Technical Memorandum

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Company:	Trinity Metals	**SLR Consulting (Africa) Proprietary Limited**	
cc:	Sam Ryumugabe	**Date:**	2 December 2025
		Project No.	713.000084.00002

RE: Trinity Metals Legacy Tailings and River Rehabilitation: Geochemical and Soil / Sediment Assessments – Musha and Ntunga Mines, 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 Musha and Ntunga mines 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 delineate 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 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 the Trinity Metals mine sites from 13 to 25 July 2025 to undertake the specialist assessments. The consultants visited the Trinity Musha and Ntunga mines from 21 to 22 July to undertake the assessments.

3.1 Sampling Program

The SLR field team worked closely with the mines geology and environmental team members 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 each mine as well as, in identifying appropriate locations for soil and sediment sampling corresponding to 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 Musha and Ntunga mines 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 rock type. The SLR consultants decided on which samples to retain largely determined by the degree of weathering and sample size.

After selecting the samples, they were described and their GPS coordinates recorded. Refer to Table 3-1 for a summary of the legacy tailings sample details and Figure 3-1 as well as Figure 3-2 for the locations of the legacy tailings piles that were sampled at each site.

Table 3-1: Musha and Ntunga Legacy Tailings Sample Summary

Mine	Field ID	Latitude	Longitude	Lithology	Report Sample ID
Musha	MU-LT-32	1°55'48.7"S	30°20'46.8"E	Sandstone	Musha Sandstone
	MU-LT-39	1°55'30.8"S	30°20'20.9"E	Sandstone	
	MU-LT-33	1°55'48.7"S	30°20'46.8"E	Quartz vein	Musha Quartz Vein
	MU-LT-40	1°55'30.8"S	30°20'20.9"E	Quartz vein	
	MU-LT-34	1°55'48.7"S	30°20'46.8"E	Quartzite	Musha Quartzite
	MU-LT-38	1°55'30.8"S	30°20'20.9"E	Quartzite	
	MU-LT-37	1°55'30.8"S	30°20'20.9"E	Schist	Musha Schist
Ntunga	NTU-LT-42	1°57'49.4"S	30°21'44.1"E	Pegmatite	Ntunga Pegmatite
	NTU-LT-43	1°57'49.4"S	30°21'44.1"E	Quartz vein	Ntunga Quartz Vein
	NTU-LT-44	1°57'49.4"S	30°21'44.1"E	Metased sandstone	Ntunga Metased Sandstone

3.1.2 River Sediment Sampling Protocol

The river sediment sampling was undertaken in consultation with the mines environmental team to identify upstream and downstream sampling positions based on the 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.

It should be noted that only a downstream sediment sample was obtained at the Ntunga mine due to the absence of a suitable upstream location in proximity to the mines footprint.

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 3-3 as well as Figure 3-4 for the locations of the sediment sampling points.

Table 3-2: Musha and Ntunga River Sediment Sample Summary

Mine	Sample ID	Latitude	Longitude	River sediment locations
Musha	MUSED-35	1°56'43.1"S	30°21'16.5"E	Upstream (Agri channel sediment)
	MUSED-36	1°55'45.6"S	30°21'31.7"E	Downstream (Agri channel sediment)
Ntunga	NTUSED-41	1°58'13.3"S	30°21'58.2"E	Downstream

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 between 0.5 and 1 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 3-5 as well as Figure 3-6 for the locations of the soil observation points.

Table 3-3: Musha and Ntunga Soil Observation Summary

Mine	Sample ID	Latitude	Longitude	Sample Depth (cm)	Sampled
Musha	MUS-01	1°56’07.8”S	30°21’17.1”E	0 - 30	Yes
	MUS-02	1°55’43.3”S	30°21’28.6”E		No
Ntunga	NTUS-01	1°58’12.6”S	30°21’58.0”E		No
	NTUS-02	1°58’17.4”S	30°22’00.1”E		Yes

Figure 3-1: Musha Mine Legacy Tailings Sampling Points

Figure 3-2: **Ntunga Mine Legacy Tailings Sampling Point**

Figure 3-3: Musha Mine River Sediment Sampling Points

Figure 3-4: Ntunga Mine River Sediment Sampling Point

Figure 3-5: Musha Mine Soil Observation Points

Figure 3-6: Ntunga 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) 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 sediments was assessed 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:

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

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 or less than the average crustal abundance, 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.

3.3 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.

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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

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, Kaolinite, Goethite, Palygorskite (Sepiolite) and Dravite. 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:

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.

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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.

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 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 Musha and Ntunga river sediment samples respectively.

The Musha River sediment samples compare well with the general particle size distribution trend as the downstream sediment (MUSED-36) is characterized by a larger distribution of fine particles (silt and clay), with no coarse fractions detected whereas the upstream sediment (MUSED-35) contains a greater distribution of medium size fractions namely sand with some coarse particles (i.e. gravel).

Due to the absence of a representative upstream location, only one sediment sample was obtained at the Ntunga mine. The downstream sediment sample (NTUSED-41) shows a greater distribution of medium and coarse particle size fractions with very minimal fine particle fractions present. This suggests that the hydrological functioning of the river system has been altered as it is anticipated that downstream sediments would consist of a larger distribution of silt and clay.

Table 4-1: Particle Size Distribution of Musha and Ntunga 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)
			%	%	%	%
Musha	MUSED-35	Upstream	3	46	29	22
	MUSED-36	Downstream	-	29	50	21
Ntunga	NTUSED-41	Downstream	25	70	4	1

4.2 Mineralogy

Refer to Table 4-2 below for an overview of the mineralogical composition of the Musha and Ntunga mines river sediment samples.

Musha Mine

The upstream sediment is dominated by Quartz (55%) with major proportions of Kaolinite (20.9%) and Muscovite (13.9%) and minor proportions of Hematite (8.77%) and Schorl (1.4%). Similarly, the downstream sediment is also dominated by Quarts, with major proportions of Kaolinite and Muscovite and minor proportions of Hematite and Schorl.

The XRD results show that the downstream sediment contains higher proportions of Kaolinite and Muscovite compared to the upstream sediment, which correlates with their particle size distribution as the downstream sediment has a higher fraction of fine particles. Furthermore, the upstream sediment contains higher proportions of Quartz and Hematite compared to the downstream sediment as well as a higher distribution of the medium particle size (i.e. sand) fraction.

Ntunga Mine

The downstream sediment is dominated by Quartz (86.95%) with minor proportions of Schorl (6.04%), Muscovite (4.33%) and Kaolinite (2.11%). There are also trace amounts (0.57%) of Hematite present in the sediment. This sample contained a greater distribution of the medium and coarse particle size fractions in which Quarts and Schorl will likely occur. Schorl is an iron-rich member of the Tourmaline group. It is a hard mineral and is chemically resistant to weathering. Therefore, it is likely to accumulate in the sediments along with Quartz due to their stability and durability.

In terms of the ability of the minerals that were identified 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 largely because it is chemically inert, has very few reactive surface sites to facilitate surface complexation and metal adsorption and does not contain neutralizing capacity.

Schorl also has a limited ability to remediate ARD because it is chemically stable and lacks acid neutralizing capacity. Conversely, it is a cyclosilicate mineral that contains borosilicate rings with surface hydroxyl groups as part of its structure which can serve as sites for metal adsorption and therefore has the ability to remediate metal leaching.

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 minimal potential to remediate metal leaching due to it relatively low 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, it has an affinity for oxyanions and will strongly adsorb arsenate and chromate. It can limit the oxidation of Pyrite and consequently reduce the formation of ARD.

Due to the presence of Hematite, Schorl, Kaolinite and Muscovite in the sediments, it is suggested that they can sequester metals and metalloids that are mobilised to the river by mining activities occurring in the vicinity of the river. This suggests that the sediments are likely to show an enrichment / accumulation of various metals that exceed average crustal abundances or background level values.

