Environmental and Social Incident Impact Assessment Report for the Tailings Dam Failure at Sino-Metals Leach Zambia Limited

Report prepared by:

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Environmental and Social Incident Impact Assessment and Recommendations for Remediation and Restoration measures regarding the Tailings Dam failure incident at Sino-Metals Leach Zambia Limited in Kalulushi District that led to the discharge of acidic leach residue into the surrounding open environment, the Chambishi Stream, Mwambashi and Kafue Rivers

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ABBREVIATIONS AND ACRONYMS USED

AOI	Area of Interest
AHPA	American Public Health Association
ASPT	Average Score Per Taxon
CBD	Convention on Biological Diversity
CBE	Citizens for a Better Environment
CCA	Canonical Correspondence Analysis
CEC	Cation Exchange Capacity
CM	Community Mapping
CNMC	China Nonferrous Metal Mining Group
CSPR	Civil Society for Poverty Reduction
DEM	Digital Elevation Model
EC	Electrical conductivity
EFZ	Evangelical Fellowship of Zambia
EIA	Environmental Impact Assessment
EMA	Environmental Management Act
EPT	Ephemeroptera, Plecoptera, Trichoptera (Mayfly, Stonefly, Caddisfly)
ERA	Ecological Risk Assessment
ESIIA	Environmental and Social Incident Impact Assessment
FAO	Food and Agriculture Organisation
FBI	Family Biotic Index
FGD	Focus Group Discussions
GGS	Green Growth Strategy
GPS	Global Positioning System
IBI	Index of Biotic Integrity
ICP	Induced Coupled Plasma
IUCN	International Union for Conservation of Nature
JCTR	Jesuit Centre for Theological Reflection
JICA	Japan International Cooperation Agency
KII	Key Informant Interviews
LSASD	Laboratory Services and Applied Science Division
LULC	Land Use/Land Cover
M&E	Monitoring and Evaluation
MIBC	Methyl Isobutyl Carbinol
MPL	Maximum Permissible Limit
MSD	Mines Safety Department
NDP	National Development Plan
NDVI	Normalised Difference Vegetation Index

NEP	National Energy Policy
NFCA	NFC Africa Mining PLC
NMDS	Non-Metric Multidimensional Scaling
NWASCO	National Water Supply and Sanitation Council
OEL	Occupational Exposure Limits
OM	Organic Matter
PCD	Pollution Control Dam
PO	Pine Oil
QA	Quality Assurance
QC	Quality Control
RDA	Redundancy Analysis
RFP	Request for proposals
RPA	Radiation Protection Authority
SADC	Southern African Development Community
SASS	South African Scoring System
SESDPROC	Environmental Sciences and Engineering Directorate's Standard Operating Procedures
Sino-Metals	Sino-Metals Leach Zambia Limited
SOP	Standard Operating Procedures
SSD	Species Sensitivity Distribution
SX-EW	Solvent Extraction and ElectroWinning
TD	Tailings Dam
TDS	Total Dissolved Solids
TIZ	Transparency International Zambia
TOR	Terms of Reference
TSF	Tailings Storage Facility
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
USEPA	United States Environmental Protection Agency
VOC	Volatile Organic Compound
WARMA	Water Resources Management Authority
WHO	World Health Organisation
ZAMCOM	Zambezi Watercourse Commission
ZCCM	Zambia Consolidated Copper Mines Limited
ZEMA	Zambia Environmental Management Agency
ZS	Zambian Standard

Chemical symbols used

B	Boron
Ca	Calcium
Cd	Cadmium
Cl	Chloride
CN^-	Cyanide
Co	Cobalt
Cr	Chromium
Cu	Copper
F	Fluorine
Fe	Iron
HCO_3^-	Bicarbonates
Hg	Mercury
K	Potassium
Mg	Magnesium
Mn	Manganese
Na	Sodium
Ni	Nickel
NO_3^-	Nitrates
Pb	Lead
PO_4^{3-}	Phosphates
Se	Selenium
SO_4^{2-}	Sulphates
U	Uranium
Zn	Zinc

Units of measurements used

ºC	Degrees Celsius
km	Kilometre
m	Metre
m^3	Cubic metre

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EXECUTIVE SUMMARY

INTRODUCTION

Background

On 18th February 2025, a breach occurred on one of the tailings dams belonging to Sino-Metals Leach Zambia Limited (Sino-Metals), known as Tailings Dam No. 15 (TD 15) located in the Chambishi area of Kalulushi District on the Copperbelt Province. The incident resulted in an uncontrolled release of acidic leach residue or tailings from the tailings dam into the open environment, flowing into Chambishi Stream, Mwambashi River and Kafue River. The tailings materials which escaped from TD 15 comprised a mixture of solids and liquid.

The Zambia Environmental Management Agency (ZEMA), relying on the provision of Section 107 of the Environmental Management Act No. 12 of 2011, engaged Applied Science and Technology Associates (Applied Science) of Kalulushi, as independent consultants, to conduct a comprehensive Environmental and Social Incident Impact Assessment (ESIIA) of the tailings discharge. ZEMA will use the findings of the study to inform appropriate mitigation, remediation and restoration measures to be undertaken by the Sino-Metals.

Objectives of the assignment

The overall objective of the Environmental and Social Incident Impact Assessment is to carry out a comprehensive evaluation of the environmental and socio-economic impacts resulting from the tailings spillage, and to propose appropriate mitigation, remediation, and restoration measures to support environmental recovery and safeguard affected communities. The three specific objectives were:

a. To assess the impacts of the tailings discharge on the biophysical environment, including water, soil, air quality, ecosystems, and biodiversity.
b. To assess the impacts of the tailings discharge on the socio-economic environment, with particular attention to livelihoods, health, social well-being, and community infrastructure.
c. To recommend appropriate mitigation, remediation, and restoration measures aimed at reducing risks, restoring affected areas, and supporting long-term environmental and social recovery.

Purpose of the Assignment

The purpose of this Environmental and Social Incident Impact Assessment is to determine the extent and significance of the impacts caused by the tailings spillage on both the natural and human environments, and to provide evidence-based guidance for effective mitigation, remediation, and restoration. The assessment aims to support informed decision-making by identifying the environmental and socio-economic consequences of the incident, establishing risks to ecosystems and communities, and recommending practical measures to restore affected areas and prevent similar incidents in the future.

Tailings Flow Path and Deposition

Following the breach of Tailings Dam No. 15 (TD 15), the released tailings flowed through the drainage channel into Tailings Dam No. 6 (TD 6)—designated as a Pollution Control Dam (PCD)—and the wetland area of WERNERS DAM (PCD). Solids from the tailings settled in TD 6, WERNERS DAM, and the upstream drainage channel.

Subsequently, the tailings from TD 6 and WERNERS DAM converged and entered a downstream wetland area known as NEW DAM (PCD), where further deposition of tailings solids occurred. Field inspections confirmed that no tailings solids were observed exiting beyond the Chambishi Stream.

NEW DAM serves as the official discharge point for the mining area which is considered to be the origin of the Chambishi Stream.

The liquid fraction of the tailings was discharged via the Chambishi Stream into the Mwambashi River and ultimately flowed into the Kafue River.

These acidic leachates (tailings) have caused impacts on the ecological service functions of the affected areas and surrounding ecosystems. Contaminated water bodies include the Chambishi Stream, the Mwambashi River, and the Kafue River.

METHODOLOGY

To achieve these objectives, an integrated, multi-media assessment was carried out along the Chambishi–Mwambashi–Kafue corridor.

Physico-chemical water quality data were collected at 512 surface-water points across 512 locations within five hydrological zones spanning from Chambishi to Itezhi-Tezhi, paired with 509 sediment samples. Composite river-water samples and augured bed sediments were analysed at Alfred H. Knight Laboratory in Kitwe for pH, electrical conductivity (EC), sulphates, major cations and trace metals, and evaluated against ZS 1182:2021 and related Zambian standards.

Groundwater was investigated through sampling and analysis of 44 shallow wells and one borehole in Kalulushi and Kitwe Districts, with 17 parameters compared against WHO drinking-water guidelines.

Soil contamination was mapped using 1,188 samples collected from 554 locations in potentially affected and control areas, with 17 parameters analysed, including key metals, sulphates, pH and EC.

Ecological effects were evaluated using 95 samples from 35 sites, covering water, sediment and riparian soils, macroinvertebrates (SASS5), riparian vegetation surveys, and Sentinel-2 NDVI validated by RTK-drone imagery. These datasets were interpreted against WHO/FAO benchmarks, ZEMA/WARMA criteria and upstream reference conditions.

Agronomic impacts were assessed using 135 agricultural soil samples collected at 124 locations and 139 crop samples from 55 locations. A stratified survey of tops oils (0–20 cm) and crop tissues was carried out, linked to visual crop-stress diagnostics and farmer questionnaires, following FAO/UNEP/ZEMA guidance.

Air quality in Kalusale Ward was screened using 11 field multi-gas readings and 11 acid-mist samples collected at 11 locations, benchmarked against ZEMA and international exposure limits.

Socio-economic data collection followed a dual approach. Secondary data collection involved the review of incident description reports, applicable legislation, the MOA compensation report, regulatory orders (ZEMA, MSD, WARMA) and SMLZ internal policies and procedures. Primary data collection was undertaken through site visits by a team of socio-economic experts, including interviews with SMLZ employees, local farmers and residents.

Fisheries effects were assessed using a rapid fisheries assessment in the Kafue River system, combining fishery-independent sampling (multi-meshed gillnets, traps and handlines across habitats, day/night) with fishery-dependent data (landed-catch assessment and fisher interviews). Fish were identified and measured, with reproductive indicators (maturity, L50) recorded, and selected species analysed for heavy metal bioaccumulation. Data were used to evaluate post-incident stock condition and potential human health risk. The livestock assessment was conducted using one health approach by incorporating animal health, human health, and the environment. The procedure included the collection of relevant data from Government ministries and agencies and conducting key informant interviews in the affected areas.

KEY FINDINGS

a. Tailings Characteristics

a) Liquor from TD 15 paddocks exhibited strong acidity (mean pH 2.42) and very high total dissolved solids (TDS) (mean ~13,700 mg/L) and electrical conductivity (EC) (27,500 µS/cm).

b) Solid tailings were less acidic (mean pH ~4.95) with lower TDS and EC but still represented an acidic residue capable of leaching metals.

c) Geochemical assays (liquor + solids) showed a dominance sequence by magnitude: sulphates > Mg > Cu > Ca > Al > Mn > K > Co > Zn > phosphates > Na.

d) Several constituents (e.g. sulphate, Cu, Co, Mn and certain trace metals) were identified as parameters of concern requiring ongoing monitoring and control.

b. Surface Water and Sediment

A common feature across all three catchments is the non-detection of highly toxic metals such as arsenic (As), cadmium (Cd), chromium (Cr), and lead (Pb) in the water. The water in Chambishi Stream and Mwambashi River exhibited elevated electrical conductivity and sulphates exceeding the Zambian Ambient Water Quality Standards. The Kafue River, on the other hand, exhibited elevated EC and sulphates in the Kitwe area and Mumbwa area.

Kafue River sediments generally show hot spots of heavy metal contamination arising from multiple sources including historical mining activities and runoff from mineral rich areas.

Along the main watercourse from Chambishi Stream through the Mwambashi River to the Kafue River, pH levels generally comply with AWQS (ZS 1182:2021).

New Dam discharge to Chambishi Stream:

The PH between 2021 and mid-2024 ranged from 6.61 to 8.29 (mean 7.64); the October 2025 pH of 8.33 is comparable to this baseline.

EC and sulphate concentrations in 2025 are below historical averages and show a downward trend.

Although the effluent was being dosed with sodium hydroxide at the time of sampling, overall data indicate no long-term deterioration in key indicators.

Chambishi Stream and Mwambashi River:

Present-day pH is neutral to slightly alkaline; EC and sulphates are elevated indicating contamination of groundwater recharging the stream from tailings deposited in Werner's Dam.

Analysis of key indicators (pH, EC/TDS, sulphates) suggests that the TD 15 spill has not caused a persistent, long-term exceedance beyond pre-incident conditions.

Kafue River:

Compared with ZS 1182: 2021 guideline values for the Kafue catchment, sulphates exceed guidelines at certain downstream sections; calcium is above guideline values along the entire reach, and magnesium exceeds the guideline at most of the downstream sections.

Copper concentrations along the Kafue River remain well below the AWQS limit.

Cobalt distribution in the Kafue River exhibits pronounced spatial variability. Except for a peak concentration of 0.906 mg/L measured approximately 10 km downstream of the confluence with the Mwambashi River, cobalt concentrations in the majority of the catchment were below the detection limit.

From the monitoring point 52.5 km downstream of TD 15 onward, manganese concentrations have consistently stayed below the AWQS limit of 0.2 mg/L.

Longitudinal profiles show a classic point-source pattern:

A core pollution zone where metals peak near a discharge or confluence (e.g. K016 area).

Rapid downstream attenuation due to dilution and mixing, followed by relative stabilisation.

Cumulative Impacts and Other Mining Sources

The Mwambashi–Kafue system receives inputs from numerous historical and current mining and mineral processing facilities, including multiple tailings dams, pollution control dams, waste rock dumps and processing plants operated by several companies. Mapping of TDS and sulphates confirms that downstream deterioration of Kafue River water quality is driven by multiple sources rather than a single incident. These sources include Musakashi stream, Lukoshi stream, Mwambashi River, Mindolo stream, Kitwe stream, and Uchi Stream.

Short-Term vs Long-Term Effects

Short-term: Historical monitoring conducted immediately after the breach shows pronounced low pH and elevated sulphates/metals in all three rivers, interruption of municipal water supply, and ecological and livelihood disruptions.

Medium to long-term (about eight months post-incident): Present data indicate that key water quality indicators in Chambishi Stream, Mwambashi River and the Kafue River have largely returned to pre-incident ranges. Current water quality issues are dominated by long-standing regional mining pressures rather than continued effects of the single spill.

Sediment Quality and Source Signatures

Calcium and magnesium show exceptionally high concentrations, far exceeding natural background expectations, consistent with inputs from tailings, lime application and industrial effluents.

Copper displays strong spatial variability and acts as a tracer of non-ferrous metal mining.

Manganese shows local peaks (e.g. at specific downstream stations), suggesting either secondary sources or geochemical remobilisation.

c. Groundwater

The analytical results do not indicate contamination of the shallow wells from tailings flow through transport of pollutants in groundwater.

The pH of ground water was low, ranging between 4.49 and 7.33 and a mean of 5.80. No significant differences were observed between the various investigation areas, which is preliminarily attributed to the nature of the local soils.

The concentration of metals was low with the significant results being cobalt and manganese, but no significant differences were found between the different investigation areas.

Sulphates in shallow wells showed significant variations across the study area. The concentration of sulphates in Bulangililo, Ipusukilo, Chipata and Luangwa was high but was below detection limit at Mwambashi and downstream wells at Kalusale. The high concentration of sulphates in the township may be attributed to sewage leachate from pit latrines, septic tanks and soak aways.

A cluster of shallow wells close to TD 6 showed contamination indicated by elevated electrical conductivity and sulphates. The contamination is most likely a result of leachate from TD 6 or the nearby Werner's Dam.

Analysis of groundwater elevations in the shallow wells shows that the overall flow direction of groundwater is in a southeasterly direction, following Chambishi Stream. In this regard, TD 6 is upstream while Mwambashi River is downstream. There is also a second, localised groundwater flow direction which discharges into Chambishi Stream from either side. This implies that pollutants cannot travel from Chambishi Stream and contaminate the shallow wells as the latter are upstream.

Potential contamination of groundwater is indicated by the quality of water in Chambishi Stream. The groundwater daylighting in Chambishi Stream from Werner's Dam was characterised by elevated EC and sulphates.

d. Soil

Soil pH Characteristics

Soils within the assessed area, including both subsoil and topsoil, are predominantly acidic, with pH values typically ranging between 5.0 and 6.0.

Heavy Metal Exceedance

The concentrations of copper and cobalt in soils regularly exceeded the guideline limits established by the Food and Agriculture Organization/World Health Organization (FAO/WHO).

Spatial Distribution Pattern of Pollutants

The concentrations of major heavy metals (such as Cu, Co, Pb, As, Mn, Cd, Zn) and sulphate ions (SO_4^{2-}) display an 'N'-shaped spatial trend along the watercourse from TD 15 to the Chambishi Stream, the Mwambashi River, and the Kafue River: increasing from TD 15 to the Chambishi Stream, decreasing toward the Mwambashi River, and rising again at the Kafue River.

Pollution Characteristics of the Chambishi Stream Sub-catchment

Soil concentrations of Co, Cu, and Mn in the Chambishi Stream Sub-catchment are significantly elevated, indicating a direct link to contamination originating from upstream and surrounding mining activities. The contribution from long-term metal accumulation through aeolian and hydraulic erosion, likely associated with the region's well-developed Cu mineralization, should also be considered.

Pollution Status in the Mwambashi River Catchment

Although Cu concentrations in the Mwambashi River catchment are elevated compared to background levels, they remain lower than those observed in the Chambishi Stream Sub-catchment and the areas adjacent to TD 15. These Cu levels are comparable to those in surface and subsurface soils of control samples. For other elements, Co and Ni exceed threshold limits but are detected only in a few localized sites.

Pollution Features along the Kafue River Section

Along the Kafue River section, exceedances of Cd, Co, Cu, Pb, and Mn have increased relative to the surrounding Mwambashi River catchment, suggesting that additional pollution sources.

Radiological Monitoring Results

No localized hotspots indicating elevated radioactivity were identified in the TD 15 area. Neutron dose rates at all monitoring points were below the detection limit, confirming the absence of neutron-emitting sources within the assessed zone.

e. Ecological Impacts

a) Severe, localized impacts persist in the up Chambishi Stream, with sediment Cu up to 1,240 mg/kg and vegetation Cu 42.4 ppm.

b) Moderate disruption in the Mwambashi River, including reduced macroinvertebrate diversity (ASPT = 4.8), chlorotic riparian vegetation, and episodic metal remobilization during flow events, shows early recovery, likely aided by emergency liming.

c) Negligible impact downstream in the Kafue River, confirming the Lukanga Swamps as a critical natural filter.

While emergency liming and operational suspension have mitigated acute water toxicity, persistent metal enrichment in sediments and biota continues to pose ecological risks. Vegetation chlorosis indicates ongoing stress.

This report integrates field data, laboratory results, remote sensing, and community observations into a diagnostic framework for recovery. It concludes that natural recovery is underway but fragile, requiring targeted intervention to secure long-term ecosystem resilience.

f. Agronomy

The agronomic assessment stratified fields into high-impact (Chambishi floodplain), medium-impact (Mwambashi), low-impact (Kafue) and control zones, and combined soil and plant tissue analyses with farmer interviews.

High-impact fields experienced direct deposition of tailings and lime, crop destruction, and visible stress symptoms (chlorosis, stunting).

Trace and heavy metals (Cu, Co, Pb, Zn, Cd, As, Se, Mn, Fe, Al) were measured in soils and plant tissues to assess crop uptake of the trace and heavy metals.

While detailed quantitative risk characterisation is presented in the main report, overall results indicate:

Elevated metals in soils in high-impact areas, including some medium impact areas, with potential for crop uptake if farming resumes without remediation;

Lower but non-negligible risk in medium and low-impact zones, particularly where irrigation water is drawn from contaminated reaches;

A need for controlled land use and phased soil remediation before normal crop production resumes in the most affected fields.

g. Air Quality

Acid mist and gas sampling at eleven sites in Kalusale Ward showed only trace concentrations of CO, SO_2, CH_4, and H_2S.

Acid mist levels were below international Occupational Exposure Limits (OELs) and ZEMA guidelines.

The reported odours and discomfort immediately after the incident do not correspond to persistent or chronic gaseous pollution; no ongoing air quality risk was detected.

h. Social Economy

In terms of demographic information, Kalulushi District is said to have a total population of 170,701 of which 84,195 are males and 86,502 are females with a population density of 164.5 individuals per km2. Kitwe on the other hand has a population of 661,901 of which 321,654 are males and 340,247 are females with a population density of 814.6 individuals per km2.

The main economic activities for the two districts are mining, forestry, and agriculture. Mining is the dominant sector, with companies focused on copper and cobalt extraction. The forestry sector involves timber trading and wood processing, which supplies raw materials to the mining industry and other businesses like ZESCO. Agriculture also plays a key role, alongside small to medium-sized activities such as small-scale mining, retail, and various informal businesses. The two economies are among the strongest on the Copperbelt due to huge investment in the mining sector and one of the highest contributors in terms of the Gross Domestic Product (GDP) and employment.

In terms of community infrastructure, the Kalulushi District has a total of twenty-four (24) Health Facilities that offer Primary Health Care services, and one (1) general hospital, namely Kalulushi General Hospital, which is the second level referral hospital, and cases requiring more specialist attention are referred to Kitwe Teaching Hospital (KTH).

There is a total of 77 health facilities in Kitwe District of which 45 are run by the Government of the Republic of Zambia (GRZ) including Kitwe Teaching Hospital and 33 by private health facilities which include 3 hospitals namely; Sino-Zam, Progress Hospital and Wusakile mine hospitals. The district has 15 government health facilities which are delivery centers.

In terms of road infrastructure, the two districts are connected by the Kitwe – Kalulushi road (M7) and the Kalulushi – Sabina Road (M16). The major economic road in the area is the Kitwe – Chingola Dual carriage way (T3) which connects Kitwe to Chingola. It is the same road used to access the SMLZ plant at the Chambishi site.

