Kansas State University

Urban Soil Suitability Analysis and Recommendations for Phytoremediation

A Study of Soil Fertility

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1. Introduction and Hypotheses

Soil, a fundamental and often overlooked natural resource, forms the very foundation of terrestrial ecosystems, underpinning nearly all life through its critical roles in facilitating plant growth, driving essential nutrient cycles, and regulating the intricate flow of water. However, the escalating global issue of soil contamination, characterized by the accumulation of harmful chemicals or physical substances, poses a significant threat to environmental integrity, the delicate balance of soil functions, and ultimately, the health and well-being of human populations. This contamination is predominately a consequence of diverse anthropogenic activities, ranging from intensive industrial operations and widespread agricultural practices to the pervasive and rapidly expanding footprint of urban development. According to studies by Havugimana (2017) document that these toxic metals can last in soil for decades, altering the chemical composition and properties of soil and the activity of soil microorganisms. Regions with many industrial factories such as Sicily and parts of Asia have evidence of long-term contamination in their soils which has effects on environmental health and quality and effects of public health.

Within urban environments, soils face a unique confluence of pressures, often acting as historical sinks for a wide array of pollutants stemming from industrial legacies, transportation networks, and diverse human activities. According to Cakmak there has been research done in green areas in Belgrade that showed that vehicle emissions, improper waste disposal and industrial by product can raise levels of many heavy metals like cadmium, Nickel (Ni) and Zinc (Zn) in soils. Recognizing the critical need to address this challenge in urban settings, this paper focuses on the suitability analysis of urban soils for phytoremediation, a promising and sustainable approach that harnesses the inherent capabilities of plants to remove, degrade, or stabilize contaminants, offering a pathway towards the restoration and revitalization of these vital urban ecosystems.

Recognizing the potential for soil contamination stemming from the former Dara's gas station operations, particularly the leakage of lead gasoline and other petroleum-derived products, we hypothesized that soil samples collected from the study site would reveal significantly elevated concentrations of lead, alongside the potential presence of other heavy metal contaminants such as cadmium, chromium, and arsenic, commonly associated with such activities. Heavy metals can affect human health in many ways, According to Petruzzelli, bioaccumulation of toxic metals like mercury and arsenic in soil can serve human health problems. These toxic metals can cause neurological damage and cancer. Furthermore, considering the documented effectiveness of *Helianthus annuus* (sunflower), a plant species native to Kansas known for its metal-accumulating properties, we proposed that it would represent a viable and environmentally friendly phytoremediation strategy for the identified lead contamination in these urban soils. However, due to the temporal constraints of this study, the practical investigation of sunflower-mediated lead removal was beyond our experimental scope.

2. Materials & Methods

2.1. Study Area Description

For this project, our team decided to focus on soil health and regenerative options. For this project, the plot of land at the corner of Anderson Ave and Denison Ave, with the geographic coordinates being 39°11’08” N and 96°35’03” W, was selected. Pictured below, the plot of land has an area of 1.99 acres, making it a perfect site for soil health studies. Historically, a local gas station chain, Dara’s Corner Market, was located on the northeast corner of this plot. The gas station eventually shut down after continuous leaks from the gasoline reservoir, causing environmental and economic problems for the business. The land was later sold to the KSU Real Estate Fund LLC. As pictured below, there has been no development since.

Figure 1: Aerial View of study area located in Manhattan, Kansas.

2.2. Experimental Design

While acquiring soil samples at the site, the decision was made to split the parcel into three equal lots, with the lots listed in the graph below:

Lot 1	Lot 2	Lot 3

Figure 2: Above is a graphic description of how the land was sectioned into three lots.

The decision to separate the parcel of land into 3 lots was due to different soil textures found while physically surveying the site. First, a noticeable difference between the two ends' soil textures was noted. This led to the conclusion of the three lots of land. Lot 1 was rich in clayey soil, which was soft and produced a large ribbon. Lot 2 consisted of a sandy/clay loam. Lot 3's soil was very sandy, with coarse soil particles and no ribboning.

