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Phytoremediation of Lead and Zinc Metals Using Sunflower: Sampled From An Abandoned Mine Tailing Dump Site In Kabwe, Zambia.

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Abstract

Kabwe the provincial headquarters of Central province has been reported to be one of the most polluted cities in the world. The pollution of the environment was brought about due to mining of two heavy metals which are Lead and Zinc. Copper, Cadmium and Silver were the mining by-products. Soil samples from the dumpsite were collected and Sunflower and Maize seeds were planted ex-situ. Ex-situ experimentation was carried out to study the bioaccumulation abilities of the plants in polluted lead soils of different concentrations. Acid digestion was used, followed by the analysis of heavy metals using the Atomic Absorption Spectrophotometer. The distribution of heavy metal pollution decreased with reduced proximity to the mine. In comparison, the dumpsite soil was more concentrated than 1km away from the dumpsite near Makululu compound. The concentration of heavy metals at Broken Hill dumpsite were 4,258 mgkg^{-1} Zn and 5,612 mg kg^{-1} Pb.; 1km away from dumpsite in Makululu compound the concentration of these heavy metals was 677 mg kg^{-1} Zn and 772 mg kg^{-1}. The plants were able to accumulate Zn and Pb from the soil. Sunflower grown in composite soil accumulated 17.25mg kg^{-1} Zn and 2.3795 mg kg^{-1} Pb. Maize grown in composite soil 0.468 mg kg^{-1} Zn and 0.237 mg kg^{-1} Pb. The composite soil is a mixture of the dumpsite soil and Makululu soil which were mixed in a 1:1 ratio .

Key Words: *Phytoremediation, Ex-Situ, Bioaccumulation, Pollution, Kabwe, Zambia, Lead, Sunflower , Maize.*

Introduction

Bioaccumulation is the accumulation of certain toxic chemicals or substances (heavy metals) such as lead (Pb) in the tissues of a living organism. The mining of Lead, Zinc, Cadmium, smelting operations and sulphuric acid production made the environment around Kabwe probably the most polluted in the whole of Central Africa (Kaoma and Salter, 1979). The pollution of surface soils by heavy metals such as; zinc (Zn), cadmium (Cd), lead (Pb) and copper (Cu) has caused contamination of land and water bodies. Lead is considered one of the most frequently encountered heavy metals of environmental concern and it is the subject of much remediation research (Tembo *el at*, 2005). Lead has no physiological importance to the human body even at low concentration and its detrimental effects have not spared the ecosystem. It destroys vegetation, pollutes underground water and also bioaccumulates in plants and animals eventually affecting humans through the food chain. In addition to mining activities, other areas of Zambia have also been affected by lead due to the use of lead paints, lead petrol, explosives in major mining areas and desposal of sewage sludge enriched with lead. Scientists around the world have come up with a very cheap technology that can be used to clean up the environment called Phytoremediation which involves the use of hyper-accumulators to clean up the environment. Over the last 10 years, there has been increasing interest in developing a plant-based technology (phytoremediation) to remediate heavy metal-contaminated soil. This is a cheap technology because it does involve the use of expensive equipment, and complicated protocol to remove the pollutants from the soil and it does disturb the ecosystem (Ahmida *et al.* 2013). Pollution is the process of making land, water, air or other parts of the environment dirty and unsafe. Phytoremediation of lead-contaminated soils encompasses two different strategies: ***phyto-stabilization*** *and* ***phyto-extraction***. Phytostabilization is the use of plants and soil amendments to reduce the intrinsic hazard of lead contaminated soil by reducing lead bioavailability in the soil. Phytoextraction is the use of plants to remove lead from contaminated soils. Phytoremediation is achieved by continously growing of the same plant over and over again in order to completely reduce the concentration of lead or another pollutant. Since plant cultivation and harvesting are relatively inexpensive processes as compared to traditional engineering practices. The goal of lead phytoextraction is to reduce lead levels in a soil to acceptable levels within a reasonable time frame (3-20 years) (Chen & Cunningham 1997). The purpose of this study is to assess the amount of lead and zinc that can be accumulated in the plant tissues from the soil dumpsite through ex-situ (off site) experimentations and to test if lead has got an effect on maize and sunflower plants germination. Maize is a Central American cereal plant which yields large grains and is staple

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crop in zambia. Sunflower is tall North American plant of the daisy family, with very large golden-rayed flowers.