Table 4-2: Musha and Ntunga Mine River Sediment XRD Mineralogy Results

Mineral	Formula	Mine		
		Musha		Ntunga
		Sample ID		
		MUSED-35	MUSED-36	NTUSED-41
		Stream Position		
		Upstream	Downstream	Downstream
Quartz	SiO_2	55.05	43.43	86.95
Hematite	Fe_2O_3	8.77	1.12	0.57
Kaolinite	$Al_2Si_2O_5(OH)_4$	20.87	34.17	2.11
Muscovite	$KAl_3Si_3O_{10}(OH)_2$	13.9	19.08	4.33
Schorl	$NaFe_3Al_6(BO_3)_3(Si_6O_{18})(OH)_4$	1.42	2.19	6.04

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:

Musha Mine:

Upstream sediment (MUSED-35)

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

Downstream sediment (MUSED-36)

a) As (WHO Drinking)
b) Fe (RS Livestock)
c) Mn (WHO Drinking and RS Irrigation)

Ntunga Mine:

Downstream sediment (NTUSED-41)

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

The SPLP results for the Musha sediments reveal that the upstream sediment reported higher Fe and Mn exceedances compared to the downstream sediment. This could be attributed to the higher proportion of Hematite in the upstream sediment which has an affinity to sorb metal ions, especially Fe.

Table 4-3: Musha and Ntunga Mine River Sediment SPLP Screening Results

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**	
Musha	Upstream	MUSED-35	0.002	8.82	0.004	0.001	0.013	0.608	0.013	0.001	11.53	0.001	0.131	0.013	0.013	0.020	0.005	0.047	0.001	0.001	0.001	12.4	0.050
	Downstream	MUSED-36	0.001	0.176	0.012	0.001	0.013	0.032	0.013	0.001	2.75	0.001	0.001	0.013	0.013	0.005	0.005	0.005	0.001	0.001	0.001	0.379	0.003
Ntunga	Downstream	NTUSED-41	0.001	2.24	0.001	0.001	0.013	0.143	0.013	0.001	4.52	0.001	0.025	0.013	0.013	0.020	0.001	0.005	0.001	0.001	0.001	2.85	0.016

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**
Musha	Upstream	MUSED-35	0.006	0.001	0.001	0.001	0.001	0.001	0.001	0.495	0.053	0.005	0.001	2.15	1.46	0.013	0.500	0.001	0.039	0.013	0.001	0.097
	Downstream	MUSED-36	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.618	0.001	0.002	0.001	0.500	0.210	0.013	0.500	0.001	0.000	0.013	0.001	0.001
Ntunga	Downstream	NTUSED-41	0.001	0.001	0.001	0.001	0.001	0.001	0.001	1.50	0.008	0.006	0.001	1.46	1.08	0.013	0.500	0.001	0.007	0.013	0.001	0.001

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**										
Musha	Upstream	MUSED-35	0.045	0.001	0.011	0.001	0.012	0.001	0.001	0.001	0.003	0.001	15.04	0.007	0.001	0.136	0.001	0.001	0.001	0.001	0.011	0.001
	Downstream	MUSED-36	0.000	0.001	0.001	0.001	0.002	0.001	0.001	0.001	0.001	0.001	6.21	0.001	0.001	0.029	0.001	0.001	0.001	0.001	0.001	0.001
Ntunga	Downstream	NTUSED-41	0.017	0.001	0.002	0.001	0.007	0.001	0.001	0.001	0.001	0.001	4.36	0.001	0.001	0.041	0.001	0.001	0.001	0.001	0.008	0.001

Mine	Stream Position	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**				
Musha	Upstream	MUSED-35	0.001	0.003	0.013	0.001	0.018	0.002	0.059	0.001	6.30	3.10	21	20	8	13	0.050	0.025	0.100	0.050	0.050	0.035
	Downstream	MUSED-36	0.001	0.001	0.013	0.001	0.001	0.001	0.013	0.001	6.30	5.20	35	16	8	7	0.050	0.025	0.200	0.050	0.050	0.035
Ntunga	Downstream	NTUSED-41	0.001	0.001	0.013	0.001	0.003	0.001	0.013	0.001	7.00	3.60	24	12	8	4	0.200	0.025	0.200	0.050	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:

Musha Mine

Upstream sediment (MUSED-35)

- As, Cu, Pb and V.

Downstream sediment (MUSED-36)

- As, Cu, Pb and V.

Ntunga Mine

Downstream sediment (NTUSED-41)

- As and Pb

The exceedances of the SSV1 limits for the various metals in the sediments show that anthropogenic activities have likely impacted the rivers in the vicinity of the Musha and Ntunga mines respectively. This can be attributed to historic and current panning activities, runoff from the legacy tailings piles and illegal mining activities along the rivers. Furthermore, most of the exceedances reported for the upstream Musha sediment were higher than those in the downstream sediment, except for As. This suggests that the upstream sediment has a greater sorption potential than the downstream sediment and could be due to the higher proportion of Hematite.

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:

Musha Mine

Upstream sediment (MUSED-35)

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

Downstream sediment sample (MUSED-36)

- B and Sn show a GAI>3 (implying significant enrichment and potential contamination)
- As shows a GAI>6 (implying extreme enrichment and likely contamination)

Ntunga Mine

Downstream sediment sample (NTUSED-41)

- As and Sn show a GAI>3 (implying significant enrichment and potential contamination)
- B shows a GAI>6 (implying extreme enrichment and likely contamination)

Table 4-4: Musha and Ntunga 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**					
Musha	Upstream	MUSED-35	0.200	10170	190	0.200	385	151	5	0.615	693	0.200	5.87	5	121	4.76	22	0.200	0.200	0.200	30074	23
	Downstream	MUSED-36	0.200	48163	209	0.200	532	51	5	1.087	200	0.200	0.55	5	74	1.76	21	0.200	0.200	0.200	58579	24
Ntunga	Downstream	NTUSED-41	0.200	23790	57	0.200	1644	91	5	1.260	200	0.200	1.04	5	94	2.89	9	0.200	0.200	0.200	39023	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**		
Musha	Upstream	MUSED-35	0.200	3.13	11.40	0.200	0.200	0.200	0.200	6983	0.409	46.2	0.200	0.200	363	5	973	34.2	0.551	25.3	0.200	1452
	Downstream	MUSED-36	0.200	2.64	15.73	0.200	0.200	0.200	0.200	9209	0.200	140.8	0.200	491	333	5	780	58.1	0.200	23.6	0.200	1434
Ntunga	Downstream	NTUSED-41	0.200	2.84	5.32	0.200	0.200	0.200	0.200	4943	0.200	182.7	0.200	905	276	5	870	18.6	0.200	15.8	0.200	1398

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*
		SSV1 (All Land Uses Protective of the Water Resource)	**20**																			
Musha	Upstream	MUSED-35	43.87	0.200	0.200	0.200	30.7	0.200	0.200	0.200	1.8	1.47	152401	0.200	12.8	22.6	5.03	0.200	0.200	2.97	8019	0.647
	Downstream	MUSED-36	40.49	0.200	0.200	0.200	12.0	0.200	0.200	0.200	5.6	0.200	160459	0.200	38.8	5	8.56	0.200	0.200	3.68	8965	0.992
Ntunga	Downstream	NTUSED-41	34.50	0.200	0.200	0.200	24.4	0.200	0.200	0.200	3.2	1.04	240125	0.200	38.2	5	23.60	0.200	0.200	2.42	3543	1.23

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**	
Musha	Upstream	MUSED-35	0.200	3.03	214.60	4.47	0.200	0.200	48.9	240
	Downstream	MUSED-36	0.200	3.39	150.68	6.16	0.200	0.200	39.6	331
Ntunga	Downstream	NTUSED-41	0.200	1.57	78.73	2.12	0.200	0.200	34.4	94

