Technical Memorandum

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cc:	Sam Ryumugabe	**Date:**	2 December 2025
		Project No.	713.000084.00001

RE: Trinity Metals Legacy Tailings and River Rehabilitation: Geochemical and Soil / Sediment Assessment – Nyakabingo Mine, Rwanda

1.0 Introduction

Trinity Metals Limited was formed in May 2022 with the amalgamation of the three mines namely, Rutongo, Musha and Nyakabingo under the Trinity Metals Group. All three mines have a long history of artisanal-scale mining which dates to the Belgian times in the late 1930's. This has resulted in significant environmental and social legacy issues, including altering the natural hydrological functioning of the river systems and associated water quality impacts.

Trinity Metals are committed to the expansion, modernisation and mechanisation of its mining operations as well as addressing the current and historical mining-related environmental and social impacts in a responsible and sustainable manner. Consequently, technical assistance (TA) programs have been developed to assist in identifying and assessing existing environmental and social (E&S) impacts to implement management plans and programs that address those E&S impacts identified. As part of TA 4, the development of legacy tailings management and river rehabilitation plans look to include different specialist studies and technical task teams to address the impacts.

Consequently, Trinity Metals has appointed SLR Consulting (Africa) Proprietary Limited (SLR) to undertake:

- A geochemical baseline assessment of the legacy tailings lithologies that are integrated with the Rutongo mines to determine their acid rock drainage and metal leaching potential risk,
- A geochemical baseline assessment of the river sediments to determine their capacity to remediate any metal leaching and acid rock drainage that might be emanating from the legacy tailings lithologies, and
- A baseline assessment of the downstream soils to assess their physical and chemical properties and their capacity to remediate any metal leaching and acid rock drainage risks that might be emanating from the legacy tailings lithologies.

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2.0 Scope of Work

The proposed scope of work to achieve the project objectives is detailed below.

1. Desktop study
    a. Gap analysis and request for information.
    b. Sampling schedule plan development using a regular point sampling methodology and expert knowledge to locate sampling points.
2. Site sampling visit to the Nyakabingo mine to:
    a. Locate QGIS and expert knowledge determined sampling points,
    b. Undertake visual soil assessment to classify the soils based on the IUSS working group reference base,
    c. Collect designated soil and sediment samples for analysis to confirm classification and identify any contaminants,
    d. Identify, describe and sample representative legacy tailings lithologies for geochemical assessment,
3. Specialist laboratory analysis program
    a. River sediment assessment analysis:
        i. Particle size distribution (PSD) analysis
        ii. X-ray diffraction (XRD) mineralogy
        iii. Synthetic Precipitation Leachate Procedure
        iv. Total metal concentrations
    b. Legacy Tailings assessment analysis:
        i. XRD minerology
        ii. Acid base accounting and sulfur speciation
        iii. Synthetic Precipitation Leachate Procedure for source term modelling
    c. Soil assessment analysis:
        i. Particle size distribution analysis
        ii. pH, electrical conductivity, cation exchange capacity, bioavailable nutrient status, organic matter content and total metal concentrations.
4. Baseline soil, sediment assessments and geochemical risk assessments for acid rock drainage and metal leaching potential of the legacy tailings lithologies.
5. Provide mitigation measures and recommendations to inform legacy tailings management and river rehabilitation plans.
6. Technical memo reporting.

3.0 Methodology

Consultants from SLR mobilised to Trinity Metals mine sites from 13 to 25 July 2025 to undertake the specialist assessments. On 23 July 2025, the consultants visited the Trinity Nyakabingo mine to undertake the assessments.

3.1 Sampling Program

The SLR field team worked closely with the Nyakabingo mine geology and environmental team to undertake the specialist assessments. Their input was crucial in identifying the representative lithologies or rock types that are associated with the legacy tailings at the mine as well as, in identifying appropriate sediment and soil sampling locations in relation to the surface water monitoring points for each site.

These monitoring points guided the SLR field team in identifying appropriate upstream and downstream areas from the mine footprint, for the river sediment sampling initiative. The downstream areas were also used to locate undisturbed areas for the visual soil assessment, classification and sample collection.

3.1.1 Legacy Tailings Sampling Protocol

Sampling of the legacy tailings piles on the Nyakabingo mine was facilitated by the mine geologist. They assisted in identifying the lithologies that are diagnostic of the site and assisted in selecting representative samples of each lithology. The SLR consultants decided on which samples to retain largely determined by the different degrees of weathering and size of the sample.

After selecting the samples, they were described and GPS coordinates recorded. A photograph of the sample was taken before bagging. Refer to Table 3-1 for a summary of the legacy tailings sample details and Figure 3-1 for the locations of the legacy tailings piles that were sampled.

Table 3-1: Nyakabingo Mine Legacy Tailings Sample Summary

Mine	Sample ID	Latitude	Longitude	Lithological Description
Nyakabingo	NYK-LT-45	1°51'48.1"S	29°58'20.8"E	Shale
	NYK-LT-46	1°51'48.1"S	29°58'20.8"E	Quartz vein
	NYK-LT-47	1°51'48.1"S	29°58'20.8"E	Metased sandstone

3.1.2 River Sediment Sampling Protocol

The river sediment sampling was undertaken in consultation with the Nyakabingo mine environmental team. They assisted in locating the upstream and downstream positions from where they obtain water samples as part of their surface water quality monitoring program. The SLR consultants assessed the locations in relation to the mines footprint as well as the presence of unauthorised (illegal) mining and quarrying activities within the vicinity of the identified locations.

Surface sediment samples from the riverbed was collected using a spade that was cleaned between sampling events. The sample description and GPS positions was recorded, and a photograph of the sample was taken. Refer to Table 3-2 for a summary of the river sediment sample details and Figure 3-2 for the locations of the sediment sampling points.

Table 3-2: Nyakabingo Mine River Sediment Sample Summary

Mine	Sample ID	Latitude	Longitude	River sediment locations
Nyakabingo	NYKSED-48	1°52'50.6"S	29°58'20.1"E	Midstream
	NYKSED-49	1°53'21.4"S	29°58'20.3"E	Downstream
	NYKSED-50	1°52'32.1"S	29°58'16.0"E	Side stream

3.1.3 Soil Classification and Sampling Protocol

The soil assessment focused on determining the soil types of the downstream areas in relation to the mine footprint, as well as assessing the physical and chemical properties of the most downstream soil type to determine its potential to remediate any metal leaching and acid rock drainage risks that might be emanating from upstream activities. This was recommended as the downstream area are receptors for the migration of materials and contaminants from upstream activities which are predominately anthropogenic. Furthermore, these areas are often closer to human settlements or agricultural land use which can provide for long-term environmental monitoring data and potential remediation planning.

Once identified, notable site conditions and GPS coordinates were recorded. A handheld soil augur was used to extract soil cores and emptied onto sheets in the sequence of removal so that the soil profile could be constructed above ground.

Coring continued up to a depth of at least 0.5 m were feasible. The soil was then visually assessed based on its physical properties and master horizons were identified and recorded on the soil log sheet. After the visual assessment, a photograph of the soil profile was taken and a top-soil sample (0 – 30 cm depth) was collected and placed into a labelled zip lock bag at each observation point. Refer to Table 3-3 for a summary of the soil observation details and Figure 3-3 for the locations of the soil observation points.

Table 3-3: Nyakabingo Mine Soil Observation Summary

Mine	Sample ID	Latitude	Longitude	Sample Depth (cm)	Sampled
Nyakabingo	NYKSS-01	1°52’51.0”S	29°58’20.5”E	0 - 30	No
	NYKSS-02	1°53’19.8”S	29°58’21.0”E		Yes

3.1.4 Return Water and Top Dam Sludge Sampling Protocol

Sampling of the slurry / sludge samples from the return water dam (Dam 3) and top dam (Dam 8) from the Nyakabingo mine was undertaken by the mines environmental team. The sludge samples were collected and stored in plastic bottles.

Figure 3-1: Nyakabingo Mine Legacy Tailings Sampling Point

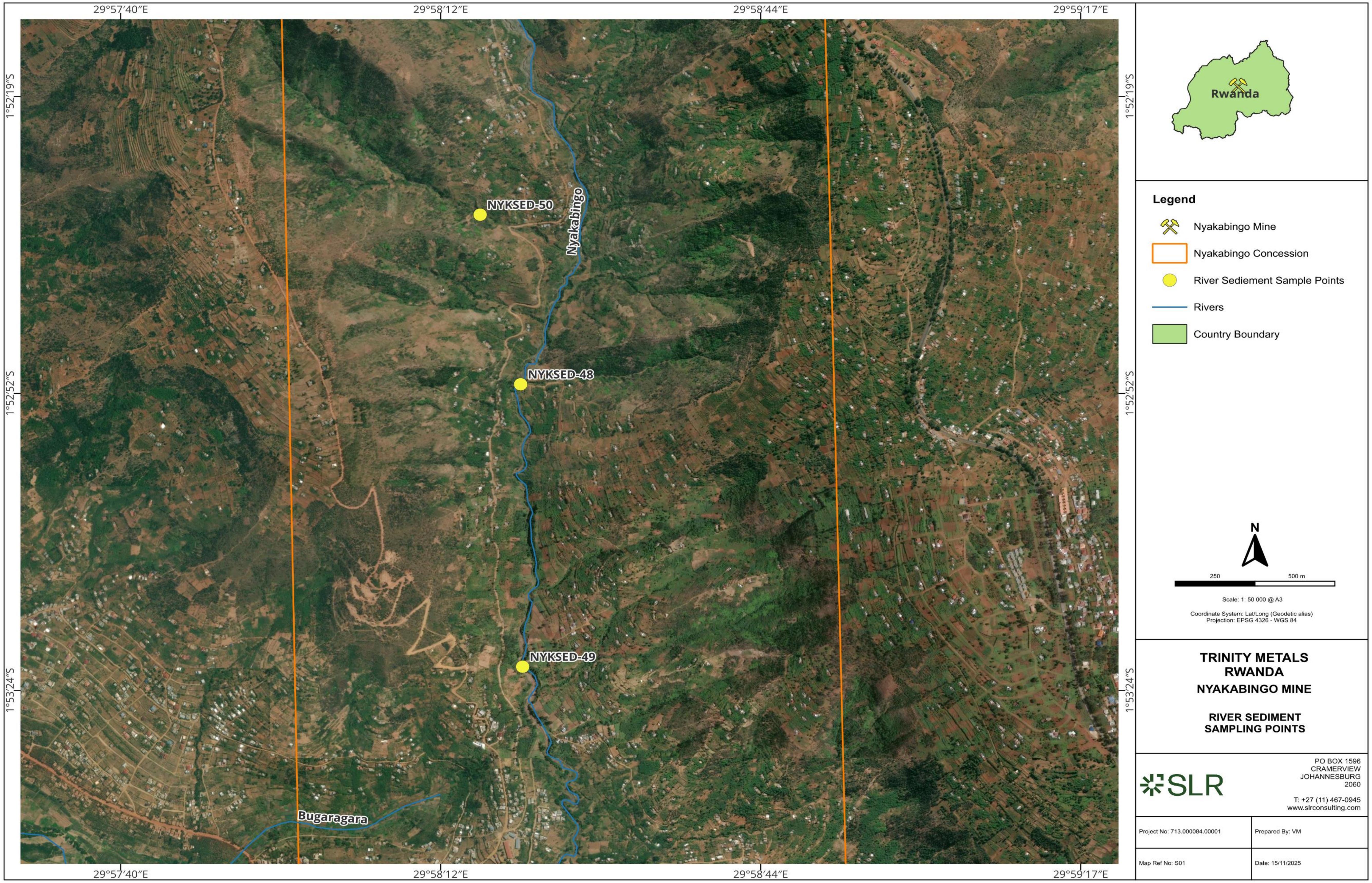

Figure 3-2: Nyakabingo Mine River Sediment Sampling Points

Figure 3-3: Nyakabingo Mine Soil Observation Points

3.2 Laboratory Analysis

3.2.1 Mineralogy: X-Ray Diffraction

Minerals are the building blocks of rocks. Mine drainage quality is generally a function of mineral dissolution (or precipitation) reactions that occur during the interaction of rocks with the atmosphere and water. X-ray Diffraction (XRD) analysis identifies the main crystalline mineral phases in each sample. XRD is conducted on whole-rock samples that have been crushed and ground into a powder. The powdered sample is then placed on a flat holder, which faces the X-ray beam. The X-rays are diffracted by the crystal planes in the minerals, with diffraction peaks at characteristic angles. The phases are identified by comparing the locations and intensities of the diffraction peaks with those of mineral reference standards (Price, 2009). Limitations of XRD include limited ability to identify non-crystalline minerals as well as minerals present in extremely low proportions.

3.2.2 Sulphur Speciation

The ABA tests assume that all sulphide (S^{2-}) minerals in a rock sample are acid-generating. Some of the sulphur in the rock may be present in non-acid-producing sulphates (SO_4^{2-}). If a significant part of the total sulphur occurs as sulphate sulphur instead of sulphide sulphur, the overall risk of acid generation is reduced. However, significant water quality impacts may result from the leaching of sulfate sulfur into local water resources.

