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Evaluation of Efficiency of Using Mechanized Processing Techniques to Recover Tin and Tantalum in Gatsibo, Eastern Province, Rwanda

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Abstract: Rwanda is known to be among the top producers of tin and tantalum, despite having low recovery and grades. This study was carried out to evaluate the efficiency of using mechanized methods to increase the recovery rate and grades of tin and tantalum mined in Gatsibo, Eastern Province, Rwanda, since the general separation techniques used are artisanal. The minerals in those mines include cassiterite (SnO_2) and colombite–tantalite ($(Fe,Mn)(Ta,Nb)_2O_5$), with impurities such as Al_2O_3, Fe_2O_3, MnO, MgO, Cao, Na_2O, K_2O, TiO_2, and P_2O_5. A combination of gravity separation techniques, including shaking tables and magnetic separation, were used as the mechanized processing techniques. The results were compared to the results obtained by artisanal processing techniques. The proposed mechanized techniques were found to increase the efficiency of tin and tantalum recovery from 60.75% to 81.85% and from 22.9% to 48.57%, respectively, and the grades of the tin and tantalum increased to 63.75% and 35.7%, respectively. Based on these results, the proposed mechanized processing techniques and the recycling of waste from artisanal processing techniques are highly recommended.

Keywords: tin; tantalum; Rwanda; mineral processing; gravity separation; magnetic separation

1. Introduction

Tantalum production in the Great Lakes region of Central and East Africa has overtaken Australian production since 2009 and the area remains the major source of tantalum production [1]. Minerals are becoming an important source of revenue for the economy of Rwanda and have shown good potential for increasing growth and economic transformation. Rwanda's mining industry is the second largest sector contributing to gross domestic production and the country is known to be among the largest producers of tantalum [1] (Figure 1). Value addition and increasing the recovery rates and grades of Rwanda's "3Ts" (tin, tungsten, and tantalum) are the main goals of the country's mining industry. Normally, all run of mine minerals have low grades and this leads to the need for mineral beneficiation techniques to recover the minerals and extract metals, as well as increase the grades [2].

The extraction techniques used in Rwanda are techniques that have been used since 19th century and are based on washing away the gangue and capturing the heavy minerals from the feed materials in the original rock [3].

The collection processes of tin and tantalum start with the ores from a particular mine with Sn–Nb–Ta, with mechanized processing at the end of whole process for Nb that is near to 90% concentration and Ta with a concentration of 78% can be recovered [4].

