Assessing the Effect of Mining Waste on the Quality of Soil; A Case of Eprocomi Mining Company in Gakenke District, Rwanda

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ISSN: 2616 - 8456

Stratford Peer Reviewed Journals and Book Publishing
Journal of Agriculture & Environmental Sciences
Volume 9||Issue 2||Page 24-39 ||April||2025|
Email: info@stratfordjournals.org ISSN: 2616-8465

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***How to cite this article*: Habinema P., & Nzabamwita J. (2025). Assessing the Effect of Mining Waste on the Quality of Soil; A Case of Eprocomi Mining Company in Gakenke District, Rwanda. *Vol* 9(2) pp. 24-39. https://doi.org/10.53819/81018102t2478**

Abstract

The mining sector plays a crucial role in Rwanda's economic growth, contributing significantly to employment, export revenues, and infrastructure growth. Even though, mining generates substantial economic benefits; the improper mining wastes management poses environmental challenges worldwide and in Rwanda as well. This study assesses the effect of mining wastes on soil quality focusing on Eprocomi Mining Company in Gakenke District from Northern Province of Rwanda. The research employed a combination of observations, field sampling, laboratory analysis, and analytical methods to evaluate key soil quality indicators of pH and heavy metals concentration. The tailings samples from mining wastes were collected in Eprocomi Mining concession for laboratory analysis to determine the extent of contamination and degradation. The collected soil samples needed to be pre-treated with air-drying, grinding, and sifting. A quantity of 3 g was weighed for each of the samples and pressed into the grinding machine under a 10 MPa pressure for 180 seconds and for testing of the samples, Niton XRF Analyzer instrument used. The findings indicate that mining activities have led to changes in soil pH and increase in concentrations of heavy metals such as lead (Pb), cadmium (Cd), and arsenic (As), which pose potential risks to soil fertility and agricultural productivity. According to Boyer and Pietrowiez's standards for interpreting soil pH, the pH of the soil varied from severely acidic to alkaline, with values ranging from 3.9 (the acid range) to 7.8 (the basic range). The concentration values for arsenic, lead and cadmium metals varies from 30 to 140 mg/kg, 92mg/kg to 200 mg/kg and 110 mg/kg to 321 mg/kg respectively which classify the area to have strongly polluted by Arsenic and moderately polluted by Chromium and Lead with reference to Germany soil regulation and Canadian standards measures. Based on the extent of environmental degradation with the influence of mining activities in the area, the study explored possible mitigation measures and recommendations to restore soil health and reduce the negative effects of mining operations on the environment and need to raise awareness about sustainable mining practices and foster collaboration between government, researchers and mining sector industry.

Keywords: *Environmental impact, Eprocomi Mining Company, GIS, Heavy metals, Mining wastes, Soil quality*

1. Introduction

Mining plays a pivotal role in Rwanda's economy, contributing to its economic development in significantly to the country's export earnings, industrialization, employment, and GDP (Rwanda Mines Petroleum and Gas Board, 2021). Rwanda is one of the world's largest producers of tin (cassiterite), tantalum (coltan), and tungsten (wolfram) and exports gold and gemstones. (Dusengemungu et al, 2021). The country also possesses a variety of minerals such as silica sands, kaolin, vermiculite, diatomite, clays, limestone, talcum, gypsum and pozzolan (Barreto et al, 2018). Mining is essential to the modern world because it produces the raw minerals needed for energy generation, infrastructure development, economic expansion, and technological advancement. The mining industry contributes approximately $1.9 trillion to the global economy each year (Escamilla,2024). Mining activity has considerably increased due to notable population growth and worldwide demand for mineral resources (Reichl et al, 2016)**.**

Mineral exports are a major share of the export revenues of Rwanda since in the year of 2017 and 2018, Rwanda has exported 783 USD million and 567.4 USD million continuously (Database, 2020). In 2023, Rwanda's mineral exports rose to over $1.1 billion, an increase from $772 million in 2022, marking a growth of 43.0%. In the previous year, Rwanda sought to achieve USD 1.5 billion outlined in the National Strategic for Transformations (NST1) which is the implementation instrument for the remainder of Vision 2020 and for the initial four years of Vision 2050 (Rwanda Mines Petroleum and Gas Board, 2024).

Previous studies globally and regionally have demonstrated the adverse effects of mining waste on soil health. These effects include soil acidification, heavy metal accumulation, nutrient imbalance, and loss of soil structure. Moreover, the contamination of soil often leads to the pollution of nearby water sources, compounding environmental damage. Throughout the different stages of the mine life cycle from runoff ore to the product, different hazardous mining wastes are generated that threaten soil quality and environmental integrity, including waste materials from mineral extractions and tailings. We can thus classify the mining sector as a threat to the environment (Manas et al, 2023).