There are two administrative systems in the two districts, and these are the central government system and the local authority system. The two towns have mining activity as the main source of income.

Just like in all districts in Zambia, the Central Administration is composed of all government departments and is headed by the District Commissioner. Heads of departments in line government ministries based in the district, report, on administrative matters to the District Commissioner and technical or professional matters directly to the Provincial Heads. The mayor represents the people and his main role is to preside over council meetings. The councillor is a channel of communication on social and economic issues between the local authority and the communities he represents. The Town Clerk heads the administrative wing of the council.

Copperbelt Province in general has good telecommunication infrastructure. Communication companies ZAMTEL, Airtel and MTN provide cellular and Internet services. These facilities are widely accessed in the province. The residents also have access to the national TV station ZNBC and the DSTV network.

The livestock owners and fishermen, subsistence and rural farmers, local residents and household owners are considered to be the most affected group of individuals. The vulnerability status was being exacerbated if the individuals involved are aged, children, pregnant women, disabled, have limited educational background and those with unfavourable economic status.

Total population and affected persons - The total headcount of individuals with some form of presence or claim in the zone is 334. Of these, a total of 158 individuals is considered directly affected and vulnerable to displacement as they are resident within the pollution control zone of the mine.

Composition and categories of occupants - The remaining 189 individuals represent a complex mix of stakeholders with varying land interests, categorized as follows:

- Tenant Farmers- these individuals rent farming fields for agriculture purposes
- Absentee owners- Individuals who claim ownership but do not reside on the land. The majority of these reside in Chambishi township.
- Purchasers- those who claim to have purchased land from unauthorized sellers. These claim to have bought farmland from parties who did not have legal title or proof of ownership for the land.
- Seasonal occupants- Individuals who erect temporary structures only during farming and harvesting periods.
- Aspiring registrants- Tenant farmers seeking to formalize their tenure but facing difficulties due to ambiguous ownership.

Impact of the incident: The collapse of the section of the dam wall at Sino Metals Leach Zambia Limited on 18th February 2025 which led to flooded and burned crops has significantly altered the population dynamics;
Despite illegally residing in the Mine area, the residents affected by the spill were paid compensation for the damaged crops. The compensation acted as an incentive; however, this has led to the return of farmers who had initially abandoned their fields.

This event has contributed to a renewed and increased interest in occupying land within the zone, further complicating the settlement picture.

i. Fisheries and livestock

Fisheries

Currently, the fisheries of the Kafue River ecosystem are threatened by high recruitment overfishing that has resulted from increased fishing pressure, water pollution and low abidance to fisheries regulations. The fisheries results in the Kafue River system, were recovering with potential for stability of the fish populations. Generally, fish exhibited unstable growth status in response to their environment, with the studied population indicating positivity towards recovery because over 98% of the fish studied were mature and breeding. After an ecological disturbance, such as the acid spill with mortality impacts and alteration of the habitat quality, breeding potential of recolonising cohorts indicates positivity towards recovery. However, the current breeding population comprises mainly younger individuals, an indication of a rather weak but recovering stock. Selected heavy metals profiled on the fish were within acceptable limits and pose no serious threat to human health, however subject to calculation of family/ species-specific bioaccumulation factors. It was concluded that with consolidated management action, the fishery has potential to bounce back.

Livestock

The study did not identify any large-scale livestock mortalities or significant production losses, indicating that the affected areas still hold strong potential for livestock development. Blood sample analyses conducted by MFL in October 2025 showed contaminant levels well below the Codex Maximum Limits and relevant safety thresholds, further confirming the low short-term risk associated with this incident.

RECOMMENDATIONS

The ESIIA proposes a package of mutually reinforcing measures, grouped into technical, social, and institutional actions.

a. Remediation and Restoration of the Physical Environment

- Stabilisation and Closure of TSF

Complete structural stabilisation and closure of decommissioned TSF, including stormwater management, catch drains, engineered spillways, internal drainage, and surface armouring to prevent overtopping and erosion.

Implement a long-term vegetation and erosion control programme on closed paddocks.

- Catchment-Scale Remediation

Construct catch drains downstream of TD 15 to intercept tailings-laden runoff and prevent further transport of sediments to Chambishi Stream.

Install and maintain silt traps along major drains and at specified points between Chambishi Metals and Chambishi Stream, and along Chambishi and Mwambashi channels.

Implement mechanical removal of significant tailings deposits at high-priority sites along Chambishi Stream and sections of Mwambashi River, prioritising zones of direct community use, spawning grounds, and irrigation abstractions.

Desludge thick deposits of lime sludge in Chambishi Stream and manage removed material as a controlled waste within engineered facilities.

- Soil Rehabilitation and Phased Phytoremediation

Based on the key findings, it is recommended to develop a comprehensive restoration plan implementing a three-phase approach to rehabilitate the affected areas as follows:

Phase One focuses on soil amendment through the application of agricultural lime, with rates based on the official clean up and remediation plan from the ESIIA. Lime will be mechanically incorporated in accessible areas and distributed to farmers for manual application in sensitive riverside zones. This phase also introduces long-term phytoremediation by planting trees like Miombo and Acacia near the tailings dam.

Phase Two involves short-term phytoremediation, where farmers will grow metal-absorbing crops such as Vetiver grass and sunflowers on at least 40% of the land. After maturity, these plants will be harvested and safely disposed of to prevent contaminants from re-entering the ecosystem.

Phase Three serves as a contingency measure, to be implemented only if residual heavy metals persist after the first two phases. It proposes using organic acids to immobilize remaining contaminants or potentially repeating lime application in a moderated manner, ensuring complete environmental restoration.

Routine ambient gamma radiation monitoring at all active and rehabilitated tailings facilities. Complete gamma spectrometry analyses to establish a radiological baseline for future comparison. Periodic pH and water quality assessments at nearby surface and groundwater points to track possible leachate migration. Strengthening site containment and rehabilitation monitoring to prevent environmental dispersion of contaminated materials. Integrating the findings into the Environmental Radioactivity Surveillance Program for consistent oversight of industrial mining operations in the Copperbelt region.

- Ecological Rehabilitation

Restore riparian buffers with indigenous tree and shrub species, including Miombo and Acacia, particularly near TD 15 and along heavily impacted stretches of Chambishi Stream.

Integrate phytoremediation with habitat restoration, using plant species that both stabilize banks and absorb metals.

b. Source Control and TSF Management

Review and upgrade the design, operation and emergency preparedness of all Sino-Metals tailings storage facilities to align with international best practice (e.g. continuous monitoring of pond levels, freeboard, seepage control, and independent audits).

Strengthen management and monitoring of TD 6 and Werner's , including installation of groundwater monitoring boreholes and surface water sampling upstream and downstream.

Enforce zero uncontrolled discharge from tailings facilities, with explicit trigger levels and automatic shutdown/containment protocols.

c. Monitoring, Early Warning and Knowledge Management

Establish a long-term monitoring programme for surface water, groundwater, soil, sediment, biota and air, with clearly defined indicators, frequencies, and responsibilities (ZEMA, WARMA, MSD, NWASCO, DoF, etc.). Prioritise routine monitoring at:

- Chambishi Stream, Mwambashi River and critical Kafue locations;
- Nkana Water intakes and other water utility abstractions;
- High-impact agricultural zones and core contaminated soils.
- Develop and implement an early-warning system for water utilities and communities, triggered by upstream exceedances of key pollutants (e.g. Mn, Cu, Co, sulphates, pH).
- Integrate monitoring data into a shared, geo-referenced database accessible to relevant agencies and used to periodically update risk maps.

d. Community Health, Livelihoods and Resettlement

Maintain precautionary restrictions on the use of shallow wells for drinking water in the affected area and promote safer alternative supplies (e.g. boreholes, treated piped water, communal taps).

In collaboration with the Ministry of Health, implement ongoing health surveillance for affected communities, using clinical data and environmental exposure information.

Provide targeted support to affected farmers, including:

- Compensation and/or livelihood restoration packages;
- Provision of lime and seeds for phytoremediation crops;
- Technical guidance on safe land use and agricultural practices during remediation.

The residents who have permanently settled in the pollution control zone of the Mine need to be resettled to a safer non-mining area urgently in line with national resettlement policy and international safeguards. Addressing this issue requires a nuanced, transparent and lawful approach that prioritizes verification, dialogue and the development of a clear equitable path forward for all affected parties.

Strengthen risk communication and community engagement, with particular attention to vulnerable groups (women, children, low-income households), ensuring clear messages on water use, fish consumption, and farming practices.

e. Governance, Capacity and Legal Compliance

Clarify and strengthen institutional mandates and coordination among ZEMA, WARMA, MSD, NWASCO, local authorities and other agencies for incident prevention, response and enforcement.

Develop national guidelines for mining-related environmental emergencies, including roles, communication protocols, and minimum response standards.

Use the polluter pays principle and existing instruments (e.g. Environmental Protection Fund, Mines and Minerals (Environmental Protection Fund) Regulations) to ensure that Sino-Metals and other responsible parties finance agreed remediation and restoration measures.

Enhance enforcement of existing legislation (EMA, Water Resources Management Act, Mines and Minerals, Fisheries, Public Health, Standards laws), including timely sanctions for non-compliance and regular inspections.

Invest in capacity building (staff, laboratories, monitoring equipment, modelling tools) for key regulatory and technical institutions, and promote collaboration with universities and research institutes for ongoing studies in the Kafue basin.

CONCLUSION

The TD 15 tailings dam breach at Sino-Metals Leach Zambia Limited has been found to be a relatively significant negative impact on surface water, soils, ecosystems and livelihoods in the Chambishi and Mwambashi catchments.

While the acute phase of the incident has passed and air quality and broad-scale ecological conditions in the Kafue River remain within acceptable bounds, the ESIIA demonstrates that:

a. Acidic, sulphate-rich tailings from TD 15 had relatively significant impact on water quality in Chambishi Stream and Mwambashi River and disrupted municipal water supply;
b. A core area of approximately 5.35 km² exhibits elevated heavy metals in soil, with associated ecological impairment and agronomic risks;
c. Groundwater used by communities is already vulnerable due to existing sanitation and historical mining activities, and shallow wells are not safe as sources of potable water;
d. The incident occurred within a context of adequate law on paper but weak implementation, highlighting systemic gaps in TSF management, enforcement, and emergency preparedness.
e. The squatting situation within the Sino Metals pollution control zone in Kalusale is multi-faceted and dynamic. The population of 338 is not homogeneous but comprises resident squatters. A variety of agricultural tenants and individuals entangled in informal and illegal land markets. The dam failure and compensation process have further complicated the scenario.

If the recommended remediation, monitoring, and governance measures are implemented in full and in a timely manner, there is a realistic prospect of restoring environmental quality, reducing long-term health and livelihood risks, and strengthening the resilience of both ecosystems and communities in the affected corridor.

This ESIIA therefore provides a technical and institutional roadmap for ZEMA, Sino-Metals and other stakeholders to move from emergency response to structured, accountable, and sustainable recovery and to ensure that similar incidents are less likely to occur in future.

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1 INTRODUCTION

1.1 Background of Sino-Metals Leach Zambia Limited

Sino-Metals Leach Zambia Limited is described as China's first large-scale copper hydrometallurgy operation abroad. Because of its leaching and solvent extraction technology, Sino-Metals can process lower-grade ore, mixed ore, and even tailings, which many traditional smelters may not handle efficiently. Its presence is part of broader China–Zambia economic cooperation. The company often cites "common development" and "shared benefits" in its corporate narrative.

1.1.1 Company details

Sino-Metals Leach Zambia Limited (sometimes called Sino-Metals) is a subsidiary of China Nonferrous Metal Mining Group (CNMC). The ownership breakdown is 55% CNMC; 30% Hong Kong Zhongfei Mining Ltd and 15% NFC Africa Mining PLC. The company was established and registered in Zambia in 2004.

1.1.2 Location

Sino-Metals is located in Chambishi, under the Kitwe District of the Copperbelt Province of Zambia, in the Zambia-China Economic and Trade Cooperation Zone.

1.1.3 Mining and mineral processing

Sino-Metals has a mining and mineral processing operation divided into two specific operations, which are Milling and Flotation. These processes turn low grade rock, often <1% Cu, into a high-grade concentrate reaching in the range 20 – 40% Cu, that can be smelted. Below is a brief process layout of Milling and Flotation.

Milling: This is the mechanical process of reducing the mined ore to fine particles to allow for the copper-bearing minerals liberated from the surrounding rock. There are two processes under Milling, aimed at reducing the copper ore to fine particles ready for flotation, and these are Crushing and Grinding.

Crushing: This involves the use of primary crusher to break large rocks into smaller pieces, usually in the range 10–20 cm. The second stage of crushing involves the use of a secondary crusher where the ore particles from the primary crusher are further reduced to a few millimeters.

Grinding: Under this process, the crushed ore from the secondary crusher is mixed with industrial water to form a pulp and channeled into the grinding circuit, where ball mills are used to grind the pulp into finer material of particle size between 100-200 microns and ensuring it's a slurry of typically 30 to 50% solids before pumping it to the flotation circuit.

Flotation: It is at the flotation circuit, where valuable copper minerals are separated from worthless minerals by exploiting differences in surface hydrophobicity. To achieve this, various chemical reagents are added to modify surface properties. The reagents added at Sino-Metals Concentrator, are as follows;

1. Xanthates (collectors) which make copper mineral surfaces hydrophobic.
2. MIBC (frothers) which create stable bubbles.
3. Depressants which prevent unwanted minerals from floating
4. Lime used as a pH modifier to control the chemistry.

The conditioned slurry is pumped to the flotation cells where air is injected to create bubbles. Hydrophobic copper minerals get attached to the bubbles and when these bubbles rise with the copper, they form a froth layer which is now rich in copper minerals. The froth is then skimmed off (now called concentrate). This is passed through several cleaner flotation stages to increase the copper grade, and thereafter it is pumped to the Filter Plant for dewatering.

At the dewatering stage, the concentrate is thickened and finally filtered to make a concentrate cake of about 8 to 12% moisture. This material is now ready for smelting and therefore transported to the Smelter for copper production

During the flotation process, where copper attaches itself to the bubbles of the conditioned slurry, the waste material, commonly known as tailings, which still contain some amount of copper, is pumped to the Leach Plant.

1.1.4 Hydrometallurgical processing

Copper leaching from concentrator tailings is an increasingly important hydrometallurgical route, especially as global ore grades decline and significant amounts of copper remain in tailings after flotation. Below is a structured discussion covering the chemistry involved, process options, design considerations, and challenges.

At Sino-Metals, the concentrator tailings often contain 0.1 to 0.5% Cu, which could not be picked by the flotation process. Flotation generally fails to recover copper from oxide copper minerals, secondary sulphides and fine or locked primary sulphides. To achieve recovery of copper from these minerals, leaching with acid is one major alternative. Leaching allows recovery of this residual copper while extending resource utilization, reducing environmental liability and, of course, generating additional revenue for the company and the country at large.

Sulfuric acid leaching is the most widely used hydrometallurgical method for extracting copper from residual copper in tailings. Sino-Metals is using the same technology on the tailings from the flotation section. This approach relies on dissolving copper minerals into an acidic aqueous solution, producing a copper-rich leach liquor suitable for solvent extraction and electrowinning (SX–EW).

The tailings from the flotation circuit at Sino-Metals Concentrator, contains readily leachable oxides, a larger percentage of which is Malachite (Cu2CO3(OH)2). The components that are generated from this leaching process, other than copper ions, are sulphates, carbon dioxide and water, expressed in the chemical formula presented below:

$$Cu_2\,(OH)_2CO_3 + 2H_2SO_4 \rightarrow 2Cu^{2+} + 2SO_4^{2-} + CO_2 + 3H_2O$$

This method produces at least 99.9% pure cathode copper. Leach residue from this process is then pumped to the tailings dam, called TD 15. However, even after most copper is leached, the solid residue still contains entrained acidic leach solution inside the pores and capillaries. Additionally, there is always a thin film of acid that remains adhering to particle surfaces. Therefore, typical tailings leach solution pumped to TD 15 is at pH<3, meaning, even the small amounts of trapped liquid keep the residue acidic.

1.1.5 Sulphate ions accumulation in tailings leach residue

When Cu^{2+} is electrolytically plated as metallic copper, sulphate ions (SO_4^{2-}) do not participate in the electrode reaction. They therefore remain in the electrolyte. This means after copper is removed, the sulphate ions stay in the solution, including some free H_2SO_4. This is the tailings leach residue which is deposited at TD 15. The TD 15 is designed to hold the tailings leach residue for recycling purposes. It is therefore a closed circuit. No tailings are discharged into the surrounding open environment.

At TD 15, some sulphates may react with minerals present there, to form sulphate-bearing solids while some remain dissolved in the tailings leach material. When the tailings leach residue is recycled back to the electrowinning section, it will typically be a sulphate rich material. Sulphuric acid is added to it to strengthen the leach solution and further extract the copper ions into solution. After electrowinning/copper plating of the target mineral to the cathode, sulphate ions remain in solution and report to TD 15. Every cycle therefore brings about an accumulation of sulphates at TD 15.

1.2 Description of the incident

1.2.1 Tailings discharge

On 18 February 2025, a breach occurred in the Tailings Storage Facility known as TD 15 at Sino-Metals in the Chambishi area of Kalulushi District. The breach resulted in an uncontrolled discharge of an estimated 50,000 cubic meters of acidic leach residue or tailings to the open environment affecting Chambishi Stream, Mwambashi River and Kafue River1.

A portion of the tailings discharged from TD 15 settled in the area between the TD 15 and Chambishi Stream. This region encompasses Tailings Dam No. 6 (TD 6), originally constructed by Zambia Consolidated Copper Mines Limited (ZCCM) and currently licensed to NFC Africa Mining PLC (NFCA) as a Pollution Control Dam (PCD). Another notable site where tailings sedimented is known locally as Werner's Dam, which likely was a wetland before becoming infilled with tailings from historical deposition activities. Before Sino-Metals Leach Zambia existed, these two locations served as sedimentation points where significant amounts of tailings materials were deposited, and are currently being referred to as historical deposition.

Regarding the February 18th incident, the acidic leach residue or tailings, after traversing through TD 6 and Werner's Dam, merged and entered a wetland known as New Dam where more tailings sedimented. The excess tailings moved downstream from the New Dam into the Chambishi Stream, entered the Mwambashi River and eventually the Kafue River.

The discharged acidic leach residue or tailings caused considerable negative impact on the ecosystem services along and around the impacted corridor. Some of the visible ecosystem services impacted upon include freshwater, fish, crops, nutrient cycling and habitats for species. The surface waterbodies impacted are Chambishi Stream, Mwambashi River and the Kafue River.

1.2.2 Materials

The materials involved were the tailings stored at Tailings Dam No. 15. This is a byproduct of the Concentrator and Electrowinning process. The copper ore as raw material is crushed at the Crushing Plant and milled at the Milling Plant from which the end product, the conditioned slurry, is then pumped to the flotation cells where air is injected to create bubbles. Hydrophobic copper minerals get attached to the bubbles and when these bubbles rise with the copper, they form a froth layer which is now rich in copper minerals. The froth is then skimmed off (now called concentrate).

[1] ZEMA, REQUEST FOR PROPOSALS RFP No.: RFP- ZEMA/RFP/CS/21/08/2025

This is passed through several cleaner flotation stages to increase the copper grade, and thereafter it is pumped to the Filter Plant for dewatering. The byproduct from this section is what is commonly known as the tailings. The tailings material is further processed to recover more copper, at the Electrowinning Plant. Sulphuric Acid is added to leach more copper from the tailings, and the solution (Copper Sulphate) is pumped to the Electrowinning Plant. During this process, copper ions are deposited on the cathode, and the sulphate ions remain in solution together with free sulphuric acid. The final tails that are pumped to TD 15 are acid and contain sulphate ions. These tails are commonly known as tailings leach residue. This is the material that got discharged into the open environment on 18th February 2025. The total footprint of Tailings Dam No. 15[2] is approximately 460,000 m², with a total storage capacity of about 6.986 million m³.

The tailings, therefore, comprise a combination of:

1. Ground ore rock, clay, sand and silt particles, from which minerals of interest are extracted for economic benefits (King, 2019).
2. Chemical reagents used in the whole extraction process, as mentioned above. These are Mixed Monohydric Alcohol (frother), Sodium Isobutyl Xanthate, Coagulants, pH regulators.
3. Process water including makeup water added to process streams after waste streams exit the plant circuit for process water balancing and a means of transportation of the tailings (Cacciuttolo et al., 2023).
4. The tailings leach residue may contain other minerals, the residue unrecoverable minerals of interest and have low economic value or toxic substances from the ore body (King, 2019).

The tailings at discharge into the tailings dam exists as a thick solid-liquid mixture or fluid/slurry/paste, which over time undergoes a settling of the solid particles through the liquor, the aqueous (water based) phase by gravity or via consolidation as the more settled solids expel liquor when the solid phase becomes denser and more compacted. Additionally, due to the high diversity of chemicals in the tailings because of its mineralogy, this waste is prone to changes when chemical reactions (such as hydrolysis, oxidation, reduction) occur as it interacts with the environment leading to the formation of other products such as acid rock drainage (Cacciuttolo et al., 2023). Therefore, the integrity of the tailings' storage facility should be engineered to withstand any stresses it is subjected to, to avoid structural failures and process run-aways.