Methods and Materials

The area of study is Kabwe town which is the provincial head quarters of central province. Kabwe which is located at $28^{0}26`$E and $14^{0}27`$S.

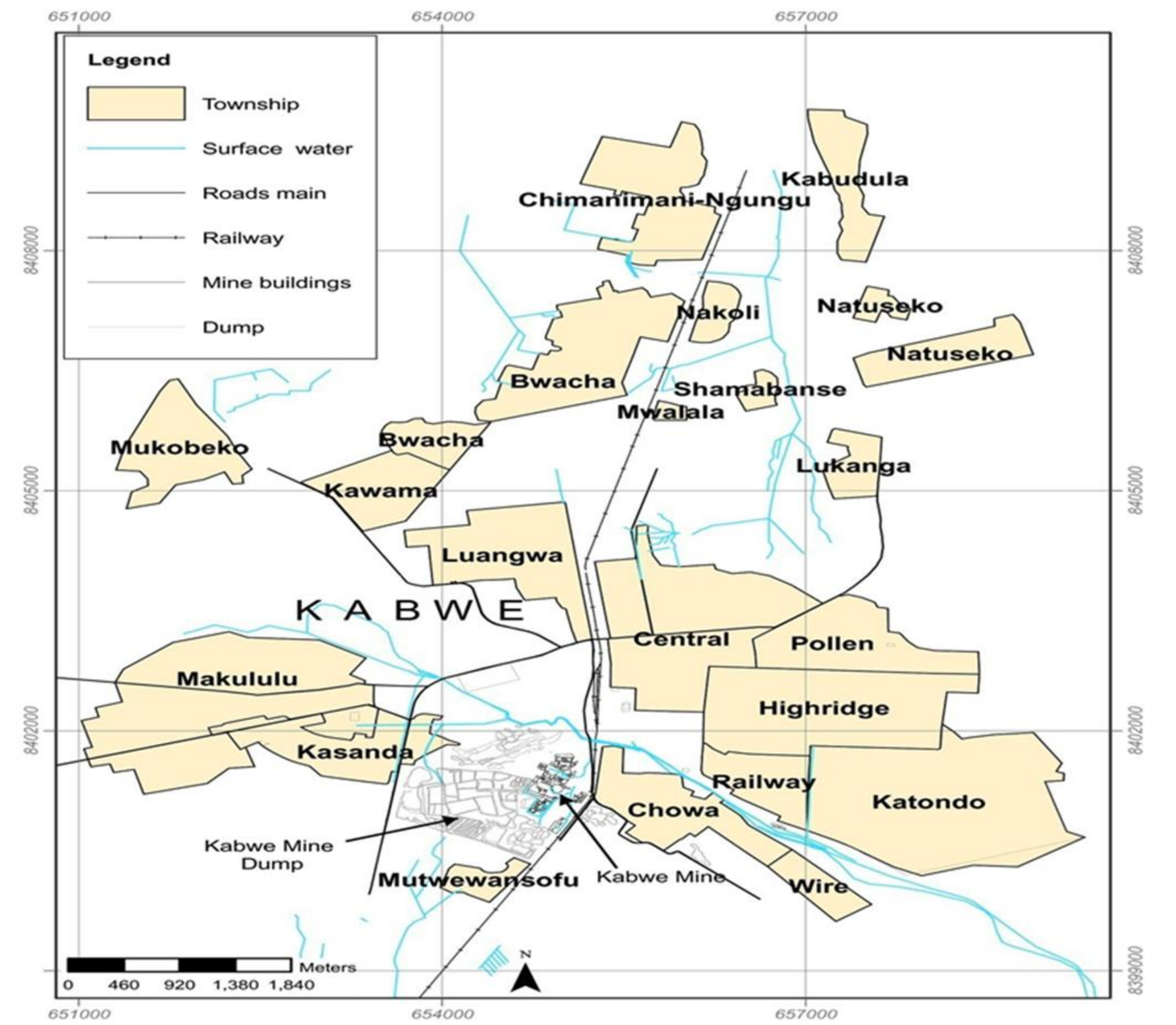

Figure 1: Map of Kabwe from ZCCM. Showing the location of the Broken Hill mine (Kabwe mine) and Makululu compound located about 1km away from the mine.

Figure 2. Showing the location of the Broken Hill dumpsite, which is located near Sable Zinc (Source; Google Earth 2017).

Sample Preparation

The soil sample were analysed using the pH meter (Hanna) and the results were collected. Thereafter, the soil was dried using a hot plate to reduce the moisture content of the soil. Moisture affects the results of the analytical balance. The soil was ground to make it homogenous.Thereafter, it was sieved with a 2 mm sieve. 0.5 g of soil was weighed , then 30ml of Nitric acid (70%, Merck Chemicals) was added and 3 drops of concentrated Hydrofluoric acid (55%, Merck Chemicals). After adding the acids, it was digested for about 30 minutes. Then 10ml of distilled water was added after it had cooled. The digested samples were then filtered using ash-less filter paper (whatmann 1442-055). Then 500ml of distilled water was added to dilute the solution. Atomic absorption spectrophotometer (Perkin Elmer, absorbance 200) was used for heavy metal detection.

Plant sample analysis

The plant samples were grown for about 4 weeks in the green house with controlled conditions. Thereafter, the plant samples were harvested and then dried at 70˚C in an oven for 24 hours. Then 30mls of Nitric acid (70%, Merck Chemicals) was added and heated for

