MUSHA CONCESSION AREA FRESHWATER ECOSYSTEM ASSESSMENTS

Trinity Metals

DRAFT

GroundTruth

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EXECUTIVE SUMMARY

GroundTruth was appointed by Trinity Metals to perform a baseline freshwater ecosystem assessment for the Musha Concession Area, encompassing the Musha and Ntunga mines in Rwanda. This study constitutes Phase 1 of the Legacy Tailings Management and River Rehabilitation Programme and aims to align project activities with International Finance Corporation Performance Standards, specifically regarding biodiversity conservation and achieving a "no net loss" or "net gain". Through desktop mapping and field surveys conducted in 2025, specialists characterised the extent, ecological condition, and functioning of local wetlands and rivers using frameworks such as WET-Health, WET-EcoServices, and the Index of Habitat Integrity.

The findings reveal that the landscape is substantially modified from its natural state, primarily due to intensive subsistence and co-operative agriculture, *Eucalyptus* woodlots, and mining activities. These anthropogenic pressures have led to increased surface runoff, high erosion, and extensive sedimentation, resulting in most assessed freshwater systems being classified as Largely to Seriously Modified (Category D or E). Aquatic biodiversity is notably compromised; for instance, the Gashahi River downstream of the Ntunga Mine exhibited heavy sedimentation and very low macroinvertebrate diversity, while the Nyirabigaji River system near Musha is heavily impacted by drainage for crop cultivation.

A critical finding is that the demand for regulating ecosystem services - such as flood attenuation, sediment trapping, and water purification - is high, but the supply from these degraded habitats is currently very low. Nevertheless, local communities remain highly dependent on these systems for provisioning services, including water for household use and land for farming. To mitigate these impacts in Phase 2, the report recommends prioritising source control of pollution and adopting nature-based solutions, such as "grey-green" hybrid infrastructure (including biofiltration systems and vegetated swales) and the creation of constructed wetlands to provide ecological buffering. Additionally, the study emphasises the importance of catchment rehabilitation together with stormwater management, sustainable land-use pilot projects, and a robust monitoring and adaptive management framework to ensure long-term resilience and water security

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LIST OF ACRONYMS

Acronym	Explanation
ASPT	Average Score Per Taxon
BAP	Biodiversity Action Plan
CHA	Critical Habitat Assessment
DDS	Development Strategy
DRC	Democratic Republic of the Congo
DWS	Department of Water and Sanitation
EIA	Environmental Impact Assessment
ERA5	ECMWF Reanalysis 5
ESA	European Space Agency
ESIA	Environmental and Social Impact Assessment
ESMP	Environmental and Social Management Plan
FIP	Forest Investment Program
GDP	Gross Domestic Product
GIS	Geographic Information System
HGM	Hydrogeomorphic
IFC	International Finance Corporation
IHI	Index of Habitat Integrity
ISO	International Organization for Standardization
IWRM	Integrated Water Resources Management
KAB	Karagwe-Ankole Belt
KIB	Kibara Belt
MAP	Mean Annual Precipitation
MoE	Ministry of Environment
NST1	National Strategy for Transformation 1
NST2	Second National Strategy for Transformation
PES	Present Ecological State
PFM	Public Financial Management
PS6	Performance Standard 6
PTV	Pollution Tolerant Valves
RFA	Rwanda Forestry Authority
REMA	Rwanda Environment Management Authority

Acronym	Explanation
RWB	Rwanda Water Resources Board
SASS5	South African Scoring System (Version 5)
SCC	Species of Conservation Concern
SDGs	Sustainable Development Goals
SPI	Specific Pollution Sensitivity Index
SWG's	Sector Working Group
UN	United Nations
WRI	World Resources Institute
WSE	Water Surface Elevations

1. INTRODUCTION

GroundTruth were appointed by Trinity Metals to undertake a broad range of ecological, social and engineering studies across their mining concession areas in Rwanda, to contribute towards Phase 1 of Trinity Metal's Legacy Tailings Management and River Rehabilitation Programme.

Freshwater ecosystems, including rivers and wetlands, and associated biota, are crucial features within the landscape, which not only contribute towards biodiversity but provide a suite of ecosystem services that support the livelihoods of people. These systems support provisioning services such as freshwater supply, regulating services including flow regulation and water purification, cultural services linked to heritage and recreation, and processes that maintain ecological integrity and productivity. The importance of these systems has been globally assessed, and the systems have been recognised by international agreements (e.g. Convention on Biological Diversity) that guide how organisations like the IFC (International Finance Corporation) protect nature and the benefits people get from them.

This study has been initiated to assess the freshwater ecosystems within the various mining concession areas, particularly focussing on developing an understanding of the extent, ecological condition and functioning, the overall operating rules, and drivers and pressures of the freshwater ecosystems within the current landscape setting. To align with international requirements, this baseline study of the freshwater ecosystems is required, in order to ascertain whether the concession areas incorporate areas with critical habitat but are also recommended for high-risk projects potentially impacting on natural areas (IFC, 2012). The freshwater ecosystem baseline study will form the basis from which future action and mitigation strategies can be developed to achieve a net gain (or no net loss), where feasible, within the modified landscape, so as to align with the IFC requirements.

The focus area for this freshwater ecosystem report study is the Musha Concession Area, which encompasses both the Musha and Ntunga mines. The complex is located within the tin-bearing Rwamagana District of Rwanda, approximately 45 km east of Kigali. The operation incorporates several subordinate workings, the bulk of production is sourced from the Musha Mine, primarily focussing on tin, with minor outputs of tantalum and identified potential for lithium mineralisation (SLR, 2024a). **Figure 1-1** provides an overview of the study area covering the Musha and Ntunga mines.

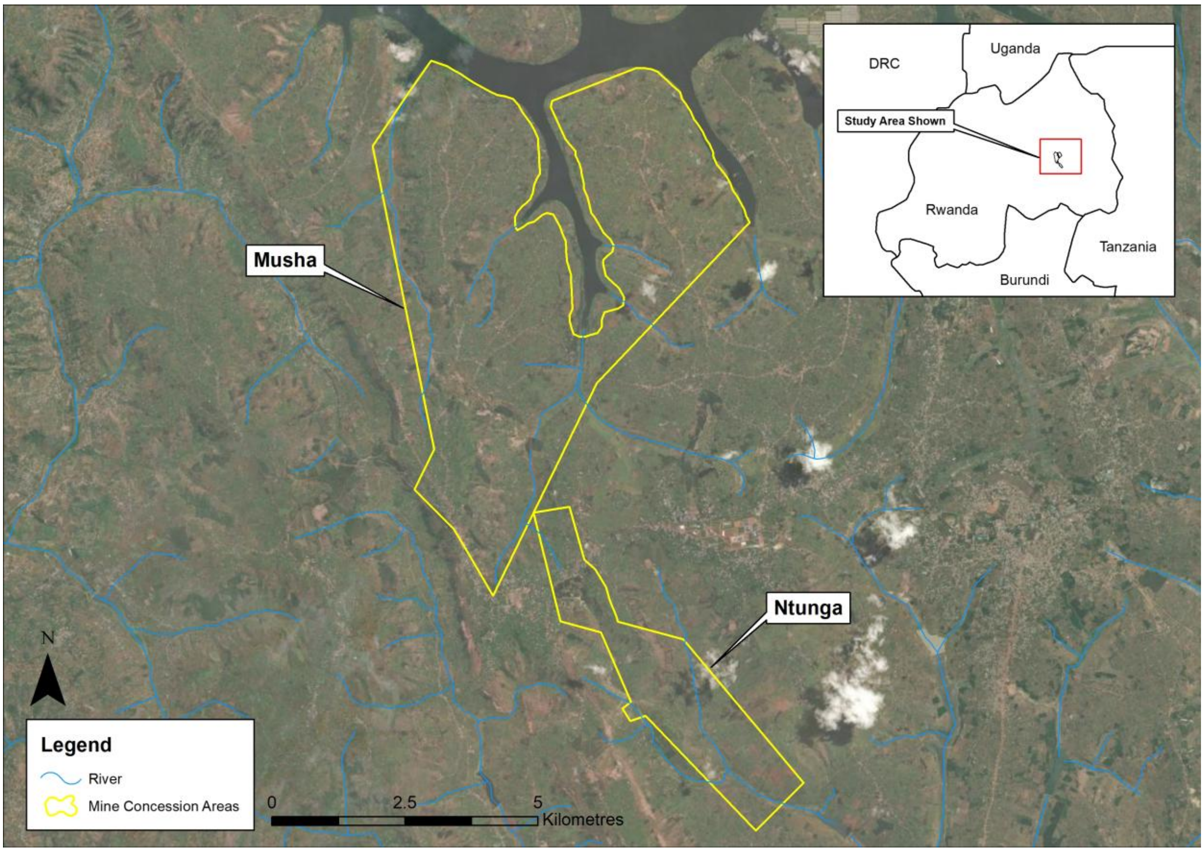


Figure 1-1 Overview of the Musha Concession area

1.1 Key Objectives

The purpose of this report is to provide a comprehensive baseline of the freshwater ecosystems within the Musha concession area. The objective of the site visit was to verify and evaluate the freshwater ecosystems, distinguishing between riverine and wetland ecosystems, and recognising their landscape linkages. Baseline information was collected to enable the assessment of ecosystem functioning and integrity, as well as to develop an understanding of the overall importance and sensitivity of these freshwater habitats. This information, together with the results of the floodline and sediment modelling, will inform impact mitigation measures and guide resilient rehabilitation planning during Phase 2 of the project.

The key objectives of the freshwater ecosystem study were to:

- Undertaking desktop studies and field-based surveys of associated ecosystems within the area of influence for each site;
- Characterise patterns and processes of freshwater systems in terms of biota (i.e. fauna and flora), vegetation, hydrology, geomorphology, etc.;
- Establish baseline ecological conditions/Present Ecological State (PES), as well as the provision of ecological benefits and services.
- Highlighting any species of conservation concern (i.e. rare, endemic, Red Data species), in particular species that trigger Criterion 1 to 3 IFC PS6 that will need to be considered in the Critical Habitat Assessments (CHA); and

- Identifying and assessing key indicators suitable for monitoring (e.g. biomonitoring) and determining additional in-situ water quality indicators for assessment and longer-term monitoring.

2. REGULATORY AND INSTITUTIONAL FRAMEWORK

2.1 National Strategy for Transformation

Following several decades of progress since the 1994 Genocide against the Tutsi, Rwanda continues its journey toward self-reliance and economic modernisation through the implementation of Vision 2050. This long-term roadmap was preceded by Vision 2020 and is being realised through a series of medium-term national development strategies. The National Strategy for Transformation 1 (NST1) served as the initial bridge for this transition between 2017 and 2024. Rwanda is now commencing the next phase through the Second National Strategy for Transformation (NST2), which spans from 2024 to 2029. This strategy continues to integrate global and regional agendas, including the UN Sustainable Development Goals (SDGs), the African Union Agenda 2063, and the East African Community Vision 2050 (Republic of Rwanda, 2024; Republic of Rwanda, 2020).

NST2 maintains the three core pillars of transformation: Economic Transformation, Social Transformation, and Transformational Governance (Republic of Rwanda, 2024).

The Economic Transformation Pillar in NST2 prioritises building resilience to climate change and the sustainable management of natural resources to ensure long-term prosperity. A critical objective within this pillar is achieving universal access to water supply for both productive use and households, with a target to scale access to all villages countrywide by 2029. The strategy aims to more than double daily water production capacity and reduce non-revenue water to enhance efficiency. These efforts are supported by integrated water resource management (IWRM) that focuses on restoring catchment areas and improving watershed management to mitigate disasters like flooding (Republic of Rwanda, 2024).

The Social Transformation Pillar focuses on enhancing human capital and the quality of life for all Rwandans. Key interventions include increasing access to quality education, reducing stunting among children under five from 33% to 15%, and scaling up access to sanitation and hygiene (WASH) services. Major infrastructure projects, such as the Kigali Centralised Sewerage System, are planned to support the sustainability of densified urban areas. Furthermore, this pillar seeks to empower households to graduate from poverty through social safety nets and the provision of technical and financial skills (Republic of Rwanda, 2024).

The Transformational Governance Pillar serves as the foundation for these gains by strengthening the rule of law and ensuring an accountable and capable state. This pillar targets a service delivery satisfaction level above 90% and emphasises citizen-centered governance through enhanced participation platforms. While not directly managing water, this pillar supports resource management by fostering international cooperation, strengthening Public Financial Management (PFM) for "green public procurement," and building institutional capacity at all levels (Republic of Rwanda, 2024).

The Government of Rwanda implements these national priorities through specialised sectors and cross-sectoral collaboration platforms, such as Sector Working Groups (SWGs). The implementation arrangement for NST2 is cascaded down to local levels through District Development Strategies (DDS), which ensure that national objectives are aligned with local economic potential and community needs. This allows all districts to prioritise interventions that contribute to the overarching national goals (Republic of Rwanda, 2024).

Ultimately, NST2 acts as the critical vehicle toward Vision 2050, which aspires for Rwanda to reach upper-middle-income status by 2035 (with a GDP per capita of over $4,036) and high-income status by 2050 (with a GDP per capita of over $12,476). The vision emphasises an inclusive model of development, recognising the collective commitment required from the government, private sector, civil society, development partners, and all Rwandan citizens to modernise the nation and ensure a high quality of life for future generations (Republic of Rwanda, 2024; Republic of Rwanda, 2020).

2.2 Applicable Rwandan regulations/legislation

Rwanda's environmental legislation is anchored in its Constitution[1], which guarantees every citizen the right to live in a healthy and balanced environment and places a duty on the state to protect natural resources while promoting sustainable development.

Rwanda's constitutional commitment to environmental protection was first translated into the 2005 Organic Law on Environmental Protection and Management, which established principles for conservation and introduced mandatory Environmental Impact Assessments (EIAs) for projects likely to affect the environment. Building on this foundation, Law No. 48/2018 on Environment strengthened the framework by expanding provisions on pollution control, waste management, biodiversity conservation, and environmental governance, while also imposing stricter penalties for violations and emphasising community participation.

The legislation's major focus areas include pollution control, waste reduction and recycling, biodiversity protection, climate change adaptation, and citizen engagement in conservation efforts. Implementation is overseen by the Ministry of Environment, enforced by the Rwanda Environment Management Authority (REMA), and supported by local governments at the grassroots level.

2.2.1 *Environmental and Freshwater Ecosystem Legislation in Rwanda*

Rwanda's environmental and freshwater ecosystem legislation is shaped by the 2018 Law on Environment, which provides a comprehensive framework for conservation, sustainable resource use, and environmental governance.

Freshwater ecosystems are safeguarded through the oversight of the Rwanda Water Resources Board (RWB), which plays a central role in managing rivers, lakes, and wetlands under the principle of Integrated Water Resources Management (IWRM). This approach ensures that water resources are allocated equitably among competing needs - such as domestic supply, agriculture, industry, and energy - while maintaining ecological integrity. Implementation is overseen by the Ministry of Environment, enforced by REMA, managed by the RWB, and supported by local governments at the grassroots level. Together, these measures ensure that Rwanda's rivers, lakes, wetlands, and broader ecosystems are protected from pollution,

[1] Article 22 of the Constitution of the Republic of Rwanda of 2003, revised in 2015.

overuse, and unsustainable development, while balancing biodiversity conservation, human needs, and climate resilience.

Wetlands are legally protected, with any conversion for agriculture, construction, or other development strictly requiring environmental assessment and government approval. Lakes and rivers are managed to balance biodiversity conservation with human needs, supporting livelihoods through regulated fishing, irrigation for food security, and hydropower generation. Rwanda's environmental legislation provides clear protections and regulated uses for its freshwater ecosystems, ensuring that conservation and sustainable utilisation are balanced. Error! Reference source not found. summarises how each ecosystem type is managed under this legislation:

Table 2-1 Freshwater Ecosystem Legislation, Protection & Use

Ecosystem Type	Legal Protection	Permitted Uses	Restrictions
Wetlands	Legally protected under Law No. 48/2018; conversion requires government approval; managed by Rwanda Environment Management Authority (REMA)	Sustainable agriculture, eco-tourism, research, regulated fishing.	No unauthorized drainage, construction, or industrial waste discharge.
Lakes	Protected as biodiversity hotspots; water quality monitored; pollution control enforced.	Fishing, irrigation, hydropower, transport, recreation are regulated through a water use permit managed by Rwanda Water Resources Board (RWB).	Ban on untreated waste disposal; restrictions on overfishing; shoreline development requires EIA.
Rivers	Managed under Integrated Water Resources Management (IWRM); protected against pollution and overuse.	Irrigation, hydropower, and domestic water supply are regulated through a water use permit managed by Rwanda Water Resources Board (RWB).	No industrial effluent discharge without treatment; sand mining and damming require permits.
Groundwater	Protected under national water policy; extraction monitored and regulated by RWB.	Domestic use, agriculture, industry (with permits).	Over-extraction prohibited; pollution from chemicals strictly controlled.

In addition, the RWB enforces strict pollution control measures, prohibiting the discharge of untreated industrial or domestic waste into water bodies and mandating continuous monitoring of water quality. These safeguards are complemented by restoration projects aimed at rehabilitating degraded wetlands and catchments, as well as community-based initiatives that involve local populations in conservation and sustainable water use. Importantly, wetlands and river systems also serve as natural buffers against climate change impacts, reducing flood risks, mitigating drought effects, and enhancing resilience to extreme weather events.

The legislation is guided by key principles, including the right to a healthy environment, precautionary measures for activities that may harm ecosystems, sustainable use of resources for future generations, and active community participation in conservation efforts.

2.3 Rwanda's Environmental Governance Institutions

2.3.1 *Ministry of Environment*

The Rwandan Ministry of Environment (MoE) is the central government body responsible for environmental protection, climate change policy, and the sustainable management of land, water, and forestry resources. Its mandate includes developing and enforcing national environmental policies and legal frameworks, coordinating climate change adaptation and mitigation programs in line with international commitments such as the Paris Agreement, overseeing sustainable land use and forest conservation, protecting biodiversity and wetlands, and integrating environmental concerns into Rwanda's broader development agenda.

The Ministry operates through specialised directorates, including the Directorate General of Environment and Climate Change, which implements climate policies and monitors emissions, and the Directorate General of Land, Water, and Forestry, which manages land use planning, water resources, and forest ecosystems. It works closely with affiliated agencies such as the Rwanda Environment Management Authority (REMA), which enforces environmental law and conducts EIAs, and the Rwanda Forestry Authority, which manages forest conservation and reforestation programs. The Ministry and its affiliated agencies work closely with the Rwanda Water Resources Board (RWB), which oversees freshwater ecosystems and Integrated Water Resources Management (IWRM) and affiliated to the Office of the Prime Minister.

As of July 2025, the Ministry is led by Bernadette Arakwiye, an expert in land restoration and environmental research with prior experience at the World Resources Institute (WRI). Under her leadership, recent initiatives include the Legacy Tree Project to preserve Rwanda's oldest native trees, international cooperation with Singapore under Article 6 of the Paris Agreement to strengthen climate action, and ongoing wetland restoration projects to rehabilitate degraded ecosystems. Central to Rwanda's sustainability agenda, the Ministry combines policy-making, enforcement, and international collaboration to protect the environment while supporting economic growth, with current priorities focused on climate resilience, biodiversity conservation, and land restoration.

2.3.2 *Rwanda Environment Management Authority*

The Rwanda Environment Management Authority (REMA), established in 2006, serves as the national authority responsible for implementing environmental policies and laws, with a mission to protect, conserve, and promote Rwanda's environment while ensuring sustainable development. Its core responsibilities include enforcing compliance with environmental legislation such as Law No. 48/2018 on Environment, reviewing and approving EIAs, monitoring pollution levels, waste management practices, and biodiversity conservation, and promoting environmental education and public awareness.

REMA also works with the Ministry of Environment to translate policies into action and coordinates Rwanda's participation in international environmental agreements. Its focus areas span pollution control, waste management, biodiversity conservation, climate change adaptation and mitigation, and community engagement in environmental decision-making. Operating under the Ministry of Environment, REMA collaborates with agencies such as the Rwanda Water Resources Board (RWB) and the Rwanda Forestry Authority, while also working closely with local governments to implement grassroots initiatives. As the enforcement arm of Rwanda's environmental governance system, REMA ensures that development projects meet environmental standards, safeguards ecosystems, and promotes sustainable resource use, playing a central role in Rwanda's vision of becoming a green, climate-resilient nation.

2.3.3 *Rwandan Water Resources Board*

The Rwanda Water Resources Board (RWB), established in 2020 by Law No. 71/2019 of 29 January 2020, is tasked with ensuring the sustainable management of the country's water resources. Its mission is to coordinate, regulate, and promote Integrated Water Resources Management (IWRM) to deliver social, economic, and environmental benefits. The Board develops national strategies for water use, allocation, and conservation, oversees water quality and pollution control, and ensures compliance with environmental laws. It manages wetlands, rivers, and lakes to balance biodiversity conservation with human needs, implements measures to strengthen climate resilience against droughts and floods, and conducts hydrological research while maintaining national water resource databases.

RWB also engages communities and local governments to promote sustainable water use. Its focus areas include pollution prevention, water supply security, hydropower development, wetland restoration, and transboundary cooperation on shared basins such as the Nile. Operating under the Office of the Prime Minister, RWB works closely with REMA on compliance, partners with the Rwanda Forestry Authority for watershed protection, and coordinates grassroots initiatives with local governments. As the guardian of Rwanda's freshwater ecosystems, RWB integrates water management across agriculture, energy, domestic use, and biodiversity conservation, ensuring that rivers, lakes, wetlands, and groundwater are protected for both present and future generations.

2.3.4 *Rwanda Forestry Authority (RFA)*

The Rwanda Forestry Authority (RFA), formally established by Law No. 72/2019 of 29 January 2020, is the national agency responsible for managing, protecting, and expanding Rwanda's forest resources to ensure sustainable development. Its mandate includes promoting forest growth and conservation, conducting forestry research and innovation, implementing national forestry policies, engaging communities in tree planting and agroforestry, and supporting climate change mitigation through reforestation and forest preservation. The Authority oversees natural forests, plantations, and agroforestry systems, regulates the sustainable harvesting of non-timber forest products such as honey, medicinal plants, and bamboo, coordinates national reforestation campaigns including Umuganda (monthly community service), enforces forestry laws to prevent illegal logging, and develops guidelines for urban forestry. Organised into specialised divisions - Forest Research, Forest Management, and Administration and Finance - the RFA combines scientific research with practical management and policy enforcement. Recent initiatives include the Forest Investment Program (FIP), which promotes agroforestry and sustainable land use in districts like Gakenke, the 2025 Urban Tree Guidelines that set standards for planting in residential and public spaces, and community mobilisation efforts encouraging citizen participation in reforestation and erosion control. As a central institution in Rwanda's environmental governance, the RFA plays a vital role in forest conservation, reforestation, and sustainable resource use, advancing the country's vision of becoming a green, climate-resilient nation.