The oversight of long-lasting mining poses a complicated environmental issue, yet the topic receives minimal attention from the public, scientific community and policy makers. The harmful environmental effects of mining waste are significant and result in harm to human health as well as the destruction and deterioration of natural ecosystems. The magnitude of this issue is worldwide as some statistics indicate, for instance, Brazil produced 3.6 billion tons of solid mining debris in disposal sites from 2008 to 2019 (Flavio et al, 2020).

The heavy metal contamination from mining wastes has been widely reported in countries like China and India, negatively affecting both soil fertility and water quality, with long-term consequences for agriculture and human health (*Chen et al, 2024*). It has been estimated that in 2016, the global mining industry was the largest waste producer, generating two billion tons of solid waste (Flavio et al, 2020). The effects on biodiversity are also severe, with mining activities in Africa and Southeast Asia causing habitat fragmentation and endangering iconic species such as orangutans and elephants.

Stratford Peer Reviewed Journals and Book Publishing
Journal of Agriculture & Environmental Sciences
Volume 9||Issue 2||Page 24-39 ||April||2025|
Email: info@stratfordjournals.org ISSN: 2616-8465

Despite the economic benefits from mining activities in Rwanda, it has also led to considerable environmental degradation particularly in areas with high mining activity such as Gakenke District area (Shanmukha et al, 2024). These challenges of mining waste and tailings management are result of inappropriate management of mining operations and an absence of effective closure and rehabilitation activities. Furthermore, it damages the biodiversity that helps in mitigating the impacts of climate change and natural disasters (Agboola, 2020). In Gakenke district, where mining is a major economic activity, the improper disposal of mining waste poses a significant threat to agricultural productivity and environmental sustainability. The soil in this region supports a large portion of the population's livelihoods through farming.

This study conducted with aims to evaluate the impact of mining wastes on soil quality in Eprocomi Mining Company from Gakenke district by analyzing soil samples from areas within of mining sites concession. The findings ought to provide valuable insights into the extent of soil degradation and inform sustainable practices for mitigating mining-related environmental impacts. Ultimately, this research will contribute the efforts to balance mining activities with environmental conservation, soil management and remediation strategies.

1.1 Research Objectives

1.1.1 General objective

The general objective of this study is to assess the effect of mining waste on the soil quality taking the case of Eprocomi Mining Company Ltd in Gakenke District of Rwanda.

1.1.2 Specific objectives

The specific objectives of this study are the followings:

i. To identify the types of mining wastes generated through various mining stages by Eprocomi Mining Company in Gakenke District
ii. To assess the soil quality properties affected by Mining wastes in Eprocomi Mining Company in Gakenke District.
iii. To analyze the relationship between mining waste and soil quality in Eprocomi Mining company in Gakenke.

2. Materials and methods

2.1 Profile of Gakenke District

The research will focus on mountainous regions of Gakenke District in Eprocomi mining company where mining activities are dominated. The Eprocomi Mining Company is situated in the District of Gakenke, one of the five districts that make up Rwanda's Northern Province. It shares borders with the districts of Rulindo on the east, Burera and Musanze on the north, Nyabihu on the west, and Kamonyi and Muhanga on the south. The District of Gakenke, the Sector of Ruli, the Cells of Ruli, Gikingo, and Rwesero are the locations of Eprocomi Ltd (*figure 3.3*). This mining company was first granted a license in 2010 and has been conducting business in Rwanda for the previous 15 years. It has 4 different mine subsites which are Rwesero, Mpanga, Musave 1and Musave 2 and is actively involved in the extraction of pegmatite, a rock type known for its valuable mineral content, such as tantalum, tin, and other rare earth elements.

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The following map grouped together map shows the location of Gakenke District at country level; map shows location of Gakenke District from Northern Province and the map shows the Eprocomi Mining company as area of interest for research project in Gikingo, Rwesero and Ruli cells, Ruli sector from Gakenke District.