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on a hot plate until the solution appeared colourless.Thereafter, 10 ml of perchloric acid ($HClO_4$, Merck Chemicals) was added and further heated for about 10-25 minutes until white fumes appeared and the solution turned colourless. The solution was cooled down and addition of 10 ml distilled water suppressed the fumes. Thereafter, the solution was filtered using ash-less filter paper (whatmann 1442-055). Analysis was done using an atomic absorption spectrophotometer (Perkin Elmer, absorbance 200).

Quality Control

Table 1: AAS conditions for Lead

	Pb
Wavelength(nm)	283
Slit Length	1.8/0.6
acetylene flow	3.62
Oxidant flow	10

Table 2. Testing for concentration of Lead (Pb) in seeds before planting.

Plant type	Concentration sample 1	Concentration sample 2	Concentration sample 3
Maize	ND	0.02 ± 0.01 mg/kg	0.03 ± 0.005 mg/kg
Sunflower	ND	ND	ND

Table 3. Testing for concentration of Zinc (Zn) in seeds before planting.

Plant type	Concentration sample 1	Concentration sample 2	Concentration sample 3
Maize	0.02 ± 0.001 mg/kg	ND	ND
Sunflower	0.01± 0.015 mg/kg	ND	0.04 ± 0.01 mg/kg

Note: ND-it means not detected by the atomic absorption spectrophotometer (AAS)

Results and Discussion

pH Results

Table 4: showing the various pH values of soil sample collected from kabwe.

Sample	pH Values
Dumpsite soil	6.32
composite soil	7.15
1km from mine soil (Makululu)	7.40

The pH values which were obtained for the dumpsite soil was indicating that the soil type was acidic. According to the results it showed that dumpsite soil formed a weak acid with a pH 6.32. The dumpsite soil was found to contain more of the two heavy metals as compared to other soil samples collected. The lower the pH value the more heavy metals in the soil, The composite soil had a pH of 7.15 and the pH of the soil obtained 1km away from the mine was 7.40

Growth of samples

Table 5: shows the growth of maize, and sunflower and the phenotypes observed when the plant was growing in the soil samples.