2.4 International Finance Corporation Performance Standards

The International Finance Corporation (IFC) Performance Standards provide an internationally recognised framework for managing environmental and social risks associated with development projects and they are widely adopted by financial institutions, development banks, and private sector lenders. Through its Environmental and Social Sustainability Policy and accompanying Performance Standards (updated in 2012), the IFC requires projects with potentially significant environmental and social impacts to align with these standards as a condition of financing. In the context of freshwater ecosystems, including rivers (and associated riparian systems), wetlands, lakes, and floodplains, the IFC framework plays an important role in integrating biodiversity conservation, ecosystem services, and sustainable water resource management into project planning and decision-making.

Freshwater ecosystems are addressed primarily through IFC Performance Standard 6 (PS6): *Biodiversity Conservation and Sustainable Management of Living Natural Resources*. PS6 explicitly recognises that conserving biodiversity, maintaining ecosystem services, and sustainably managing living natural resources are fundamental to sustainable development. Under PS6, clients are required to identify and prioritise ecosystem services through a systematic assessment process. Priority ecosystem services are defined as, 1) services on which project activities are likely to have significant impacts, particularly those affecting the well-being and livelihoods of affected communities, and 2) services on which project operations directly depend. For freshwater systems, this may include water supply, water purification, flood attenuation, fisheries, sediment regulation, groundwater recharge, and cultural or livelihood-related services associated with rivers and wetlands.

PS6 places strong emphasis on the application of the mitigation hierarchy, requiring projects to first avoid impacts, then minimise and restore impacts where feasible, and finally offset significant residual impacts where necessary. The overall objective is to achieve "no net loss" of biodiversity and ecosystem services, and where "critical habitat" is affected, a measurable "net gain" may be required. The standard also recognises the importance of maintaining ecological integrity and connectivity within freshwater systems, including the protection of environmental flows, aquatic habitats, and wetland functioning. In practice, this requires robust baseline assessments, biodiversity and aquatic ecology studies, water quality and hydrological investigations, and ongoing monitoring throughout the project lifecycle.

Under IFC PS6 and associated Guidance Note 6, habitats are classified into modified, natural, and critical habitats, with all terrestrial and freshwater ecosystems considered within this framework. Critical habitats include areas supporting threatened species, endemic or restricted-range species, highly threatened ecosystems, or globally significant biodiversity concentrations. Consequently, freshwater ecosystems such as intact wetlands, ecologically important river systems, Ramsar wetlands, or habitats supporting threatened aquatic species may qualify as critical habitat and trigger additional requirements, including Biodiversity Action Plans (BAPs), enhanced mitigation measures, and potentially biodiversity offsets.

While PS6 is the primary biodiversity standard, several other IFC Performance Standards are also relevant to freshwater ecosystems. **Performance Standard 1** (*Assessment and Management of Environmental and Social Risks and Impacts*) establishes the overarching framework for environmental and social assessment, stakeholder engagement, cumulative impact assessment, and adaptive management. **Performance Standard 3** (*Resource Efficiency and Pollution Prevention*) addresses sustainable water use, wastewater management, pollution prevention, erosion and sediment control, and efficient resource utilisation. **Performance Standard 4** (*Community Health, Safety and Security*) is relevant where changes in water quality, flooding, dam safety, or ecosystem services may affect downstream communities. Collectively, these standards reinforce the requirement for integrated and sustainable management of freshwater resources at both site and catchment scales.

The IFC Performance Standards are also closely aligned with broader international sustainability frameworks, including the Equator Principles, and therefore form a key benchmark for projects seeking international financing. As a result, freshwater ecosystem protection is increasingly considered a core component of environmental and social due diligence, requiring projects to demonstrate that development activities will not result in unacceptable degradation of rivers and wetlands, or the ecosystem services on which communities and biodiversity depend.

3. KNOWLEDGE GAPS

This section highlights the assumptions, limitations and knowledge gaps associated with this study that may influence the type of information collected and the accuracy of the data.

3.1 Assumptions

- The mapping of freshwater ecosystems within the Musha Mine Concession area was initially undertaken at a desktop-level utilising available topographical maps, current and historical aerial imagery, existing coverages, contour data, and available Geographical Information System (GIS) coverages. The desktop-level mapping was performed in a GIS at a scale of 1:5’000 to create an initial draft spatial coverage of the freshwater ecosystems within the study area. The extent of the freshwater ecosystems was later updated following the site visit in November 2025, during which stage the HGM unit type was also verified.
- Most rivers and wetlands have been significantly altered from their benchmark conditions to the extent that their original operating rules and functional processes are no longer representative. In such cases, systems are assessed against their new operating rules and reclassified into more appropriate Hydrogeomorphic (HGM) unit types, since they are unlikely to ever be reinstated to their benchmark conditions. This redefinition ensures that management reflects current functional processes rather than historic classifications.
- The catchment landcover/uses coverage was mapped at a scale of 1:20’000 using Google Earth imagery due to the extent of the Musha concession area.
- The assessment of Present Ecological State for each system was based on a rapid visual assessment of modifications to the biophysical drivers and was principally based on a brief site review of localised portions of the system, which were used to verify desktop derived information and inform the assessment of the greater system.
- Given the extensive size of the concession area and the limited time available on site, the specific locations visited were considered representative of the broader site context. Accordingly, the conditions observed during the site visit were assumed to be representative of the general condition of the systems across the wider area.

3.2 Limitations

The following limitations apply to the studies undertaken for this report:

- The assessments of the freshwater ecosystems and identified wetland/riverine habitats were based two brief site visits conducted in July/August and November 2025. As such, they represent a ‘snapshot in time’ due to budgetary and time constraints. This approach did not allow for extensive assessment across multiple seasons, meaning that some species may have been missed and temporal trends not captured. Furthermore, changes in features and characteristics within the wetlands, rivers, and their catchments—potentially influenced by seasonality and land use—may not be fully reflected. Given the long history of transformation and degradation at the site, it was not expected to support unique or highly sensitive biodiversity features.

- All assessments undertaken were based on the impacts that were noted during the time of the site visit. Should conditions onsite change, including catchment conditions, the assessments may not necessarily reflect such changes. Any subsequent changes in a systems catchment may have adverse effects on the overall system's integrity.
- The wetland/riparian assessment techniques are considered to be the most appropriate at the time of the compilation of the report, as these techniques have been compiled based on international best practice, undergoing a peer-review process during their development. However, in some instances where systems have been highly modified/transformed, these techniques may have shortfalls.
- The technique adopted for the assessment of wetland condition (i.e. WET-Health) did not account for all land use types within the Rutongo concession, and as such, modifications to wetland land cover categories were adopted, particularly to reflect the impacts of extensively drained subsistence croplands.
- As the assessment techniques have a predominant South African focus and rely on quaternary catchment information specific to South Africa, the catchment data for the Musha concession was updated using client-provided rainfall records (MAP), while runoff and evaporation values were derived from the ERA5 repository.
- Some of the HGM units were grouped according to their respective wetland complexes i.e. wetlands sharing the same characteristics and same/similar sub-catchment characteristics were clustered together to form a wetland complex.
- WET-EcoServices (Kotze *et al.,* 2020) assists in identifying the importance and sensitivity of specific wetlands/rivers but is recognised as having limitations in terms of quantifying specific impacts linked to development or changes within the landscape; and accounting for the size of the wetland and ecosystem services strongly associated with the size of the systems.
- The instream and riparian site assessments reflect the state of a particular river segment and not the state of the full length of each river, however, the knowledge and information gained from the field verification was then extrapolated for the entire river reach being assessed.
- The riparian assessments are subject to seasonal constraints as certain characteristics of the rivers are only evident at certain times of the year.

The project deliverables, including the reported results, comments, recommendations and conclusions, are based on the authors' professional knowledge as well as available information. This study is based on assessment techniques and investigations that are limited by time and budgetary constraints applicable to the type and level of survey undertaken.

4. METHODS

4.1 Site visit

The field survey was conducted on from 17th – 18th November 2025 to assess the freshwater ecosystems (rivers and wetlands) within the Trinity Musha mine concession, with additional observations from the July/August 2025 site visit also incorporated into the assessment.

4.1.1 *Wetland assessments*

Table 4-1 below shows the field survey programme that was followed for the wetland habitat assessment component of the study.

Table 4-1 Field Survey Programme for wetland habitat assessment.

Day	Date	Site
Monday	17/11/2025	Musha (Musha 1-2, 4-7) and Ntunga Mine (Ntunga 1)
Tuesday	18/11/2025	Musha Mine (Musha 3)

The wetland assessment included on-site verification of habitat extent by examining soil characteristics, landscape position, and vegetation indicators to confirm the boundaries of wetland areas. The functional assessment evaluated how well the wetlands perform key ecosystem roles and the extent to which they provide important goods and services to the surrounding landscape and communities. In addition, an integrity assessment was undertaken to compare current conditions against natural reference states by examining four key drivers namely hydrology, water quality, geomorphology, and vegetation; thereby identifying how human activities have altered the condition and functioning of the wetlands.

4.1.2 *Riverine assessments*

Table 4-2 below shows the field survey programme that was followed for the riverine assessments.

Table 4-2 Field survey programme for the riverine assessments.

Day	Date	Site
Monday	17/11/2025	Musha and Ntunga Mine (four sites)

Sampling and assessments took place at a total of four sites covering the river systems traversing the Musha concession, including the Nyirabigaji River draining the Musha Concession; and Gashahi draining the Ntunga Concession. Water clarity was measured at four sites using a clarity tube to provide a relative indication of turbidity and suspended sediment levels. Benthic diatom samples, which serve as sensitive indicators of water quality effects on aquatic life, were collected at three sites following standard protocols. Aquatic macroinvertebrates were assessed at one site with suitable habitat using the ISO-accredited SASS5 method to determine river health based on community composition and scoring metrics. In addition, the Index of Habitat Integrity (IHI) was applied at one site (i.e. the Gashahi River) to evaluate the Present Ecological State of both riparian and instream habitats.

4.2 Freshwater ecosystem classification

The freshwater ecosystem classification utilised for the study is based on the classification systems developed in South Africa, as these classification systems form the basis against which the freshwater ecosystems were assessed.

4.2.1 *Wetland classification*

Wetlands were classified into Hydrogeomorphic (HGM) units to facilitate assessment of the systems across the site. The classification approach distinguished wetland systems according to their functional characteristics and hydrological setting (Error! Reference source not found.).

Table 4-3 A description of the various HGM unit types

(Ollis *et al.* 2013)

Landscape unit	HGM unit	Description of HGM Units (Ollis *et al.* 2013)
Plain[2]	Floodplain	A wetland area on the mostly flat or gently-sloping land adjacent to and formed by an alluvial river channel, under its present climate and sediment load, which is subject to periodic inundation by over-topping of the channel bank.
Valley Floor[3]	Channelled valley-bottom	Valley-bottom areas with a clearly defined stream channel but lacking characteristic floodplain features. May be gently sloped and characterised by the net accumulation of alluvial deposits or may have stepper slopes and be characterised by the net loss of sediment. Water inputs from main channel (when channel banks overspill) and from adjacent slopes.
	Unchannelled valley-bottom	A valley-bottom area with no clearly defined stream channel, usually gently sloped and characterised by alluvial sediment deposition, generally leading to a net accumulation of sediment. Water inputs mainly from channel entering the wetland and also from adjacent slopes.
Slope[4]	Hillslope seep	A wetland area located on gently to steeply sloping land and dominated by colluvial (i.e., gravity-driven), unidirectional movement of water and material downslope. Seeps are often located on the side slopes of a valley, but they do not typically extend onto the valley floor.
Bench[5]	Depression	A wetland or aquatic ecosystem with closed (or near-closed) elevation contours, which increases in depth from the perimeter to a central area of greatest depth and within which water typically accumulates.

[2] Plain – an extensive area of low relief. These areas are generally characterized by relatively level, gently undulating or uniformly sloping land with a very gentle gradient that is not located within a valley. Gradient is typically less than 0.01 or 1:100.

[3] Valley-floor - the base of a valley, situated between two distinct valley- side-slopes, where alluvial or fluvial processes typically dominate.

[4] Slope – an inclined stretch of ground typically located on the side of a mountain, hill or valley, not forming part of a valley floor. Includes scarp slopes, mid-slopes and foot-slopes.

[5] Bench – a relatively discrete area of mostly level or nearly level high ground (relative to the broad surroundings), including hilltops, saddles and shelves. Benches are significantly less extensive than plains, typically being less than 50ha in area.

Landscape unit	HGM unit	Description of HGM Units (Ollis *et al.* 2013)
Plain/bench	Flat	A level or near-level wetland area that is not fed by water from a river channel, and which is typically situated on a plain or a bench. Closed elevation contours are not evident around the edge of a wetland flat.

The HGM units identified within the Trinity Musha Mine area have been classified as valley-bottom wetlands. It should be noted that even though historically some of the wetlands may have been classified as a specific HGM unit type, some systems functional processes have changed significantly and no longer function as per their benchmark conditions and therefore, have been reclassified as a new HGM unit type which is more suited to the current functional processes. This reclassification was done in the view that these systems cannot ever be reinstated back to their benchmark conditions, and therefore, redefining them based on their current functional processes is more suitable for long-term management objectives.

4.2.2 *River classification*

Rivers are defined as linear landforms with distinct beds and banks that permanently or periodically carry concentrated water flow. Similar to the wetland classification, the South Africa river classification was used for the systems within the Trinity Musha Concession whereby river reaches were categorised into longitudinal geomorphological zones primarily based on their characteristic gradient and diagnostic channel characteristics, such as substratum type. These classes were used to define the type of riverine systems identified within the concession area and includes mountain headwater streams, mountain streams, transitional rivers, upper foothill rivers, and lower foothill rivers (Rowntree *et al.*2000), with the following river types generally defining the systems that were assessed in relation to the Musha and Ntunga Mines:

- *Mountain Stream:* Steep (4.0 – 9.9%) gradient stream dominated by bedrock and boulders, locally cobble or coarse gravels in pools. Reach type include cascades, bedrock fall, step-pool. Approximate equal distribution of vertical' and 'horizontal' flow compartments.
- *Transitional:* Moderately steep (2.0 – 3.9%), cobble-bed or mixed bedrock-cobble bed channel, with plain-bed, pool-riffle, or pool-rapid reach types. Length of pools and riffles/rapids similar. Narrow floodplain of sand, gravel, or cobble often present.
- *Upper Foothills:* Moderately steep (0.5 – 1.9%), cobble-bed or mixed bedrock-cobble bed channel, with plain-bed, pool-riffle, or pool-rapid reach types. Length of pools and riffles/rapids similar. Narrow floodplain of sand, gravel, or cobble often present.
- *Lower Foothills:* Lower (0.1 – 0.5%) gradient mixed bed alluvial channel with sand and gravel dominating bed, locally may be bedrock controlled. Reach types typically include pool- riffle or pool- rapid, sand bars common in pools. Pools of significantly greater extent than rapids or riffles. Flood plain often present.

The river types on-site were characterised mainly on gradient rahter than substrate largely due to the largely altered nature of instream channel features and habitats. Rivers can be further subdivided into its active channel (i.e. the portion regularly inundated to maintain channel form) and its riparian zone, which consists of the area directly adjacent to the channel influenced by river-induced processes.

4.3 Freshwater Ecosystem Assessment

The following sections outlines the approaches adopted in the assessment of the freshwater ecosystems in the mining concession areas.

4.3.1 *Assessment of wetland ecological condition*

The application of biological assessments to specify the health or integrity of a wetland is common practice internationally, as illustrated by the review of international assessment methods by Ollis and Malan (2014). While these internationally recognised approaches may be applicable to a Rwandan context, Kotze *et al.,* (2009) highlight that the variability of environmental conditions and the range of wetland systems in sub-Saharan Africa, are likely to affect the applicability of international approaches.

To circumvent these challenges, an assessment approach referred to as WET-Health (Macfarlane *et al.,* 2020), has been widely adopted in sub-Saharan Africa to assess ecosystem integrity (Kotze *et al.,* 2009; Walters *et al.,* 2011; Macfarlane *et al.,* 2012). Although other assessment methods exist within South Africa, alongside the Wetland-Index of Habitat Integrity (DWAF 2007), Ollis and Malan (2014) describe WET-Health as the most advanced assessment method to determine wetland integrity. Considering this and the fact that WET-Health includes a comprehensive level of assessment, the method was viewed as an appropriate means of assessing wetlands as the basis for monitoring changes in ecosystem integrity especially in areas that may be affected by mining and/or restoration activities.

The assessment of ecosystem integrity was undertaken using the assessment framework, WET-Health Version 2 (Macfarlane *et al.,* 2020) Level 1B, which was performed for the HGM Units within the mining concession areas. The WET-Health assessment technique gives an indication of the deviation of the systems from the wetlands' natural reference condition for the following biophysical drivers:

- Hydrology – defined as the distribution and movement of water through a wetland its soils.
- Water quality – is defined as the physio-chemical attributes of the water in the wetland.
- Geomorphology – is defined as the physical processes that are currently shaping and modifying wetland evolution as well as the three-dimensional shape (structure) of sediment deposits on which wetland habitat is established.
- Vegetation – is defined as the structural and compositional state of the vegetation within a wetland.

The impacts on the wetland, determined by features of the wetlands and their catchments, were scored based on the extent and intensity of the identified disturbance units. These disturbance units, derived for each of the components, were scored based on a suite of sub-categories using a scale of 0-10, prior to being combined to determine the overall magnitude-of-impact scores. From these scores the overall impact score and Ecological Categories (**Table 4-4**) were determined, which reflects the extent to which anthropogenic changes have impacted the wetland from the benchmark/desired state.

Table 4-4 Description of the Ecological Categories typically used for PES assessments of inland aquatic ecosystems in South Africa, together with

the applicable range of Impact Scores and PES Scores for each category (after Kleynhans, 1996; Macfarlane *et al.*, 2008).

(Macfarlane *et al.*, 2020, p.30)

Impact Category	Description	Impact Score Range (0-10)	PES Score	Ecological Category
None	Unmodified, natural.	0-0.9	**90-100**	A
Small	Largely natural with few modifications. A slight change in ecosystem processes is discernible and a small loss of natural habitats and biota may have taken place.	1-1.9	**80-89**	B
Moderate	Moderately modified. A moderate change in ecosystem processes and loss of natural habitats has taken place but the natural habitat remains predominantly intact.	2-3.9	**60-79**	C
Large	Largely modified. A large change in ecosystem processes and loss of natural habitat and biota has occurred.	4-5.9	**40-59**	D
Serious	The change in ecosystem processes and loss of natural habitat and biota is great but some remaining natural habitat features are still recognisable.	6-7.9	**20-39**	E
Critical	Modifications have reached a critical level and the ecosystem processes have been modified completely with an almost complete loss of natural habitat and biota.	8-10	**0-19**	F

The scores for hydrology, geomorphology, water quality and vegetation were simplified into a composite impact score. The combined impact score provided the basis for the calculation of the hectare equivalents (also referred to as a functional area), which can be described as the health of a wetland expressed as an area. The hectare equivalents calculation is a means of deriving a common unit of "currency" to measure the losses and gains, and how the ecosystem integrity has changed in response to anthropogenic impacts, based on the WET-Health results for the biophysical drivers.

4.3.2 *Assessment of freshwater ecosystem functioning*

A WET-EcoServices Version 2 (Kotze *et al.*, 2021) assessment was performed for the freshwater ecosystems within the mining concession areas to quantify the level of functionality[6] of the systems, and to highlight their relative importance in providing ecosystem benefits and services at a landscape level. The assessment provides a method to measure the ability of a wetland or riparian area to provide sixteen (16) ecosystem services (**Table 4-5**).

The WET-EcoServices assessment technique focuses on assessing the extent to which a benefit is being supplied by each freshwater ecosystem, based on both:

- The supply of the wetland to provide the benefits; and

[6] Functionality refers to the ecological importance and sensitivity of the freshwater ecosystems.

- The demand of the particular wetland in providing the benefit.

The ecosystem services mentioned above include an assessment of direct and indirect benefits to society and the surrounding landscape, by rating various characteristics of the freshwater ecosystems and their surrounding catchments based on the categories shown in **Table 4-5** as presented within Kotze *et al.* (2021).

Table 4-5 Ecosystem services supplied by wetlands and rivers.

(Kotze *et al.,* 2021, p3)

Services contributing to indirect benefits	Regulating and supporting services	Flood attenuation		The spreading out and slowing down of floodwaters in the wetland/riparian area, thereby reducing the severity of floods downstream
		Stream flow regulation		Sustaining streamflow during low flow periods
		Water quality enhancement benefits	Sediment trapping	The trapping and retention in the wetland/riparian area of sediment carried by runoff waters
			Phosphate assimilation	Removal by the wetland/riparian area of phosphates carried by runoff water, thereby enhancing water quality
			Nitrate assimilation	Removal by the wetland/riparian area of nitrates carried by runoff water, thereby enhancing water quality
			Toxicant assimilation	Removal by the wetland/riparian area of toxicants (e.g. metals, biocides and salts) carried by runoff water, thereby enhancing water quality
			Erosion control	Controlling of erosion at the wetland/riparian area, principally through the protection provided by vegetation
		Carbon storage		The trapping of carbon by the wetland/riparian area, principally as soil organic matter
Services contributing to direct benefits	**Biodiversity maintenance**[7]			Through the provision of habitat and maintenance of natural process by the wetland/riparian area, a contribution is made to maintaining biodiversity
	Provisioning services	Provision of water for human use		The provision of water which is taken directly from the wetland/riparian area for domestic, agricultural or other purposes
		Provision of harvestable resources		The provision of natural resources from the wetland/riparian area - including craft plants, fish, wood etc.
		Food for livestock		The provision of grazing for livestock
		Provision of cultivated foods		The provision of cultivated foods from within the wetland/riparian area
	Cultural (non-	Cultural heritage		Places of special cultural significance in the wetland/riparian area - e.g. for baptisms or gathering of culturally significant plants

[7] It is recognised that biodiversity maintenance is not an ecosystem service in the strict sense and is framed in less anthropocentric terms than all of the other services, but it underpins many other services and is widely acknowledged as having high value to society broadly, even in the absence of any local or downstream beneficiaries.

		Tourism and recreation	Sites of value for tourism and recreation in the wetland/riparian area, often associated with scenic beauty and abundant birdlife[8]
		Education and research	Sites of value in the wetland/riparian area for education or research (McInnes and Everard 2017)

In addition to providing individual scores for each ecosystem service provided by the individual wetland and riparian areas, the WET-EcoServices Version 2 (Kotze *et al.*, 2021) assessment technique also allows for the derivation of a consolidated/integrated overall importance score (**Table 4-6**), by combining the supply and demand scores for each of the ecosystem services.

