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Study of the Distribution and Level of Soil Contamination by Trace Metallic Elements in the Mining Areas of Ruashi: Application to the Kawama, Luano, and Kalukuluku Neighborhoods of the Ruashi Municipality, City of Lubumbashi, Democratic Republic of Congo

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ABSTRACT
This study focused on a physicochemical characterization of the soil at the sites surrounding the mining activity. These three sites are Luano, Kalukuluku and Kawama. To achieve this, we used a methodology that allowed us to determine the pH, humidity, organic matter and trace metal elements. We first started by taking samples in each area at two depths, 20 cm and 40 cm, and finally to study the mobility of Trace metallic elements in the soil. From this we found practically neutral pH values in the Kawama and Kalukuluku area and an acidic pH for the Luano soil. The soil in these three areas is poor in organic matter with an average content of 1.37 %. The site shows a maximum humidity value of 4.09 %, which is explained by the fact that the samples were taken during the dry season towards the end. For this study we analyzed some heavy metals that have a certain toxicity namely: Copper, Cobalt, Zinc, Cadmium, Manganese, Lead and Nickel. This analysis showed a pollution in trace metal elements of the following elements: Copper, Zinc, Cobalt, Cadmium, Manganese and Lead. The calculated pollution indices made it possible to highlight soil pollution with values of 3.99 for Luano, 5.54 for Kalukuluku and 8.15 for Kawama. As the three sites have values greater than 1, these are polluted in Trace metallic elements.

Keywords: Trace metal elements, Ruashi mining, Pollution index, Metalloid

1. Introduction

The soil is a vital component a medium composed of nutrients and unconsolidated materials that forms the life-supporting layer for plants [1]. It is a fundamental element for sustaining life within the biosphere, in addition to its nutritional functions, the soil can also act as an efficient environmental filter by purifying

the water that percolates through it from various pollutants capable of contaminating the food chain and groundwater [2, 3].

A soil is considered contaminated by trace metallic elements when the concentration of a given element significantly exceeds its natural background level in the studied soil [4]. When the contamination of a soil by trace elements leads to a disturbance of the ecosystem or interferes with its normal use, the site is regarded as polluted [5].

Environmental pollution and the continuous exposure of humans to trace metallic elements, commonly referred to as heavy metals, have become major global concerns, increasingly exacerbated by modern industrialization [6, 7, 8]. The growth of industrial activities (particularly metallurgical and chemical industries) and agricultural practices (use of pesticides and fertilizers) since the past century has led to substantial inputs of these elements, which have consequently become environmental pollutants [9]. Even at low concentrations, they can pose serious health risks due to their toxicity and bioaccumulative nature [10].

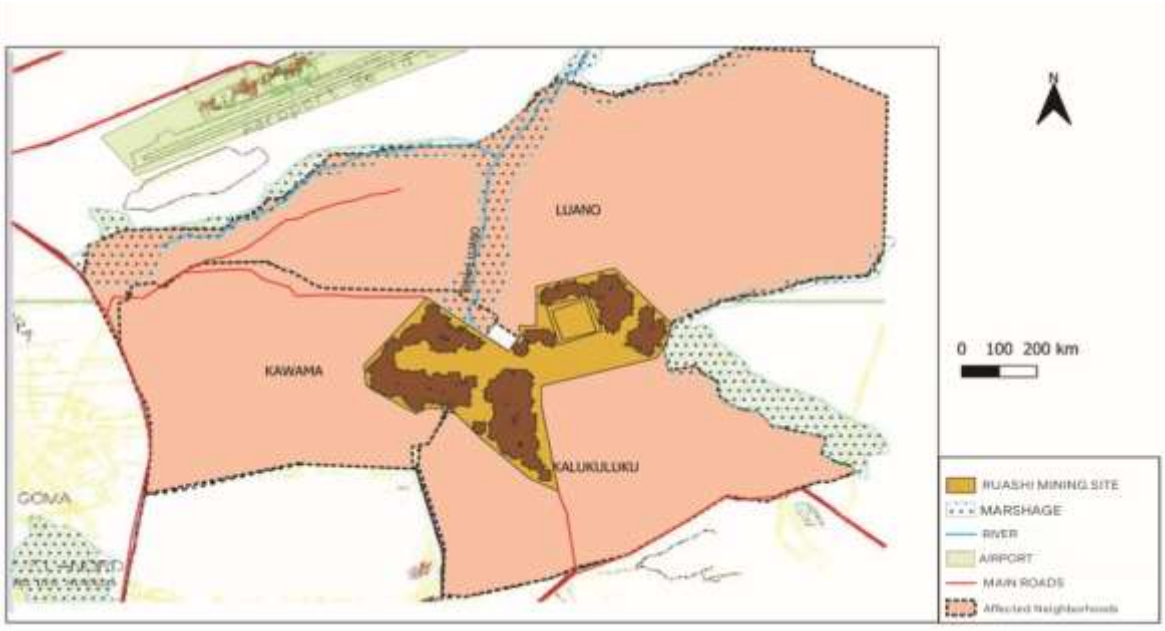
The Luano, Kawama, and Kalukuluku sites are neighborhoods within the Ruashi municipality, located in the northeastern part of the city of Lubumbashi. Following complaints from local residents, these three sites have been the subject of several investigations [11]. In this context, the present study aims to perform a physicochemical characterization in order to assess the soil quality in this area of the city of Lubumbashi.