Growth of Sunflower and Maize

Date	**Activity**	**Observation**
Week 1	• Planting of sunflower and maize • Measuring the amount of lead in the soil • Planting sunflower and maize in the control. • Temperature 32℃ • Number of seeds	• No germination observed • 16 seeds planted • 4 in each pot
Week 1	• Checking for germination • Checking for water concentration	• Sunflower germinated 5 seeds • Maize has germinated all seeds (6 seeds)

	• Replanting in lead polluted soil were some seeds did not germinate • Number of seed replanted	• It was difficult for sunflower to germinate in soil from dump site • 2 sunflower seeds
Week 2	• Checking if all seeds have germinated • Checking for changes in the phenotype	• All seeds have germinated
Week 3	• Checking for any changes in phenotype	• Leaves of plants grown in Lead polluted soil were small, light in colour and were short as compared to the normal
Week 4	• Checking for any changes	• No plant died in both lead soil and normal soil • Maize was easy to grow in polluted lead soil
Week 5	• Plants were harvested • Measured the amount of lead and zinc concentration which remained in the in all the soil and the amount of those two heavy metals in the plants using AAS	• It was observed that both plants were bioaccumulators. • It was observed that maize and sunflower are able to grow health in polluted lead soil.

The plant samples were grown for about 4 weeks. The plants were harvested on the first day of the last week. The phenotypes were also studied when the plant was growing. This was done to see if lead pollution has got an effect on germination and growth of sunflower and maize. It was observed that lead has got an effect on germination and growth of the two-plant species above. The first experiment which was carried out in dumpsite soil (5,612 mg kg^{-1} Pb) to test germination of these plants failed as no germination was seen. This was due to the fact that the concentration of lead was too high in the soil. The plants only managed to germinate when a composite soil sample was used. Composite soil was a mixture of dumpsite and Makululu soils with a ratio 1:1. This means that 5 kg Makululu soil was mixed with 5 kg of dumpsite soil.

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Concentration of lead metal

Table 6. Showing the concentration of lead metals in soil and plant samples (mg/kg) average concentrations of metals ± SD.

Samples	Lead concentration before planting	Lead concentration after planting
Dumpsite soil	5,612 ± 16.0 mg/kg	5,612 ± 16.0 mg/kg
composite soil	3,553 ± 11.5 mg/kg	2,154 ± 3.0 mg/kg
1km from mine soil (Makululu)	772 ± 1.0 mg/kg	502 ± 6.0 mg/kg
Normal soil sample	ND	ND
Sunflower planted in composite soil	ND	2.3795 ± 0.0498 mg/kg
Maize planted in composite soil	ND	0.237 ± 0.0185 mg/kg
Sunflower planted in soil 1km from mine	ND	0.438 ± 0.009 mg/kg
Maize planted in soil 1km from mine	ND	0.351 ± 0.0055 mg/kg

Note: ND-it means not detected by the atomic absorption atomic spectrophotometer (AAS).

The dumpsite was the most concentrated soil sample with lead (5,612 mg kg-1 Pb). The composite soil sample was second with 3,553 mg kg^{-1} Pb, then Makululu soil which had a concentration of 772 mg kg^{-1} Pb. When sunflower was grown in the composite soil mixture 3,553 mg kg^{-1} Pb) it was able to accumulate about 2.3795 mg kg^{-1} Pb within a period of 4 weeks. Maize did not accumulate alot of Pb from the soil. The concentration of lead found in maize was 0.237 mg kg^{-1}. This showed that sunflower accumulates a lot of lead from the soil as compared to maize.

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Concentration of Zinc metal

Table 7: This table is showing the concentration of zinc metals in soil and plant samples(mg/kg) average concentrations of metals ± SD.

