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The Impact of Artisanal Mining on Soil Quality in Solwezi District of Zambia

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Abstract

Soil is a complex system comprised of minerals, soil organic matter (SOM), water, and air. This study aimed at assessing the impact of artisanal mining activities on soil quality in Solwezi District. This study employed the experimental design which involved analyzing soil samples near the mining site in order to determine the content of heavy metals in the soil. 15 soil samples were collected and analyzed, after analysis it was discovered that heavy metals have a negative effect on soil quality and subsequently affect the health of humans. The study revealed that Nitrogen was low in the soil samples and this can be improved by the application of green manure and NPK fertilizers. The amount of heavy metals in samples which were within the distance of 500m from the cement plant had high content of heavy metals with chromium and lead having highest content site A, B and C were polluted with lead and chromium. Site A had lead (Pb) content of 712 against the permissible value of 85mg/kg, the soil within 200m proximity was highly polluted with lead. Chromium, the soil content was 141 against the permissible value of 100, this means that the site A was polluted with chromium. It can be concluded that lead and chromium are the only heavy metals which were in highly concentrated in all the three sites within the proximity of 600m from the cement plant. Other heavy metal s such as copper (Cu) and zinc (Zn) were below the permissible level. The two control sites were not polluted by any of the heavy metals since they were far from the mining site. The study therefore indicated that artisanal mining leads to the accumulation of heavy metals such as lead and chromium.

Keywords: Assess, Impact, Artisanal Mining Activities, Soil Quality, Solwezi, District

1. Introduction

1.1 Background

Artisanal mining activities have become a significant contributor to soil contamination in various parts of Zambia, particularly in mining-intensive areas such as Solwezi District, located in the North-Western Province. These informal mining operations are often carried out without adequate environmental management practices, leading to soil degradation, heavy metal contamination, and adverse effects on agricultural productivity and human health. The mining process generates large amounts of waste materials, which, when improperly disposed of, release harmful substances into the surrounding soil. Given that local communities in Solwezi rely heavily on soil resources for agriculture and other livelihood activities, understanding the impact of artisanal mining on soil quality is crucial (Joseph *et al*., 2012; Torres *et al*., 2012).

Solwezi District is known for its rich mineral deposits, particularly copper, manganese, and zinc. Artisanal mining activities often occur with minimal or no environmental oversight, resulting in the direct release of heavy metals into soils. Heavy metals such as manganese, copper, cadmium, lead, and zinc are released during mining and processing activities and are eventually deposited in surrounding soils. This is particularly problematic in areas where mining residues are disposed of improperly, allowing these metals to persist in the environment due to their non-biodegradable nature (Ismail *et al*., 2001; Mohammad & Shashi, 2006).

Heavy metal contamination in soils poses significant risks to agricultural productivity and ecological sustainability. Metals like copper and zinc are essential nutrients required by plants in small amounts but become toxic when present in excessive concentrations. On the other hand, elements such as cadmium and lead are toxic even at trace levels, posing health risks to both plants and humans when they accumulate in the food chain (Lindahl, 2014 [10]; Okuku, 2007).

Studies have shown that human activities, especially mining, have drastically altered the natural biogeochemical balance of heavy metals in various ecosystems. This has led to increased pollution in soil and Soil resources globally. In the case of Solwezi District, improper disposal of mining waste, tailings, and slags contributes to soil contamination, which can have long-term detrimental effects on soil fertility and agricultural productivity (Bebbington & Williams, 2008; Bud *et al*., 2017 [9]).

The lack of proper environmental regulations and enforcement in the artisanal mining sector exacerbates soil contamination problems. Additionally, the continuous expansion of mining activities in the region increases the risk of soil degradation, impacting the livelihoods of local communities who rely heavily on agriculture. Soil contamination resulting from artisanal mining activities poses a threat to food security, environmental sustainability, and public health in Solwezi District (Kithiia *et al*., 2011).

1.2 Statement of the Problem

Artisanal mining activities in Solwezi District have increased significantly over the past decade due to the region's rich mineral resources. These unregulated mining practices have resulted in improper disposal of mining waste, leading to soil contamination through the release of heavy metals such as copper, manganese, cadmium, lead, and zinc. Studies have shown that soil contamination by heavy metals poses serious environmental and health risks, particularly when the levels exceed permissible limits (Kambole & Chilumbo, 2001; Joseph *et al*., 2012).

Heavy metals are persistent in the environment, and their accumulation in soils can degrade soil quality, reduce agricultural productivity, and pose health risks to communities dependent on these soils for food production (Torres *et al*., 2012; Lindahl, 2014 [10]).

Furthermore, the lack of natural elimination processes for heavy metals exacerbates their adverse impacts on the ecosystem (Mohammad & Shashi, 2006). Despite the evident environmental concerns, limited studies have been conducted to assess the extent of heavy metal contamination in Solwezi District. Therefore, this research seeks to fill the knowledge gap by providing comprehensive data on heavy metal concentrations in soils affected by artisanal mining activities and evaluating the potential impacts on soil quality and agricultural productivity. The findings will contribute to the development of appropriate policies and interventions aimed at mitigating soil contamination and promoting sustainable mining practices in the region.

1.3 Objectives

1. To collect and analyze soil samples from areas affected by artisanal mining activities in Solwezi District to determine the concentration levels of heavy metals such as copper, manganese, cadmium, lead, and zinc.
2. To evaluate the potential health risks posed by contaminated soils to local communities relying on these soils for agriculture and other livelihood activities.
3. To provide recommendations for sustainable mining practices and improved soil management strategies aimed at mitigating heavy metal contamination and enhancing soil quality.