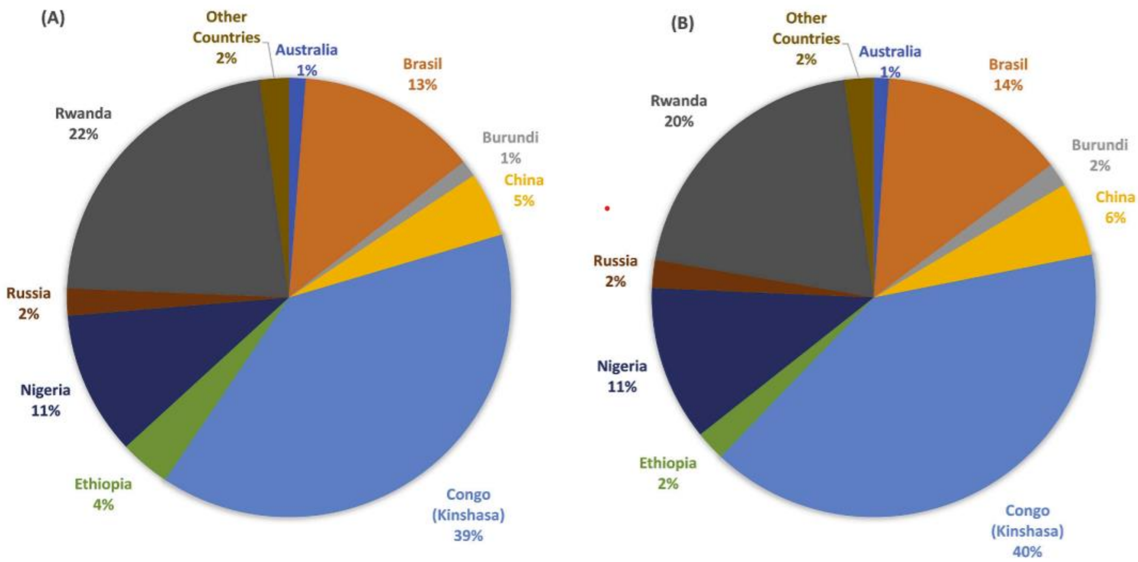

Figure 1. World tantalum production in 2018 (**A**) and 2019 (**B**).

According to [5], the use of mechanized techniques is highly recommend due to the increase in concentration that is obtained after using gravity separation. The use of panning is known to be efficient, but it depends on various factors, such as the skill and experience of operator, and only a small volume can be used for better efficiency. For better efficiency, it is highly recommended to use further separation techniques or different mechanized techniques [6].

Company X is located 125 km east of Rwanda (Kigali–Kayonza–Kabarore road, Rwanda). Its main mission is to produce minerals to contribute to the well-being of its members and neighboring populations as well as boost the economy of the country, which can be achieved by increasing its mineral recovery rates and grades. The geology of this area is largely underlain by a Kibaran orogeny rock system that predominantly consists of basement and Mesoproterozoic rock that has been intruded by different generations of granitic and mafic rock [7]. The Mesoproterozoic formations comprise three lithologies: low-to-medium grade metavolcanic and metasedimentary formations, large granite batholiths (with inliers of basic and metasedimentary rock), and large formations of high-grade metasediments and amphibolite with granite, gneisses, and magmatites. Tin and tantalum mined in this area are extracted from pegmatite ore and quartz veins by panning or ground sluicing. The unmechanized way of processing (Figure 2) and liberating the minerals and the pre-treatment process are key factors to be improved to achieve better results in the recovery of minerals and metals [8].

To achieve high separation efficiency and increase the mineral grades, it is highly recommended to use multiple and successive separation techniques [9,10], with better communition to reduce the size and enhance the liberation of ore minerals from gangue at the coarsest possible particle size [11,12]. The lack of appropriate technology for processing [13] leads to the loss of different minerals. There was a previous study carried out that was related to the efficiency of mineral recovery techniques in different parts of Rwanda in which the author recommended the use of mechanized methods [14], but there have been no previous studies in this area or the eastern part of Rwanda. Inspired by that work, this study aimed to investigate the efficiency of using mechanized separation techniques (gravity and magnetic separation) to increase tin and tantalum recovery rates and grades in the eastern part of the country, and especially for Company X. This will hopefully contribute to the economic growth of Rwanda and attract investors.

(**A**) (**B**)

Figure 2. The general ground sluicing method (**A**) [1] and panning method (**B**) of Company X.

2. Materials and Methods

2.1. Methodology

2.1.1. Geology and Geographical Sample Points

The geology of the study area was examined with the help of different literature reviews on the geology of Rwanda as well as the observations of the authors. The minerals recovered in this area are from quartz veins and pegmatites. GPS was used to collect geographic coordinates, and a geological compass and geological hammer were used in this study to obtain different geological information about the site. ArcGIS software was used to locate the area (Figure 3).