1.2.3 Immediate concerns and emergency response

1.2.3.1 Immediate concerns

The tailings discharge adversely impacted the Chambishi Stream, Mwambashi River and the Kafue River, causing severe environmental damage and affecting the availability of clean water resources for communities in the affected area. The reported adverse impacts of the tailings discharge on the biophysical and socioeconomic environment include the following:

- Pollution of water sources leading to disruption to water supply in Kitwe for several days

[2] Source: Sino Metals

- Destruction of crops in gardens located on the banks of the affected surface water bodies
- Death of fish and other aquatic living organisms.
- Soil contamination
- Damage to aquatic flora
- Risk to public health through various pathways such as consuming contaminated fish

1.2.3.2 Emergency response

As an emergency response, Sino-Metals closed off the walls that were compromised and used motorised equipment to reprofile the affected sites in order to arrest further discharge of the acidic leach residue or tailings materials while liming the affected areas. During the same intervention period, Sino-Metals management moved into the affected communities and sensitized them against use of water from Chambishi Stream and Mwambashi River. As an alternative, the company committed to providing potable water to the community on a daily basis until an incident assessment is comprehensively done and appropriate remedial measures are put in place to guarantee access to clean water for domestic.

Other immediate interventions recommended following the implementation of emergency response measures, were as follows:

1. The stabilisation of TD 15 by Sino-Metals to include stormwater management.
2. Construction of a catch drain downstream of TD 15 to prevent transportation of tailings or silt to the stream through runoff stormwater.
3. Construction of silt traps on the major drains in the area to prevent sedimentation of the wetlands.
4. Management of multiple reclamation of tailings in the area that have the potential to pollute the streams and rivers in the area during the rainy season.
5. Construction of silt traps at six sites along the drain from Chambishi Metals to Chambishi Stream.
6. Mechanical removal of suspected tailings deposition along the Chambishi Stream and Mwambashi River.
7. Desludging the thick deposits of lime sludge in Chambishi Stream which settled in the stream from dosing operations.
8. Liming of fields that are affected by tailings discharge along Chambishi Stream and Mwambashi River to raise the pH of the soil. This was intended to enhance the regrowth of vegetation during the rainy season.
9. Planting trees to prevent soil erosion caused by wind or runoff rainwater. It was recommended that Sino-Metals in collaboration with the local Forestry Department take advantage of the oncoming rainy season and embark on a tree planting program of bare areas around the mine.
10. Phytoremediation of affected areas to be done in collaboration with the Ministry of Agriculture.
11. Sino-Metals has been providing drinking water to the community in Kalusale in sachets. The area is now littered with empty plastic sachets. There is a need to clean up the

environment and to conduct education and awareness regarding waste management. It is recommended that Sino-Metals engages a third party to conduct education and awareness.

12. The community of Kalusale has settled in a mine license area belonging to NFCA. Ultimately, relocation of the settlement is the long-term solution to the exposure of the residents to the hazards in the area.

1.3 Rationale for the Environmental and Social Incident Impact Assessment

The rationale for conducting the Environmental and Social Incident Impact Assessment stems from the need to understand and address the consequences of the tailings spillage by Sino-Metals. Tailings discharges can have significant impacts on both the natural environment and the socio-economic conditions of surrounding communities. Without a comprehensive assessment, the extent of environmental degradation, risks to public health, and socio-economic disruptions may remain unknown, potentially leading to further harm and ineffective response measures.

This assessment provides a structured approach to:

1. Identify and evaluate the environmental impacts on soil, water, air, and ecosystems.
2. Assess the socio-economic implications for affected communities, including livelihoods, health, and infrastructure.
3. Inform evidence-based recommendations for mitigation, remediation, and restoration.
4. Support regulatory compliance, corporate accountability, and stakeholder engagement.

By undertaking this assessment, stakeholders are equipped with information to make informed decisions, prioritise interventions, and ensure that the environmental and social impacts of the incident are addressed in a timely and effective manner.

1.4 Purpose of the Environmental and Social Incident Impact Assessment

The purpose of this Environmental and Social Incident Impact Assessment is to evaluate the environmental and socio-economic consequences of the Sino-Metals acidic leach residue discharge and to provide evidence-based guidance for addressing these impacts. The assessment seeks to identify the extent of harm to the biophysical and human environments, determine associated risks, and recommend appropriate mitigation, remediation, and restoration measures. Ultimately, it aims to support informed decision-making, promote sustainable environmental management, and safeguard the well-being of affected communities.

1.5 Objectives of the Environmental and Social Incident Impact Assessment

The overall objective of the Environmental and Social Incident Impact Assessment is to carry out a comprehensive assessment of the environmental and socio-economic impact of the tailings spillage on the environment and to recommend remediation and restoration measures. The Terms of Reference (TOR) provided by ZEMA in the Request for Proposals (RFP) outlined three broad objectives as described below:

1. To assess the impact of the tailings discharge on the biophysical environment. This objective involves the following:
    a. Identifying the pollutants present in the biota and environmental media, namely surface water, groundwater, air, plant life, soil and stream sediment and determining their concentrations.

   b. Assessing the spatial extent and magnitude of the contamination arising from the discharge of tailings into the environment.
   c. Identifying and assessing the immediate and future impacts and risks related to soil, sediments, surface water and groundwater, biodiversity and air.
   d. Assessing the impact of the pollution on infrastructure and equipment in the affected areas, including downstream facilities.
   e. Evaluating the environmental impacts on the Chambishi Stream, Mwambashi and Kafue Rivers as well as their respective ecosystems.

2. To assess the impact of the tailings discharge on the socio-economic environment, involving:
   a. Evaluation of the potential social and economic impacts on the affected entities and communities.
   b. Valuation of the affected area including but not limited to land, fisheries, livestock, agriculture, tourism, culture, heritage sites, and any other ecosystem service affected by the pollution.
   c. Detailed risk assessment to human health, livestock and aquatic life.

3. To recommend appropriate mitigation, remediation and restoration measures covering the following aspects:
   a. Remediation and restoration measures of affected areas.
   b. Estimating the time frame and financial resources required for remediation and restoration measures.
   c. Developing an implementation plan for remediation that will focus on reducing or eliminating contamination levels in the affected water bodies and surrounding areas.
   d. Developing a comprehensive monitoring and evaluation plan for the environmental aspects which shall include water, soils, fauna, flora, and the general population
   e. Developing and emergency preparedness and response plan to address similar future incidents.

1.6 Scope of the Environmental and Social Incident Impact Assessment

The scope of the Environmental and Social Incident Impact Assessment encompasses both the environmental and socio-economic aspects of the tailings spillage by Sino-Metals. It covers:

1. Geographical Scope – The affected area, including surrounding land, water bodies, ecosystems, and communities impacted by the discharge.
2. Environmental Components – Assessment of the biophysical environment, including soil, water, air quality, flora, fauna, and ecosystem health.
3. Socio-Economic Components – Evaluation of impacts on human health, livelihoods, community infrastructure, and overall socio-economic well-being of affected populations.

4. Temporal Scope – Consideration of both immediate and short-term impacts following the incident, as well as potential longer-term effects on the environment and communities.
5. Assessment Focus – Identification of risks, evaluation of impacts, and formulation of recommendations for appropriate mitigation, remediation, and restoration measures.

Table 1-1: Scope of the ESIIA of Sino-Metals' Acidic Leach Residue Discharge

Discipline	**Scope of study**
Geographical area:	The riparian and aquatic environment involving Chambishi Stream, Mwambashi and Kafue Rivers from TD 15 to Itezhi-Tezhi Dam.
Types of environmental media to be investigated:	1. Surface water 2. Groundwater 3. Soil 4. Stream and river sediment 5. Terrestrial and aquatic biota 6. Air
Environmental and Social aspects to be studied	1. Biophysical 2. Public health 3. Socio-economic 4. Infrastructure and equipment
Temporal scope	Consideration of both immediate and short-term impacts following the incident, as well as potential long-term effects on the environment and the communities
Assessment focus	1. Identification of risks 2. Evidence of impacts 3. Formulation of recommendations for appropriate mitigation, remediation and restoration measures
Time frame for analysis:	Two and half months

The assessment is designed to provide a comprehensive understanding of the incident's consequences, enabling informed decision-making, effective management of environmental and social risks, and support for sustainable recovery efforts.

1.7 Interpretation and perspective of the report

The significance of the *Sino-Metals Environmental and Social Incident Impact Assessment* lies in its role in addressing the environmental and socio-economic consequences of the acidic leach residue discharge. By systematically evaluating the impacts on ecosystems, water, soil, air quality, and affected communities, the assessment provides critical information for decision-makers, regulators, and stakeholders.

The project is significant because it:

1. Informs mitigation and remediation efforts – providing evidence-based recommendations to restore affected areas and prevent further environmental degradation.
2. Supports community well-being – by identifying socio-economic impacts and guiding interventions to protect livelihoods, health, and infrastructure.
3. Ensures regulatory compliance and corporate accountability – aligning the project with environmental standards, policies, and best practices.
4. Promotes sustainable environmental management – helping to prevent recurrence and fostering long-term ecological and social resilience.

Overall, this assessment contributes to protecting both the natural environment and the socio-economic fabric of the affected communities while enabling informed and responsible decision-making.

1.8 Description of the study area

1.8.1 Background

On 18 February 2025, a dam at Sino-Metals Leach Zambia Limited in the Chambishi area of Kalulushi District was breached, causing acidic waste material containing both liquid and solid substances to leak into the environment. The waste flowed into Chambishi Stream and then into the Mwambashi and Kafue Rivers.

1.8.2 Geographical location & climate conditions

The incident affected communities in Kalusale, Ipusukilo, Bulangililo, and Luangwa, as well as other settlements along the Kafue River, including areas in Machiya, Ngabwe, and Itezhi-Tezhi Districts. Consequently, the study area comprised communities located along the Chambishi Stream, Mwambashi River, and downstream sections of the Kafue River, extending from Kalulushi District in Copperbelt Province to parts of Luangwa, Machiya, Ngabwe, and Itezhi-Tezhi Districts.

These areas were selected due to their location along the flow path of the contaminated water and the reliance of communities on the affected water bodies for domestic use, agriculture, fishing, and livestock watering. The assessment focused on determining the extent of environmental contamination and the potential impacts on human health and livelihoods following the incident.

1.8.2.1 Kalusale in Kalulushi District

Kalusale is a rural settlement and farming community located approximately 10 km southwest of Chambishi town, in Kalulushi District of Copperbelt Province. The village lies along the Mwambashi stream, a tributary of the Kafue River, within the mine license area. Its approximate geographic coordinates are -12.696916 S latitude and 28.068833 N longitude. The satellite image in Figure 1-1 on the next page shows its location.

Kalusale, located in Kalulushi District of Zambia's Copperbelt Province, experiences a tropical savanna climate characterized by distinct wet and dry seasons. Average annual temperatures range between 20 °C and 25 °C, with the hottest months from September to November reaching highs of 28–32 °C, and the coolest months in June and July dropping to 10–12 °C at night. The area receives approximately 1,200–1,400 mm of rainfall annually, mostly concentrated in the rainy season from November to April, often accompanied by afternoon thunderstorms, while the dry season from May to October is relatively dry with lower humidity. Humidity is generally high during the rainy season (70–80%) and moderate during the dry months (40–50%), and winds are typically light to moderate. These climatic conditions support subsistence agriculture, including maize, groundnuts, cassava, and vegetables, although intense rains can occasionally lead to localized flooding along streams such as the Mwambashi.

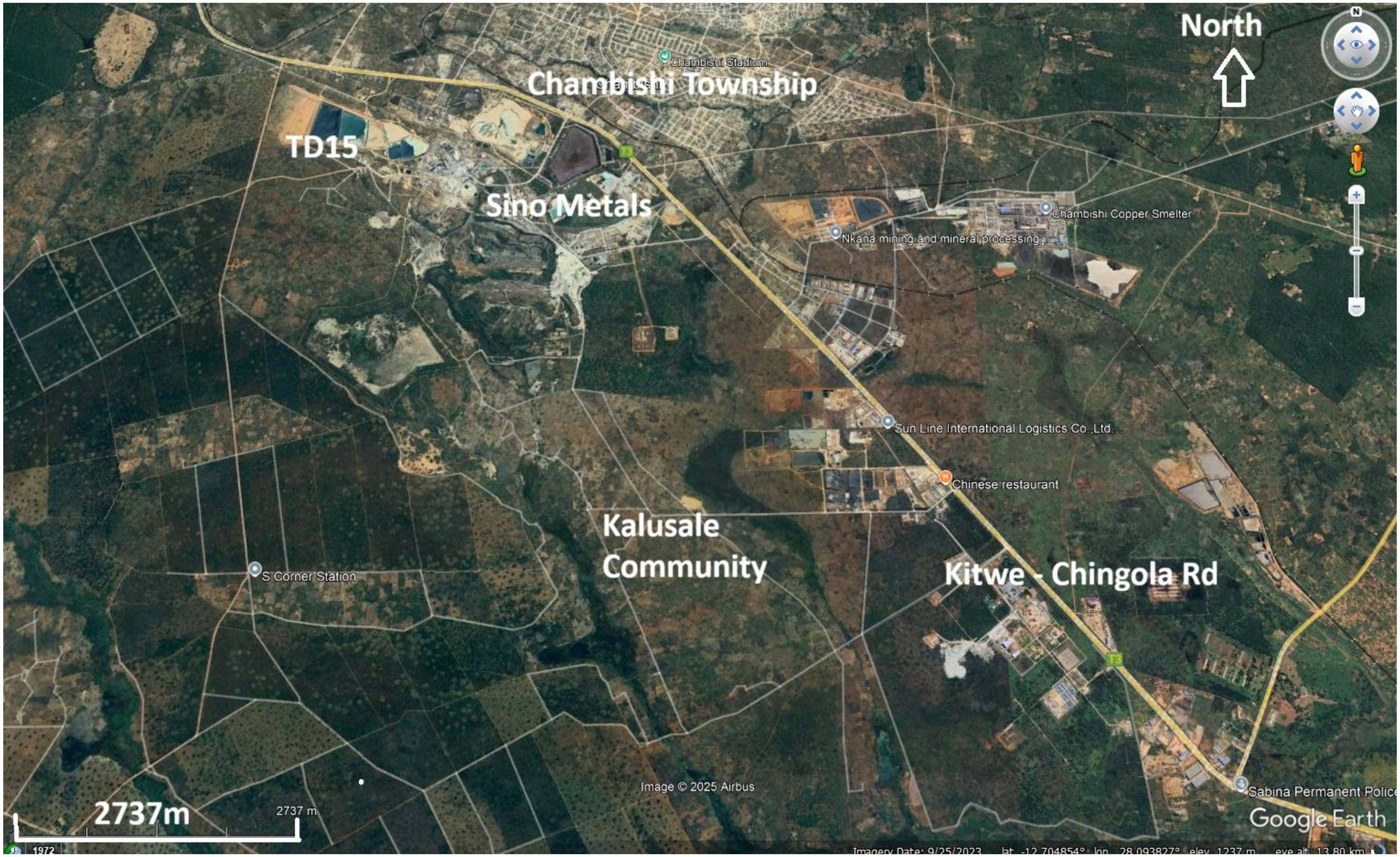


Figure 1-1: Google map showing location of Kalusale

1.8.2.2 Bulangililo & Ipusukilo in Kitwe District

Bulangililo and Ipusukilo are localities within the Copperbelt Province of Zambia, located in Kitwe, on the Copperbelt. The two communities which are neighbours to each other and located along the Kafue River, are about 8 km north east of Kitwe District. The respective and approximate geographic coordinates are -12.7692585 S latitude; 28.22539 longitude for Bulangililo and -12776791 S latitude; 28.238601 N longitude for Ipusukilo. The map in Figure 1-2 and 1-3 shows the location of the two townships.

Bulangililo and Ipusukilo communities in Kitwe District experience a tropical savanna climate characterized by distinct wet and dry seasons. The rainy season occurs from November to April, with average annual rainfall of about 1,200–1,300 mm, often falling in short, high-intensity storms that can cause localized flooding in low-lying areas. The cool dry season extends from May to August, marked by lower temperatures and minimal rainfall, while the hot dry season from September to October is characterized by high temperatures and dry, dusty conditions. Mean annual temperatures range between 20 and 22 °C, with cooler season minima of 8–12 °C and hot season maxima reaching 30–33 °C. Recent climate variability, including erratic rainfall patterns and prolonged dry spells, increases risks related to flooding, water stress, and public health, which are relevant considerations for project planning and impact assessment.

Figure 1-2: Location map of Bulangililo and Ipusukilo

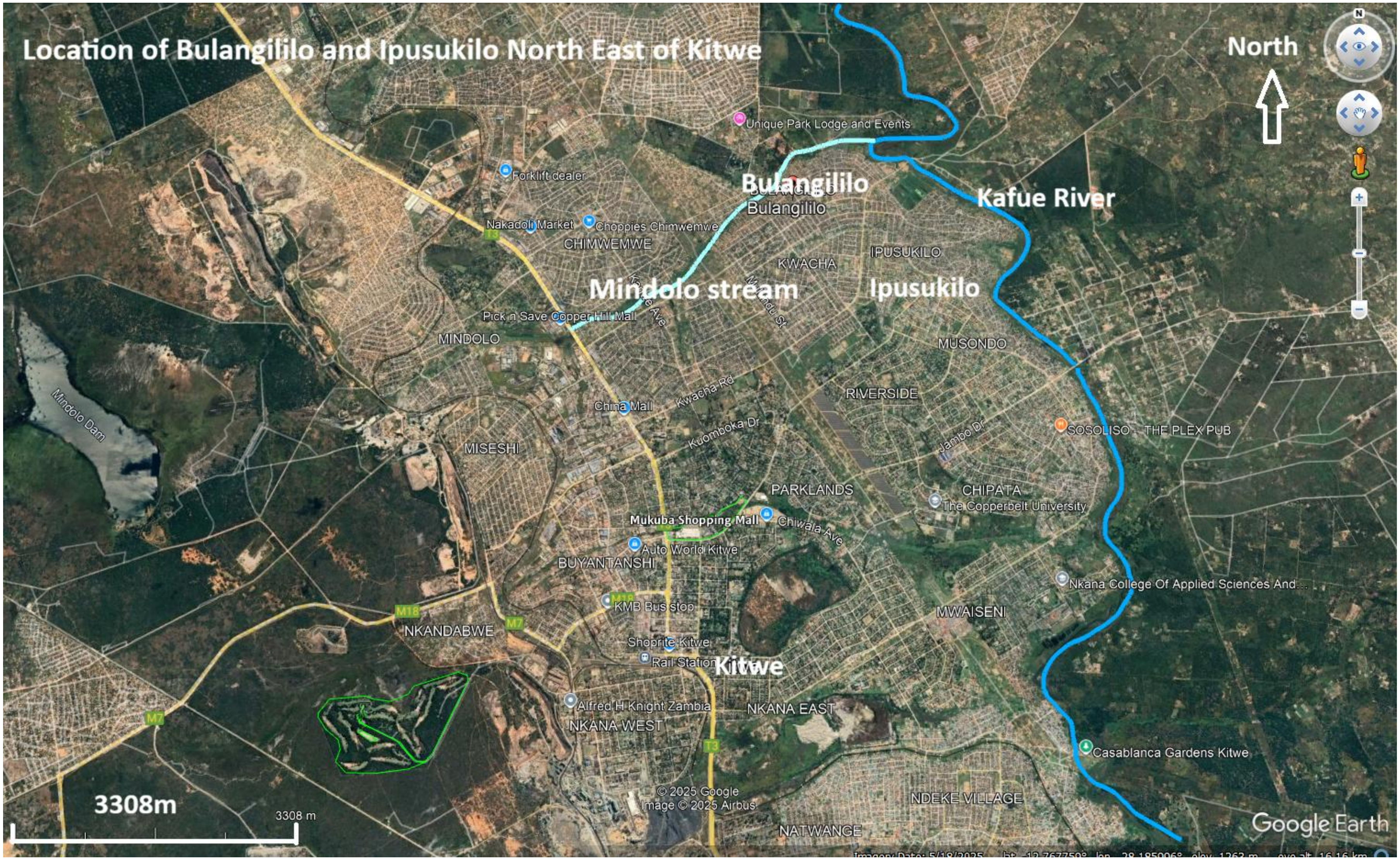


Figure 1-3: Location of Bulangililo and Ipusukilo North East of Kitwe

1.8.2.3 Luangwa in Kitwe District

Luangwa Township lies southeast of the Kitwe Central Business District (CBD) and is situated along the Ndola - Kitwe Road. It is one of the older high-density residential areas in Kitwe and is bordered by other community settlements such as Mulenga and Wusakile. Its approximate geographic coordinates are –12.879441 S latitude and 28.244756 N longitude. The map in Figure 1-4 below shows its location.

Similar to Bulangililo and Ipusukilo, Luangwa township experiences the same tropical savanna climate characterized by distinct wet and dry seasons. The rainy season occurs from November to April, with average annual rainfall of about 1,200–1,300 mm, often falling in short, high-intensity storms that can cause localized flooding in low-lying areas. The cool dry season extends from May to August, marked by lower temperatures and minimal rainfall, while the hot dry season from September to October is characterized by high temperatures and dry, dusty conditions. Mean annual temperatures range between 20 and 22 °C, with cooler season minima of 8–12 °C and hot season maxima reaching 30–33 °C. Recent climate variability, including erratic rainfall patterns and prolonged dry spells, increases risks related to flooding, water stress, and public health, which are relevant considerations for project planning and impact assessment.