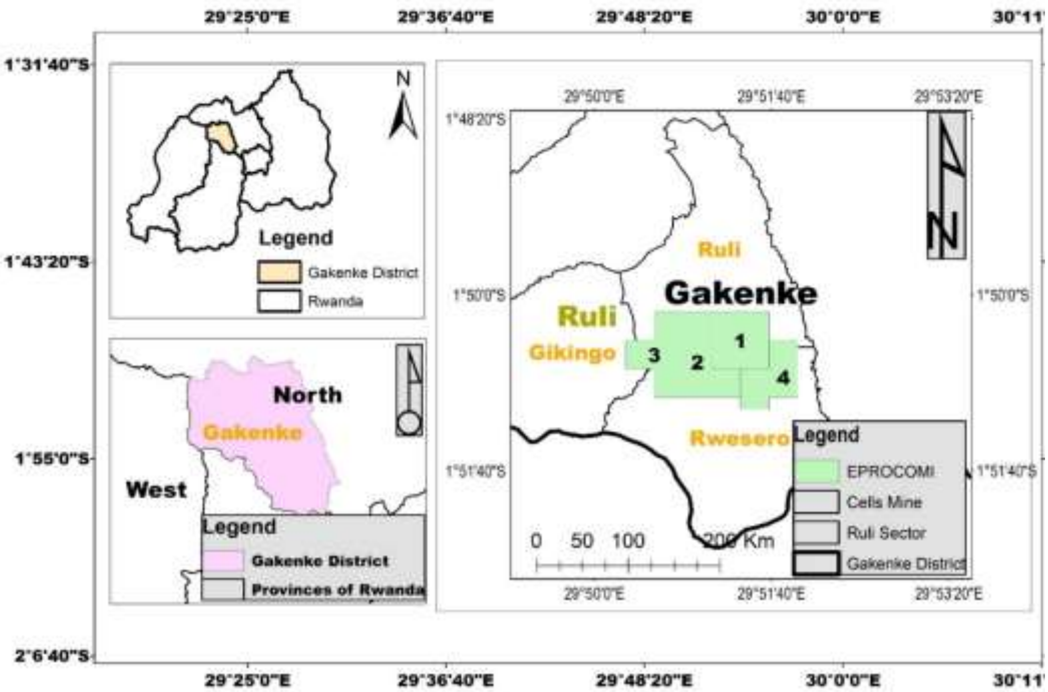

Figure 3.3: Geographical location map of the study area in Eprocomi Mine
Source: Map produced with the help of ArcGIS software.

2.2 Research design and data collection methods

To effectively investigate the effects of mining wastes on soil quality in the Eprocomi Mining concession, this study adopted a mixed-methods research design, integrating both quantitative and qualitative methodologies. The quantitative aspect focused on field surveys and laboratory analyses to obtain measurable data on soil chemical properties, particularly pH levels and heavy metal concentrations (Pb, Hg, As, Cd). Tailings samples were systematically collected from mining waste disposal sites within Eprocomi and analyzed using a Niton XRF Analyzer to determine contamination levels. This approach allowed the study to assess the extent and spatial distribution of soil degradation caused by mining activities.

The qualitative component enriched the quantitative analysis by incorporating field observations and document reviews. Observations provided context on the visible impacts of mining activities, such as erosion and vegetation loss, while policy documents, mining regulations, and environmental impact reports helped frame the study within Rwanda's governance framework for mining operations (Horta et al., 2015). These documents provided essential insights into the environmental management practices and regulatory measures in place within the Rwandan mining sector.

Data collection utilized both primary and secondary sources. Primary data included firsthand field observations and soil sample collection from four key zones within the mining concession—Musave 1, Musave 2, Mpanga, and Rwesero. These areas were stratified based on contamination risk levels (high, moderate, low/control) and sampling

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points were randomly selected within each zone. Stratified random sampling ensured representative coverage across zones of varying contamination intensity. A total of 19 tailings samples were selected using Slovin's formula, accounting for a known population of 20 mining waste disposal sites, with a 95% confidence level and 0.05 margin of error.

Samples were collected using soil augers and hand trowels, mixed thoroughly, stored in polythene bags, and labeled accordingly. The sampling sites were georeferenced using GPS for spatial consistency. After air drying, the samples were ground to a fine powder using a ball milling machine and analyzed for pH and heavy metal concentrations.

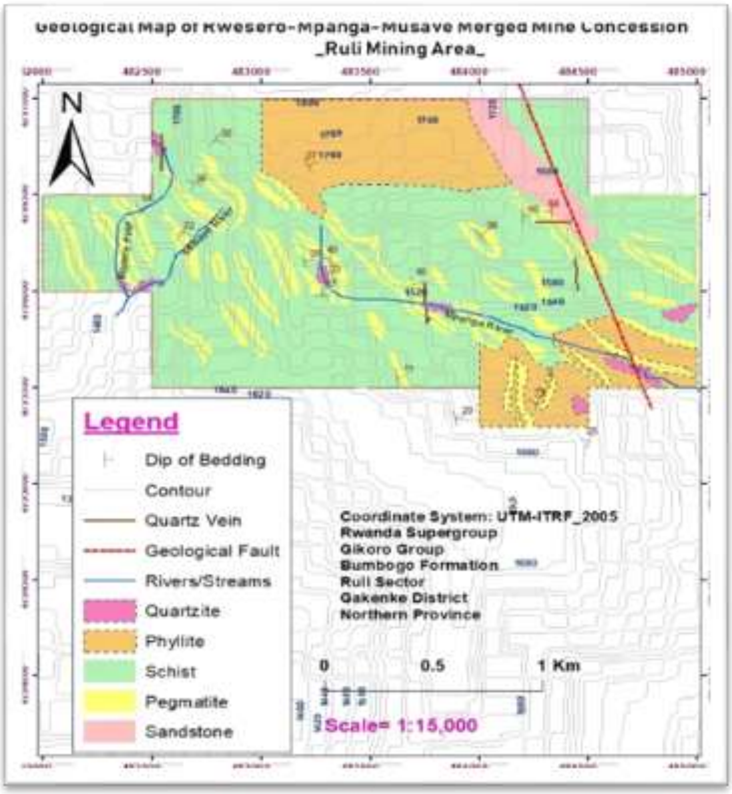

Figure 2.1 Produced Geological Map of EPROCOMI Mining Company
Source: Map produced with the help of ArcGIS software