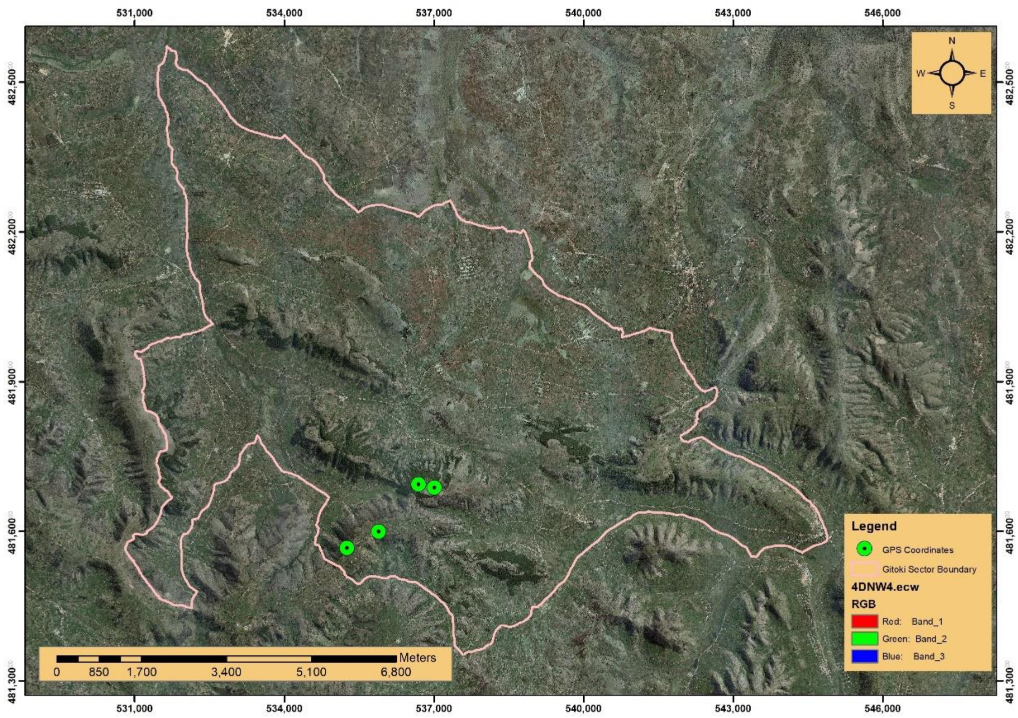

Figure 3. GIS map of the studied area.

Figure 1 shows the mining perimeter of Company X in the Gatsibo District and the mine concession from which the samples were collected. The green points show the four sub-mine sites (MUK A, GIT, RUS A, and RUS B) from which the samples were taken.

2.1.2. Ore Samples

The samples used in this study were collected in 2019 by Company X, which is in Karubungo and Nyamirama cells, Gitoki sector of the Gatsibo District in Eastern Province, Rwanda. The samples were collected from four different sub-mine sites of this company, as indicated on the map (Figure 3). The sampling points were chosen based on the known locations of pegmatites and quartz veins. Different particles of tin and tantalite could be seen with the naked eye. Different samples, such as run of mine, were collected from underground tunnels and shafts, and tailings were collected from tailing deposits where erosion and landslides had occurred. A total of 120 kg of ore samples and tailing samples collected from the different sub-sites (RUS A, RUS B, GIT, and MUK A) were sent to the University of Rwanda, where the samples were sieved.

Representative samples weighing 12 kg each were sent to Ngororero Mining Company for mechanized separation (gravity separation and magnetic separation). A quartering method was used to collect samples after separation, which were sent to the Sustainable Development of Mining in Rwanda (SDMR) to be analyzed using an XRF analyzer. At every stage of sampling, a cone and quartering method was used in which the samples were poured into a conical heap, flattened, and divided into four equal parts using a metal cutter.

2.1.3. Ore Preconcentration

Ore preconcentration is the first step for better recovery rates and grades, as well as being an easy extraction process. The pre-treatment of different ores, including cassiterite and colombite–tantalite, involves mineral liberation, such as crushing, grinding, jigging, and sieving.

The appropriate ore pre-treatment method depends on the type of separation technique that is to be used. In this research, since gravity separation and magnetic separation were the targeted separation techniques, a coarse grind was used to avoid mineral loss as fine particulates. Particle size distribution and mineral liberation were performed using a grinding machine and sieving to avoid the loss of fine particles.

2.1.4. Selection of Separation Techniques

Gravity separation, especially the use of shaking tables, was chosen based on different factors, such as the types of ores and their mineralogy, liberation size, the economy of the process, and possible communition size. Magnetic separation was chosen due to the fact that the minerals being handled had different magnetic susceptibilities.