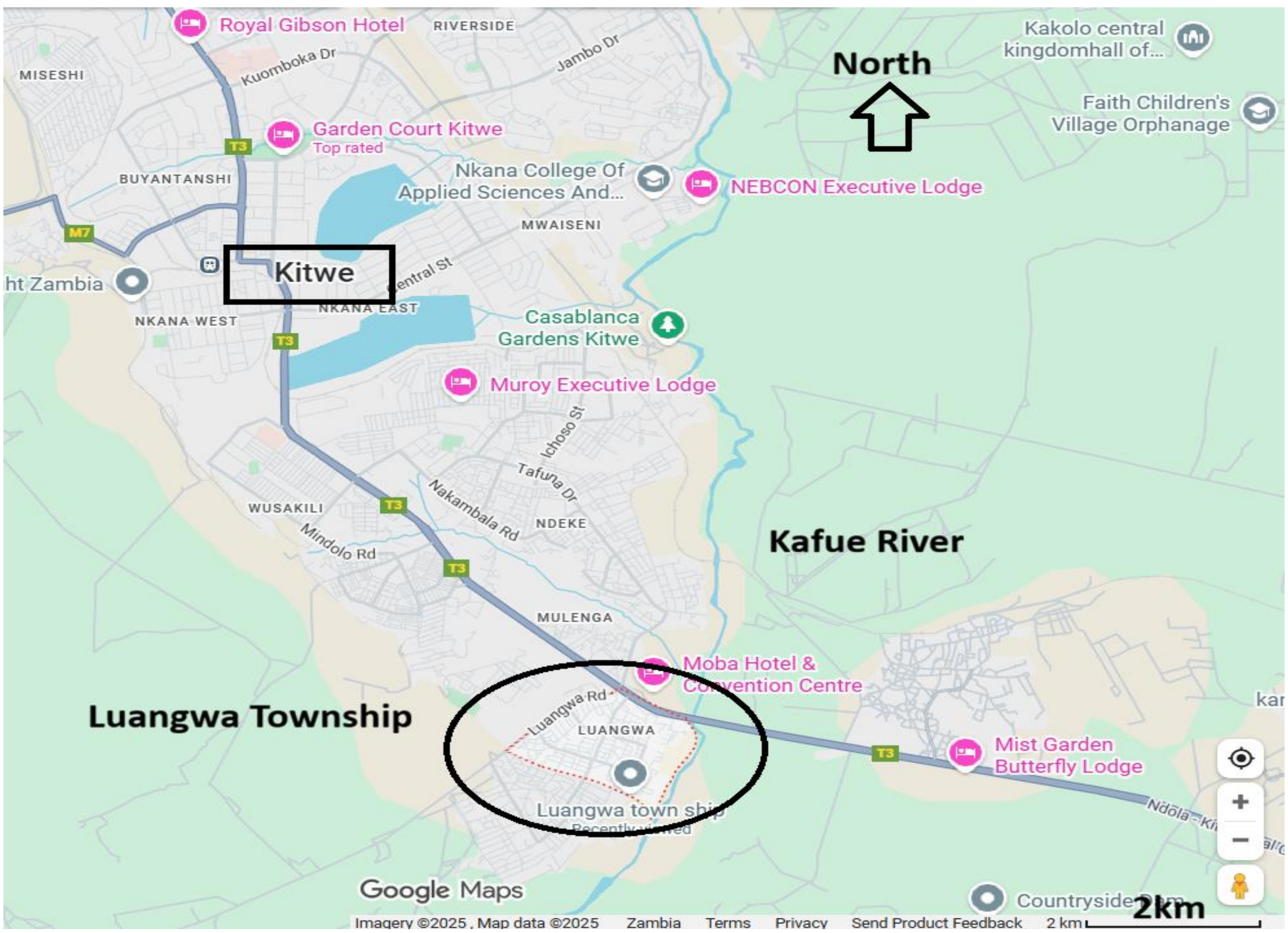


Figure 1-4: Map showing location of Luangwa Township in Kitwe

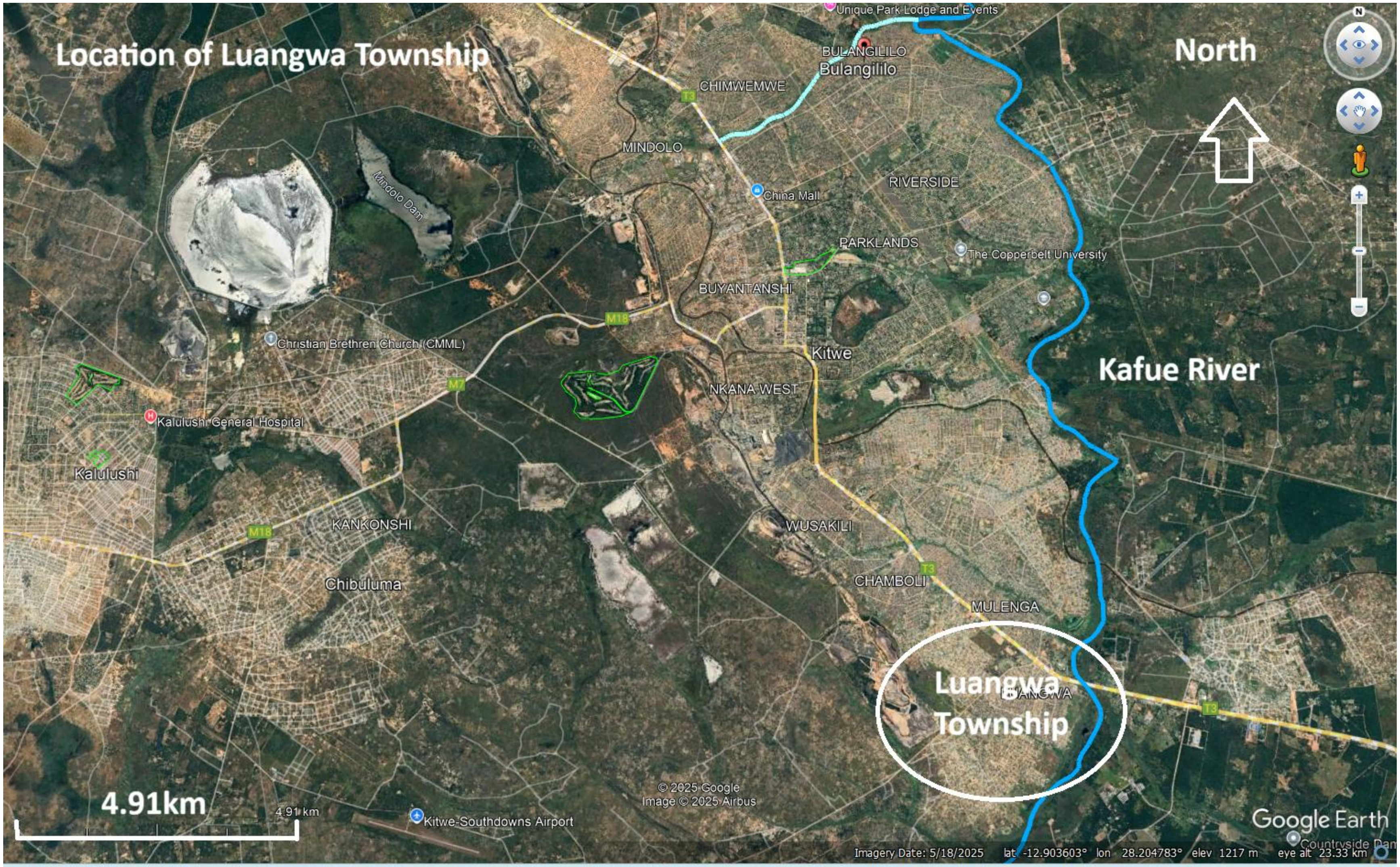


Figure 1-5: Google map showing location of Luangwa Township

1.8.2.4 Milyashi in Luanshya District

Milyashi is a ward in Luanshya District of Copperbelt Province. It lies within the Copperbelt mining region and is part of the Luanshya municipal area's political subdivisions. It is a populated area or community in the Copperbelt region.

The Milyashi/Luanshya area experiences a tropical savanna climate characterised by distinct wet and dry seasons. The rainy season occurs from November to April, with the heaviest rainfall in January and February, averaging around 200–240 mm per month, and high relative humidity of 80–90%. The dry season spans May to October, with minimal rainfall, lower humidity, and cooler temperatures, particularly from June to August, when night temperatures can drop to around 10–11 °C. Average daytime temperatures range from 25 °C in the cooler months to 33–34 °C during the hottest months of October and September. The map in Figure 1-6 and 1-7 shows the location of Milyashi in relation to the Kafue River, which was negatively impacted by the Sino Metals pollution plume.

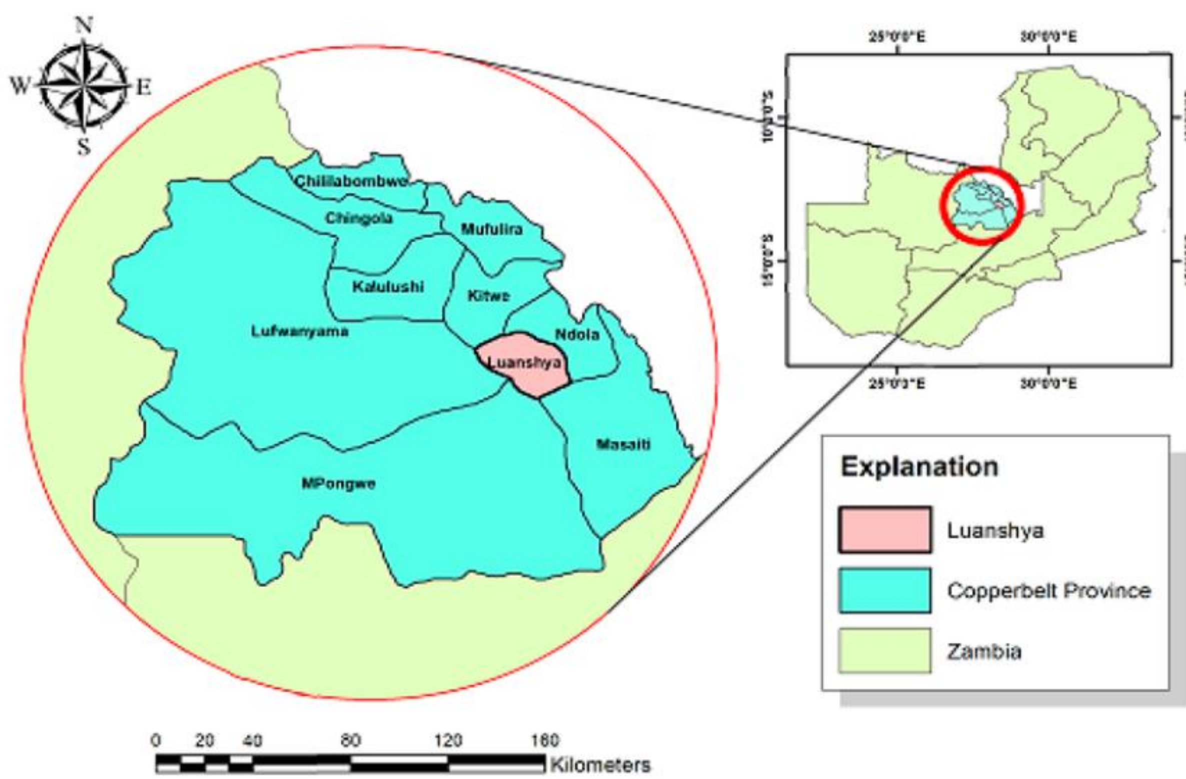


Figure 1-6: Map showing location of Luanshya on the Copperbelt

Figure 1-7: Google satellite showing location of Milyashi and Kafue River.

1.8.2.5 Machiya in Mpongwe District

Machiya is a rural community located about 73 km southwest of Mpongwe District, within the Copperbelt Province of Zambia. It is situated along the Kafue River basin, with portions of the community lying close to riverine floodplains. The community's location provides access to water resources that support domestic use, small-scale irrigation, fishing, and livestock rearing, which is one of the reasons to identify Machiya as one of the study areas. Its approximate geographic coordinates are -13.699222 S latitude and 27.602377 N longitude. The map in Figure 1-8 below shows its location.

The Machiya area in Mpongwe District (Copperbelt Province, Zambia) has a tropical savanna climate with distinct wet and dry seasons, similar to the broader Mpongwe region. The rainy season typically runs from November to March with the bulk of annual rainfall—often over 1,100 mm per year—occurring in this period, bringing humid, overcast conditions and regular afternoon storms. Temperatures are warm year-round: the hottest months are usually September–October, with daytime highs reaching the low-30s °C, while the coolest months are June–July, when nights can be cooler and daytime highs are milder. During the dry season from April to October, rain is scarce, skies are clearer, and humidity is lower, leading to warm, sunny days and cooler nights. These conditions support rain-fed farming but mean that agriculture depends heavily on seasonal rains.

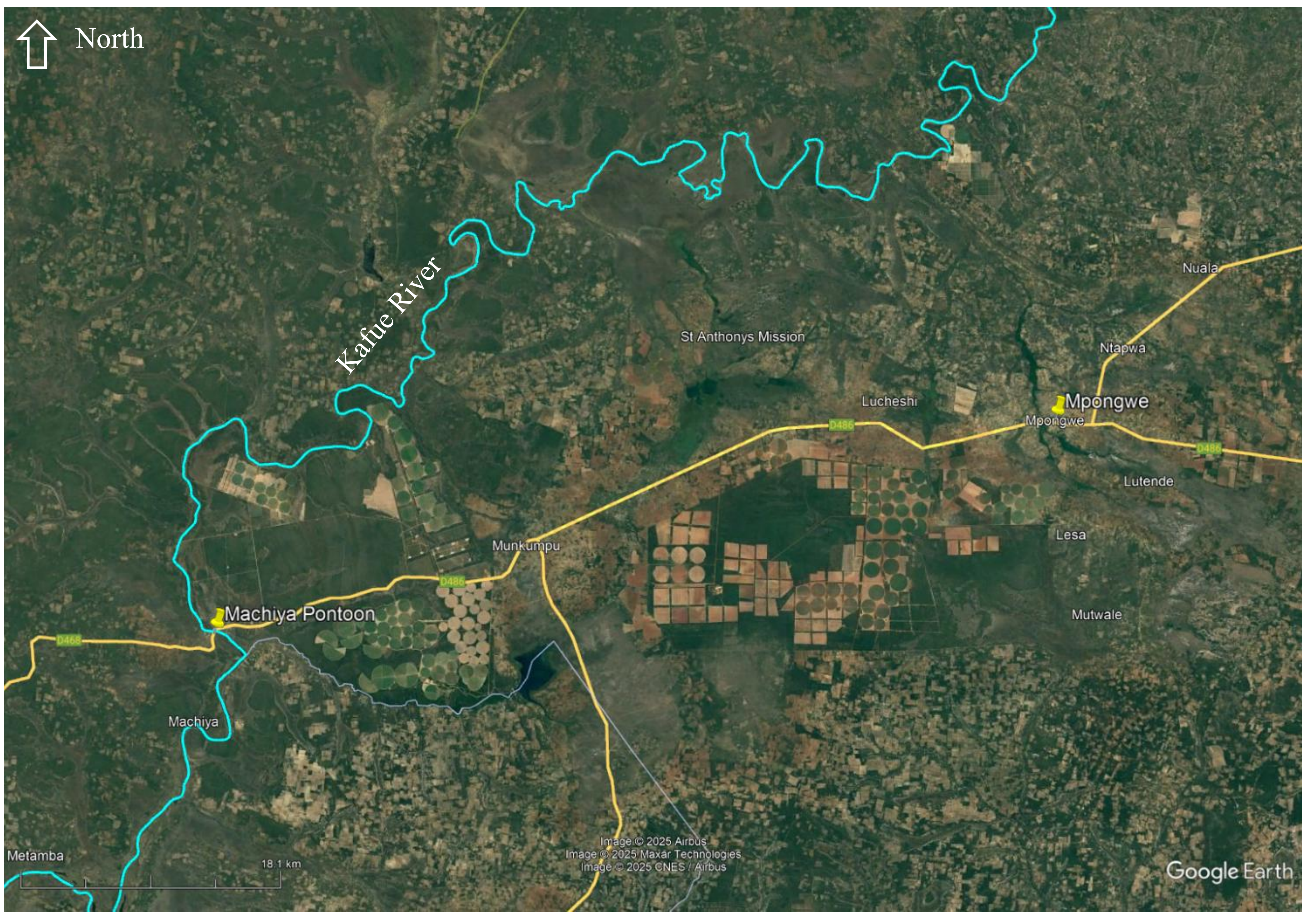


Figure 1-8: Location of Machiya in Mpongwe District

1.8.2.6 Ngabwe District

Ngabwe District is located in Central Province, Zambia, situated in the central-southern part of the country. It lies west of Kapiri Mposhi District and east of Itezhi-Tezhi District. The distance from Kabwe CBD to Ngabwe District is approximately 140 kilometres northwest. Established in 2012 after being carved out of Kapiri Mposhi District, Ngabwe is accessible primarily via road networks connecting it to neighbouring districts and towns, facilitating administration and local development. Its approximate geographic coordinates are -14.076869 S latitude and 28.681690 N longitude.

Ngabwe District, in Central Province of Zambia, experiences a tropical savanna climate with distinct wet and dry seasons. The rainy season occurs from November to April, bringing most of the district's annual rainfall of approximately 900–1,200 mm, often accompanied by humid conditions and afternoon thunderstorms. The dry season, from May to October, is characterized by minimal rainfall, clear skies, lower humidity, and cooler temperatures, especially during June and July. Average temperatures range from 15 °C to 28 °C, with the hottest months typically between September and November. These climatic conditions support rain-fed agriculture, which is the main livelihood in the district, although reliance on seasonal rains makes farming vulnerable to droughts or irregular rainfall.

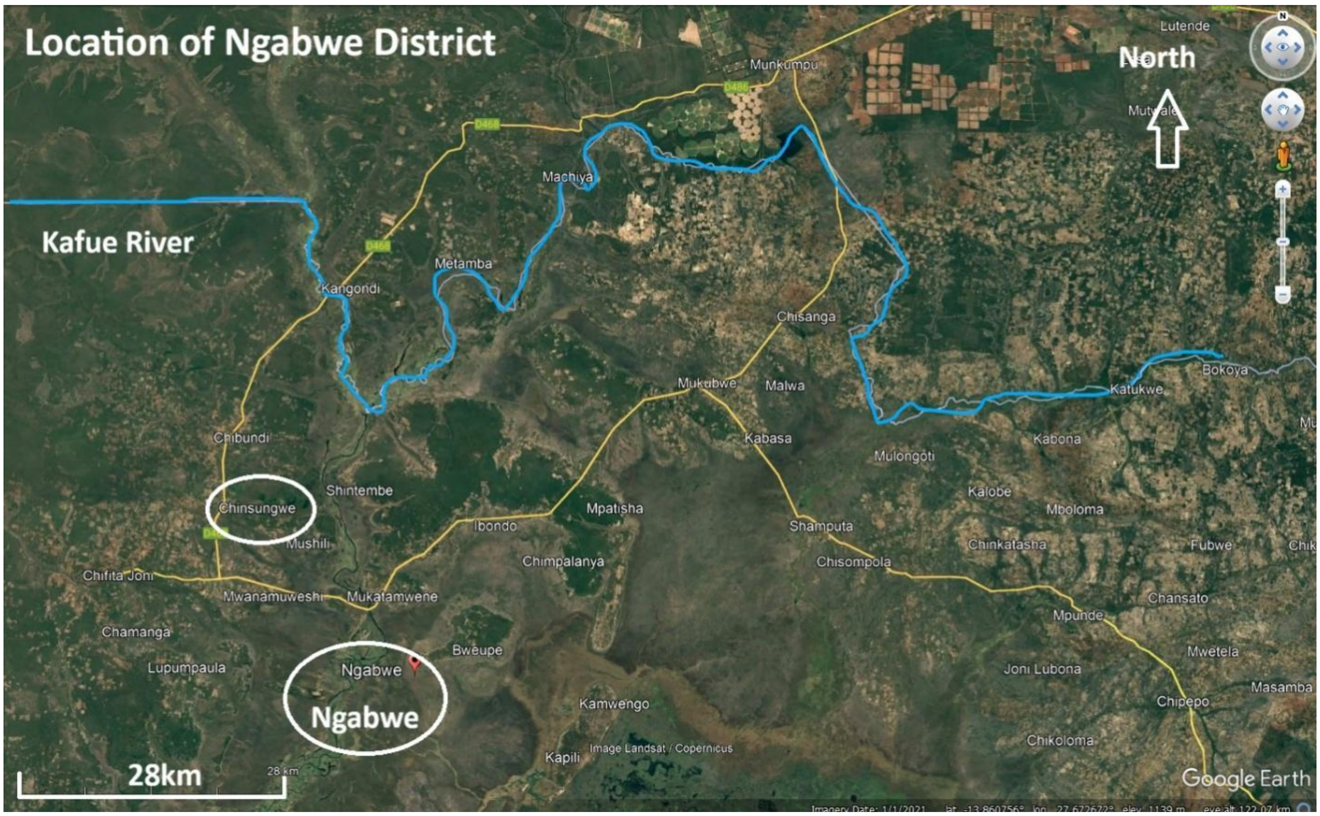


Figure 1-9: Google map showing location of Ngabwe District

1.8.2.7 Itezhi-Tezhi District

Itezhi-Tezhi is a district in Zambia's Southern Province, known for its vast area and proximity to the Kafue River system, located southwest of Lusaka, roughly 250-300 km away, requiring a drive of several hours through areas like Mumbwa, offering access to Kafue National Park and its stunning dam. The settlements in the area are largely unplanned and scattered, with some settled along the Kafue River and the reservoir shoreline. Its approximate geographic coordinates are -15.741093 latitude and 26.042318 longitude. Figure 1-10 below is the map showing the location of the district.