1.4 Literature Review

According to Jayanta *et al*. (2017) [4] heavy metals exhibit toxicity to soil microorganisms, and consequently affect different microbially mediated soil processes of agricultural importance. Manifestation of toxicity is mostly observed through inhibition of growth, morphology and activities of various groups of microorganisms including symbiotic N2 fixers like R. leguminosarum, Mesorhizobium ciceri, Rhizobium sp. and Bradyrhizobium sp. (Vigna) and Sinorhizobium (Ghosh *et al*. 2012).

The avenues through which humans come into contact with heavy metals vary greatly between different contaminants and among different populations. Ingestion represents the main route of exposure for most human population groups (Kabir *et al*., 2022). Affected individuals generally include those living close to contaminated areas, those accidentally exposed to pollutants and occupationally-exposed individuals. Inhalation (Briffa *et al*., 2020) and, to a lesser extent, dermal contact may also represent more relevant exposure routes for special populations, such as workers engaged in mining smelting (Xu *et al*., 2021; Li *et al*., 2020) or in the production and application of herbicides, pesticides, and fertilizers. Human exposure to heavy metals includes, at least, ten different interconnected exposure pathways. These pathways include affected food and drinking water resources and lead to the wide distribution of hazardous heavy metals in the tissues, organs, and fluids of the human body (Zhao *et al*., 2022).

Mitigation of heavy metal bioaccumulation, contamination and pollution is very much imperative in terms of the environment, as widespread pollution increases human exposure and will definitely cause debilitating effects on the human body. Several strategies exist for the decontamination and removal of heavy metals from both the environment and the human body (Wang *et al*., 2022a; Kowalczyk *et al*., 2021). Since the discovery of the problem of environmentally accumulated heavy metals, various technologies have been developed to reduce or eliminate the concentration of heavy metals that have polluted the soil and water. The three main technologies are in situ stabilization and phytoremediation in the environment and chelation therapy to reduce metal induced oxidative stress, signal transduction, and organ-specific physiology within human beings (Kumar *et al*., 2023).

2. Materials and Methods

This study employed the experimental design, the design involved analyzing the physical and chemical properties of the soil samples which were collected from various spots in the proximity of artisanal mining site.

The study used stratified random sampling to collect soil samples from various spots, the study site was divided into five sections and from each section 3 soil samples were collected. Site 5 was a control site which was 400 m from the mining site. The control site was used to compare the stratified systematic and keen box sampling methods respectively, which analyze the physical and chemical properties of soil fertility in the proximity of artisanal mining site in Solwezi district of north western Zambia. The soil samples were collected at 5 different sites and from each site 3 samples were random collected. Data were

Analyzed using excel. The findings were presented in form of tables and figures.

3. Findings

Table 1: Characteristics of the sampled sites

S. No	Sites	Lab No.	Site description	Distance from the plant
1	A	0257	Samples from the first site closest to the plant	200m
2		0258		
3		0259		
4	B	0260	Samples from the second site closer to the plant	400m
5		0261		
6		0262		
7	C	0263	Samples from the third site close to the plant	600m
8		0264		
9		0265		
10	D	0266	Samples from the first control site far from the plant	5Km
11		0267		
12		0268		
13	E	0269	Samples from the second control site far from the plant	10Km
14		0270		
15		0271		

The characteristics of the sampled sites were as follows; sample 1, 2 and 3 (site A) were collected from the same site but at different locations, all the three samples were collected from the site 200M away from the plant. Samples 4, 5 and 6 (site B) where from the second site which was 400M away from the Cooperative mine site while samples 7, 8, and 9 (site C) were from the third site which was 600m away from the Cooperative mining area. Samples 10, 11, and 12 (site D) were collected from the first control site which was 5Km away from the mining site and the other three which included samples 13, 14 and 15 (site E) were collected from the second control site which was located 10Km away from the mining area. The figures under the column lab No. (From 0257 to 0271) present the numbers which were attached to each soil sample during the analysis in the laboratory.

Table 2: Chemical composition (organic matter, potassium, nitrogen and pH)

Sample	Lab No,	pH $CaCl_2$	Org C%	P ppm	N %
1	0257	5.6	2.59	4	0.18
2	0258	5.8	2.60	4	0.19
3	0259	5.9	2.60	4	0.18
4	0260	4.9	0.89	4	0.19
5	0261	4.8	0.88	4	0.20
6	0262	4.8	0.90	4	0.19
7	0263	4.3	0.96	12	0.17
8	0264	4.4	0.96	13	0.18
9	0265	4.3	0.98	12	0.17
10	0266	4.8	1.67	71	0.15
11	0267	5.0	1.69	72	0.17
12	0268	4.9	1.68	71	0.16
13	0269	5.1	2.39	91	0.14
14	0270	5.2	2.38	91	0.13
15	0271	5.2	2.40	90	0.14
Critical levels		4.5	1.58	15	0.1

Table 3: Chemical composition (Ca, Mg, K, Na and Cu)

Sample	Lab No,	Ca Ppm	Mg ppm	K Ppm	Na ppm	Cu ppm
1	0257	284	190	117	209	8.7
2	0258	283	189	115	208	8.8
3	0259	284	191	116	209	8.7
4	0260	200	222	101	212	14
5	0261	202	224	100	213	14
6	0262	201	224	102	213	14
7	0263	185	204	58	265	16
8	0264	184	203	58	264	17
9	0265	184	203	57	265	17
10	0266	230	115	54	247	6.3
11	0267	230	115	55	248	6.4
12	0268	230	115	55	248	6.4
13	0269	271	176	38	236	4.8
14	0270	270	177	38	236	4.9
15	0271	272	176	38	237	4.9
Critical levels		**200**	**50**	40	**200**	**1.0**