This map underscores the area's placement within the Rwanda Supergroup of the Karagwe-Ankole Belt, known for pegmatite-rich mineral deposits including coltan, cassiterite, lepidolite, and other rare metals (Muchez et al., 2014; Fernandez et al., 2011). Secondary data was obtained from government and NGO reports, land-use maps, and satellite imagery (e.g., Google Earth). This data helped assess historical land degradation, policy compliance, and prior rehabilitation efforts.

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Table 2.1: Table of Data Collection Instruments

Category	Instrument used
Visual assessment	Phone camera, Notebook (to capture visual evidence of soil conditions, record field observations and site conditions respectively)
Field Sampling	Soil Auger, GPS, Sample Bugs (for extracting soil samples, to record the exact locations of sampling sites and for storing soil samples respectively)
Secondary Data	Government Reports, GIS Software, Satellite images with Google Earth (for mining waste disposal practices and soil impact assessments, analyzing soil contamination spread and tracking land degradation over time respectively).
Lab Analysis	pH, heavy metals concentration (Pb, Hg, As, Cd) in tailings samples analyzed with Nitron XRF Analyzer

Source: Researcher, 2025

The data collection instruments are summarized in Table 2.1 which includes visual tools (camera, notebook), field tools (GPS, soil auger, sampling bags), secondary data sources (GIS software, satellite imagery), and laboratory instruments (Niton XRF Analyzer for heavy metals and pH testing). To ensure data quality, control samples, duplicates, and certified reference materials were used in both field and laboratory settings. GIS data was ground-truthed to validate remote sensing accuracy, ensuring comprehensive and reliable data for analysis.

2.3 Data analysis

Geospatial analysis was conducted using GIS software to map contamination spread and identify affected zones. For chemical analysis, soil samples were tested at Ets Munsad Minerals Ltd and Mining Access Window Rwanda Ltd using an XRF Nitron Analyzer. Key parameters such as pH and concentrations of heavy metals like Arsenic (As), Cadmium (Cd), and Lead (Pb) were analyzed. Standard analytical techniques were employed to calculate contamination indices. These included the Contamination Factor Index (Cf), Potential Ecological Risk Index (Er), and Degree of Contamination Index (mCd), following the models of Håkanson (1980) and Abrahim. These indices allowed a comprehensive assessment of pollution levels and potential ecological risks, ensuring a robust evaluation of the impact of mining waste on soil quality.

3.1 Results

3.1.1 Identification of Mining Waste Types from Eprocomi Mining company

The Eprocomi mine generates a variety of mining waste at different stages of its operations, each posing distinct environmental challenges and impacts on soil quality. Identifying these wastes generated from Eprocomi mine’s operations was one of the objectives of this research study. The types of mining wastes generated from Eprocomi mine identified include Overburden, waste rock, mine dust, tailings and slags. Overburden consists of the soil and rock layers removed to access mineral deposits. Although relatively inert, overburden can cause physical soil degradation by altering landforms, leading to erosion and loss of topsoil fertility; waste rock resulted as a large, non-ore-bearing rock fragments displaced during mining may disrupt soil structure and hydrology, contributing to surface runoff and sedimentation issues. Mine dust is particulate matter generated from blasting and crushing operations settle on surrounding soils, altering their texture and potentially

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introducing trace metal contaminants.

Eprocomi has an operating equipment which is Jackhammers used to break and penetrate into the rock mountain to access the minerals, and other operating machines from processing plants include crushers used in minerals beneficiation to separate valuable minerals from the gangue. Tailings are finely ground residues left after the extraction of valuable minerals often contain high concentrations of heavy metals and chemical reagents used in the extraction process, making them a significant source of soil contamination. This research focused on this specific type of waste based on the fact, they are sources of minerals.

Finally, from mining wastes identified in Eprocomi mining operations; slag wastes considered as by-product results from the smelting of extracted ores. This wastes specifically resulted from Eprocomi after processing minerals to the next stage of drying process by removing the water content and other wastes which is addressed as slag. Slag materials may contain residual metals and other compounds that leach into the soil, affecting its chemical balance and long-term health.

The figure 3.5 below shows different photos taken from Eprocomi mine sites which clarifies the different types of mining wastes generated at different stage of mining operations from mining initiation to the processing stage (Ore/minerals are accessed by removing top layers (soil) which are overburden materials, and once the ore have been accessed through the tunnels and open pits, they are taken out to be processed into washing/processing plants to separate valuable minerals from tailings and slug.