Itezhi-Tezhi, located in southern-central Zambia along the Kafue River, experiences a tropical savanna climate with distinct wet and dry seasons. The rainy season occurs from November to April, during which the area receives the bulk of its annual rainfall, averaging around 900–1,200 mm, often accompanied by high humidity and afternoon thunderstorms. The dry season, from May to October, is generally warm, sunny, and less humid, with cooler nights, particularly in June and July. Temperatures in the district typically range from 15 °C to 28 °C, with the hottest months from September to November. These climatic conditions support rain-fed agriculture and sustain the Kafue River ecosystem, though variability in rainfall can affect crop yields and water levels in the Itezhi-Tezhi Dam.

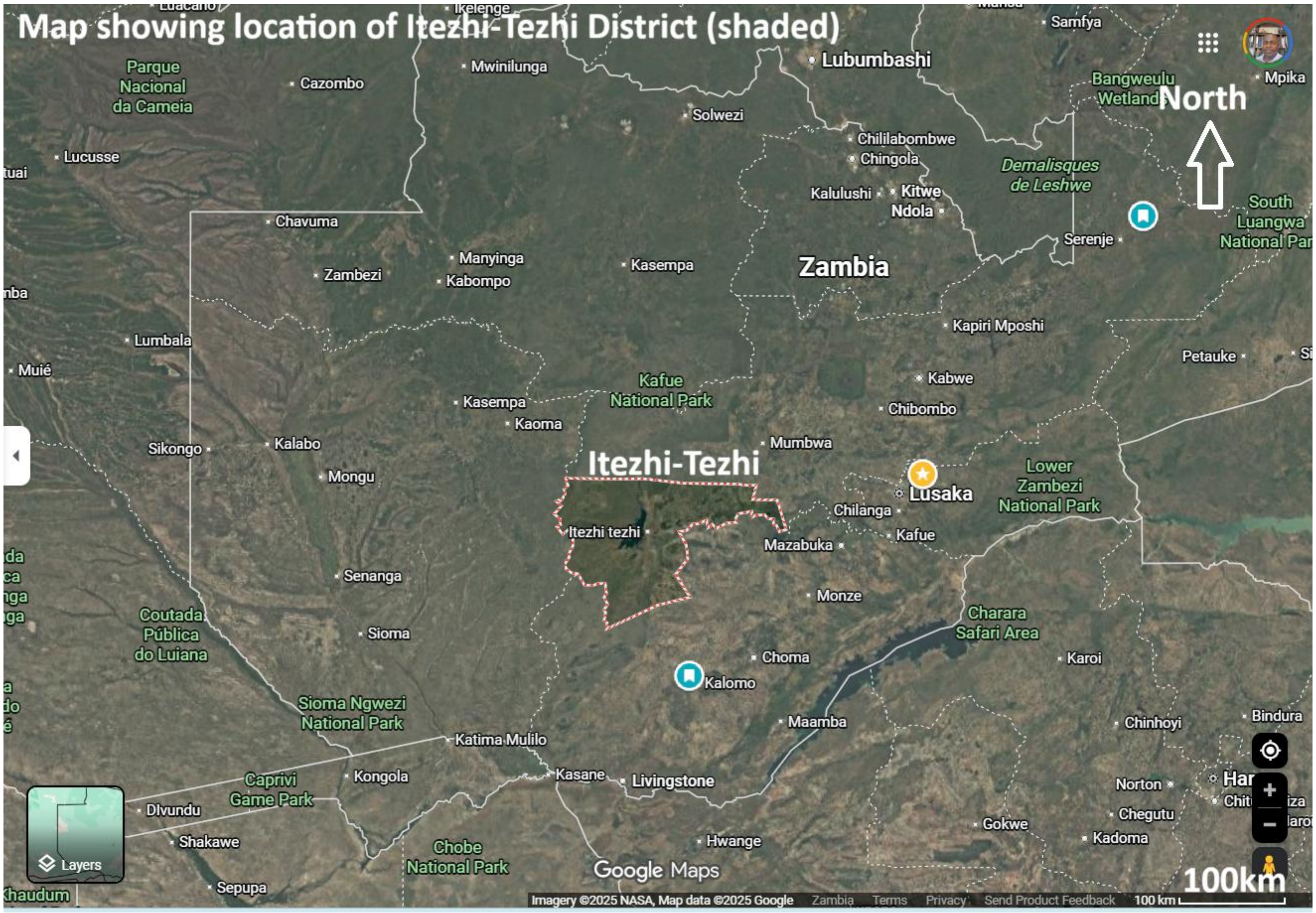


Figure 1-10: Google map showing location of Itezhi-Tezhi District

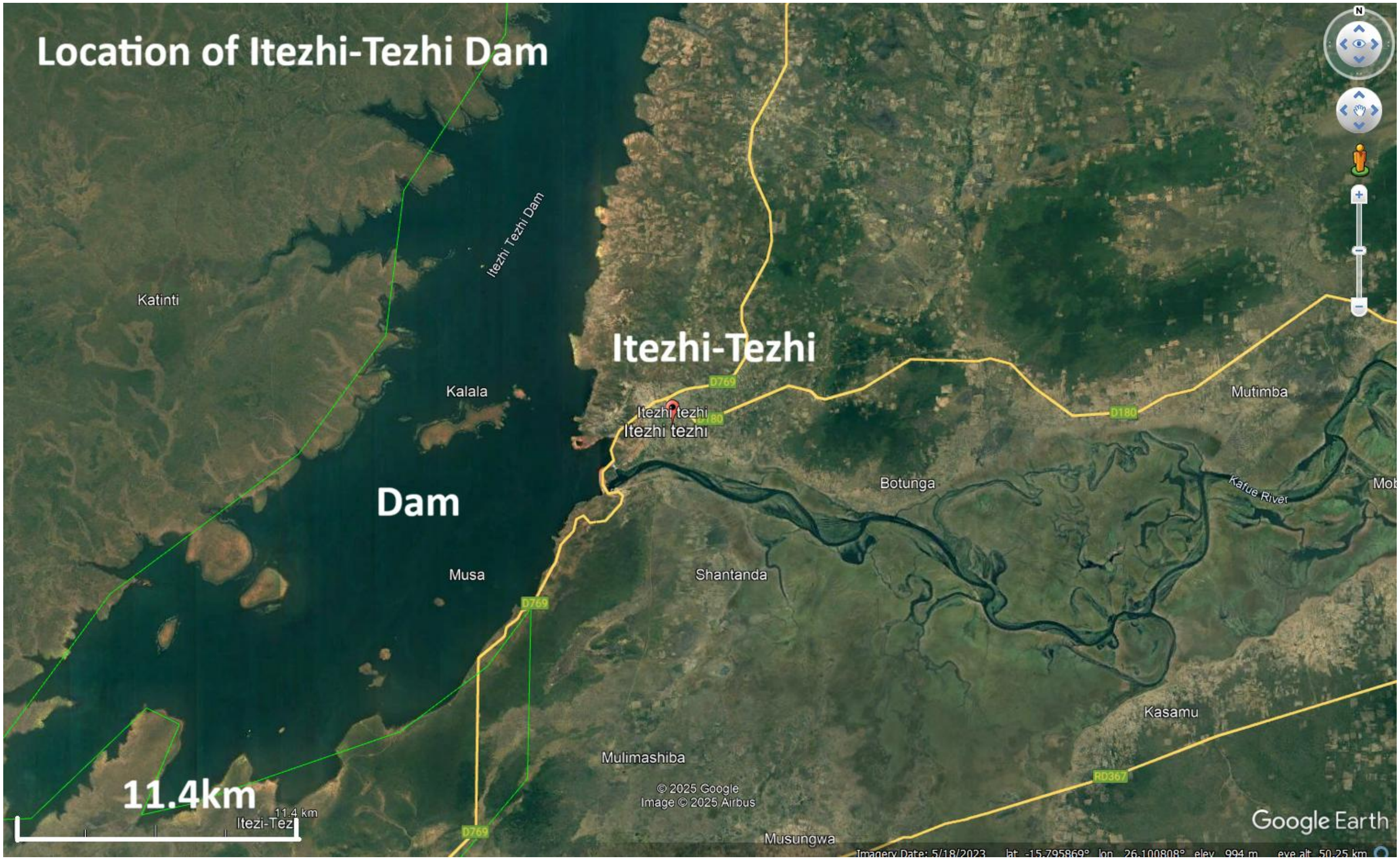


Figure 1-11: Google map showing Itezhi-Tezhi Town and the dam

1.8.2.8 Study Area Integrated

The study area encompasses a hydrological and ecological continuum extending from Chambishi Stream in the Copperbelt Province, through the Mwambashi and Kafue Rivers, and culminating at the Itezhi-Tezhi Dam in Central Province. This area represents a critical water system in Zambia, linking mining-intensive landscapes in the Copperbelt to downstream agricultural, ecological, and socio-economic systems.

Chambishi Stream, located in a heavily mined region, is influenced by industrial and mining activities, leading to elevated sediment loads, heavy metal contamination, and altered flow regimes. These impacts are particularly pronounced during the rainy season, when runoff carries pollutants downstream. The stream feeds into the Mwambashi River, which continues the hydrological connection to the larger Kafue River system. The Mwambashi serves as a significant tributary, supporting both ecological processes and community livelihoods, including irrigation, livestock watering, and small-scale fishing.

The Kafue River is one of Zambia's largest and most ecologically important rivers, traversing rural, peri-urban, and protected areas. Along its course, it supports extensive floodplains, wetlands, and riparian habitats, which are crucial for biodiversity conservation, groundwater recharge, and seasonal flood regulation. Local communities depend on the river for agriculture, fisheries, domestic water supply, and livestock, making it a vital resource for livelihoods. The river system is, however, vulnerable to pollution, sedimentation, and flow alterations originating from upstream mining, agriculture, and urban settlements.

Further downstream, the Itezhi-Tezhi Dam and reservoir represent a major hydrological and economic feature. The dam regulates river flow, provides hydroelectric power, supports fisheries, enables irrigation, and promotes tourism, while also altering the natural hydrology and affecting downstream ecosystems. The reservoir and surrounding wetlands are ecologically significant, providing habitats for aquatic and semi-aquatic species and supporting a range of ecosystem services, including flood mitigation and water storage during dry periods.

Throughout this continuum, the study area encompasses a mix of land uses, including mining, subsistence and commercial agriculture, livestock rearing, informal settlements, and conservation or protected areas. These diverse land uses interact to influence water quality, soil health, biodiversity, and ecosystem function. Key environmental pressures include heavy metal contamination from mining, sedimentation, nutrient runoff from agriculture, wetland degradation, and hydrological alterations from infrastructure such as dams and diversions.

Overall, the study area represents a complex, interconnected system where upstream activities directly affect downstream water quality, ecosystem integrity, and community livelihoods. Effective management of this continuum requires integrated approaches that balance mining, agriculture, hydropower, and conservation objectives, while mitigating environmental and social risks across the entire catchment. The map in Figure 1-12 shows an integrated hydrological system discussed above.

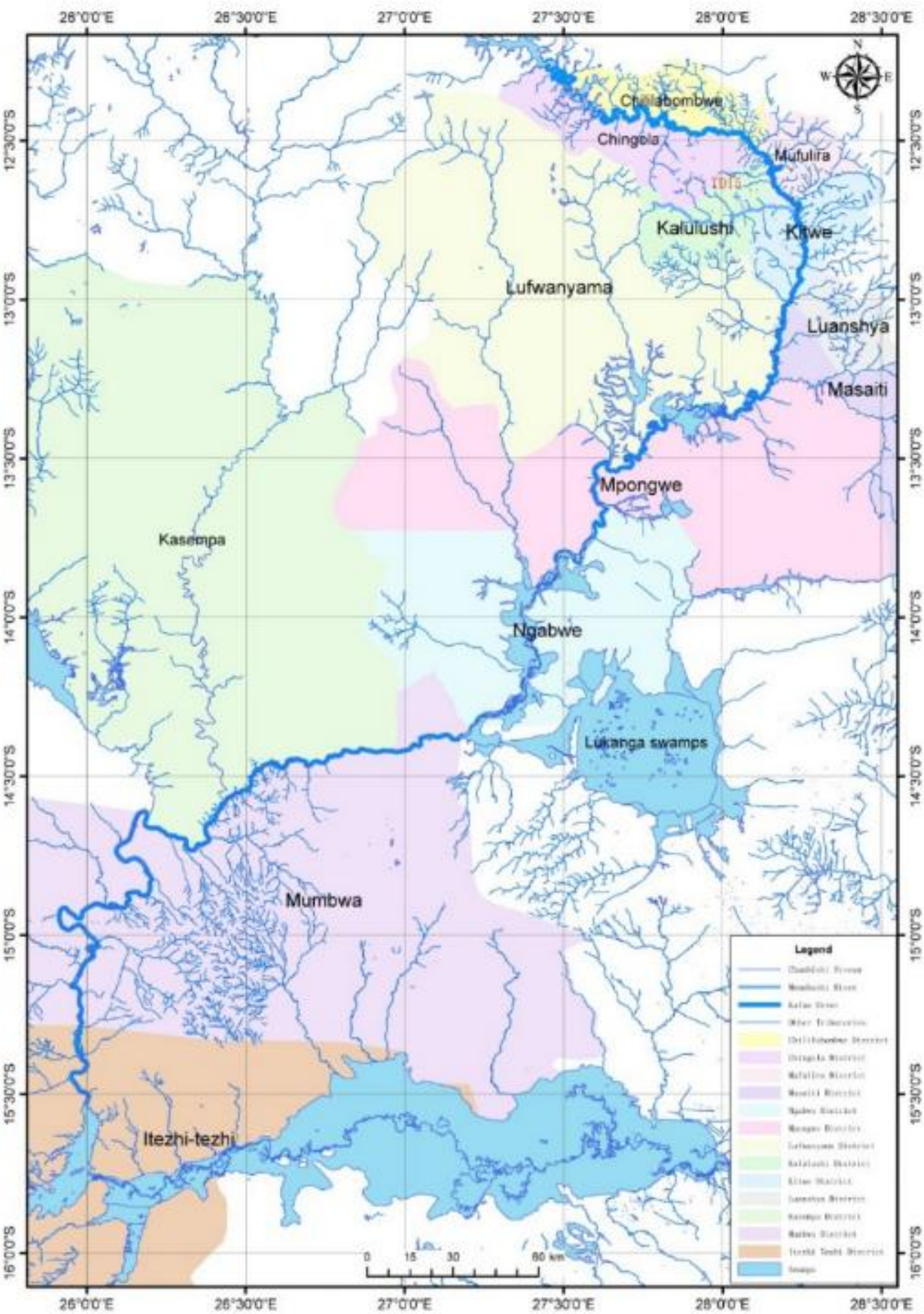


Figure 1-12: Map showing Kafue River and its major tributaries and the districts

1.8.3 Physical and environmental characteristics

1.8.3.1 Kalusale Community

1. Rivers and Wetlands

Kalusale is drained by a network of seasonal rivers and streams that support agriculture, livestock, and domestic water needs, with flows peaking during the rainy season and declining in the dry months. The area also contains wetlands and low-lying floodplains that provide critical ecological functions, including water retention, groundwater recharge, and habitat for aquatic species. These rivers and wetlands are sensitive to upstream activities, soil erosion, and encroachment, making them important both for local livelihoods and environmental sustainability.

2. Soil types

The soils in Kalusale are predominantly sandy-loam to clay-loam, typical of the Copperbelt region. They are moderately fertile, supporting subsistence agriculture, including crops such as maize, cassava, groundnuts, and vegetables. Soils in low-lying areas near rivers and wetlands tend to be more alluvial and moisture-retentive, suitable for crop cultivation but prone to waterlogging during heavy rains. Uplands and slopes often have well-drained, slightly acidic soils that are more susceptible to erosion if vegetation cover is removed.

Soil fertility is influenced by organic matter content, rainfall, and land management practices, with limited use of fertilizers or soil amendments in rural farming systems. Soil erosion, compaction, and nutrient depletion are potential risks, particularly in areas of intensive cultivation, bare land, or near riverbanks.

Overall, soils in Kalusale are moderately fertile but variable, requiring careful management to sustain agricultural productivity and prevent degradation.

1.8.3.2 Bulangililo, Ipusukilo and Luangwa communities

1. Rivers and wetlands

In Kitwe's Bulangililo, Ipusukilo, and Luangwa areas, the primary river is the Kafue River, a major Zambian waterway flowing north-to-south, creating floodplains and high water tables that lead to seasonal flooding in these townships, with smaller streams like Uchi, Kitwe, and Mindolo feeding into it; these riparian zones support local livelihoods but face pollution and flood risks, with Luangwa being further from the main river but experiencing peripheral impacts.

2. Soil types

Kitwe, including areas like Bulangililo, Ipusukilo, and Luangwa, sits on Zambia's Copperbelt, characterized by diverse soils including Nitosols, Luvisols, Vertisols, Arenosols, Leptosols, and Solonetz, influenced by underlying geology (gneiss, quartzite) and terrain, with some areas having reddish, well-drained soils (Nitosols/Luvisols) suitable for farming, while floodplains might have darker, cracking soils (Vertisols) and drier spots have shallow or sandy soils, with local variations near mining areas.

1.8.3.3 Milyashi community

1. Rivers and wetlands

The main river in the Luanshya district is the **Luanshya River**, from which the town derives its name. The district also contains various **wetlands** (known locally as "dambos"), which play an important role in local ecology and water management.

a. Rivers in Milyashi **of Luanshya District**

1. **Luanshya River**: This is the primary river in the area and is historically significant as the site where copper deposits were first discovered, leading to the establishment of the Roan Antelope mines.
2. **Kafue River**: While not directly within the Milyashi area, the Luanshya district's drainage eventually flows into the wider Kafue River basin, one of Zambia's major river systems. There have been studies and concerns about the impact of mining on the water quality of streams in Luanshya and their subsequent effect on the Kafue River.

b. Wetlands in Milyashi of Luanshya District

- **Dambos**: The Luanshya region features numerous "dambo"-type wetlands, which are seasonally or permanently wet, poorly drained soils that inhibit tree growth and support specific vegetation. These wetlands are vital for the local ecosystem, water filtration, and community livelihoods, including fishing and pastoral activities.
- **Mine Drainage Wetlands**: Specific wetlands in the area have been the subject of scientific study due to their natural ability to filter and improve the quality of neutral mine drainage from mining waste, reducing concentrations of metals like iron, manganese, copper, and cobalt through natural processes.

2. Soil types

Milyashi in Luanshya likely features varied soils, common in Zambia's Copperbelt, including Nitosols (fertile red soils), Luvisols (alkaline), and dambo soils (grey, organic, potentially peaty/clayey), with sandy/sandy-loam types also present, often showing signs of acidity and potential heavy metal contamination from nearby mining activities. Expect challenges like erosion, poor water retention in some areas, and pH issues affecting nutrient availability, typical for the region.

1.8.3.4 Machiya community

1. Rivers and wetlands

Machiya is drained by a network of small rivers, seasonal streams, and tributaries that contribute to larger river systems in the district. These watercourses are vital for agriculture, livestock watering, and domestic use, with flows peaking during the rainy season (November to April) and significantly reduced during the dry season. The rivers and streams are generally shallow and may experience siltation, seasonal drying, and localized flooding, influenced by rainfall patterns and land management practices.

The area also contains wetlands and low-lying floodplains, which provide essential ecological functions, including water retention, groundwater recharge, flood buffering, and habitat for aquatic and semi-aquatic species. Wetlands support biodiversity and local livelihoods, particularly small-scale fishing and dry-season grazing, but are sensitive to drainage, agricultural expansion, and soil erosion.

Overall, rivers and wetlands in Machiya are seasonal, ecologically significant, and critical for sustaining livelihoods, while remaining vulnerable to environmental pressures from land use and climate variability.

2. Soil types

Soils in Machiya, Mpongwe District, are predominantly sandy-loam to clay-loam, moderately fertile, and suitable for subsistence farming of crops such as maize, cassava, groundnuts, beans, and vegetables. Low-lying areas near rivers and wetlands have moisture-retentive alluvial soils, while upland and sloped areas are well-drained but more prone to erosion. Soil fertility is influenced by organic matter content, rainfall, and land management, with risks of nutrient depletion, compaction, and erosion in intensively cultivated or bare areas.

1.8.3.5 Ngabwe District

1. Rivers and wetlands

Ngabwe District in Zambia is defined by significant rivers and wetlands, primarily the mighty Kafue River and the crucial, Zambia-wide Lukanga Swamp, which are vital for livelihoods (fishing, farming), biodiversity (hippos, waterbuck), water supply, and tourism, though facing threats like invasive weeds and pollution. These water bodies support rich ecosystems, providing opportunities for agriculture (rice, sugarcane) and recreation, but require careful management to balance development with conservation.

Key Rivers & Wetlands in Ngabwe include the following;

a. Kafue River: A major river system, with over 120km running through Ngabwe, supporting tourism, wildlife (hippos), and potential for irrigation and hydropower.
b. Lukanga Swamp: Zambia's largest permanent wetland, a Ramsar site, crucial for fishing, water source for the Kafue, and home to diverse species, but threatened by Kariba weed.
c. Other waterways: The district has numerous other rivers and waterways, offering potential for water harvesting and irrigation

2. Soil types

Ngabwe district, located in Central Province, Zambia, features a diversity of soil types due to its position in the country's main agricultural region and proximity to the Kafue River floodplains.

