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# Influence of Vat Leach Reprocessed Tailings on Heavy Metals Levels around Sekenke Gold Mine, Iramba District, Tanzania

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***Research article***

## ABSTRACT

Soil pollution is a worldwide phenomenon which results from both natural and anthropogenic activities. This has resulted in several health and physiological problems in both plants and human. This study investigated the concentration of heavy metal contaminants at Senkenke gold mining areas in nine tailings samples before processing and in nine tailing samples after processing using XRF Rigaku Nex CG and arsenic was determined using AAS equipped with a continuous flow of VGA. Arsenic mean concentration in unprocessed samples was 32.873 ± 26.284 mg/kg, while in processed tailings was 24.390 ± 19.394 mg/kg. The mean concentration of Pb in unprocessed tailing was 44.012 ± 37.091mg/kg, while in processed tailing was 38.402 ± 28.270 mg/kg. The mean concentration of Cd in unprocessed tailing was 4.513 ± 1.022 mg/kg, while in processed tailing was 3.089 ± 1.329 mg/kg. Chromium mean concentration in unprocessed tailing was 194.526± 22.670 mg/kg while in processed tailing was 141.352 ± 30.726 mg/kg. The Igeo values found in the following increasing order in unprocessed tailing Zn < Fe < Pb < Cr < As < Cd while in processed tailing was in the following increasing order Zn < Fe < Cr < As < Pb < Cd. The PLI values calculated for tailing samples are found to 4.423 for unprocessed tailing and 2.807 for processed tailing which shows that the soils are polluted and the environment is deteriorated in their quality. The findings revealed that the soils and mine tailings in the study area were polluted with heavy metals, particularly As, Pb and Cr and mostly Cd. The heavy metal concentrations decrease from unprocessed tailing to processed tailings. This pollution poses significant environmental and health risks.

## INTRODUCTION

Mining is a crucial driver of global economic growth, with the extraction of precious metals serving as a significant source of foreign exchange for many developing nations. Tanzania, rich in minerals and natural resources such as gold, diamonds, coal and natural gas, generated around 3.6 billion U.S. dollars from mineral exports. This was a rise from 2.3 billion U.S. dollars in 2023 (Cowling, 2024). Gold was the largest contributor to the country's mineral export earnings.

The extraction and processing of precious metals often come with considerable environmental and public health risks. For example, mine tailings

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from gold ore processing can pollute the environment (Roussel *et al*., 2000). These tailings commonly contain heavy metals and leftover reagents such as cyanide. Several researchers (Raji *et al*., 2021, Shapi *et al*., 2021) have documented high concentrations of heavy metals in water streams near gold mines, while Miller (2022) indicated heavy metals from mining activities can remain in surface soil layers for many years.

Tailings are a mix of finely ground rock residues left after valuable minerals have been extracted, combined with the water used in processing. In countries with limited environmental regulation enforcement, large volumes of open-dumped tailings are common (Baker and Banfield, 2003). The chemical and physical makeup of tailings resembles that of typical river sand and silt, shaped by factors such as ore type, geochemistry, extraction methods, particle size, and specific chemical treatments used in processing (Davies and Rice, 2001; Franks *et al*., 2011). Gold mine tailings, in particular, have poor physical qualities, including low aggregation, high hydraulic conductivity, fine texture, and weak cohesion (Khan *et al*., 2023). These characteristics set tailings apart from natural soil (Vega *et al*., 2004; Blight and Fourie, 2005), with low cohesion contributing to fluctuations in moisture content and temperature within this hazardous waste.

Gold extraction generates a substantial amount of tailings, which are waste materials discarded after ore processing. These tailings often contain various contaminants, including mercury, arsenic, antimony, cyanide, and residuals (Uddin *et al*., 2021). The process of mining gold can release numerous toxic pollutants, which pose health risks even at low concentrations. According to Olise *et al*. (2019), artisanal gold mining is a well-known source of toxic metals in soil, sediment, and water, releasing harmful substances such as cadmium, arsenic, copper, lead, iron, chromium, nickel, and zinc into the environment.