Table 4-6 Categories used for reporting the overall importance of ecosystem services

(Kotze *et al.,* 2021, p. 27)

Importance Category		Description
Very Low	0-0.79	The importance of services supplied is very low relative to that supplied by other wetlands.
Low	0.8-1.29	The importance of services supplied is low relative to that supplied by other wetlands.
Moderately Low	1.3-1.69	The importance of services supplied is moderately low relative to that supplied by other wetlands.
Moderate	1.7-2.29	The importance of services supplied is moderate relative to that supplied by other wetlands.
Moderately High	2.3-2.69	The importance of services supplied is moderately high relative to that supplied by other wetlands.
High	2.7-3.19	The importance of services supplied is high relative to that supplied by other wetlands.
Very High	3.2-4.0	The importance of services supplied is very high relative to that supplied by other wetlands.

It should be noted that Wet-EcoServices assists in identifying the importance and sensitivity of specific freshwater ecosystems, but is recognised as having limitations in terms of:

- The scores obtained cannot be used to deduce the economic value of the wetland/riparian area.
- Fine-scale differentiation of ecosystem service provisions cannot be made.
- The demand of ecosystem services by users is considered at a coarse scale.
- The level of dependency and level of diversity of dependency does not necessarily correlate to one another, nor does it account for the socio-economic factors contributing to the dependency or differing levels of dependency among users.

[8] WET-EcoServices focuses on recreational services which are specifically nature-based, e.g. bird watching. It does not account specifically for recreational services from wetland/riparian areas that have been converted into sports grounds, children's playgrounds, or other built infrastructure.

- Quantifying specific impacts linked to development or changes within the landscape.
- Accounting for the size of the wetland and ecosystem services strongly associated with the size of the systems.

4.3.3 *Riverine habitat assessments*

The applied methodology drew on the latest river assessment tools developed from South Africa and that have been applied throughout sub-Saharan Africa for assessing the Present Ecological State (PES) of aquatic and riparian habitats, with the choice of methods tailored to site-specific habitat characteristics, prevailing flow conditions, and other biophysical constraints. A field survey was undertaken to establish a baseline of river health and catchment condition, providing insights into how ecological integrity is shaped by broader landscape drivers and pressures. Data and assessments from the 2023 aquatic baseline study by Nepid (2024) were collated and used to inform the updated PES.

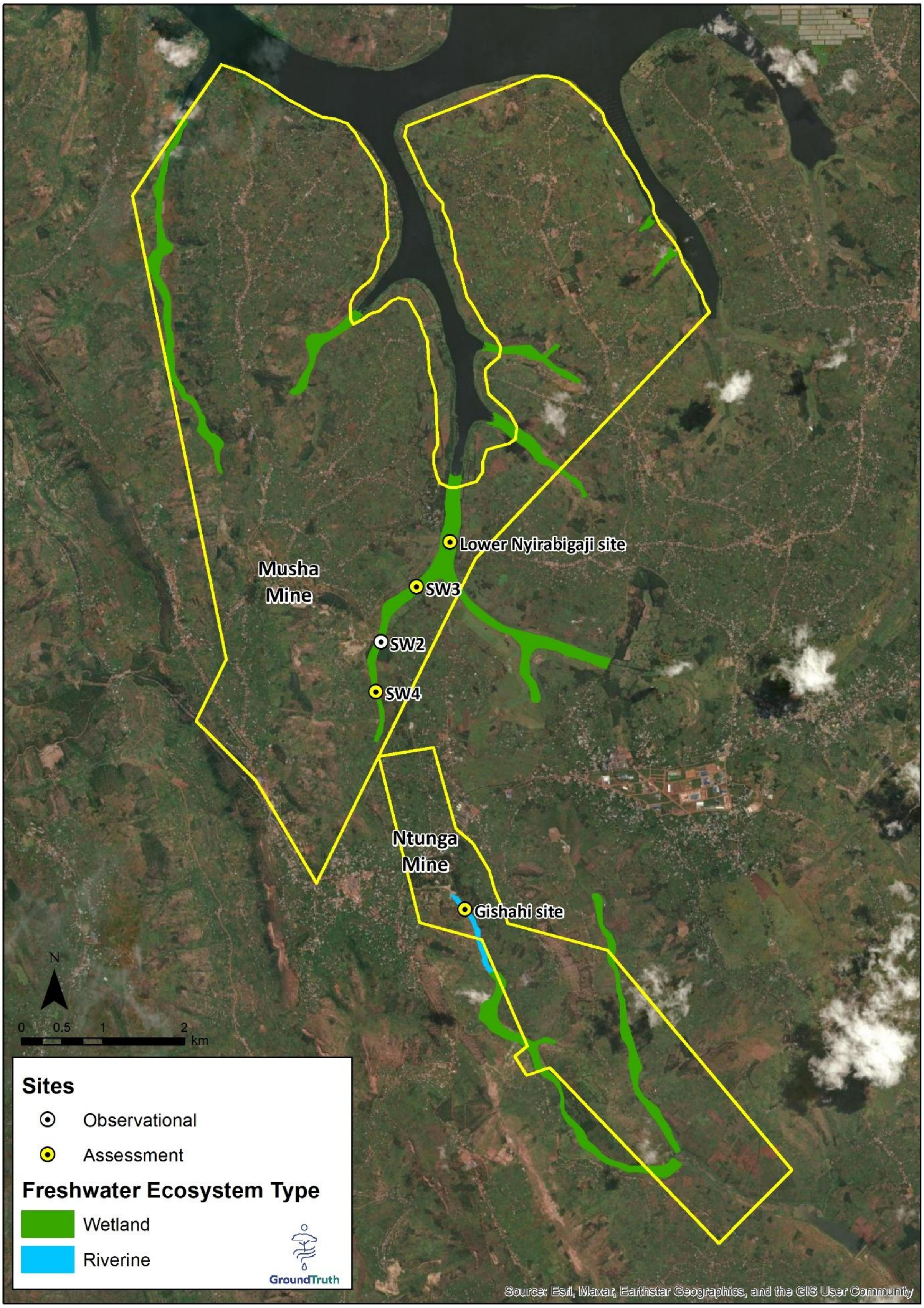


Figure 4-1 Overview of river sites visited and assessed within the Musha Mine Concession area.

4.3.3.1 Benthic diatoms (as primary producers)

Benthic diatoms are single-celled microalgae that inhabit submerged substrates such as sediment, rocks, and aquatic vegetation, forming a key part of aquatic food webs. Their ecology provides valuable insight into water quality, as they respond directly to chemical parameters, nutrients, salinity, pH, and heavy metals. Unlike larger biotic indicators, diatoms are less dependent on diverse habitats, and their species composition reflects river conditions over several weeks, offering a medium-term view of ecological impacts. Their silica frustules also persist after death, enabling reconstruction of historical water quality.

Sampling followed standard protocols (Taylor *et al.,* 2005). At each site, five small rocks were collected from flowing positions across the river channel. The exposed surfaces were scraped with a toothbrush, dislodging diatoms into <100 ml of river water. The combined subsamples were transferred to a bottle, preserved with ~10% ethanol, and submitted to Diamon Laboratory in South Africa for species-level identification. Results were interpreted using established indices (Harding and Taylor, 2011), including the Specific Pollution Sensitivity Index (SPI), which scores species by tolerance to nutrient enrichment and organic waste, and the Percentage Pollution Tolerant Valves (%PTV), which quantifies the proportion of tolerant taxa. Together, these indices provide a robust assessment of river health and water quality.

Benthic diatoms were sampled during the November 2025 field survey at specific designated sites as presented in **Figure 4-1**. A total of seven diatom samples were collected from Musha/Ntunga. However, following initial screening of the samples only three were found to contain diatom cells highlighting the severity of sedimentation impacts emanating from formal and unauthorised mining of minerals and aggregate. Results from the three diatom samples were interpreted according to the Specific Pollution sensitivity Index (SPI) to determine river "health status" (CEMAGREF, 1982). Other useful diatom indices used to further infer water quality conditions were the Percentage of pollution Tolerant Valves (% PTV), which was the proportion of diatoms in the sample that are tolerant to pollution, and the percentage of deformed cells, which was the proportion of diatoms in the sample which were deformed as a result of toxicants in the water. River health classes for the sampled sites were determined according to **Table 4-7**, and interpreted using **Table 4-8**.

Table 4-7 Diatom index scores for relevant health classes (derived from Harding and Taylor, 2011).

River Health Class		Benthic Diatom Species Specific Pollution Index (SPI)
Natural	≥	17.0
Good	≥	13.0
Fair	≥	9.0
Poor	≥	5.0
Seriously Modified	≤	5.0

Table 4-8 River health classes and their attendant ecological and management perspectives (derived from WRC, 2008).

Category	river Health Classes	Ecological Perspective	Management Perspective
A	Natural	No or negligible modification of in-stream and riparian habitats and biota.	Protected rivers; relatively untouched by human hands; no discharges or impoundments allowed.
B	Good	Ecosystems essentially in good state; biodiversity largely intact.	Some human-related disturbance but mostly of low impact potential.
C	Fair	A few sensitive species may be lost; lower abundances of biological populations may occur.	Zones of competing uses; developmental pressures are dominant feature.
D	Poor	Habitat diversity and availability have declined; mostly only tolerant species present; species present are often diseased; population dynamics have been disrupted (e.g. biota can no longer breed, or alien species have invaded the ecosystem).	Often characterised by high human densities or extensive resource exploitation. Management intervention is needed to improve river health – e.g. to restore flow patterns, river habitats or water quality.
E	Seriously Modified	Loss of habitat availability and high levels of pollution, result in few families being present due to the loss on most intolerant forms.	Often characterised by high human densities, pollution or extensive resource exploitation and modification. Management intervention is needed for improvement to occur.

4.3.3.2 Aquatic macroinvertebrates (as primary consumers)

Aquatic macroinvertebrates include insects in their larval and nymph stages, as well as snails, worms, crustaceans, and clams that spend part of their life in water. They are widely recognised as reliable indicators of river health due to their varying sensitivity to pollution, rapid responsiveness and recovery, and ease of identification. Changes in macroinvertebrate community structure directly reflect shifts in water quality, flow, and habitat, integrating multiple stressors over time. While tolerance can vary geographically, taxa generally exhibit predictable sensitivity levels, making them effective biological indicators for use in river health assessments.

For this project, macroinvertebrates were sampled to inform the assessment of river PES and to understand how macroinvertebrate communities are affected by prevailing land use and mining activities. Sampling followed the accredited South African Scoring System, version 5 (SASS5) (Dickens and Graham, 2002), conducted by a SASS5 accredited practitioners at sites where suitable conditions were available (e.g. flowing water, accessible biotopes, wade-able depth). SASS5 evaluates diversity and abundance at family level, with results recorded on standard datasheets. Key outputs include the SASS score (i.e. the sum of sensitivity values for all taxa) and the Average Score Per Taxon (ASPT), calculated by dividing the SASS score by the number of taxa. Each taxon is assigned a value from 1 (tolerant) to 15 (sensitive). These results are interpreted to determine PES, providing a robust measure of ecological integrity across river sites.

4.3.3.3 Index of Habitat Integrity

Riparian vegetation refers to the distinct plant communities that occur along river corridors, particularly perennial rivers, and form a critical component of the broader river ecosystem. These communities shape the interface between terrestrial areas instream/aquatic habitats, exerting direct and indirect influences on physical and chemical processes. Key functions include supplying organic and inorganic material (e.g. leaves, twigs, large woody debris) that underpin aquatic food webs and habitat complexity; regulating water temperature through canopy shading, vital for cold-water species; filtering sediments, nutrients, and pollutants via root and soil systems; and moderating hydrology by slowing runoff and promoting groundwater recharge. Additionally, riparian vegetation provides structural habitat such as overhanging banks and root refuges for fish and aquatic invertebrates.

The composition and structure of riparian vegetation are primarily driven by hydrology and geomorphology, with flooding and other disturbances shaping riverbanks and instream habitats. Disturbances can blur or eliminate vegetation zones, promote encroachment of terrestrial species, alter abundance and growth forms, and facilitate invasive alien plants. These changes cascade into instream impacts (e.g. reduced bank stability and increased erosion, higher nutrient and pollutant load due to diminished filtering, and reduced habitat complexity from fewer woody debris inputs). Collectively, such degradation undermines instream habitat integrity and ecosystem function.

To establish baseline conditions, riparian and instream habitats at sampling sites were assessed using the Index of Habitat Integrity (IHI) method (Kleynhans *et al.,* 2009). This approach evaluates factors such as channel modification, physico-chemical alteration, exotic vegetation, and dumping, providing a comprehensive measure of habitat integrity across defined river reaches. The results inform understanding of how riparian vegetation condition influences aquatic communities and overall river health (**Table 4-10**).

Table 4-9 Index of Habitat Integrity (IHI) scores for deriving river health classes (derived from Kleynhans, 2009).

River Health Class		Index of Habitat Integrity (IHI)
Natural	≥	90
Good	≥	80
Fair	≥	60
Poor	≥	40
Seriously Modified	≤	40

4.4 Expertise of the specialists

Due to the nature of the study, the project team included personnel with experience in mapping, delineation, assessment, rehabilitation, enhancement and creation of freshwater ecosystems (**Table 4-10**).

Table 4-10 Team members, roles, experience and qualifications

Specialist	Role in the Study	Experience Level	Qualifications
Craig Cowden	• Review of the project report.	25+ years' experience with input into various wetland studies: • Delineation. • Assessments. • Rehabilitation planning. • Mitigation and offset requirements. • Monitoring and evaluation of rehabilitation projects	M.Sc. (Environmental Science). Pr.Sci.Nat – Ecology.
Gary de Winnaar	• Site visit; • GIS processing and mapping; • Riverine and riparian assessments; and • Compilation of the project report.	18 years' experience with inputs into various aquatic and terrestrial biodiversity studies, including: • Terrestrial and aquatic biodiversity surveys; • Assessments; • Delineation; • Monitoring and evaluation of riverine rehabilitation projects; and • Mitigation & offset studies.	M.Sc. (Hydrology) Pr. Sci. Nat - Ecology DWS SASS5 accredited practitioner
Fiona Eggers	• Site visit; • GIS processing and mapping; • Wetland assessments; and • Compilation of the project report.	15 years' experience, with input into various wetland studies, including: • Delineation; • Assessments; • Rehabilitation planning; • Monitoring and evaluation of wetland rehabilitation projects; • Mitigation & offset studies; and • Wetland creation.	M.Sc. (Botany). Pr.Sci.Nat – Ecology.
Steven Ellery	• Site visit.	6 years' experience, with input into various wetland studies, including: • Delineation; • Assessments; • Rehabilitation planning; • Monitoring and evaluation of wetland rehabilitation projects; and • Mitigation & offset studies.	M.Sc. (Geography). Pr.Sci.Nat – Ecology.
Esi Bossman	• Compilation of the project report	~3 years' experience, with input into: • Macroinvertebrate identification • Dragonfly identification • Biomonitoring • Statistical analysis	M.Sc. (Freshwater Ecology). Cand.Sci.Nat – Aquatic Science

5. MUSHA/NTUNGA CONCESSION AREA BASELINE

The Musha Mine concession and broader region is characterised by undulating mountainous terrain. The Musha concession area lies between 1'461 m to 1'651 m above sea level, while the Ntunga Mine concession area lies between 1'486 m and 1'519 m (SLR, 2024b).

The following section provides an overview of the current condition of the freshwater ecosystems within the Musha/Ntunga Mine Concession area. **Figure 5-1** depicts the two mining concession areas along with the various freshwater ecosystems associated with these concession areas.

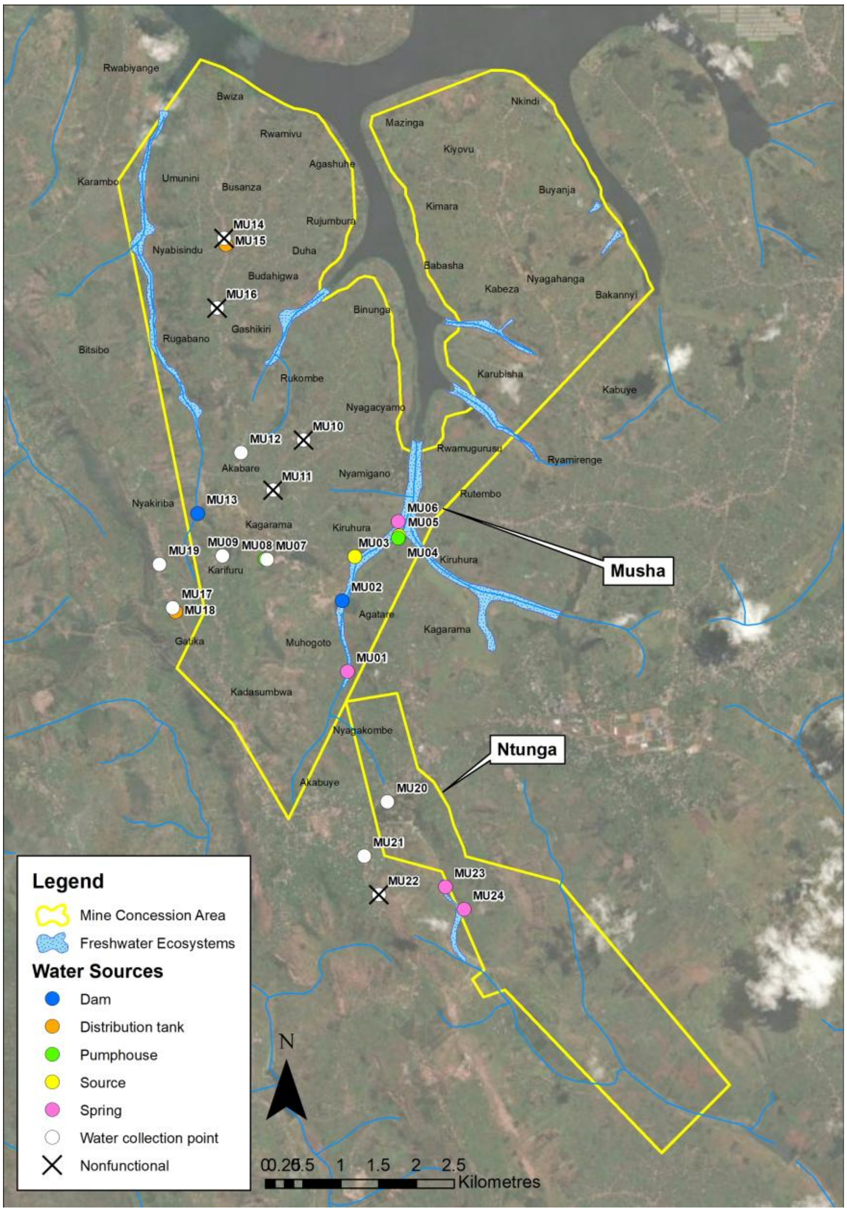


Figure 5-1 Overview of the Musha and Ntunga mining concession areas and the associated freshwater ecosystems within these areas.

5.1 Study area and site description

The following sections provide an overview of the Trinity Musha Mine concession area focussing on climate, geomorphology, hydrology, floodlines and land uses. This background information formed the basis for the assessment of the freshwater ecosystems.

5.1.1 *Climate*

Rwanda's tropical climate is heavily influenced by its diverse topography, which rises along a general elevational gradient from east to west. Based on altitude and geographical position, the country is divided into four primary climatic regions (World Bank, 2021; SLR, 2024a; **Table 5-1**):

Table 5-1 Climatic conditions of the four climatic regions of Rwanda

Climatic Region	Annual Rainfall (mm)	Avg. Temperature (°C)	Geographic Features
Eastern Plains	700 – 1100	20 – 22	Low-lying eastern borderlands.
Central Plateau	1100 – 1300	18 – 20	Mid-altitude rolling hills.
Highlands	1300 – 1600	10 – 18	Congo-Nile Ridge & Virunga volcanic chains.
Lake Kivu / Bugarama	1200 – 1500	18 – 22	Western rift valley and Bugarama plains.

The Musha-Ntunga Concession is primarily situated within the transition zone between the Eastern Plains and Central Plateau, regions characterised by moderate to high rainfall and temperate thermal regimes.

The hydrological cycle in Rwanda is governed by a bimodal rainfall pattern, resulting in four distinct seasons. This seasonality is a critical factor in the sediment transport capacity of the rejuvenated river network, as peak transport events typically coincide with the height of the wet seasons.

- Short dry season (January – February): A transitional period of reduced rainfall.
- Long rainy season (March – May): Historically associated with the highest intensity rainfall events and peak annual discharges.
- Long dry season (June – August): A period of minimal precipitation and baseflow conditions in the freshwater ecosystem.
- Short rainy season (October – December): Characterised by frequent convective storms.

Musha's climate is characterised by stable temperatures and a distinct bimodal rainfall pattern. Temperatures typically fluctuate between an average of 20.35°C (June) and 21.59°C (February), remaining relatively stable throughout the year (based on data between 2018 to 2021). A typical bimodal rainfall distribution is evident, based on 43 years of records (1981–2023), where rainfall peaks in April (mean = 155.42 mm) and October (mean = 154.84 mm), and is generally at its lowest during July (mean = 8.42 mm), then June (mean = 16.23 mm). The overall mean annual precipitation (MAP) for the region is 1084.42 mm over those 42 years. Based on data collected from ERA5, which covers both the entire Musha-Ntunga area, the mean annual PET is 2171.50 mm (**Figure 5-2**).

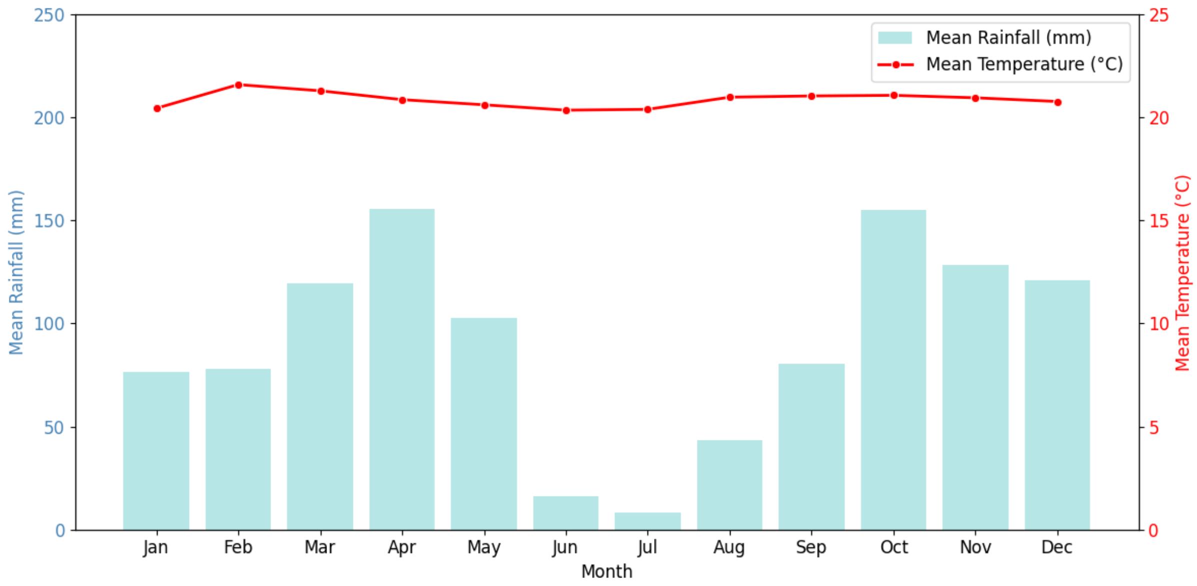


Figure 5-2 A climatograph showing average monthly rainfall over 1981 to 2023 and typical mean monthly temperatures for the years 2018 to 2021.