(a (b (c) (d) (e)

Figure 3.5: Figure shows different types of mining wastes generated from Eprocomi Mine operations through cycle of mining (a,b,c,d and e)

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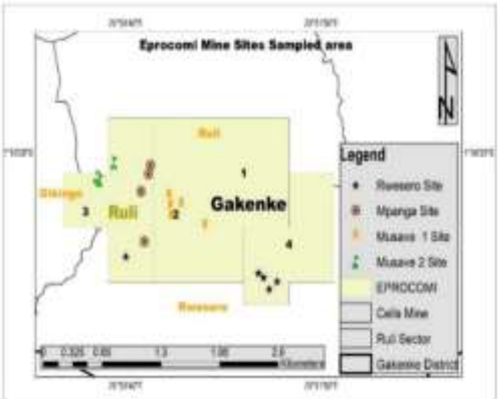
3.1.2 Assessment of Soil Quality Properties Affected by Mining Wastes in Eprocomi Mine

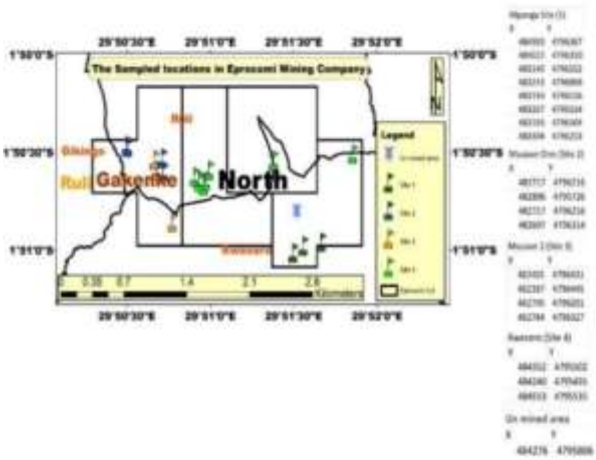
The second objective of this research work was to assess the effect of mining wastes on the soil quality. The assessment of soil quality properties affected by mining wastes at the Eprocomi mine focused on understanding the extent of chemical alterations caused by mining wastes/tailings deposition. The Chemical Properties assessed include pH levels and Heavy Metal Concentrations of toxic metal elements such as Lead, Arsenic and Cadmium from sampled tailings in Eprocomi mine.

3.1.2.1 Identification of the potential sites sampled for contamination levels

The tailings samples from mining wastes, were collected in Eprocomi Mining concession for laboratory analysis. The collected soil samples needed to be pre-treated with air-drying, grinding, and sifting. A quantity of 3 g was weighed for each of the samples and pressed into grinding samples machine under a 10 MPa pressure for 180 seconds) and for testing of the samples, Niton XRF Analyzer instrument used. The pH & concentrations of the heavy metals in the 19 collected soil samples are listed in Table 3.2.



(a)



(b)

Figure 3. 6: Maps of identified tailings sampled sites in Eprocomi Mine (a&b)

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(a)


(b)

Figure 3.7: Aerial Maps showing different sampled locations and how mining wastes are distributed in the mine concession of EPROCOMI respectively

3.2 Discussion

3.2.1 Chemical properties of tailings samples collected in Eprocomi Mine

3.2.1.1 Laboratory results

The laboratory results show pH and concentration of metals from tailings such as Pb (Lead), As (Arsenic) and Cd (cadmium) and concentration of other minerals with primary metals such as tantalum (Ta), Niobium (Nb) and tin (Sn) in the mining wastes/tailings as summarized in Table 3.2.

The tailings contain concentration/grade of minerals such as cassiterite content (tin - SnO_2 (%)) and coltan (tantalum- Ta_2O_5 (%), niobium - Nb_2O_5 (%)) confirmed that the tailings were processed from ore contains mixed coltan and cassiterite extracted from which Eprocomi mining company mine.

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Table 3.2: The laboratory results of the heavy metals from Eprocomi mining company