Table 4: Chemical composition (Mn, Fe, Zn, CEC and lime require)

Sample	Lab No,	Mn ppm	Fe ppm	Zn ppm	CEC me%	Lime Req Kg/Ha
1	0257	126	86	10	4.3	NIL
2	0258	126	86	10	4.3	NIL
3	0259	126	86	10	4.3	NIL
4	0260	282	69	7.4	4.2	1000Kg/Ha
5	0261	282	69	7.3	4.2	1000Kg/Ha
6	0262	282	69	7.4	4.2	1000Kg/Ha
7	0263	64	43	<1	4.2	1500Kg/Ha
8	0264	64	43	<1	4.2	1500Kg/Ha
9	0265	64	43	<1	4.2	1500Kg/Ha
10	0266	92	96	32	3.5	1000Kg/Ha
11	0267	92	96	33	3.5	1000Kg/Ha
12	0268	92	96	32	3.5	1000Kg/Ha
13	0269	273	83	30	4.1	1000Kg/Ha
14	0270	274	83	29	4.1	1000Kg/Ha
15	0271	274	83	30	4.1	1000Kg/Ha
Critical levels			**1.0**	**1.0**		

Table 5: Heavy metal content in the soil

No	Pb	Cu ppm	Cr	Mn ppm	Fe ppm	Zn ppm	$S(SO_4)$mg/k
1	712.1	8.7	99.8	126	86	10	182.69
2	688.2	8.8	99.8	126	86	10	182.69
3	712.1	8.7	96.4	126	86	10	182.69
4	709.8	14	140.6	282	69	7.4	133.8
5	712.1	14	141.2	282	69	7.3	134
6	688.2	14	140.1	282	69	7.4	134.1
7	268	16	98.8	64	43	<1	9.8
8	266	17	99.8	64	43	<1	9.8
9	267	17	96.4	64	43	<1	10
10	99.8	6.3	19	92	96	32	16.8
11	98.9	6.4	18.8	92	96	33	15.9
12	100	6.4	18.8	92	96	32	16
13	66.8	4.8	18.8	273	83	30	28.60
14	66.9	4.9	18.8	274	83	29	28.40
15	66.8	4.9	18.8	274	83	30	28.30

Source: Author, 2025

Regarding the presence of heavy metals in the soil samples, site A (samples 1, 2 and 3) contained lead (Pb) in quantities of 712.1, 688.2 and 712.1 respectively, site B (samples 4, 5 and 6) 709.8, 712.1 and 688.2 respectively. For site C (samples 7, 8 and 9) contained 268, 266 and 267 respectively while D (samples 10, 11, and 12) had 99.8, 98.9 and 100 and site E (samples 13, 14 and 15) had 66.8, 66.9 and 66.8 respectively.

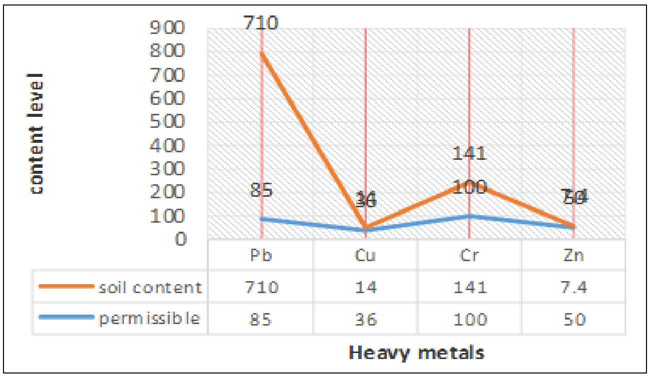
The presence of copper (Cu) in the soil samples was as follows: site A (samples 1, 2 and 3) contained 8.7, 8.8 and

8.7 respectively, site B (samples 4, 5 and 6) had 140.6, 92.2 and 64.1 respectively. For site C (samples 7, 8 and 9) contained 16, 17 and 17 respectively while D (samples 10, 11, and 12) contained 6.3, 6.4 and 6.4 respectively and site E (samples 13, 14 and 15) had 4.8, 4.9 and 4.9 respectively. The presence of Chromium (Cr) in the soil samples was as follows: site A (samples 1, 2 and 3) contained 99.8, 99.8 and 96.4 respectively, site B (samples 4, 5 and 6) had 140.6, 141.2 and 140.1 respectively. For site C (samples 7, 8 and 9) contained 98.8, 99.8 and 96.4 respectively while D (samples 10, 11, and 12) contained 19, 18.8 and 18.8 respectively and site E (samples 13, 14 and 15) all had 18.8. The soil samples also contained Manganese (Mn) in the following proportions: site A (samples 1, 2 and 3) contained 126, site B (samples 4, 5 and 6) had 282. For site C (samples 7, 8 and 9) contained 64 while D (samples 10, 11, and 12) contained 92and site E (samples 13, 14 and 15) all had 273.
Additionally, the presence of Iron (Fe) in the soil samples was as follows: site A (samples 1, 2 and 3) contained 86, site B (samples 4, 5 and 6) had 69. For site C (samples 7, 8 and 9) contained 43 while D (samples 10, 11, and 12) contained 96 and site E (samples 13, 14 and 15) had 83. The soil samples contained Zinc and Sulphur. Site A (samples 1, 2 and 3) contained 10, site B (samples 4, 5 and 6) had 7.4, 7.4 and 7.4 respectively. For site C (samples 7, 8 and 9) contained less than one (<1) while D (samples 10, 11, and 12) contained 32, 33 and32 and site E (samples 13, 14 and 15) had 30, 29 and 30 respectively.
Sulphur was one of the pollutants identified and occurred in the various proportions. Samples from Site A (samples 1, 2 and 3) contained 182.69 Sulphur, site B (samples 4, 5 and 6) had 133.8, 134 and 134.1 respectively. Those from site C (samples 7, 8 and 9) contained 9.8, 10 and 9.8 while D (samples 10, 11, and 12) contained 16.8, 15.9 and 16 and those from site E (samples 13, 14 and 15) had 30, 29 and 30 respectively. 28.60, 28.40 and 28.30 respectively.