Zinc and iron are among the most abundant element on earth (Quintero-Gutiérrez *et al*., 2008) and is a biologically essential component of every living organism (Aisen *et al*., 2001). Arsenic (As), a naturally occurring and abundant element in the earth's crust both organic and inorganic forms can be found in soil, with the latter being a very toxic form (Shrivastava *et al*., 2015). Arsenic can be due to smelting of gold, mining processes like smelting pharmaceutical waste, wastewater in mining site or combustion of fossil fuels (Bhardwaj *et al*., 2020; Biamont-Rojas *et al*., 2023). Cadmium is frequently used in production of polyvinylchloride (PVC) products, alloys, pigments and batteries (Wilson, 1988; Yuan *et al*., 2019). Chromium can be found in metal plating and paints, and pigments, rubber, photography, tanning and mining and metallurgy/metal purification (Sharma *et al*., 2021). Lead Combustion of fossil fuels, paints and pigments; application of lead in gasoline, and solid waste, explosives, ceramics and dishware, solid waste combustion, paints and pigments, industrial dust and fumes, manufacturing of lead-acid batteries, pesticides, mining and metallurgy, some types of PVC, urban runoff (Obeng-Gyasi, 2019). Even though long-term exposure to heavy metals is linked to serious health problems like cancer, the public remains largely unaware of the associated risks. This contamination can harm human health through both direct and indirect exposure to these toxic metals (Muradoglu *et al*., 2015; Jin *et al*., 2019; Liu *et al*., 2020). According to Clancy *et al*. 2012, several acute and chronic toxic effects of heavy metals affect different body organs. Gastrointestinal and kidney dysfunction, nervous system disorders, skin lesions, vascular damage, immune system dysfunction, birth defects, and cancer are examples of the complications of heavy metals toxic effects.

Vat leaching is a process that involves using chemicals, such as cyanide or sulfuric acid, to extract gold from ore. When the leftover material, known as tailings, is reprocessed, these chemicals as well as heavy metals like arsenic, mercury, lead, and cadmium, which are often present in the ore can seep into nearby soil and water systems. Consequently, evaluating the impact of these tailings on heavy metal levels is essential for assessing potential contamination of local ecosystems. To address this knowledge gap, this study aims to determine levels of heavy metals in tailings before processing and compare them with levels that remain after processing. Specifically, this study will utilize XRD to analyze samples from Senkenke mining areas, to determine the concentrations of heavy metals and assess pollution load through statistical analysis.

## Materials and Methods

### Study Area

The study was conducted at the Sekenke small-scale gold mine in Iramba District, Tanzania. Located on a low rise in the Wembere depression at 03°57′S and 34°15′E, gold was discovered here before 1914, leading to significant development, making it the largest reef-gold producer in the country. The mine spans approximately 252 hectares and includes 9 unprocessed tailings heaps, each containing around 5,000 tons of soil material. Additionally, there are 9 reprocessed tailings heaps, totaling about 12,000 tons, situated around various processing plants.

### Soil Sample Collection

One sample from each tail was taken by opening small trenches/holes with a spade and using chisels for sampling. The collected 18 tailing samples were stored in Teflon bags, tightened separately and taken to the Geological Survey of Tanzania (GST) Laboratory for analysis. In the laboratory samples were air-dried under a controlled environment to achieve constant weight.

### Sample Preparation

The samples were dried at 50-105ºC for 24 hours to remove the moisture. The samples were grounded and then sieved to remove coarse debris and rubble with a size greater than 2.0mm. A non-metallic sieve was used to avoid contamination of metals. Each sample was divided into three different potions (triplicate). From sample 1g of fine soil sample undergoes *aqua regia* digestion ($HCl/HNO_3$: 3/1) to attack a wide range of soil and geological materials, heated slowly near dryness. After the process of digestion, 20ml of distilled water was added to each sample, filtered and kept in a 100 ml volumetric flask, which was then diluted to the mark. The sample solutions were stored well in Teflon bottles and analyzed by XRD instrument.

The XRD operates by measuring the characteristic secondary radiation emitted from a sample that has been excited with an X-ray source. It is rapid, reliable, non-destructive and often quicker than other analysis techniques (Karathanasis and Hajek, 1996). To maintain the accuracy of the machine, three blank samples of silica sand collected from the Coastal region were prepared following all protocols of collected soil samples from the mine site and then analysed simultaneously with the soil samples.

### Evaluation of Heavy Metal Pollution

The degree of contamination was analyzed by three indices for environmental assessment of soil in small scale mining of Sekenke Singida Municipality. The indices are Geo-accumulation index ($I_{geo}$) and Contamination Factor ($C_f$).