Note: Values in grey text represent below detection limit concentrations

Table 4-5: Musha and Ntunga Mines 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 (possible contamination)																				
		2. GAI ≥ 6: Extreme enrichment (likely contamination)																				
Musha	Upstream	MUSED-35	0.200	-3.56	5.99	0.200	4.68	-2.09	5	1.04	-2.70	0.200	-3.52	5	-1.31	0.08	-2.04	0.200	0.200	0.200	-1.32	-0.12
	Downstream	MUSED-36	0.200	-1.32	6.12	0.200	5.15	-3.67	5	1.86	200	0.200	-6.93	5	-2.03	-1.35	-2.10	0.200	0.200	0.200	-0.36	-0.08
Ntunga	Downstream	NTUSED-41	0.200	-2.33	4.25	0.200	6.78	-2.83	5	2.07	200	0.200	-6.01	5	-1.68	-0.64	-3.40	0.200	0.200	0.200	-0.94	-0.65

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 (possible contamination)																				
		2. GAI ≥ 6: Extreme enrichment (likely contamination)																				
Musha	Upstream	MUSED-35	0.200	-2.84	NV	0.200	0.200	0.200	0.200	-2.48	NV	0.04	0.200	0.200	-1.89	5	-5.21	0.19	-6.09	-2.25	0.200	-0.05
	Downstream	MUSED-36	0.200	-3.09	NV	0.200	0.200	0.200	0.200	-2.08	NV	1.65	0.200	-6.00	-2.02	5	-5.53	0.95	0.200	-2.34	0.200	-0.07
Ntunga	Downstream	NTUSED-41	0.200	-2.99	NV	0.200	0.200	0.200	0.200	-2.98	NV	2.02	0.200	-5.12	-2.29	5	-5.37	-0.69	0.200	-2.93	0.200	-0.10

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 (possible contamination)																				
		2. GAI ≥ 6: Extreme enrichment (likely contamination)																				
Musha	Upstream	MUSED-35	0.87	0.200	0.200	0.200	-2.55	0.200	0.200	0.200	NV	3.45	-1.41	0.200	1.78	-4.54	0.75	0.200	0.200	-2.34	0.10	-1.21
	Downstream	MUSED-36	0.75	0.200	0.200	0.200	-3.90	0.200	0.200	0.200	NV	0.200	-1.34	0.200	3.37	5	1.51	0.200	0.200	-2.03	0.26	-0.60
Ntunga	Downstream	NTUSED-41	0.52	0.200	0.200	0.200	-2.88	0.200	0.200	0.200	NV	2.95	-0.75	0.200	3.35	5	2.98	0.200	0.200	-2.63	-1.08	-0.29

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 (possible contamination)								
		2. GAI ≥ 6: Extreme enrichment (likely contamination)								
Musha	Upstream	MUSED-35	0.200	-0.57	-0.07	1.57	0.200	0.200	-1.10	0.00
	Downstream	MUSED-36	0.200	-0.41	-0.58	2.04	0.200	0.200	-1.41	0.47
Ntunga	Downstream	NTUSED-41	0.200	-1.52	-1.51	0.50	0.200	0.200	-1.61	-1.35

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 Musha and Ntunga mine legacy tailings lithologies. The primary lithologies that are diagnostic of the Musha mine include Schist, Sandstone, Quartz Vein and Quartzite whereas the Ntunga mine legacy tailings comprises Pegmatite, Quartz Vein and metasedimentary Sandstone.

The Musha Schist is dominated by Quartz (63.1%) and Dravite (20.2%) with major proportions of Muscovite (16.0%) and trace amounts of Palygorskite (0.7%). The Musha Sandstone primarily consists of Quartz (94.3%) with minor proportions of Goethite (3.3%) and Muscovite (2.4%). The Musha Quartz vein and Quartzite reported the same mineralogy. However, the Quartz vein is dominated by Quartz (97.4%) with minor proportions of Muscovite (2.6%) whereas the Quartzite is dominated by Quartz (99.2%) with trace proportions (0.8%) of Muscovite.

The Ntunga Pegmatite is dominated by Quartz (58.8%) and Muscovite (37.3%) with minor proportions of Kaolinite (2.7%) and Palygorskite (1.2%). The Ntunga Quartz vein consists entirely of Quartz while the metasedimentary sandstone is dominated by Quartz (68.2%) and Muscovite (24.66%) with minor proportions of Kaolinite (7.1%).

The XRD analyses did not detect the presence of acid producing minerals (like sulfides) in association with any of the Musha and Ntunga mine legacy tailings lithologies. Furthermore, none of the minerals that were detected during the XRD analysis are acid generating, suggesting the tailings lithologies are likely to display minimal to low acid rock drainage (ARD) risk.

Table 5-1: Musha and Ntunga Legacy Tailings XRD Results

		Mine						
		Musha				Ntunga		
		Sample ID						
		MU-LT-37	MU-LT-32 & MU-LT-39	MU-LY-33 & MU-LT-40	MU-LT-34 & MU-LT-38	NTU-LT-42	NTU-LT-43	NTU-LT-44
		Rock Type						
		Schist	Sandstone	Quartz Vein	Quartzite	Pegmatite	Quartz Vein	Metased Sandstone
Mineral	Formula							
Quartz	SiO_2	63.09	94.34	97.44	99.16	58.82	100	68.21
Muscovite	$KAl_3Si_3O_{10}(OH)_2$	15.96	2.39	2.56	0.84	37.28	-	24.66
Kaolinite	$Al_2Si_2O_5(OH)_4$	-	-	-	-	2.68	-	7.13
Goethite	$Fe_2O_3.H_2O$	-	3.28	-	-	-	-	-
Palygorskite	$Mg_5Si_8O_{20}(OH)_2\cdot 8H_2O$	0.72	-	-	-	1.21	-	-
Dravite	$NaMg_3Al_6(BO_3)_3Si_6O_{18}(OH)_4$	20.23	-	-	-	-	-	-
Hematite	Fe_2O_3	-	-	-	-	-	-	-

5.2 Acid Base Accounting

Sulphur speciation and Acid Base Accounting analysis were undertaken on the Musha and Ntunga legacy tailings materials. The results are presented in Table 5-2 and Table 5-3 respectively.

The sulfur speciation results reported for the Musha legacy tailings lithologies show minor total sulfur percentages. The Musha Schist and Sandstone samples returned the highest total sulfur percentages which mostly consist of sulfide S. However, the sulfide percentages of these samples are < 0.30% and are considered non-potential acid generating. Furthermore, the Musha Quartz vein consist of mostly sulfate S while the Quartzite returned below detection limit values for sulfide and sulfate S, respectively.

The Ntunga legacy tailings lithologies also reported negligible to minor total sulfur percentages. Furthermore, all the lithologies showed below detection limit values for sulfide S and are likely to be non-potential acid generating. The Ntunga metasedimentary Sandstone as well as Quartz vein mainly consist of sulfate S.

Due to the absence of elevated sulfide S (>0.3%) and total sulfur contents in the legacy tailings samples, it confirms that they have a minimal to low risk for ARD.

Table 5-2: Musha and Ntunga Legacy Tailings Sulfur Speciation Results

Mine	Rock Type	Sample ID	Total Sulphur	Sulphide S	Sulphate Sulphur
			%	%	%
Musha	Schist	MU-LT-37	0.023	0.019	<0.010
	Sandstone	MU-LT-32 & MU-LT-39	0.018	0.014	<0.010
	Quartz Vein	MU-LY-33 & MU-LT-40	0.011	<0.010	0.011
	Quartzite	MU-LT-34 & MU-LT-38	0.013	<0.010	<0.010
Ntunga	Pegmatite	NTU-LT-42	<0.010	<0.010	<0.010
	Quartz Vein	NTU-LT-43	0.012	<0.010	0.011
	Metased Sandstone	NTU-LT-44	0.035	<0.010	0.032

The ABA results show the following for the Musha mine legacy tailings lithologies:

Schist

Has an alkaline paste pH value (8.3) with a Neutralisation Potential Ratio (NPR) value less than 1 (0.341) and a Net Neutralisation Potential (NNP) value between -20 and 20 (-0.964). These indicators suggest that the sample is potential acid generating (PAG).