EPROCOMI Ltd							
SN & Sample Code	Grade &Concentration						
	pH	Ta2O5 (%)	Nb2O 5 (%)	SnO2 (%)	As (mg/kg)	Pd (mg/kg)	Cd (mg/kg)
Tailings Sample							
Sample 1 (MUS 1)	6.1	0.061	0.017	0.007	45	112	1.54
Sample 2 (MUS 2)	5.1	0.054	0.017	0.009	76	125	1.46
Sample 3 (MUS 3)	3.9	0.05	0.01	0.009	80	130	3.21
Sample4 (MUS4)	5.9	0.057	0.01	0.009	140	98	2.34
Sample 5 (2MUS6)	6.8	0.064	0.007	0.009	95	100	2.50
Sample 6 (2MUS7)	7.0	0.065	0.001	0.009	49	105	2.12
Sample 7 (2MUS8)	7.5	0.043	0.008	0.009	64	114	2.43
Sample 8 (2MUS22)	6.5	0.067	0.009	0.01	65	125	1.70
Sample9(MPANGA Site 9)	5.2	0.058	0.013	0.01	70	132	1.88
Sample10(MPANGA Site 10	7.6	0.054	0.01	0.008	51	121	1.59
Sample11(MPANGA Site 11	7.2	0.048	0.009	0.009	3	135	1.60
Sample12(MPANGA Site 12	6.7	0.06	0.015	0.009	69	200	1.52
Sample13(MPANGA Site 13	6.1	0.108	0.031	0.012	72	127	154
Sample14(MPANGA Site 14	6.2	0.054	0.008	0.009	71	145	1.62
Sample15(MPANGA Site 15	6.5	0.033	0.01	0.01	68	142	1.25
Sample16(MPANGA Site 16	6.9	0.038	0.005	0.008	50	140	1.36
Sample17(RW 17)	7.7	0.135	0.037	0.009	38	101	1.30
Sample18(RW 18)	7.5	0.045	0.014	0.008	45	98	1.25
Sample19 (RW 19)	7.8	0.071	0.026	0.009	30	92	1.10
International Standards							
GSR (2007)		-	-	-	10	25	3
CS (2012)		-	-	-	12	400	0.9
WHO (1996)		-	-	-	-	85	0.8

The analysis of the laboratory results has been conducted with reference to the international values of heavy metals concentration of Canadian Standards (CS, 2012), German Soil Regulation (GSR, 2007) and World Health organization (WHO,1996) measured in mgkg-1. Table 3.2 shows the result from laboratory work and analysis focused on assessment of their pH values and contamination level to the soil quality of the area within Eprocomi mining concession.

The results obtained for pH indicated that the soil pH of the study area ranges from 3.9 to 7.8. The greatest pH values (8.2) were observed in the site of Rwesero which has minimal mining operations and nearby farm fields whereas the lowest values (3.9) were detected most active mine sites of Musave 1& Musave 2. According to soil pH interpretation standards set by Boyer and Pietrowiez the soil pH of Eprocomi mining sites ranges from highly acidic to alkaline. (Boyer, 2015). Low pH increases the solubility processes of heavy metal concentrations leading to greater environmental contamination in the environment and J. P Anderson found that the degree of solubility determines the toxicity of heavy metals and that they are more toxic at low pH of less than 3.5 because they are more mobile. (Anderson et al, 2000).

The concentration values for As (arsenic) metal varies from 30 to 140 mg/kg, the concentration values for Pb (Lead) varies from 92mg/kg to 200 Mg/kg and the concentration of Cd (Cadmium) varies from 110 mg/kg to 321 mg/kg. The result for Arsenic (As) indicated concentration significantly exceeding the maximum concentration levels (12 mg/kg and 10 mgkg-1), permitted by Canadian Standards (CS, 2007). As (Arsenic) is a vital trace element for animals. However, it is acknowledged as a hazardous component, particularly in soils, which are thought to be largely caused by major human activities, notably industrial ones like chemical and metallurgical sprays. is a highly toxic element that, even in trace amounts, can cause internal tumors and diseases linked to arsenicosis. (Hubert at al, 2019).

The result for Pb shows high concentration levels than 25 (mg/kg) recommended by Germany Soil Regulation but also referring to Canadian Soil Quality Guidelines (400 mg/kg), it showed that the concentration of Pb in the sampled tailings could not affect the quality of the soil since it below to the allowed concentration of 400 Mg/kg. The result for Cd shows that the tailings sampled have concentration above concentration levels allowed by Canadian standards which is 0.9 Mg/kg. According to WHO guidelines, the allowed concentration of heavy metals in soil varies depending on the specific metal, with cadmium (Cd) having the lowest permissible limit at around 0.8 mg/kg, while zinc (Zn) can be present at a higher concentration of around 50 mg/kg, copper (Cu) at 36 mg/kg, and chromium (Cr) at 100 mg/kg. (Ashiqur et al, 2016)).

Lead (Pb) and Cadmium (Cd) metals significantly reduce soil quality by inhibiting plant growth, disrupting microbial activity, impacting nutrient availability, and generally harming the soil ecosystem, making it a serious contaminant when present in excessive amounts.