2. Materials and methods

2.1 Study area

The Ruashi municipality is one of the seven municipalities of the city of Lubumbashi, located in the Haut-Katanga province of the Democratic Republic of Congo. It lies within the humid tropical zone, which is currently characterized by a rainy season lasting approximately six to seven months per year (from October to mid-April) [12, 13, 14]. The three study sites namely the Kawama, Luano, and Kalukuluku neighborhoods are situated within this municipality. Figure (1) below illustrates the three zones impacted by the Ruashi Mining Company.

Figure 1. Ruashi Mining and the surrounding neighborhoods [2]



2.2 Location of sample collection points

A total of 30 samples were collected using an auger set from three zones, with 10 samples taken from each. The three zones are Luano, Kalukuluku, and Kawama, at two depths of 20 cm and 40 cm. Table (1) and Figure (2) below present the geographical coordinates of the sampling points.

Table 1. Geographical Coordinates of Soil Sampling Points

Point	Latitude	Longitude
P1-1	11°36'12.97"S	27°33'14.85"E
P1-2	11°36'19.92"S	27°33'4.79"E
P1-3	11°36'0.39"S	27°33'9.13"E
P1-4	11°36'2.03"S	27°32'40.43"E
P1-5	11°36'2.37"S	27°32'54.66"E
P2-1	11°37'2.99"S	27°31'59.44"E
P2-2	11°36'41.79"S	27°32'0.04"E
P2-3	11°37'0.29"S	27°31'35.43"E
P2-4	11°37'12.53"S	27°32'10.78"E
P2-5	11°37'23.88"S	27°32'18.77"E
P3-1	11°38'0.75"S	27°33'26.58"E
P3-2	11°37'17.84"S	27°33'21.26"E
P3-3	11°37'35.21"S	27°32'36.33"E
P3-4	11°37'29.73"S	27°32'30.29"E
P3-5	11°37'25.65"S	27°32'11.93"E

P1-1 to P1-5: sampling points in the Luano zone; P2-1 to P2-5: sampling points in the Kawama zone; and P3-1 to P3-5: sampling points in the Kalukuluku zone.

Figure 2. Satellite Photograph of the Sampling Points

2.3. Sampling

Sampling is the first and one of the most important stages of characterization. It aims to reduce the size of the portion to be studied and to define a procedure that ensures representativeness. Indeed, regardless of the precision of the analytical methods used, if the sample is not representative, the assessment and resulting conclusions may not accurately reflect the actual conditions of the studied area [15]. Sampling is therefore the operation of collecting samples that represent the entire surface of the study area [16].

For this study, sampling was carried out randomly, following the direction of the prevailing wind. The sampling campaign covered the three sites Luano, Kawama, and Kalukuluku. In each zone, 10 samples were collected at depths of 20 cm and 40 cm, giving a total of 30 samples.

The reference point for the sampling operation was the Ruashi Mining Company. For each site, the first sample was taken near the company premises, and subsequent samples were collected progressively farther away, within the surrounding residential areas.

2.4. Organic matter, pH and moisture content

To determine the moisture content, the collected samples were first stored in plastic containers and transp-

orted to the laboratory. They were then placed in an oven at 105 °C for 24 hours. This operation, known as drying or oven-drying, allowed for the determination of moisture content as the difference in weight before and after drying, expressed as a percentage. To determine the organic matter content, the oven-dried samples were then placed in a muffle furnace and calcined at 500 °C for 5 hours to eliminate organic substances. The organic matter percentage was calculated as the weight difference before and after calcination.

For soil pH, a 1:5 soil-to-water ratio was used. The mixture was homogenized for 1 hour using a magnetic stirrer, then allowed to settle for 2 hours. The pH of the supernatant was then measured using a pH meter [17], [18].