5.1.2 *Broad geomorphic and fluvial setting*

Rwanda is situated on the eastern shoulder of the Kivu–Tanganyika rift, a region defined by active continental rifting driven by the divergence of the Victoria and Nubia plates (Moeyersons, 2003; Depicker *et al.,* 2021). The country's topography is characterised by a significant elevational gradient, rising from approximately 1000 m above sea level in the east to over 2600 m at the crest of the western rift shoulder (Moeyersons, 2003). This tectonic uplift has initiated a process of landscape rejuvenation, where rivers actively incise the terrain to adapt to new base levels (Depicker *et al.,* 2021). Consequently, this geomorphic setting creates a high-relief environment where energetic rivers and steepened hillslopes lead to a significant potential for erosion (Moeyersons, 2003; Depicker *et al.,* 2021).

5.1.3 *Geology*

The Karagwe-Ankole Belt (KAB) in East Africa forms part of the Mesoproterozoic Kibara Belt (KIB) of Central Africa, a major metallogenic province rich in granite-related ore deposits, particularly tantalum–tin–tungsten (SLR, 2024d). Extending across Rwanda, Burundi, southwest Uganda, northwest Tanzania, and the Kivu-Muniema region of the Democratic Republic of the Congo (DRC), the KAB is divided into two contrasting domains: the Western Domain, underlain by Proterozoic basement and intensely deformed, and the Eastern Domain, underlain by Archean basement. The Western Domain is especially significant, hosting tin, tungsten, tantalum, and gold deposits mined throughout the region (SLR, 2024d).

Trinity Musha Mine lies within the Karagwe-Ankolean Supergroup, a Neoproterozoic formation of metavolcanic and metasedimentary rocks. Tungsten mineralization is associated with quartz veins and greisenized granite. At Musha and Ntunga, mineralogy is dominated by quartz, muscovite, and kaolinite, with minor to trace amounts of dravite, schorl, hematite, goethite, anatase, and elbaite. No significant carbonates or sulphides have been reported at either site (SLR, 2024d).

5.1.4 *Slope and erodibility*

The western and central highlands of Rwanda exist in a state of geomorphological disequilibrium characterised by active river incision and steep V-shaped valleys (Moeyersons, 2003; Depicker *et al.,* 2021). The eastern portion of the country, however, including the Rwamagana District where the Musha-Ntunga concession is situated, occupies a more geomorphologically stable position. This landscape, located on the Eastern Plateau, is characterised by a dissected plateau of rolling hills with moderate slope gradients and broader, more mature valleys (Verdoodt and Van Ranst, 2006).

The relative stability of this eastern region is reflected in its significantly lower erosion risk. For instance, while the national average erosion rate is 250 t ha^{-1} yr^{-1} (Karamage *et al.,* 2016a) and the high-relief Nyabarongo catchment reaches 490 t ha^{-1} yr^{-1} (Karamage *et al.,* 2016b), the Eastern Plateau has an estimated mean soil loss of approximately 20.6 t ha^{-1} yr^{-1} (Nambajimana and He, 2020).

Despite these lower baseline rates, erodibility remains a significant factor due to anthropogenic drivers. Across this broader region, croplands occupy a vast majority of the land area and are responsible for nearly 95% of total annual soil loss (Karamage *et al.,* 2016a). The synergy of agricultural land use and a supply of unconsolidated material derived primarily from deeply weathered tropical soils characteristic of the Eastern Plateau (Verdoodt and Van Ranst, 2006), creates a persistent sediment flux environment. Consequently, even on these gentler slopes, the landscape remains capable of mobilising and transporting sediment loads during the high-intensity rainfall events of the region’s bimodal climate.

5.1.5 *Hydrology*

The Musha concession lies on the southern shores of Lake Muhazi, an artificial impoundment covering ~44 km^2 and extending ~46 km along the Nyabugogo River. Lake Muhazi flows west to join the Nyabugogo River, a major tributary of the Nyabarongo, which ultimately drains into Lake Rweru in the upper Kagera Catchment of the Nile Basin (Nepid Consultants, 2024a; SLR, 2024b). Mining operations at Musha Mine are adjacent to the Bisinia Dam, a 5.5 ha earth impoundment fed by the Rwasama River and discharging via outlet pipe into the Nyirabigaji River. The dam also impounds the Nyakagezi Wetland, one of several unprotected valley-bottom wetlands draining into Lake Muhazi. Mining occurs within 130 m of this wetland, specifically near the tailings dam (SLR, 2024b).

The Ntunga Mine is located in the headwaters of the Gashahi River, which drains south into Lake Mugesera before joining the Nyabarongo. In proximity to the mine, the Gashahi River functions as a channelled valley-bottom wetland, altered by agricultural drains. The prominent Kamirazovu Cyaruhogo wetland lies ~3 km downstream of Ntunga concession activities (Nepid Consultants, 2024a; SLR, 2024b). Hydrologically, the Nyakagezi Wetland at Musha Mine and freshwater ecosystems at Ntunga generally behave as gaining systems, receiving groundwater as baseflow, but may act as losing systems where channel elevations exceed groundwater levels (SLR, 2024b). Communities rely on diverse water sources, with springs preferred for domestic use, though these often dry up in the dry season, forcing reliance on alternative supplies (GroundTruth, 2025; SLR, 2024b). Mining at Musha Mine is ~30 m from the Bisinia Dam, outside the regulated 10 m buffer zone, while Ntunga Mine falls within the 2 m buffer zone of the Gashahi River headwaters (SLR, 2024b).

5.1.6 *Hydrogeology*

The ore deposit is structurally controlled by faults and fractures, which also influence groundwater ingress into mine workings. Aquifers in the Musha and Ntunga concession areas can be classified as follows (SLR, 2024d):

- Weathered Aquifer: Shallow, unconfined, within 5–30 m of weathered sandstone and schist, with low to moderate yield.
- Primary Alluvial Aquifer: Along the Rusine and Nyabugogo Rivers and streams, composed of gravel and sand, with moderate to high parameters, recharged by surface inflow.
- Secondary Fractured Aquifer: Deeper, semi-confined, in unweathered shale and quartzite, where groundwater flows through fractures; generally low to moderate yield, occasionally high.

Overall, the aquifer system is moderate-yielding, with reported yields of 0.1–0.5 l/sec. The weathered zone averages ~10 m thick, underlain by a clay-rich zone up to 110 m, while in alluvial areas the weathered zone reaches 30–40 m. Groundwater occurs in fractures and bedrock contacts, recharged by rainfall through saturated sands, lithological contacts, unconformities, or dolerite dykes. Springs form where these structures daylight in low-lying areas. Recharge is estimated at 1–5% of mean annual precipitation, with groundwater flow following topography from high divides to valleys (SLR, 2024d).

Water quality is generally good, though slight acidity promotes leaching of metals, elevating aluminium, arsenic, iron, and manganese. Concentrations are mostly marginally above guideline limits and considered natural. Exceptions include iron at one site, pH below livestock watering limits at two boreholes, and chloride exceeding livestock limits at one site (SLR, 2024d).

5.1.7 *Floodline data*

The hydrological and hydraulic modelling undertaken for the Musha–Ntunga concession delineated floodlines for the 2-year, 25-year, and 100-year return periods under both present conditions and projected climate change scenarios (GroundTruth 2026a).

At Musha, the wide, low-gradient floodplain, which is heavily modified by agricultural drainage channels, results in extensive flood extents even during lower return period events. Increases in peak discharge are expressed primarily as greater water surface elevations (WSE) and flow depths rather than significant lateral expansion of the flood footprint. At Ntunga, the upstream channel contains lower flows under smaller events, but overtops during higher return periods, leading to increased flooding extent. Downstream, the system behaves similarly to Musha, with agricultural modifications influencing flow distribution and floodplain behaviour (GroundTruth 2026a).

Under climate change scenarios, changes in flood extent are generally minor, with small decreases or increases depending on the return period. In contrast, changes in WSE are more pronounced, though typically less than 100 mm, and distributed relatively uniformly across flooded areas. This indicates that the primary system response to climate change is vertical adjustment in water levels rather than lateral expansion of flood lines (GroundTruth 2026a).

5.1.8 *Land cover and use*

Typically, the Eastern Province in Rwanda would have been dominated by savannah and woodland vegetation, interspersed with wetlands in the low-lying areas and natural forest patches. This province is considered to be one of the most degraded. The Musha and Ntunga concession areas lie within the Victoria Basin Forest–Savanna Mosaic ecoregion, historically characterised by tropical forest and savanna woodlands. Today, however, vegetation is heavily modified and degraded due to farming (subsistence and co-operative), woodlots/forestry, and mining resulting in low biodiversity value and limited potential to support Species of Conservation Concern (SCC) (SLR, 2024c).

Land use changes have been significant within the concession area, with the approximately 60% being linked to agricultural activities including subsistence agriculture, co-operative farming, orchards, woodlots/plantations and aquaculture. However, the catchments also have a high percentage of urban development (+-35%) with a number of industries being located within the catchment area. These changes all contributed to the integrity if the freshwater ecosystems within the concession.

Nowadays, the majority of the concession area no longer comprises of natural land cover, but mostly croplands as depicted in **Figure 5-3**, which is derived from the ESA (European Space Agency) landcover data from Rwanda. As a consequence of this significant change in land cover, the impacts on the hydrology of the catchment and associated freshwater ecosystems include the following:

- Reduction in infiltration.
- Reductions in ground water recharge and therefore of baseflows.
- A reduction in lag times.
- An increase in the magnitudes of peak flows.
- Reductions in water retention.
- An increase in erosion and thus sedimentation.
- A reduction in water quality.
- An increase in topsoil losses.

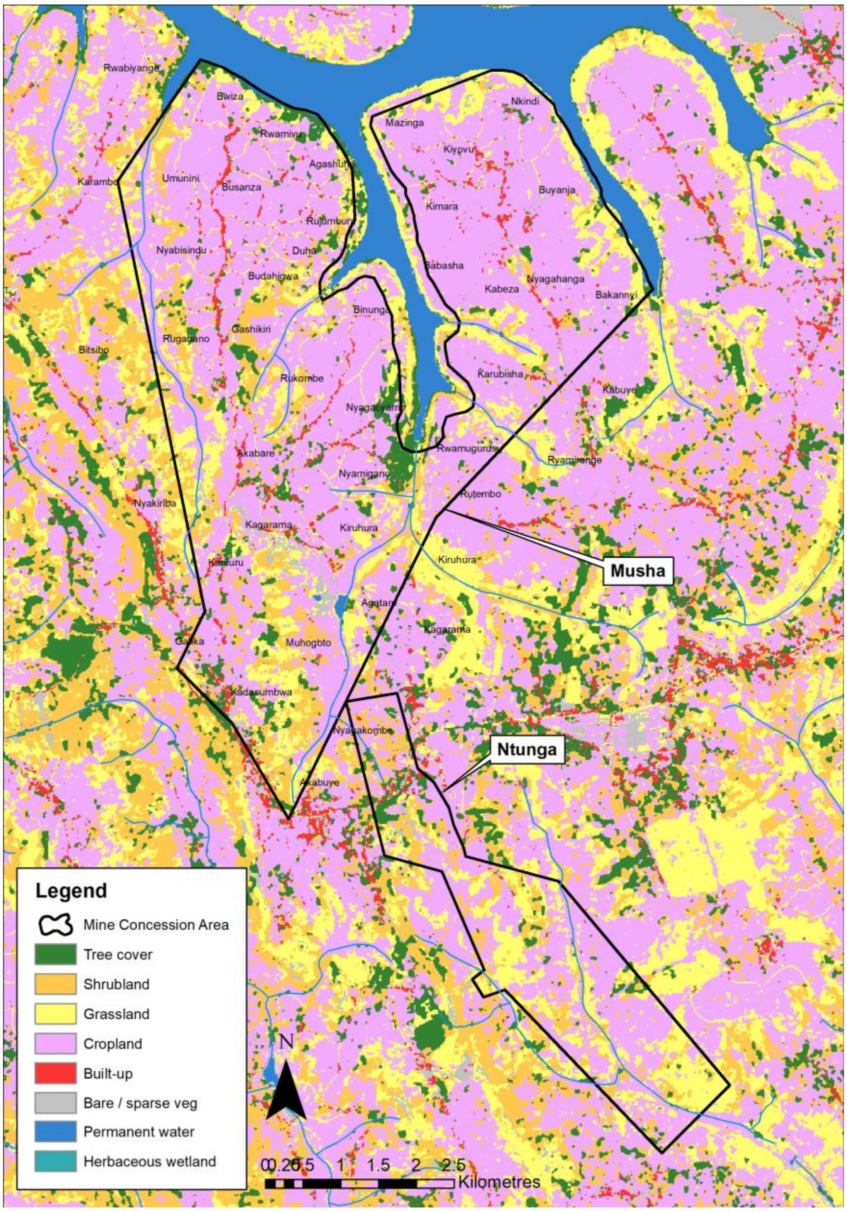


Figure 5-3 ESA landcover data for the Trinity Musha Mine, which highlights the level of transformation within the region.

For the purpose of this study the landcover for the area was refined to reflect a more updated cover and to distinguish between various land use activities e.g. woodlots and subsistence agricultural activities, as these differentiations are important to note in the assessment of the freshwater ecosystems. **Figure 5-4** provides an overview of the refined landcover map for the catchment areas associated with the freshwater ecosystems assessed.

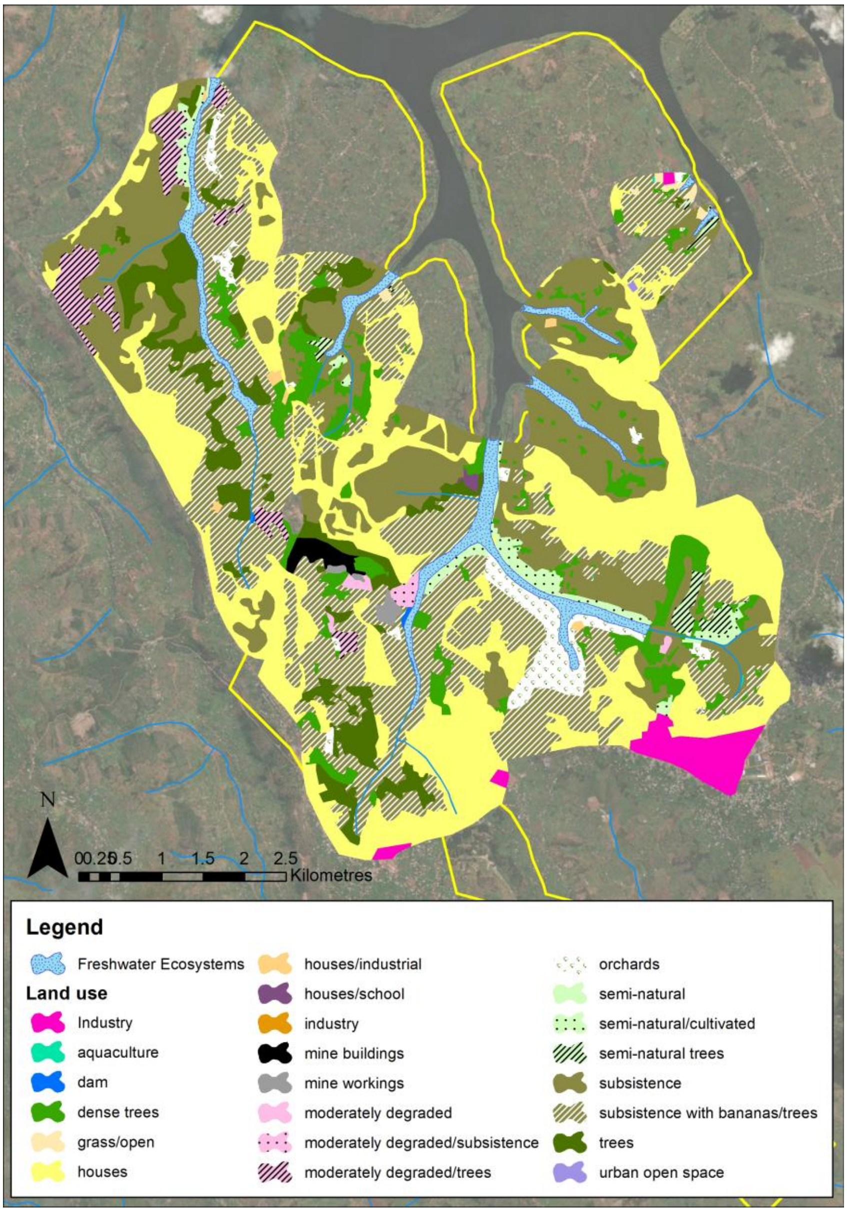


Figure 5-4 Overview of the updated landcover data used in the assessment of the freshwater ecosystems.

5.1.9 *Aquatic Biodiversity*

The Musha Mine Concession is situated within the Lake Victoria Basin Freshwater Ecoregion (https://www.feow.org/ecoregions/details/521), a region recognised for its exceptional global freshwater biodiversity significance. This ecoregion includes Lakes Victoria, Kivu, Edward, and several associated satellite lakes, and has been classified as Globally Outstanding in terms of biological distinctiveness. It is regarded as having a Critical conservation status with a Very High conservation priority (Oyugi & Chapman, 2008). The region supports more than 600 fish species, approximately 79% of which are endemic, with haplochromine cichlids forming the majority (Sayer *et al.*, 2018). While biodiversity value is concentrated in the major lake systems, smaller rivers and streams in the immediate project area generally support lower diversity assemblages of river-adapted fauna provided that water quality conditions are not severely compromised.

From a hydrological perspective, the project area falls within the Nile River Basin and the upper reaches of the Kagera River Catchment. The Musha Concession drains into the Nyakagezi Wetland, a tributary of Lake Muhazi, itself an artificial impoundment on the Nyabugogo River (Nepid Consulting, 2024). The Ntunga Concession lies within the upper Kabacuzi Stream, which flows southwards into Lake Mugesera. Together, these drainage systems form part of the broader freshwater network that ultimately contributes to the Nile River system.

Rwanda contains nine protected areas, with Akagera National Park representing the largest formally protected conservation area. The nearest recognised biodiversity priority area to the project is the Nyabarongo Key Biodiversity Area (KBA), located ~38 km east of the project area (Nepid Consulting, 2024). This KBA comprises swamps and marshes associated with the Nyabarongo River and supports several threatened wetland-dependent species. However, given that the Musha and Ntunga concessions are located in separate catchments, direct impacts on the Nyabarongo KBA are considered unlikely.

Despite the high regional biodiversity significance, aquatic habitats within the Project Area of Influence are considered to be in a Modified ecological state. Extensive anthropogenic disturbances, including formal and unauthorised mining, subsistence agriculture, and livestock grazing, have substantially altered ecological functioning. Riparian vegetation is heavily degraded, with little intact natural habitat remaining, and alien species such as Eucalyptus and Lantana camara are widespread (Nepid Consulting, 2024). A notable biodiversity feature is the occurrence of an undescribed cichlid, Haplochromis sp. “musha” (IFC, 2019), believed to have a restricted distribution (~5,000 km^2 across the Nyabugogo and Akanyaru catchments). Despite its limited range, the species is not currently considered threatened, as it appears well adapted to disturbed and turbid environments.

Within the Musha Mine area, aquatic ecosystems include the Bisinia Dam (artificial impoundment), the Nyakagezi Wetland (channelled valley-bottom wetland), and the Gashahi River, a transitional stream originating in the Ntunga concession (Nepid Consultants, 2024a). Seep wetlands along the Gashahi valley provide limited habitat diversity in an otherwise modified landscape (onsite observations). Previous sampling downstream of Ntunga Mine revealed no benthic diatoms, only five macroinvertebrate taxa and one fish species, attributed to sedimentation and poor habitat availability. The river was classified as Critically to Seriously modified (Nepid Consultants, 2024a). By contrast, the Nyakagezi Wetland showed stronger ecological condition, with 34–37 benthic diatom species, 22–24 macroinvertebrate taxa, and nine fish species recorded by Nepid Consultants (2024). These systems were rated moderately modified, though nutrient enrichment, salinity, and vegetation alteration were evident. Alien fish species such as guppy (*Poecilia reticulata*) and blue-spotted tilapia (*Oreochromis leucostictus*) were also present (Nepid Consultants, 2024). Overall, aquatic ecosystems at Musha Mine were rated Largely modified, driven by stream channel alterations, crop cultivation within wetlands, and vegetation loss. A small section of the Nyakagezi Wetland has shown partial recovery following the cessation of cultivation, now dominated by sedges and hydrophilic grasses that provide habitat for aquatic species despite drainage networks (onsite observations).

5.2 Freshwater Ecosystem Results

The results of the studies and investigations undertaken for the Trinity Musha Mine are outlined in the following sections.

5.2.1 *General catchment characteristics*

As highlighted in Section 5.1.8, the catchments associated with freshwater ecosystems within the concession areas have been substantially altered from their historical state, which was once dominated by forests and natural vegetation. Agricultural expansion has been the primary driver of change, with cropland steadily replacing forest cover and diminishing the catchments' natural capacity to regulate water flow. This shift has led to greater surface runoff, soil erosion, and reduced infiltration into groundwater systems.

The region's topography, characterised by moderate slope gradients and broader, more mature valleys, thus has a less detrimental impact on the downstream systems than areas defined by a steeper topography. Changes in vegetation cover have accelerated erosion (**Figure 5-5**), particularly in areas dominated by farming practices (including subsistence farming, co-operative farming, orchards) or in timber production areas which are dominated by *Eucalyptus* trees (**Figure 5-6**). These processes not only degrade soil stability but also indirectly reduce groundwater recharge, undermining the long-term resilience of the catchments. In some areas however, grassland-type areas have been established (**Figure 5-7**). The grass is cut and sold for livestock fodder.

Not all catchments are equally affected, as differences in farming practices and conservation measures play a significant role. Where terracing and soil conservation are widely adopted, erosion during heavy rainfall events is noticeably reduced. In contrast, areas dominated by unsustainable subsistence farming or dense stands of *Eucalyptus* trees experience accelerated soil loss. The catchments within the western portion of the Musha concession generally have a higher percentage of woodlots/plantations than the catchments in the eastern portion of the concession. Additionally, it appears as co-operative agricultural activities also dominate this western area.

Figure 5-5 View of examples of erosion within the concession area. Barren areas in Musha (left), and erodiing hillside in Ntunga (right).