#### ***Geoaccumulation Index*** ($I_{geo}$)

The $I_{geo}$ is a pollution degree evaluation index proposed by Müller (1979) and is widely used to evaluate the pollution degree of single metal in water, ocean, and soil environments (Banu *et al*., 2013). The calculation formula can be expressed as follows:

$$I_{geo} = \log_2\left(\frac{C_i}{1.5B_i}\right) \quad (1)$$

Where $C_i$ represents the concentration of heavy metals measured in the soil (mg/kg), and $B_i$ refers to the geochemical background values based on the Average Composition of Shales as proposed by Turekian and Wedepohl (1961). These shale values were chosen for calculating pollution indices as they allow for meaningful comparisons across different regions, aiding in the understanding of global trends in element enrichment and contamination (Turekian and Wedepohl, 1961; Ali *et al*., 2016). Shale values offer a consistent, standardized reference point and are relatively stable, minimizing significant variations in elemental composition over time.The background values adopted from Edori and Kpee (2017) where: As= 13; Fe = 47,200; Cr = 90; Pb = 20; Cd = 0.3 and Zn = 95 both in mg/kg.

Förstner *et al*. (1993) listed geo-accumulation classes and the corresponding contamination intensity for different indices Table 1.

**Table 1: Geo-accumulation Index Classification**

| Soil $I_{geo}$ Contamination | $I_{geo}$ Accumulation Class Intensity | Index $I_{geo}$ |
|---|---|---|
| >5 | 6 | Very Strong |
| >4 - 5 | 5 | Strong to very strong |
| >3 - 4 | 4 | Strong |
| >2 -3 | 3 | Moderate to strong |
| >1 - 2 | 2 | Moderate |
| >0 - 1 | 1 | Uncontaminated to moderate |
| <0 | 0 | Practically uncontaminated |

### Contamination Factor

Contamination factor ($C_f$) was determined using Single Pollution Index Model. This is a basic and useful tool for detecting toxic metal contamination. This $C_f$ used to evaluate the individual toxic metal contamination in the soil. The standard employed for the interpretation of the contamination factor values was adopted from Edori and Kpee (2017) as given in Eq. (2):

$$= \frac{C_m}{C_b} \quad (2)$$

Where: $C_f$ = Contamination factor; = $C_m$ = the concentration of the metal and $C_b$ = the background value.

Hakanson, (1980) suggested four categories of Cf to assess the metal contamination levels as when $C_f < 1$: Indicates low contamination (or no contamination). The concentration of the contaminant is less than the background level. When $1 \leq C_f < 3$ indicates moderate contamination while $3 \leq C_f < 6$ indicates considerable contamination and $C_f \geq 6$: Indicates very high contamination.

Hakanson, (1980) proposed the contamination degree (Cdeg) of the soil and was computed based on the sum of all contamination factors using the formula (equation 3)

$$C_{\deg} = \sum_{i=1}^{n} Cf \qquad (3)$$

Where n is the number of analyzed metals. Thecontamination degree of soil is divided into four groups: low ($C_{deg} < 8$), moderate ($8 \leq C_{deg} < 16$), considerable ($16 \leq C_{deg} < 32$) and very high contamination degree ($C_{deg} \geq 32$).

A modified form of the contamination degree equation for the calculation of the overall degree of contamination was presented by Abrahim and Parker (2008). The modified degree of contamination $C_{deg}$, m) was calculated by the sum of all contamination factor ($C_f$) for a given set of soil pollutants divided by the number of analyzed pollutants. This was calculated by the following formula (equation 4).

$$C_{\deg,m} = \sum_{i=1}^{n} \frac{C_f}{n} \qquad (4)$$

The classifications of the modified degree of contamination ($C_{deg,m}$) in soil are as follows: $C_{deg,m} < 15$, very low degree of contamination; $15 < C_{deg,m} < 2$, low degree of contamination; $2 < C_{deg,\,m} < 4$, moderate degree of contamination; $4 < C_{deg,m} < 8$, high degree of contamination; $8 < C_{deg,m} < 16$, very high degree of contamination; $16 < C_{deg,m} < 32$, extremely high degree of contamination; $C_{deg,m} > 32$, ultra high degree of contamination spatial.