Samples	**Zinc concentration before planting**	**Zinc concentration after Planting**
Dumpsite soil	4,258 ± 8.219 mg/kg	4,258 ± 8.219 mg/kg
composite soil	2,212 ± 6.0 mg/kg	1,474 ± 7.0 mg/kg
1km from mine soil	677 ± 1.5 mg/kg	633 ± 6.5 mg/kg
Normal soil sample	ND	ND
Sunflower planted in composite soil	ND	17.25 ± 0.125 mg/kg
Maize planted in composite soil	ND	0.468 ± 0.009 mg/kg
Sunflower planted in soil 1km from mine	ND	1.236 ± 0.018 mg/kg
Maize planted in soil 1km from mine	ND	0.5325 ± 0.00125 mg/ kg

ND-it means not detected by the atomic absorption atomic spectrophotometer (ASS).

The concentration of zinc metal found in dumpsite soil was less compared to lead. Sunflower was also able to accumulate of zinc from the composite soil (2212 mg kg-1) within a period of 4 weeks and concentration of zinc in sunfllower was about (17.25 mg kg^{-1} Zn).

Heavy metals like zinc and lead when dissolved in water they form cations which are positively charged Zn^{2+} and Pb^{2+}. Acid have got a high affinity for positively charged metals. When the pH is low in the soil it means that most of soil can easily dissolve the heavy metal (Zn and Pb) which can also be easily absorbed by the plant. So the pH is important to consider when analysing heavy metals.

Comparing the rate at which sunflower was able to accumulate to maize, it can be suggested that sunflower accumulates heavy metal at faster rate than maize, as seen in table

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3 and 4 especially in the dumpsite soil. The concentration of lead in soil was above recommended WHO/FAO standards of lead found in soil (FAO/WHO, 1987) showing that the environment around the sampled area is polluted with lead.These results has environmental as well as human implications, results of high lead concentrations in humans especially children have been linked to low IQ values (Tembo, 2006). The amount of Lead (2.3795 mg kg^{-1}) in sunflower grown in composite soil for only 4 weeks, also had concentration above WHO/FAO recommended standards for lead present in food and vegetables (WHO, 2006). These results suggests that sunflower is a hyperaccumulator of the heavy metal lead and can be used potentially in phytoremediation studies and possibly used to clean up contaminated areas like the sampled site.The results obtained can also be used to advise the locals of the implication of growing sunflower which from this study have accumulates lead easily. Similiar results were obtained by (Tembo, 2006 and Imasiku *et al,* 2013) of lead in the soils sampled with the concentrations all above the WHO soil standards.

During the mining operation there were no pollution laws regulating emissions from the mine and smelter plant. As a result, contamination cases in terms of air, soil, and vegetation where high. Lead is one of the neurotoxins that has affected most people of Kabwe. These metals have resulted in causing alot of debilitating diseases (Brain disease, heart diseases and nerve damage) in animals and humans that can cause irreversible changes in the bodies biochemical reactions, especially in the central nervous system leading to psychotic disorders and other ailments. This results in the retardation of mental growth in children was noted by (Lewis *et al*, 1992) . Lead pollution can also cause loss of vegetation.

Conclusion

The results from the Makululu compound situated 1 km fom the abandoned mine had 772 mg/kg Pb concentration suggests that the sampled area in kabwe is highly polluted with lead and this can pose as a potential risk to humans and vegetation in the area. Phytoremediation is one of the cheap biotechnological process that can be applied to clean up the environment in Lead polluted areas like Kabwe. Sunflower was observed to accumulate Lead easily as compared to maize. Therefore, Sunflower should not be grown in areas where they are high concencentration of lead as sunflower can easily accumulate it. The dumpsite soil contained 5,612mg kg^{-1} Lead metal and 4,258 mg kg^{-1} zinc which were all above the WHO/FAO recommended standards (FAO/WHO, 2006). The dumpsite soil could not germinate any plants according to the ex-situ experiments which proved that Lead can affect the germination and growth of plants.

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