Figure 5-6 Example of a catchments within the concession dominated by *Eucalyptus* plantations. A catchment in the Musha area (left) and Ntunga area (right)

Figure 5-7 Culitvation of grasses which are harvested and sold for livestock fodder

Mining activities within the Musha (Nyirabigaji River) and Ntunga (Gashahi River) catchments have also left a legacy of environmental pressure. The mining impacts between these two areas have had significantly different physical impacts on the receiving environment. Musha mining activities are considered to be relatively contained to the mining footprint area, whereas in Ntunga there is evidence of aggregate and sediment mobilisation into the downstream areas. However, this does not account for the indirect impacts associated with water quality (refer to the Source Path Receptor Analysis report for additional information (GroundTruth, 2026b)).

Figure 5-8 View of the Musha mine (left) where the physical distrubance is limited to the mining footprint area. Impacts associated with the Ntunga mine (right), which inlcudes the mobilisation of aggregate and sediments into the dowsnteam freshwater ecosystems.

Downstream of the two mining areas are two large lake systems, namely Lake Muhazi which is associated with the Musha mining activities, and Lake Mugesera, which is downstream of the Ntunga mining activities. Both of these lakes are considered to be regionally important, and both drain into the Nyabarongo River, which forms part of the headwaters of the Nile.

5.2.2 *Freshwater ecosystem overview*

The freshwater ecosystems across the concession area have been extensively altered, not only by catchment-level pressures but also by direct in-system impacts predominantly subsistence and co-operative agriculture (**Figure 5-9**). The valley-bottom wetlands are vitally important systems within the landscape, as the adjacent communities are reliant on the fertile soils within these systems for crop production. Historically, the wetlands would have been heavily waterlogged systems, however, with the introduction of extensive drainage networks and channel modification, i.e. channel straightening, the wetland areas have become accessible for cultivation (**Figure 5-10**). The drainage networks serve to direct flows away from the fields and towards the main channel as efficiently as possible. In return, the drains serve to lower the natural water table of the wetland and allow crops to be planted in areas that would otherwise remain saturated. These changes reduce the capacity of the wetland to store and slowly release flows, and as such, the ability of the wetland to buffer again seasonal rainfall variability is reduced. Additionally, raised beds are also commonly built within the wetland soils, elevating crops above residual moisture and enabling year-round cultivation of vegetables and staples. Not only do these practices influence the hydrology of the systems but also the mobilisation of sediments. In many instances, the drains/channels that have been cut and/or straightened become incised, leading to both bank erosion and headcut erosion, thereby further lowering the water table within the systems. However, generally due to the gentle slope within the wetlands, headcut erosion is limited. The sediments mobilised from these activities are transported downstream, contributing to the siltation of the downstream lakes.

Figure 5-9 An example of co-operative farming (left) and subsistence farming (right)

Figure 5-10 Examples of channel straightening and the raised beds and drainge network alongside the main drains channels.

Wetland habitat within the landscape is extremely limited, with the exception of the wetland habitat along the lower portion of the Nyirabigaji River, below the confluence of the two channels. This area shows signs of historically having been cultivated however, it has been abandoned – potentially to the severity of the waterlogged conditions. The only other wetland habitat remaining within the landscape is where the streams decant into Lake Muhazi, permanent wetland conditions persistent, i.e. dominated by reedbed wetland habitat, and are thus not suitable for cultivation (**Figure 5-11**).

Figure 5-11 Example of the intact wetland at the confluence of the Nyirabigaji River and another unnamed stream (left), and permanent wetalnd habitat upstream of Lake Muhazi (right)

Local communities remain highly dependent on these freshwater ecosystems. Wetlands provide fertile soils for farming, while streams and springs are vital sources of water for personal/household use. Fishing, small-scale aquaculture, and the harvesting of wetland plants continue to support livelihoods, underscoring the importance of safeguarding these ecosystems even as they face mounting pressures.

5.2.3 *Musha*

The Musha mine and concession drain towards Lake Muhazi, which is considered to be a regionally important water resource. Within the concession area there are 7 wetland systems with a small river channel, which has been artificially formed within the Nyirabigaji wetland system (Musha 3) by ongoing cultivation practices within the throughout the valley bottom wetland system (**Figure 5-12**). Riverine assessments were used with limited application to provide some measure of ecosystem health for the Nyirabigaji system.

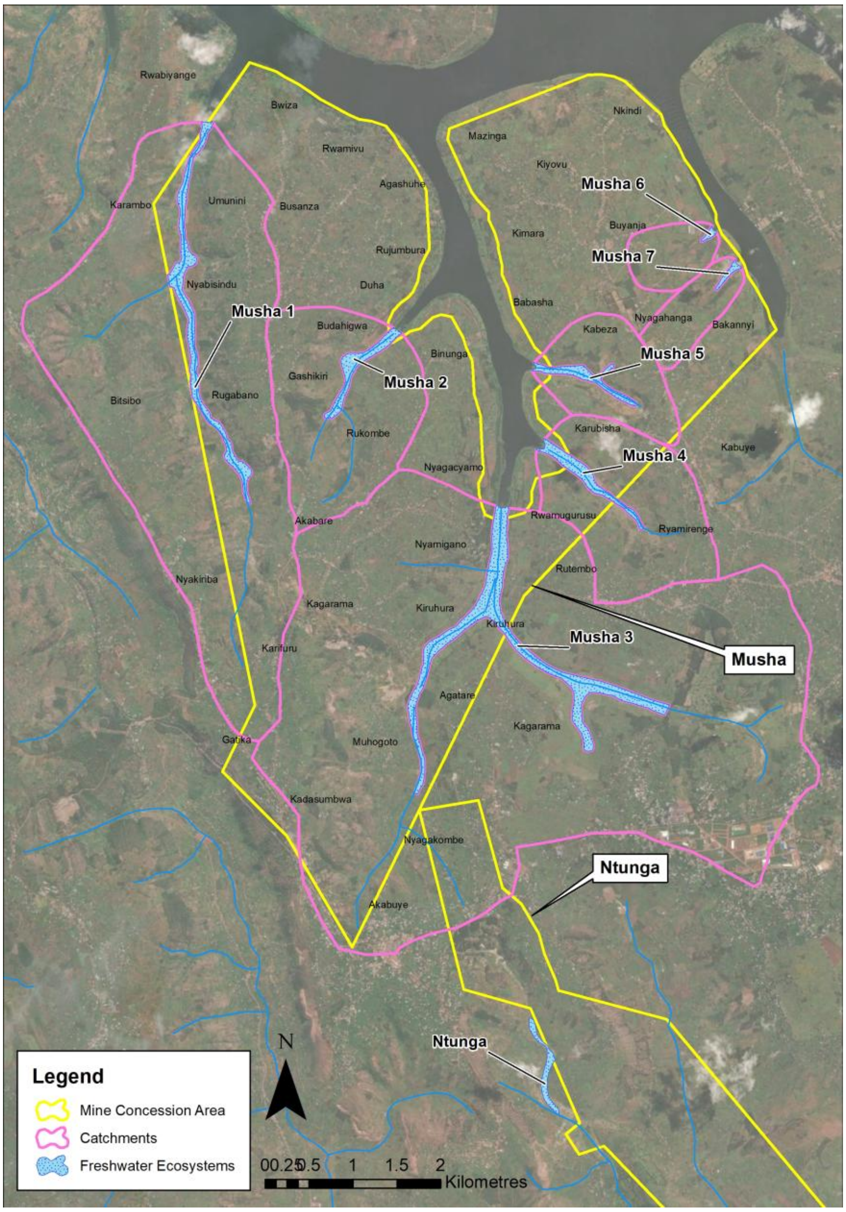


Figure 5-12 Overview of the freshwater ecosystems within the Musha mining concession area

5.2.3.1 Functionality and integrity

The following section provides a summary of the integrity of the freshwater ecosystems associated with the Musha mining concession.

5.2.3.1.1 *Rwakiramba (Musha 1)*

Rwakiramba (Musha 1)			
Date Assessed	18/11/2025	**Assessment Level**	Level 1B
HGM Type Modelled	Valley-bottom	**HGM Type Verified Infield**	Unchannelled Valley-bottom
Latitude	9790037,09706	**Longitude**	203149,68156
Overview of HGM Unit:			

In-system photos

Looking upstream from the crossing

Looking downstream from the crossing

Catchment area and dominant landcover (top 5):

Catchment area = 1157.58 ha

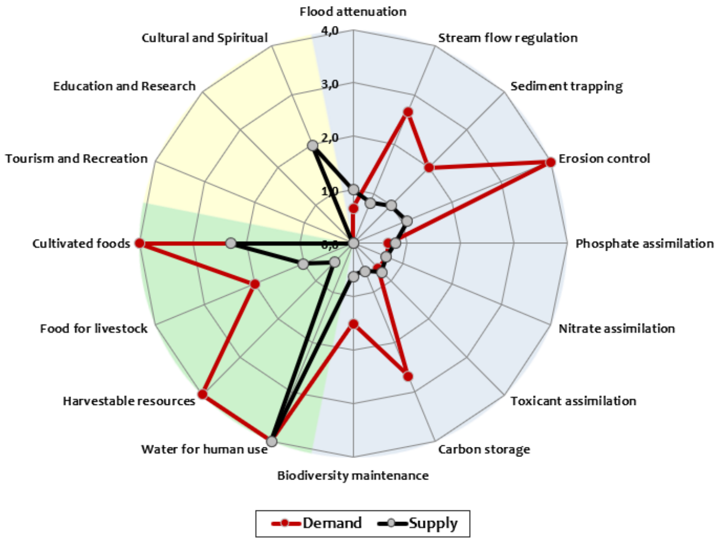
Order	Catchment	Within Wetland
1	Subsistence crops (51.96%)	Subsistence/Co-op crops (drained) (85.35%)
2	Urban Residential – low density (22.46%)	Subsistence crops (7.45%)
3	Woodlots/Tree plantations (14.55%)	Shallow flooding from impoundments (3.3%)
4	Invasive alien plants (7.18%)	Semi-natural (drained) (1.53%)
5	Semi-natural (1.31%)	Deep flooding from impoundments (1.2%)

Site assessment:

Wetland PES			
	Score	5.8	
	Category	D	
	Wetland size (ha)	36.4	
	Hectare equivalents	15.3	
	Anticipated trajectory of change	→	

- The predominant modification to the catchment is associated with the change from near-natural conditions (historically) to a landscape that is being intensively cultivated primarily for subsistence purposes. Additionally, modifications include woodlots/plantations. For the majority of the catchment the houses and/or more developed areas are located within the higher lying areas, whilst the subsistence activities are within the mid-slopes and to the valley-bottom.
- The wetland habitat has been significantly modified through the incorporation of extensive drainage networks and raised beds for crop cultivation. The main channel has also been straightened thereby effectively diverting flows out of the system. Towards the mid- and lower-portion of the system the central drain is 1.5-2m below the level of the crops.
- The loss of wetland habitat and its associated vegetation linked to co-operative agricultural activities – sugarcane.

EcoServices



Regulating and Supporting Services:

- Most regulating functions (flood attenuation, stream flow regulation, sediment trapping, carbon storage, biodiversity maintenance) show a low supply due to the modified nature of the system, however, the demand for these services is higher.

Provisioning Services

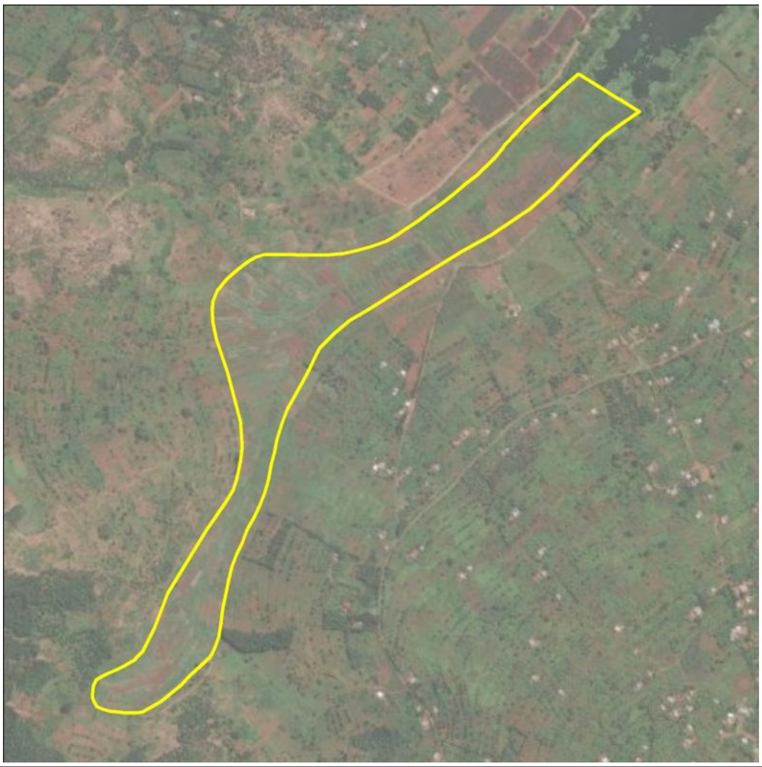
- Water for human use and cultivated foods are the most significant provisioning functions of wetland.
- Harvestable resources and food for livestock show high demand but limited supply, resulting in lower importance. This indicates wetlands contribute, but less substantially, to resource extraction and livestock feeding compared to their primary role in water and crop provision.

Cultural Services

- Cultural and spiritual values are rated moderate, however, the demand for these services is unknown.
- Tourism, recreation, education, and research are all rated very low.

5.2.3.1.2 *Nyabigugu (Musha 2)*

Nyabigugu (Musha 2)			
Date Assessed	18/11/2025	**Assessment Level**	Level 1B
HGM Type Modelled	Valley-bottom	**HGM Type Verified Infield**	Unchannelled Valley-bottom
Latitude	9789438,81702	**Longitude**	204968,54362
Overview of HGM Unit:			
Overview image here			



In-system photos

Overview of the system

Main drainage channel within the system

Catchment area and dominant landcover (top 5):

Catchment area = 322.18ha

Order	Catchment	Within Wetland
1	Subsistence crops (55.94%)	Subsistence crops (61.26%)
2	Woodlot/Tree plantations (22.77%)	Subsistence crops (drained) (27.36%)
3	Urban Residential – low density (19.29%)	Shallow flooding from impoundments (11.0%)
4	Semi-natural (1.77%)	Invasive alien plants (0.24%)
5	Orchards and vineyards (0.22%)	Infilling (0.14%)

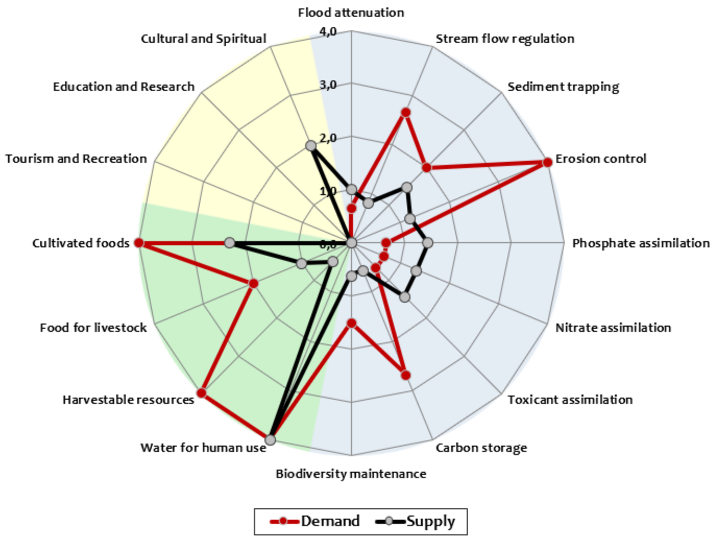
Site assessment:

<table>
<tr><td rowspan="5">Wetland PES</td><td>Score</td><td>6.2</td><td rowspan="5">

The predominant modification to the catchment is associated with the change from near-natural conditions (historically) to a landscape that is being intensively cultivated primarily for subsistence purposes, including woodlots (22.77%). Portions of the catchment have also been converted to orchards (nuts and avocados); however, this remains to still be nominal.
The communities are generally located within the higher lying areas, whilst the subsistence activities are within the mid-slopes and to the valley-bottom.
The wetland habitat has been significantly modified through the incorporation of extensive drainage networks and raised beds for crop cultivation particularly along the southern banks of the system.
The lowest portion of the system is characterised by dense stands of reeds, which is associated with the back flood waters of Muhazi Lake, and thus is too wet to cultivate.

</td></tr>
<tr><td>Category</td><td>E</td></tr>
<tr><td>Wetland size (ha)</td><td>13.2</td></tr>
<tr><td>Hectare equivalents</td><td>5.0</td></tr>
<tr><td>Anticipated trajectory of change</td><td>→</td></tr>
</table>

EcoServices



Regulating and Supporting Services:

- Most regulating functions (flood attenuation, stream flow regulation, phosphate assimilation, nitrate assimilation, toxicant assimilation, carbon storage, and biodiversity maintenance) shows a low supply due to the modified nature of the system, however, the demand for these services is considered to be moderately high to high.

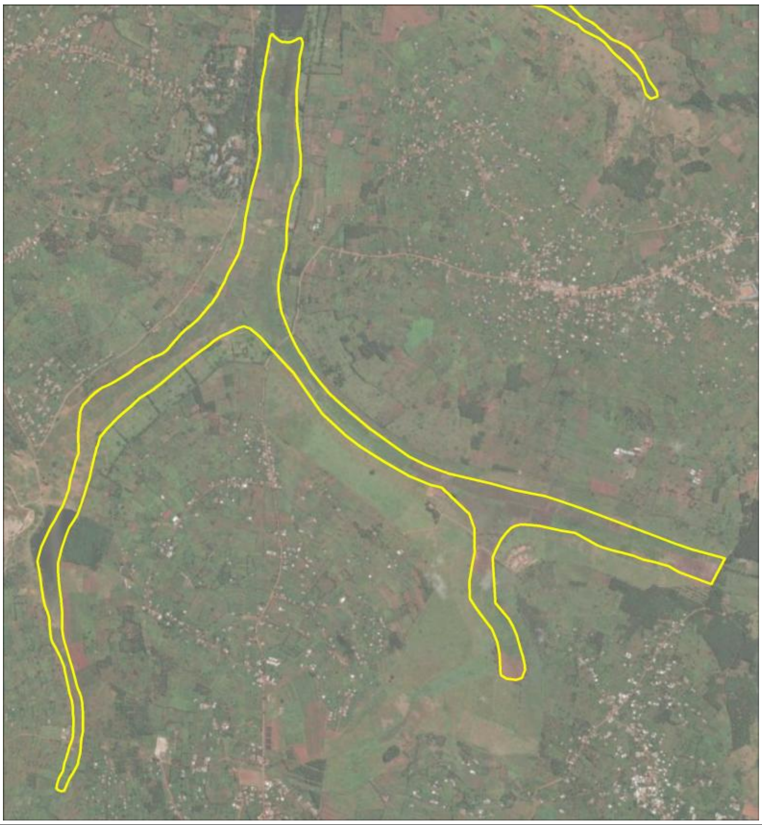
Provisioning Services

- Water for human use and cultivated foods are the most significant provisioning functions of wetland with both the demand and supply being High to Very High.
- Harvestable resources and food for livestock show high demand but limited supply, resulting in lower importance.

Cultural Services

- Cultural and spiritual values are rated moderate supply, however, the demand for these services is unknown.
- Tourism, recreation, education, and research are all rated very low.

5.2.3.1.3 *Nyirabigaji (Musha 3)*

Nyirabigaji (Musha 3)			
Date Assessed	17/11/2025	**Assessment Level**	Level 1B
HGM Type Modelled	Valley-bottom	**HGM Type Verified Infield**	Unchannelled Valley-bottom
Latitude	9786298,56496	**Longitude**	206766,79086
Overview of HGM Unit:			
Overview image here 			
In-system photos			
 View of Bisinia Dam and the trench below the Musha mining activities			

View of the intact wetland habitat withi the lower portion of the system

Catchment area and dominant landcover (top 5):

Catchment area = 2'224.51ha

Order	Catchment	Within Wetland
1	Subsistence crops (41.75%)	Subsistence crops (drained) (66.14%)
2	Urban Residential – low density (33.24%)	Shallow flooding from impoundments (8.83%)
3	Woodlots/Tree plantations (12.11%)	Semi-natural (undrained) (7.74%)
4	Urban Industrial/Commercial (4.54%)	Subsistence crops (6.51%)
5	Orchards and vineyards (4.12%)	Deep flooding from impoundments (5.31%)

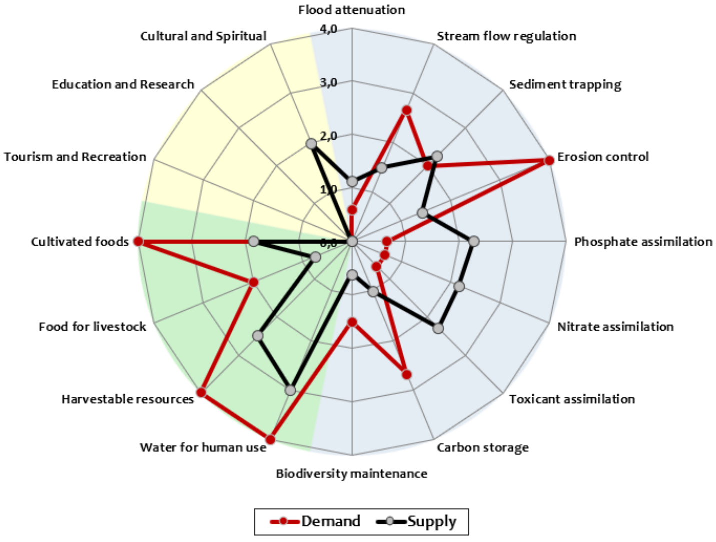
Site assessment:

<table>
<tr><td rowspan="5">Wetland PES</td><td>Score</td><td>5.1</td><td rowspan="5">

The predominant modification to the catchment is associated with the change from near-natural conditions (historically) to a landscape that is being intensively cultivated primarily for subsistence purposes. Portions of the catchment have also been converted to orchards (nuts and avocados) with just over 4% having been converted.
The Musha mining activities are located within the catchment of the upper portion of the system. The impacts linked physical disturbance of the system are confined to the catchment and the mine site.
The Nyirabigaji Stream has been dammed within the upper portion, which is referred to the Bisinia Dam. Water is abstracted from the dam for the mining operations, whilst the community is also reliant on the dam for fish.
The communities are generally located within the higher lying areas, with some of industries within the catchment too.
Large portions of the wetland have been significantly modified through the incorporation of extensive drainage networks and raised beds for crop cultivation.
At the confluence of the two streams, the eastern banks of the wetland have been allowed to revert back to near-natural conditions. This is likely due to the area being too wet to cultivate.
Up and downstream of the road crossing (lower portion of the system) are several aquaculture ponds, which serve as an additional food source to the community members.
The lowest portion of the system is characterized by dense stands of reeds, which is associated with the back flood waters of Muhazi Lake, and is too wet to cultivate.