Table 6: Target and permissible value for heavy metals

Elements	Target value of soil (mg/kg)	Permissible value of plant (mg/kg)
Cd	0.8	0.02
Zn	50	0.60
Cu	36	10
Cr	100	1.30
Pb	85	2
Ni	35	10
Source: (WHO, 1994)		

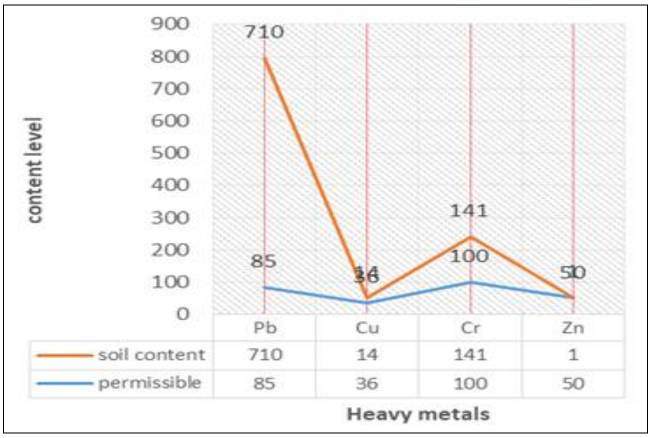
Target values are specified to indicate desirable maximum levels of elements in unpolluted soils. According to the table above the permissive value for Cd is 0.8 and the maximum amount needed in the plants are 0.02mg/kg. As for Zn the maximum amount of zinc needed in the soil is 50 and plants needs only o.60mg/kg while copper (Cu) permissive value in the soil is 36 and plants needs only 10mg/kg. Other heavy metals are chromium whose soil permissive value is 100 and plant requirement of 1.30mg/kg as for lead the maximum value should be 85 and in mining sites only 2mg/kg, nickel is only needed in smaller quantity of about 35 while plants need only 10mg/kg anything above that is considered dangerous.
Heavy metal content in the soil was compared with the permissible value provided by WHO and as shown in the figure above (Fig. 4), site A which was closest to the plant had lead (Pb) content of 712 against the permissible value of 85mg/kg, the soil within 200m proximity was highly polluted with lead. Copper (Cu) was less than the permissible value, the permissible value for copper is 36mg/kg, for chromium (Cr), the soil content was 141 against the permissible value of 100, this means that the site A was polluted with chromium. The permissible value for Zinc (Zn) was 50mg/kg while soil content was 10 which indicates that Zinc content is lower than the permissible value hence the soil at site A has not been polluted with Zinc.



Source: Author, 2025

Fig 1: Soil Content versus permissible values for site B

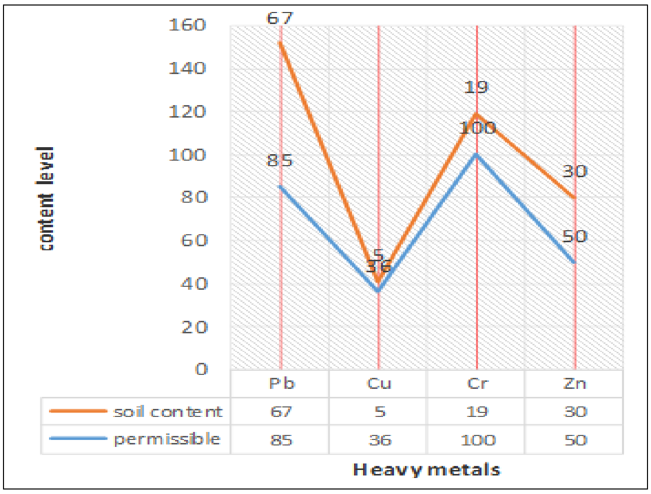
Heavy metal content in the soil was compared with the permissible value provided by WHO and as shown in the figure above (Fig. 5), site B which was 400m form the plant had lead (Pb) content of 710 against the permissible value of 85mg/kg, the soil within 400m proximity was highly polluted with lead. Copper (Cu) content for site B was 14, the permissible value for copper is 36mg/kg, for chromium (Cr), the soil content was 141 against the permissible value of 100, and this means that the site B was polluted with chromium. The permissible value for Zinc (Zn) was 50mg/kg while soil content was 7.4 which indicates that Zinc content is lower than the permissible value hence the soil at site B has not been polluted with Zinc.



Source: Author, 2025

Fig 2: Soil Content versus permissible values for site C

Heavy metal content in the soil was compared with the permissible value provided by WHO and as shown in the figure above (Fig. 6), site C which was 600m away from the plant had lead (Pb) content of 268 against the permissible value of 85mg/kg, the soil within 600m proximity was highly polluted with lead. Copper (Cu) content for site B was 17 while the permissible value for copper is 36mg/kg, for chromium (Cr), the soil content was 99 against the permissible value of 100, and this means that the site B was not polluted with chromium because the soil content is less than the permissible value. The permissible value for Zinc (Zn) was 50mg/kg while soil content was less <1 which indicates that Zinc content is lower than the permissible value hence the soil at site C has not been polluted with Zinc.