3.2.3 Acid Base Accounting (ABA)

3.2.3.1 Acid Potential and Neutralisation Potential

Acid-Base Accounting is an internationally accepted analytical procedure developed to assess the acid-producing and acid-neutralising potential of rocks. The Acid Potential (AP) is calculated as the total sulphide sulphur content in per cent multiplied by 31.25, which is derived from the oxidation of sulphide minerals in a rock sample.

The Acid Neutralising Potential (NP) is a measure of the total acid a material can neutralise and is predominantly a result of neutralising bases, mostly carbonates, to a limited extent silicate minerals, as the latter have slow reaction kinetics. AP and NP are both reported as Kg CaCO3 /Tonne.

The ABA tests assume that all sulfide minerals in a rock sample are acid-generating. Some of the sulfur in the rock may be present in non-acid producing sulfates. If a significant part of the total sulfur occurs as sulfate sulfur instead of sulfide sulfur, the overall risk of acid generation is reduced.

3.2.3.2 Net Neutralization Potential

The difference between acid-generating mineral phases (AP) and acid-neutralising mineral phases (NP) is referred to as the net neutralisation potential (NNP). Thus, the NNP is calculated by subtracting the AP from the Acid NP as follows:

$$\mathbf{NNP = NP - AP}$$

Results are reported in kg of calcium carbonate per tonne of overburden (or parts per thousand). The NNP allows for the classification of the samples as potentially acid-generating or acid-consuming as follows:

- Negative NNP indicates the potential to generate acid.
- Positive NNP indicates excess acid-neutralising potential.

3.2.3.3 Neutralization Potential Ratio

Acid-Base Accounting data is also described using the neutralisation potential ratio (NPR). The NPR is calculated by dividing the NP by the AP as follows:

NPR = NP/AP

The NPR can be used to identify potentially acid-generating rocks as follows:

- NPR ratios larger than 2 indicate non-potentially acid generating (non-PAG);
- ratios between 1 and 2 are considered inconclusive / possibly acid-generating and
- NPR ratios below 1 indicate potential acid generation (PAG).

3.2.4 Synthetic Precipitation Leaching Procedure

The Synthetic Precipitation Leaching Procedure (SPLP) is a quick and inexpensive method to determine:

- The mobility/leachability of low volatility organic and inorganic analytes in liquids, soils, and wastes.
- The measure of desorption of contaminants from soil (rather than adsorption).
- The possibility of leaching metals into ground and surface waters.
- A site-specific impact to groundwater soil remediation standard.

Since the test uses custom pH levels to simulate rainfall in a particular geographic region, this test is often recommended over other methods when predicting leachate quality and risk to ground water.

Many factors can affect the leaching potential of organic constituents: pH, redox conditions, liquid-to-solid ratio, solubility, partitioning, presence of organic carbon, and non-aqueous phase extraction. Therefore, SPLP concentrations are used as input concentrations to Geochemical models to simulate realistic field conditions and produce more accurate source terms.

As part of this assessment, the SPLP results were subject to preliminary screening to identify constituents of potential concern (COPCs) by comparing the results to the following relevant water quality and effluent standards:

- International Finance Corporation (IFC) – Mining Effluent Guidelines (IFC, 2007);
- World Health Organisation (WHO) Guidelines for drinking-water quality (WHO, 2017);
- World Health Organisation (WHO) Guidelines on Recreational use (WHO, 2021);
- Rwanda Standard RS 109 (2009): Effluent standard, specifies the limits for the discharge of treated industrial wastewater effluent into the environment (RS 109);
- Rwanda Standards RS 188 (2013): Irrigation use, specifies the tolerance limits for water intended for irrigation purposes (RS 188); and
- Rwanda Standards RS 190 (2013): Livestock watering, specifies the characteristics, requirements to be used for livestock watering (RW 190).

3.2.5 Total Metal Concentrations and Geochemical Abundance Index (GAI)

The total metal concentration analyses were considered because it provides the overall composition of the material. The results were subject to preliminary screening to identify if any element is a potential contaminant in the soils / sediments by comparing the results to the Soil Screening Value 1 (SSV1: all land uses, protective of water resources) threshold as promulgated in GN R 331 of 2014 in accordance with the National Norms and Standards for the Remediation of Contaminated Land and Soil Quality in the Republic of South Africa.

The SSV1 thresholds are applicable to soil quality values that are protective of both human health and eco-toxicological risk for multi-exposure pathways, inclusive of contaminant migration to the water resource.

As part of the assessment, the degree of elemental enrichment in the river sediments was determined by calculating the geochemical abundance index (GAI) for the analysed elements. The GAI compares the measured concentration of an element in a sample with the estimated average crustal abundance of the element (INAP, 2014)[1] using the following equation:

$$\mathbf{GAI = log_2(\frac{Cn}{1.5 \times Bn})}$$

Where:

Cn is the measured concentration of the metal in the sediment sample

Bn is the average crustal abundance of the metal

1.5 is a correction factor for natural variability in background/average crustal values

For this assessment, the average crustal abundance in the earth's crust as per Smith and Huyck (1999)[2] were used as background values.

A GAI value of ≤0 indicates the element is present at a concentration similar to or less than the average crustal abundance which implies no enrichment suggesting no contamination.

A GAI value of ≥3 implies significant enrichment suggesting potential contamination, and

A GAI value of ≥6 implies extreme enrichment suggesting likely contamination.

3.2.6 Particle Size Distribution Analysis of Soil / Sediments

The particle size distribution of a given material is an important physical parameter in quality control processes and research applications, because many other properties are directly related to it. Particle size distribution influences material properties like flow and conveying behaviour (for bulk materials), reactivity, abrasiveness, solubility, extraction and reaction behaviour. It is also an important parameter to consider when delineating the potential for migration of contaminants in an aqueous environment.

3.2.7 Cation Exchange Capacity and Bioavailable Nutrients of Soil

Cation exchange capacity (CEC) is a measure of the soil's ability to hold positively charged ions. It is a very important soil chemical property influencing soil structure stability, nutrient availability, pH buffering and the soil's reaction to fertilisers and scavenging of heavy metals.

The soil capacity to supply nutrients is termed soil nutrient bioavailability and is the ability of the soil system to supply essential plant nutrients for plant metabolism. Release of nutrients

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[1] INAP (International Network for Acid Prevention). 2014. Global Acid Rock Drainage Guide (GARD Guide). http://www.gardguide.com/

[2] Smith, K.S. and Huyck, H.L.O. 1999. An Overview of the Abundance, Relative Mobility, Bioavailability, and Human Toxicity of Metals. In G.S. Plumlee and M.J. Logsdon (Eds.), The Environmental Chemistry of Mineral Deposits, Reviews in Economic Geology, Volume 6A, pp. 29-70.

from the solid phase to the soil solution is controlled by the physiochemical processes of desorption and dissolution. It is also a biochemical process by way of mineralization.

3.2.8 Waste Assessment

Rwanda does not have its own waste classification system and for this study it was recommended that the South African National Norms and Standards for the assessment of waste for landfill disposal be referred to, to determine the waste types of the Dam 3 and Dam 8 sludge samples respectively. Thus, the objective of the work is underpinned by the legal provisions of the National Environmental Management: Waste Act, 2008 (ACT NO. 59 OF 2008) which prescribes the following in terms of waste streams:

- Undertake a waste type assessment in terms of GN R. 635 (23 August 2013); and
- Determine the liner requirements as per the amendments to the National Norms and Standards for Disposal of Waste to Landfill, 2013 GN R. 636. (7 November 2024).

The South African waste classification regulations provide norms and standards for assessing/classifying (GN Regulation 635) waste material. Although the Norms and Standards refer to landfills, the definition of waste in South Africa includes mine residues such as tailings/slimes and waste rock and therefore the norms and standards apply to mine residue classification.

In terms of the regulations, the total concentration (TC) of chemical substances specified in Section 6 of GN R. 635 that are known to occur, likely to occur or can reasonably be expected to occur are determined. The TC of the chemical substances is compared to the total concentration threshold (TCT) limits specified in Section 6 of GN R. 635. The leachable concentrations (LC) of the chemical substances must be determined and compared to the leachable concentration threshold (LCT) limits specified in Section 6 of GN R. 635.

The TC and LC limits of elements and chemical substances in the waste material exceeding the corresponding TCT and LCT limits determine the specific waste type according to Section 7 of GN R. 635. The waste type and related risk-based assessment approach is used to inform the potential liner requirements. Figure 3-4 illustrates the flow diagram of the general processes to be followed to determine the waste type and the associated liner requirements.

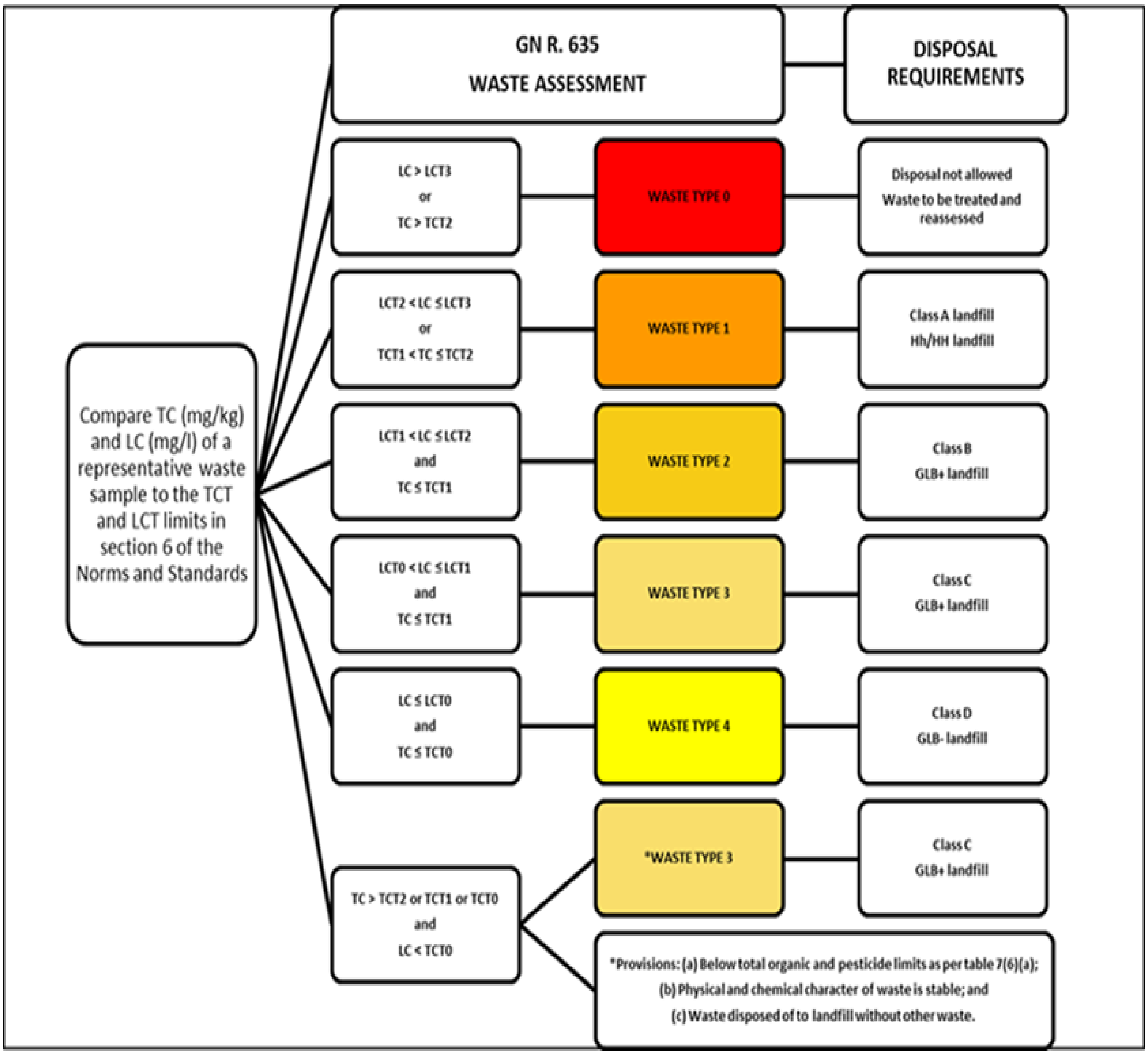

Figure 3-4: Flow Diagram for Assessing Waste in Terms of South African Waste Assessment Regulations (GN R. 635 of 2013)

3.3 Geochemical Source Terms

The SPLP results will be used as input concentrations to generate leachate source terms for the site. Laboratory leachate results are only an indicator of site drainage water quality, due to the test conditions not fully representing field conditions, most especially the liquid to solid ratio and varying redox settings.

PHREEQC is a geochemical software which can be used to perform geochemical calculations to predict mineral speciation, surface complexation, ion exchange equilibria and kinetic reactions. PREEEQC includes thermodynamic databases for a wide range of inorganic parameters relevant to industrial water quality and the field conditions they are subject to.

The generated geochemical source terms (predicted analyte concentrations) can then be input into a groundwater model to predict the significance and extent of contamination. A comprehensive geochemical and geohydrological assessment will assist in gaining a better understanding of potential risks and how to minimise those risks in the context of the site.

3.3.1 Model Code

This assessment applies the pH, Redox, Equilibrium Code (PHREEQC) for hydrogeochemical modelling (Parkhurst and Appelo, 2013)[3].