**Table 2: Classification of Different Pollution Indices**

| $I_{geo}$ **value**[a] | **Description** | $C_f$ **value**[b] | **Description** | **PLI value**[c] | **Description** |
|---|---|---|---|---|---|
| $I_{geo} < 0$ | Practically Uncontaminated | $C_f < 1$ | Low contamination | PLI = 0 | Excellent |
| $0 < I_{geo} < 1$ | Uncontaminated to moderate contaminated | $1 \leq C_f < 2$ | Low to moderate contamination | PLI = 1 | Baseline level of pollutants |
| $1 < I_{geo} < 2$ | Moderate Contaminated | $2 \leq C_f < 3$ | Moderate contamination | PLI > 1 | Polluted |
| $2 < I_{geo} < 3$ | Moderate to heavily contaminated | $3 \leq C_f < 4$ | Moderate to high contamination | | |
| $3 < I_{geo} < 4$ | Heavily contaminated | $4 \leq C_f < 5$ | High contamination | | |
| $4 < I_{geo} < 5$ | Heavily to extremely contaminated | $5 \leq C_f < 6$ | High to very high contamination | | |
| $5 < I_{geo}$ | Extremely contaminated | $C_f \geq 6$ | Extreme contamination | | |

[a]Muller (1969), [b] Ma *et al*. (2022), [c]Mkude *et al*. (2021)

***The Pollution Load Index (PLI)***

The Pollution Load Index (PLI) is obtained as Concentration Factors ($C_f$). This $C_f$ is the quotient obtained by dividing the concentration of each metal. The PLI of the place are calculated by obtaining the n-root from the n-$C_f$ that was obtained for all the metals. With the PLI obtained from sampling site. Generally pollution load index (PLI) as developed by Lacatusu (2000) which is as follows (equation5):

$$PLI = (C_{f1} \times C_{f2} \times C_{f3} \times \dots C_{fn})^{1/n} \qquad (5)$$

Where: PLI is Pollution Load Index, $C_f$ contamination factor of respective metal, n = number of metals.

Table 2 shows different classifications into which the contamination factor **(**$C_f$**),** Geo accumulation Index ($I_{geo}$) and Pollution load index (PLI) are categorized.

**Statistical Analysis**

A comprehensive statistical analysis was conducted on heavy metal data collected samples of two tiling categories. This analysis included the calculation of mean values, standard deviation (SD), and range. All statistical evaluations were performed using IBM SPSS Statistics (v. 20). To evaluate the contamination of tailing, the concentration, contamination factor ($C_f$), geo-accumulation index ($I_{geo}$), and pollution load index (PLI) were applied.

## RESULTS AND DISCUSSION

### The Concentration of Heavy metals in Tailings Samples

The concentration (amount) of heavy metals in unprocessed and processed tailings is presented in Table 3. Arsenic was detected in both unprocessed and processed samples, as well as in all heaps. In unprocessed samples, arsenic concentrations ranged from 12.993 to 80.531 mg/kg, with a mean of 32.873 ± 26.284 mg/kg. Approximately 67% of the unprocessed tailings samples had arsenic levels exceeding the WHO/FAO (2011) maximum acceptable limit of 20.0 mg/kg. In processed tailings, arsenic levels ranged from 7.243 to 61.116 mg/kg, with a mean of 24.390 ± 19.394 mg/kg. About 44% of the processed tailings samples exceeded the WHO/FAO acceptable limit. Overall, arsenic concentrations were lower in processed tailings compared to unprocessed tailings. Previous studies (Harmanescu *et al*., 2011; Tóth *et al*., 2016) have indicated a strong correlation between arsenic (As), cadmium (Cd), mercury (Hg), lead (Pb), and gold mining activities. The Arsenic levels in this study were lower than those found in earlier research in Ghana, where a maximum concentration of 8305 mg/kg was reported (Ahmad and Carboo, 2000), and in another study with a maximum concentration of 1752 mg/kg in gold mine tailings (Bempah *et al*., 2013). High levels of Arsenic contamination are concerning due to its potential health impacts, with previous epidemiological studies (Tchounwou *et al*., 2003) highlighting a strong link between Arsenic exposure and an increased risk of both carcinogenic and systemic health effects.

Lead has many different industrial, agricultural and domestic applications. It is currently used in the production of lead-acid based batteries, ammunitions, metal products (solder and pipes), and devices to shield x-rays (Gabby, 2006). Lead is the most systemic toxicant that affects several organs in the body including the kidneys, liver, central nervous system, hematopoetic system, endocrine system, and reproductive system (Tsai *et al.*, 2017; Pirkle *et al*., 1998).