Source: Author, 2025

Fig 3: Comparison of heavy metals in the soil with permissible values for control site

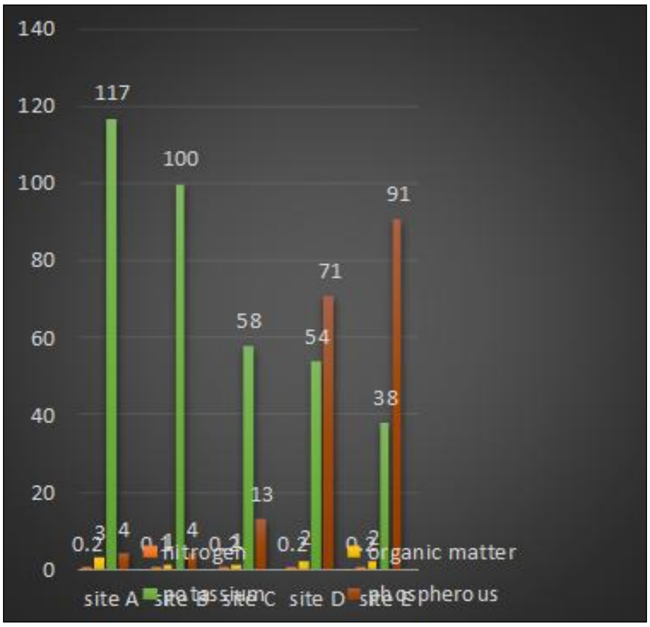
Heavy metal content in the soil was compared with the permissible value provided by WHO and as shown in the figure above (Fig. 7), the control site which was the furthest from the plant had lead (Pb) content of 67 against the permissible value of 85mg/kg this means that the control site was not polluted with lead. Copper (Cu) content for this site was 4.9 while the permissible value for copper is 36mg/kg, for chromium (Cr), the soil content was 18 against the permissible value of 100, and this means that the site was not polluted with chromium because the soil content is less than the permissible value. The permissible value for Zinc (Zn) was 50mg/kg while soil content was 30 which indicates that Zinc content is lower than the permissible value hence the soil at this site has not been polluted with Zinc.

Table 7: Physical properties of soil samples

No.	Conductivity(us/cm)	Particle Size	Soil texture
1 2 3	104.25	%sand = 54.6%, %clay = 18.8% %silt = 26.6%	Loamy sand
4 5 6	134.89	%sand=70.6%, %clay=14.8%, %silt=14.6%	Sandy loam
7 8 9	133.58	%sand=71.2%, %clay=18.8%, %silt=10%	Sandy loam
10 11 12	110.99	%sand=77.2%, %clay=12.8%, %silt=12.8%	Sandy loam
13 14 15	74.43	%sand=85.2%, %clay=8.8%, %silt=6%	Sandy loam

Source: Author, 2025

The above table contains physical properties of the soil samples and conductivity, samples 1, 2 and 3 had conductivity of 104.25 with particle percentages of sand = 54.6%, clay = 18.8% and silt = 26.6%. The soil texture was loamy sandy. Samples 4, 5, and 6 had conductivity of 134.89 with particle percentages of sand=70.6%, clay=14.8%, silt=14.6%. The soil texture was loamy sandy. Samples 7, 8, and 9 had conductivity of 110.99 with particle percentages of sand=71.2%, clay=18.8%, silt=10%. The soil texture was Sandy loam. Samples 10, 11, and 12 had conductivity of 133.58 with particle percentages of sand=77.2%, clay=12.8%, silt=12.8%. The soil texture was Sandy loam. Samples 13, 14, and 15 had conductivity of 74.43 with particle percentages of sand=85.2%, clay=8.8%, silt=6%. The soil texture was Sandy loam.



Source: Author, 2025

Fig 4: Soil fertility in the proximity of artisanal mining

Soil fertility was determined based on amount of potassium (K), phosphorous (P), nitrogen (N) and organic matter. As shown in the figure about site A contained 117 potassium, site B had 100, site C had 58, site D had 54 while site E had 38. Nitrogen was 0.18 at site A, site B had 0.2, site C had 0.17, site D had 0.17 and E had 0.2. Phosphorous was as follows: site A and B contained 4, site C contained 13 while site D had 71 and site E contained 91. Site A contained 117 potassium, site B had 100, and site C contained 58 while site D had 54 while site E contained 38. Organic matter at site A was 2.60, site B had 0.90, site C had 0.96 and site D had 1.60 while site E contained 2.40 organic matter.

4. Discussion

The chemical properties of the soil samples were analyzed based on chemical elements which include; soil pH, organic matter (carbon), phosphorus (P) nitrogen (N), calcium (Ca), magnesium (Mg), potassium (K), Manganese (Mn), sodium (Na), copper (Cu), iron (Fe), and zinc (Zn). Soil samples were collected from five (5) samples named A, B, C, D and E. the soil samples were numbered from 1 to 15 with three samples collected from each site. Sites A, B, C where among the samples collected closer to the Cooperative mines while two sites D and E which were 5Km and 15Km were regarded as control sites for they were not influenced by the discharge from the mine. The sites which were close to the Cooperative mines were compared to control sites.