PHREEQC is a versatile geochemical model initially developed in 1995 by the United States Geological Survey. It has undergone extensive use, testing and validation by third parties with version 3 released in January 2015. This assessment used version 3.4.0.12927 (released 9th November 2017).

PHREEQC can perform low-temperature aqueous geochemical calculations, including speciation, saturation indices, batch reaction and 1-dimensional transport calculations. PHREEQC can account for aqueous, mineral, gas, solid solution, surface complexation and ion exchange equilibria, as well as kinetic reactions.

It is widely used for environmental geochemical modelling because it is freely available, open source, and flexible. It includes thermodynamic databases for a wide range of inorganic parameters relevant to mine water quality.

3.3.2 Model Inputs

The key model inputs are the contact water quality determined from laboratory leach tests (Appendix A). The input data concentrations were adjusted to achieve a charge balance equilibrium (CBE) < 10%. Concentrations indicated as below detection limit were entered as one-half of the detection limit or omitted were practical.

It is assumed that the sediment materials have a field moisture capacity of about 20%. The column of waste material can only generate seepage if the water content exceeds this value. No analysis was conducted to confirm this.

3.3.3 Boundary Conditions

The model boundary conditions are summarised in Table 3-4 below.

Table 3-4: Model boundary conditions

Boundary Conditions	Description
Gas phase	It is assumed that there is little biological activity in the material and the $CO_2(g)$ pressure was set to $10^{-3.5}$ atm.
Minerals	Based on the mineralogical analysis the pure phase that can react reversibly with the aqueous phase is Quartz, Muscovite and Kaolinite. Mineral phases to simulate only precipitation reactions were added for each sample modelled if they were over saturated in the solution.
Adsorption surface	Metal cations can sorb to charged surfaces. In this simulation no such sorption was simulated.

3.3.4 Model Algorithm

The algorithm comprised the following:

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[3] Parkhurst, D.L. and Appelo, C.A.J. (2013) Description of Input and Examples for PHREEQC Version 3—A Computer Program for Speciation, Batch-Reaction, One-Dimensional Transport, and Inverse Geochemical Calculations. US Geological Survey Techniques and Methods, Book 6, Chapter A43, 497 p. http://pubs.usgs.gov/tm/06/a43

1. For simulations were mixing of different solutions were required the solutions were proportioned according to the determined ratios.
2. Determine pore water quality by adjusting solid-liquid ratio of leach test to expected ratio at field capacity. This was done by modelling the removal of water from the solution.
3. Establish equilibrium composition of pore water in sediments, allowing relevant minerals to dissolve/precipitate.

3.3.5 Model Limitations

Predicting water qualities from an evaporation and settling setting, requires some assumptions and has limitations. The statistician George Box said: all models are wrong, but some models are useful (Box, 1976)[4]. This statement captures the essential truth that all model's approximate reality in that they reduce complex systems to a limited number of significant processes. How "useful" a model is depending on how closely the selected processes approximate reality.

Predicting the water qualities of complex systems demands assumptions. Even a rigorous sampling and analysis programme cannot precisely determine the physical and geochemical characteristics of the system. Nor can they precisely indicate how these characteristics may change over time.

Table 3-5 below summarises the key limitations of the input data and the hydrogeochemical model used for this assessment.

Table 3-5: Model limitations

No	Limitations	Description
1	Predicting field scale water quality from lab scale test results is an approximation.	Leaching of salts and metals at the field scale is variable in time and controlled by factors not fully applied at the lab scale. Amongst others, these factors include temperature, evaporation, nature of the leaching solution, the solution to solid ratio, solution-solid contact time and particle size of the solid. The modelled quality of water due to interaction with tailings/slimes or waste is an informed estimate.
2	The geochemical database is relevant to the system being modelled.	Hydrogeochemical modelling uses the inherently uncertain laboratory results and water qualities as inputs. These are processed using thermodynamic data determined in the laboratory on ideal materials and solutions. The laboratory determined constants may not be directly applicable to the materials, solutions, and chemical context of the waste material. The llnl.dat database was used for the model.
3	The modelling assumes thermodynamic equilibrium in the model system.	In the field, all chemical components are subject to kinetic variation and the system might, at best, be in a state of quasi equilibrium. This may suggest that attempts to simulate or predict the state of these complex systems have questionable value. However, geochemical evaluations of natural and mine waters over the last few decades have shown that the equilibrium assumption is a powerful tool that in many

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[4] George E. P. Box. "Science and Statistics." Journal of the American Statistical Association, vol. 71, no. 356, 1976, pp. 791–99. JSTOR, https://doi.org/10.2307/2286841. Accessed 2 Dec. 2025.

No	Limitations	Description
		circumstances produces results that accurately describe the general chemistry of such waters.
4	Adsorption surface	Metal cations can sorb to charged surfaces. There is no data to quantify either these surfaces, or their effect on water quality. Cation sorption linked to the amount of ferrihydrite precipitating was not modelled.

Considering the uncertainties outlined above, the available information is sufficient to provide the preliminary estimated seepage quality presented in this report. However, even though this report presents deterministic concentration values, these should be viewed as first-order approximations. As such, the predicted concentrations in this report indicate the likely order of magnitude concentrations.

4.0 River Sediment Results and Interpretations

4.1 Particle Size Distribution

Typically, downstream locations are characterised by a higher distribution of fine fractions like silt and clay whereas upstream locations are characterised by a larger distribution of coarse to medium fractions like gravel, cobble, pebbles and sand.

It is also established that there is a connection between sediment particle size and contamination, and it is suggested that downstream areas are likely to be more impacted than upstream locations. This is attributed to the accumulation of finer particles in downstream locations which can react more effectively due to their larger surface areas compared to coarser fractions. This can cause contamination concerns, especially during dry seasons where water flow is low but has enough energy to transport and deposit fine sediments downstream which accumulate and can serve as contamination zones.

Table 4-1 below shows the particle size distribution of the Nyakabingo mine river sediment samples.

It is noted that the upstream sediment (NYKSED-50) has a greater distribution of coarse particles (gravel fraction) as well as fine particles (silt and clay) compared to the mid-stream and downstream sediments respectively. Furthermore, the sand fraction of the upstream sediment is nearly half of the distribution in the mid-stream and downstream sediments. These differences in the distribution of the sand and fine particle size fractions between the sediment positions are likely attributed to the alteration of the hydrological functioning of the river system due to illegal mining as well as quarrying activities further upstream.

Table 4-1: Particle Size Distribution of Nyakabingo Mine River Sediment Materials

Mine	Sample ID	Stream Position	Gravel (2 - 75 mm)	Sand (0.05 - 2 mm)	Silt (0.002 - 0.05 mm)	Clay (< 0.002 mm)
			%	%	%	%
Nyakabingo	NYKSED-50	Upstream	5	33	40	22
	NYKSED-48	Mid-stream	4	62	31	3
	NYKSED-49	Downstream	2	60	37	1

4.2 Mineralogy

Refer to Table 4-2 below for an overview of the mineralogical composition of the river sediment samples. The upstream sediment is dominated by Quartz (48%) and Muscovite (39%) with major proportions of Kaolinite (10.8%) and minor proportions of Hematite (1.9%). The mid-stream and downstream sediments are also dominated by Quarts with major proportions of Muscovite with minor Kaolinite and trace proportions (<1%) of Hematite present in the sediments.

The mineralogical composition of the river sediment samples corroborates well with their particle size distribution. It was shown that the upstream sediment sample contains more fine particles (silt and clay) compared to the mid-stream and downstream sediments. Similarly, the XRD results show that the upstream sediment contains the highest amounts of Hematite, Muscovite and Kaolinite compared to the other sample locations. These minerals are typically associated with the fine particle size fractions like silt and clay.

In terms of the ability of the minerals in the river sediments to remediate metal leaching and acid rock drainage risks, the following is noted:

Quartz has a very limited ability to assist in remediating metal leaching and acid rock drainage risks. This is mainly because it is chemically inert, has very few reactive surface sites to facilitate surface complexation and metal adsorption and has no inherent neutralizing capacity.

Muscovite has a limited potential to remediate acid rock drainage mainly because of its slow dissolution kinetics compared to the rapid acid generating potential of Pyrite oxidation. Furthermore, it has low potential to remediate metal leaching due to it relatively minor surface area which can facilitate metal adsorption.

Kaolinite has the potential for remediating metal leaching because of its surface chemistry and structural properties. Kaolinite surfaces are also dominated by hydroxyl groups which can bind metal ions through electrostatic bonds.

Hematite is very effective in remediating metal leaching due to the abundance of hydroxyl groups on its surface that can bind several metal ions through adsorption and inner-sphere surface complexation. Furthermore, Hematite facets display notable selectivity for oxyanions, like arsenate which is influenced by the exposed facets of the Hematite crystal faces. The (001) facet shows stronger selectivity (i.e. adsorption potential) for arsenate than the (110) facet[5]. It also prevents the oxidation of Pyrite and can limit the formation of ARD.

Due to the presence of Hematite, Kaolinite and Muscovite in the sediments, it is suggested that they can sequester metals and metalloids that are mobilised to the river because of historic and current mining activities occurring in the vicinity of the river. This suggests that the sediments are likely to show an enrichment of various metals.

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[5] Liu, H, Xie, X, Wang, Y. 2024. “Competitive adsorption of arsenate and phosphate on hematite facets: Molecular insights for enhanced arsenic retention”. *Water Research* Vol 271.

Table 4-2: Nyakabingo Mine River Sediment XRD Mineralogy Results

Mineral	Formula	Mine		
		Nyakabingo		
		Sample ID		
		NYKSED-48	NYKSED-49	NYKSED-50
		Stream Position		
		Upstream	Midstream	Downstream
		Composition (%)		
Quartz	SiO_2	48.36	80.53	84.82
Hematite	Fe_2O_3	1.92	0.80	0.71
Kaolinite	$Al_2Si_2O_5(OH)_4$	10.74	3.11	2.29
Muscovite	$KAl_3Si_3O_{10}(OH)_2$	38.97	15.56	12.18
Schorl	$NaFe_3Al_6(BO_3)_3(Si_6O_{18})(OH)_4$	-	-	-

4.3 Synthetic Leaching Precipitation Procedure

The Synthetic Precipitation Leaching Procedure (SPLP) results are provided in Table 4-3. Based on the results, the following analytes exceeded applicable local and international water quality and effluent standard limits and could potentially be COPCs.

Referring to the screening tables below, the following exceedances were reported for the river sediment samples:

<u>Upstream sample (NYKSED-50)</u>

a) As and Pb (WHO Drinking)
b) Fe (IFC, RS Effluent, RS Irrigation and RS Livestock)
c) Mn (WHO Drinking, RS Irrigation and RS Livestock)

<u>Mid-stream sample (NYKSED-48)</u>

a) As (WHO Drinking)
b) Co (RS Irrigation)
c) Ni (WHO Drinking and RS Irrigation)
d) Cu (IFC, RS Irrigation and Livestock)
e) Mn (RS Livestock)
f) pH (IFC; RS Effluent and Livestock)

<u>Downstream sample (NYKSED-49)</u>

a) Co (RS Irrigation)
b) Cu (IFC, RS Irrigation and Livestock)
c) Mn (RS Livestock)
d) Ni (WHO Drinking)
e) pH (IFC; RS Effluent and Livestock)

The SPLP results show that there are more exceedances of the water quality and effluent standard limits associated with the mid-stream and downstream sediment samples compared to the upstream sample. This is likely attributed to the acidic pH of these samples which can cause a decrease in the negative surface charge of the sediment surface complexes which can lead to the desorption of metals at these pH conditions. It is also suggested that the sediments contain trace amounts of Arsenopyrite, that could not be detected during the XRD analyses. It is possible that during the SPLP procedure that the residual Arsenopyrite underwent dissolution which generates acid and could contribute to the acidic status of these sediments.