Lead concentration in unprocessed tailing varied largely from 20.181 to 119.427 mg/kg with mean of 44.012 ± 37.091mg/kg. The concentration in processed tailing ranges from 18.219 to 97.233 mg/kg with mean of 38.402 ± 28.270 mg/kg. The detected levels in both unprocessed and processed are higher than the maximum acceptable limit (WHO/FAO, 2011). The concentration in processed tailing is lower than in unprocessed tailing by the factor of 1.15. The values obtained in this study are lower than the one detected in similar study (Ogola *et al*., 2002) where the level of Pb in gold mining soils have been reported to be 510 mg/kg of Pb concentrations in Kenya.

Zn plays a key role during physiological growth and fulfills an immune function. It is vital for the functionality of more than 300 enzymes, for the stabilization of DNA, and for gene expression (Costa *et al.*, 2023). Although some iron enzymes are sensitive to iron deficiency (Dallman, 1990), their activity has not been used as a successful routine measure of iron status. The most significant and common cause of anemia is iron deficiency (WHO/CDC, 2008). If iron intake is limited or inadequate due to poor dietary intake, anemia may occur.

**Table 3: Concentrations of Heavy Metals (mg/kg)**

| Sample No. | Concentration in Unprocessed Tailings | | | | | | Concentration in Processed Tailings | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | As | Pb | Cd | Fe | Zn | Cr | As | Pb | Cd | Fe | Zn | Cr |
| **1** | 13.782 | 31.681 | 4.413 | 22960.03 | 43.617 | 182.332 | 9.267 | 27.287 | 5.978 | 22011.47 | 40.200 | 179.174 |
| **2** | 23.161 | 119.427 | 6.261 | 24463.80 | 169.589 | 220.024 | 21.341 | 77.013 | 4.112 | 23414.64 | 171.118 | 118.321 |
| **3** | 26.567 | 20.181 | 3.833 | 25307.94 | 76.251 | 179.467 | 15.413 | 18.219 | 1.468 | 24000.12 | 66.726 | 137.226 |
| **4** | 75.978 | 23.138 | 3.528 | 30089.13 | 80.408 | 148.881 | 61.116 | 26.871 | 2.973 | 26242.00 | 78.842 | 142.474 |
| **5** | 13.922 | 28.864 | 3.913 | 22864.25 | 50.064 | 204.119 | 11.519 | 24.172 | 2.242 | 20177.43 | 44.221 | 144.387 |
| **6** | 23.199 | 97.233 | 6.230 | 24476.98 | 147.219 | 196.354 | 22.011 | 97.233 | 3.104 | 25221.25 | 74.544 | 124.933 |
| **7** | 25.726 | 21.386 | 3.877 | 25323.16 | 78.341 | 188.739 | 18.252 | 21.386 | 2.711 | 22824.77 | 81.663 | 110.439 |
| **8** | 80.531 | 24.188 | 4.148 | 30102.12 | 69.961 | 214.638 | 53.347 | 24.188 | 1.988 | 23446.43 | 52.194 | 178.642 |
| **9** | 12.993 | 30.014 | 4.418 | 23003.28 | 44.784 | 216.183 | 7.243 | 29.248 | 3.229 | 23684.40 | 44.007 | 199.573 |
| **Mean 1** | 32.873 | 44.012 | 4.513 | 25398.96 | 84.470 | 194.526 | 24.390 | 38.402 | 3.089 | 23446.95 | 72.613 | 141.352 |
| **STD ( ±)** | 26.284 | 37.091 | 1.022 | 2827.729 | 44.641 | 22.670 | 19.394 | 28.270 | 1.329 | 1748.619 | 40.240 | 30.726 |
| **WHO/FAO (2011)** | 20.0 | 50.0 | 3.0 | - | 300 | 50 | 20.0 | 50.0 | 3.0 | - | 300 | 50 |

Zinc concentration in unprocessed tailing ranges from 43.617 to 169.589 mg/kg with mean of 88.470 ± 44.641 mg/kg. The concentration of analyzed samples is lower than maximum acceptable limit by WHO/FAO (2011). The concentration in processed tailing ranges from 40.200 to 171.118 mg/kg with mean of 72.613± 40.240 mg/kg. Surprisingly, the concentration in unprocessed tailing is lower than of the tailings processed tailing. This is due to the existing in geochemical environment where mostly in mining sites acid is and they mobilize zinc from sulfide minerals, concentrating it in the processed tailings (Miler *et al.*, 2022). This redistribution lead to increase zinc concentrations in the processed material (Gleisner and Herbert, 2002). The values obtained in this study are higher than the value detected earlier in Ghana (Koranteng *et* *al*., 2011), where the mean Zn concentrations in the sand soil samples ranged between 4.17±1.23 mg/kg and 43.17±4.75 mg/kg.