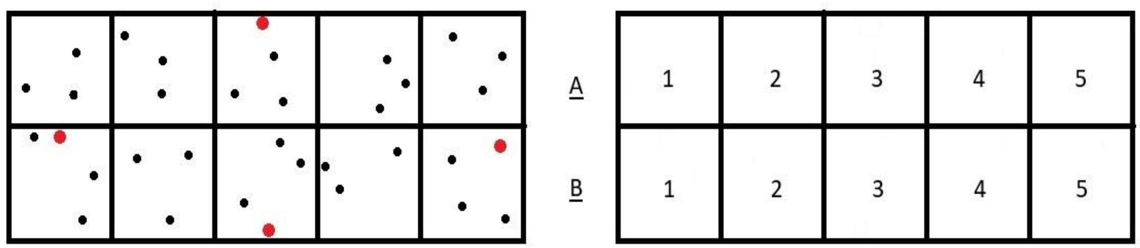

Figure 3: (Left) Soil Sampling Diagram used for sampling. (Right) Labeling schematic of soil sample grids.

Figure 3 is a graphical representation of the sampling locations and grid sampling used for the sampling plan. We used four bulk density samples to demonstrate compaction variability across the land. These are represented by the larger red dots. The small black dots represent the regular soil samples used for all other testing.

A soil core instrument was used to gather the soil for the rest of our samples. In total, we took 90 core samples: 3 core samples for one locational sample, and three locational samples per grid area. This ensured we had collected enough soil mass for all the testing we wanted done. The core instrument allowed us to sample many of the different layers in the soil columns, thus giving an average of the soil column.

2.3. Soil Quality Assessment and Characterization

2.3.1. Physical Properties

2.3.1.1. Bulk Density

One of the most important sampling methods in soil study's is Bulk Density. Bulk density is important for soil health as it is essentially a measurement of soil, water, and air pores within a specified volume. This is important for soil health because compaction causes low pore space, leading to less water infiltration and more runoff. For this test, we used a bulk density sampler, which we borrowed from the Kansas State University Soil Lab. Healthy soil is composed of a low bulk density, due to the high number of pores found within the soil that contain air and water, which evaporate during the drying process, (*Soil Test Interpretation Guide*).

$$Pb = M_{Soil} / V_{Soil}$$

Equation 1: Bulk Desnity Formula

Soil bulk density (ρ_B), or dry bulk density, is a ratio of the weight of dry soil (M_{Soil}) divided by the total soil volume (V_{Soil}). This gives us a ratio that allows us to understand the pores that are contained within the soil column. Using this method allows us to quantify the soil bulk density and porosity, along with the composition of sand, clay, and soil within the soil column, (*Soil Test Interpretation Guide*). By understanding these characteristics of the soil column, we can start to think of suitable plants for root growth and water permeability. Water permeability is very important for soil health and plant growth as it refers to the hydraulic movement of water into the soil column vertically. Soil that does not allow for water permeability is typically bare and contains poor soil characteristics like compaction and drainage.

2.3.1.2. Porosity

Porosity is another important measurement of the soil. Porosity refers to the amount of water, air, and soil found within a soil sample. This calculation allows us to understand the relationship between pores and pore space within a soil sample. Soil pores are very important to soil due to the relationship between water, soil, and air, and the importance these three components have on plant growth. A healthy soil should have a higher porosity value due to the relationship between dry bulk density and true soil density, (*Soil Test Interpretation Guide*). If a soil sample has a low bulk density, the porosity value should be on the higher side. The formula for this calculation is illustrated below, where p_b is the bulk density of the soil sample, while p_T is true density. The true density of soil is 2.65 g/cm^3.

$$\varepsilon = 1 - (p_b / p_T)$$

Equation 2: Porosity Formula

2.3.1.3 Soil Texture

Soil texture is also important to understand for soil health. As soil science has progressed through the years, research has shown that soil texture is correlated with soil porosity and soil bulk density. This is due to the different soil particles that are found within soil. There are three types: sand, silt, and clay. Sand particles are large, being about 0.05mm-2mm in size, allowing for large pore, which allows for increased infiltration and decreased saturation. Silt particles are medium-sized, around 0.002mm-0.05mm in size. Lastly, clay particles are very small, being less than 0.002mm in size. Typically, soils are made up of a mixture of all three kinds of soil. Soils that are heavy in sand particles have poor water capacity due to the large pores in the soil. Soils heavy with clay tend to be wet, with poor infiltration and high saturation. This mixture of sand, silt, and clay is what gives soil its texture, (*Soil Test Interpretation Guide*).