Table 4-3: Nyakabingo Mine River Sediment SPLP Screening Results

River Sediments Leachable Concentrations																					
Mine	**Stream Position**	**Analytes**	**Ag**	**Al**	**As**	**Au**	**B**	**Ba**	**Be**	**Bi**	**Ca**	**Cd**	**Ce**	**Co**	**Cr (total)**	**Cr(VI)**	**Cs**	**Cu**	**Dy**	**Er**	**Eu**	**Fe**	**Ga**
		Unit	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*
		1. WHO: Drinking Water (2022)			**0.01**		**2.4**	**1.3**				**0.003**			**0.05**		**2**						
		2. WHO: Recreational Use (2021)		**18**	**0.2**										**1**		**40**						
		3. IFC: Mining Effluent			**0.1**							**0.05**						**0.3**				**2**	
		4. RS 109 of 2009: Effluent Standards				**0.01**												**3**				**3.5**	
		5. RS 188 (2013): Irrigation Use			**5**	**0.1**			**0.1**			**0.01**		**0.05**	**0.1**			**0.2**				**5**	
		6. RS 190 (2013): Livestock Watering			**5**	**2**					**200**	**0.5**		**1**	**1**			**0.5**				**0.3**	
Nyakabingo	Upstream	NYKSED-50	0.001	5.20	0.010	0.001	0.013	0.392	0.013	0.001	5.19	0.001	0.096	0.013	0.013	0.005	0.005	0.039	0.001	0.001	0.001	7.18	0.034
	Mid-stream	NYKSED-48	0.001	8.63	0.034	0.001	0.013	0.056	0.013	0.001	23.63	0.001	0.098	0.213	0.013	0.005	0.005	0.584	0.001	0.001	0.001	0.287	0.004
	Downstream	NYKSED-49	0.001	2.11	0.004	0.001	0.013	0.087	0.013	0.001	12.03	0.001	0.029	0.123	0.013	0.005	0.005	0.517	0.001	0.001	0.001	0.040	0.007

River Sediments Leachable Concentrations																					
Mine	**Stream Position**	**Analytes**	**Gd**	**Ge**	**Hf**	**Hg**	**Ho**	**In**	**Ir**	**K**	**La**	**Li**	**Lu**	**Mg**	**Mn**	**Mo**	**Na**	**Nb**	**Nd**	**Ni**	**Os**	**P**
		Unit	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*
		1. WHO: Drinking Water (2022)				**0.006**									**0.08**		**50**			**0.07**		
		2. WHO: Recreational Use (2021)													**8**					**1.4**		
		3. IFC: Mining Effluent				**0.002**														**0.5**		
		4. RS 109 of 2009: Effluent Standards				**0.002**														**3**		
		5. RS 188 (2013): Irrigation Use										**2.5**			**0.2**	**0.01**	**3**			**0.2**		
		6. RS 190 (2013): Livestock Watering				**0.05**				**20**				**80**	**0.5**		**100**			**1**		**1**
Nyakabingo	Upstream	NYKSED-50	0.004	0.001	0.001	0.001	0.001	0.001	0.001	1.92	0.042	0.001	0.001	2.19	0.740	0.013	0.500	0.001	0.030	0.013	0.001	0.146
	Mid-stream	NYKSED-48	0.011	0.001	0.001	0.001	0.001	0.001	0.001	1.41	0.048	0.004	0.001	6.17	5.31	0.013	0.500	0.001	0.050	0.217	0.001	0.001
	Downstream	NYKSED-49	0.003	0.001	0.001	0.001	0.001	0.001	0.001	0.863	0.012	0.003	0.001	2.20	1.48	0.013	0.500	0.001	0.015	0.158	0.001	0.001

River Sediments Leachable Concentrations																					
Mine	**Stream Position**	**Analytes**	**Pb**	**Pd**	**Pr**	**Pt**	**Rb**	**Rh**	**Ru**	**Sb**	**Sc**	**Se**	**Si**	**Sm**	**Sn**	**Sr**	**Ta**	**Tb**	**Te**	**Th**	**Ti**	**Tl**
		Unit	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*
		1. WHO: Drinking Water (2022)	**0.01**							**0.02**		**0.04**										
		2. WHO: Recreational Use (2021)																				
		3. IFC: Mining Effluent	**0.2**																			
		4. RS 109 of 2009: Effluent Standards	**0.1**									**0.02**										
		5. RS 188 (2013): Irrigation Use	**5**									**0.02**										
		6. RS 190 (2013): Livestock Watering	**0.05**									**0.5**										
Nyakabingo	Upstream	NYKSED-50	0.016	0.001	0.008	0.001	0.005	0.001	0.001	0.001	0.002	0.001	8.65	0.005	0.001	0.061	0.001	0.001	0.001	0.002	0.109	0.001
	Mid-stream	NYKSED-48	0.001	0.001	0.012	0.001	0.007	0.001	0.001	0.001	0.001	0.004	1.28	0.010	0.001	0.080	0.001	0.002	0.001	0.001	0.001	0.001
	Downstream	NYKSED-49	0.001	0.001	0.003	0.001	0.002	0.001	0.001	0.001	0.001	0.006	1.48	0.003	0.001	0.060	0.001	0.001	0.001	0.001	0.001	0.001

Table 5-3: Nyakabingo Mine River Sediment SPLP Screening Results Continued

Mine	Stream Position	River Sediments Leachable Concentrations																				
		Analytes	**Tm**	**U**	**V**	**W**	**Y**	**Yb**	**Zn**	**Zr**	**pH**	**EC**	**TDS**	**Tot Alk**	**Cl**	**SO4**	**NO3**	**NO2**	**F**	**Free NH3**	**Ortho-P**	**Total Cn**
		Unit	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*		*mS/m*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*
		1. WHO: Drinking Water (2022)		**0.03**													**50**	**3**	**1.5**			
		2. WHO: Recreational Use (2021)																				
		3. IFC: Mining Effluent							**0.5**		**6-9**											**1**
		4. RS 109 of 2009: Effluent Standards							**5**		**5-9**		**2000**									
		5. RS 188 (2013): Irrigation Use			**0.1**				**2**				**450**				**5**		**1**			
		6. RS 190 (2013): Livestock Watering		**0.2**	**0.1**				**25**		**6-9**		**1000**	**500**	**100**	**250**	**25**	**10**				
Nyakabingo	Upstream	NYKSED-50	0.001	0.001	0.013	0.001	0.008	0.001	0.013	0.001	6.40	6.40	17	16	4	5	0.100	0.025	0.200	0.050	0.050	0.035
	Mid-stream	NYKSED-48	0.001	0.003	0.013	0.001	0.037	0.004	0.475	0.001	3.50	42.80	287	3	2	180	0.050	0.025	0.200	0.700	0.050	0.035
	Downstream	NYKSED-49	0.001	0.001	0.013	0.001	0.013	0.001	0.363	0.001	3.90	18.60	125	3	1	67	0.400	0.025	0.200	0.100	0.050	0.035

Note: Values in grey text represent below detection limit values.

4.4 Total Metal Concentrations and Geochemical Abundance Index

Table 4-4 shows the total metal concentration results of the sediment samples that were screened against the SSV1 (all land uses) thresholds to assess if any element is a potential contaminant. Based on the screening results, the following exceedances were reported for the river sediment samples and could potentially be contaminants.

The following exceedances were reported:

Upstream sediment sample (NYKSED-50)

- As, Cu and Pb.

Mid-stream sediment sample (NYKSED-48)

- As, Cu, Hg and Pb

Downstream sediment sample (NYKSED-49)

- As, Cu, Hg and Pb

The total metal concentration results of the sediment samples show that anthropogenic activities have likely impacted the river system in the vicinity of the Nyakabingo mine. This is likely attributed to historic and current panning and illegal mining activities along the river, and runoff from the legacy tailings piles. Furthermore, the mid-stream and downstream sediments reported higher metal concentrations as well as more exceedances of the SSV1 limits which imply that they are more impacted.

Table 4-5 shows the GAI values that were compared to the estimated average crustal abundance of the various elements analysed to assess the significance of elemental enrichment in the sediments and determine the likelihood of contamination. Based on the calculated GAI values of the metals that were analysed, the following is noted:

Upstream sediment sample (NYKSED-50)

- As and B show a GAI>3 (implying significant enrichment and potential contamination)

Mid-stream sediment sample (NYKSED-48)

- Hg and Se show a GAI>3 (implying significant enrichment and potential contamination)
- As and W show a GAI>6 (implying extreme enrichment and likely contamination)

Downstream sediment sample (NYKSED-49)

- Hg and Se show a GAI>3 (implying significant enrichment and potential contamination)
- As and W show a GAI>6 (implying extreme enrichment and likely contamination)

Table 4-4: Nyakabingo Mine River Sediment Total Metal Concentration Screening Results

Mine	Stream Position	Analytes	Ag	Al	As	Au	B	Ba	Be	Bi	Ca	Cd	Ce	Co	Cr (total)	Cs	Cu	Dy	Er	Eu	Fe	Ga
		Unit	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*
		SSV1 (All Land Uses Protective of the Water Resource)			**5.8**							**7.5**		**300**			**16**					
Nyakabingo	Upstream	NYKSED-50	0.200	41159	127	0.200	130	102	5	0.471	200	0.200	0.91	5	90	0.471	32	0.200	0.200	0.200	52507	23
	Mid-stream	NYKSED-48	0.200	25288	542	0.200	90	130	5	1.037	200	0.200	1.00	5	72	0.200	38	0.200	0.200	0.200	37701	15
	Downstream	NYKSED-49	0.200	25886	417	0.200	101	175	5	1.271	200	0.200	5.87	5	159	0.541	49	0.200	0.200	0.200	45347	16

Mine	Stream Position	Analytes	Gd	Ge	Hf	Hg	Ho	In	Ir	K	La	Li	Lu	Mg	Mn	Mo	Na	Nb	Nd	Ni	Os	P
		Unit	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*
		SSV1 (All Land Uses Protective of the Water Resource)				**1**									**740**					**91**		
Nyakabingo	Upstream	NYKSED-50	0.200	1.96	9.57	0.200	0.200	0.200	0.200	20589	0.200	10.3	0.200	0.200	224	5	2176	32.9	0.200	28.4	0.200	1381
	Mid-stream	NYKSED-48	0.200	1.76	0.71	3.32	0.200	0.200	0.200	11652	0.200	9.6	0.200	487	213	5	448	20.4	0.200	13.4	0.200	1543
	Downstream	NYKSED-49	0.200	2.03	0.200	5.79	0.200	0.200	0.200	10295	0.472	8.2	0.200	413	252	5	646	30.4	0.629	16.8	0.200	1567

Mine	Stream Position	Analytes	Tm	U	V	W	Y	Yb	Zn	Zr
		Unit	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*
		SSV1 (All Land Uses Protective of the Water Resource)			**150**				**240**	
Nyakabingo	Upstream	NYKSED-50	0.200	3.37	137.62	8.41	0.200	0.200	29.0	190
	Mid-stream	NYKSED-48	0.200	3.46	70.23	687	0.200	0.200	23.2	161
	Downstream	NYKSED-49	0.200	4.46	79.21	1076	0.200	0.200	38.4	166

Note: Values in grey text represent below detection limit concentrations

Table 4-5: Nyakabingo Mine River Sediment GAI Screening Results

Mine	Stream Position	Analytes	Ag	Al	As	Au	B	Ba	Be	Bi	Ca	Cd	Ce	Co	Cr (total)	Cs	Cu	Dy	Er	Eu	Fe	Ga
		Unit	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*
		Average Crustal Abundance (Smith and Huyck, 1999)	**0.07**	**80000**	**2**	**0.004**	**10**	**430**	**3**	**0.2**	**3000**	**0.18**	**45**	**25**	**200**	**3**	**60**	**4.5**		**1.2**	**50000**	**17**
		1. GAI ≥ 3: Significant enrichment (potential contamination)																				
		2. GAI ≥ 6: Extreme enrichment (likely contamination)																				
Nyakabingo	Upstream	NYKSED-50	0.200	-1.54	5.40	0.200	3.11	-2.66	5	0.65	200	0.200	-6.21	5	-1.74	-3.25	-1.48	0.200	0.200	0.200	-0.51	-0.17
	Mid-stream	NYKSED-48	0.200	-2.25	7.50	0.200	2.59	-2.32	5	1.79	200	0.200	-6.08	5	-2.06	0.200	-1.25	0.200	0.200	0.200	-0.99	-0.75
	Downstream	NYKSED-49	0.200	-2.21	7.12	0.200	2.74	-1.88	5	2.08	200	0.200	-3.52	5	-0.92	-3.06	-0.89	0.200	0.200	0.200	-0.73	-0.66

Mine	Stream Position	Analytes	Gd	Ge	Hf	Hg	Ho	In	Ir	K	La	Li	Lu	Mg	Mn	Mo	Na	Nb	Nd	Ni	Os	P
		Unit	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*
		Average Crustal Abundance (Smith and Huyck, 1999)	**7**	**15**		**0.08**		**0.1**	**0.001**	**26000**		**30**	**0.9**	**21000**	**900**	**2**	**24000**	**20**	**25**	**80**		**1000**
		1. GAI ≥ 3: Significant enrichment (potential contamination)																				
		2. GAI ≥ 6: Extreme enrichment (likely contamination)																				
Nyakabingo	Upstream	NYKSED-50	0.200	-3.52	NV	0.200	0.200	0.200	0.200	-0.92	NV	0.200	-2.75	0.200	-2.59	5	-4.05	0.13	0.200	-2.08	0.200	-0.12
	Mid-stream	NYKSED-48	0.200	-3.68	NV	4.79	0.200	0.200	0.200	-1.74	NV	0.200	-2.75	-6.02	-2.67	5	-6.33	-0.55	0.200	-3.16	0.200	0.04
	Downstream	NYKSED-49	0.200	-3.47	NV	5.59	0.200	0.200	0.200	-1.92	NV	0.200	-2.75	-6.25	-2.42	5	-5.80	0.02	-5.90	-2.84	0.200	0.06

Mine	Stream Position	Analytes	Pb	Pd	Pr	Pt	Rb	Rh	Ru	Sb	Sc	Se	Si	Sm	Sn	Sr	Ta	Tb	Te	Th	Ti	Tl
		Unit	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*
		Average Crustal Abundance (Smith and Huyck, 1999)	**16**	**0.01**		**0.005**	**120**					**0.09**	**270000**	**7**	**2.5**	**350**	**2**			**10**	**5000**	**1**
		1. GAI ≥ 3: Significant enrichment (potential contamination)																				
		2. GAI ≥ 6: Extreme enrichment (likely contamination)																				
Nyakabingo	Upstream	NYKSED-50	0.33	0.200	0.200	0.200	-2.19	0.200	0.200	0.200	NV	0.200	-1.20	-5.71	-0.31	5	0.70	0.200	NV	-1.71	0.51	-0.53
	Mid-stream	NYKSED-48	0.31	0.200	0.200	0.200	-3.10	0.200	0.200	0.200	NV	3.86	-0.89	-5.71	-0.08	5	0.28	0.200	NV	-1.98	0.30	-1.48
	Downstream	NYKSED-49	0.68	0.200	0.200	0.200	-2.82	0.200	0.200	0.200	NV	3.56	-0.85	-5.71	-0.18	-5.51	0.82	0.200	NV	-0.86	1.03	-1.41

Mine	Stream Position	Analytes	Tm	U	V	W	Y	Yb	Zn	Zr
		Unit	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*
		Average Crustal Abundance (Smith and Huyck, 1999)		**3**	**150**	**1**	**30**	**3**	**70**	**160**
		1. GAI ≥ 3: Significant enrichment (potential contamination)								
		2. GAI ≥ 6: Extreme enrichment (likely contamination)								
Nyakabingo	Upstream	NYKSED-50	0.200	-0.42	-0.71	2.49	0.200	0.200	-1.86	-0.34
	Mid-stream	NYKSED-48	0.200	-0.38	-1.68	8.84	0.200	0.200	-2.18	-0.58
	Downstream	NYKSED-49	0.200	-0.01	-1.51	9.49	0.200	0.200	-1.45	-0.53

Note: Values in grey text show below detection limit concentrations and no GAI value was calculated whereas NV implies no value calculated due to absence of an average crustal abundance.