2.1.5. Sample Preparation and Experimental Approach

Before using gravity concentration (specifically, a shaking table), different parameters had to be taken into consideration, such as the angle of inclination (deck angle), frequency, and the length of the table. This study was limited to the use of 4° as the inclination angle with a frequency of 170 Hz, wash water volume of 2 m/t/h, 18 mm stroke length, and the table deck measurements of 35 inches by 96 inches.

Samples were prepared using a sieve shaker. According to [11], the efficient sample grain size for the mechanized processing methods (gravity) is between 63 μm and 500 μm. Approximately 25 kg was sieved to obtain at least 12 kg of samples at −500 μm. This amount was based on a study by [12] that reported that more than 12 kg can be recovered using gravity separation and mechanical separation. These 12 kg samples were used for gravity separation and the samples were then selected from gravity concentration, dried, and used for magnetic separation to remove magnetite and any other impurities remaining in the concentrate.

The choice of using gravity separation was based on density, and the physical characteristics of cassiterite and its gangue make it ideal for gravity separation techniques.

In this study, a Shimadzu X-ray fluorescent analyzer-1800 (XRF-1800, Shimadzum Kyoto, Japan (XRF-1800) (Figure 4) was used for the elemental characterization and quantification. The samples were measured three times and their averages were considered as the accurate mineral grades.

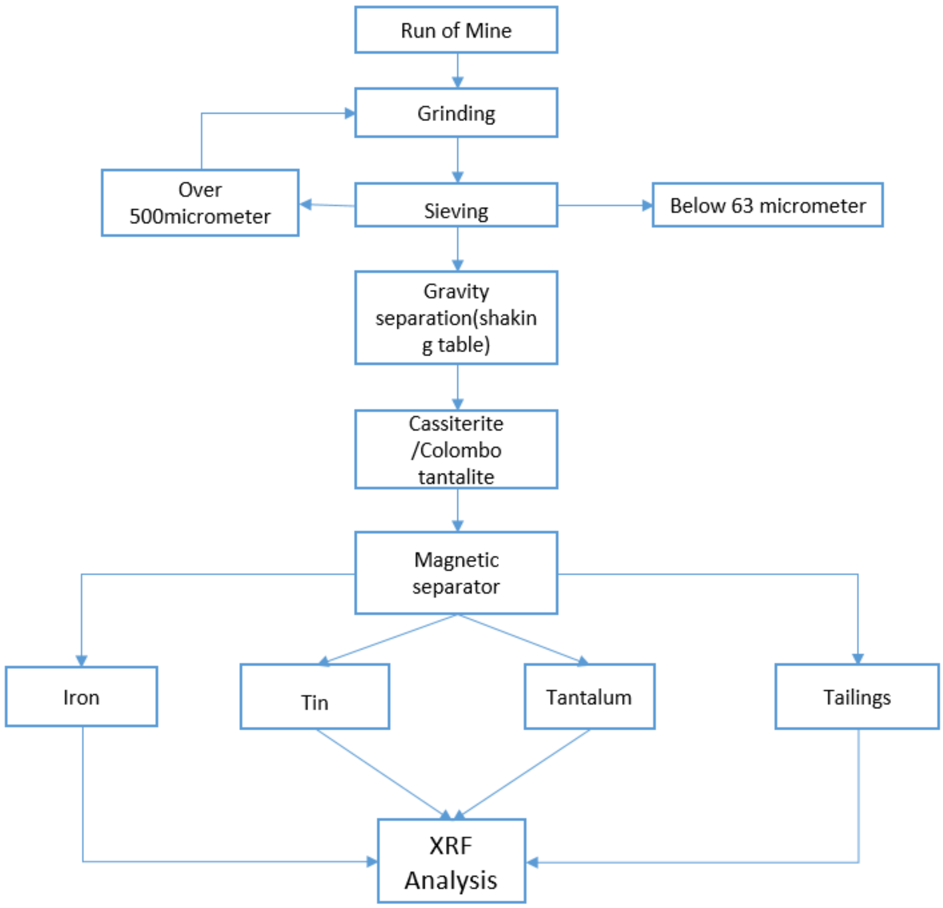

Figure 4. A flowchart showing the steps followed.