To test this, the hydrometer method was conducted to receive readings of sand, silt, and clay in percentages of makeup in the sample, (*Soil Test Interpretation Guide*). To start this test, soil samples are treated with sodium hexametaphosphate, which breaks down soil aggregates and suspends organic materials in the solution. The density of soil suspension is determined using a hydrometer, which reads the grams of solids per liter after sand particles have settled and again after the silt has settled. This process takes a full day, as silt particles do not settle until hours after the sand has settled. Measuring again after silt particles have settled allows the reader to then calculate the percentage of sand, silt, and clay found in the soil sample.

A soil core instrument was used to gather the soil for the rest of our samples. In total, we took 90 core samples: 3 core samples for one locational sample, and three locational samples per grid area. This ensured we had collected enough soil mass for all the testing we wanted done. The core instrument allowed us to sample many of the different layers in the soil columns, thus giving an average of the soil column.

2.3.2 Chemical and Functional Properties

Understanding the chemical and functional properties is essential as it provides information on behaviors and processes of the soil environment. These properties provide crucial insights into soil behavior and response to natural and anthropogenic effects. Samples for Soil organic matter (SOM), K, CEC, Total C%, Total N%, Heavy Metals and EC testing were all sent to Kansas State Soil Testing Lab.

2.3.2.1. Soil Organic Matter (OM) Content

For this test the Loss of Weight on Ignition procedure was used. This procedure involves using 1g of soil, drying at 150° for two hours then igniting at 400° for three hours. The percentage LOI is determined by the following formula

%LOI= ((wt. at 150°C)−(wt. at 400°C)×100)÷wt. at 150°C

Estimation of OM from LOI is done by regression analysis. The OM content is estimated using a regression model that links LOI values to organic matter content, as described by Combs and Nathan (1998).

2.3.2.2. Soil Nutrient Status

2.3.2.2.1. Potassium (K)

Potassium concentrations were determined by 1M ammonium acetate (pH of 7.0) extraction. It is then analyzed by Flame Atomic Adsorption or ICP Spectrometry (Kansas State University, 2024).

2.3.2.2.2. Cation Exchange Capacity (CEC)

Cation Exchange Capacity (CEC) was determined using the displacement method using ammonium acetate. The concentrations found were then summed (Kansas State University, 2024). CEC is important indicator of soils ability to retain nutrients.

2.3.2.2.*3. Total C% and Total N%*

A LECO TruSpec CN combustion analyzer was used to determine the total levels (inorganic and organic) of C and N on a weight percent basis (Kansas State University, 2024).

2.3.2.3. Soil Contaminant Levels

The soil sample provided underwent nitric acid digestion. This involves the use of concentrated nitric acid to break down the soil matrix, releasing the metals into a solution that can then be analyzed by Atomic Absorption Spectroscopy. To find the concentrations of each metal (Pb, As, Cd and Cr) the solution obtained from digestion was placed into an atomic adsorption spectrometer (Hseu, 2003).

2.3.2.4. Electrical conductivity (EC)

Electrical conductivity was determined using the Saturated Paste Method. This method is widely used because it directly relates the saturated moisture percentage to field moisture (Combs and Nathan, 1998).

3. Results and Discussions

3.1. Soil Physical Properties

Bulk density is an important factor in soil health. It is a good indicator to assess soil compaction and water movement. The bulk density till root restrictions per texture class are listed below.

Sandy: >1.80 g/cm^3

Silty: > 1.65 g/cm^3

Clayey: >1.47 g/cm^3

Results from testing showed the western, clayey portion of the plot was highly compacted at a 1.7 g/*cm3.* This is notable because bulk density values higher than 1.8 g/cm in sandy soil types indicate compaction which is detrimental to root growth and infiltration. The samples pulled from the middle; silty section of the plot was at 1.49 and 1.47 g/*cm3*, suggesting no compaction. Lastly the third section resulted in 1.67g/*cm3* suggesting no compaction which correlates to its sandy texture.

Table 1: Bulk Density & Porosity Results

Soil Properties	1	2	3	4
Bulk Density	1.7 g/cm^3	1.49 g/cm^3	1.42 g/cm^3	1.67 g/cm^3
Porosity	0.36	0.44	0.46	0.37

3.2. Soil texture

Soil texture is an important indicator of water movement, nutrient enrichment, root growth and susceptibility of erosion. By knowing these things, we can make inferences about the behavior of the soil. Clay loams and silty clay types suggest moderate water retention which is important in many aspects of plant growth. The following table shows textures across the sampling plot.