5.0 Legacy Tailings Results and Interpretations

5.1 Mineralogy

Table 5-1 shows the XRD results of the Nyakabingo mine legacy tailings piles. The primary lithologies that are diagnostic of the site include Shale, Quartz Vein and Meta Sandstone.

The Nyakabingo Shale is dominated by Muscovite (60.7%) and Quartz (36.5%) with minor proportions (2.77%) of Kaolinite. The Nyakabingo Meta Sandstone is also dominated by Quartz (87.2%) with minor proportions of Kaolinite (7.17%) and Muscovite (5.65%) respectively. Lastly, the Nyakabingo Quartz vein consists entirely of Quartz with no accessory minerals detected during the analysis.

The XRD analyses did not detect the presence of acid producing minerals (like sulfides) in association with any of the legacy tailings lithologies. This suggests that the tailings are likely to have a low acid rock drainage (ARD) risk.

Table 5-1: Nyakabingo Mine Legacy Tailings XRD Results

Mineral	Formula	Mine		
		Nyakabingo		
		Sample ID		
		NYK-LT-45	NYK-LT-46	NYK-LT-47
		Rock Type		
		Shale	Quartz Vein	Meta Sandstone
		Composition (%)		
Quartz	SiO_2	36.5	100	87.2
Muscovite	$KAl_3Si_3O_{10}(OH)_2$	60.73	-	5.65
Kaolinite	$Al_2Si_2O_5(OH)_4$	2.77	-	7.15
Goethite	$Fe_2O_3.H_2O$	-	-	-
Palygorskite	$Mg_5Si_8O_{20}(OH)_2 \cdot 8H_2O$	-	-	-
Dravite	$NaMg_3Al_6(BO_3)_3Si_6O_{18}(OH)_4$	-	-	-
Hematite	Fe_2O_3	-	-	-

5.2 Acid Base Accounting

Sulphur speciation and Acid Base Accounting (ABA) analysis were undertaken on the Nyakabingo mine legacy tailings materials. The results are presented in Table 5-2 and Table 5-3 respectively.

The sulfur speciation results reported for the legacy tailings samples show negligible to minor total sulfur percentages. Only the Nyakabingo Quartz Vein sample reported a detectable amount whilst the Shale and Meta Sandstone samples returned below detection limit values. Furthermore, the total sulfur of the Quartz Vein sample is wholly made up of sulfate S which is supported by the findings of the XRD analyses as no sulfides were detected in any of the legacy tailings samples. Due to the absence of notable total sulfur contents and Sulfide S in the legacy tailings samples, it reinforces their minimal to low ARD risk status.

Table 5-2: Nyakabingo Mine Legacy Tailings Sulfur Speciation Results

Mine	Rock Type	Sample ID	Total Sulphur	Sulphide S	Sulphate Sulphur
			%	%	%
Nyakabingo	Shale	NYK-LT-45	<0.010	<0.010	<0.010
	Quartz Vein	NYK-LT-46	0.011	<0.010	0.010
	Meta Sandstone	NYK-LT-47	<0.010	<0.010	<0.010

The ABA results shows that the Nyakabingo Shale reported an alkaline paste pH value (8), a Neutralisation Potential Ratio (NPR) value between 1 and 4 (3.16) and a Net Neutralisation Potential (NNP) value between -20 and 20 (-1.30). These indicators show that the sample is non potential acid generating (non-PAG).

The Nyakabingo Quartz Vein reported a circum-neutral paste pH value (6.5), NPR value between 1 and 4 (3.61) as well as a NNP value of between -20 and 20 (0.90). These results classify the sample is also non-PAG.

Lastly, the Nyakabingo Meta Sandstone sample has a weakly acidic paste pH value (6.1) and NPR between 1 and 4 (1.58) as well as a NNP value between -20 and 20 (-0.81). This suggests that the material has an intermediate potential to generate acid.

ABA tests are based on determining the sulphur/sulphide content of a material to calculate the sulphide acid potential (SAP) and neutralisation potential (NP), which is determined by the proportion of carbonate and other alkaline minerals. This evaluation determines whether materials will have a net acid-generating or neutralising potential. Consequently, ABA tests do not directly measure acid production over time but estimate the potential for acid generation based on the mineralogical composition of a material.

The NP values for the Nyakabingo Shale and Meta Sandstone samples are less than their AP values which is attributed to the lack of rapidly dissolving or reacting neutralising minerals, such as carbonates and the presence of poorly crystalline / amorphous sulphide minerals in the samples which were not detected during the XRD analysis.

Due to the contradictions between complex in-field and laboratory test conditions when determining the acid generation potential of mine waste materials, geochemists often use phase diagrams where sample data is plotted on Paste pH vs NPR charts. This is used to graphically classify otherwise inconclusive results that could potentially occur.

In Figure 5-1 below:

- Nyakabingo Shale and Quartz Vein samples are distinctly classified as non-PAG.
- Nyakabingo Meta Sandstone is classified as having an intermediate potential to generate acid.

Table 5-3: Nyakabingo Mine Legacy Tailings ABA Results

Mine	Rock Type	Sample ID	Paste pH	Total S	Sulphide Acid Potential (AP)	Neutralization Potential (NP)	Neutralisation potential ratio (NPR)	Nett Neutralization Potential (NNP)	Classification
			-	**%**	**kg/t $CaCO_3$**	**kg/t $CaCO_3$**		**Kg/t $CaCO_3$**	
		Non-PAG	**>5.5**	**<0.3**			**>4**	**>20**	
		Intermediate	**3.5-5.5**				**1 to 4**	**-20 to 20**	
		PAG/AG	**<3.5**	**>0.3**			**<1**	**<-20**	
Nyakabingo	Shale	NYK-LT-45	8.1	<0.010	0.313	-0.988	3.16	-1.30	Non-PAG
	Quartz Vein	NYK-LT-46	6.5	0.011	0.344	1.24	3.61	0.896	Non-PAG
	Meta Sandstone	NYK-LT-47	6.1	<0.010	0.313	-0.493	1.58	-0.805	Intermediate

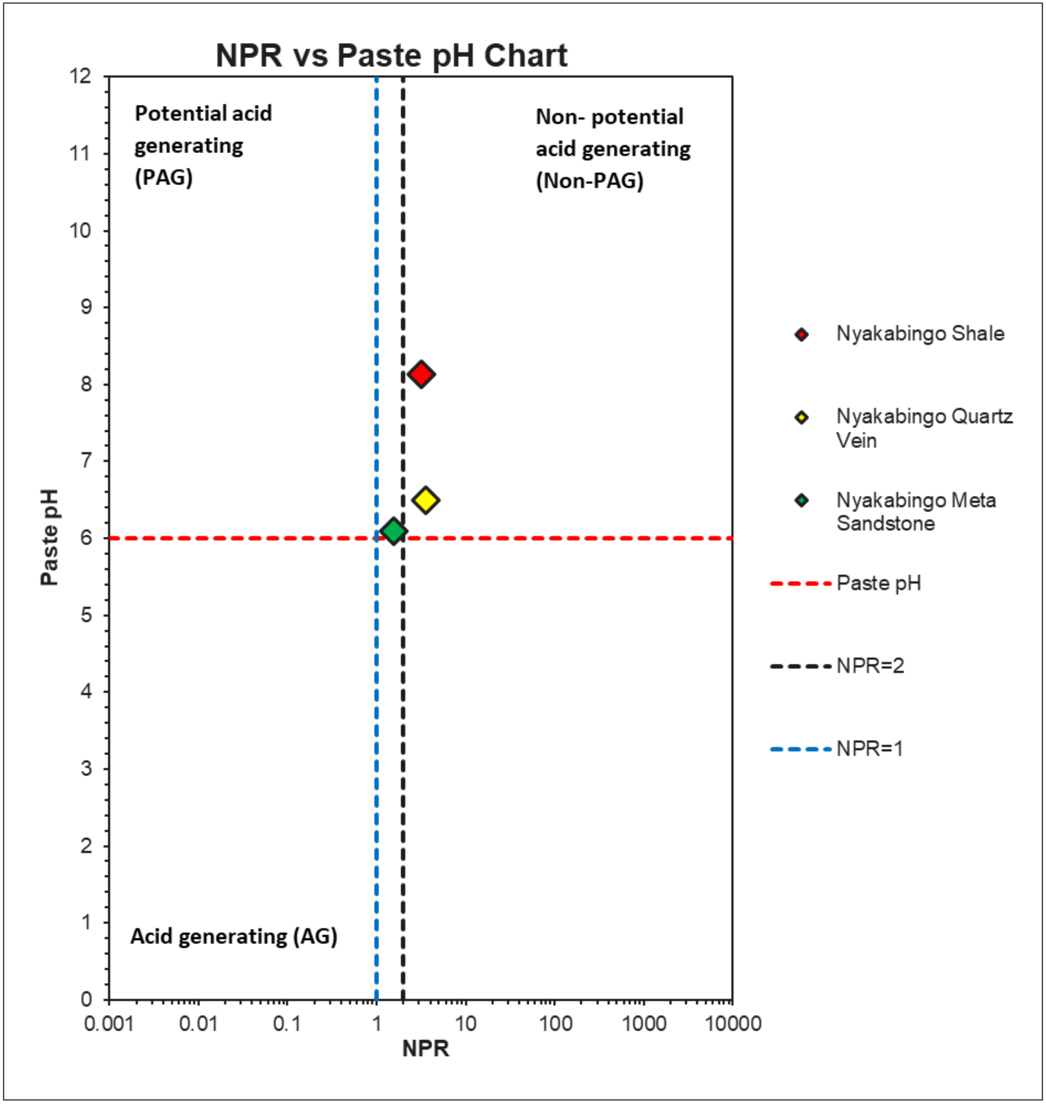

Figure 5-1: Nyakabingo Mine Legacy Tailings Materials Acid Generating Potential Plot

5.3 Synthetic Precipitation Leaching Procedure Screening

The Synthetic Precipitation Leaching Procedure (SPLP) results are provided in Table 5-4. Based on the results, the following analytes exceeded applicable local and international water quality and effluent standard limits and could potentially be COPCs.

Referring to the screening tables below, the following exceedances were reported for the:

Nyakabingo Quartz Vein:

- Mn (WHO Drinking and RS Irrigation)

Nyakabingo Meta Sandstone:

- Mn (WHO Drinking and RS Irrigation)
- pH (IFC and RS Livestock)

The Nyakabingo shale SPLP results did not report any exceedances.