2.5. Chemical analysis of trace metallic elements

For the chemical analysis of trace metallic elements, the atomic emission spectrometry method was used. This instrumental technique was performed with an Inductively Coupled Plasma Atomic Emission Spectrometer (ICP-AES). This method is based on the principle that atoms emit characteristic radiation specific to each element when excited. The prepared sample (dissolved and diluted) is aspirated through a capillary tube, nebulized, and then injected into an argon plasma torch. The plasma, which can reach temperatures up to 10,000 K, dries the sample and causes molecular bond dissociation, atomization, and/or ionization and excitation [19].

3. Results And discussion

3.1. Chemical Characterization of Trace Metallic Elements

Trace metallic elements are toxic substances that occur in trace amounts in the environment and pose potential risks to human, animal, and plant health [4]. The results of the chemical characterization for the three study zones are presented as follows.

Table 2. Results of Chemical Analysis for the Luano Zone at a Depth of 20 cm

Sample (ECH)	Cd (mg/kg)	Co (mg/kg)	Cu (mg/kg)	Mn (mg/kg)	Ni (mg/kg)	Pb (mg/kg)	Zn (mg/kg)
ECH 1	7.21	109.60	341.80	681.30	32.54	167.30	172.50
ECH 2	3.62	45.00	449.10	3246.00	45.30	132.10	1284.00
ECH 3	3.22	80.69	262.00	315.70	11.38	301.50	86.97
ECH 4	5.29	27.59	272.80	133.80	25.67	293.00	59.73
ECH 5	2.84	36.40	164.70	84.89	54.61	10.87	96.40
Maximum	7.21	109.60	449.10	3246.00	54.61	301.50	1284.00
Minimum	2.84	27.59	164.70	84.89	11.38	10.87	59.73
Average	4.43	59.86	298.08	892.34	33.90	180.95	339.92
Standard deviation	1.81	34.35	105.42	1336.42	16.85	121.02	529.41
SD	2.00	30.00	100.00	90.00	50.00	100.00	300.00

SD: represents the AFNOR standard NF U-44-041.

Table 3. Results of chemical analyses of the Luano zone to a depth of 40 cm

Sample (ECH)	Cd (mg/Kg)	Co (mg/Kg)	Cu (mg/Kg	Mn (mg/kg)	Ni (mg/Kg)	Pb (mg/Kg)	Zn (mg/Kg)
ECH 1	12.12	71.69	326.50	1355.00	41.79	144.70	98.00
ECH 2	5.50	58.53	188.20	404.40	35.25	402.70	106.40
ECH 3	4.62	29.85	1225.00	6649.00	51.48	78.73	3356.00
ECH 4	6.81	38.13	148.70	142.10	40.27	5.08	111.90
ECH 5	3.93	30.74	186.20	944.60	37.00	106.80	539.10
Maximum	12.12	71.69	1225.00	6649.00	51.48	402.70	3356.00
Minimum	3.93	29.85	148.70	142.10	35.25	5.08	98.00
Average	6.60	45.79	414.92	1899.02	41.16	147.60	842.28
Standard deviation	3.27	18.52	457.89	2696.75	6.32	151.50	1417.71
SD	2.00	30.00	100.00	90.00	50.00	100.00	300.00

SD: represents the AFNOR standard NF U-44-041.

Figure 3. Average of trace metal elements in the soil of the LUANO district at a depth of 20 cm