Table 2: Soil Texture Classification Results

Soil Components	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6
% clay	9.79	30.79	32.72	38.72	11.72	28.72
% silt	33.16	45.58	52.81	52.88	36.10	56.52
%sand	57.05	23.62	14.47	8.40	52.18	14.76
Soil Classification	Sandy Loam	Clay Loam	Silty Clay Loam	Silty Clay Loam	Sandy Loam	Silty Clay Loam

3.3. Chemical and Functional Properties: Results

3.3.1 Potassium

Our analysis of potassium levels across the sampled urban soils revealed considerable variability. Sample B-1-3 exhibited the highest concentration at 366 ppm, while sample A-4-1 showed the lowest at 123 ppm. These findings suggest a heterogeneous distribution of potassium within the study area. While there is no specific recommended level of potassium present in soil, Ohio State University provides a guideline based on soil type; a soil potassium test between 100 to 160 ppm is considered acceptable, (*Soil Test Interpretation Guide*).

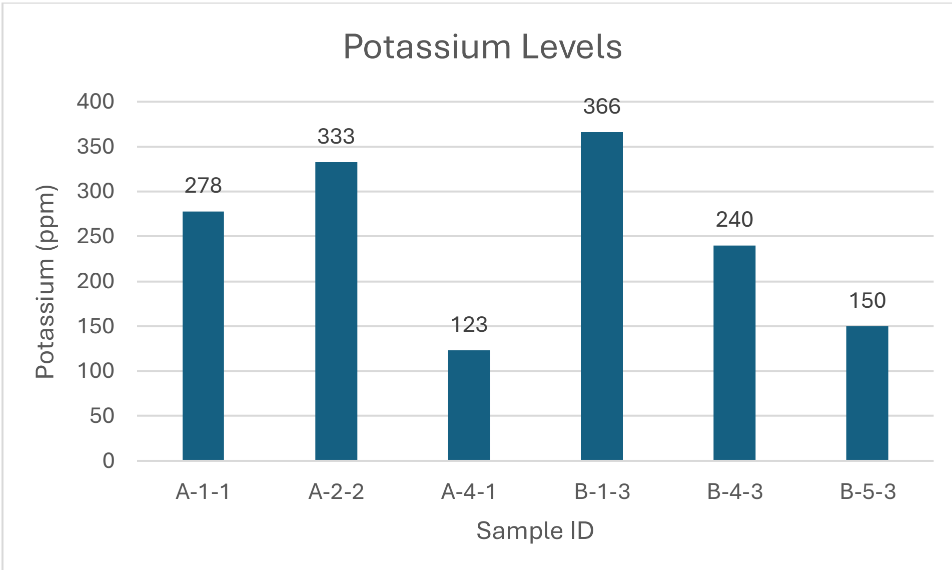

Figure 4: Soil Potassium Levels.

3.3.2. Cation Exchange Capacity

The data for CEC shows that clay loam and silty clay loam textures have higher CEC values compared to sandy loam (Figure 5). This is consistent with other findings, as clay-textured soils typically contain more organic matter and have greater retention capacities, both of which contribute to higher CEC.