Sandstone

Has a moderately acidic paste pH (6.3) with an NPR value less than 1 (0.004) and NNP value between -20 and 20 (-0.560). These indicators infers that the sample is PAG.

Quartz vein

Has a neutral paste pH (7.2) with an NPR value between 1 and 4 (2.150) and NNP value between -20 and 20 (-1.080). These indicators suggest that the sample is non-potential acid generating.

Quartzite

Has a neutral paste pH (7.1) with an NPR value between 1 and 4 (1.210) and NNP value between -20 and 20 (-0.899). These indicators suggest that the sample has an intermediate acid generating potential.

The ABA results show the following for the Ntunga mine legacy tailings lithologies:

Pegmatite

Has an alkaline paste pH value (8.3) with an NPR value less than 1 (0.008) and a NNP value between -20 and 20 (-0.310). These indicators suggest that the sample is PAG.

Quartz vein

Has a neutral paste pH (7.3) with an NPR value between 1 and 4 (1.330) and NNP value between -20 and 20 (0.122). These indicators suggest that the sample has an intermediate acid generating potential.

Metasedimentary Sandstone

Has an alkaline paste pH value (7.9) with an NPR value less than 1 (0.450) and a NNP value between -20 and 20 (-1.590). These indicators suggest that the sample is PAG.

The ABA tests are based on determining the sulphur/sulphide content of a material to calculate the sulphide acid potential (AP) 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.

On average, the NP values for the Musha and Ntunga legacy tailings lithologies are less than their AP values. However, this is not due to an abundance of acid generating minerals (like Pyrite) but rather a lack of rapidly dissolving neutralising minerals like carbonates.

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 conflicting results that could potentially occur.

In Figure 5-1 below the:

- Musha Schist and Sandstone as well as Ntunga Pegmatite and metasedimentary sandstone are all distinctly classified as PAG,
- Musha Quartz vein is classified as non-PAG, and
- Musha Quartzite and Ntunga Quartz vein are classified as having an intermediate potential to generate acid.

Table 5-3: Musha and Ntunga 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**	
Musha	Schist	MU-LT-37	8.3	0.023	0.719	-0.25	0.341	-0.964	PAG
	Sandstone	MU-LT-32 & MU-LT-39	6.3	0.018	0.563	0.002	0.004	-0.560	PAG
	Quartz Vein	MU-LY-33 & MU-LT-40	7.2	0.011	0.344	-0.740	2.150	-1.080	Non-PAG
	Quartzite	MU-LT-34 & MU-LT-38	7.1	0.013	0.406	-0.493	1.210	-0.899	Intermediate
Ntunga	Pegmatite	NTU-LT-42	8.3	<0.010	0.313	0.002	0.008	-0.310	PAG
	Quartz Vein	NTU-LT-43	7.3	0.012	0.375	0.497	1.330	0.122	Intermediate
	Metased Sandstone	NTU-LT-44	7.9	0.035	1.09	-0.493	0.450	-1.590	PAG

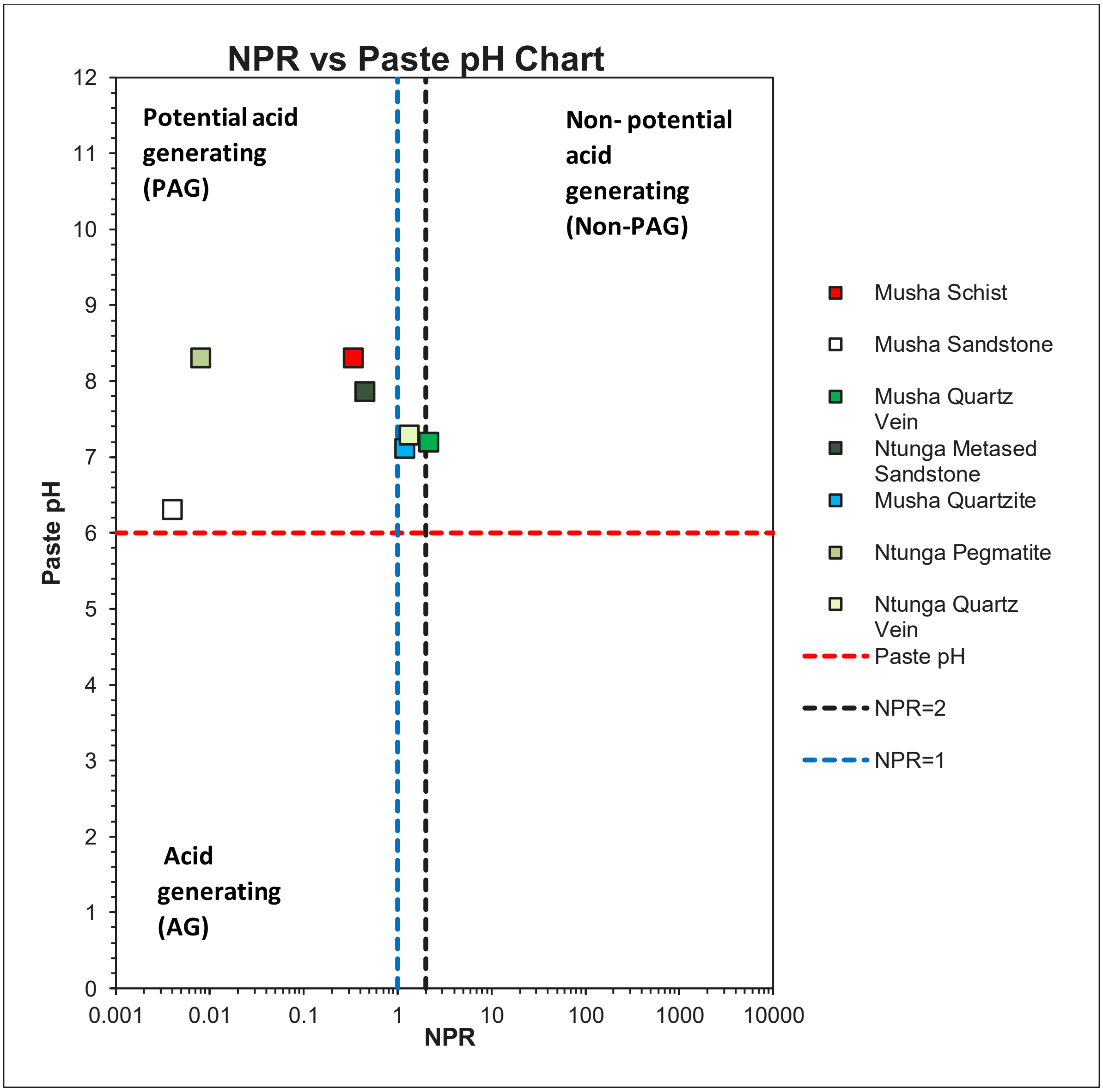

Figure 5-1: Musha and Ntunga Legacy Tailings Materials Acid Generating Potential Plot

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:

Musha Sandstone:

- Mn (WHO Drinking)

Musha Quartzite:

- Mn (WHO Drinking and RS Irrigation)

Musha Quartz vein:

- Mn (WHO Drinking and RS Irrigation)

- pH (IFC and RS Livestock)

Ntunga Quartz vein:

- Mn (WHO Drinking and RS Irrigation)