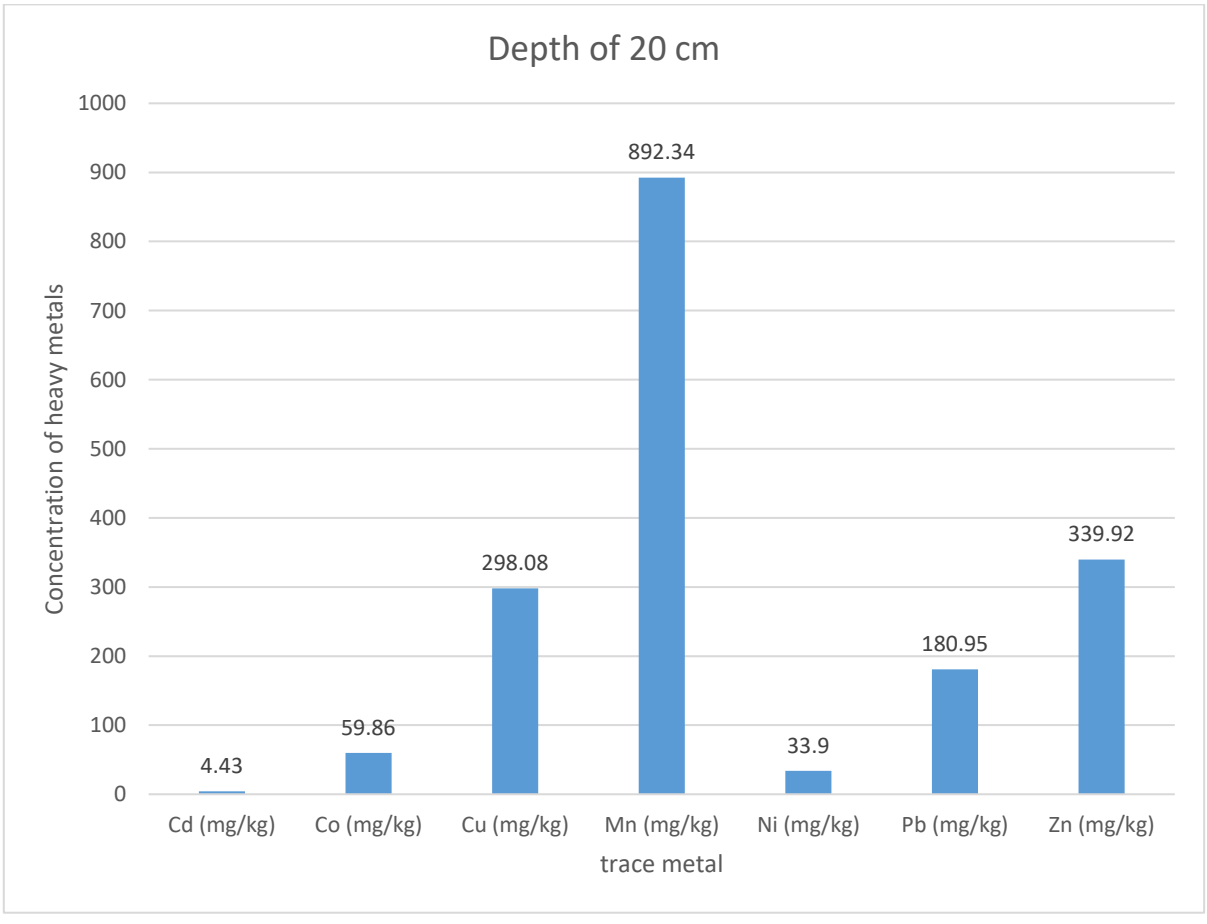


Figure 4. Average of trace metal elements in the soil of the LUANO district at a depth of 40 cm