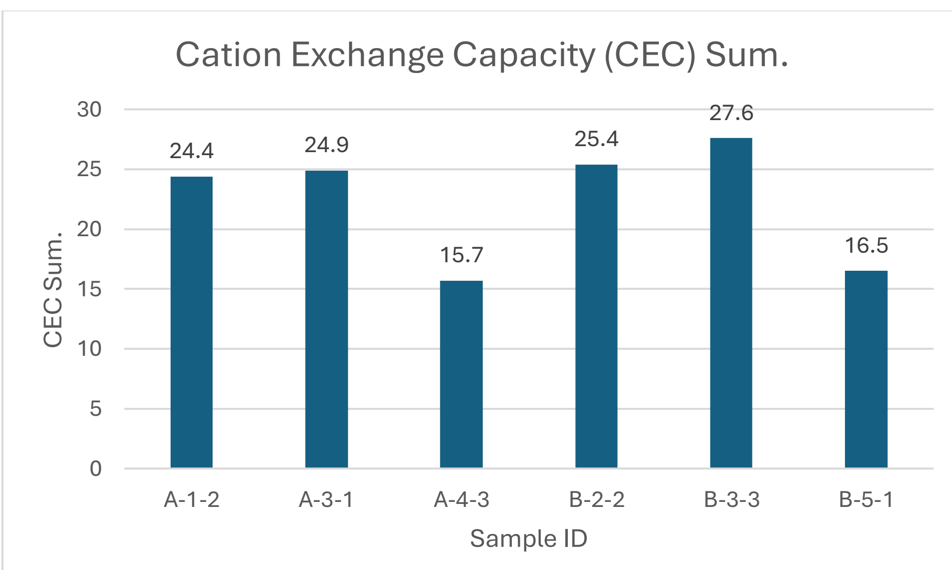

Figure 5: Cation Exchange Capacity Graph.

3.3.3. Carbon and Nitrogen

Our results of Total Carbon and Nitrogen percentages compare the total carbon % and total nitrogen % across six of our soil samples. Sample A-4-2 had the highest Carbon content at 3.74 percent and the highest nitrogen at .2 percent suggesting rich organic matter in that sample. Sample A-2-3 had the lowest results with 1.24 percent and nitrogen at .11 percent. All samples show that carbon percentages are higher than nitrogen which is good for soil. According to the USDA "C:N ratio for organic matter of agricultural soils ideally averages about 10:1". While our samples are a little low compared to 24:1 C: N this lot is not used for agricultural use, and if you want to improve this you can add high carbon materials like sawdust.

Table 3: Nitrogen Ration Table

Sample ID	Carbon (%)	Nitrogen (%)	C: N Ratio
A-1-3	1.83	0.16	11.4
A-2-3	1.24	0.11	11.3
A-4-2	3.74	0.20	18.7
B-1-1	2.16	0.17	12.7
B-3-1	1.77	0.13	13.6
B-4-1	1.65	0.12	13.8

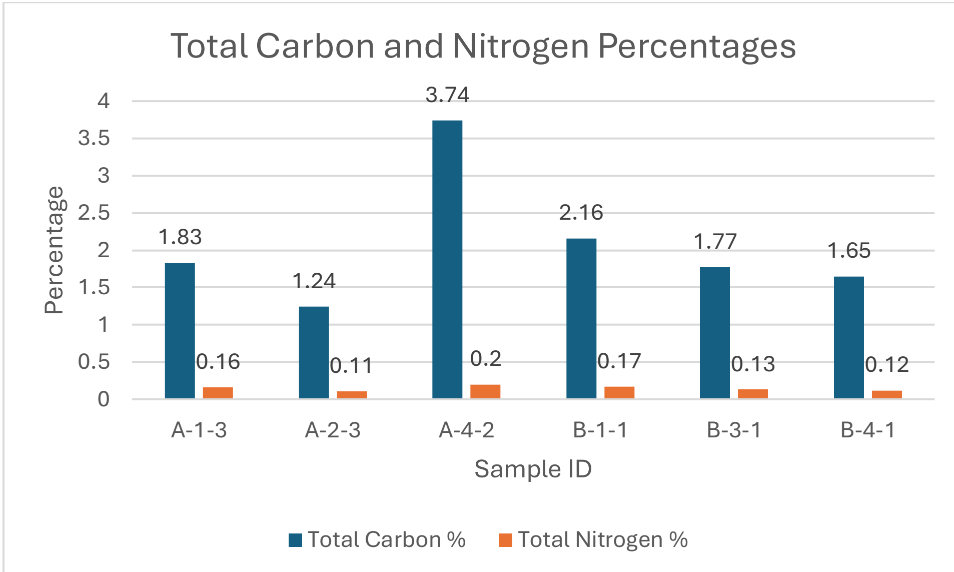

Figure 6: Total Carbon & Nitrogen Graph calculated in percentages.

3.3.4 Heavy Metals

Testing of heavy metals showed that the clay textured soils (Sample B-1-2) had higher concentrations than the sandy texture (Figure 7). This could be correlated to the porosity of clay textured soils, as this texture tends to have greater retention than a sandy texture with large porosity. Overall, the concentration of heavy metals at this site are low and do not present significant environmental risk when compared to the levels established by the US EPA (Table 3).