Moreover, Cd is the more toxic to enzymes than Pb because of its greater mobility and lower affinity for soil colloids. Pb decreases the activities of urease, catalase, invertase and acid phosphatase significantly. (Singh et al, 2015). The results from laboratory work showed that the As concentrations, Pb concentrations, Cd concentration decreases as moving forwards closer to the area with less mining operations in Rwesero mine site and nearby farm fields used in agriculture activities and other associated work compared with other sampled sites with high mining operations. The area with highly mining operations showed high level of heavy metals concentration such as Musave 1 (Site1) & Musave 2 (Site 2). These results make sense based on the same field of study conducted by on (Hirwa et al, 2019) on evaluation of Soil Contamination in Gifurwe mine; showed that the mining site is gradually becoming contaminated due to concentration of heavy metals such as mercury (Hg), Chromium (Cr) and Arsenic (As). The study indicated that the concentration

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of As in Gifurwe mining sites ranges from 170 to 531mg/kg in upstream areas and agricultural fields (close to Cyeru River). The test results indicated that the arsenic concentrations in Gifurwe mining site of agriculture areas, were significantly higher than the maximum concentration levels (12 and 10 mg/kg) allowed by Canadian Standards. The analysis of the laboratory results for this study concluded that the soil at Eprocomi mining site is highly contaminated by Arsenic and moderately contaminated with Cadmium and Lead.

3.2.1.2 Analytical results from Soil Quality Assessment

Calculation of CF (Contamination factor index)

The contamination factor which was proposed by Håkanson (1980) was used and its expression is:

$$C_f^i = \frac{C_i}{C_n^i}$$

Where, Ci is the measured value of trace element I in the soil sample (mg/kg) and Cn is the geo-chemical background value of trace element i.

This factor used to determine the level of contamination in the soil, the Cf value was divided into four categories: Cf< 1 as low contamination; Cf< 3 as moderate contamination; Cf< 6 considerable contaminations; and Cf > 6 as very high contamination (*Cheng et al., 2018*).

Table 3.3: Contamination factor Index of heavy metals in tailings from Eprocomi Mine

SN & Sample Code	Contamination factor Index		
Tailings Sample	As (mg/kg)	Pd (mg/kg)	Cd (mg/kg)
Sample 1 (MUS 1)	3.5	3.48	0.5
Sample 2 (MUS 2)	7.6	5	0.48
Sample 3 (MUS 3)	8	5.2	1.07
Sample4 (MUS4)	1.4	3.92	0.78
Sample 5 (2MUS6)	9.5	4	0.83
Sample 6 (2MUS7)	3.9	3.2	0.70
Sample 7 (2MUS8)	6.4	3.56	0.81
Sample 8 (2MUS22)	6.5	5	0.56
Sample9(MPANGA Site 9)	7	5.28	0.62
Sample10(MPANGA Site 10	5.1	3.84	0.53
Sample11(MPANGA Site 11	0.3	5.4	0.53
Sample12(MPANGA Site 12	6.9	8	0.50
Sample13(MPANGA Site 13	7.2	5.08	0.51
Sample14(MPANGA Site 14	7.1	5.8	0.54
Sample15(MPANGA Site 15	6.8	5.68	0.41
Sample16(MPANGA Site 16	5	5.6	0.45
Sample17(RW 17)	3.8	3.04	0.43
Sample18(RW 18)	3.5	3.92	0.41
Sample19(RW 19)	3	3.68	0.36
Standard used: Germany Soil Regulation			

GSR (2012) - Geo-chemical background value of trace element	10	25	3

The contamination factor used to determine the level of contaminant in the soil, and from different values obtained shows different contamination level by analyzing each sample.

For Arsenic (As); sample 11 falls in category of Cf< 1 as low contamination, samples 4 &19 falls into category of: Cf< 3 as moderate contamination, sample 1,10,16,17,18 fall into category of Cf< 6 considerable contaminations and sample 2,3,5,7,8,9,12,13,14,15 fall into category of Cf > 6 as very high contamination. Therefore, with reference to table *3.3*; we can conclude that the area of Eprocomi falls into category of high contamination with arsenic heavy metal since, majority of the tailing's contamination level falls into this category.

For Pb (Lead); there are no samples fall within category of Cf< 1 as low contamination and category of Cf< 3 as moderate contamination. Sample 1 up to 11, sample 13 up to 19 falls into category of Cf< 6 considerable contaminations and only one sample 12 fall into category of Cf > 6 as very high contamination. Therefore, we can conclude that the area is in category of considerable contamination of lead heavy metal since, majority of the tailings fall into this category.

For Cd (Cadmium); there are no samples falls within category of Cf< 3 as moderate contamination, category of Cf< 6 considerable contaminations and category of Cf > 6 as very high contamination.

All the tailings fall into the category of Cf< 1 as low contamination.

Therefore, based on the data from table 3.3, we can conclude that the area is in category of low contamination of heavy metal since, majority of the tailings falls into this category.

Calculation Degree of Contamination Index

The degree of contamination mCd is defined as the sum of all contamination factors for various heavy metals over the number of analyzed elements. The degree of contamination was calculated based on Abrahim's modification of the Håkanson contamination degree Cd. mCd represents a generalized form of the overall degree of contamination at a sampling point (Håkanson, 1980 and Abrahim, 2005), (Ashiqur et al, 2016).