Table 5-4: Musha and Ntunga 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**	
Musha	Schist	MU-LT-37	0.0005	0.207	0.006	0.0005	0.013	0.013	0.013	0.0005	0.50	0.0005	0.004	0.013	0.013	0.005	0.005	0.005	0.0005	0.0005	0.0005	0.132	0.0005
	Sandstone	MU-LT-32 & MU-LT-39	0.002	0.0005	0.0005	0.0005	0.013	0.013	0.013	0.0005	1.00	0.0005	0.0005	0.013	0.013	0.005	0.005	0.005	0.0005	0.0005	0.0005	0.013	0.0005
	Quartz Vein	MU-LY-33 & MU-LT-40	0.0005	0.0005	0.0005	0.0005	0.013	0.013	0.013	0.0005	1.00	0.0005	0.0005	0.013	0.013	0.005	0.005	0.005	0.0005	0.0005	0.0005	0.179	0.0005
	Quartzite	MU-LT-34 & MU-LT-38	0.0005	0.0005	0.0005	0.0005	0.013	0.013	0.013	0.0005	1.00	0.0005	0.0005	0.013	0.013	0.005	0.005	0.005	0.0005	0.0005	0.0005	0.136	0.0005
Ntunga	Pegmatite	NTU-LT-42	0.0005	0.0005	0.0005	0.0005	0.013	0.013	0.013	0.0005	0.50	0.0005	0.0005	0.013	0.013	0.005	0.005	0.005	0.0005	0.0005	0.0005	0.013	0.0005
	Quartz Vein	NTU-LT-43	0.0005	0.0005	0.0005	0.0005	0.013	0.013	0.013	0.0005	0.50	0.0005	0.0005	0.013	0.013	0.005	0.005	0.005	0.0005	0.0005	0.0005	0.2	0.0005
	Metased Sandstone	NTU-LT-44	0.0005	0.0005	0.0005	0.0005	0.013	0.013	0.013	0.0005	0.50	0.0005	0.0005	0.013	0.013	0.005	0.005	0.005	0.0005	0.0005	0.0005	0.013	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**
Musha	Schist	MU-LT-37	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	2.80	0.002	0.030	0.0005	0.500	0.040	0.013	0.500	0.0005	0.002	0.013	0.0005	0.058
	Sandstone	MU-LT-32 & MU-LT-39	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.250	0.0005	0.0005	0.0005	0.500	0.086	0.013	0.500	0.0005	0.0005	0.013	0.0005	0.0005
	Quartz Vein	MU-LY-33 & MU-LT-40	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.250	0.0005	0.007	0.0005	0.500	0.390	0.013	0.500	0.0005	0.0005	0.013	0.0005	0.006
	Quartzite	MU-LT-34 & MU-LT-38	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.250	0.0005	0.003	0.0005	0.500	0.364	0.013	0.500	0.0005	0.0005	0.013	0.0005	0.0005
Ntunga	Pegmatite	NTU-LT-42	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	1.49	0.0005	0.011	0.0005	0.500	0.013	0.013	0.500	0.0005	0.0005	0.013	0.0005	0.032
	Quartz Vein	NTU-LT-43	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.250	0.0005	0.008	0.0005	0.500	0.42	0.013	0.500	0.0005	0.0005	0.013	0.0005	0.008
	Metased Sandstone	NTU-LT-44	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	1.34	0.0005	0.035	0.0005	0.500	0.013	0.013	0.500	0.0005	0.0005	0.013	0.0005	0.045

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**										
Musha	Schist	MU-LT-37	0.0005	0.0005	0.0005	0.0005	0.019	0.0005	0.0005	0.0005	0.0005	0.0005	1.187	0.0005	0.0005	0.013	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
	Sandstone	MU-LT-32 & MU-LT-39	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.401	0.0005	0.0005	0.013	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
	Quartz Vein	MU-LY-33 & MU-LT-40	0.0005	0.0005	0.0005	0.0005	0.004	0.0005	0.0005	0.0005	0.0005	0.0005	0.195	0.0005	0.0005	0.013	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
	Quartzite	MU-LT-34 & MU-LT-38	0.0005	0.0005	0.0005	0.0005	0.001	0.0005	0.0005	0.0005	0.0005	0.0005	0.241	0.0005	0.0005	0.013	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Ntunga	Pegmatite	NTU-LT-42	0.0005	0.0005	0.0005	0.0005	0.046	0.0005	0.0005	0.0005	0.0005	0.0005	0.430	0.0005	0.0005	0.013	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
	Quartz Vein	NTU-LT-43	0.0005	0.0005	0.0005	0.0005	0.002	0.0005	0.0005	0.0005	0.0005	0.0005	0.251	0.0005	0.0005	0.013	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
	Metased Sandstone	NTU-LT-44	0.0005	0.0005	0.0005	0.0005	0.024	0.0005	0.0005	0.0005	0.0005	0.005	0.532	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**				
Musha	Schist	MU-LT-37	0.0005	0.0005	0.013	0.0005	0.0005	0.0005	0.013	0.0005	7.10	2.20	42	30	1	1	0.05	0.025	0.1	0.05	0.05	0.035
	Sandstone	MU-LT-32 & MU-LT-39	0.0005	0.0005	0.013	0.0005	0.0005	0.0005	0.013	0.0005	6.40	1.40	24	30	1	1	0.05	0.025	0.1	0.05	0.05	0.035
	Quartz Vein	MU-LY-33 & MU-LT-40	0.0005	0.0005	0.013	0.0005	0.0005	0.0005	0.013	0.0005	5.70	1.20	10	20	1	1	0.05	0.025	0.1	0.05	0.05	0.035
	Quartzite	MU-LT-34 & MU-LT-38	0.0005	0.0005	0.013	0.0005	0.0005	0.0005	0.013	0.0005	6.10	1.30	10	40	1	1	0.05	0.025	0.1	0.05	0.05	0.035
Ntunga	Pegmatite	NTU-LT-42	0.0005	0.0005	0.013	0.0005	0.0005	0.0005	0.013	0.0005	6.40	1.30	24	10	1	1	0.05	0.025	0.1	0.05	0.05	0.035
	Quartz Vein	NTU-LT-43	0.0005	0.0005	0.013	0.0005	0.0005	0.0005	0.013	0.0005	6.30	1.50	22	20	1	1	0.05	0.025	0.1	0.05	0.05	0.035
	Metased Sandstone	NTU-LT-44	0.0005	0.0005	0.013	0.0005	0.0005	0.0005	0.013	0.0005	7.10	3.10	10	20	1	1	0.05	0.025	0.1	0.900	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 Musha and Ntunga mine legacy tailings pile lithologies.

To simulate the conditions that the legacy tailings piles will be subject to, the model was developed by allowing a 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 and Table 5-6. 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 the various legacy tailings materials for each mine:

Musha

Sandstone:

- Mn (WHO Drinking)

Quartzite:

- Mn (WHO Drinking and RS Irrigation)

Quartz vein:

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

Ntunga

Quartz vein:

- Mn (WHO Drinking and RS Irrigation)