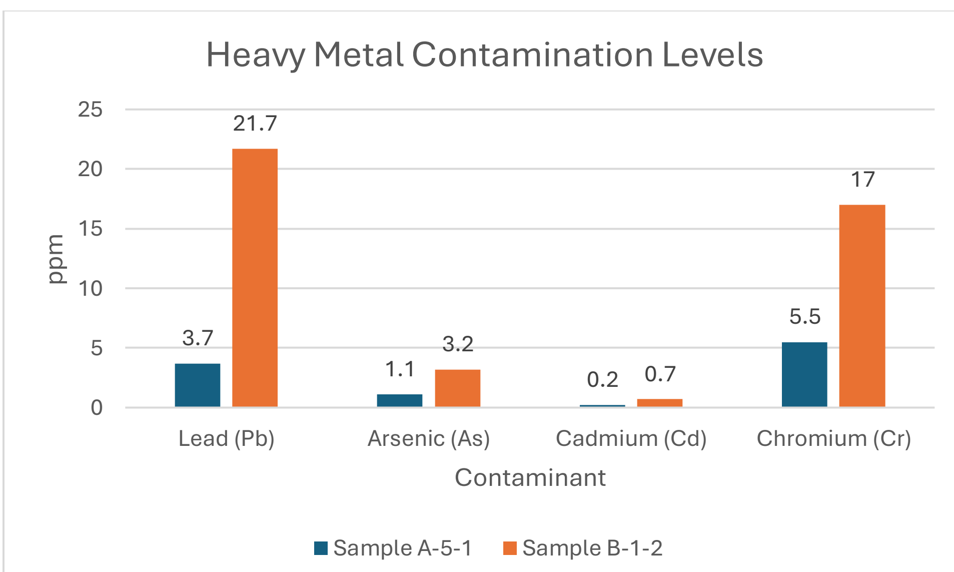

Figure 7: Heavy Metal Contamination Graph.

Table 3: Levels of Heavy Metals requiring clean up as recommended by US EPA (Grubinger, 2023)

	Cadmium (Cd)	Chromium (Cr)	Lead (Pb)	Zinc (Zn)
US EPA level	70 mg/kg	230 mg/kg	400 mg/kg	23,600 mg/kg

Our data and bar graph on Heavy Metals presents the concentration (ppm) of four heavy metals- Lead (Pb), Arsenic (As), Cadmium (Cd) and Chromium (Cr). These metals were measured in two samples A-5-1 and B-1-2. Overall, B-1-2 has significantly higher levels of concentrated metals over sample A-5-1. B-1-2 lead concentrated was over 5 times more than A-5-1. B-1-2 Chromium concentration was three times higher than A-5-1. The results show that sample B-1-2 is significantly more polluted than A-5-1. For both samples of soil none of the heavy metals exceed the EPA threshold. This shows that the soil is not toxic and is safe for residential use.

3.3.5 Electrical Conductivity

The Electrical conductivity graph shows the salinity levels of the different soil samples; we took five samples which according to NRCS soil survey all fall under the non-saline class. Ds/m= 1 mS/cm. This plot of land is suitable for agriculture because it has low salinity.

