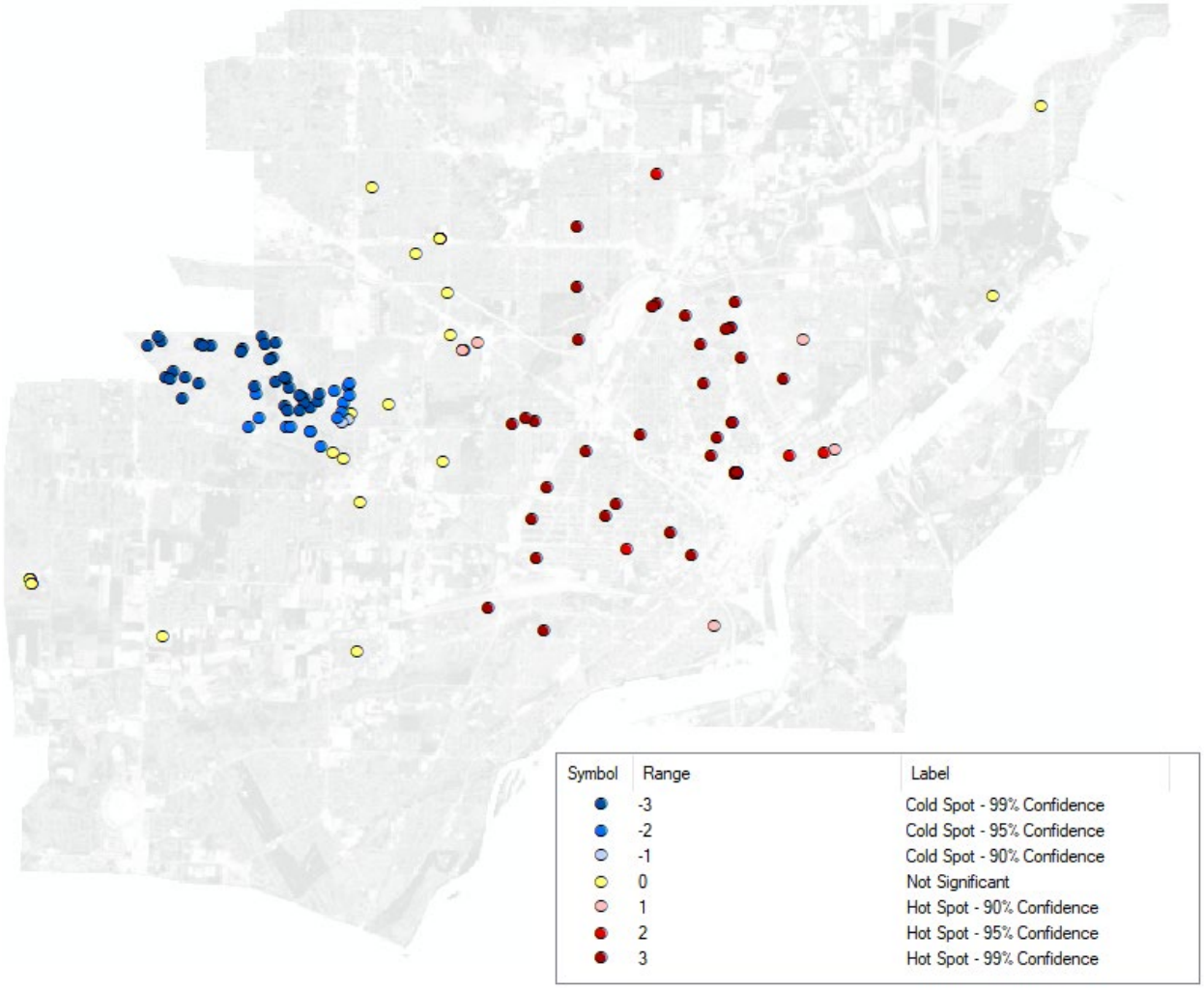


Figure 21. Hot Spot Analysis of zinc soil concentration values. Each point displays clusters of samples with similar concentrations, with tones defining the reliability of each area.



APPENDIX G. TABLES

Table 1. Summary statistics for elemental concentrations. Mean, median, standard deviation, the calculated percent above the USEPA screening levels, and percentage above background levels. The Ohio EPA background upper limits were used for As, Ba, Cr, Pb, Mn, and Ni (2015). The Cox-Colvin & Associates background levels were used for Al, Cd, Co, Cu, Fe, K, Zn (1996). All data are recorded in ppm.

Element	Mean	Median	Standard Deviation	Range	USEPA screening levels	Percent of Samples over screening levels	Background levels	Percent over background levels
Aluminum	8945.11	8698.05	3240.88	25414.364-3522.750	7700	57	8,180	54
Arsenic	7.810	6.019	6.262	2.422-44.632	3.5	73	9.7	16
Barium	79.676	64.640	59.489	15.707-462.578	1500	0	90.1	28
Calcium	13672.9	10253.2	12133.6	1065.3-79459.0	N/A	N/A	N/A	N/A
Cadmium	1.840	1.658	0.896	1.710-6.064	7.1	0	0.507	100
Cobalt	4.338	3.950	1.858	1.336-11.171	2.3	91	6.42	12
Chromium	19.445	16.620	13.268	4.059-98.662	12,000	0	22.2	27
Copper	26.561	18.450	32.468	1.727-278.0278	310	0	11.8	68
Iron	10872.05	9986.32	4540.71	3323.69-27172.93	5500	7	18,400	6
Lead	133.145	41.665	247.718	3.692-1903.409	400	7	17	72
Potassium	1641.37	1513.84	913.84	606.30-6339.78	N/A	N/A	709	88
Magnesium	4915.21	3987.07	3503.40	606.30-17046.62	N/A	N/A	N/A	N/A
Manganese	227.482	211.397	119.777	47.443-601.618	180	58	459	6
Molybdenum	0.973	0.776	0.717	0.335-5.867	39	0	N/A	N/A
Sodium	226.55	166.80	247.92	66.04-2469.79	N/A	N/A	N/A	N/A
Nickel	11.524	10.071	6.582	2.792-39.140	150	0	22.45	7
Selenium	3.727	3.558	0.340	3.501-4.312	39	0	N/A	N/A
Strontium	54.924	36.059	59.374	7.563-446.401	4700	0	N/A	N/A
Titanium	222.47	220.67	65.37	108.33-540.38	14000	0	N/A	N/A
Zinc	127.480	74.298	132.927	6.932-762.147	2300	0	42.7	73

Table 2. Comparison of Toledo heavy metals to Detroit. Detroit residential average surface and subsurface soils taken in accordance with 1983 USEPA methods with the Toledo average from this study (Murray et al., 2004).

Element	Detroit Surface (ppm)	Detroit Subsurface (ppm)	Toledo average (ppm)
Arsenic	6.3	2.3	7.810
Cadmium	1.1	0.4	1.840
Chromium	31	25	19.445
Lead	160	34	133.145
Nickel	24	11	11.524
Zinc	120	66	127.480