The prevalent soil types in the district include:

Red to brown clayey to loamy soils: These are the most common and considered among Zambia's most fertile agricultural soils, suitable for crops such as maize, soybeans, and groundnuts. They are, however, often moderately to strongly leached and characterized by soil acidity, low organic matter, and low nutrient retention capacity.

i) **Dambo soils (wetland soils)**: In the dambo (shallow wetland) areas and near the Kafue Flats, soils can be categorized into:

  - **Grey dambo soils**: These typically have grey mottled loams to sands in the center with dark topsoils.
  - **Black dambo clays (Vertisols)**: These are cracking clay soils found in floodplains and dambos, known for poor workability when wet.

ii) **Other varying types**: The broader region also contains pockets of various other soil types, including **Nitosols, Luvisols, Arenosols, Leptosols, and Solonetz**, which range from slightly acidic to alkaline.

The physical characteristics of these soils (e.g., low water-holding capacity in sandier areas and potential for hardpans in some dambos) are important considerations for agriculture and land management in the district.

1.8.3.6 Itezhi-Tezhi

1. Rivers and Wetlands

Itezhi-Tezhi District is characterized by a network of rivers, streams, and wetlands that support both livelihoods and biodiversity. The **Kafue River** is the main watercourse, forming the **Itezhi-Tezhi Dam** and providing water for agriculture, domestic use, and hydroelectric power. It is fed by numerous smaller tributaries and seasonal streams, such as the Lukanga and Mulungushi, which flow mainly during the rainy season. Extensive **floodplains and wetlands** along the river and its tributaries serve as important habitats for fish, birds, and other wildlife, while also supporting agriculture by retaining moisture during the dry season. These water systems exhibit strong seasonal dynamics, with streams and wetlands expanding during the rains and contracting in the dry months.

2. Soil types

The Itezhi-Tezhi district in Zambia contains a diversity of soil types, including **Nitosols, Luvisols, Vertisols, Arenosols, Leptosols, and Solonetz**.

The specific soil types and their characteristics vary across different areas of the district:

i) **Floodplains and Dambos:** These areas are characterized by problems of wetness and poor water-holding capacity, and include "cracking clay soils" (likely Vertisols). The soils here are often alluvial in nature.

ii) **Hills and Escarpment Zones:** Soils in these elevated regions often face hazards such as erosion and limited soil depth. The underlying bedrock is frequently granite, resulting in residual soils developed on this material.

iii) **General Characteristics:** The soils in the region range from slightly acidic (Nitosols) to alkaline (Luvisols). Some areas also have issues with salinity and sodicity (high sodium content).

1.8.4 Socio-economic setting

1.8.4.1 Kalusale community (Kalulushi District)

1. Population and settlement pattern

The community predominantly comprises smallholder households engaged in subsistence agriculture. While official population data specific to Kalusale is limited, Kalulushi District has experienced population growth with both rural and urban residents, indicating significant human settlement and economic activity in the region.

2. Economic activities

Agriculture is the backbone of livelihoods in Kalusale. Most residents cultivate maize, groundnuts, vegetables, and other subsistence crops, relying on both rain-fed and stream-fed agriculture. Farming is largely small-scale and household-driven, with produce used primarily for domestic consumption and limited local trade. Livestock rearing (such as poultry, goats, and cattle) is not common in the area, except the community does fishing from the Mwambashi Stream and Kafue River, to support household food security and incomes.

3. Health and social services

Access to formal health and education facilities in rural wards like Kalusale is typically limited compared to urban centres in Kalulushi District. Residents often travel to nearby towns (e.g., Chambishi or Kalulushi) for healthcare, schooling, and administrative services. Sanitation, potable water supply, and infrastructure remain key developmental gaps.

4. **Market and economic networ**ks

Kalusale's proximity to Chambishi and Kalulushi allows residents to participate in local markets for selling surplus farm produce and purchasing goods. Kalulushi District hosts several operational markets and a range of small businesses, reflecting a mixed economic environment of agriculture, trade, and mining-related services.

5. Impact of mining and environmental risks

Kalusale lies within the broader Copperbelt mining landscape, where mineral extraction and processing industries have historically shaped local economies and employment. However, closures and economic contractions in mining have contributed to unemployment and social challenges in the district. The 2025 pollution incident has heightened concerns over environmental health, water security, farmland viability, requiring immediate interventions.

1.8.4.2 Bulangililo and Ipusukilo communities (Kitwe District)

1. Population and Settlement Pattern

Ipusukilo is a high-density urban settlement/ward within Kitwe City, largely informal and low-income in character. It has long grown as a result of rural-urban migration, with people moving into the city for employment opportunities, particularly associated with mining and informal work. According to available estimates, Ipusukilo's population is roughly around 31,000–35,000 people living in about 4,200 housing units, reflecting its dense settlement structure with limited formal housing and many informal dwellings.

Bulangililo is another ward/suburb of Kitwe located near Ipusukilo and adjacent to other residential areas like Kamitondo. Based on the 2010 census data, Bulangililo had a population of about 28,000 people, demonstrating that it too is a significant residential area within the city's urban fabric.

Both areas reflect the broader urban settlement pattern of Kitwe, where rapid population growth tied to industrial and mining activity has led to the proliferation of high-density, mixed formal and informal residential zones with modest infrastructure and services compared with more established suburbs.

2. Economic activities

Bulangililo and Ipusukilo in Kitwe are predominantly high-density, low-income urban settlements where livelihoods are largely based on the informal economy. Main economic activities include small-scale trading and vending, casual labour, construction work, and employment in mining and mining-related services, with some households also engaging in backyard gardening and poultry keeping. Despite their economic vibrancy, both areas face significant infrastructure challenges, including overcrowded housing, limited access to safe water and adequate sanitation, poorly maintained and unpaved roads that are prone to flooding, frequent electricity outages, and inadequate solid waste management. These constraints place pressure on living conditions and public health, particularly during the rainy season.

3. Health and social services

Bulangililo and Ipusukilo have limited health and social services, typical of high-density urban settlements in Kitwe. Primary healthcare is mainly provided through public health centres and clinics located within or near the communities, which offer basic services such as outpatient care, maternal and child health, and immunisation, but are often overstretched due to high population demand. Residents frequently rely on Kitwe Teaching Hospital and other urban facilities for secondary and referral care. Social services include primary and secondary schools, churches, community halls, and youth or women's groups, which play an important role in social support and community organisation. However, challenges such as overcrowded classrooms, limited health staff, inadequate facilities, and constrained access to social welfare services persist, affecting service quality and coverage.

4. Market and economic networks

Bulangililo and Ipusukilo are integrated into Kitwe's wider urban market and economic networks, with livelihoods closely linked to nearby residential, industrial, and commercial areas. Residents participate in informal trading networks, selling foodstuffs, groceries, second-hand clothing, charcoal, and household goods through roadside stalls, markets, and home-based shops. These communities are economically connected to central Kitwe markets, local bus stations, and nearby industrial and mining zones, which provide both customers and employment opportunities. Small-scale enterprises rely heavily on daily cash transactions, local supply chains, and social networks, while limited access to formal credit and secure trading spaces constrain business growth. Despite these challenges, strong community-based economic linkages help sustain household incomes and local commerce.

5. Impact of mining and environmental risks

Mining activities in and around Kitwe have had a significant influence on Bulangililo and Ipusukilo, presenting both economic benefits and environmental risks. While mining provides employment opportunities and supports local businesses, communities face exposure to environmental hazards such as air pollution from dust and emissions, potential contamination of surface and groundwater, and soil degradation linked to mining waste and tailings transport corridors. Poor drainage and waste management in these high-density settlements can exacerbate the spread of pollutants, increasing risks to public health. Residents are particularly vulnerable to respiratory illnesses, waterborne diseases, and other health impacts, highlighting the need for improved environmental management, monitoring, and community health protection measures.

1.8.4.3 Luangwa community (Kitwe District)

1. Population and settlement pattern

Luangwa Community in Kitwe City (Copperbelt Province, Zambia) is an administrative ward and residential area within the larger urban structure of the city. According to the 2010 Zambia Census, this ward had a population of approximately 30,626 people, with a roughly even split between males and females, reflecting its status as a significant residential zone on the city's periphery.

The settlement pattern in Luangwa is typical of many peri-urban and high-density wards in Kitwe: it combines planned and unplanned residential zones, with housing ranging from formal structures to more informal and semi-structured dwellings. The area lies in the southern to southeastern part of Kitwe and borders other residential wards such as Malembeka and Mulenga, forming a network of communities that have grown as Kitwe has expanded over time. Residential development is closely tied to mining-related urban growth, rural-urban migration, and the city's broader socio-economic dynamics, resulting in a dense settlement pattern with strong links to economic activity, transport routes, and community infrastructure

2. Economic activities

Economic activity in Luangwa community of Kitwe is largely driven by the informal and semi-formal urban economy, reflecting its high-density and peri-urban character. Most residents are engaged in small-scale trading and vending, including the sale of foodstuffs, groceries, second-hand clothing, charcoal, and household goods. Casual labour is common, particularly in construction, domestic work, and small workshops, while some residents are employed in mining and mining-related services within Kitwe and surrounding areas. Backyard gardening, poultry keeping, and other small household enterprises supplement incomes for many families.

These activities are closely linked to Kitwe's wider market and transport networks, although limited access to formal employment, credit, and infrastructure constrains economic growth and income stability.

3. Health and social services

Health and social services in Luangwa community, Kitwe, are provided through a mix of public, community, and private facilities, though capacity is often limited relative to the population size. Primary healthcare services are mainly delivered through nearby public health centres and clinics, offering outpatient care, maternal and child health services, and immunisation, while more specialised and referral services are accessed at Kitwe Teaching Hospital. Social services include primary and secondary schools, churches, community halls, and local markets, which serve as important centres for education, social support, and community interaction. However, the community faces challenges such as overcrowded health facilities and classrooms, shortages of medical staff and learning materials, and limited access to social welfare programmes, particularly affecting vulnerable groups, including children, the elderly, and low-income households.

4. Market and economic networks

Luangwa community in Kitwe is well integrated into the city's market and economic networks, with livelihoods closely linked to nearby residential, commercial, and industrial areas. Residents participate mainly in informal trading networks, operating roadside stalls, small shops, and home-based businesses that sell food, groceries, charcoal, second-hand clothing, and household goods. The community is economically connected to central Kitwe markets, bus routes, and mining and industrial zones, which provide both employment opportunities and access to suppliers and customers. Economic activities rely heavily on daily cash transactions, local supply chains, and social networks, while limited access to formal credit, secure trading spaces, and market infrastructure constrain business expansion and income stability.

5. Impact of mining and environmental risks

As discussed under Bulangililo and Ipusukilo, mining activities around Kitwe have a significant influence on Luangwa community, shaping both livelihoods and environmental conditions. While the mining sector provides employment and supports local economic activity, it also presents environmental risks associated with air pollution from dust and emissions, noise, and potential contamination of soil and water from mine waste, tailings transport routes, and industrial effluents. Poor drainage and waste management within the settlement can intensify these impacts, especially during the rainy season when pollutants may spread more widely. As a result, residents may face increased health risks, including respiratory illnesses and water-related diseases, highlighting the need for effective environmental monitoring, improved urban infrastructure, and community health protection measures.

1.8.4.4 Milyashi community (Luanshya District)

1. Population and settlement pattern

Milyashi is an administrative ward in Luanshya District on the Copperbelt, which had about 6,327 residents in the 2010 Zambia Census, living in roughly 1,220 households; the population was split fairly evenly between males and females at that time. The settlement pattern in Milyashi reflects a mixed urban–peri-urban character, with residential clusters around local amenities and road networks typical of Copperbelt towns. As a ward in a former mining district, its development has been shaped by proximity to mining activity and associated employment, but, like many areas in the region, it may also include smaller, lower-density residential zones outside core township centres. Population growth since 2010 is likely influenced by broader regional urbanisation trends and economic shifts in mining and informal activities.

2. Economic activities

In Milyashi Ward, Luanshya District, residents engage in a mix of mining-related employment, informal trading, and small-scale agriculture. Some work in nearby copper mines or provide supporting services, while many participate in small-scale vending, retail, and casual labour such as construction and domestic work. Backyard gardening, poultry keeping, and local enterprises like carpentry, tailoring, and repairs supplement household income. This combination of formal and informal activities reflects the ward's peri-urban character and the broader economic influence of the Copperbelt mining region

3. Health and social services

In Milyashi Ward, Luanshya District, health and social services are limited but accessible through a combination of public facilities, community initiatives, and small private clinics. Primary healthcare is provided at local clinics, offering outpatient care, maternal and child health services, immunizations, and treatment of common illnesses, while more specialized care is accessed at hospitals in Luanshya town. Social services include primary and secondary schools, community centres, churches, and local youth or women's groups, which support education, social cohesion, and community development. However, the ward faces challenges such as overcrowded health and educational facilities, shortages of medical staff and learning materials, and limited access to social welfare programs, which can constrain service delivery and affect vulnerable populations.

4. Market and economic networks

In Milyashi Ward, Luanshya District, residents are integrated into local and regional market and economic networks that connect them to Luanshya town and surrounding Copperbelt communities. The local economy is dominated by informal trading, with small-scale vendors selling foodstuffs, groceries, charcoal, household goods, and other daily necessities in roadside stalls and local markets. Residents also engage in service-based enterprises such as carpentry, tailoring, welding, and bicycle or motorcycle repairs. Economic activity is supported by daily cash transactions, social networks, and supply chains linking local producers and consumers, while limited access to formal credit and secure trading spaces constrain business growth. The ward's proximity to mining operations further links households to employment opportunities and business markets associated with the Copperbelt mining sector.

5. Impact of mining and environmental risks

Mining activities in and around Milyashi Ward, Luanshya District, have a significant influence on the community's livelihoods and environment. While mining provides employment and supports local economic activity, it also generates environmental risks, including air pollution from dust and emissions, soil degradation, and potential contamination of water sources from mine effluents and tailings. Poor drainage and waste management in the ward can exacerbate these impacts, particularly during the rainy season, increasing the risk of waterborne diseases and respiratory illnesses among residents. These environmental challenges highlight the need for effective mine waste management, regular monitoring, and community health interventions to reduce the adverse effects of mining on human health and local ecosystems.

1.8.4.5 Machiya community (Mpongwe District)

1. Population and settlement pattern

Machiya is one of the rural communities/settlement areas in Mpongwe District, which lies in the southern part of the Copperbelt Province. The district's population is predominantly rural and dispersed, with settlements like Machiya clustered around community centres and along main roads such as the Mpongwe–Machiya Road, reflecting a pattern where people live in small villages and hamlets rather than dense urban centres. Larger settlements in the district (e.g., Ibenga, Nampamba, Mpongwe Central) have higher population concentrations, while areas like Machiya tend to be smaller and less densely populated, serving as local service and agricultural hubs for surrounding farming communities. Overall, the settlement pattern in and around Machiya is typical of rural Zambia, with spread-out homesteads near arable land and transport routes, and social services clustered at community centres.

2. Economic activity

In Machiya, Mpongwe District, the local economy is predominantly rural and agriculture-based, reflecting the area's dispersed settlement pattern and fertile soils. The majority of residents engage in subsistence farming, cultivating crops such as maize, cassava, groundnuts, vegetables, and sweet potatoes primarily for household consumption, with surplus occasionally sold in local markets. Small-scale livestock rearing (chickens, goats, and cattle) supplements household income and nutrition. Fishing is limited and mainly practiced in nearby streams or seasonal water bodies. Other economic activities include informal trading, petty commerce, and casual labour, often connected to local agricultural production or nearby towns. Limited formal employment opportunities mean that livelihoods rely heavily on natural resources, local markets, and social networks, making households vulnerable to climatic variability and environmental changes.

3. Health and social services

In Machiya, Mpongwe District, health and social services are limited but accessible through a combination of local clinics, health posts, and community initiatives. Primary healthcare is provided at rural health centres and outreach posts, offering basic medical care, maternal and child health services, immunizations, and treatment of common illnesses, while more specialized services are accessed in larger towns such as Mpongwe or Kasama. Social services include primary and secondary schools, community halls, churches, and local youth or women's groups, which support education, social cohesion, and community development. However, residents face challenges such as overcrowded classrooms, understaffed health facilities, limited medical supplies, and constrained access to social welfare programs, which affect service quality and accessibility, particularly for vulnerable groups in this rural setting.

4. Market and economic networks

In Machiya, Mpongwe District, residents participate in local and regional market and economic networks that connect rural households to nearby trading centres and towns. Economic activity is primarily agriculture-based, with surplus crops such as maize, groundnuts, cassava, and vegetables sold at local markets or transported to larger markets in Mpongwe and surrounding districts. Small-scale livestock sales, petty trading, and informal commerce also support household incomes. These economic networks rely on road connectivity, social ties, and local supply chains, though limited infrastructure, seasonal road conditions, and scarce access to formal credit constrain trade efficiency and income generation. Community-based trading networks are vital in sustaining livelihoods and linking households to broader regional economies.

5. Impact of mining and environmental risks

In Machiya, Mpongwe District, mining activities in surrounding areas, particularly in the Copperbelt, have indirect but notable impacts on the community. While Machiya itself is primarily rural and agricultural, residents can be affected by environmental risks associated with mining, including air and water pollution from dust, heavy metals, and effluents carried downstream from nearby mines. Soil contamination and sedimentation in streams may reduce agricultural productivity, while improper disposal of mining waste can threaten water quality and aquatic ecosystems. These environmental pressures, combined with limited infrastructure for water treatment and waste management, increase the risk of health issues, such as respiratory illnesses and waterborne diseases, and can undermine the community's subsistence-based livelihoods.

1.8.4.6 Ngabwe District

1. Population and settlement pattern

In Ngabwe District, the population is predominantly rural and dispersed, with small villages and homesteads scattered across the landscape. As of the 2022 Zambian Census, the population of Ngabwe District in Central Province is approximately 42,104 to 42,262 people, with sources slightly varying but confirming this range, showing around 21,544 males and 20,718 females. Settlements are generally clustered near water sources, arable land, and rural roads, with higher concentrations around trading centres, schools, and health facilities. Household sizes are typically large, reflecting extended family living arrangements, and livelihoods are mainly based on subsistence farming, which shapes settlement patterns. Population density is low in remote areas, with some seasonal movement linked to agricultural activities.

2. Economic activities

Economic activities in Ngabwe District are predominantly agrarian, reflecting the rural nature of the district. The majority of households engage in subsistence crop farming, cultivating staple crops such as maize, millet, cassava, groundnuts, and various vegetables, both for household consumption and local trade. Crop production is largely rain-fed, with limited access to irrigation, making yields vulnerable to seasonal rainfall variability.

Livestock farming forms another key component of the local economy. Many households keep small stock, including goats, chickens, and pigs, while some practice cattle rearing. Livestock serves as a source of food, income, and social capital, though herds are generally small due to limited grazing land and resources.

Fishing and small-scale aquaculture are practiced along rivers, streams, and wetlands, providing both nutrition and income, particularly in communities located near water bodies.

Informal trade and petty businesses are common, with local markets serving as hubs for buying and selling agricultural produce, household goods, and artisanal products. Some residents supplement their livelihoods through small-scale retail, carpentry, brick-making, or transport services.

A small proportion of the population engages in formal employment, often in public service, education, or private sector jobs in nearby urban centres. However, limited infrastructure, such as roads, electricity, and access to commercial markets, constrains large-scale agricultural production and industrial activities. Consequently, the local economy remains largely subsistence-oriented, with households relying on multiple livelihood strategies to meet their needs.

3. Health and social services

In Ngabwe District, health and social services are limited and primarily concentrated in larger villages and trading centres. The district is served by rural health posts, clinics, and a few health centres providing basic outpatient care, maternal and child health services, immunizations, and treatment of common illnesses, with referrals to hospitals in nearby towns for specialized care. Community health programs, supported by village health committees and NGOs, focus on hygiene, sanitation, malaria prevention, and health education. Social services for vulnerable groups are minimal, and limited access to clean water and sanitation contributes to preventable health challenges.

4. Market and economic networks

Market and economic networks in rural districts like Ngabwe are predominantly local and informal, reflecting the subsistence-oriented nature of the economy. Local markets and trading centres serve as key nodes where agricultural produce, livestock, and household goods are bought and sold. Farmers and small-scale traders often rely on these markets to sell surplus crops, purchase inputs, and access essential goods, while informal trading networks link villages to nearby towns.

Economic linkages with larger regional and urban centres are limited due to poor road infrastructure, inadequate transport services, and low connectivity, constraining access to broader commercial opportunities. Traders often operate through personal networks, cooperatives, or community associations to facilitate trade and reduce transaction costs. Some households supplement their income through wage employment, artisanal activities, and small-scale businesses, creating localized economic networks that support livelihoods.

5. Impact of mining and environmental risks

Mining activities in and around communities in Ngabwe District pose significant environmental and health risks. Contamination of water sources, soil degradation, air pollution, and improper waste management, including tailings, can negatively affect agriculture, livestock, and fisheries. Exposure to pollutants increases health risks, particularly for vulnerable groups, while mining can also lead to social impacts such as in-migration, pressure on local infrastructure, and changes in traditional livelihoods. Although mining provides economic opportunities and employment, these benefits are often offset by environmental degradation and health hazards, highlighting the need for effective management and mitigation measures.