Iron concentration in unprocessed tailing ranges from 22844.250 to 30102.120 mg/kg with mean of 25398.96 ± 2827.729 mg/kg. The concentration in processed tailing ranges from 22011.470 to 26242.00 mg/kg with mean of 23446.95 ± 1748.619 mg/kg. The concentration observed in this study in in line with similar study in Nigeria (Fagbenro *et al*., 2021) where the mean concentration was 20,560.4 ± 84.30.

Cadmium compounds are classified as human carcinogens by several regulatory agencies (IARC, 1993). Cadmium is a severe pulmonary and gastrointestinal irritant, which can be fatal if inhaled or ingested. After acute ingestion, symptoms such as abdominal pain, burning sensation, nausea, vomiting, salivation, muscle cramps, vertigo, shock, loss of consciousness and convulsions usually appear within 15 to 30 min (Baselt. and Cravey, 1995). Acute cadmium ingestion can also cause gastrointestinal tract erosion, pulmonary, hepatic or renal injury and coma, depending on the route of poisoning (Baselt, 2000).

Cadmium concentration in unprocessed tailing ranges from 3.528 to 6.261 mg/kg with mean of 4.513 ± 1.022 mg/kg. About 100% of the analyzed samples have higher level than maximum acceptable limit by WHO/FAO (2011). The concentration in processed tailing ranges from 1.988 to5.978 mg/kg with mean of 3.089 ± 1.329 mg/kg. About 44% of the samples analyzed have higher level than maximum acceptable limit by WHO/FAO (2011). The values obtained in this study are lower than one detected in similar study (Bitala *et al*., 2009) where the level of Cd in gold mining soils have been reported to range between 6.4 to 11.7 mg/kg of Cd concentrations in Tanzania.

Chromium (Cr) is a naturally occurring element present in the earth's crust, with oxidation states (or valence states) ranging from chromium (II) to chromium (VI) (Jacobs and Testa 2005). Industries with the largest contribution to chromium release include metal processing, tannery facilities, chromate production, stainless steel welding, and ferrochrome and chrome pigment production. The main health problems seen in animals following ingestion of chromium (VI) compounds are irritation and ulcers in the stomach and small intestine, anemia, sperm damage and male reproductive system damage. Also it connected with cardiovascular, gastrointestinal, hematological, hepatic, renal, and neurological effects as part of the sequelae leading to death or in patients who survived because of medical treatment (ATSDR, 2008).

Chromium concentration in unprocessed tailing ranges from 148.881 to 220.024 mg/kg with mean of 194.526± 22.670 mg/kg. The concentration in processed tailing ranges from 110.439 to 199.573 mg/kg with mean of 141.352 ± 30.726 mg/kg. All samples analyzed detected higher level than maximum acceptable limit by WHO/FAO (2011). The concentration in processed tailing is lower than in unprocessed tailing by the factor of 1.38. The values obtained in this study are lower than the one detected in similar study in Oman (Abdul-Wahab and Marikar, 2012) where the level of Cr in gold mining soils reported to be 486 mg/kg in gold mine tailings.