Table 5-4: Nyakabingo Mine Legacy Tailings Materials SPLP Screening Results

Mine	Rock Type	Analytes	Ag	Al	As	Au	B	Ba	Be	Bi	Ca	Cd	Ce	Co	Cr (total)	Cr(VI)	Cs	Cu	Dy	Er	Eu	Fe	Ga
		Unit	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*
		1. WHO: Drinking Water (2022)			**0.01**		**2.4**	**1.3**				**0.003**			**0.05**		**2**						
		2. WHO: Recreational Use (2021)		**18**	**0.2**										**1**		**40**						
		3. IFC: Mining Effluent			**0.1**							**0.05**						**0.3**				**2**	
		4. RS 109 of 2009: Effluent Standards				**0.01**												**3**				**3.5**	
		5. RS 188 (2013): Irrigation Use			**5**	**0.1**			**0.1**			**0.01**		**0.05**	**0.1**			**0.2**				**5**	
		6. RS 190 (2013): Livestock Watering			**5**	**2**					**200**	**0.5**		**1**	**1**			**0.5**				**0.3**	
Nyakabingo	Shale	NYK-LT-45	0.0005	0.0005	0.004	0.0005	0.013	0.013	0.013	0.0005	0.50	0.0005	0.0005	0.013	0.005	0.013	0.0005	0.0005	0.0005	0.0005	0.0005	0.013	0.0005
	Quartz Vein	NYK-LT-46	0.0005	0.0005	0.0005	0.0005	0.013	0.013	0.013	0.0005	1.36	0.0005	0.0005	0.013	0.005	0.013	0.002	0.0005	0.0005	0.0005	0.0005	0.013	0.0005
	Meta Sandstone	NYK-LT-47	0.0005	0.0005	0.0005	0.0005	0.013	0.013	0.013	0.0005	2.83	0.0005	0.0005	0.013	0.005	0.013	0.0005	0.0005	0.0005	0.0005	0.0005	0.125	0.0005

Mine	Rock Type	Analytes	Gd	Ge	Hf	Hg	Ho	In	Ir	K	La	Li	Lu	Mg	Mn	Mo	Na	Nb	Nd	Ni	Os	P
		Unit	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*
		1. WHO: Drinking Water (2022)				**0.006**									**0.08**		**50**			**0.07**		
		2. WHO: Recreational Use (2021)													**8**					**1.4**		
		3. IFC: Mining Effluent				**0.002**														**0.5**		
		4. RS 109 of 2009: Effluent Standards				**0.002**														**3**		
		5. RS 188 (2013): Irrigation Use										**2.5**			**0.2**	**0.01**	**3**			**0.2**		
		6. RS 190 (2013): Livestock Watering				**0.05**				**20**				**80**	**0.5**		**100**			**1**		**1**
Nyakabingo	Shale	NYK-LT-45	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	3.93	0.0005	0.0005	0.0005	0.500	0.013	0.013	0.500	0.0005	0.0005	0.013	0.0005	0.058
	Quartz Vein	NYK-LT-46	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.25	0.0005	0.0005	0.0005	0.500	0.420	0.013	0.500	0.0005	0.0005	0.013	0.0005	0.194
	Meta Sandstone	NYK-LT-47	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	1.22	0.0005	0.0005	0.0005	0.500	0.275	0.013	0.500	0.0005	0.0005	0.013	0.0005	0.0005

Mine	Rock Type	Analytes	Pb	Pd	Pr	Pt	Rb	Rh	Ru	Sb	Sc	Se	Si	Sm	Sn	Sr	Ta	Tb	Te	Th	Ti	Tl
		Unit	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*
		1. WHO: Drinking Water (2022)	**0.01**							**0.02**		**0.04**										
		2. WHO: Recreational Use (2021)																				
		3. IFC: Mining Effluent	**0.2**																			
		4. RS 109 of 2009: Effluent Standards	**0.1**									**0.02**										
		5. RS 188 (2013): Irrigation Use	**5**									**0.02**										
		6. RS 190 (2013): Livestock Watering	**0.05**									**0.5**										
Nyakabingo	Shale	NYK-LT-45	0.0005	0.0005	0.0005	0.0005	0.011	0.0005	0.0005	0.0005	0.0005	0.0005	1.136	0.0005	0.0005	0.013	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
	Quartz Vein	NYK-LT-46	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.211	0.0005	0.0005	0.013	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
	Meta Sandstone	NYK-LT-47	0.0005	0.0005	0.0005	0.0005	0.004	0.0005	0.0005	0.0005	0.0005	0.0005	0.481	0.0005	0.0005	0.013	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005

Mine	Rock Type	Analytes	Tm	U	V	W	Y	Yb	Zn	Zr	pH	EC	TDS	Tot Alk	Cl	SO4	NO3	NO2	F	Free NH3	Ortho-P	Total Cn
		Unit	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*		*mS/m*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*
		1. WHO: Drinking Water (2022)		**0.03**													**50**	**3**	**1.5**			
		2. WHO: Recreational Use (2021)																				
		3. IFC: Mining Effluent							**0.5**		**6-9**											**1**
		4. RS 109 of 2009: Effluent Standards							**5**		**5-9**		**2000**									
		5. RS 188 (2013): Irrigation Use			**0.1**				**2**				**450**				**5**		**1**			
		6. RS 190 (2013): Livestock Watering		**0.2**	**0.1**				**25**		**6-9**		**1000**	**500**	**100**	**250**	**25**	**10**				
Nyakabingo	Shale	NYK-LT-45	0.0005	0.0005	0.013	0.0005	0.0005	0.0005	0.013	0.0005	7.10	1.30	38	20	1	1	1.1	0.025	0.1	0.3	0.05	0.035
	Quartz Vein	NYK-LT-46	0.0005	0.0005	0.013	0.0005	0.0005	0.0005	0.013	0.0005	6.00	1.50	5	30	1	1	0.05	0.025	0.1	0.05	0.1	0.035
	Meta Sandstone	NYK-LT-47	0.0005	0.0005	0.013	0.0005	0.0005	0.0005	0.013	0.0005	5.80	4.00	14	20	1	1	2.6	0.025	0.1	0.3	0.05	0.035

Note: Values in grey text represent below detection limit concentrations

5.4 Geochemical Source Terms

To assess or predict impacts to surface and groundwater resources from any material or waste facility that may be a significant source of contamination, a source term should be derived. Preliminary source terms have been modelled for the Nyakabingo mine legacy tailings pile lithologies.

To simulate the conditions that the Nyakabingo mine legacy tailings piles will be subject to, the model was developed by allowing freely available supply of oxygen to the tailings piles thereby representing unlimited contact between the Earth’s atmosphere and the lithologies in the tailings piles.

Evaporation was not modelled due to PHREEQC's limitations in concentrating mixtures over time steps. The source term results are summarised in Table 5-5. Half detection limits were used for those common major and trace elements that reported below detection limits.

Based on the modelled source terms, the following exceedances are noted for two of the legacy tailings lithologies at the Nyakabingo mine.

Quartz Vein and Meta Sandstone samples:

- Mn (WHO Drinking and RS Irrigation)

Table 5-5: Nyakabingo Mine Legacy Tailings Materials Source Term Screening Results

Nyakabingo Mine Legacy Tailings Geochemical Source Terms										
Element	**Units**	**WHO: Drinking Water (2022)**	**WHO: Recreational Use (2021)**	**IFC: Mining Effluent**	**RS 109 (2009): Effluent Standards**	**RS 188 (2013): Irrigation Use**	**RS 190 (2013): Livestock Watering**	**Nyakabingo Shale**	**Nyakabingo Quartz Vein**	**Nyakabingo Meta Sandstone**
Ag	mg/L							0.000	0.000	0.000
Al	mg/L		**18**					0.000	0.000	0.000
As	mg/L	**0.01**	**0.2**	**0.1**		**5**	**5**	0.004	0.000	0.000
Au	mg/L				**0.01**	**0.1**	**2**	0.000	0.000	0.000
B	mg/L	**2.4**						0.007	0.007	0.007
Ba	mg/L	**1.3**						0.006	0.006	0.006
Be	mg/L					**0.1**		0.007	0.007	0.007
HCO_3^-	mg/L							22.60	30.96	20.72
Ca	mg/L						**200**	0.250	1.36	2.38
Cd	mg/L	**0.003**		**0.05**		**0.01**	**0.5**	0.000	0.000	0.000
Ce	mg/L							0.000	0.000	0.000
Cl	mg/L						**100**	0.500	0.500	0.500
Co	mg/L					**0.05**	**1**	0.003	0.003	0.003
Cr	mg/L	**0.05**	**1**			**0.1**	**1**	0.001	0.001	0.001
Cs	mg/L	**2**	**40**					0.000	0.002	0.002
Cu	mg/L			**0.3**	**3**	**0.2**	**0.5**	0.000	0.000	0.000
Dy	mg/L							0.000	0.000	0.000
Er	mg/L							0.000	0.000	0.000
Eu	mg/L							0.000	0.000	0.000
F	mg/L	**1.5**				**1**		0.050	0.050	0.050
Fe	mg/L			**2**	**3.5**	**5**	**0.3**	0.007	0.007	0.125
Ga	mg/L							0.000	0.000	0.000
Gd	mg/L							0.000	0.000	0.000
He	mg/L							1.24	1.23	1.23
Hf	mg/L							0.000	0.000	0.000
Hg	mg/L	**0.006**		**0.002**	**0.002**		**0.05**	0.000	0.000	0.000
Ho	mg/L							0.000	0.000	0.000
In	mg/L							0.000	0.000	0.000
K	mg/L						**20**	5.00	9.41	10.11
La	mg/L							0.000	0.000	0.000
Li	mg/L					**2.5**		0.000	0.000	0.000
Lu	mg/L							0.000	0.000	0.000
Mg	mg/L						**80**	0.250	0.250	0.250
Mn	mg/L	**0.08**	**8**			**0.2**	**0.5**	0.006	**0.420**	**0.275**
Mo	mg/L					**0.01**		0.007	0.007	0.007
NO_3^-	mg/L	**50**				**5**	**25**	2.21	0.133	3.71
Na	mg/L	**50**				**3**	**100**	0.250	0.250	0.250
Nd	mg/L							0.000	0.000	0.000
Ni	mg/L	**0.07**	**1.4**	**0.5**	**3**	**0.2**	**1**	0.007	0.007	0.007
P	mg/L							0.058	0.194	0.000
Pb	mg/L	**0.01**		**0.2**	**0.1**	**5**	**0.05**	0.000	0.000	0.000
Pd	mg/L							0.000	0.000	0.000
Pr	mg/L							0.000	0.000	0.000
Rb	mg/L							0.011	0.011	0.004
SO_4^{2-}	mg/L						250	0.500	0.500	0.500
Sb	mg/L	**0.02**						0.000	0.000	0.000

Nyakabingo Mine Legacy Tailings Geochemical Source Terms										
Element	Units	**WHO: Drinking Water (2022)**	**WHO: Recreational Use (2021)**	**IFC: Mining Effluent**	**RS 109 (2009): Effluent Standards**	**RS 188 (2013): Irrigation Use**	**RS 190 (2013): Livestock Watering**	**Nyakabingo Shale**	**Nyakabingo Quartz Vein**	**Nyakabingo Meta Sandstone**
Sc	mg/L							0.000	0.000	0.000
Se	mg/L	**0.04**			**0.02**	**0.02**	**0.5**	0.000	0.000	0.000
Si	mg/L							2.64	2.64	2.64
Sm	mg/L							0.000	0.000	0.000
Sn	mg/L							0.000	0.000	0.000
Sr	mg/L							0.007	0.007	0.007
Tb	mg/L							0.000	0.000	0.000
Th	mg/L							0.000	0.000	0.000
Ti	mg/L							0.000	0.000	0.000
Tl	mg/L							0.000	0.000	0.000
Tm	mg/L							0.000	0.000	0.000
U	mg/L	**0.03**					**0.2**	0.000	0.000	0.000
V	mg/L					**0.1**	**0.1**	0.007	0.007	0.007
W	mg/L							0.000	0.000	0.000
Y	mg/L							0.000	0.000	0.000
Yb	mg/L							0.000	0.000	0.000
Zn	mg/L			**0.5**	**5**	**2**	**25**	0.006	0.006	0.006
Zr	mg/L							0.000	0.000	0.000
pH				**6-9**	**5-9**		**6-9**	7.27	7.00	6.97

6.0 Soil Results and Interpretations

The soil assessment focused on the downstream areas in relation to the mine footprint. Two locations were identified for the visual soil assessment / classification, and a soil sample was collected from the most downstream observation point for the required laboratory analysis.

6.1 Soil Classification

Refer to Table 6-1 for the observations and descriptions of the soil classification assessment for the Nyakabingo mine. The soils in the downstream areas of the mine footprint were classified as a Ferralsol according to the IUSS Working Group WRB (2022)[6] International Soil Classification System.

Ferralsol

Ferralsols are characterized by a Ferralic horizon which are mainly mineral horizons and are formed because of long and intense weathering. They are common in humid tropical and subtropical regions and often have a red or yellow hue due to the abundance of Fe and Al oxides. These soils are mineralogically characterized by primary Quartz with the clay fraction being dominated by low activity clay minerals (i.e. 1:1 minerals), like Kaolinite, which exhibit a low potential to shrink or swell as well as a relatively low cation exchange capacity. Furthermore, the silt and sand fractions are dominated by highly resistant minerals like Goethite, Hematite and Gibbsite[7].

These soils have a limited capacity to store available water for plants as they are well drained and are often characterized by extensive depths, with stable microstructures that prompt good porosity and infiltration capabilities. Chemically, they are considered poor and infertile as they usually contain low contents of nitrogen, potassium and secondary nutrients like calcium, magnesium and sulphur[8]. This is largely attributed to their susceptibility to leaching, which removes cations from surfaces complexes and contributes to nutrient depletion. Furthermore, these soils are typically acidic and have a low CEC that is pH dependent and can readily fix phosphate by retaining it on soil colloids.

Ferralsols can contribute to remediating metal leaching through the retention of metals and metalloids in the terrestrial environment. However, this ability is often insufficient to fully remediate significant contamination concerns and must be coupled with specific management strategies.

It should also be noted that the presence of Fe and Al oxides in Ferralsols plays a key role in regulating the mobility and retention of metals and metalloids. These oxides have variable surface charges and high surface areas which assists in adsorbing metals like Cu, Pb, Zn, Ni, Cr and As. However, the sorbed metals can remobilise if soil pH conditions change to an acidic range.