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

Element	Unit	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	Musha Schist	Musha Quartz Vein	Musha Quartzite	Musha Meta Sandstone
Ag	mg/L							0.000	0.000	0.000	0.002
Al	mg/L		18					0.002	0.001	0.001	0.000
As	mg/L	0.01	0.2	0.1		5	5	0.006	0.000	0.000	0.000
Au	mg/L				0.01	0.1	2	0.000	0.000	0.000	0.000
B	mg/L	2.4						0.000	0.007	0.007	0.007
Ba	mg/L	1.3						0.006	0.006	0.006	0.006
Be	mg/L					0.1		0.007	0.007	0.007	0.007
HCO3	mg/L							37.53	13.81	27.39	27.57
Ca	mg/L						200	0.250	1.000	1.000	1.000
Cd	mg/L	0.003		0.05		0.01	0.5	0.000	0.000	0.000	0.000
Ce	mg/L							0.004	0.000	0.000	0.000
Cl	mg/L						100	0.500	0.500	0.500	0.500
Co	mg/L					0.05	1	0.003	0.003	0.003	0.003
Cr	mg/L	0.05	1			0.1	1	0.001	0.001	0.001	0.001
Cs	mg/L	2	40					0.003	0.003	0.003	0.003
Cu	mg/L			0.3	3	0.2	0.5	0.000	0.000	0.000	0.000
Dy	mg/L							0.000	0.000	0.000	0.000
Er	mg/L							0.000	0.000	0.000	0.000
Eu	mg/L							0.000	0.000	0.000	0.000
F	mg/L	1.5				1		0.050	0.050	0.050	0.050
Fe	mg/L			2	3.5	5	0.3	0.132	0.179	0.136	0.000
Ga	mg/L							0.000	0.000	0.000	0.000
Gd	mg/L							0.000	0.000	0.000	0.000
He	mg/L							1.24	1.23	1.22	1.23
Hf	mg/L							0.000	0.000	0.000	0.000
Hg	mg/L	0.006		0.002	0.002		0.05	0.000	0.000	0.000	0.000
Ho	mg/L							0.000	0.000	0.000	0.000
In	mg/L							0.000	0.000	0.000	0.000
K	mg/L						20	2.72	0.13	0.13	0.13
La	mg/L							0.002	0.001	0.002	0.002
Li	mg/L					2.5		0.030	0.007	0.003	0.030
Lu	mg/L							0.000	0.000	0.000	0.000
Mg	mg/L						80	2.077	0.250	0.250	0.250
Mn	mg/L	0.08	8			0.2	0.5	0.040	**0.390**	**0.364**	**0.086**
Mo	mg/L					0.01		0.007	0.007	0.007	0.007
NO3	mg/L	50				5	25	0.13	0.133	0.133	0.13
Na	mg/L	50				3	100	0.245	0.250	0.250	0.250
Nd	mg/L							0.002	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	0.007
P	mg/L							0.058	0.006	0.000	0.000
Pb	mg/L	0.01		0.2	0.1	5	0.05	0.000	0.000	0.000	0.000
Pd	mg/L							0.000	0.000	0.000	0.000
Pr	mg/L							0.000	0.000	0.000	0.000
Rb	mg/L							0.019	0.004	0.001	0.000
SO42-	mg/L						250	0.500	0.500	0.500	0.500
Sb	mg/L	0.02						0.000	0.000	0.000	0.000
Sc	mg/L							0.000	0.000	0.000	0.000

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	Musha Schist	Musha Quartz Vein	Musha Quartzite	Musha Meta Sandstone
Se	mg/L	**0.04**			**0.02**	**0.02**	**0.5**	0.000	0.000	0.000	0.000
Si	mg/L							2.86	2.63	2.63	2.64
Sm	mg/L							0.000	0.000	0.000	0.000
Sn	mg/L							0.000	0.000	0.000	0.000
Sr	mg/L							0.007	0.007	0.007	0.007
Tb	mg/L							0.000	0.000	0.000	0.000
Th	mg/L							0.000	0.000	0.000	0.000
Ti	mg/L							0.000	0.000	0.000	0.000
Tl	mg/L							0.000	0.000	0.000	0.000
Tm	mg/L							0.000	0.000	0.000	0.000
U	mg/L	**0.03**					**0.2**	0.000	0.000	0.000	0.000
V	mg/L					**0.1**	**0.1**	0.007	0.007	0.007	0.007
W	mg/L							0.000	0.000	0.000	0.000
Y	mg/L							0.000	0.000	0.000	0.000
Yb	mg/L							0.000	0.000	0.000	0.000
Zn	mg/L			**0.5**	**5**	**2**	**25**	0.006	0.006	0.006	0.006
Zr	mg/L							0.000	0.000	0.000	0.000
pH				**6-9**	**5-9**		**6-9**	8.86	5.96	6.00	6.70

Table 5-6: Ntunga Mine Legacy Tailings Materials Source Term Screening Results

Element	Unit	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	Ntunga Pegmatite	Ntunga Quartz Vein	Ntunga Metased Sandstone
Ag	mg/L							0.000	0.000	0.000
Al	mg/L		18					0.003	0.000	0.000
As	mg/L	0.01	0.2	0.1		5	5	0.000	0.000	0.000
Au	mg/L				0.01	0.1	2	0.000	0.000	0.000
B	mg/L	2.4						0.006	0.007	0.007
Ba	mg/L	1.3						0.006	0.006	0.006
Be	mg/L					0.1		0.006	0.007	0.007
HCO3	mg/L							13.17	17.56	22.56
Ca	mg/L						200	0.249	0.250	0.250
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	0.498	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					0.002	0.003	0.003
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	0.006	0.200	0.007
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	1.24
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	2.37	0.12	5.10
La	mg/L							0.000	0.000	0.000
Li	mg/L					2.5		0.011	0.008	0.035
Lu	mg/L							0.000	0.000	0.000
Mg	mg/L						80	1.72	0.250	0.250
Mn	mg/L	0.08	8			0.2	0.5	0.006	**0.420**	0.006
Mo	mg/L					0.01		0.006	0.007	0.007
NO3	mg/L	50				5	25	0.13	0.133	3.319
Na	mg/L	50				3	100	0.249	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	0.006	0.007	0.007
P	mg/L							0.032	0.008	0.045
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							0.046	0.002	0.024
SO42-	mg/L						250	0.498	0.500	0.500
Sb	mg/L	0.02						0.000	0.000	0.000
Sc	mg/L							0.000	0.000	0.000
Se	mg/L	0.04			0.02	0.02	0.5	0.000	0.000	0.005

Element	Unit	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	Ntunga Pegmatite	Ntunga Quartz Vein	Ntunga Metased Sandstone
Si	mg/L							2.88	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							0.006	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**	0.006	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**	8.89	6.57	7.26

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 for each mine, and a soil sample was collected from the most downstream observation point of each site for the required laboratory analysis.

6.1 Soil Classification

Refer to Table 6-1 and Table 6-2 for the observations and descriptions of the soil classification assessment for the Musha and Ntunga mines, respectively. The soils in the downstream areas of the Musha mine were classified as a Ferralsol according to the IUSS Working Group WRB (2022)[5] International Soil Classification System. However, the soils that were observed and classified for the downstream areas of the Ntunga mine include a Nitisol.

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[6].

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[7]. 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[3].

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[3]. 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

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[5] 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.

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

[7] 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.

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.

Nitisol

Nitisols are strongly weathered soils which resemble have similar properties to Ferralsols but are usually more fertile. These soils are deep, well-drained and are characterised by a red hue with diffuse horizon boundaries. Furthermore, the subsurface horizon usually consists of more than 30 percent clay and has a moderate to strong angular blocky structure that breaks easily and is known for its characteristic shiny, polyhedric (‘nutty’) elements. Although these soils drain freely, their infiltration capacity decreases with depth which is largely affected by textural changes, specifically increased clay contents. This can lead to waterlogged zones in the profile and the development of iron-manganese concretions (i.e. mottles) in deeper layers[8].

The mineralogy of the clay fraction of Nitisols is dominated by Kaolinite and Halloysite with minor proportions of Illite, Vermiculite and randomly interstratified clay minerals. The mineralogical composition of the sand fraction depends on the parent material, although weathering-resistant minerals like Quartz predominate. Furthermore, minor quantities of Feldspars, Apatite, or Amphiboles can be present indicating that Nitisols are less strongly weathered than associated Ferralsols.

Chemically, they are considered moderately fertile as they contain a reasonable amount of organic carbon and nitrogen. Furthermore, these soils are typically acidic (like Ferralsols) but can have a higher cation exchange capacity (CEC). The high CEC is attributed to a higher clay content, despite the clay minerals being low-activity clays (1:1 clay minerals). It is also noted that these soils can fix phosphorus, with acute deficiencies seldomly occurring, unless under poor phosphorus management especially in low input agricultural systems. Generally, they contain sufficient micronutrients but can be deficient in copper and boron.