Mathematically, degree of contamination index mCd was calculated as follow:

$$mC_d = \frac{\sum_{i=1}^{N} C_f^i}{N}$$

Where, N is the number of elements analyzed and Cf is the contamination factor. Grades' classifications of mCd were used to analyze the degree of contamination of the soil in the studied area. The classifications were in seven grades: mCd< 1.5, unpolluted; 1.5 <= mCd < 2, slightly polluted; 2 <= mCd< 4, moderately polluted; 4 <= mCd< 8, considerably polluted; 8 <= mCd< 16, highly polluted; 16 <= mCd< 32, strongly polluted; and mCd>= 32, extremely polluted. (Olanrewaju et al, 2022).

Figure 3.4: Degree of Contamination factor Index of Heavy Metals from Eprocomi tailings

SN & Sample Code	Degree of Contamination factor Index		
Tailings Sample	**As (mg/kg)**	**Pd (mg/kg)**	**Cd (mg/kg)**
Sample 1 (MUS 1)	3.5	3.48	0.5
Sample 2 (MUS 2)	7.6	5	0.48
Sample 3 (MUS 3)	8	5.2	1.07
Sample4 (MUS4)	1.4	3.92	0.78
Sample 5 (2MUS6)	9.5	4	0.83
Sample 6 (2MUS7)	3.9	3.2	0.70
Sample 7 (2MUS8)	6.4	3.56	0.81
Sample 8 (2MUS22)	6.5	5	0.56
Sample9(MPANGA Site 9)	7	5.28	0.62
Sample10(MPANGA Site 10	5.1	3.84	0.53
Sample11(MPANGA Site 11	0.3	5.4	0.53
Sample12(MPANGA Site 12	6.9	8	0.50
Sample13(MPANGA Site 13	7.2	5.08	0.51
Sample14(MPANGA Site 14	7.1	5.8	0.54
Sample15(MPANGA Site 15	6.8	5.68	0.41
Sample16(MPANGA Site 16	5	5.6	0.45
Sample17(RW 17)	3.8	3.04	0.43
Sample18(RW 18)	3.5	3.92	0.41
Sample 19 (RW 19)	3	3.68	0.36
Sum of contamination factor for each heavy metal	**105.5**	**93.68**	**11.02**
Degree of Contamination Index (N=3)	**70.06**		

Very significant contamination was indicated by the highest contamination factor values; based on the fact that, degree of contamination index is used to analyze the degree of contamination of the soil in the studied area; The value of 70.06 mg/kg falls in the range of mCd>= 32, which shows extremely polluted of the soil within the area under mining operations of Eprocomi Mining Company. Extremely high levels of environmental heavy metal contamination are always linked to mining and processing activities. (Barkouch et al, 2016).

3.2.2 Relationship between mining wastes and soil quality in Eprocomi Mine

By identifying the types of mining wastes generated from Eprocomi Mine and consider tailings from these wastes as most abundant and impactful wastes types in the area, the laboratory analysis of the tailings sample have been conducted to examine their contamination level from contained toxic heavy metals pH and concentration such as lead, cadmium and arsenic; the result identified in table 3.2; table 3.3 and table 3.4 shows that the concentration of present toxic heavy metals from the samples exceed the standards based on Germany soil organization, World Health organization and Canadian standards. The study has concluded that mining wastes do have significant effects on the soil quality in Eprocomi Mining Company in Gakenke District as the result has shown that the soil has strongly polluted from exceeding of heavy metal concentration level.

4. Conclusion

In conclusion, this study sought to assess the effect of mining wastes on the soil quality in Eprocomi Mine from Gakenke District. The research identified the types of mining wastes generated from Eprocomi Mine and assessed their effect on the soil quality with a particular emphasis on heavy metal contamination. The Analysis of soil samples from mining-affected areas revealed significantly elevated concentrations of heavy metals such as lead (Pb), cadmium (Cd) and arsenic (As), exceeding permissible limits set by international environmental standards. These heavy metals tested are known for their toxicity, persistence in the environment, and bioaccumulation, posing serious threats to agricultural productivity, ecosystem health, and human well-being. The accumulation of heavy metals in the soil alters its chemical composition, leading to reduced fertility and imbalances in essential nutrients. High levels of cadmium and lead inhibit plant growth by interfering with nutrient uptake, while arsenic contributes to soil acidification and microbial toxicity. Furthermore, the mobility of these metals through soil erosion and water runoff increases the risk of contaminating nearby water bodies and agricultural lands, exacerbating the environmental impact. The long-term presence of heavy metals in soil also has significant implications for food safety. The study concluded that the soil at Eprocomi mine is strongly polluted by Arsenic and moderately polluted by Chromium and Lead.

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Stratford Peer Reviewed Journals and Book Publishing
Journal of Agriculture & Environmental Sciences
Volume 9||Issue 2||Page 24-39 ||April||2025|
Email: info@stratfordjournals.org ISSN: 2616-8465

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