It should also be noted that Ferralsols have a limited ability to remediate acid rock drainage because of their low CEC and acidic nature. This implies a limited buffering capacity to neutralize acidity that is introduced by acid rock drainage. Consequently, the overall capacity of Ferralsols to remediate metal leaching and acid rock drainage is limited.

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[6] IUSS Working Group WRB. 2022. World Reference Base for Soil Resources. International soil classification system for naming soils and creating legends for soil maps. 4th edition. International Union of Soil Sciences (IUSS), Vienna, Austria.

[7] Deckers, J, Mantel, S, Nachtergaele, F and Vancampenhout, K. 2024. WRB Documentation Centre. Prototype Version 1. Example: Ferralsols.

[8] El Mellouki, M, Boularbah, A and Kebede, F. 2025. “Quantitative evaluation of potentially toxic elements and associated risks in Acrisols and Ferralsols of western Ghana.” *Front. Soil Sci* 01-14.

Table 6-1: Nyakabingo Mine Downstream Soil Descriptions and Classification

Mine	Observation ID	Coordinates		Depth (m)	Description	WRB Soil Group
		Latitude	Longitude			
Nyakabingo	NYKSS-01	1°52’51.05”S	29°58’20.5”E	0 – 0.03	The soil is dry and has a light brown hue with a few fine roots. The transition to the underlying horizon is gradual.	Ferralsol
				0.03 – 0.32	The soil is dry with a light brown hue and contains a 10 – 20% stone fraction in its matrix. There are a few medium sized roots present, but the matrix consists of mainly weathered material indicative of a mineral layer. It has a sandy loam texture with a massive structure and demonstrates a loose cohesionless sub-structure. It shows signs of good drainage capability and the transition to the underlying material is gradual.	
				0.32 – 1.07	The soil is slightly moist and has a reddish-brown hue. There is more clay present than in the overlying material. It is characterized by a silty clay loam texture with a sub-angular blocky structure. The transition to the underlying material is abrupt due to a marked increase in clay content.	
				1.07 – 1.40	The soil is slightly moist and has a dark brown hue. It has a predominantly clay texture and demonstrates a sub-angular blocky structure with a polyhedral unit sub-structure which is typical of high clay content soils. There appears to be some Mn mottles present at the bottom of the profile as black specs which may be due to waterlogged conditions owing to increased clay content of the horizon.	
	NYKSS-02	1°53’19.8”S	29°58’21.0”E	0 – 0.03	The soil is dry and populated with a fine mated root structure. It has a light brown hue and transitions gradually to the underlying material.	
				0.03 – 0.30	The soil is dry and has a brown hue with a massive, cohesionless structure. It is characterized by a sandy clay loam texture with marked clay enrichment towards the bottom of the profile. Refusal was intersected at 0.30 m and auguring was aborted.	

Note: A soil sample was obtained from NYKSS-02 for the laboratory analysis.

6.2 Physicochemical Soil Properties

Table 6-2 shows the physicochemical properties of the downstream soil sample that was analysed as part of the Nyakabingo mine soil assessment. The soil has a sandy clay loam texture with a higher percentage of sand (55%) compared to the silt and clay fractions. This suggests that the soil has good porosity and infiltration capabilities as indicative of a Ferralsol.

The organic carbon content is low and could be attributed to the rapid decomposition of organic matter due to the climate of the region. Furthermore, the absence of high activity clay minerals (i.e. 2:1 minerals) or the abundance of Fe and Al oxides can contribute to the low organic carbon content as these oxides do not tend to complex with organic carbon. The low organic carbon content of the downstream soil sample implies a limited acid buffering capacity, thus making it more prone to acidification and nutrient leaching.

The pH of the soil is classified as acidic (5.7) and falls within a range that reduces the availability of several essential nutrients like N, K, Ca and Mg. Furthermore, certain trace and heavy metals become more available at this pH level and can potentially reach phytotoxic levels.

It is also noted that the solubility of metals and metalloids can increase under such pH conditions because of the saturation of surface complex sites with H^+ ions. This releases metal ions into the soil solution making them more mobile and contributes to a leaching risk. On average, the soil has a low CEC (<10 cmol+/kg) which is typically of sandy textured soils. This suggests that the soil is prone to leaching and is unlikely to buffer changes in pH.

Table 6-2: Nyakabingo Mine Downstream Soil Physicochemical Properties

Mine	Sample ID	Particle size (%)			Soil Texture Class	Density (g/cm^3)	Organic Carbon (%)	pH (H_2O)	EC (µS/cm)	Cation Exchange Capacity (cmol$_c$/kg)
		Sand	Silt	Clay						
Nyakabingo	NYKSS-02	55	22	23	Sandy clay loam	1.09	1.00	5.72	52	5.56

6.3 Nutrient Status

Table 6-3 shows the primary, secondary and micro-nutrient status of the downstream soil sample that was analysed as part of the assessment. The purpose of determining the soils nutrient status is not to provide a fertilizer recommendation which is crop specific and requires input by several specialists. Instead, it is used to provide an overview of the availability of nutrients in the soil. For this assessment, the Mehlich 3 (Mehlich, 1984)[9] extraction was used to determine the plant available (i.e. bio-available) nutrient status of the soil.

Based on the available nutrient status, the soil is characterised by relatively low proportions of P (<10 mg/kg) and K (<50 mg/kg). The Mg content is suitable and falls within the general range which is considered ideal for most crops (50-120 mg/kg). However, the Ca and S contents are below the general range associated with these nutrients. In terms of the micro-nutrient status, the soil shows no excessive trace metal contents that could lead to phytotoxicity risks. It is also noted that the relatively high Fe status is likely attributed to the abundance of Fe oxides associated with Ferralsols while the Mn status is suggested to be derived from the parent material.

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[9] Mehlich, A. (1984) Mehlich 3 Soil Test Extractant. A Modification of the Mehlich 2 Extractant. Communications in Soil Science and Plant Analysis, 15, 1409-1416.

Table 6-3: Nyakabingo Mine Downstream Soil Bio-Available Nutrient Status

Mine	Sample ID	Nutrient Status (mg/kg)													
		Primary		Secondary			Trace								
		P	K	Ca	Mg	S	Fe	Mn	Zn	Cu	B	Mo	Co	Si	Ni
Nyakabingo	NYKSS-02	6	29	418	107	7.84	192.96	112.19	2.18	3.74	0.6	0.13	0.11	78.1	0.10

Note: N could not be determined by the M3 extraction.

6.4 Total Metal Concentrations

Table 6-4 shows the total metal concentration results that were screened against the SSV1 thresholds to assess if any element is a potential contaminant in the downstream soil sample. Based on the total metal concentration results, the following exceedance was reported for the Nyakabingo mine downstream soil sample.

Referring to the screening tables below, only the downstream soil sample (NYKSS-02) reported Cu exceedance. It is suggested that the elevated Cu content is derived from the mineralogy of the parent material from which the soil is derived and is not necessarily due to mining activities, impacting the downstream areas.

Table 6-4: Nyakabingo Mine Downstream Total Metal Concentration Screening Results

Mine	Analytes	Ag	As	B	Ba	Be	Bi	Cd	Co	Cr (total)	Cu	Ge	Hg	Mn	Mo	Nb	Ni
	Unit	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*
	SSV1 (All Land Uses Protective of the Water Resource)		**5.8**					**7.5**	**300**		**16**		**1**	**740**			**91**
Nyakabingo	NYKSS-02	4.50	<0.01	0.71	65.12	0.48	<0.01	<0.01	6.91	22.05	23.79	4.80	<0.01	564	<0.01	12.04	5.24

Mine	Analytes	Pb	Pd	Sb	Se	Si	Sn	Sr	Ta	Te	Th	Ti	Tl	U	V	Zn	Zr
	Unit	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*
	SSV1 (All Land Uses Protective of the Water Resource)	**20**													**150**	**240**	
Nyakabingo	NYKSS-02	1.99	315	<0.01	<0.01	111	<0.01	10.91	<0.01	<0.01	19.47	321	<0.01	93.41	33.66	42.08	2.4

6.5 Return Water and Top Dam Sludge Waste Assessment

To assess what type of waste facilities would be able to accept the Nyakabingo dam sludge, a waste type classification was recommended to ensure responsible disposal of these materials.

6.5.1 Total and Leachable Concentrations

The waste assessment (WA) according to the total and leachable concentrations for the Nyakabingo return water dam and top dam sludge samples are presented in Table 6-5 and Table 6-6 respectively. A summary of the waste type classification and barrier requirements for disposal into a storage facility is presented in Table 6-7.

The main findings of the WA are as follows:

- The Return water dam (Dam 3) sludge sample reported an exceedance of the TCT2 limit for Arsenic as well as exceedances of the TCT0 limits for Barium, Cobalt, Copper, Mercury, Manganese, Nickel, Lead and Zinc. Furthermore, LCT0 exceedances of Arsenic and Sulphate is also reported for this sample.
- The Top dam (Dam 8) sludge sample reported an exceedance of the TCT1 limit for Arsenic as well as exceedances of the TCT0 limits for Barium, Copper, and Manganese. LCT0 exceedances of Barium and Total dissolved solids is also reported for this material.

Based on the total and leachable concentration exceedances reported and in terms of the NEMWA, the following clauses apply to the Nyakabingo dams sludge samples that were assessed:

For the <u>Return water dam (Dam 3) sludge sample</u>

In accordance with **GN R. 635 of 2013, Section 7 (4)**, if the total concentration (TC) of an element or chemical substance is above the TCT2 limit and the concentration cannot be reduced to below the TCT2 limit, but the leachable concentration (LC) for the particular element or chemical substance is below the LCT3 limit, the waste is considered to be **Type 1** waste.

For the <u>Top dam (Dam 8) sludge sample</u>

In accordance with **GN R. 635 of 2013, Section 7 (2b)**, for a material to be considered as a **Type 1** waste, the results must meet the following criteria:

“Wastes with any element or chemical substance concentration above the LCT2 but below or equal to the LCT3 limits, or above the TCT1 but below or equal to the TCT2 limits (LCT2 < LC ≤ LCT3 or TCT1< TC ≤ TCT2) are Type 1 wastes”.

Table 6-5: Nyakabingo Mine Return Water and Top Dam Sludge Samples Total Concentration Screening

Analyses	Units	TCT0	TCT1	TCT2	Return Water Dam (D3)	Top Dam (Dam 8)
As, Arsenic	mg/kg	5.8	500	2000	8388	728
B, Boron	mg/kg	150	1500	6000	14	23
Ba, Barium	mg/kg	62.5	6250	25000	507	101
Cd, Cadmium	mg/kg	7.5	260	1040	5.48	2.41
Co, Cobalt	mg/kg	50	5000	20000	132	41
Cr_{Total}, Chromium Total	mg/kg	46000	800000	N/A	108	<10
Cu, Copper	mg/kg	16	19500	78000	804	245
Hg, Mercury	mg/kg	0.93	160	640	2.09	<0.400
Mn, Manganese	mg/kg	1000	25000	100000	1337	1026
Mo, Molybdenum	mg/kg	40	1000	4000	<10	<10
Ni, Nickel	mg/kg	91	10600	42400	159	46
Pb, Lead	mg/kg	20	1900	7600	32	2.71
Sb, Antimony	mg/kg	10	75	300	<0.400	<0.400
Se, Selenium	mg/kg	10	50	200	<0.400	0.457
V, Vanadium	mg/kg	150	2680	10720	50	<10
Zn, Zinc	mg/kg	240	160000	640000	342	111
Cr(VI), Chromium (VI) Total	mg/kg	6.5	500	2000	<2	<2
Total Fluoride	mg/kg	100	10000	40000	<0.5	12.58
Total Cyanide as CN	mg/kg	14	10500	42000	<1.55	<1.55

Table 6-6: Nyakabingo Mine Return Water and Top Dam Sludge Samples Leachable Concentration Screening

Analyses	Units	LCT0	LCT1	LCT2	LCT3	Return Water Dam (Dam 3)	Top Dam (Dam 8)
As, Arsenic	mg/l	0.01	0.5	1	4	0.254	0.004
B, Boron	mg/l	0.5	25	50	200	<0.025	<0.025
Ba, Barium	mg/l	0.7	35	70	280	0.039	3.11
Cd, Cadmium	mg/l	0.003	0.15	0.3	1.2	<0.001	<0.001
Co, Cobalt	mg/l	0.5	25	50	200	<0.025	<0.025
CrTotal, Chromium Total	mg/l	0.1	5	10	40	<0.025	<0.025
Cr(VI), Chromium (VI)	mg/l	0.05	2.5	5	20	<0.010	<0.010
Cu, Copper	mg/l	2	100	200	800	<0.010	<0.010
Hg, Mercury	mg/l	0.006	0.3	0.6	2.4	<0.001	<0.001
Mn, Manganese	mg/l	0.5	25	50	200	<0.025	<0.025
Mo, Molybdenum	mg/l	0.07	3.5	7	28	<0.025	<0.025
Ni, Nickel	mg/l	0.07	3.5	7	28	<0.025	<0.025
Pb, Lead	mg/l	0.01	0.5	1	4	<0.001	<0.001
Sb, Antimony	mg/l	0.02	1	2	8	<0.001	<0.001
Se, Selenium	mg/l	0.01	0.5	1	4	0.003	0.004
V, Vanadium	mg/l	0.2	10	20	80	<0.025	<0.025
Zn, Zinc	mg/l	5	250	500	2000	<0.025	<0.025
Total Dissolved Solids*	mg/l	1000	12500	25000	100000	436	1678
Chloride as Cl	mg/l	300	15000	30000	120000	<2	3
Sulphate as SO4	mg/l	250	12500	25000	100000	260	<2
Nitrate as N	mg/l	11	550	1100	4400	0.300	<0.1
Fluoride as F	mg/l	1.5	75	150	600	0.200	0.700
Total Cyanide as CN [o]	mg/l	0.07	3.5	7	28	<0.07	<0.07
pH		**NA**				11.10	12.70

Table 6-7: Nyakabingo Mine Return Water and Top Dam Sludge Samples Waste Type Assessment Results

Sample Name	Waste Type	Reason for Classification	Landfill Disposal Requirement
Return Water Dam (Dam 3)	1	Total concentration of As exceeds the TCT2 limit, but the leachable concentration of As is below the LCT3 limit.	Class A
Top Dam (Dam 8)		Total concentration of As exceeds the TCT1 limit. Furthermore, the leachable concentrations of Ba and TDS exceed the LCT0 limits, and the total concentrations of Ba, Cu and Mn exceeds the TCT0 limits. (LCT2<LC≤LCT3 or TCT1<TC≤TCT2)	

6.5.2 Determining Landfill Class and Liner Requirements

The waste assessment shows that the Nyakabingo mine Return water dam (Dam 3) and Top dam (Dam 8) sludge samples are classified as Type 1 wastes. Therefore, disposal or incorporation of the sludge into a storage facility will require a **Class A** landfill liner or similar constructed barrier. Refer to Figure 6-1 which provides an example of a class A liner requirement.