Like Ferralsols, Nitisols 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 Nitisols 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. However, the sorbed metals can remobilise if soil pH conditions change to an acidic range.

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[8] Deckers, J, Kimaro, D, Kimaro, O, Njore, R, Nachtergaele, F and Van Ranst, E. 2025. WRB Documentation Centre Nitisols-Lecture Notes. IUSS WRB Working Group webpage and KU-Leuven soil monolith webpage.

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

Mine	Profile ID	Coordinates		Depth (m)	Description	WRB Reference Soil Group
		Latitude	Longitude			
Musha	MUS-01	1°56’07.8”S	30°21’17.1”E	0 – 0.03	The soil is dry and has reddish brown hue with a few medium sized roots in the matrix. The transition to the underlying material is abrupt due to a distinct textural change.	Ferralsol
				0.03 – 0.21	The soil is dry and characterized by reddish brown hue. It has a 10 – 20 % stone fraction in its matrix which consists of mainly weathered material. It has a sandy loam soil texture with good drainage capability and a primary soil structure that is massive with a secondary loose granular sub-structure.	
				0.21 – 0.73	The soil is slightly moist and has a red-brown hue with a sandy clay loam texture. It has a sub-angular blocky structure with good drainage capability. The transition to the underlying horizon is abrupt due to an increase in the clay content likely through eluviation.	
				0.73 – 1.26	The soil is slightly moist and consists of mainly weathered material which is symbolic of a mineral layer. It contains about 2-10% stones and has a dark brown hue. It shows a silty clay texture, with an angular blocky structure. The clay faces have a shiny film or coating and there were some fragments of mica at the bottom.	
	MUS-02	1°55’43.3”S	30°21’28.6”E	0 – 0.065	The soil is dry and has a light brown hue with a dense matted root structure. The transition to the underlying material is gradual.	
				0.065 – 0.70	The soil is dry with a light brown hue and contains 10 – 20% stone fraction in its matrix. There are a few medium sized roots present but consist of mainly weathered material representing a mineral layer. It has a sandy loam texture with a massive structure and demonstrates a loose cohesionless sub-structure, with good drainage capability. The transition to the underlying horizon is gradual.	
				0.70 – 1.12	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 sandy clay loam texture with a sub-angular blocky structure. The transition to the underlying horizon is abrupt due to a marked increase in clay content.	
				1.21 – 1.63	The soil is slightly moist and has a reddish-brown hue. It has a clay loam texture with an angular blocky structure. Some Fe oxides were present towards the bottom of the horizon as orange mottles.	

Note: A soil sample was obtained from MUS-01 for the laboratory analysis.

Table 6-2: Ntunga Mine Downstream Soil Descriptions and Classification

Mine	Profile ID	Coordinates		Depth (m)	Description	WRB Reference Soil Group
		Latitude	Longitude			
Ntunga	NTUS-01	1°58’12.6”S	30°21’58.0”E	0 - 0.02	The soil is moist with sparse roots. It has a dark reddish-brown hue and a clayey texture, with a cloddy structure.	Nitisol
				0.02 - 0.38	The soil is wet and has a brownish red hue. It has a clay loam texture and is mixed with small aggregates or weathered rock material. It has a sub-angular blocky structure and shows firm consistency. The water table was intersected at 0.34 m.	
	NTUS-02	1°58’17.4”S	30°22’00.1”E	0 - 0.14	The soil is slightly moist and has a light reddish-brown hue. There is about 2-10% stones in the matrix with minimal roots. It has a loose, granular structure.	
				0.14 - 0.46	The soil is slightly moist and has a reddish-brown hue. It is characterized by a sandy clay loam texture and has a sub-angular blocky structure. It is more compact than the overlying horizon.	
				0.46 – 0.87	The soil is slight moist and has about 2 – 10% stone fraction in its matrix. It has an orange-brown hue and a silty clay texture. The structure resembles an angular blocky structure, typical of clay rich horizons. There is an abrupt transition to the underlying horizon due to marked clay increase.	
				0.87 – 1.56	The soil grades between slight moist and wet. It has a brown hue and consists of a very thick package of clay. Its texture is primarily clay and there are some Mn mottles at the bottom. The water table was intersected at 1.37 m.	

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

6.2 Physicochemical Soil Properties

Table 6-3 below shows the physicochemical properties of the downstream soil samples that were analysed as part of the Musha and Ntunga mines soil assessment.

The Musha soil sample (MUS-01) has a sandy clay texture with a higher percentage of sand (50%) compared to the silt and clay fractions. However, the Ntunga soil sample has a sandy loam texture and is also characterized by a high percentage of sand, with silt as the secondary particle size fraction which contributes to its loamy character. The Musha soil sample is likely to have good porosity and infiltration capabilities as indicative of a Ferralsol but the drainage of the Ntunga sample is likely to decrease with depth due to its increased clay content, which is typical of Nitisols.

The organic carbon contents of the Musha and Ntunga soils are both low and could be attributed to the rapid decomposition of organic matter due to the climate of the region. Furthermore, the lack of high activity clay minerals (i.e. 2:1 minerals) that are not commonly associated with these soil types as well as 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. This implies that the Musha and Ntunga soil samples are likely to have a limited acid buffering capacity, making them more prone to acidification.

The pH of the Musha soil sample shows that it is acidic (pH<6) which is expected of Ferralsols and implies that the soil is likely to be susceptible to nutrient leaching. Furthermore, the pH level of the Musha soil sample suggests that there will be a reduced availability of several essential nutrients like N, K, Ca and Mg and certain trace and heavy metals can become available at this pH level and potentially reach phytotoxic levels. However, the pH of the Ntunga soil sample is slightly acidic and falls within a range whereby a slightly reduced availability of essential nutrients can occur suggesting that the soil has some productive (fertility) capability associated to it. Both soils have a low CEC (<10 cmol+/kg), with the Ntunga soil sample reporting the highest value. This suggests that the soils are unlikely to buffer changes in pH.

Table 6-3: Musha and Ntunga 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						
Musha	MUS-01	50	11	39	Sandy clay	1.2	1.40	4.67	32	2.64
Ntunga	NTUS-02	67	18	17	Sandy loam	0.98	1.40	6.06	121	5.45

6.3 Nutrient Status

Table 6-4 shows the primary, secondary and micro-nutrient status of the downstream soil samples that were analysed as part of the Musha and Ntunga soil assessments. The purpose of determining the soils nutrient status is not to provide a fertilizer recommendation but to give an indication 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 downstream soils.

Based on the available nutrient status of the soils, both soil samples are characterised by relatively low proportions of P (<10 mg/kg) and K (<50 mg/kg) as primary nutrients. The Mg content of the Ntunga soil sample is above the general range which is suitable for most crops whereas the Mg content of the Musha soil sample is slightly below the range (50 – 120 mg/kg). Furthermore, the Ca and S contents are below the general range associated with these nutrients. In terms of the micro-nutrient status, none of the soils show 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 and Nitisols respectively, while the Mn status is suggested to be derived from the parent material.

Table 6-4: Musha and Ntunga 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
Musha	MUS-01	3	22	274	48	16.43	69.33	56.22	0.8	2.85	0.32	0.2	0.03	76.9	0.06
Ntunga	NTUS-02	3	21	445	131	9.15	91.28	80.79	2.31	2.09	0.17	0.09	0.02	78.5	0.06

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

6.4 Total Metal Concentrations

Table 6-5 shows the total metal concentration results that were screened against the SSV1 (all land uses) thresholds to assess if any element is a potential contaminant in the downstream soil sample. Based on the total metal concentration results, Cu exceedance is reported for both Musha and Ntunga mines downstream soil samples and could be a COPC.