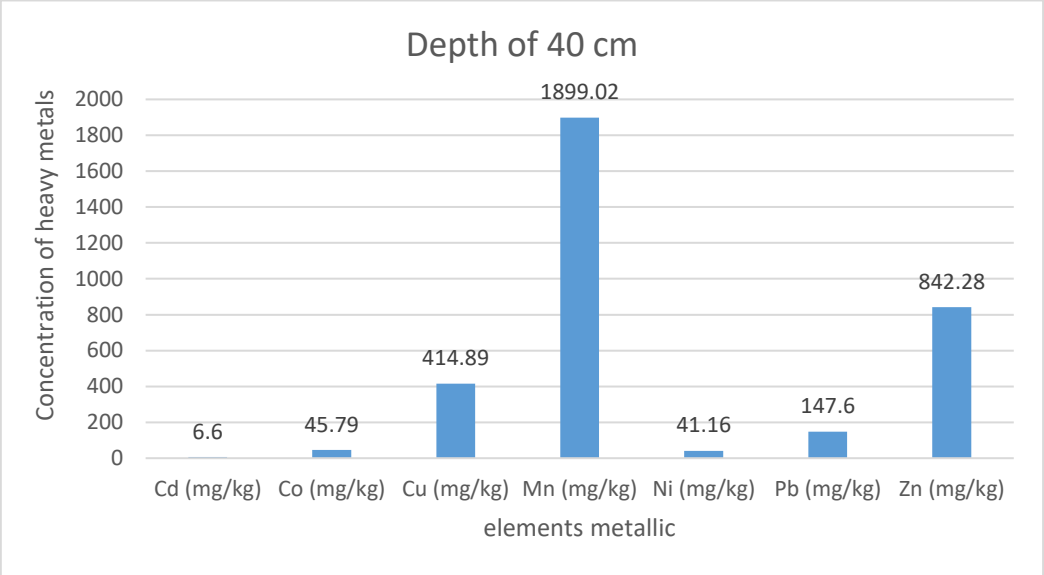


Table 4. Results of chemical analyses of the Kawama zone to a depth of 20 cm

Sample (ECH)	Cd (mg/kg)	Co (mg/kg)	Cu (mg/kg)	Mn (mg/kg)	Ni (mg/kg)	Pb (mg/kg)	Zn (mg/kg)
ECH 1	6.40	463.10	2913.00	1316.00	15.21	208.00	161.40
ECH 2	6.57	671.10	3131.00	6652.00	41.01	716.10	111.50
ECH 3	6.39	29.19	163.10	467.70	37.68	488.80	102.50
ECH 4	8.08	105.50	1819.00	1133.00	31.50	652.60	395.40
ECH 5	11.50	463.70	1427.00	2111.00	46.38	833.90	164.00
Maximum	11.50	671.10	3131.00	6652.00	46.38	833.90	395.40
Minimum	6.39	29.19	163.10	467.70	15.21	208.00	102.50
Average	7.79	346.52	1890.62	2335.94	34.36	579.88	186.96
Standard deviation	2.19	269.94	1202.93	2482.77	11.99	242.36	119.85
SD	2.00	30.00	100.00	90.00	50.00	100.00	300.00

SD: represents the AFNOR NF U-44-041 standard.

Table 5. Results of chemical analyses Kawama Zone to a depth of 40 cm

Sample (ECH)	Cd (mg/kg)	Co (mg/kg)	Cu (mg/kg)	Mn (mg/kg)	Ni (mg/kg)	Pb (mg/kg)	Zn (mg/kg)
ECH 1	7.86	440.30	3447.00	1298.00	10.23	32.97	120.90
ECH 2	6.01	187.60	881.20	974.10	28.84	91.05	331.60
ECH 3	5.81	61.90	276.70	412.90	47.45	543.60	129.40
ECH 4	11.77	213.50	1132.00	1979.00	24.33	1015.00	240.60
ECH 5	13.81	327.10	1142.00	1941.00	35.72	434.30	151.90
Maximum	13.81	440.30	3447.00	1979.00	47.45	1015.00	331.60
Minimum	5.81	61.90	276.70	412.90	10.23	32.97	120.90
Average	9.05	246.08	1375.78	1321.00	29.31	423.38	194.88

Standard deviation	3.58	143.78	1210.02	663.87	13.78	396.06	89.99
SD	2.00	30.00	100.00	90.00	50.00	100.00	300.00

SD: represents the AFNOR NF U-44-041 standard.

Figure 5. Average of trace metal elements in the soil of the KAWAMA district at a depth of 20 cm

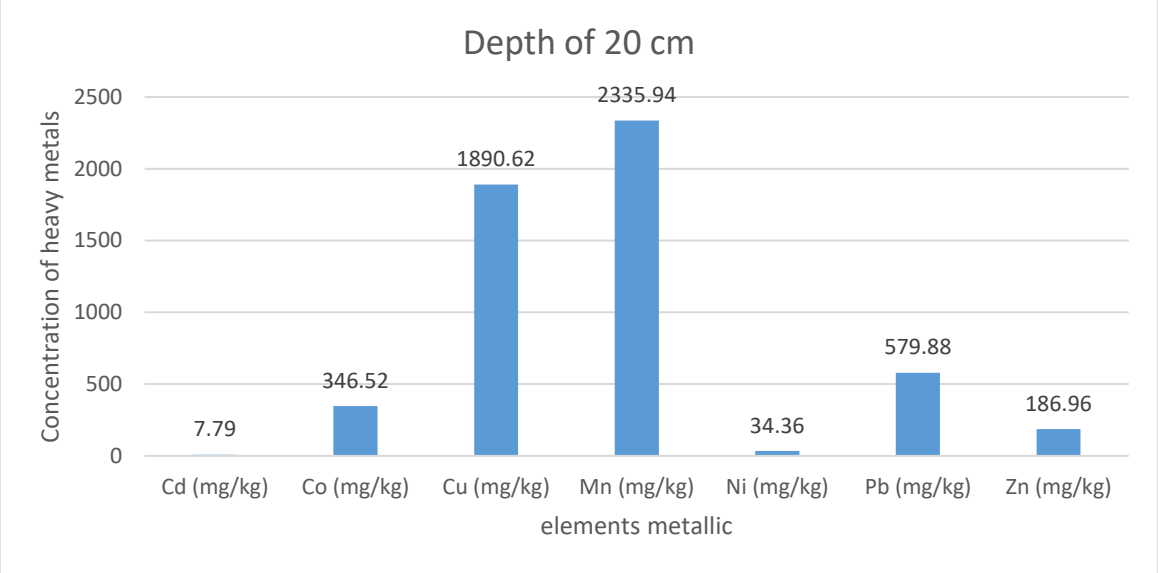


Figure 6. Average of trace metal elements in the soil of the KAWAMA district at a depth of 40 cm