</td></tr>
<tr><td>Category</td><td>D</td></tr>
<tr><td>Wetland size (ha)</td><td>73.9</td></tr>
<tr><td>Hectare equivalents</td><td>36.2</td></tr>
<tr><td>Anticipated trajectory of change</td><td>→</td></tr>
</table>

EcoServices

	Regulating and Supporting Services: • The supply of the most regulating functions (sediment trapping, phosphate, nitrate and toxicant assimilation) are high, however, the demand is generally low except for erosion control which is also high. Provisioning Services • The demand for water for human use , harvestable resources, and cultivated foods are very high. • Food for livestock shows a moderate demand but limited supply, resulting in lower importance. This indicates wetland contributes, but less substantially, to livestock feeding compared to their primary role in water and crop provision. Cultural Services • Cultural and spiritual values are rated moderate, however, the demand for these services is unknown. • Tourism, recreation, education, and research are all rated very low.

Nyirabigaji River upstream of Bisinia Dam at SW4			
Sample Date	17/11/2025	**Altitude**	1,480 m.a.s.l.
River	Nyirabigaji	**Geomorphological zone**	Transitional
Latitude	-1.940886	**Longitude**	30.354067

River reach overview: The site is considered a control site, located at SW4 upstream of Bisinia Dam and Musha mining operations.

Upstream	Downstream
	

Site assessments:

Water Quality

During the August and November 2023 assessments by Nepid Consulting (2024) water quality was moderately turbid (108 to 126 NTU) but alkaline (pH 7.5 to 7.9) with moderate conductivity (43 mS/m). Water clarity measurement taken during the November 2025 assessment was 10 cm indicating moderate to high turbidity.

Water quality based on drinking/potable standards: The upper Nyirabigaji shows drinking water exceedances of iron (mean: 0.42 mg/L; limit: 0.30 mg/L), manganese (mean: 0.37 mg/L; limit: 0.080 mg/L) and total ammonia (mean: 0.63 mg/L; limit: 0.50 mg/L). Excess iron causes organoleptic problems (reddish discolouration, metallic taste), staining of fixtures and promotion of iron-oxidising bacteria in distribution systems (DWAF 1996, Vol. 1). Manganese above 0.08 mg/L causes black deposits in pipes, aesthetic complaints and is associated with neurotoxic effects at high chronic exposures; requires oxidation-filtration treatment (SANS 241:2015; WHO 2022). Ammonia in raw water indicates sewage or organic pollution; while not directly toxic at guideline levels, it reacts with chlorine to form chloramines, reducing disinfection efficacy (DWAF 1996, Vol. 1). **Water quality based on aquatic ecology standards:** Lead is the only aquatic life exceedance recorded from the upper Nyirabigaji (mean: 0.0032 mg/L; limit: 0.0020 mg/L). Lead bioaccumulates in bone and soft tissues of fish. Sublethal effects include behavioural changes and reproductive impairment, with cascading effects up the food web (DWAF 1996, Vol. 7).	
Diatoms	
River Health Class: **SERIOUSLY MODIFIED**	The diatom sample contained no identifiable cells and consisted entirely of fine sediment highting the severity of sedimentation within the river channel.
Macroinvertebrates	
River Health Class: **SERIOUSLY MODIFIED**	Macroinvertebrates were assessed by Nepid Consulting (2024). Although subsistence cultivation influences the overall wetland habitat upstream of Bisinia Dam, the site at SW4 still supports a relatively low diversity of macroinvertebrates with 10 and 12 SASS taxa recorded during August and November 2024 respectively. Dominant taxa included hemipterans (Belostomatidae), caddisflies (Hydropsychidae), flies (Chironomidae and Simuliidae) and snails (Planorbidae). Macroinvertebrate assemblage suggests a system under moderate pressure but is able to retain some ecological function. Overall river health was rated Seriously Modified (Category D), reflecting the disturbance from land use / agricultural activities but still supporting aquatic fauna.

Nyirabigaji River downstream of Bisinia Dam at SW2			
Sample Date	17/11/2025	**Altitude**	1,470 m.a.s.l.
River	Nyirabigaji	**Geomorphological zone**	Transitional
Latitude	-1.935528	**Longitude**	30.354591
River reach overview: The site is located at SW2 at the outflow of Bisinia Dam.			

Upstream	Downstream
	

Site assessments:

Water Quality

During the August and November 2023 assessments by Nepid Consulting (2024) water quality was clearer than SW4 upstream with low turbidity (8 to 21 NTU), alkaline (pH 7.5 to 7.9) with moderate conductivity (41 mS/m). Water clarity measurement taken during the November 2025 assessment was 16 cm indicating moderate turbidity, and an improvement from upstream due to some settling out of sediments within the dam.

Water quality based on drinking/potable standards:

SW2 shows exceedances of manganese (mean: 0.12 mg/L; limit: 0.080 mg/L) and total ammonia (mean: 0.63 mg/L; limit: 0.50 mg/L). Manganese above the health-related guideline of 0.5 mg/L is linked to neurodevelopmental deficits, particularly in young children (Ljung & Vahter, 2007). Total ammonia suggests organic waste input and can cause taste and odour problems while promoting nitrification within the downstream environment.

Water quality based on aquatic ecology standards:

The principal aquatic life exceedance at SW2 is lead (mean: 0.0024 mg/L; min limit: 0.0020 mg/L), which is among the most ecotoxicologically significant metals in freshwater systems. The DWAF (1996c) chronic guideline for lead (0.0020 mg/L) is set at a low level to protect sensitive invertebrate taxa and early fish life stages from sub-lethal effects. Chronic lead exposure impairs haem synthesis, causing anaemia, and disrupts the endocrine and nervous systems in fish, reducing reproductive success and larval survival (DWAF, 1996c). Sensitive macroinvertebrate taxa such as Ephemeroptera, Plecoptera, and Trichoptera (EPT) are expected to decline where lead exceeds chronic guideline values. Lead bioaccumulates through the food chain, posing secondary risks to piscivorous birds and mammals in the catchment.

Diatoms	
River Health Class: **N/A**	The diatom samples were not collected from the site.
Macroinvertebrates	
River Health Class: **POOR/SERIOUSLY MODIFIED**	The site supported the highest diversity of macroinvertebrate compared to other sites in the Nyirabigaji with 13 and 18 SASS taxa recorded by Nepid Consulting (2024) in August and November 2023 respectively. Dominant macroinvertebrates included low sensitivity, pollution-tolerant taxa such as flies (Simuliidae), hemipterans (Gerridae and Naucoridae) and snails (Lymnaeidae and Planorbidae). The macroinvertebrate community indicates that the site was largely to seriously modified (Category D/E).

Nyirabigaji River at SW3 downstream of Musha Mine			
Sample Date	17/11/2025	**Altitude**	1,460 m.a.s.l.
River	Nyirabigaji	**Geomorphological zone**	Transitional
Latitude	-1.929348	**Longitude**	30.358548

River reach overview: The site is located at SW3 approximately 900 m downstream of Bisinia Dam and it downstream of the mining operations at Musha Mine.

Upstream

Site assessments:

Water Quality

During the August and November 2023 assessments by Nepid Consulting (2024) water quality remained similar to SW2, i.e. clear to light brown, alkaline (pH 7.7 to 8.3), with turbidity ranging between 11 and 25 NTU.

Water quality based on drinking/potable standards:

SW3 shows exceedances of iron, manganese, arsenic and total ammonia for drinking water quality, suggesting multiparameter contamination. Arsenic exceedance is a serious carcinogenic risk associated with skin lesions, bladder, and lung cancer with prolonged exposure, even at low doses (WHO, 2011). Manganese above the health-related guideline of 0.5 mg/L is linked to neurodevelopmental deficits, particularly in young children (Ljung & Vahter, 2007). Iron and aluminium primarily cause aesthetic degradation (taste, colour, staining) but elevated aluminium has been associated with neurotoxicity at chronic doses (DWAF, 1996a). Total ammonia suggests organic waste input and can cause taste and odour problems while promoting nitrification within distribution infrastructure.

Water quality based on aquatic ecology standards:

The principal aquatic life exceedance at SW3 is lead (mean: 0.0024 mg/L; min limit: 0.0020 mg/L), which is among the most ecotoxicologically significant metals in freshwater systems. The DWAF (1996c) chronic guideline for lead (0.0020 mg/L) is set at a low level to protect sensitive invertebrate taxa and early fish life stages from sub-lethal effects. Chronic lead exposure impairs haem synthesis, causing anaemia, and disrupts the endocrine and nervous systems in fish, reducing reproductive success and larval survival (DWAF, 1996c). Sensitive macroinvertebrate taxa such as Ephemeroptera, Plecoptera, and Trichoptera (EPT) are expected to decline where lead exceeds chronic guideline values. Lead bioaccumulates through the food chain, posing secondary risks to piscivorous birds and mammals in the catchment. The source of lead should be investigated, as diffuse pollution from vehicle emissions, informal settlements, or artisanal activities are likely contributors.

Diatoms

River Health Class:

POOR

No. of species	SPI core	%PTV	%Deformed cells
30	7.5	66.3	0.0

The diatom community was observed to be in a poor river health class at this site, and only slightly better when comparing the SPI values from the other sites where diatoms were recorded. The dominant diatom species at this site was *Gomphonema parvulum* making up 60% of the community, followed by *Achnanthidium minutissimum* (8%) and *Nitzschia sp.* (7%). *G. parvulum*, a species highly tolerant of extremely polluted waters, and it thrives in polluted systems where more sensitive species fail to survive. Although *A. minutissimum* favours clean water, it does have a very wide tolerance range and is known to quickly colonise disturbed habitats.

Macroinvertebrates

River Health Class:

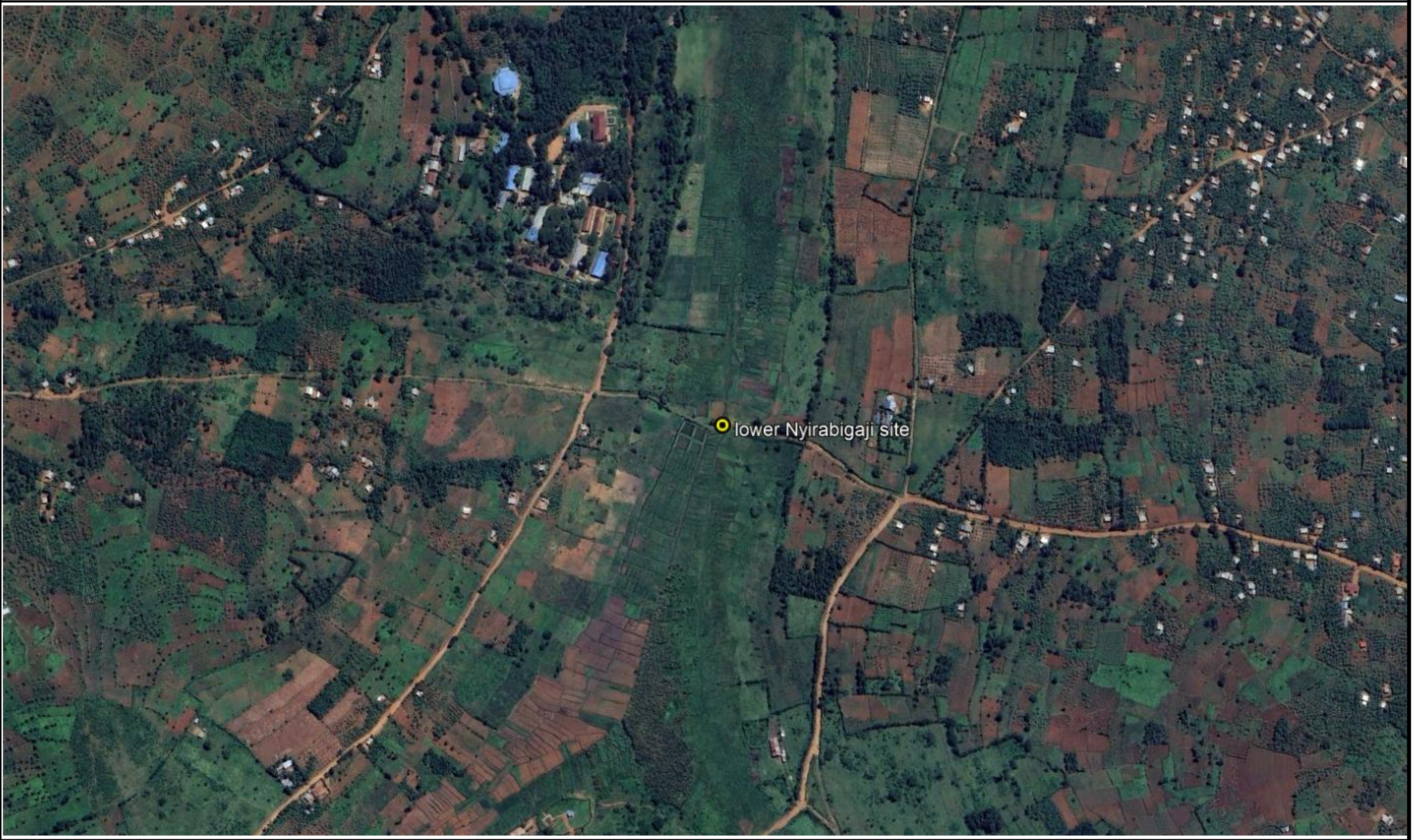
SERIOUSLY MODIFIED

Macroinvertebrates were assessed by Nepid Consulting (2024) and found to be similar in diversity and condition to SW2 upstream suggesting a negligible impact from ongoing agriculture in the wetland as well as from Musha Mine. A total of 15 SASS taxa were recorded on both occasions (August and November 2023). Dominant macroinvertebrates included low sensitivity, pollution-tolerant taxa such as flies (Chironomidae and Simuliidae), hemipterans (Belostomatidae and Gerridae) and snails (Lymnaeidae, Planorbidae and Thiaridae), but also moderately tolerant Caenidae mayflies. The macroinvertebrate community indicates that the site was largely to seriously modified (Category D/E).

Lower Nyirabigaji River downstream of SW3

Sample Date	17/11/2025	**Altitude**	1,450 m.a.s.l.
River	Nyirabigaji	**Geomorphological zone**	Transitional
Latitude	-1.924446	**Longitude**	30.362275

River reach overview: The site is located approximately 750 m downstream of SW3 and upstream of Lake Muhazi.



Upstream	Downstream
	

Site assessments:

Water Quality

The site is not a routine water sampling site. During the 2023 assessment the water quality was found to be similar to SW3 with an alkaline pH of between 7.5 and 7.8) and turbidity between 14 and 23 NTU. During the November 2025 assessment, turbidity was moderately high with a clarity of 13 cm.

Diatoms

River Health Class:

GOOD

No. of species	SPI core	%PTV	%Deformed cells
16	16.8	7.0	0.0

In August 2023 (dry season), the diatom community at the Nyakagezi Wetland at SW3b was observed to be in a in a good to moderately modified health class (Nepid Consulting, 2024). Nutrient levels and salinity content were elevated, and organic load was low. The dominant species were from the genera *Achnanthidium, Brachysira, Gomphonema* and *Nitzschia*. *Achnanthidium* is typically associated with well-oxygenated stream conditions, whereas *Brachysira* favours acidic, nutrient-poor environments (Taylor and Cocquyt, 2016).

In November 2023 (wet season), the diatom community was observed to be in a moderately modified river health class (Nepid Consulting, 2024). As with the dry season survey, nutrient levels and salinity content were elevated, organic load was low and pollution levels were moderate. Species from the genus *Achnanthidium* decreased between August and November 2023, reflecting that lower flow and lower oxygenation rates were present in November 2023. Higher nutrient levels were present in November 2023 than in August 2023, and this was reflected by an increased abundance of the genera *Nitzschia* and *Navicula*, which consist of motile species (Nepid Consulting, 2024). *Craticula* species were also dominant and suggested that salinity content increased between October and November 2023.

In November 2025, the diatom community was observed to be in a good river health class. The dominant diatom species at this site were *Achnanthidium sp.* (45%), *Achnanthidium catenatum* (41%) and *Gomphonema parvulum* (6%). *Achnanthidium sp.* is present in moderate to good quality waters and *Achnanthidium catenatum* is tolerant of waters with moderate levels of organic pollution. Of the three species *G. parvulum* is the most widespread and considered to be tolerant of extremely polluted waters.

The diatom community at SW3b shows a general improvement in river health between 2023 and 2025, moving from a moderately modified to a good health class by November 2025. However, the site remained under persistent anthropogenic pressure throughout 2023, with elevated nutrients and salinity attributed to agricultural runoff and informal settlements, driving seasonal shifts toward stress-tolerant genera such as *Nitzschia, Navicula*, and *Craticula*. The absence of valve deformities across all surveys indicates that mining-related metal contamination was not a detectable biological stressor. While the dominance of *Achnanthidium* in 2025 reflects improved water quality, the co-occurrence of *G. parvulum* (tolerant of heavily polluted conditions) suggests residual enrichment persists and may be attributable to intensive cultivation practices within the wetland system.

Macroinvertebrates

River Health Class:

POOR

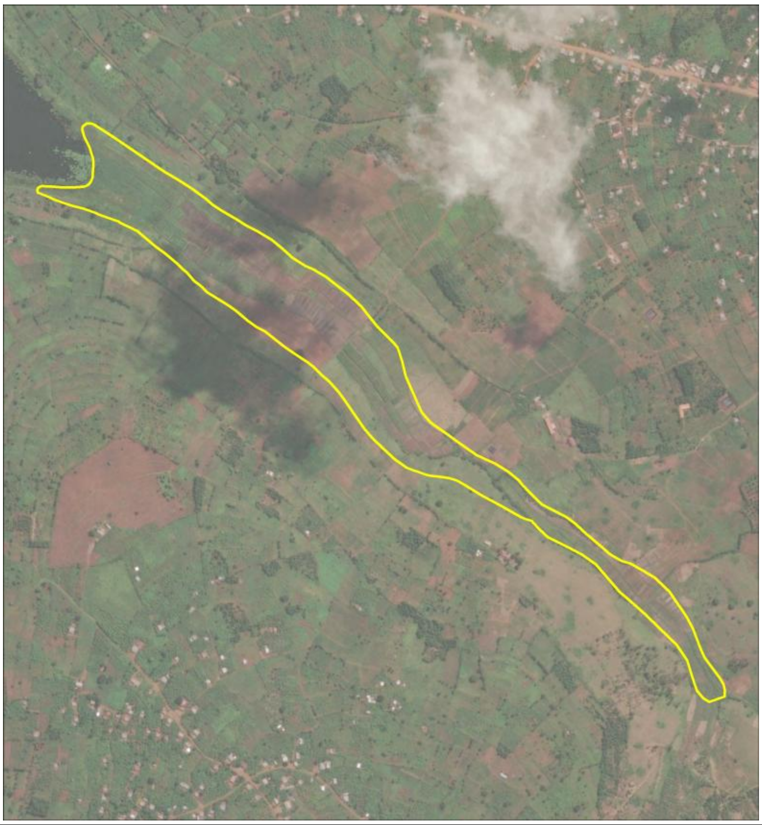
SASS Score	No. of taxa	ASPT	Ecological Category	Class
77	17	4.53	D	Poor

During the 2023 assessments, Nepid Consulting (2024) reported that the macroinvertebrate community at the site was generally lower than other sites in the system, dominated by flies (Chironomidae and Simuliidae), hemipterans (Belostomatidae, Corixidae, Gerridae), and snails (Lymnaeidae, Planorbidae and Thiaridae), but also moderately tolerant Caenidae mayflies. The macroinvertebrate community indicates that the site was seriously modified (Category D/E).

During the November 2025 assessment the site showed a moderate improvement in SASS Score and ASPT but was still recorded to be in a poor ecological condition with the macroinvertebrate community continuing to be dominated by moderately tolerant taxa with medium to low sensitivities. Most taxa were associated with the vegetation biotope, suggesting that marginal vegetation provided the primary available habitat for macroinvertebrates.

5.2.3.1.4 *Rubonobono (Musha 4)*

Rubonobono (Musha 4)			
Date Assessed	18/11/2025	**Assessment Level**	Level 1B
HGM Type Modelled	Valley-bottom	**HGM Type Verified Infield**	Unchannelled Valley-bottom
Latitude	9788230,83963	**Longitude**	207533,73357
Overview of HGM Unit:			
Overview image here			



In-system photos

Overview of Rubonobono

Catchment area and dominant landcover (top 5):		
Catchment area = 280.33ha		
Order	**Catchment**	**Within Wetland**
1	Subsistence crops (56.0%)	Subsistence crops (drained) (75.12%)

2	Urban Residential – low density (37.64%)	Shallow flooding from impoundments (15.2%)
3	Woodlots/Tree plantations (5.66%)	Semi-natural (undrained) (8.88%)
4	Orchards and vineyards (0.7%)	Infilling (incl, infrastructure) (0.79%)
5	-	-

Site assessment:

Wetland PES	Score	5.1	• The catchment of the wetland has been significantly modified from its historical condition, which is mainly attributed to subsistence agricultural practices (56%) and the communities within the higher lying areas (+-37%). • Approximately 75% of the wetland has been modified through subsistence agricultural activities, which includes the adoption of an extensive drainage network and raised beds for crop cultivation. In many instances the drainage network effectively diverts flow around the cultivated areas. • The lower portion of the system is largely unaffected due to the area being too wet as a result of the back flooding of the Muhazi Lake.
	Category	D	
	Wetland size (ha)	13.6	
	Hectare equivalents	6.6	
	Anticipated trajectory of change	→	

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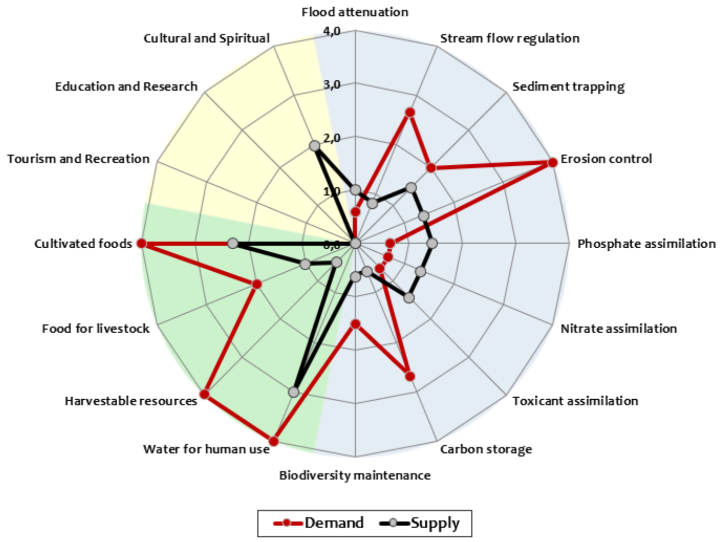


Regulating and Supporting Services:

- Due to the modified nature of the system, the efficacy at the system supplying regulating and supporting services is considered to be moderately-low, however, the demand often exceeds this.

Provisioning Services

- Water for human use, harvestable resources and cultivated foods are the most significant provisioning functions of wetland. However, the efficacy of the system to supply these services is lower than the demand.