It is suggested that the elevated Cu content is derived from the mineralogy of the parent material from which the soils are derived and is not necessarily due to mining activities, impacting the downstream areas.

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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 6-5: Musha and Ntunga Mine Downstream Soil 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**
Musha	MUS-01	0.10	<0.01	0.90	23.26	1.34	<0.01	<0.01	5.95	50.17	19.34	5.90	<0.01	553	<0.01	14.61	8.86
Ntunga	NTUS-02	1.70	<0.01	0.19	40.15	1.33	<0.01	<0.01	2.80	15.70	13.78	2.40	<0.01	381	<0.01	6.35	4.30

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**	
Musha	MUS-01	9.50	356	<0.01	<0.01	174	<0.01	8.07	<0.01	<0.01	26.89	358	<0.01	117.38	68.39	21.79	10.0
Ntunga	NTUS-02	4.35	175	<0.01	<0.01	105	<0.01	11.15	<0.01	<0.01	9.52	178	<0.01	47.26	28.61	13.27	2.0

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 be emanating from the legacy tailings lithologies, and
- A geochemical baseline assessment of the legacy tailings lithologies that are integrated with the Musha and Ntunga mines to determine their acid rock drainage and metal leaching potential risk,
- 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.

River Sediment Assessment

The Musha River sediment samples compare well with the general particle size distribution trends as the downstream sediment is characterized by a larger distribution of fine particles compared to the upstream sediment sample which contains a greater distribution of medium size fractions with some coarse particles. Only one sediment sample was obtained at the Ntunga mine which shows a distribution of medium and coarse particle size fractions with very minimal fine particle fractions present.

Both Musha sediment samples are dominated by Quartz with major proportions of Kaolinite and Muscovite as well as minor proportions of Hematite and Schorl. However, the downstream sediment contains higher proportions of Kaolinite and Muscovite compared to the upstream sediment, which correlate well with their particle size distribution analysis. Furthermore, the upstream sediment contains higher proportions of Quartz and Hematite compared to the downstream sediment as well as a higher distribution of the medium particle size (i.e. sand) fraction.

The Ntunga sediment sample is dominated by Quartz with minor proportions of Schorl, Muscovite and Kaolinite. There are also trace amounts of Hematite present in the sediment. This sample contained a greater distribution of the medium and coarse particle size fractions in which Quarts and Schorl likely occur.

Due to the presence of Hematite, Schorl, 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 / accumulation of various metals that exceed average crustal abundances or background level values.

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

<u>Musha mine:</u> Fe (both), Mn (both), Pb (upstream) and As (downstream)

<u>Ntunga mine:</u> Fe, Mn and Pb (all downstream)

The SPLP results for the Musha sediments reveal that the upstream sediment reported higher Fe and Mn exceedances compared to the downstream sediment. This could be attributed to the higher proportion of Hematite in the upstream sediment which has an affinity to sorb metal ions, especially Fe.

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

Musha mine: As, Cu, Pb and V (both)

Ntunga mine: As and Pb (downstream)

The exceedances of the SSV1 limits for the various metals in the sediments show that anthropogenic activities have likely impacted the rivers in the vicinity of the Musha and Ntunga mines respectively. This is likely attributed to historic and current panning activities, runoff from the legacy tailings piles and illegal mining activities along the rivers. Furthermore, most of the exceedances reported for the upstream Musha sediment were higher than those in the downstream sediment, except for As. This suggests that the upstream sediment has a greater sorption potential than the downstream sediment and likely due to the higher proportion of Hematite.

The GAI values were compared to the estimated average crustal abundance of the various elements to assess the significance of elemental enrichment in the river sediments obtained from each mine to determine the likelihood of contamination. Based on the calculated GAI values of the metals that were analysed, the following is noted:

Musha mine:
As, B, Se and Sn show a GAI>3
As shows a GAI>6

Ntunga mine:
As and Sn show a GAI>3
B shows a GAI>6

The geochemical baseline assessment of the Musha and Ntunga 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. However, the sediments possess some potential to remediate metal leaching risks because of the presence of Hematite, Schorl, Kaolinite and Muscovite which can facilitate the adsorption of metal ions on their surfaces.

Legacy Tailings Assessment

The Musha Schist is dominated by Quartz and Dravite with major proportions of Muscovite and trace amounts of Palygorskite. The Musha Sandstone primarily consists of Quartz with minor proportions of Goethite and Muscovite. The Musha Quartz vein and Quartzite reported the same mineralogy. However, the Quartz vein is dominated by Quartz with minor proportions of Muscovite whereas the Quartzite is dominated by Quartz with trace proportions of Muscovite.

The Ntunga Pegmatite is dominated by Quartz and Muscovite with minor proportions of Kaolinite and Palygorskite, respectively. The Ntunga Quartz vein consists entirely of Quartz while the metasedimentary sandstone is dominated by Quartz and Muscovite with minor proportions of Kaolinite. It should be noted that these minerals do not contribute to acid generation nor are there acid producing minerals (like sulfides) associated with any of the lithologies. Therefore, there is a minimal to low ARD risk associated with the Musha and Ntunga mine legacy tailings piles.

However, the ABA assessment classified the Musha Schist and Sandstone lithologies as potential acid generating due to their low NPR and NNP values whereas the Musha Quartz vein was classified as non-PAG. The Quartzite was assessed as having an intermediate acid generating potential due to their neutral paste pH values, moderately low NPR and NNP values, respectively. Similarly, the ABA assessment classified the Ntunga Pegmatite and metasedimentary Sandstone lithologies as PAG due to their low NPR and NNP values despite reporting neutral to alkaline paste pH values. The Ntunga Quartz vein is classified as having an intermediate acid generating potential due to its neutral paste pH value, moderately low NPR and NNP values, respectively. However, the low NPR and NNP values for the Musha and Ntunga legacy tailings lithologies are more due to a lack of rapidly dissolving neutralising minerals like carbonates than an abundance of acid generating minerals (like Pyrite).

The SPLP test only detected Mn as a COPC when compared to national and international water quality guidelines for the Musha Sandstone, Quartz vein and Quartzite as well as Ntunga Quartz vein 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 Musha and Ntunga legacy tailings lithologies exhibits a geochemical character that indicates a marginal risk for ARD mainly due to the absence of neutralising minerals associated with the rock minerology. Furthermore, the lithologies pose a moderate risk for metal leaching, which could potentially impact the environment with Mn reported as the only COPC.

Soil Assessment

The soil assessment of Musha and Ntunga mines classified the soils as Ferralsol and Nitisol, respectively.

Ferralsols are mineralogically characterized by Quartz, Kaolinite, Goethite, Hematite and Gibbsite whereas Nitisols also comprise these minerals in addition to Halloysite with minor proportions of Illite, Vermiculite, Feldspars, Apatite or Amphiboles depending on their parent material. Both soils are characterised by the presence of Fe and Al oxides which contribute to metal adsorption and remediation of metal leaching.

The organic carbon content of both soils is low which implies that they have a limited acid buffering capacity making it prone to acidification and nutrient leaching. The downstream soil for the Musha mine is acidic and will consequently experience a reduced availability of several essential nutrients. However, the pH of the Ntunga soil sample is slightly acidic and is likely to experience reduced availability of essential nutrients. Both soils have a low CEC with the Ntunga soil sample reporting the highest value. This suggests that the soils are unlikely to buffer changes in pH. Furthermore, Cu exceeded the SSV1 threshold for both soil types and could be a COPC. The elevated Cu content is likely derived from the mineralogy of the parent material and is not necessarily due to mining activities.

The soil baseline assessment shows that Ferralsols and Nitisols 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, especially if they are impacted by ARD.

Recommendations

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

1. Undertake a comprehensive static geochemical assessment of the Musha and Ntunga mines individual legacy tailings piles to determine each piles acid rock drainage and metal leaching potential risk to develop a risk register for each 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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