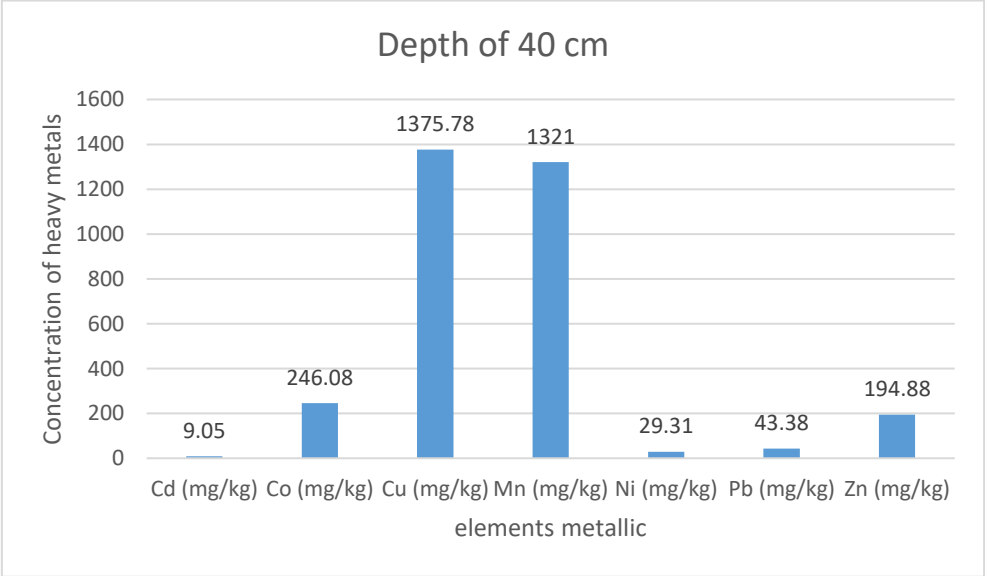


Table 6. Results of chemical analyses of the Kalukuluku area to a depth of 20 cm

Sample (ECH)	Cd (mg/kg)	Co (mg/kg)	Cu (mg/kg)	Mn (mg/kg)	Ni (mg/kg)	Pb (mg/kg)	Zn (mg/kg)
ECH 1	8.47	329.70	996.30	1958.00	60.38	379.20	2008.00
ECH 2	7.44	95.52	278.60	685.80	27.55	559.70	328.10
ECH 3	17.55	106.40	567.60	326.00	41.73	225.80	81.42

ECH 4	7.53	172.60	695.80	1149.00	30.41	277.50	137.00
ECH 5	101.7	90.30	602.10	437.60	39.64	334.80	166.80
Maximum	17.55	329.70	996.30	1958.00	60.38	559.70	2008.00
Minimum	7.44	90.30	278.60	326.00	27.55	225.80	81.42
Average	10.23	158.90	628.08	911.28	39.94	355.40	544.26
Standard deviation	4.24	101.04	258.19	665.19	12.90	128.06	823.38
SD	2.00	30.00	100.00	90.00	50.00	100.00	300.00

SD: represents the AFNOR NF U-44-041 standard.

Table 7. Results of chemical analyses Kalukuluku Zone to a depth of 40 cm

Sample (ECH)	Cd (mg/kg)	Co (mg/kg)	Cu (mg/kg)	Mn (mg/kg)	Ni (mg/kg)	Pb (mg/kg)	Zn (mg/kg)
ECH 1	15.34	390.20	1280.00	1997.00	41.86	751.90	198.00
ECH 2	7.16	116.20	402.20	801.90	24.90	380.80	151.60
ECH 3	15.46	229.10	731.20	459.80	24.11	594.30	88.71
ECH 4	7.51	168.90	849.10	930.20	14.58	147.40	319.20
ECH 5	12.15	86.11	605.90	486.30	40.84	4558.00	227.80
Maximum	15.46	390.20	1280.00	1997.00	41.86	4558.00	319.20
Minimum	7.16	86.11	402.20	459.80	14.58	147.40	88.71
Average	11.52	198.10	773.68	935.04	29.26	1286.48	197.06
Standard deviation	4.05	120.38	327.87	627.04	11.77	1842.93	86.13
SD	2.00	30.00	100.00	90.00	50.00	100.00	300.00

SD: represents the AFNOR NF U-44-041 standard.