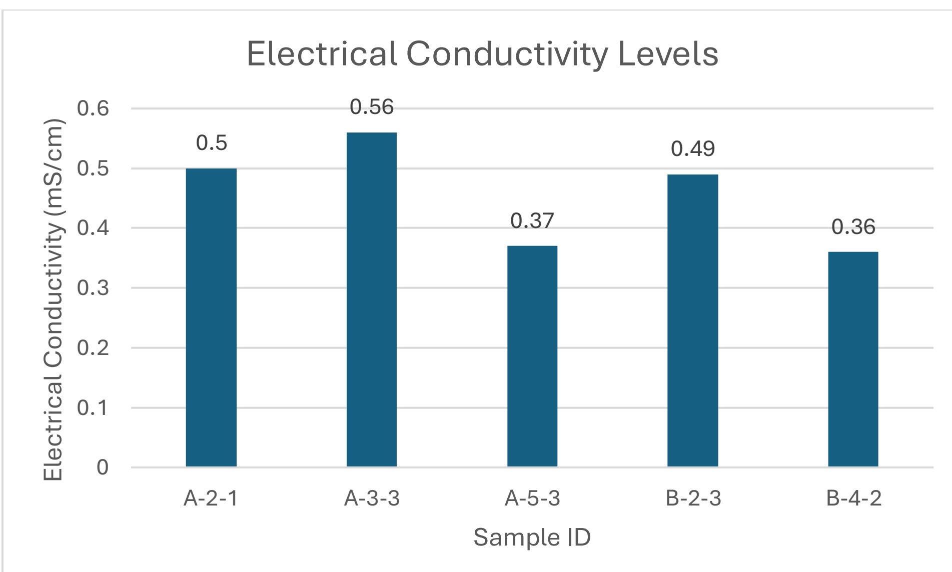

Figure 8: Electrical Conductivity Graph

Table 4: Classes of salinity and EC 1 dS/m = 1mS/cm; adapted from NRCS Soil Survey Handbook

Table 1. Classes of salinity and EC (1 dS/m = 1 mmhos/cm; adapted from NRCS Soil Survey Handbook)

EC (dS/m)	Salinity Class
0 < 2	Non-saline
2 < 4	Very slightly saline
4 < 8	Slightly saline
8 < 16	Moderately saline
≥ 16	Strongly saline

4. Analysis of Phytoremediation

4.1. Phytoremediation

One of the main goals of this project is to identify the possibility of the phytoremediation of this plot of land. Phytoremediation, which is defined as the treatment of pollutants or waste (as in contaminated soil or groundwater) using plants that remove, degrade, or stabilize undesirable substances (such as toxic metals.) Phytoremediation can be used for many different purposes: green areas, cleanup, economic gains, and soil health regeneration, (Abhijith et al., 2023).

4.1.1. Physical Remediation

Physical Remediation techniques can involve isolation removal or treatment of contaminated soils. Some of the most used methods are soil replacement, thermal desorption and soil excavation. These methods are effective in removing pollutants, but they do have drawbacks according to Azhar (2022) these methods are often expensive and disrupt the natural environment. These methods are hard to use for widespread areas and apply them. When pollution is severe physical methods are used this occur in industrial sites or mining areas.

4.1.2. Chemical Remediation

Chemical remediation uses treatments to immobilize or transform pollutants into less harmful substances. Some of these techniques are soil washing, chemical stabilization also leaching agents can be used to reduce the mobility of contaminants. (Mishra 2016) talks about how the methods can achieve fast reductions in pollutants in the soils, but this can be a double-edged sword and can affect and alter the native soil chemistry. The challenge of chemical remediation is balancing pollutant removal and long-term health of the soil.

4.1.3. Biological Remediation

Bioremediation and phytoremediation use the natural properties of microorganisms and plants to degrade pollutants. This method is very good for sustainability and small environmental impact. Some bacteria can metabolize organic pollutants, also some plants can accumulate heavy metals in their tissues- many of this research has been done by Havugimana and many others. The downside of biological methods is that they are slower than chemical and physical counter parts. They are also less effective in heavily polluted sites where the natural biota has been affected by soil pollution.

Phytoremediation can be used to remove heavy metals and hydrocarbons from the soil. By using the appropriate plant species, we can work towards creating a plan to reclaim this soil site. Some phytoremediation efforts that can be analyzed for this plot of land include phyto-extraction and phytodegradation.

4.2. Phytoremediation Options

4.2.1 Phytoextraction

Phytoextraction, or sometimes referred to as phytoaccumulation, is a process of phytoremediation that focuses on the extraction of contaminants using plants. One common technique of phytoextraction is using sunflowers to remove heavy metals from the soil, (Bolund et al., 2015). This technique utilizes plants that can withstand the contaminated soil, as well as take up some of these contaminants in the soil. Furthermore, this technique is cost-effective, showing a decreased cost of 10 times per hectare compared to conventional methods, (Bolund et al., 2015). Another branch of this kind of phytoremediation is phytomining. In this case, phytomining is associated with the commercial mining of metals in areas of high heavy metal concentrations. Below is a basic graphic of phytomining.