The amount of chemical elements and other factors that affect the soil chemistry was determined based on the location and comparisons were made. The soil pH for sample 1, 2 and three from site A which was 200m away from the Cooperative mine had pH value between 5.6 and 5.9 which shows that the soil was slightly acidic because the values were above pH value of 5. Samples from site B which had samples 4, 5, 6 about 400m away from the Cooperative mine site had pH values between 4.8 and 4.9 and this shows that samples from site A was less acidic compared to those from site B. samples form site C (samples 7, 8 and 9) which was 600m away from the Cooperative mining area had pH value between 4.3 and 4.4 this site therefore was the most acidic for it has the lowest pH value of 4.3. Soil samples 10, 11, and 12 from the first control site 5Km (site D) away from the Cooperative mine site had pH values between 4.9 and 5 which was almost the same as site B while the samples from site E which was control number 15Km away from the Cooperative mining site had pH values between 5.1 and 5.2 which give a weak acidic medium. The soils from all the sites beyond 200m were more acidic that the one within the proximity of 200m. As such lime is recommended except for site A which has a normal slightly medium of 5.9. This can further be sated that generally the soil in Solwezi is acidic. This is because any pH value below the value of 7 are acidic and the smaller the pH value the more concentrated the acid is and the opposite means a week acid.

Olayinka *et al*. (2016) conducted a study and their findings are similar in some cases and different in others Soil pH was highest (8.09) in Location IFK and lowest (5.7) in Location ILA while organic matter in the soil varied between 2.58 to 8.37. It was observed that deposition of mine dust emerging from the mines affected the physical and chemical properties of the soil. Soil pH was alkaline, varying over a narrow range except in location ILA (control) where the soil pH was acidic. This indicated that artisanal mining emissions could alter soil pH when they settle on soil. Another study reported a soil pH range of 6.5 to 8.6 in Ashaka mining site, Gombe State, Nigeria, which was in line with the findings of this study with the moderately acidic (mean of 5.8) pH recorded. However, acidic pH in location ILA (control) may have been due to the partial neutralization of the soil by high acidic gas emissions that may have been produced at the mining sites.

Singh and Lamare (2019) discovered that the effect of dust deposition on soil is more in the areas nearer to the mining sites. Based on our findings, it can be concluded that if such trend of dust deposition continues, soil properties of a vast area around the Cooperative mines are likely to change in terms of its physico-chemical properties. These changes will in turn have multiple deleterious effects particularly on agriculture, flora, fauna and socio-economy of the area in the near future. The organic matter content for the soils samples and sites were as follows: site A samples had carbon content between 2.59 and 2.60 respectively. Those from site B had carbon content of 0.89, 0.88 and 0.90 respectively while samples from site C had carbon content of 0.96, 0.96 and 0.98 respectively. Those from site D had carbon content of 1.67, 1.68 and 1.68 respectively and those from site E had carbon content of 2.39, 2.38 and 2.40 respectively. The study shows that site A had the highest carbon content of 2.60 while site B had the lowest carbon content of 0.88 which is below the critical value of 1.58. Phosphorous was the same in all samples from site A with the value of 4, samples from site B has phosphorous content of 4, from samples from site C had between 12 and 13 on the other hand samples from site D contained phosphorous content of 71, 72, and 70 respectively and Phosphorous was the same in all samples with the value of 92. According to the findings those sites whose values fall below 15 which is the critical value need special consideration.

Nitrogen was between 0.18 and 0.19 the samples from site A (samples 1, 2, and 3). Nitrogen was between 0.19 and 0.20 among the three samples (4, 5, and 6), from samples from site C was between 0.17 and 0.18 among the three samples (7, 8, and 9). On the other samples from site D Nitrogen was between 0.17 and 0.18 among the three samples (10, 11, and 12) respectively and site E had Nitrogen between 0.13 and 0.14 among the three samples (13, 14, and 15). According to the findings those sites whose values fall below 0.1 which is the critical value need special consideration, and in this study site E had values close to the critical value which shows that nitrogen content in samples from site E was low compared to other sites. Olayinka *et al.* (2016) in their study says Levels of nitrogen oxides (NOx) ranged from 0.10 to 0.20 ppm with a mean concentration of 0.14±0.05 ppm. Mean concentration of SO2 14.75±6.37 ppm and it varied between 7.00 and 25.00 ppm.

Calcium (Ca) was between 283 and 284 from site A, was between 200 and 201 from site B and between 184 and 185 from site C. site D had calcium content of 230 while from site E were 271, 270 and 271 respectively. The critical value for nitrogen is 200, hence samples with less than 200 contain nitrogen below the required amount which is site B. Mg for the samples 1, 2 and 3 from site A had 190, 189 and 191 respectively, samples 4, 5 and 6 from site B were 222, 224 and 224 respectively while Mg for the samples 7, 8 and 9 were 204, 203 and 203 respectively. Samples 10, 11 and 12 was 115 for all the samples from site D. while samples 13, 14 and 15 from site E was between 176 and 177 for all the samples. All the sites had enough magnesium with values above 50 which is a critical value.

Potassium (K) was 117, 115 and 116 respectively foe samples from site A, 101, 100 and 102 respectively for site B, while 58, 58 and 57 were values for samples from site C respectively. Samples from site D contained 54, 55 and 55 potassium respectively and 38, for all the three samples from site E. this shows that site E which was the furthest from the Cooperative mine sites had the lowest value of potassium below the critical value of 50. Regarding sodium (Na) was between 208 and 209 for the three samples from site A and between 212 and 213 for the three samples from site B. while samples from site C had between 264 and 265, between 247 and 248 for samples from site D and between 236 and 237 for samples from site E. the critical value for potassium is 40 and this shows that all the soil samples had enough amount of potassium in the soil.

Khadka *et al*. (2017) suggested that Soil fertility evaluation of an area or region is most basic decision-making tool for the sustainable soil nutrient management. The collected samples were analyzed for their texture, structure, colour, pH, OM, N, P 2O5, K 2O, Ca, Mg, S, B, Fe, Zn, Cu and Mn status. The soil structure was granular to sub-angular blocky and varied between brown- dark grayish brown and dark gray in colour. The sand, silt and clay content were 30.32±1.4%, 48.92±0.89% and 20.76±0.92%, respectively and categorized as loam, potassium (134.12±4.91 ppm), and available manganese (18.15±1.15 ppm) exhibits high status, while available iron (244.7±19.70 ppm) was very high. The fertilizer recommendation can be done based on determined soil fertility status to economize crop production.