2.1.6. Metallurgical Equations Used in Calculations

This work was carried out based on two important metallurgical equations: the recovery rate and mass recovery calculations. The grades were determined using an XRF analyzer. The samples were analyzed three times and the indicated grades are the averages, to ensure accurate results.

The recovery rate was calculated with the following formula:

$R = 100\,c\,(f - t)/f\,(c - t)$ (= recovery %), where c is the concentrated weight, f is the feed assay, t is the tailings assay and R is the recovery rate.

Mass recovery was calculated by:

Mass recovery = (Pure/impure) * 100

3. Results

3.1. Recovery Analysis Results

The recovery results were obtained by considering feed, concentrates, and tailings. The results in Figures 5 and 6 were obtained by comparing the results of the artisanal and mechanized processing techniques.

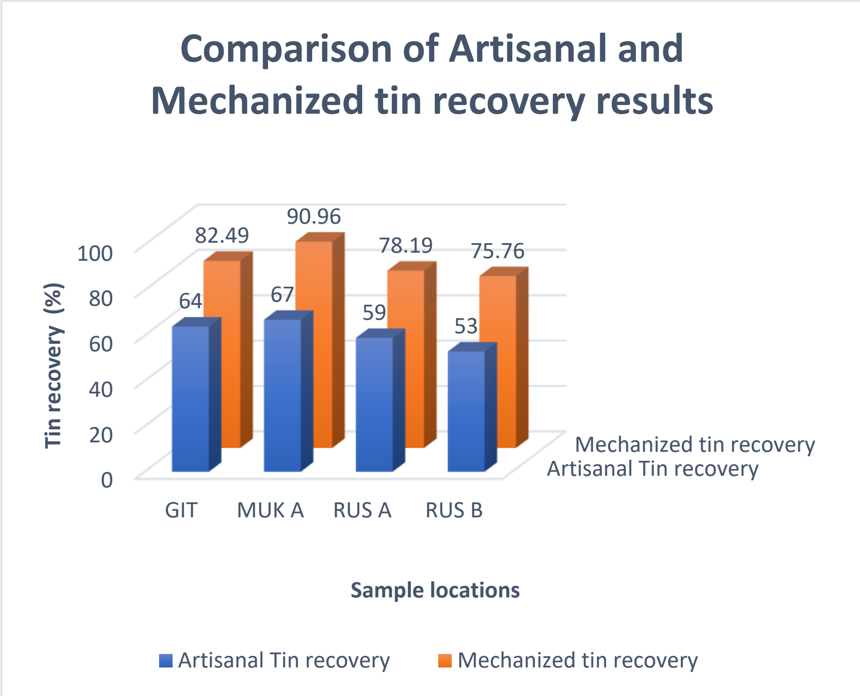

Figure 5. Comparison between the artisanal and mechanized recovery of tin.