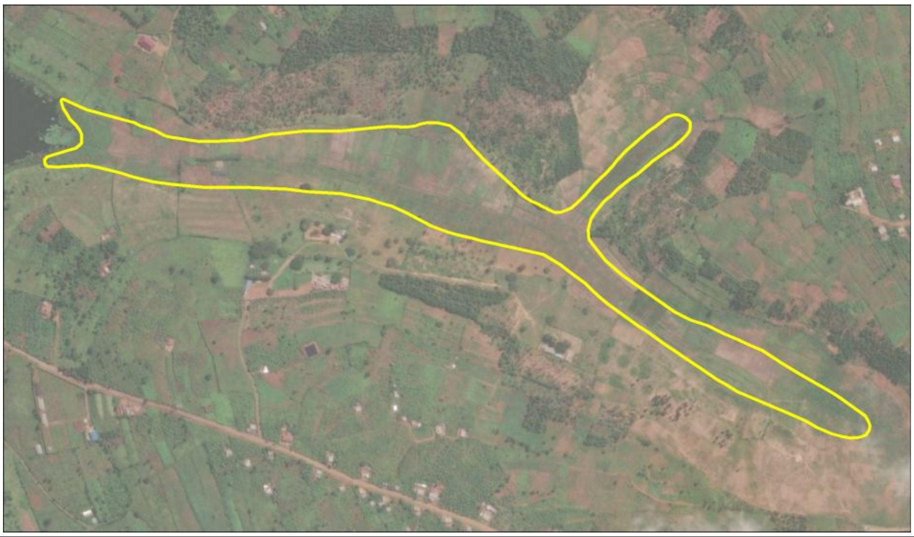
Cultural Services

- Cultural and spiritual values are rated moderate, however, the demand for these services is unknown.
- Tourism, recreation, education, and research are all rated very low.

5.2.3.1.5 *Rukombe (Musha 5)*

Rukombe (Musha 5)			
Date Assessed	18/11/2025	**Assessment Level**	Level 1B
HGM Type Modelled	Valley-bottom	**HGM Type Verified Infield**	Unchannelled Valley-bottom
Latitude	9789328,56648	**Longitude**	207545,12266
Overview of HGM Unit:			

Overview image here



In-system photos

View of the lower portion of the wetland and its assoicated catchment

View of the upper portion of the wetland and its associated catchment

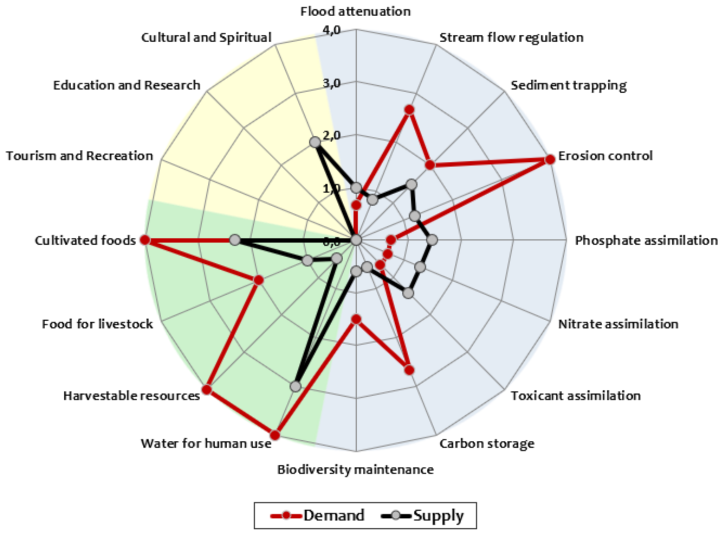
Catchment area and dominant landcover (top 5):		
Catchment area = 138.55ha		
Order	**Catchment**	**Within Wetland**
1	Subsistence crops (63.93%)	Subsistence crops (drained) (86.1%)
2	Urban Residential – low density (26.11%)	Subsistence crops (5.71%)
3	Woodlots/Tree plantations (8.94%)	Shallow flooding from impoundments (5.63%)
4	Urban Industrial/Commercial (1.01%)	Orchards and vineyards (1.29%)
5	-	Semi-natural (undrained) (1.28%)

Site assessment:

Wetland PES		
	Score	5.7
	Category	D
	Wetland size (ha)	10.1
	Hectare equivalents	4.4
	Anticipated trajectory of change	→

- The catchment of the wetland has been significantly modified through subsistence agricultural activities (63%), and the communities located within the higher lying areas of the catchment. Furthermore, about 9% has been converted to woodlots.
- Almost the entire wetland has been transformed to some form of subsistence agricultural activities, with over 85% of the wetland having an extensive drainage network and raised beds.
- Similar to the other systems, the lower portion is unaffected by these agricultural practices as it is too wet, which is linked to the back flooding from the Muhazi Lake.

EcoServices



Regulating and Supporting Services:

- Most regulating functions (e.g. flood attenuation, stream flow regulation, sediment trapping, carbon storage, biodiversity maintenance) show a low to moderately low supply due to the modified nature of the system, however, the demand for these services is higher.

Provisioning Services

- Water for human use, harvestable resources and cultivated foods are the most significant provisioning functions of wetland. However, the efficacy of the system to supply these services is lower than the demand.

Cultural Services

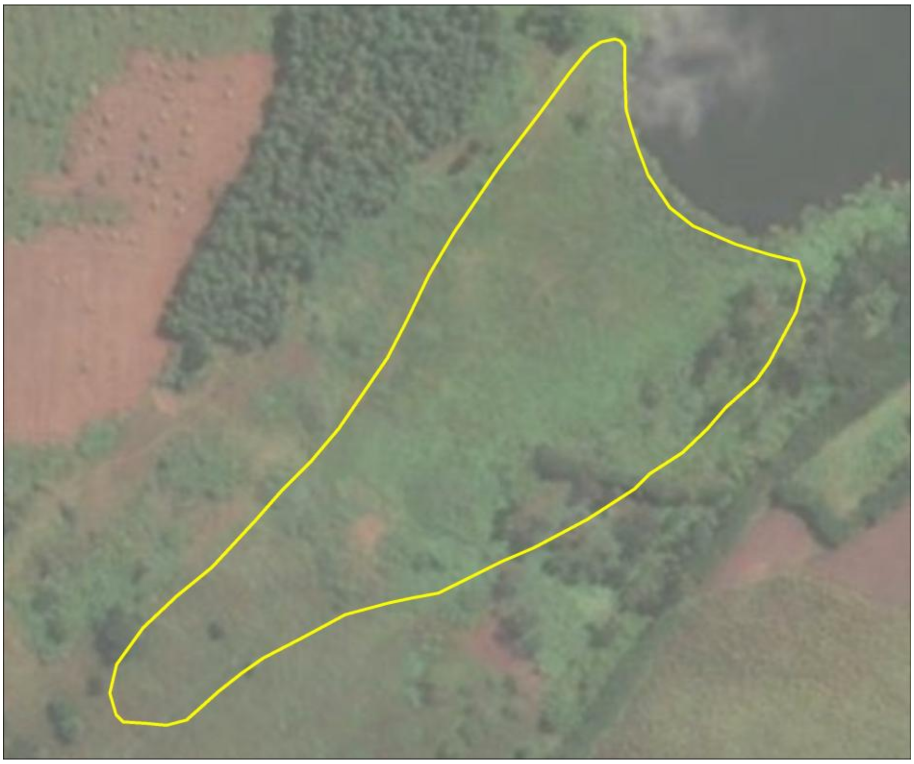
- Cultural and spiritual values are rated moderate, however, the demand for these services is unknown.

5.2.3.1.6 *Muryango 1 (Musha 6)*

Muryango 1 (Musha 6)			
Date Assessed	18/11/2025	**Assessment Level**	Level 1B
HGM Type Modelled	Valley-bottom	**HGM Type Verified Infield**	Unchannelled valley-bottom
Latitude	9790950,41854	**Longitude**	208965,45072

Overview of HGM Unit:

Overview image here



In-system photos

No site photos available. Wetland was not visited due to limited time and accessibility

Catchment area and dominant landcover:

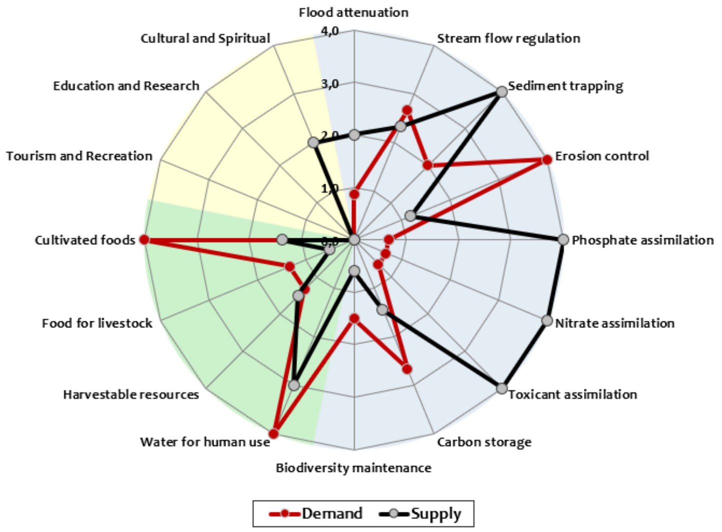
Catchment area = 62.32ha

Order	Catchment	Within Wetland
1	Subsistence crops (68.84%)	Shallow flooding from impoundments (74.04%)
2	Semi-natural (9.11%)	Subsistence crops (17.37%)
3	Woodlots/Tree plantations (8.39%)	Invasive alien plants (8.59%)
4	Urban Residential – low density (8.38%)	-
5	Urban Industrial/Commercial (3.03%)	-

Site assessment:

Wetland PES			
	Score	4.1	• Although this system is relatively intact with limited subsistence agricultural activities within the system, the back flooding from the Muhazi Lake has altered the system from its historical conditions. • The catchment has been significantly modified through subsistence crops, the communities in the higher lying areas, and some industries.
	Category	D	
	Wetland size (ha)	1.1	

	Hectare equivalents	0.6	
	Anticipated trajectory of change	→	

EcoServices	
	Regulating and Supporting Services: • The supply of regulating functions (e.g. water quality enhancement, sediment trapping etc.) show a higher ability to supply the services than other systems, which is linked to the fact that a limited areas has been converted to subsistence agricultural activities in comparison to other systems. Provisioning Services • Water for human use and cultivated foods are the most significant provisioning functions of wetland. However, the efficacy of the system to supply these services is lower than the demand. Cultural Services • Cultural and spiritual values have a higher supply than the demand for these services is unknown.

5.2.3.1.7 *Muryango 2 (Musha 7)*

Muryango 2 (Musha 7)			
Date Assessed	18/11/2025	**Assessment Level**	Level 1B
HGM Type Modelled	Valley-bottom	**HGM Type Verified Infield**	Unchannelled valley-bottom
Latitude	9790509,39057	**Longitude**	209185,82563
Overview of HGM Unit:			

Overview image here

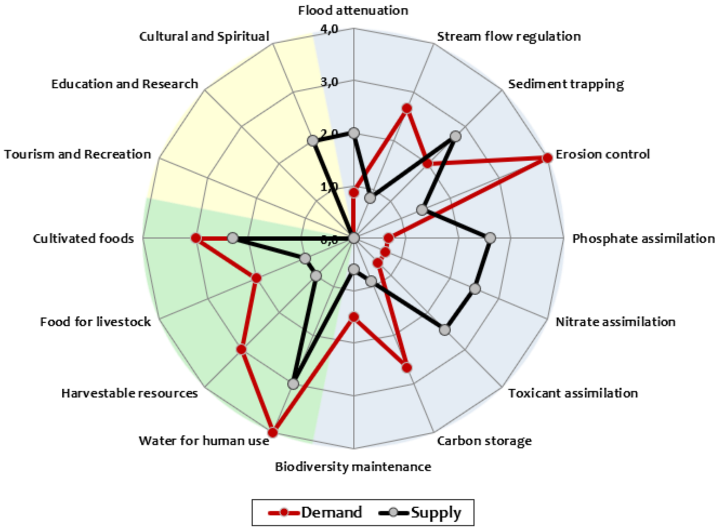
In-system photos
No site photos available. Wetland was not visited due to limited time and accessibility

Catchment area and dominant landcover:		
Catchment area = 68.12ha		
Order	**Catchment**	**Within Wetland**
1	Subsistence crops (63.25%)	Subsistence crops (65.42%)
2	Urban Residential – low density (20.96%)	Shallow flooding from impoundments (34.58%)
3	Woodlots/Tree plantations (11.47%)	-
4	Semi-natural (2.58%)	-
5	Urban Open Space (1.35%)	-

Site assessment:			
Wetland PES	Score	5.6	• The catchment of the wetland has been significantly modified due to subsistence activities e.g. crops and woodlots, and communities, with very limited semi-natural habitat remaining (less than 3%). • Similarly, the wetland has been transformed with two-thirds of the system supporting subsistence agricultural activities. The remainder of the system is too wet as it is within the back waters of the Muhazi lake system.
	Category	D	
	Wetland size (ha)	2.0	
	Hectare equivalents	0.9	

	Anticipated trajectory of change	→	

EcoServices



Regulating and Supporting Services:

- The supply of regulating functions (e.g. water quality enhancement, sediment trapping etc.) generally shows a higher ability to supply the services than other systems, which is linked to the fact that there is habitat available to supply these services.

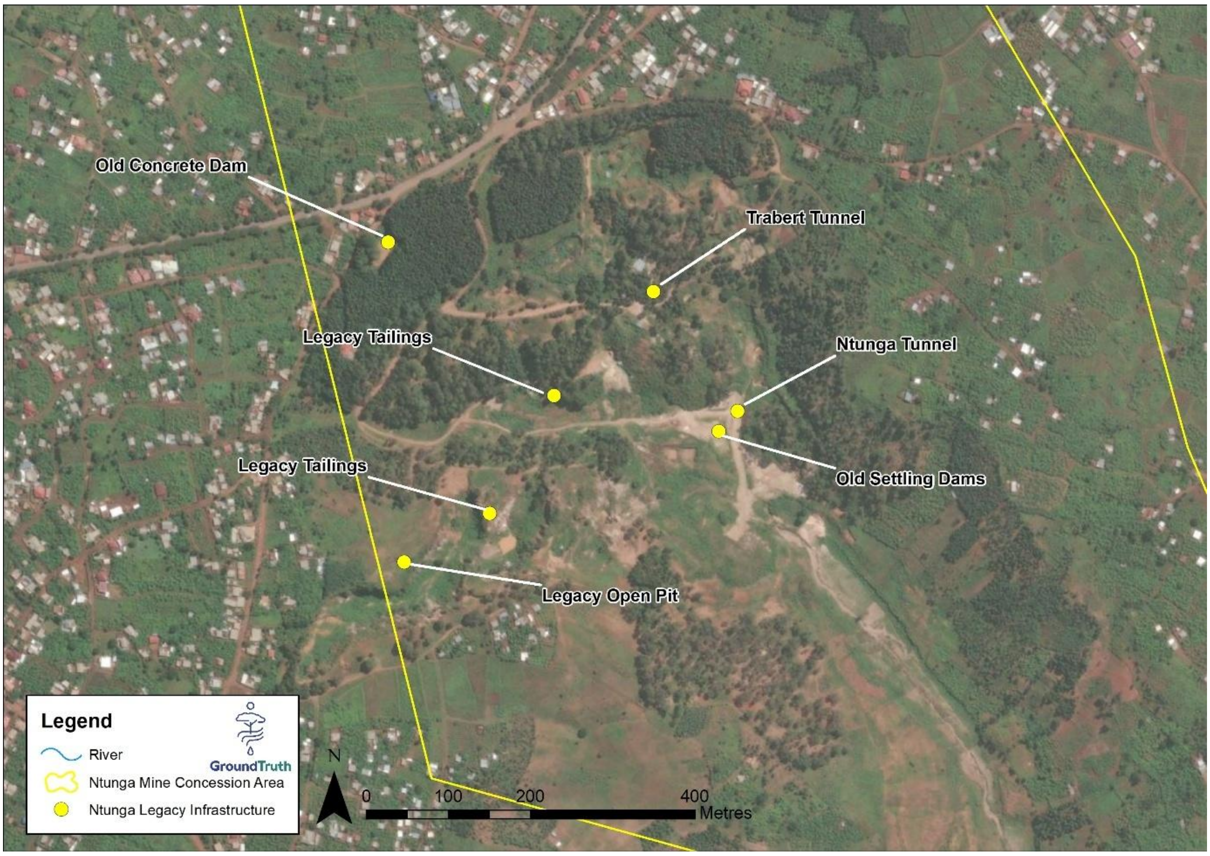
Provisioning Services

- Water for human use, harvestable resources, and cultivated foods are the most significant provisioning functions of wetland. However, the efficacy of the system to supply these services is lower than the demand.

Cultural Services

- Cultural and spiritual values have a higher supply than the demand for these services is unknown.

5.2.4 *Ntunga*



5.2.4.1 Functionality and integrity

The two wetlands within the Ntunga concession area are fundamentally the same, in that they have been substantially modified from their original benchmark state. Subsistence agricultural activities within the system are the predominant modification, which includes the adoption of raised beds and extensive drainage networks (**Figure 5-13**). The drainage network serves to redirect flows around the beds and lower the water table of the system and therefore, more accessible for cultivation. The catchments have also seen significant modifications through similar impacts resulting in an alteration of catchment processes that drive the system, notably surface runoff, subsurface flows and groundwater recharge.

The distinguishing feature between the two systems is that the western system (Ntunga 1) has the Ntunga mining activities located within the upstream catchment. Connecting the upper parts of the catchment from just downstream of the active mining area down the Ntunga 1 wetland system is a drainage feature that functions like an ephemeral river (Ntunga 3). This system, or part thereof, was once an extension of Ntunga 1 wetland, however, over time through land transformation, erosion and channel incision the system has become altered into a degraded drainage feature with accelerated impacts from mining activities in more recent years. The main impact of the mining activities includes the mobilisation of aggregate and sediments into the drainage feature (**Figure 5-14**) and eventually into the Ntunga 1 wetland. The additional mobilisation of materials within the upper parts of the system has modified the overall nature of the system and overarching functionality, potentially changing the upper portion of the freshwater ecosystem from seepage wetland to a drainage feature which is ever-changing with the mobilisation and deposition of materials. Resultantly, a gully and headcut has formed just below the Ntunga mine which is advancing up the valley (**Figure 5-15**).

Figure 5-13 An example of the subisistence activities within the wetland

Figure 5-14 View of sediments and aggregates that have been mobilised into the freshwater ecosystem downstream of the Ntunga Mine

Figure 5-15 Gully erosion directly downstream of the Ntunga Mine

5.2.4.1.1 *Ntunga 1*

Ntunga 1			
Date Assessed	17/11/2025	**Assessment Level**	Level 1B
HGM Type Modelled	Valley-bottom	**HGM Type Verified Infield**	Channelled valley-bottom
Latitude	9780490,62242	**Longitude**	207865,82224

Overview of HGM Unit:

In-system photos

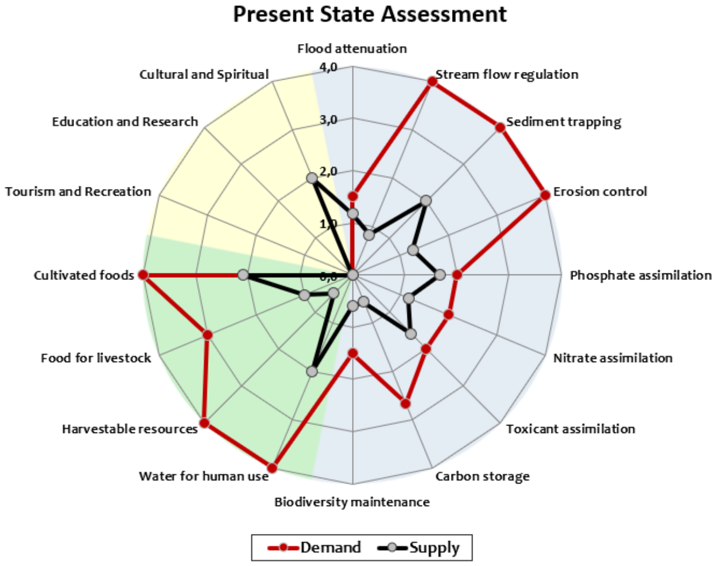
View of a portion of the system depicting the subsistence agricultural activities, along with channel straightening and draingae network

Catchment area and dominant landcover:

Catchment area = 917.44ha

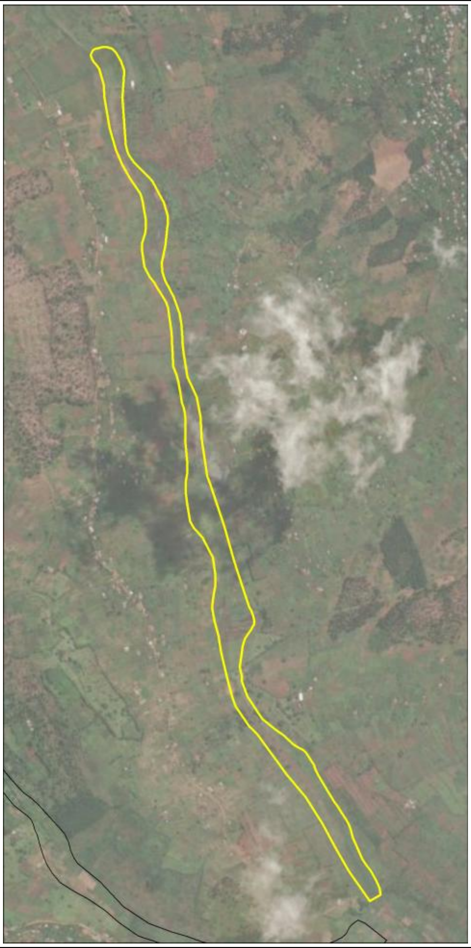
Order	Catchment	Within Wetland
1	Subsistence crops (53.17%)	Subsistence (drained) (78.14%)
2	Woodlots/Tree plantations (16.11%)	Semi-natural (10.70%)
3	Moderately degraded land (12.70%)	Subsistence crops (undrained) (7.56%)
4	Urban Residential – low density (5.41%)	Woodlots/Tree plantations (2.46%)
5	Urban Residential – high density (5.34%)	Moderately degraded land (0.91%)

<table>
<tr><th colspan="4">Site assessment:</th></tr>
<tr><td rowspan="5">Wetland PES</td><td>Score</td><td>5.5</td><td rowspan="5">

The catchment of the wetland has been significantly modified due to subsistence activities e.g. crops and woodlots, and communities, with very limited semi-natural habitat remaining (less than 3%).
Similarly, the wetland has been transformed with the majority of the system being under subsistence agricultural activities, which include channel straightening and an extensive drainage network. Although there are some patches within the system which are considered to be in a semi-natural condition.
</td></tr>
<tr><td>Category</td><td>D</td></tr>
<tr><td>Wetland size (ha)</td><td>35.4</td></tr>
<tr><td>Hectare equivalents</td><td>15.9</td></tr>
<tr><td>Anticipated trajectory of change</td><td>→</td></tr>
<tr><th colspan="4">EcoServices</th></tr>
<tr><td colspan="3">
</td><td>
Regulating and Supporting Services:
The supply of regulating functions (e.g. water quality enhancement, sediment trapping etc.) generally shows a higher demand for these services than the supply, which is attributed to the highly modified nature of the system.
Provisioning Services
Water for human use, harvestable resources, and cultivated foods are in higher demand than the system can supply, which is attributed to there being little natural wetland habitat remaining.
Cultural Services
Cultural and spiritual values are rated moderate, however, the demand for these services is unknown.
Tourism, recreation, education, and research are all rated very low.
</td></tr>
</table>

5.2.4.1.2 *Ntunga 2*

Ntunga 2			
Date Assessed	17/11/2025	**Assessment Level**	Level 1B
HGM Type Modelled	Valley-bottom	**HGM Type Verified Infield**	Channelled valley-bottom
Latitude	9781061,38985	**Longitude**	208778,01971
Overview of HGM Unit:			

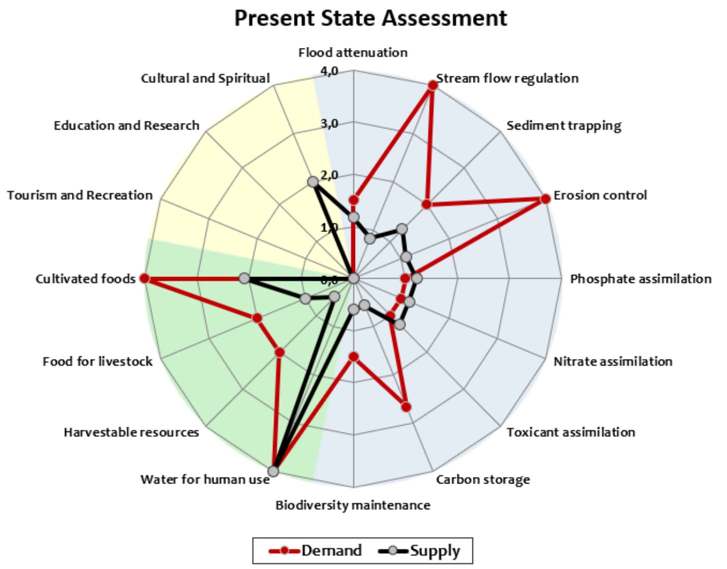


In-system photos
No site photos available.