1.8.4.7 Itezhi-Tezhi District

1. Population and settlement pattern

Itezhi-Tezhi District has a predominantly rural population with low population density. Settlements are dispersed, and the population structure is youthful, with a high proportion of children and working-age adults dependent on natural resource-based livelihoods. Household sizes are generally large, reflecting extended family arrangements and traditional social structures.

Population mobility is influenced by seasonal fishing activities, agricultural cycles, and employment opportunities associated with hydropower operations and tourism-related activities near Kafue National Park.

Settlements are largely unplanned and scattered, with villages and homesteads located near:

- The Kafue River and reservoir shoreline
- Floodplains and dambos
- Access roads and trading points

Land tenure is predominantly customary, administered through traditional leadership structures. Land is used primarily for agriculture, grazing, fishing camps, and settlement development, with limited formal land demarcation.

2. Economic Activities

Agriculture is a primary livelihood activity, practiced mainly at subsistence level. Households cultivate crops such as maize, sorghum, cassava, groundnuts, beans, and vegetables. Floodplain and dambo cultivation support dry-season production. Agricultural productivity is constrained by limited access to inputs, mechanization, irrigation infrastructure, and extension services.

Fishing is a critical economic activity, particularly along the Kafue River and within the Itezhi-Tezhi Reservoir. Fish provides a major source of protein and income for local households.

Seasonal fishing camps attract traders and migrant fishers, contributing to informal economic activity but also placing pressure on fish stocks.

Livestock rearing—primarily cattle, goats, and poultry—supplements household livelihoods. Grazing is common on floodplains and communal lands. Livestock contributes to food security, income generation, and cultural practices.

The district benefits indirectly from tourism associated with Kafue National Park, including small-scale employment, craft sales, and service provision. However, community participation in the tourism value chain remains limited.

Most economic activities are informal and include crop trading, fish marketing, charcoal production, small retail businesses, and casual labour. Formal employment opportunities are limited, resulting in reliance on natural resource-based livelihoods.

3. Health and social services

Access to healthcare services is limited, particularly in remote communities. Health facilities are few and widely spaced, leading to long travel distances for primary healthcare, maternal services, and emergency care. Common health challenges include malaria, water-borne diseases, malnutrition, and limited access to clean water.

Educational infrastructure is available at primary level in some settlements, but access to secondary education is limited. School attendance is affected by poverty, long distances to schools, and household labour demands, particularly during fishing and farming seasons.

Despite proximity to major water bodies, access to **safe drinking water** is limited. Communities rely on surface water, shallow wells, and hand-pumped boreholes. Sanitation facilities are basic, increasing vulnerability to water-borne diseases, especially during flood periods.

Road infrastructure is poorly developed, consisting mainly of gravel and earth roads that become difficult to access during the rainy season. Limited transport connectivity constrains access to markets, social services, and emergency response.

Communities in Itezhi-Tezhi District exhibit high vulnerability due to:

- Dependence on climate-sensitive livelihoods (fishing and rain-fed agriculture)
- Seasonal flooding and fluctuating water levels linked to dam operations
- Environmental degradation and pressure on fisheries resources
- Limited livelihood diversification and income opportunities
- Restricted access to health, education, and markets

Women, children, fishing-dependent households, and the elderly are particularly vulnerable to livelihood disruptions.

4. Market and economic networks

Market and economic networks in Itezhi-Tezhi District are largely local and informal, reflecting the subsistence-oriented nature of the economy. Local trading centres and periodic markets serve as key hubs where agricultural produce, livestock, fish, and household goods are bought and sold. Farmers and small-scale traders rely on these markets to sell surplus crops, purchase farming inputs, and access essential goods.

Linkages to regional or urban markets are limited due to poor road infrastructure, seasonal accessibility challenges, and low transport availability, restricting opportunities for broader commercial trade. Informal networks, including cooperatives, community groups, and personal relationships, often facilitate trade and reduce transaction costs. Some households supplement their livelihoods through petty businesses, artisanal activities, or wage employment, creating localized economic networks that support household incomes.

Overall, market and economic networks in Itezhi-Tezhi are localized, informal, and constrained by infrastructure, but they play a critical role in sustaining livelihoods and connecting communities to regional economic systems.

5. Impact of mining and environmental risks

Mining activities in and around Itezhi-Tezhi District can pose environmental and health risks, including contamination of water and soil, air pollution, and ecosystem degradation, which may affect agriculture, livestock, and fisheries. Exposure to pollutants increases health risks, especially for vulnerable groups, while mining can also lead to social impacts such as in-migration, pressure on local infrastructure, and changes in traditional livelihoods. Although mining provides some economic benefits and employment, these are limited, highlighting the need for effective management and mitigation measures to protect communities and the environment.

It must be noted that livelihoods in the district are closely linked to the Kafue River system, wetlands, and reservoir ecosystems. Changes in water levels, water quality, fish stocks, or land access—whether from dam operations, climate variability, or development projects—can directly affect household income, food security, and public health.

1.9 Characterisation of tailings

1.9.1 Composition of tailings

Tailings, being waste products/tails from a mining metallurgical process, i.e. extraction of copper from the ore, consists of a combination of materials, the most significant of which are listed below:

- Ground ore rock, clay, sand and silt particles, from which minerals of interest are extracted for economic benefits (King, 2019). The rock/ore body in these process plants is crashed to a fine sand for purposes of increasing the surface area of the ore to the extracting chemicals during the removal of targeted minerals from the ore.
- Chemical reagents used in the whole extraction process, such as extractants, thickeners, frothers, activators, depressants, coagulants, collectors and pH regulators (See Appendix for Sino-Metals Material Safety Data Sheets).
- Process water including makeup water added to process streams after waste streams exit the plant circuit for process water balancing and a means of transportation of the tailings (Cacciuttolo et al., 2023).
- Minerals, which may include residue unrecoverable minerals of interest, other non-targeted minerals due to their low economic value or toxic substances from the ore body (King, 2019).

Therefore, tailings will always contain residue target minerals. But the higher the efficiency of the separation technologies, the lower the amount of minerals of interest that find their way to the tailings.

1.9.2 Analysis of the tailings samples

Samples of tailings solids and liquor were collected from various paddocks that make up TD 15 during the period 22nd–24th September 2025. The samples were submitted to Alfred H Knight Laboratory for chemical analysis. Tailings solids were also submitted to Controlab, a geotechnical laboratory in Lusaka for analysis of particle size distribution. The sites where tailings samples were collected from are shown in Figure 1-13 below. The results of the certificates of analysis are in the Appendix.

1.9.3 Identification of key pollutants in the tailings

Tables 1-2 and 1-3 summarise the key physical parameters analysed in nine (09) liquor samples and six (06) tailings solids samples. Tailings sampling was done. The full certificates of analysis are attached in the Appendix.

Based on the analytical results, the parameters that were assessed to be significant for investigation in various environmental media are aluminium (Al), arsenic (As), Boron (B), calcium (Ca), cadmium (Cd), cobalt (Co), chromium (Cr), copper (Cu), magnesium (Mg), nickel (Ni), lead (Pb), selenium (Se), zinc (Zn), manganese (Mn), sulphates (SO_4^{2-}), pH and electrical conductivity (EC).

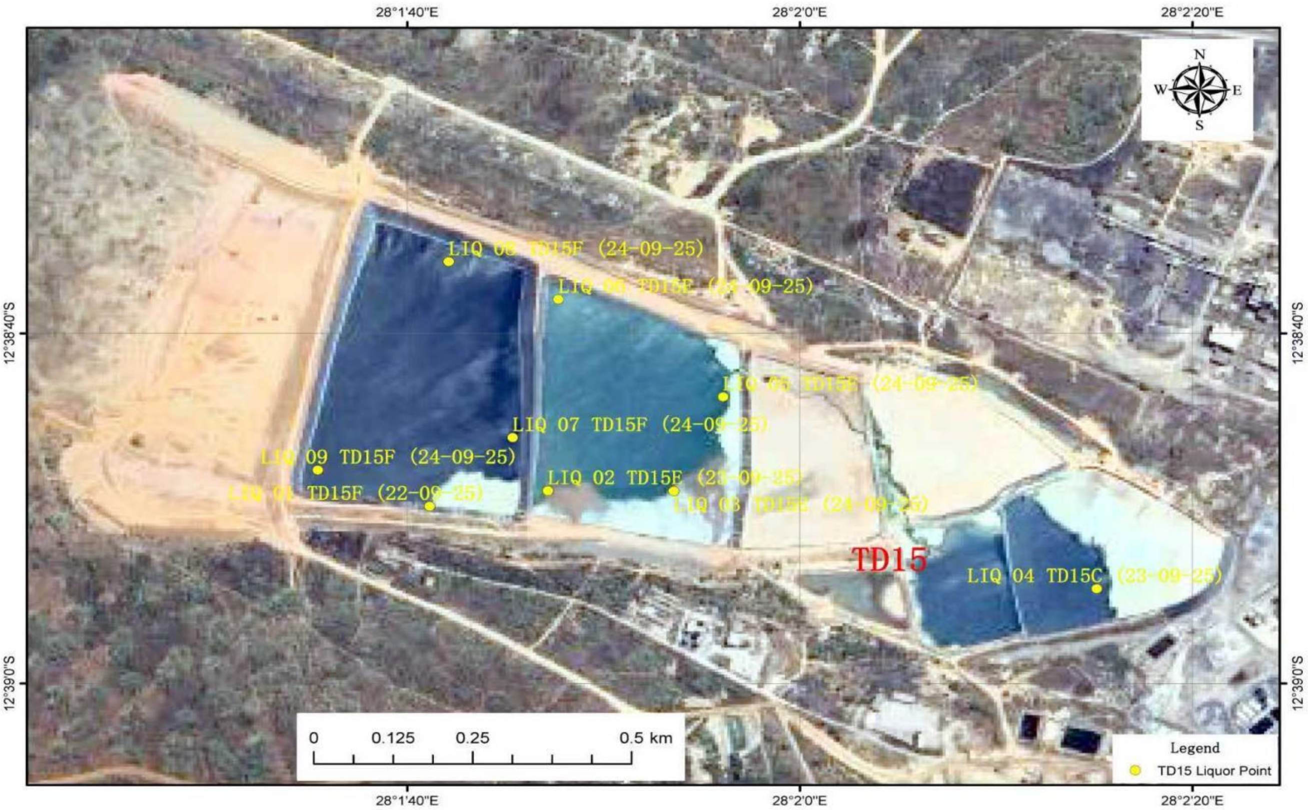


Figure 1-13: Map of liquor sampling points

Table 1-2: Liquor physical parameters

Description	Alk	pH	TDS	EC
Sample reference	**mg/L**	**-**	**mg/L**	**µS/cm**
LIQ 01 TD 15E (23-09-25)	<1.2	1.65	14875.0	29750.0
LIQ 02 TD 15F (22-09-25)	<1.2	2.59	12500.0	25000.0
LIQ 03 TD 15E (24-09-25)	<1.2	2.49	12570.0	25140.0
LIQ 04 TD 15C (23-09-25)	<1.2	2.93	11660.0	23320.0
LIQ 05 TD 15E (24-09-25)	<1.2	4.49	12506.0	25010.0
LIQ 06 TD 15F (24-09-25)	<1.2	2.57	11776.0	23550.0
LIQ 07 TD 15F (24-09-25)	<1.2	1.89	15900.0	31800.0
LIQ 08 TD 15F (24-09-25)	<1.2	1.70	15860.0	31700.0
LIQ 09 TD 15E (24-09-25)	<1.2	2.71	16050.0	32100.0
*ZEMA allowable limits for discharge of effluent into the environment	-	6.5-8.5	1500	4300
Mean	1.2	2.42	13744.11	27485.56
Standard Deviation (SD)	0	0.92	1884.05	3765.7
Relative Std error (%)	0	12.63	4.57	4.57

***Note:** ZEMA limits for discharge of effluent into the environment do not formally apply to tailings liquor retained within the impoundment. In this study they were used solely as a conservative benchmark to assess potential risk in the event that tailings liquor accidentally escapes from the tailings dam.

The physical parameters revealed an acidic liquor with a mean pH of 2.42 (SD of 0.92 and 13% relative standard deviation) that needs to be neutralised before discharge to receiving waters. Equally, the liquor's total dissolved solids (TDS) mean value was 13744.11 (SD of 1884 and 5% relative standard deviation), which was about 7 – 10 times above the ZEMA maximum allowable effluent limit of 1500 mg/L.

From this analysis of the liquor samples, it can be concluded that the three physical parameters, pH, TDS and EC require constant monitoring further downstream and remediated to ensure that their lie below the maximum allowable limits.

Table 1-3: Solid physical parameters

Description	Alk	pH	TDS	EC
Sample reference	**µg/g**	**-**	**µg/g**	**µS/cm**
SOL-01	<1.2	3.81	1430.0	2857.0
SOL-03	<1.2	5.77	626.0	1252.0
SOL-04	<1.2	5.01	380.0	760.0
SOL-05	<1.2	5.79	1376.0	2751.0
SOL-06	<1.2	4.60	674.0	1348.0
SOL-07	<1.2	4.73	710.0	1420.0

Mean	1.2	4.95	866.00	1731.33
Standard Deviation	0	0.76	432.02	863.01
Rel. Std Error (%)	0	15.25	49.89	49.85

For the solid samples shown in Table 1-3, it was observed that the alkalinity was the same as that in the liquor, which is expected. A mean value of less than 1.2 mg/L (0 SD) was recorded. The pH values in the solids were slightly less acidic with a mean value of 4.95 (SD of 0.76 and relative standard deviation of 15%) than in the liquor which was at a mean pH of 2.42 (see Table 1-2). Additionally, the TDS and EC in the tailings were significantly lower than in the liquor because most of the dissolved salts or minerals were deposited in the liquor, which was expected at those pH conditions.

1.9.4 Conclusion

In conclusion, analysis of the physical and chemical parameters of the tailings solids and spent liquor were conducted and, where applicable, comparisons were made to the set maximum allowable limits in effluents and soils. The physical parameters to be monitored include pH, TDS and EC as they were generally above the acceptable ZEMA allowable limit in effluents. For the chemical analyses, it is vital that the parameters identified as existing in high concentrations than their set limits in the liquor and tailings be monitored downstream and their potential impacts on land, the aquatic environment and air assessed. Additionally, and to a larger extent, the parameters to monitor and assess are different in each impact assessment study being conducted by the expert and so parameters to monitor will be guided largely by these experts who look at different impacts of these minerals in the ecosystem.

This study has managed to analyse and determine parameters with high concentration (in magnitude) and those that are above or below acceptable limits, were applicable. The geochemical assays of the tailings (solids and liquor combined) in relation to the magnitude in concentration not impact, revealed the following order: sulphates > magnesium > copper > calcium > aluminium > manganese > potassium > cobalt > zinc > phosphates > sodium.

The total petroleum hydrocarbons, sodium, arsenic, chromium, boron, selenium, uranium, lead, fluorine, hydrogen bicarbonate and cyanide ions, chloride, nitrates and mercury, were significantly lower in concentration (based on magnitude not impact) in the liquor and solids but should be equally monitored in different media (soil, water, crops) as guidance and determined by key experts.

Parameters with existing maximum effluent allowable limits, should be closely monitored to ensure they comply with laid down regulations. On the other hand, the heavy metals and metalloids identified, which do not have stated set limits, should equally be assessed and their concentrations monitored and profiled to identify any spikes or reductions in the concentrations over time and study their different impacts in varied environments.

2 METHODOLOGY AND LIMITATIONS

2.1 Technical approach

The technical approach that was used to conduct the ESIIA is illustrated in the workflow in Figure 2-1 below. The figure shows the five stages for the execution of the assignment, the main activities to be carried out during each phase and the deliverables. The detailed workflow is presented in Figure 2-2 and the outcome of the assessment is in Figure 2-3.