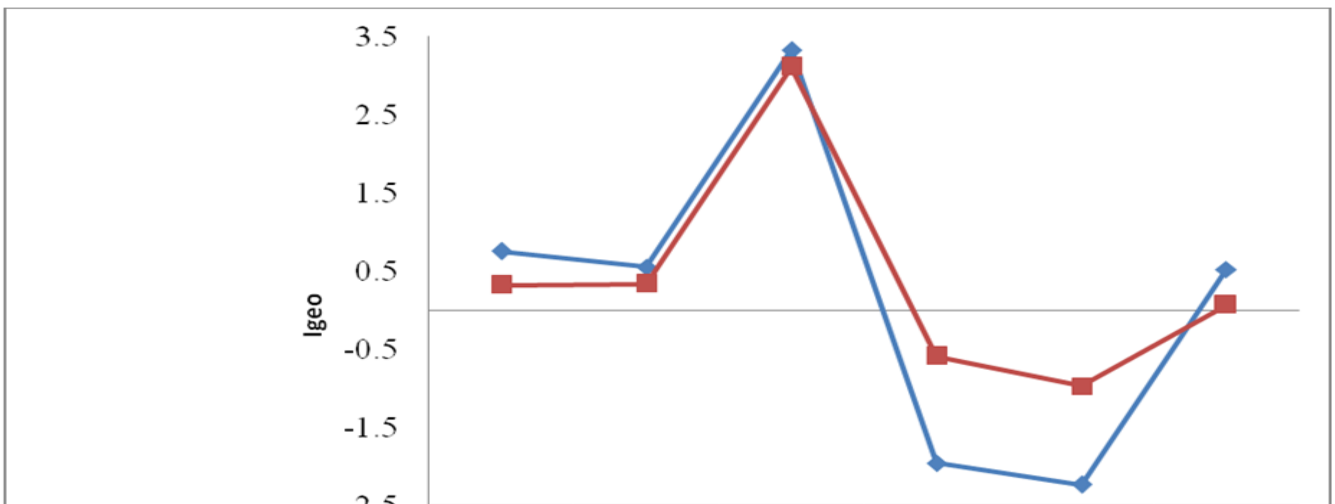
## Heavy Metals Pollution Levels

### Geo-accumulation Indices

The calculated index of geo-accumulation (Igeo) for the investigated trace metals in the tailings are illustrated in Figures 1.

The *Igeo* values obtained range from -2.237 to 3.326 in unprocessed tailing and -0.970 to 3.3116 in processed tailings. The index of geo accumulation (Igeo) was assessed based on the values proposed by Müller (1969) and their Igeo values estimated is found in the following increasing order in unprocessed tailing Zn < Fe < Pb < Cr < As < Cd while in processed tailing was in the following increasing order Zn < Fe < Cr < As < Pb < Cd. According to the Müller scale, the calculated results of Igeo values indicate that Cd can be classified in class 4 (strong pollutes) for both unprocessed and processed tailings (Figure 1).

These findings differ from a previous study on the enrichment factor (Igeo) of arsenic in surface sediments in Malaysia (Abdullah *et al*., 2020), which reported that 13% of the sampling stations were classified as moderately polluted, 52.2% as unpolluted to moderately polluted, and the rest as unpolluted.




| | As | Pb | Cd | Fe | Zn | Cr |
|---|---|---|---|---|---|---|
| Unprocessed Tailings | 0.753 | 0.551 | 3.326 | -1.955 | -2.237 | 0.525 |
| Processed Tailings | 0.319 | 0.335 | 3.116 | -0.591 | -0.97 | 0.063 |

**Figure 1:** ***Geo-accumulation Indices Values for Unprocessed and Processed Tailings***

### Contamination Factor ($C_f$)

Figure 2 shows the Contamination Factors (Cf) for unprocessed tailings and processed tailing. The $C_f$ for unprocessed tailings and processed tailing for As, Pb, Cd, Fe, Zn and Cr were observed in the ranges of 2.529 to 1.876, 2.201 to 1.920, 15.043 to 10.297, 0.538to 0.497, 0.889 to 0.764, and 2.161 to 1.571 respectively.