Cation exchange capacity (CEC) was found to be 4.2 for samples from site A, 4.2 cation exchange capacity (CEC) was for site B and 3.5 cation exchange capacity (CEC) was for site C and 4.1 was for site D and E. copper (Cu) was 8.7, 8.8, 8.7 respectively for site A. from site B (Cu) was 14 for all three samples and site C and had between 17 and 18. Site D had between 6.3 and 6.4 while site E had between 4.8 and 4.9 for all three samples. Samples 1, 2 and 3 from site A had manganese content of 126. While Samples 4, 5 and 6 had manganese content of 282. Samples 10, 11 and 12 from site D had manganese content of 92 and Samples 13, 14 and 15 form site E had manganese content of 273, 274 and 274 respectively. Iron (Fe) was 86 and Zinc was 10 for site A while site B had 69 iron and Zinc was between 7.3 and 7.4. For site C while iron (Fe) was 43 and Zinc was < 1, samples from site D iron (Fe) was 96 and Zinc was between 32 and 33 and for site E iron (Fe) was 83 and Zinc was between 29 and 30.

Olayinka *et al*. (2016) revealed in the study the concentrations for Cu ranged between 50.72- 531.75, while the concentrations for Zn ranged between 80.37±3.26 µg/g-537.35±13.65 µg/g. Concentrations of Mn ranged between 83.5±2.12 µg/g-267.85±4.59. A consistently higher concentration for Mn was recorded from the NE and the differences obtained for the two seasons were significant ($p<0.05$).

Heavy metal content in the soil was compared with the permissible value provided by WHO and as shown in the figures above (Fig. 4), site A which was closest to the plant had lead (Pb) content of 712 against the permissible value of 85mg/kg, the soil within 200m proximity was highly polluted with lead. Copper (Cu) was less than the permissible value, the permissible value for copper is 36mg/kg, for chromium (Cr), the soil content was 141 against the permissible value of 100, this means that the site A was polluted with chromium. The permissible value for Zinc (Zn) was 50mg/kg while soil content was 10 which indicates that Zinc content is lower than the permissible value hence the soil at site A has not been polluted with Zinc.

Site B which was 400m form the plant had lead (Pb) content of 710 against the permissible value of 85mg/kg, the soil within 400m proximity was highly polluted with lead. Copper (Cu) content for site B was 14, the permissible value for copper is 36mg/kg, for chromium (Cr), the soil content was 141 against the permissible value of 100, and this means that the site B was polluted with chromium. The permissible value for Zinc (Zn) was 50mg/kg while soil content was 7.4 which indicates that Zinc content is lower than the permissible value hence the soil at site B has not been polluted with Zinc. Site C which was 600m away from the plant had lead (Pb) content of 268 against the permissible value of 85mg/kg, the soil within 600m proximity was highly polluted with lead. Copper (Cu) content for site B was 17 while the permissible value for copper is 36mg/kg, for chromium (Cr), the soil content was 99 against the permissible value of 100, and this means that the site B was not polluted with chromium because the soil content is less than the permissible value. The permissible value for Zinc (Zn) was 50mg/kg while soil content was less <1 which indicates that Zinc content is lower than the permissible value hence the soil at site C has not been polluted with Zinc. The control site which was the furthest from the plant had lead (Pb) content of 67 against the permissible value of 85mg/kg this means that the control site was not polluted with lead. Copper (Cu) content for this site was 4.9 while the permissible value for copper is 36mg/kg, for chromium (Cr), the soil content was 18 against the permissible value of 100, and this means that the site was not polluted with chromium because the soil content is less than the permissible value. The permissible value for Zinc (Zn) was 50mg/kg while soil content was 30 which indicates that Zinc content is lower than the permissible value hence the soil at this site has not been polluted with Zinc.

Heavy metals such as Pb and Cd are lethal even in very small doses.

Lead has a negative influence on the somatic development, decreases the visual acuity and additive thresholds. Acute exposure to lead causes brain damage, neurological symptoms and could lead to death (Musenge and Mamontov, 2018) [7]. According to the study by Mahdi *et al*., (2016) [5] the dust has sat on the leaves of three species of oak and black Tello and reed which contain significant concentrations of metals such as silver, barium, bismuth, cesium, chromium, cobalt, cadmium and arsenic. So away from the factory, the concentration of these elements can be reduced in both species. This means that the highest concentration of these elements is observed near the factory. The arrival of this group of compounds causes not only disorder in the metabolic activities of the plants, but the origin of many dangerous human diseases such as cancer for human.

Jadoon *et al*., (2016) showed that the chemical composition of cement is a mixture of calcium aluminum silicate also, a trace amount of Cd, Pb, Fe, Ti and silica. According to several chemical analyses the area surrounding industries observed that the further the area is from the factory, the better as soil pollution decreases.

Soil samples from all the five sites were analyzed for physical properties and conductivity. Samples 1, 2 and 3 from site A had conductivity of 104.25 with particle percentages of sand = 54.6%, clay = 18.8% and silt = 26.6%. The soil texture was loamy sandy. Samples 4, 5, and 6 from site B had conductivity of 134.89 with particle percentages of sand=70.6%, clay=14.8%, silt=14.6%. The soil texture was loamy sandy.