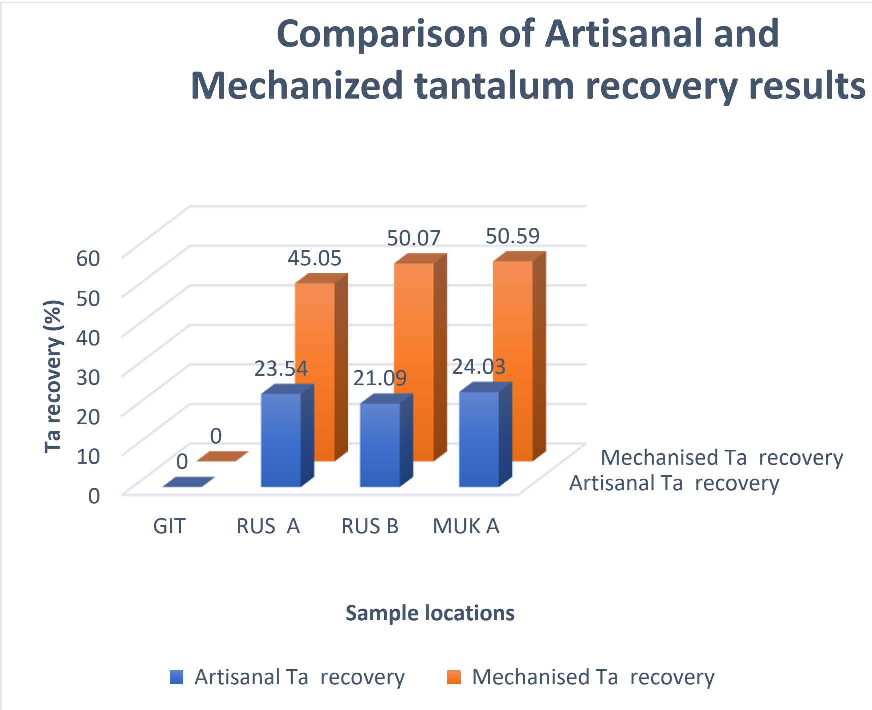

Figure 6. Comparison between the artisanal and mechanized recovery of tantalum.

3.2. Grade Analysis Results

Figures 7 and 8 show the results of the separated mineral (cassiterite and tantalite) grades, which were characterized and quantified using the XRF analyzer. The results of both mechanized and unmechanized techniques were analyzed and compared to evaluate the most efficient way to obtain high grades.

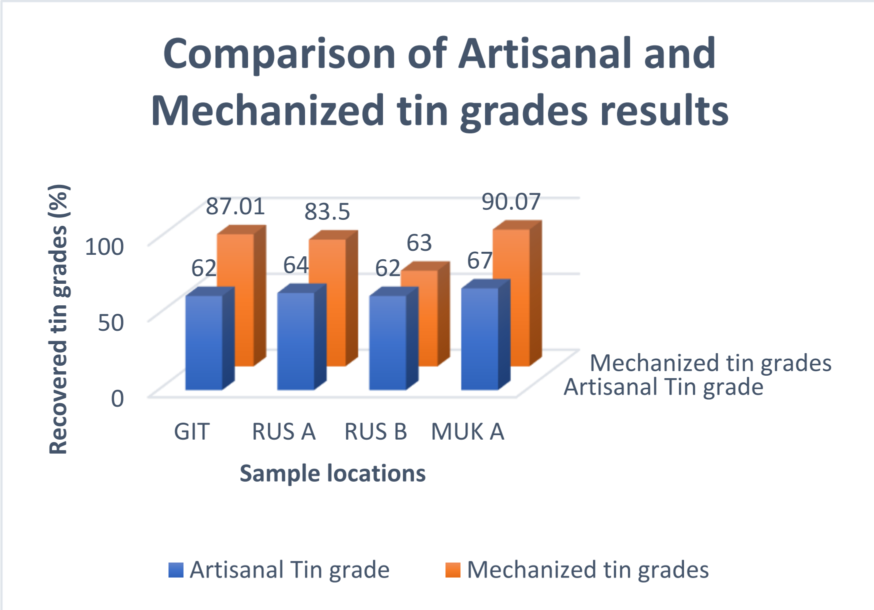

Figure 7. Comparison between tin grades from artisanal and mechanized recovery.