Catchment area and dominant landcover:		
Catchment area = 919.08ha		
Order	**Catchment**	**Within Wetland**
1	Subsistence crops (63.97%)	Subsistence (drained) (79.69%)
2	Woodlots/Tree plantations (13.48%)	Abandoned lands (9.73%)
3	Urban Residential – high density (13.45%)	Semi-natural (drained) (7.31%)
4	Urban Residential – low density (6.13%)	Woodlots/Tree plantations (1.39%)
5	Co-operative agriculture (2.97%)	Subsistence crops (undrained) (1.32%)

Site assessment:			
Wet	Score	5.6	

	Category	D	• The catchment of the wetland has been significantly modified due to subsistence activities e.g. crops and woodlots, and communities, altering the functioning of the system in comparison to baseline conditions. • Similarly, the wetland has been transformed with the majority of the system being under subsistence agricultural activities, which include channel straightening and an extensive drainage network. The areas that are not currently actively cultivated show evidence of historical utilisation which includes an extensive drainage network.
	Wetland size (ha)	24.2	
	Hectare equivalents	10.7	
	Anticipated trajectory of change	→	
EcoServices			



Regulating and Supporting Services:

- The supply of regulating functions (e.g. streamflow regulation, sediment trapping etc.) generally shows a higher demand for these services than the supply, which is attributed to the highly modified nature of the system.

Provisioning Services

- Water for human use, harvestable resources, and cultivated foods are in higher demand than the system can supply, which is attributed to there being little natural wetland habitat remaining.

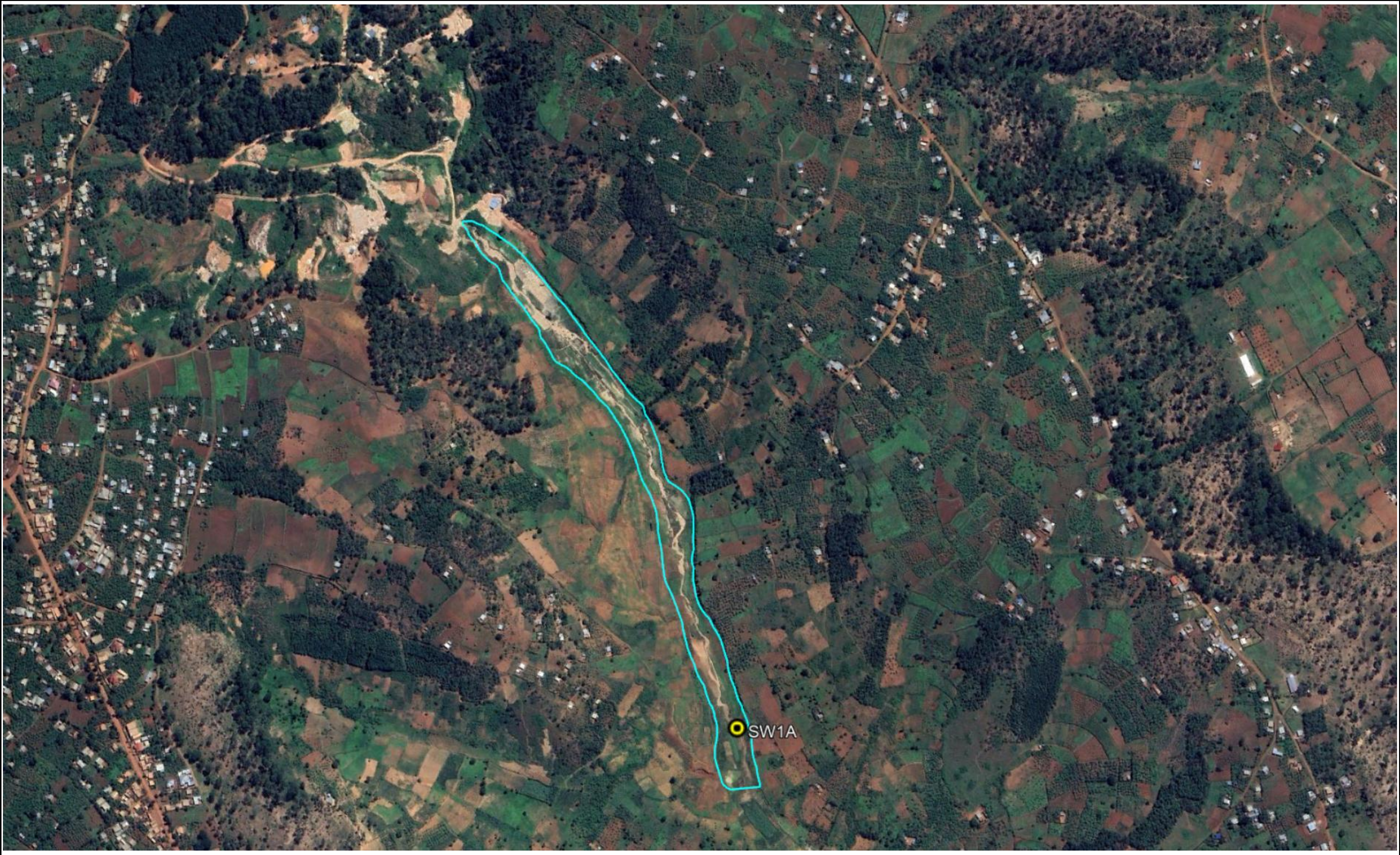
Cultural Services

- Cultural and spiritual values are rated moderate, however, the demand for these services is unknown.
- Tourism, recreation, education, and research are all rated very low.

5.2.4.1.3 *Ntunga 3*

Gishahi River downstream of Ntunga Mine			
Sample Date	17/11/2025	**Altitude**	1,590 m.a.s.l.
River	Gishahi	**Geomorphological zone**	Mountain Stream
Latitude	-1.966965	**Longitude**	30.365090

River reach overview: The site extends ~1,085 m downstream of Ntunga Mine before entering the channelled-valley bottom wetland system (Ntunga 1). The site includes the routine water sampling site SW1A.



Upstream	Downstream
	

Site assessments:

Water Quality

During the August and November 2023 assessments by Nepid Consulting (2024) water quality was confirmed as clear but slightly acidic (pH 6.2) with turbidity at 28 NTU. Water clarity was not measured during the November 2025 due to absence of flow. Shallow seepage water towards the lower end of the system was observed to be clear.

Water quality based on drinking/potable standards:

The Gishahi River generally has drinking water exceedances for manganese, ammonia, nickel, and mercury. Manganese above 0.08 mg/L causes black deposits in pipes, aesthetic complaints and is associated with neurotoxic effects at high chronic exposures; requires oxidation-filtration treatment (SANS 241:2015; WHO 2022). Ammonia in raw water indicates sewage or organic pollution; while not directly toxic at guideline levels, it reacts with chlorine to form chloramines, reducing disinfection efficacy (DWAF 1996, Vol. 1). Nickel exceedances above 0.02 mg/L present chronic health concerns including dermatitis and potential carcinogenicity; often associated with geogenic or industrial sources (SANS 241:2015; WHO 2022). Mercury above 0.001 mg/L poses severe neurological and renal risks; a potential indicator of industrial pollution requiring immediate remediation (SANS 241:2015).

Water quality based on aquatic ecology standards:

Lead is the only aquatic life exceedance recorded from the Gishahi River. Lead bioaccumulates in bone and soft tissues of fish; sublethal effects include behavioural changes and reproductive impairment, with cascading effects up the food web (DWAF 1996, Vol. 7).

Diatoms

River Health Class: **SERIOUSLY MODIFIED**	Benthic diatoms were not sampled during the November 2025 assessment due to absence of flow and limited sampling conditions. Diatoms were collected by Nepid Consulting (2024) but found to be absent, likely due to abrasion from suspended material, leading to a classification of seriously modified (Category E).

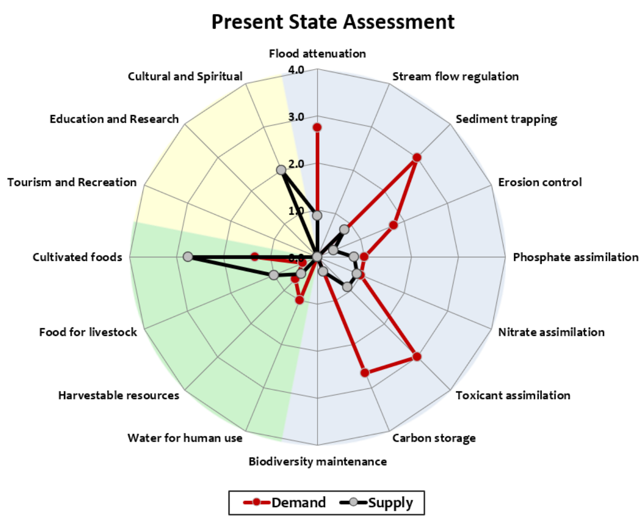
Macroinvertebrates

River Health Class: **SERIOUSLY MODIFIED**	Macroinvertebrates were assessed by Nepid Consulting (2024). The diversity of macroinvertebrate was found to be very low (only 5 taxa), and dominated by pollution-tolerant taxa such as midges (Chironomidae) and leeches (Hirudinea). Sensitive taxa were absent, and the river health based on macroinvertebrate PES was determined as seriously modified (Category E/f), reflecting severe ecological stress and indicating a system under heavy degradation from upstream mining-related impacts and adjacent agricultural practices.

Instream and Riparian Habitats

Instream Habitat Class: **POOR/SERIOUSLY MODIFIED**	Instream habitat condition was poor to seriously modified (score 40, Class D/E) mostly as a result of extensive bed and channel modification (very large to extreme impact), attributed to increased stormwater runoff and channel erosion and incision, as well as physico-chemical modification (very large impact) linked to upstream mining activities.
Riparian Habitat Class: **SERIOUSLY MODIFIED**	Riparian habitat condition seriously modified (score 35, Class E) due to vegetation removal (very large impact) from cultivation and establishment of croplands down the entire length of the valley bottom, followed by bank erosion (large impact) and channel modification (moderately large impact) due to increased runoff and erosion caused by land transformation. The ongoing disturbance to riparian areas also leads to altered instream habitats, flow regimes and fluvial processes, thereby severely reducing riverine functioning overall.

Riverine Ecosystem Services



Regulating and Supporting Services:

The river's ability to regulate floods, trap sediment, and control erosion is limited compared to the high demand, leaving downstream communities and their croplands within Ntunga 1 exposed and vulnerable. Pollution assimilation is exceptionally poor, placing further stress on water quality. Collectively, these services are important for soil fertility and reducing disaster risk, but catchment modification and degradation of the freshwater ecosystem has drastically compromised their effectiveness to deliver key ecosystem services.

Provisioning Services:

Water supply is in low demand very low supply, however, this has likely been compromised by the ecosystem functional shift and degradation, which has been further exacerbated by water quality impacts. Cultivated food provision is secondary but remains important for household subsistence.

Cultural Services:

	Cultural and spiritual values are of very low importance, with little demand. Tourism, recreation, and education are minimal, reflecting the diminished ecological integrity of the Gishahi River.

6. RECOMMENDATIONS AND CONCLUSION

The following section provides some recommendations that may be considered as part of Phase 2 of the project.

6.1 Recommendations

Based on the findings from the Source Pathway Receptor report (GroundTruth 2026b) and sediment report (GroundTruth, 2026c), remediation will be required in both the short and long term, with priority actions directed at controlling dust emissions, managing legacy tailings, preventing contaminated runoff and seepage, and restoring impacted river systems, which includes the management of sediments. In line with international best practice, interventions should emphasise pollution prevention at source before downstream treatment or discharge management. These findings provide a strong technical foundation for Trinity Metal's future Legacy Tailings Management and River Rehabilitation Programme, supporting targeted investment in practical measures that reduce risk, enhance water quality, and restore ecosystem function over time. A critical focus will also be the protection and restoration of the Gashahi River headwaters and associated groundwater feeder systems to ensure water security for downstream communities.

For legacy and abandoned mines, the pollution prevention hierarchy proposed by Novakowski *et al.* (2023), source control, water management, treatment, and finally discharge, provides a clear framework for action. Preliminary remediation opportunities for the Musha and Ntunga Mines are outlined in **Table 7-1** of the SPR report (GroundTruth 2026b) and should be further investigated during Phase 2 of the Legacy Tailings Management and River Rehabilitation Programme to confirm site-specific suitability and efficacy.

The management and operation of the tailings and waste must be managed through engineered designs, which aim to prevent the mobilisation of sediments and aggregates into the downstream freshwater ecosystems and/or the prevention of contaminated water being discharged and/or leaching into the adjacent freshwater ecosystems. Trinity Metals is currently looking at adopting some engineered designs/solutions to address some of these matters at some of their mines. However, to further support this initiative and encourage best-practice, and to be aligned with IFC Standard 6, additional nature-based solutions[9] should be considered.

To encourage more sustainable operations at the Musha and Ntunga mine sites, it is recommended that additional measures of prevention are considered are adopted beyond the mining footprint area i.e., that a more nature-based solution approach is adopted. Some considerations that could be adopted at either of the mine sites includes:

- Tailings and waste rock surface management:

[9] Nature-based solutions (NbS) are defined as actions that protect, conserve, restore, and sustainably manage natural or modified ecosystems to address social, economic, and environmental challenges, while simultaneously delivering benefits for human well-being, ecosystem services, resilience, and biodiversity (UNEP 2026).

  - Preventing contaminant mobilisation at source is the most effective strategy for protecting the downstream receiving environment. Additional measures that may be considered during the future planning and design of the mines includes:
    - Revegetation of tailings storage facilities using indigenous plant communities would provide long-term stability while reducing surface erosion, runoff volumes and velocities, and the mobilisation of sediments by wind and water.
    - Suitable design of waste rock dumps to mimic natural topography (where applicable). Incorporating this design approach from the outset can facilitate more effective and efficient rehabilitation during mine closure.
- Grey-green hybrid solutions
  - The adoption of purely nature-based solutions is often not feasible at mine sites due to the large volumes of water and other operational constraints that must be managed. As a result, hybrid approaches that combine engineered and nature-based solutions are often more practical and effective. Some of the grey-green infrastructure solutions that may be considered include:
    - Biofiltration systems could be incorporated into the future design of the mine to assist with further polishing of water discharged from the mine site. These systems use microorganisms that attach to substrates to remove the contaminates from the water column through biological processes, rather than relying on chemical additions, if applicable.
    - Vegetated drainage channels, such as swales and bioswales, can be used in place of concrete-lined channels to manage surface runoff more sustainably. By reducing the velocity of the flows, these systems reduce erosion and peak runoff while allowing sediments and some pollutants to settle out or be taken up by vegetation. In addition to improving water quality, vegetated channels also enhance site stability and integrate more naturally with the surrounding landscape.
    - Treatment trains for the polishing of the water column, may incorporate a series of interventions including an initial dosing area followed by passive reactive barriers prior to being discharged into a constructed wetland for further polishing. A multi-stage approach maximises treatment efficiency and provides greater operational resilience.
- Wetland habitat creation near mining sites
  - Constructed wetland/s may be established adjacent or downstream of the mining operations to manage site-derived contact water, trap sediments, and improve water quality prior to discharge with a more controlled flow release to help manage velocity and erosion downstream. These wetlands can also support local biodiversity and provide ecological buffering to downstream receiving environments.

  - Constructed wetlands can assist with polishing contaminated water through combining physical, chemical, and biological processes to reduce acidity, remove metals, and improve overall water quality[10].
  - Design enhancements, including targeted microbial inoculation, phytoremediation using selected macrophyte species, and the incorporation of controlled aerobic and anaerobic treatment zones, may be implemented to optimise treatment performance and further improve the efficacy of the system.
  - A treatment train may be considered and integrated as this approach allows for a modular and scalable design, allowing expansion to occur incrementally as site conditions evolve.
- Catchment rehabilitation and sustainable land-use practices
  - Launch pilot projects to integrate sustainable subsistence and small-scale agricultural practices, including soil conservation measures (e.g. contour farming, mulching, reduced tillage), agroforestry systems, and water-efficient cropping techniques. These practices aim to reduce soil loss, improve infiltration and soil structure, and limit sediment transport to downstream drainage systems, while maintaining or enhancing local livelihoods and food security.
  - The adoption of buffer areas and/or natural filter strips around freshwater ecosystems should be considered. These features function as important ecological infrastructure within the landscape, particularly for freshwater systems, as they assist in reducing sediment inputs, encouraging infiltration, reducing runoff velocities, and increasing soil moisture retention. These functions play a crucial role in reducing peak runoff generation and sediment yields, thereby improving the hydrological resilience of downstream river systems. As a result, the implementation of buffers/filter strips is widely recognised as a key element of nature-based solutions for broader, catchment-scale ecological restoration/rehabilitation.
  - Existing tools such as the WET-Sustainable Use guidelines (Kotze, 2010) provide a structured approach for assessing and guiding the ecological sustainability of agricultural activities within freshwater ecosystems, including cultivation, grazing, and vegetation harvesting. The tool evaluates sustainability based on land use types, the number of people dependent on these activities, and the intensity of use, while recognising the influence of social, economic, political, and environmental drivers. Without the promotion of sustainable use, wetlands are at risk of over-utilisation and degradation, leading to a decline in the goods and services they provide. The WET-Sustainable Use tool supports a holistic understanding of wetland condition and context, enabling site-specific, sustainable management decisions. In addition, the application of the “five-fingers” rule in subsistence agricultural settings offers a practical framework for promoting key soil and water conservation principles.

[10] It should be noted that constructed wetlands have limitations in their ability to improve water quality, which must be considered during design and application. In addition, the maintenance of the systems is crucial in maintaining their level of efficacy.

    - Incorporate Nature-based Solutions (NbS) to stabilise disturbed slopes, restore natural hydrological functioning and increase ecosystem resilience. Such measures may include strategic revegetation with indigenous species, establishment of riparian buffer zones, creation of vegetated infiltration areas, and installation of erosion control features such as live check structures and bio-engineering techniques.
- Community engagement and capacity building
    - Long-term environmental management and resilience of rehabilitated/restored/created systems is underpinned by active and structured community engagement, thereby ensuring that community members are meaningfully involved in any activities beyond the onsite operational activities.
    - Incorporating participatory monitoring and citizen science tools not only empowers communities but can further strengthen transparency and accountability while providing valuable supplementary data for adaptive management. By aligning rehabilitation activities with local livelihood needs and socio-economic priorities, this approach fosters community ownership, enhances long-term sustainability of interventions, and reduces the risk of post-closure land-use conflicts, thereby supporting both environmental outcomes and social resilience.
- Monitoring and adaptive management
    - Develop a comprehensive and robust monitoring framework to systematically assess the performance of the adopted mitigation measures within the mine, and mine-influenced areas.
    - Monitoring programmes should be tailored to the specific mitigation measures implemented at each mine site. Monitoring locations, sampling frequencies, and data parameters should be defined in accordance with the objectives and performance requirements of each mitigation activity.
    - However, ongoing monitoring of water quality parameters within key locations of the mine and within the downstream freshwater ecosystems is nonetheless crucial.
    - An adaptive management approach should be applied whereby monitoring data are periodically reviewed and used to evaluate the effectiveness of implemented interventions. Where performance criteria or trigger thresholds are not met, management actions should be refined through adjustment of design elements, operational practices, or maintenance regimes. This iterative process supports continuous improvement, enhances system resilience under changing climatic or operational conditions, and ensures that rehabilitation measures remain effective over the life of mine and into closure and post-closure phases.

6.2 Conclusion

The freshwater ecosystems within the Musha and Ntunga Concession areas have been significantly modified mainly as a result of long-standing subsistence agricultural practices that are vital to the communities dependent on the land. These activities, which form the basis of local livelihoods, have led to changes in both catchment-scale processes and in-system hydrology and geomorphology. Of the nine wetlands and riverine systems assessed, only two are directly influenced by mining-related activities, with the remaining systems reflecting broader catchment-wide transformation associated with agricultural land use.

Rehabilitation/restoration of the wetland habitats impacted by the mining activities is not considered feasible due to the reliance of the local communities on these systems. However, the adoption of sustainable land-use practices could be considered to prevent further degradation of the systems, thereby securing the ecosystem services that support local livelihoods.

To mitigate against the impacts on the downstream systems, the implementation of onsite grey-green infrastructure, nature-based solutions and/or modular treatment trains should be considered, where feasible. The adoption of such measures at, or directly downstream of, mining activities should be considered as it supports compliance with IFC Standard 6 but also reduces the impacts on the receiving environment and dependent communities.

Together, these interventions support more sustainable land and water management within the concession, better aligning human use with long-term environmental integrity.

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