Samples 7, 8, and 9 from site C had conductivity of 110.99 with particle percentages of sand=71.2%, clay=18.8%, silt=10%. The soil texture was Sandy loam. Samples 10, 11, and 12 from site D had conductivity of 133.58 with particle percentages of sand=77.2%, clay=12.8%, silt=12.8%. The soil texture was Sandy loam. Samples 13, 14, and 15 from site E had conductivity of 74.43 with particle percentages of sand=85.2%, clay=8.8%, silt=6%. The soil texture was Sandy loam.

Busa *et al*. (2014) in their study revealed that the soil organic carbon content ranged from 1.50±0.10 (Location IFK) to 4.86±1.90 % (Location TFG). Organic matter content (2.58% to 8.37%) recorded in this study disagreed with the findings in Calabar cement factory where a moderate value (mean of 2.54%) was observed. Meanwhile, the observation in this study was above the range of 2.01 to 3.33% in a cement factory in Karachi. In this study it was observed that the soil in the cement kiln had the highest organic matter content which agreed with the assertion that cement-polluted soil was significantly high in organic matter as a result of the synergistic deposition effects from cement production operations. In addition, organic matter was higher in the cement kiln than at other locations.

Soil fertility was determined based on amount of potassium (K), phosphorous (P), nitrogen (N) and organic matter. As shown in the figure about site A contained 117 potassium, site B had 100, site C had 58, site D had 54 while site E had 38. Nitrogen was 0.18 at site A, site B had 0.2, site C had 0.17, site D had 0.17 and E had 0.2. Phosphorous was as follows: site A and B contained 4, site C contained 13 while site D had 71 and site E contained 91.

Site A contained 117 potassium, site B had 100, and site C contained 58 while site D had 54 while site E contained 38. Organic matter at site A was 2.60, site B had 0.90, site C had 0.96 and site D had 1.60 while site E contained 2.40 organic matter. Chandrakala *et al*., (2018) conducted the study in the results revealed that Soils of the Elamdesam block is varied in soil fertility status. Soils are high in organic matter and acidic in reaction. Amelioration of soil acidity and external inputs of essential nutrients is necessary for successful crop production. The status of available nutrition provides the basis for soil and crop specific mineral nutrition recommendation in all the land uses in order to maintain soil nutrient balance and also to enhance higher crop production and productivity.

5. Conclusion

The study aimed at assessing the impact of artisanal mining activities on soil quality**.** The study revealed that the soil pH in the soil samples from site A was slightly acidic, and does not need liming with Dolomite material (Agric lime) than the soil sample sites B, C, D and E and will need liming at the rate of 1000kg/ha, 1500kg/ha. Lime application will help to neutralize the acidic soil and make it idea for crop production but the slight acidic soil does not need liming. Phosphorous Deficient is bound to affect the establishment of rooting system and subsequent dwarfing of crops; in this case the soil samples from site A, B and C have low Phosphorous. Fertilization with an NPK (D- compound) fertilizer as per recommendation will help improve this level of phosphorus. While the soil samples from site D and E have very high level of phosphorous.

Nitrogen was low in the soil samples; but it's normal for most soils to have very low to low levels of Nitrogen in most soils in Zambia. Application of both basal and top dressing is required to provide the crop with adequate nitrogen. Application of Green manure could help loosen up the soils. Top dressing with CAN is recommended. Organic matter is low in the soil samples from site B and C; use of manure could have a positive bearing on increasing the organic matter in the soil, while the soil samples from site A, D and E have organic matter. Organic matter acts as a store house for most nutrients (zinc, copper). In this study the level of Potassium in the soil was medium, as the value from the analysis of the soil sample, is <36, but the level of potassium in the soil sample from site E is medium but below the critical value which 40. Application of NPK fertilizers will help maintain the levels of K in the soil. Potash will help improve plants resistance to diseases and potash equally helps prolong the shelf life of the fruits. Cation Exchange Capacity is low in the soil samples. Mostly CEC is rated to soil type and soil type while Iron levels are ok in the soil sample. Trace metal content was as follows: Level of copper in the soil samples was ok and is above the critical value. Level of zinc is low in the soil sample from site C and is below the critical value. Improvement of organic matter will help to improve the level of zinc in the soil; application of zinc fertilizers such as zinc sulphate or zinc oxide will also unlock the zinc in the soil and make it available to the crops. Recommended application rate of zinc sulphate is in the range of 5 to 100Kg/Ha.

The amount of heavy metals in samples which were within the distance of 600m from the cement plant had high content of heavy metals with chromium and lead having highest content site A, B and C were polluted with lead and chromium. Site A had lead (Pb) content of 712 against the permissible value of 85mg/kg, the soil within 200m proximity was highly polluted with lead. Chromium, the soil content was 141 against the permissible value of 100, this means that the site A was polluted with chromium. It can be concluded that lead and chromium are the only heavy metals which were in highly concentrated in all the three sites within the proximity of 600m from the cement plant. Other heavy metal s such as copper (Cu) and zinc (Zn) were below the permissible level. The two control sites were not polluted by any of the heavy metals since they were far from the mining site. The study therefore indicated that artisanal mining leads to the accumulation of heavy metals such as lead and chromium.

6. Recommendations

- Since the level of zinc is low in the soil samples from site C and is below the critical value. Improvement of organic matter will help to improve the level of zinc in the soil.
- Levels of sodium are high in the soil samples, and since sodium is only needed by the crops in small quantities similar to micronutrients. There is need for the application of NPK fertilizer to help improve the levels of sodium in the soil above the critical value.
- Organic matter is low in the soil samples from site B and C hence use of manure would be helpful to increase organic matter in the soil.
- Since Nitrogen is low in the soil samples, there is need to apply both basal and top dressing is required to provide the crop with adequate nitrogen and green manure could help loosen up the soils.

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