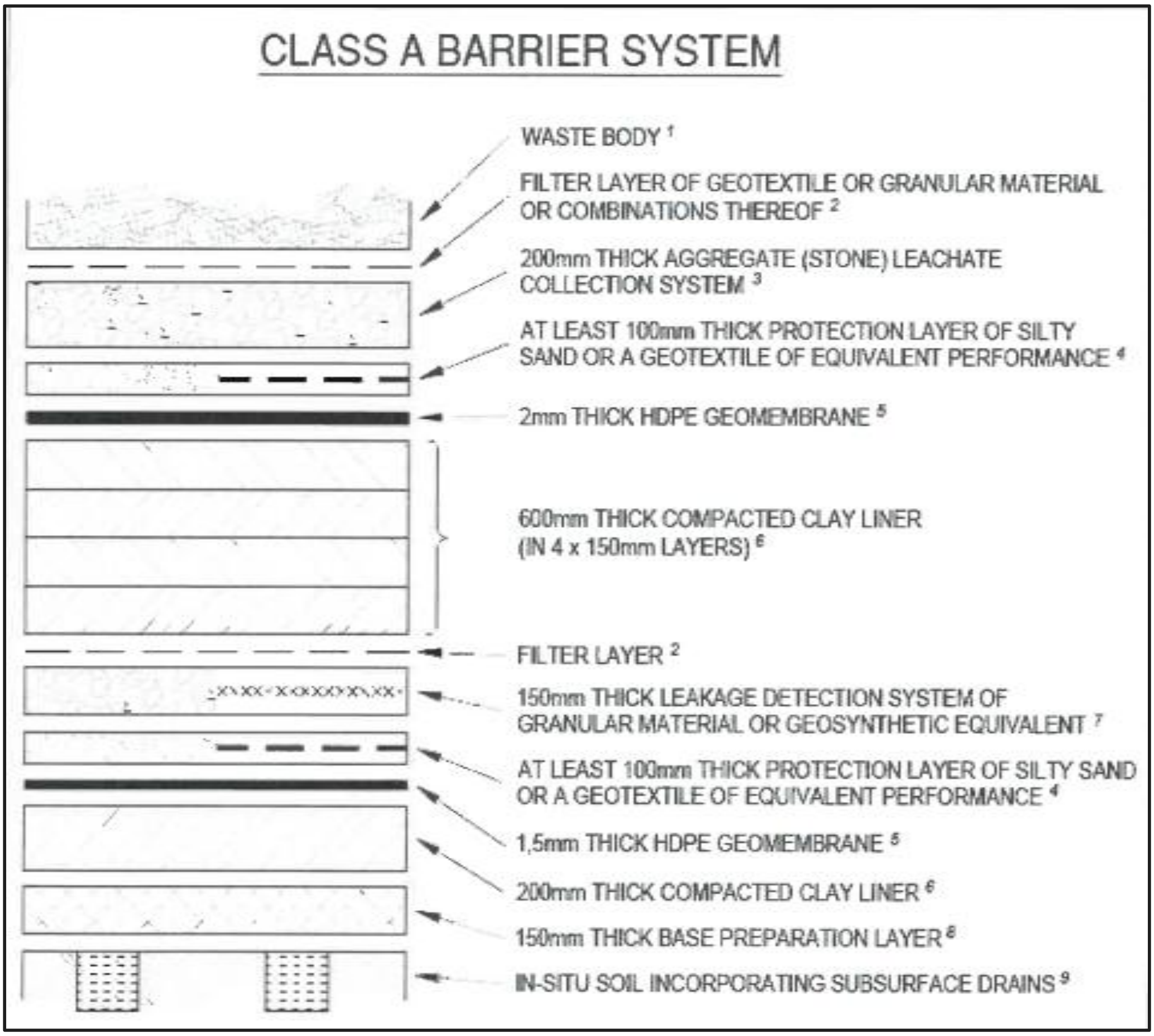

Figure 6-1: Class A landfill prescribed liner

7.0 Summary

The following has been undertaken:

- A geochemical baseline assessment of the river sediments to determine their capacity to remediate any metal leaching and acid rock drainage that might emanate from the legacy tailings lithologies,
- A geochemical baseline assessment of the legacy tailings lithologies that are integrated with the Nyakabingo mine to determine their acid rock drainage and metal leaching potential risk, and
- A baseline assessment of the downstream soils to assess their physical and chemical properties as well as their capacity to remediate any metal leaching and acid rock drainage that might emanate from the legacy tailings lithologies.

River Sediment Assessment

The river sediment assessment showed that the upstream sediment contained a greater distribution of coarse and fine particles compared to the mid-stream and downstream sediments. This shows that the alteration of the hydrological functioning of the river has occurred.

The upstream sediment is dominated by Quartz and Muscovite with major Kaolinite and minor Hematite proportions whereas the mid-stream and downstream sediments are dominated by Quarts with major Muscovite, minor Kaolinite and trace proportions of Hematite.

Due to the presence of Hematite, Kaolinite and Muscovite in the sediments, it is suggested that they can sequester metals and metalloids that are mobilised to the river from mining activities occurring in the vicinity of the river. This suggests that the sediments are likely to show an enrichment of various metals.

The SPLP test noted the following analytes as potential COPCs for the river sediments when compared to national and international water guidelines:

Upstream sediment: As, Pb, Fe and Mn

Mid-stream sediment: As, Co, Ni, Cu, Mn and pH

Downstream sediment: As, Co, Cu, Mn, Ni and pH

The SPLP results show more exceedances of the water quality and effluent standard limits for the mid-stream and downstream sediment samples compared to the upstream sample. This is likely attributed to the acidic pH of these samples which can lead to the desorption of metals from surface complexes. It is also suggested that these sediments contain trace amounts of Arsenopyrite, that could not be detected during the XRD analyses. It is possible that during the SPLP procedure that the residual Arsenopyrite underwent dissolution which generates acid and could contribute to the acidic status of these sediments.

The total metal concentration results reported the following exceedances of the SSV1 limits for the river sediments:

Upstream sediment: As, Cu and Pb

Mid-stream sediment: As, Cu, Hg and Pb

Downstream sediment: As, Cu, Hg and Pb

The total metal concentrations show that anthropogenic activities have likely impacted the river system in the vicinity of the Nyakabingo mine due to historic and current panning activities and illegal mining activities along the river and runoff from the legacy tailings piles. Furthermore, the mid-stream and downstream sediments are more impacted because of higher metal concentrations and more exceedances of the SSV1 limits.

The GAI values were compared to the estimated average crustal abundance of the various elements to assess the significance of elemental enrichment in the sediments and determine the likelihood of contamination. The following is noted:

<u>Upstream sediment</u>

As and B (GAI>3; significant enrichment and potential contamination)

<u>Mid-stream sediment</u>

Hg and Se (GAI>3; significant enrichment and potential contamination)

As and W (GAI>6; extreme enrichment and likely contamination)

<u>Downstream sediment</u>

Hg and Se (GAI>3; significant enrichment and potential contamination)

As and W (GAI>6; extreme enrichment and likely contamination)

The geochemical assessment of the river sediments exhibits a geochemical character that has a limited potential to remediate ARD mainly due to the absence of primary and secondary neutralizing minerals. Furthermore, it is suggested that the sediments contain trace amounts of Arsenopyrite which is acid generating. However, the sediments possess a moderate potential to remediate metal leaching risks because of the presence of Hematite, Kaolinite and Muscovite which can facilitate the adsorption of metal ions on their surfaces.

Legacy Tailings Assessment

The legacy tailings assessment showed that the primary lithologies that are diagnostic of the Nyakabingo mine include Shale, Quartz Vein and Meta Sandstone. The Nyakabingo Shale is dominated by Muscovite and Quartz with minor proportions of Kaolinite whilst the Meta Sandstone is dominated by Quartz with minor proportions of Kaolinite and Muscovite. The Quartz vein consists entirely of Quartz with no accessory minerals. It should be noted that these minerals do not contribute to acid generation and no acid producing minerals (like sulphides) were reported in any of the lithologies. Therefore, there is a minimal to low ARD risk associated with the Nyakabingo mine legacy tailings piles.

The ABA assessment classified the Nyakabingo Shale and Quartz Vein as non-potential acid generating due to their alkaline to circum-neutral paste pH values and NPR values being greater than 2. However, the ABA assessment classified the Meta Sandstone as intermediate potential to generate acid due to its weakly acidic paste pH value, low NPR and NNP values respectively.

The SPLP test only detected Mn as a COPC when compared to national and international water guidelines for the Nyakabingo Quartz Vein and Meta Sandstone legacy tailings lithologies. Similarly, the geochemically modelled source terms predicts that Mn will exceed local and international thresholds for each of the abovementioned tailings lithologies.

The geochemical baseline assessment of the Nyakabingo legacy tailings lithologies exhibits a geochemical character that indicates a reduced risk for ARD. However, the lithologies pose a moderate risk for metal leaching, which could potentially impact the environment as Mn was the only COPC identified.

Soil Assessment

The soil assessment identified Ferralsol as the soil group in the downstream area in relation to the mine footprint. These soils are mineralogically characterized by Quartz, Kaolinite, Goethite, Hematite and Gibbsite. The presence of Fe and Al oxides can contribute to metal adsorption and remediation of metal leaching, but this is pH dependent. The organic carbon content of the soil is low and implies a limited acid buffering capacity making it prone to acidification and nutrient leaching. The soil is classified as acidic and experiences reduced availability of several essential nutrients like P, K, Ca and S. It has a low CEC rating which is typically of sandy textured soils making it susceptible to leaching and is unlikely to buffer changes in pH. Furthermore, Cu exceeded the SSV1 threshold and could be a potential COPC but it is suggested that the elevated Cu content is derived from the mineralogy of the parent material and not necessarily due to mining activities.

The soil baseline assessment shows that Ferralsols have a limited capacity to remediate metal leaching and ARD risks. This is largely due to their low CEC, acidic nature and consequently limited buffering capacity. However, this ability can be improved with specific management strategies like soil liming.

Dam Slurry Waste Assessment

The waste assessment of the Nyakabingo mine return water and top dam sludge samples are as follows:

The Return water dam (Dam 3) sludge sample reported an exceedance of the TCT2 limit for Arsenic as well as exceedances of the TCT0 limits for Barium, Cobalt, Copper, Mercury, Manganese, Nickel, Lead and Zinc. Furthermore, LCT0 exceedances of Arsenic and Sulphate is also reported for this sample. According to GN R. 635 of 2013, Section 7 (4), this sample is classified as a Type 1 waste.

The Top dam (Dam 8) sludge sample reported an exceedance of the TCT1 limit for Arsenic as well as exceedances of the TCT0 limits for Barium, Copper, and Manganese. LCT0 exceedances of Barium and Total dissolved solids is also reported for this material. According to GN R. 635 of 2013, Section 7 (2b), this material is classified as a Type 1 waste.

If the waste streams will be deposited into a storage facility, it is recommended that this facility needs to be designed according to the liner requirements for a Type 1 waste as indicative of the highest-class A liner.

Recommendations

Notwithstanding the findings of this study, SLR would like to recommend the following:

1. Undertake a comprehensive static geochemical assessment of the Nyakabingo mine individual legacy tailings piles to determine each piles acid rock drainage and metal leaching potential risk to develop a risk register for the site to prioritise the remediation of high-risk legacy tailings piles.
2. Undertake a comprehensive static geochemical assessment of the individual particle size fractions of the river sediments to delineate which fraction is most contaminated to identify suitable remediation options as part of the rehabilitation process.

Regards,

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