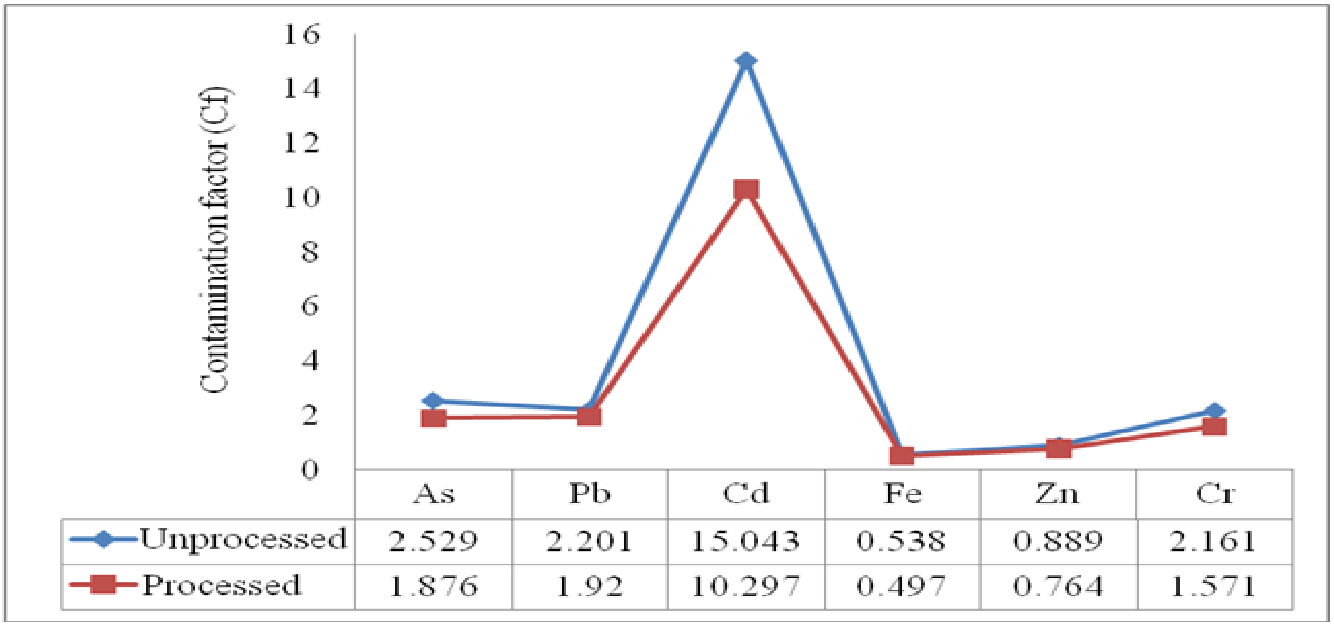



***Figure 2 Contamination Factors for Unprocessed and Processed Tailings***

Accordingly, tailing samples can be classified as exhibiting low or no contamination with respect to Zn and Fe for all sampling tailings. The results are lower than those detected earlier (Fagbenro *et al*., 2021), where the average contamination factor for Fe was 1.15 and Zn was 1.06. For As, Pb, and Cr the $C_f$ is in the range1 $\leq C_f <$ 3indicating moderate contamination Cd, the $C_f$ is in the range $C_f \geq 6$ indicating very high contamination.

The degree of contamination for unprocessed and processed tailing sample is 23.361 and 16.925 respectively. This indicates the tailings are considerable contaminate. For the modified degree of contamination the unprocessed tailing have the value of 4.671 which shows high degree of contamination and processed tailing has the value of 3.385 which shows moderate degree of contamination. These results concur with previous study (Hamad *et al*., 2019), indicating the highest enrichment factor for Cr, Zn, Pb and As were 25.05 (very high), 7.21 (moderate), 5.07 (deficiency to minimum) and 5.67 (deficiency to minimum) respectively.

### *The Pollution Load Index (PLI)*

The pollution load index (PLI) was estimated to better realize the pollution level. In addition, it also provides useful data to the decision makers on the pollution level of the area. The PLI values calculated for tailing samples are found to 4.423 for unprocessed tailing and 2.807 for processed tailing which shows that the soils are polluted and the environment is deteriorated in their quality. This shows the site is strongly affected by mining activities and soils in this region is seriously contaminated by heavy metals. The values in this study are higher than those detected earlier (Hamad *et al*., 2019), where the PLI determined ranged from 2.58 to 3.63.

## CONCLUSION & RECOMMENDATIONS

Heavy metals do not degrade easily and can accumulate over time in soil, water, and biota, posing prolonged risks to plant and animal health and contaminating food and water supplies. The heavy metals like arsenic, cadmium and lead can accumulate in organisms and magnify through food chains, impacting human health and biodiversity. They can cause chronic health issues (e.g., cancer, neurological damage) from direct and indirect exposure is crucial, especially in populations near mining sites.

Soil is a major pool for contaminants as it encompasses ability to bond with various chemical materials and media for transportation of forms of various pollutants in the atmosphere, hydrosphere, and biomass. The results obtained in the present research of As, Pb, Cd, Fe, Zn and Cr in soil sample collected around unprocessed tailing and processed tailing showed that soil quality in the mine and areas around the gold mining is degrading.

The studied area is extremely contaminated due to many years of mining activities. Our data disclose that Cd, As, Zn, Pb and Cr concentrations in soil samples are higher than WHO/FAO maximum acceptable limits The pollution assessment methods showed that soils in the studied area are significantly contaminated by Cd, As, Zn, Pb and Cr, where the concentration in processed tailing is lower than in unprocessed tailing by the factor of about 1.38. Thus, in future, based on the environmental quality criteria for soils, the site would need remediation. It is hereby recommended using plants and microorganisms to extract or stabilize heavy metals in contaminated soils, which can be cost-effective and sustainable over the long term. Also there is a need to engage local communities in monitoring efforts and educating them about safe practices, reducing exposure risks and fostering awareness of potential health impacts.

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