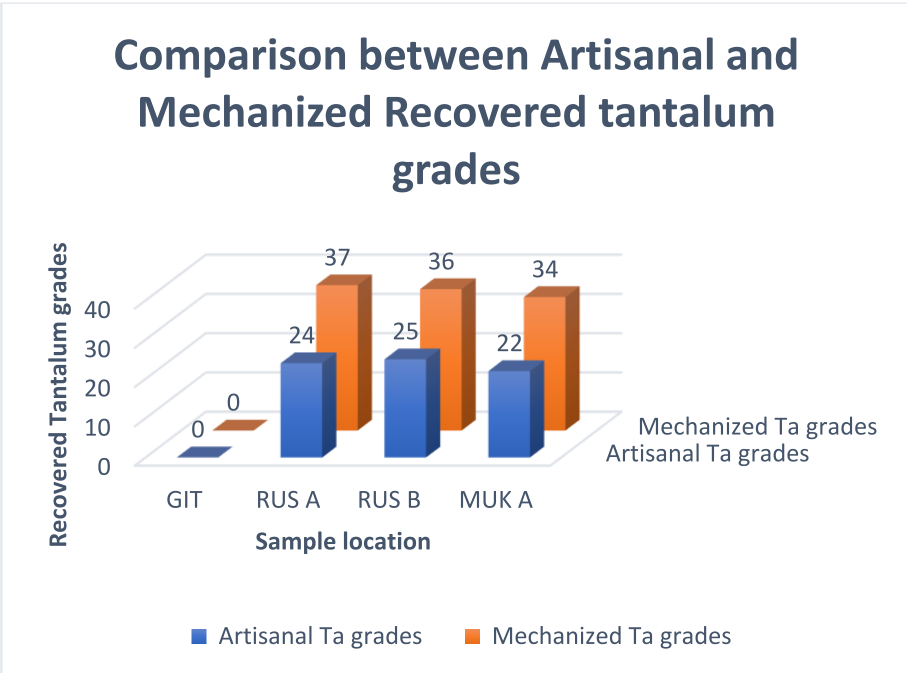

Figure 8. Comparison between tantalum grades from artisanal and mechanized recovery.

3.3. Artisanal Processing Technique Results (Ground Sluicing)

To work efficiently, the samples were collected at the same point and processed using ground sluicing: an artisanal processing technique (normally used at the chosen site). The results in Table 1 show the recovery rates and grades obtained for both tantalite and cassiterite using artisanal techniques, which were compared to the results from the mechanized techniques to establish the most efficient way to recover these minerals.

Table 1. Artisanal processing results.

Sites	RUS A (%)		RUS B (%)		MUK A (%)		GIT (%)
Recovery	SnO_2	Ta_2O_5	SnO_2	Ta_2O_5	SnO_2	Ta_2O_5	SnO_2
	59	27	53	32	67	22	64
Grades	64	24	62	25	67	22	62

3.4. Tested Mechanized Technique Results

Tables 1–5 show the total mass recovery, recovery, and grades obtained using mechanized separation methods.

Table 2. RUS A mechanized processing results.

RUS A (ROM)(Mixed Tantalum and Tin)	Tantalum Grade (%)	Tantalum Recovery (%)	Tin Grade (%)	Tin Recovery (%)	Mass Weight (%)
Feed	0.9	-	2.9	-	-
Concentrate	37	45.05	83.50	78.19	2.33
Waste	0.5	53.71	0.65	21.81	97.67

Table 3. GIT mechanized processing results.

GIT (ROM)	Tin Grade (%)	Tin Recovery (%)	Mass Weight (%)
Feed	2.4	-	-
Concentrates	87.01	82.49	1.83
Waste	0.43	17.51	98.17

Table 4. RUS B mechanized processing results.

RUS B (ROM) (Mixed Tantalum and Tin)	Tantalum Grade (%)	Tantalum Recovery (%)	Tin Grade (%)	Tin Recovery (%)	Mass Weight (%)
Feed	0.92	-	1.3	-	-
Concentrate	36	50.07	63.71	75.76	2.58
Waste	0.41	43.9	0.32	24.24	97.42

Table 5. MUK A mechanized processing results.

MUK A (ROM) (Mixed Tantalum and Tin)	Tantalum Grade (%)	Tantalum Recovery (%)	Tin Grade (%)	Tin Recovery (%)	Mass Weight (%)
Feed	0.8	-	2.9	-	-
Concentrate	34	50.59	90	90.96	3.3
Waste	0.4	49.41	0.27	9.04	96.7

4. Findings

Poor mineral liberation, tools, and processing techniques are the main factors affecting the grades and recovery of minerals. The minerals used in this study were sieved and ground to obtain fully liberated minerals. Different mechanized processing techniques were examined to evaluate their efficiency in increasing the grades and recovery of the minerals.