Figure 7. Average of trace metal elements in the soil of the KALUKULUKU district at a depth of 20 cm

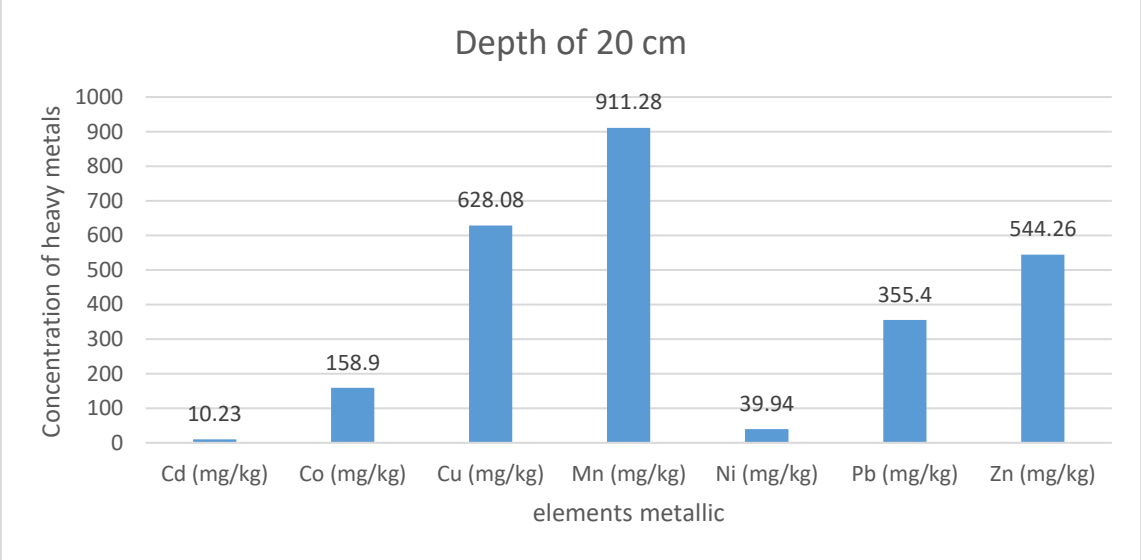
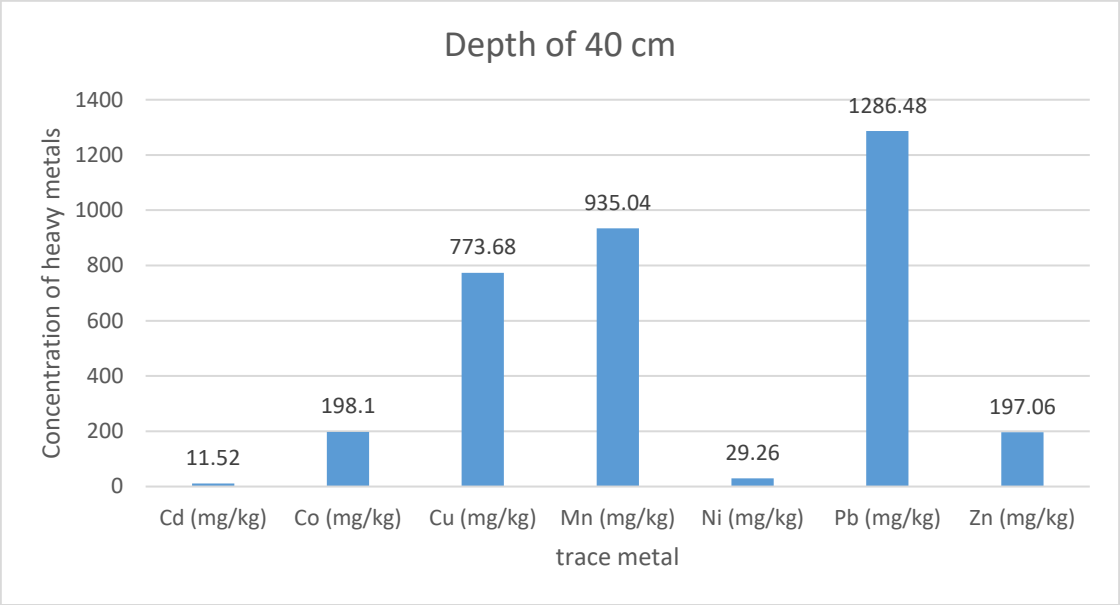


Figure 8. Average of trace metal elements in the soil of the KALUKULUKU district at a depth of 40 cm



Congolese legislation, which does not yet provide for regulations concerning the quantity of Trace metal elements not to be exceeded, compares the results of this work with the international standard AFNOR NF U-44-041.

The analysis was conducted at two depths: 20 cm and 40 cm. We observed that depth influences the level of pollution. In the Luano district, the average levels of certain trace metals at the surface are lower than those at a depth of 40 cm, a phenomenon opposite to that observed in the other two districts, Kawama and Kalukuluku. This can be explained by the fact that the average pH of this area is 5.81. This pH promotes the leaching of certain trace metals that accumulate at the surface, thus facilitating their filtration into the soil.