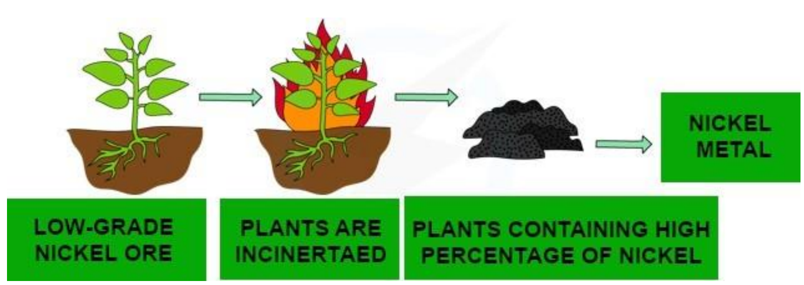

Figure 8: Basic Phytomining Diagram showing the process of removing heavy metals.

To collect these metals, the plants are burned, roasted, or smelted, leaving behind an ash that is rich in heavy metals, ready for extraction. Phyto mining not only has the potential to remove heavy metals from contaminated soil but also provides a clean and environmentally friendly approach to recovering abandoned mining sites.

4.2.2 Phytodegradation

Phytodegradation is another phytoremediation technique being studied today. Instead of extracting or confining contaminants into the soil, phytodegradation focuses on the degradation of pollutants from soil and water, (Bolund et al., 2015). This allows the pollutants to be slowly broken down and stored in areas of the plant that do not release them into the soil. This technique is great for enzyme research, as one of the main processes of degrading pollutants in this technique is using a plant's

4.3. Site Suitability of Phytoremediation

After analyzing our results, it was concluded that the site did not need to undergo phytoremediation efforts for petroleum product contamination. As discussed in our results, heavy metal concentrations were lower than expected, defeating the purpose of phytoremediation. However, phytoremediation can still be used on this area of land for research on soil fertility analysis. Research on soil fertility at this site could potentially be used to understand the relationship between urban environments and their impact on local soils

5. Recommendation's

5.1. Site Suitability and Risk Assessment

Our recommendation for this parcel of land is to be used as a long-term research project to understand the relationship between urban environments and the soils within. Some common pollutants found in urban areas include heavy metals, excess nutrients, pesticides, herbicides, and petroleum hydrocarbons.

For this research, the phytodegradation option would be best. This is due to a certain study of enzymes that are typically focused on in this method. These enzymes impact the soil health as they allow plants to break down pollutants into nutrients that can be absorbed. By researching enzymes found within plant tissues, we can start to understand the relationship between a plant's ability to break down pollutants. This research is significant to areas of large pollution, such as construction sites, landfills, and mining sites. By understanding the process by which plants use enzymes to break down pollutants, we can potentially start to understand how to amplify that process to decontaminate areas of high pollution quickly.

The plant that should be used for this project should be from the plant family Asteraceae. Some notifiable plants from this family are the taraxacum officinale, or the dandelion, and helianthus annus, or the common sunflower, (Bolund et al., 2015). These plants all have deep root structures, which allow the plants to grow deep into the soil column to access nutrients. Sunflowers are especially good due to their role as hyperaccumulators. Hyperaccumulators are plants that accumulate nutrients and grow at a fast rate. In this case, we suggest the common sunflower for this project. Another strength of using sunflowers is due to their low cost and low maintenance.

Because sunflowers can grow very fast, a constant monitoring and maintenance plan needs to be created. This plan would include weekly checks of plant health, including height, stem diameter, and leaf chlorophyll content. These three measurements can result in a simple examination of sunflowers in polluted soils compared to sunflowers in healthy soil. Maintenance would include the removal of plants and the replanting of sunflowers due to the rapid rate of growth. This plan would have to be for a long-term research project studying the effects of hyperaccumulators in petroleum-contaminated soils.

6. Conclusion

Phytoremediation is a sustainable soil option for decreasing pollutants that are found in soils. Although our test results did not correspond as we originally hypothesized, this location could still be used for research on soil fertility and the relationship between urban environments and their impact on local soils. Today's research on enzymes and the effectiveness of using plants for decontamination is strongly understood. This research could potentially lead to an understanding of how enzymes can be manipulated to use phytoremediation in polluted areas. By adding this research project at this location, not only is an educational service provided by the environment, but also an aesthetically pleasing environment for the community. Technically, this would be classified as a green area. Adding green areas to our community strengthens our knowledge of the impact plants have on our ecosystem, as well as lifts the pride of the community of the City of Manhattan, as well as Kansas State University.

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