Generally, a remarkable increase in grade and recovery was found using mechanized techniques. Considering Figure 5, the increases in the recovery of tin were found to be as follows:

1. The tin recovery from RUS A was 19.19% higher than that from the artisanal techniques;
2. The tin recovery from GIT was 18.49% higher than that from the artisanal techniques;
3. The tin recovery from RUS B was 22.76% higher than that from the artisanal techniques;
4. The tin recovery from MUK A was 23.96% higher than that from the artisanal techniques

Considering Figure 6, the increases in the recovery of tantalum were found to be as follows:

1. The recovery rate from RUS A was 21.51% higher than that from artisanal processing techniques;
2. The recovery rate from RUS B was 22.76% higher than that from artisanal processing techniques;
3. The recovery rate from MUK A was 26.56% higher than that from artisanal processing techniques.

A high increase in tin recovery was found in MUK A, where the extracted ores were in quartz veins. These sites do not have mechanized machines that can perform crushing, grinding, and sieving to fully liberate the minerals. By optimizing the liberation size, the mineral recovery rate was increased.

The other recovery rate increase was based on particle size distribution. Normally, considering the pegmatite mineralization of this mining perimeter, it is recommended to use particles that are large enough to handle, since smaller size particles are easily washed out by water. By sieving and separating minerals based on their size, the recovery rate was increased.

Considering Figure 7, the increases in tin grades from using mechanized processing techniques were found to be as follows:

- Tin grades from the GIT site were about 25% higher than those from artisanal processing techniques;
- Tine grades from the RUSH A site were 19.5% higher than those from artisanal processing techniques;
- Tin grades from the RUS B site were 1% higher than those from artisanal processing techniques;
- Tin grades from the MUK A site were 23.07% higher than those from artisanal processing techniques.

Considering Figure 8, the increases in tantalum grades from using mechanized processing techniques were found to be as follows:

- No tantalum was extracted from GIT;
- Tantalum grades from the RUS A site were 13% higher than those from artisanal processing techniques;
- Tantalum grades from the RUS B site were 11% higher than those from artisanal processing techniques;
- Tantalum grades from the MUK A site were 12% higher than those from artisanal processing techniques.

The increase in grades was based on removing impurities by using the magnetic separator, where minerals with high magnetic susceptibility, including iron, were removed. This increased the purity of the recovered minerals, such as cassiterite and tantalite. Considering Table 3 of the GIT site, high tin grades were obtained due to its high concentration of iron, which was removed by magnetic separation.

RUS B tin did not show a high increase in grade since no penalty elements nor high concentrations of magnetic impurities were found at that site.

Normally, recovery is inversely proportional to grade, but this depends on theoretical mineral grades and for Company X's mining perimeter, it is highly recommended to use mechanized techniques to increase recovery and grades. Further research is needed on recovering minerals under 2 μm and providing a more efficient way to reach 100% mineral recovery.

Conditions for efficient separation included:

- The main causes of low recovery in this area are poor liberation techniques and mineral handling size;
- For tin and cassiterite, many minerals are lost due to ineffective liberation. This study recommends that cassiterite minerals from this site can be liberated at a size between 63 µm and 500 µm;
- At least 12 kg can be used on a shaking table for efficient recovery results;
- The use of magnetic separation methods helps to remove magnetic impurities as well as penalty elements;
- The authors recommend recycling the tailings of sites with a mechanized technique;
- The authors recommend further research on different separation techniques that can be used to improve the grades and recovery of Rwandan minerals;
- Based on the data obtained, this site shows concentrations of different rare earth elements, which require further studies to confirm.

5. Conclusions

A novel mechanized technique to efficiently recover tin and tantalum from Company X's mining perimeter was developed. The proposed process consisted of three major steps: communition and sieving for particle size distribution as the pre-treatment; shaking for gravity separation, with a recommended particle size of 35 µm to 500 µm and feeding of at least 12 kg; and the use of a magnetic separator to remove penalty elements, impurities, and magnetic minerals as well as separating tin and tantalum for mixed Sn and Ta. By using the recommended techniques, an average of up to 81.15% tin and 48.57% tantalum was recovered and concentrate grades of 80.895% and 35.7%were obtained, respectively.

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Conflicts of Interest: The authors declare that there are no conflict of interest.

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