At these two depths, the following trace metals copper (Cu), cadmium (Cd), cobalt (Co), lead (Pb), zinc (Zn), and manganese (Mn) are present in concentrations exceeding the standards. This indicates that the soil is polluted by copper (Cu), cadmium (Cd), cobalt (Co), lead (Pb), zinc (Zn), and manganese (Mn). Nickel, whose concentration is below the standard, does not pollute the environment.

3.2 Pollution index

The pollution index is a parameter used to assess the degree of soil pollution. When it is less than 1, the soil is considered unpolluted, but contaminated [15]. It indicates, in general, whether the soil is polluted or not, based on all the elements it contains. To determine this index, we used the following formula :

$$IP = \frac{\frac{Cd}{2} + \frac{Mn}{90} + \frac{Co}{30} + \frac{Cu}{100} + \frac{Ni}{50} + \frac{Pb}{100} + \frac{Zn}{300}}{7} \quad (1)$$

With: IP: pollution index

Table 8. Pollution index values

Area	Pollution Index
Luano	3.99
Kawama	8.15

Kalukuluku	5.54

This shows that the three areas are heavily polluted by trace metals and that the Kawama area is more polluted with an index of 8.15, much higher than the other two areas which contain 3.99 for Luano and 5.54 for Kalukuluku.

3.3 Mobility factors

These factors influence the transfer of an element to pass into the soil compartments where it is less and less energetically retained with the liquid phase or in some cases the soil atmosphere as the ultimate compartment [20, 21].

Table 9. Moisture, Organic Matter and pH

Sample	Humidity (%)	Organic matter (%)	pH
E1-1	3	0.97	5.82
E1-2	4.09	1.02	5.84
E2-1	3.66	0.91	6.98
E2-2	3.93	0.92	6.98
E3-1	1.89	1.37	6.76
E3-2	1.76	1.31	6.77

These samples present the average values for each zone at depths of 20 and 40 cm, with E1-1 and E1-2 for the Luano zone, E2-1 and E2-2 for the Kawama zone, and E3-1 and E3-2 for the Kalukuluku zone. Based on the data in this table, the soils in these three zones are less humid, indicating that the sampling was carried out towards the end of the dry season. Regarding organic matter, the soil in these sites is poor, with a minimum average value of 1.37 %. The soil pH in the Luano zone is acidic, which facilitates the solubilization of certain metals compared to the other zones, which have practically neutral values. The results show that depth does not influence any of the three parameters.

Conclusion

The objective of this work was to assess the pollution levels in three neighborhoods surrounding the Ruashi mining company. To achieve this objective, we began with a literature review, which involved examining dissertations, doctoral theses, and relevant reports within our research topic to gain insight into the methodology and gather the necessary information about our study area.

Next, we carried out sampling at the sites surrounding the Ruashi mining company. This part of the work consisted of collecting 10 samples in each area at depths of 20 cm and 40 cm. The samples were then taken to the laboratory of the Congolese Office of Control for various physicochemical analyses, including pH, organic matter content, moisture content, and chemical analysis of metallic elements.

Regarding pH, the luano zone is acidic, with an average value of 5.81, compared to the other two zones which have practically neutral pH values. This is due to the luano zone being located very close to the company's wastewater treatment basin. An acidic pH facilitates the solubilization of certain metals.

In all three of these zones, the quantity of organic matter, including moisture, has very low average levels, which explains why the sampling was done during the dry season and why the soil in these three zones is

poor in organic matter.

Chemical analysis of trace metal elements showed that the site surrounding the company is polluted with values exceeding the standard and a pollution index greater than 1 in each zone.

For these three areas, higher concentrations were observed at a depth of 20 cm than at 40 cm in the Kawama and Kalukuluku areas . This is explained by atmospheric deposition of trace metals at the surface. These two sites have a practically neutral pH, so the metals remain at the surface. In the Luano area , the opposite phenomenon occurs: higher quantities of certain trace metals are found at a depth of 40 cm than at a depth of 20 cm. This is explained by the fact that the basin discharges liquid waste, and the acidic pH together facilitates the infiltration of these trace metals into the soil, where they dissolve.

The pollution indices showed that the Kawama area is the most polluted with an index value of 8.15 followed by the Kalukuluku area with 5.54 and finally Luano with 3.99.

From this, we subsequently suggest studies on soil pollution remediation methods at three sites (Luano, Kawama, and Kalukuluku). This could reduce pollution at these sites to some extent.

Conflict of Interest

The authors declare that there is no conflict of interest regarding this work. The research was conducted independently, without external funding or influence.

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