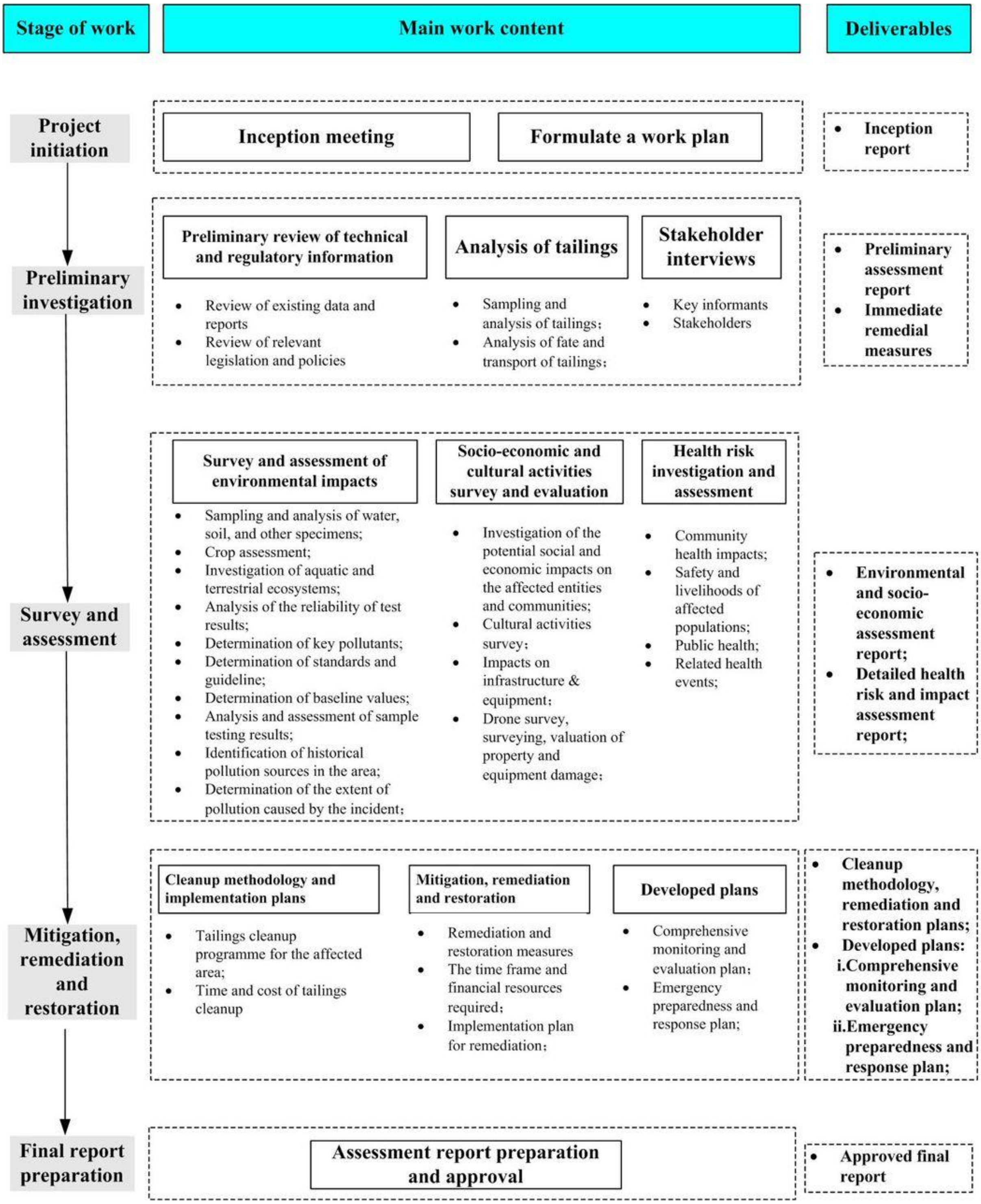


Figure 2-1: Workflow for the Environment Incident Impact Assessment

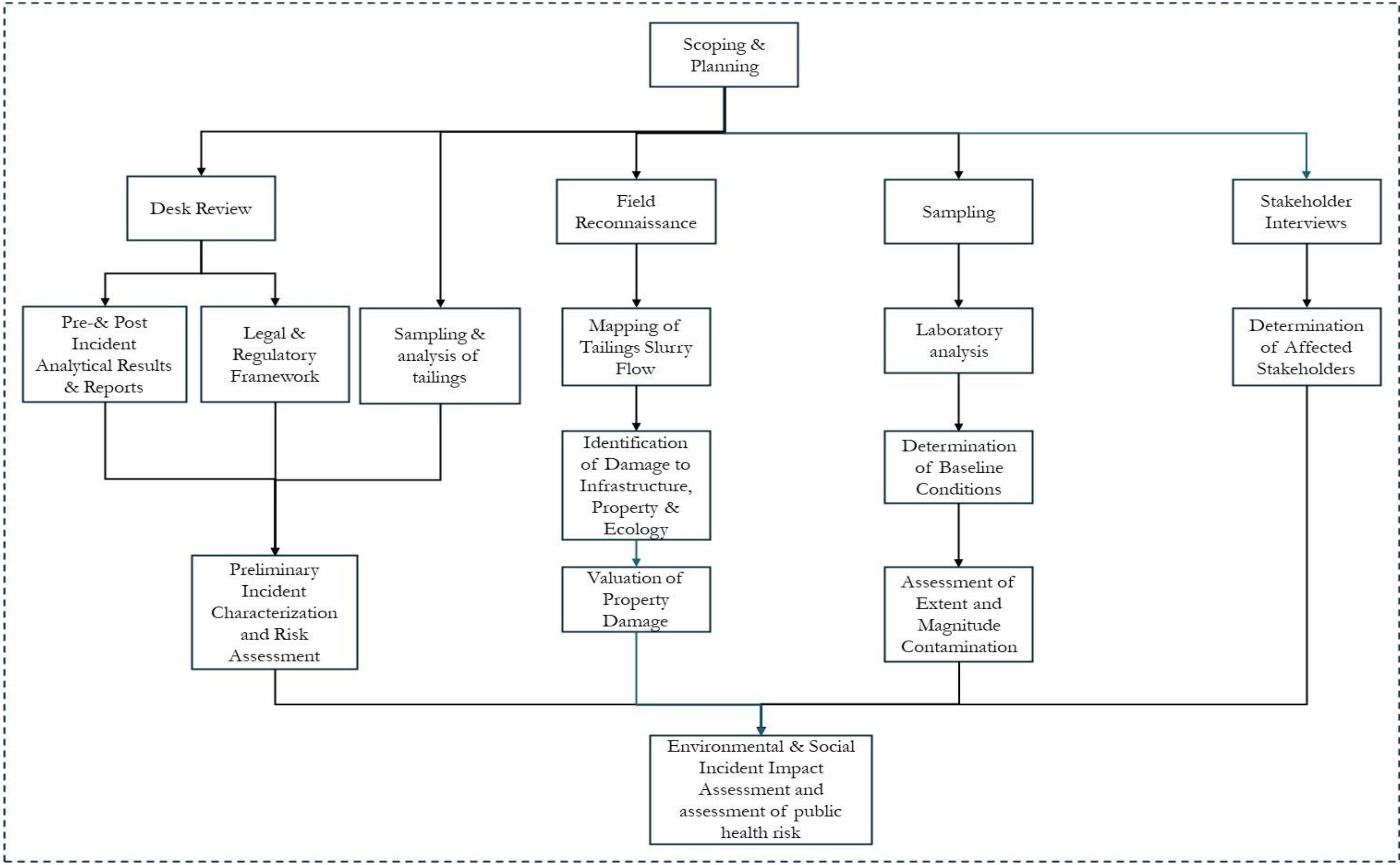


Figure 2-2: Detailed workflow for the Environment Incident Impact Assessment

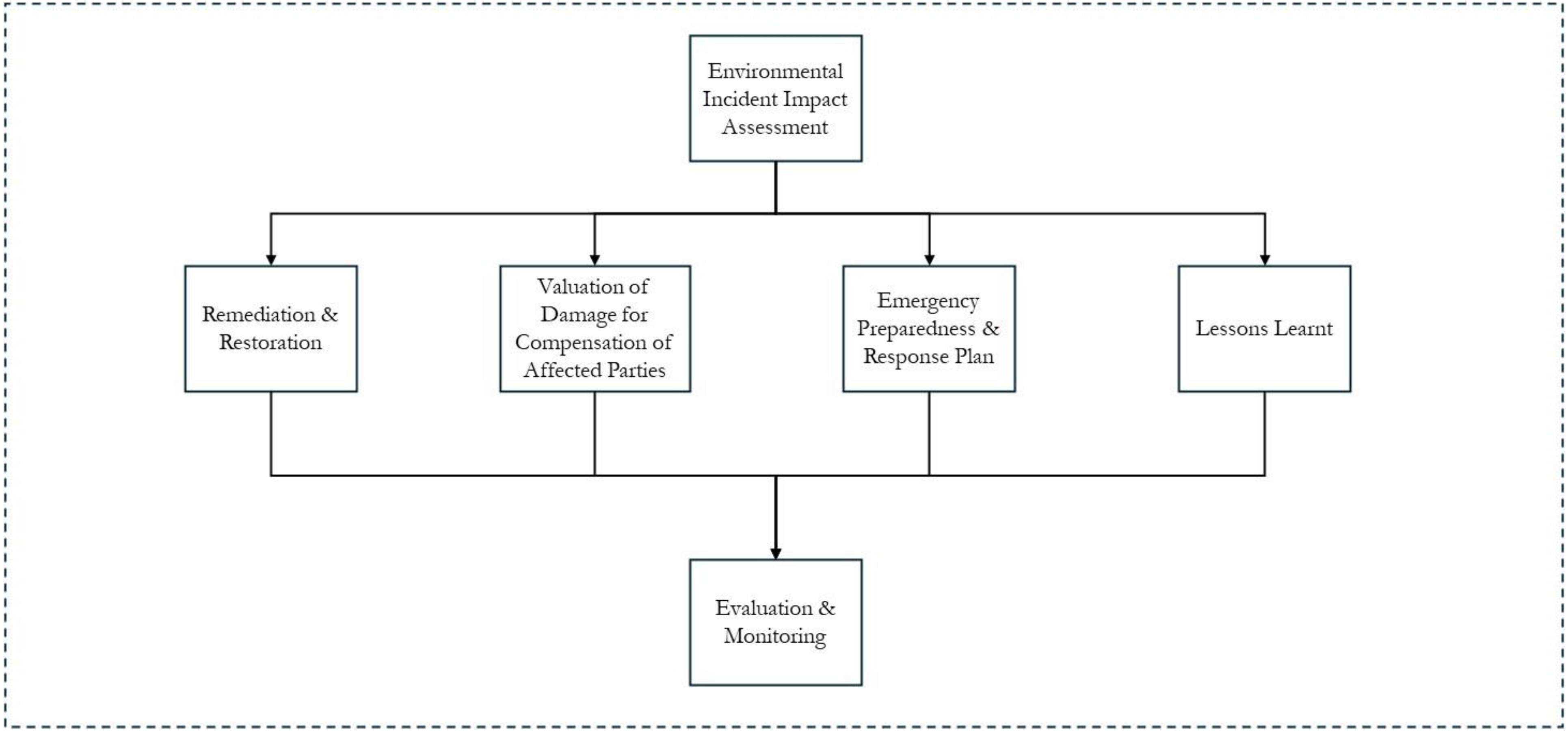


Figure 2-3: Outcomes of the Environment Incident Impact Assessment

2.2 Activities carried out

The following activities were carried out during the assessment.

1. Drone aerial photography of the area between TD 15 and confluence of Chambishi Stream with Mwambashi River
2. Surveying of the tailings flow path
3. Stakeholder consultations with Civil Society Organisations and key stakeholders like the local authorities and Nkana Water Supply and Sanitation Company Limited.
4. Radiation assessment of TD 15 and the surrounding area was carried out by the Radiation Protection Authority.
5. Sampling and analysis of tailings from TD 15 to determine the physical and chemical composition.
6. Soil sampling and analysis from TD 15 to Itezhi-Tezhi Dam
7. Surface water and sediment sampling and analysis from Chambishi Stream, Mwambashi River and its tributaries, Kafue River from upstream of Mwambashi River to Itezhi-Tezhi Dam.
8. Sampling and analysis of groundwater samples collected from shallow wells in selected areas in Kitwe.
9. Socio-economic assessment of key communities involving Kalusale, Ipusukilo, Machiya, Ngabwe and Itezhi-Tezhi.
10. Agronomy assessment of selected farming areas between Chambishi and Itezhi-Tezhi
11. Ecological assessment of the Chambishi Stream, Mwambashi River and Kafue River going down to Itezhi-Tezhi.
12. Assessment of the impact on public health and risk assessment by analysing the clinical data and the analytical metal content of soil, water and crops.

2.3 Overall assessment design

The Environmental and Social Incident Impact Assessment (ESIIA) was designed as an integrated, multi-media study covering the full impact corridor from TD 15 through Chambishi Stream and Mwambashi River to the Kafue River, as well as priority affected communities in Kalulushi and Kitwe Districts.

The assessment combined:

- Field sampling and monitoring of surface water, groundwater, soil, sediment, air, biota and crops;
- Laboratory analysis using accredited methods for physico-chemical parameters and trace/heavy metals;
- Remote sensing and GIS for catchment and vegetation analysis; and
- Socio-economic surveys and document review to characterise livelihoods, vulnerabilities and incident-related losses.

All work was undertaken to generate defensible, decision-grade evidence to support remediation, restoration and long-term management of the incident.

2.4 Study area delineation

The assessment focused on the full impact pathway of the spill, starting from the discharge point at the Sino-Metals tailings dams, where acidic leach residue (low pH) entered the open environment and flowed along the Chambishi Stream, into the Mwambashi River and subsequently the Kafue River. The spatial scope covered both upstream stretches (used as control/reference sites) and downstream reaches extending as far as the Itezhi-Tezhi Dam.

Socio-economic work focused on Kalulushi and Kitwe Districts, particularly farming areas, riparian communities and Kalusale Ward identified in Government compensation and reconnaissance studies.

2.5 Media-specific methods

2.5.1 Surface water and sediment

Sampling and analysis status: Sediment: 509 samples collected; Surface water: 512 samples collected.

Sampling procedure: At each site, composite water samples (left, mid-channel, right) and augered bed sediments (0–10 cm) were collected under documented SOPs and stored in cooled conditions.

Laboratory analysis: Samples were analysed at Alfred H. Knight Laboratory (Kitwe) for pH, electrical conductivity (EC), sulphate, major cations and metals (arsenic (As), aluminium (Al), cadmium (Cd), chromium (Cr), cobalt (Co), copper (Cu), iron (Fe), lead (Pb), manganese (Mn), nickel (Ni), selenium (Se), zinc (Zn)) using accredited methods.

Assessment benchmarks: Results were evaluated against Ambient Water Quality Standards ZS 1182:2021 for the Kafue catchment, with historical data used to distinguish incident-related changes from background mining impacts.

2.5.2 Groundwater

Sampling and analysis status: 44 shallow wells and one borehole were collected and analysed.

Hydrocensus and well survey: A hydrocensus was undertaken in Kalulushi and Kitwe Districts, covering Kalusale, Ipusukilo, Bulangililo, Chipata and Luangwa. Selected shallow wells were surveyed for collar coordinates and elevation.

Laboratory analysis: Samples were analysed at Alfred H. Knight for 17 indicators, including pH, electrical conductivity (EC), major ions and trace metals.

Assessment benchmarks: Results were compared against WHO drinking-water guidelines and interpreted together with groundwater flow direction and local land-use/sanitation conditions.

2.5.3 Soil

Sampling framework: In potentially impacted and control areas around TD 15 and along the Chambishi, Mwambashi and Kafue catchments, 554 locations were sampled using a combination of systematic grid and purposive sampling; 1,188 soil samples (topsoil and subsoil) were collected.

Laboratory analysis: All samples were analysed for 17 parameters: aluminum (Al), arsenic (As), boron (B), calcium (Ca), cadmium (Cd), cobalt (Co), chromium (Cr), copper (Cu), magnesium (Mg), manganese (Mn), nickel (Ni), lead (Pb), selenium (Se), zinc (Zn), sulphate (SO_4^{2-}), pH, electrical conductivity (EC) using accredited methods.

Assessment approach: Contamination indices, spatial analysis and comparison with FAO/WHO guidelines and regional baselines were used to delineate the 5.35 km² core affected area and identify hotspots.

2.5.4 Ecological assessment

Sampling and analysis status: 95 samples from 35 sites were collected and analysed.

Field methods:

Macroinvertebrates: SASS5 protocol (kick-net, family-level ID, SASS/ASPT scores);

Riparian vegetation: Quadrats along bank-perpendicular transects, recording species, cover, height and stress symptoms.

Fish: Opportunistic sampling in selected reaches (where feasible).

Remote sensing: Sentinel-2 NDVI time series (January, March, October 2025) were processed and validated with RTK-enabled drone imagery and field quadrats to diagnose vegetation stress and recovery patterns.

2.5.5 Agronomic assessment

Sampling and analysis status: 135 agricultural soil samples collected and analysed at 124 locations and 139 crop samples from 55 locations.

Stratification: Fields were stratified into high-, medium- and low-impact zones and control sites along the river corridor.

Sampling: Composite topsoil (0–20 cm) and plant tissue samples (edible and leafy parts) were collected from georeferenced plots; farmer questionnaires and visual crop-stress diagnostics (chlorosis, necrosis, stunting, leaf curling) were recorded.

Analysis: Soils and tissues were analysed for pH, EC, microbial biomass (where available) and trace/heavy metals. Results were interpreted in line with FAO/UNEP/ZEMA guidance to assess agronomic risk and food-chain implications.

2.5.6 Air quality

Sampling and analysis status: 11 field gas samples were collected and analysed, and 11 acid-mist sampling also conducted.

Methods: Gases (CO, CO_2, SO_2, CH_4, O_2, H_2S) were measured in situ using a calibrated Dräger X-am 5600; acid mist was sampled using a GilAir Plus pump and Dreschel bottles (NaOH + indicator), following NIOSH 7908 principles.

Assessment benchmarks: Results were assessed against ZEMA statutory limits and recognised international occupational exposure guidelines.

2.5.7 Socio-economic assessment

Desktop review: Incident reports, legislation, ZEMA/MSD/WARMA compliance orders, Ministry of Agriculture and Fisheries compensation reports, and relevant policies were reviewed.

Fieldwork: Reconnaissance visits, GIS mapping of farmsteads, and structured/semi-structured interviews were conducted with:

- Affected farmers and livestock owners;
- Fishermen and local residents;
- SMLZ employees;
- District and ward-level government officials.

Analysis: Impacts on livelihoods, health, community infrastructure, social cohesion and vulnerable groups were identified and used to design compensation, CSR, restoration and resettlement measures.

2.5.8 Fisheries assessment

The fisheries impact assessment was conducted using a rapid fisheries assessment method to evaluate post-incident fishery status in the Kafue River system. The study employed a mixed-method approach combining fishery-independent and fishery-dependent data collection. Fishery-independent sampling utilized multi-meshed experimental gillnets, meshed traps and handlines deployed across multiple habitats during both day and night to capture a broad range of species. Fishery-dependent information was obtained through assessment and purchase of landed catches to include species not directly sampled. key informant interviews with local fishers were conducted to incorporate indigenous ecological knowledge on fishery status, fishing practices and observed impacts. Collected fish were identified to species or family level, and biometric data including length, weight, sex and gonadal maturity were recorded. Growth status was assessed using length–weight relationships and condition factors, while reproductive potential was evaluated through gonadal staging and estimation of size at first maturity (L50). Selected indicator species were analysed for heavy metal bioaccumulation using whole-fish laboratory analysis. Data analysis focused on population structure, growth patterns, reproductive status and human health risk, providing an integrated assessment of fisheries condition following the pollution incident.

The livestock assessment was conducted using the one health approach by incorporating the animal health, human health and environment. The procedure included the collection of relevant data from Government ministries and agencies and conducting key informant interviews in the affected areas.

2.5.9 Quality Assurance and Quality Control (QA/QC)

Across all media, strict QA/QC procedures were applied, including:

Use of standard sampling protocols and trained field teams;

Clean containers, triple rinsing (for water), and appropriate preservation;

Maintenance of cold chain and chain-of-custody documentation from field to laboratory;

Collection of field duplicates, blanks and control samples where applicable;

Use of ISO/IEC 17025-accredited laboratories and certified analytical methods;

Cross-checking field measurements with laboratory results and historical datasets.

These controls were designed to ensure that the data are robust, traceable and suitable for regulatory and technical decision-making.

2.6 Assumptions and Risks

Despite the rigorous methodology, several limitations and uncertainties should be acknowledged:

1. Timing of the Study
   Most field campaigns were conducted approximately eight months after the incident.

   Short-term peak concentrations immediately following the spill could only be inferred from historical data and incident reports, not directly measured by this ESIIA.

2. Site Accessibility and Coverage
   Certain river reaches, wetlands and farm plots were difficult to access due to dense vegetation, steep banks, security constraints or low water levels.

   In such cases, sampling locations were adjusted, which may introduce minor spatial bias.

3. Historical Data Gaps and Quality
   Historical monitoring data from various institutions often lacked coordinates, QA/QC metadata or complete parameter sets.

These datasets were used cautiously—primarily to identify trends and orders of magnitude, rather than as precise baselines.

4. Detection Limits and Analytical Constraints
   Some parameters in groundwater and surface water were below Method Detection Limits, which may obscure very low-level contamination.

   Radiological monitoring was limited to dose-rate screening and gamma spectroscopy; long-term radionuclide speciation was beyond the scope of this ESIIA.

5. Attribution of Sources
   The Kafue basin is a multi-source, historically impacted system with numerous mines, tailings dams, industrial plants and urban settlements.

   While geochemical fingerprints and spatial patterns strongly link certain impacts to TD 15 and upstream mining, complete separation of incident-specific effects from legacy and regional mining influences is not always possible.

6. Ecological and Agronomic Variability
   Biological responses (e.g. macroinvertebrate indices, crop uptake) are influenced by seasonality, hydrology, soil type, farming practices and species physiology.

   Results therefore represent a snapshot under the specific conditions of the survey period, and ongoing monitoring is required to confirm trends.

7. Socio-Economic Data Constraints
   Socio-economic findings rely on self-reported information, existing Government compensation assessments, and a finite sample of interviews.

   While triangulated where possible, some under- or over-reporting of losses and vulnerabilities cannot be fully excluded.

Overall, these limitations do not invalidate the conclusions of the ESIIA, because the assessment applied an integrated multi-media approach with adequate sampling coverage and upstream control/reference sites, supported by strict QA/QC to minimise bias and strengthen the reliability of the findings. However, these limitations should be considered when interpreting the magnitude of impacts and prioritising remediation. They also reinforce the need for continued monitoring, adaptive management, and periodic updating of the assessment as new data become available.

3 POLICY, LEGAL AND REGULATORY FRAMEWORK

This section presents an analysis of the policy, legal and regulatory framework in Zambia as it relates to the sound management of the environment and natural resources and the concept of sustainable development vis-à-vis pollution prevention and control. This section is divided into three subsections as follows:

3.1 Policy and Legal Framework

3.1.1 Policy Framework

The discussion and analysis of the policies was undertaken, taking into account the assignment on the impact assessment of the tailing discharge incident of February, 2025 at Sino Metals in the Copperbelt Province of the Republic of Zambia. The following policy instruments have been identified for purposes of the assignment.

3.1.1.1 National Policy on Environment, 2025

The first National Policy on Environment (NPE) was adopted in 2007 by the GRZ after a consultative policy development process with the goal of providing a framework for sustainable management of Zambia's environment to facilitate retention of its integrity to support the needs of current and future generations. In December 2025 the GRZ launched a new National Policy on Environment ("the 2nd NPE") as part of a triple policy reform to strengthen environmental governance and climate resilience. The overall objective of the 2nd NPE is to provide a framework for the sustainable management of Zambia's environment and natural resources. For purposes of the assessment, suffice to mention that specific object number (iv) of the 2nd NPE is to enhance measures to prevent, control and manage pollution[3]. The Policy essentially provides a comprehensive and principle-based framework for effective environmental management and utilisation of natural resources through multi-sectoral approaches at different levels of governance, in order to ensure sustainable management of natural resources, prevent environmental degradation and align Zambia's environmental efforts with regional and international environmental commitments.

The Policy recognises the fact that "Although extractive industries such as mining contribute significantly to the Country's Gross Domestic Product (GDP), unsustainable mining activities have led to adverse environmental impacts such as air, soil and water pollution, land degradation, sinkholes, deforestation, erosion and loss of biological diversity"[4]. This policy is therefore relevant to the February 18th incident as it is the foundational policy for environmental and natural resources management in Zambia. It provided measures for prevention, control and management of pollution, some of which include the following:

1. Strengthening environmental compliance and enforcement at all levels;
2. Strengthening the development and implementation of environmental management tools;
3. Facilitating the development of strategies for sound management of chemicals and waste;
4. Strengthening waste management;

3 Ibid

4 Ibid at page 5

5. Strengthening water pollution prevention and control systems;
6. Enhancing land pollution control measures and monitoring systems.

The policy remains an important instrument in the sound management of the environment and natural resources, as it relates to the February incident at Sino Metals.

3.1.1.2 National Minerals Resources Development Policy, 2022

The National Mineral Resources Development Policy (NMRDP) is the principal policy instrument of the government of Zambia on mineral resources development. The NMRDP was adopted in 2022 by the government of Zambia. The vision of the NMRDP is a smart, sustainable, diversified and growth-centred mining sector**.** Amongst the objectives of the policy, of relevance to this assignment are the following, in the order they appear in the policy;

Objective 4: Enhance the monitoring of operations and compliance in mining and non-mining rights. One of the measures to achieve this objective, and relevant to the Sino Metal incident, is the development of a monitoring and evaluation framework, to record the performance of a mining company.

Objective 5: Facilitate the attainment of a socially responsible and environmentally sound mining for health, safety and environmental protection. Some very important measures to achieve this objective and indeed relevant to Sino Metals incident include the following;

i) Strengthen regulatory framework on health, safety and environmental protection; and
ii) Promote environmental rehabilitation and remediation

Objective 9: Promote Corporate and Social Responsibility in the mining sector. Some identified measures to achieve this objective and relevant to the Sino Metal incident include the facilitation of the development of local environmental management plans around mining areas.

3.1.1.3 National Water Policy, 2024

The National Water Policy, 2024 ("NWP") is the principal policy on water resources management in Zambia. This Policy brings together the two sub-sectors namely: water resources management and development, and water supply and sanitation to ensure integrated and effective development, management and provision of water supply and sanitation services. Sustainable water resources management ensures the long-term availability of water resources for both the current and future generations. In addition, sustainable water resources management ensures that the country's water resources are managed in an integrated and participatory manner.

However, related to the Sino Metal incident, mining generates huge volumes of waste at various stages of production. Such wastes contain, in most cases, heavy metal pollutants that pose health and ecological risks.

Despite the Government's effort to ensure that the country's water resources are conserved and protected, some of the measures already developed, such as developing catchment or river restoration plans which include the ***Restoration and Protection Plan for Magoye River Catchment*** to protect and restore degraded river catchment, are yet to be fully implemented.

Other measures, related to the incident, include the Ambient Water Quality Standards and guidelines which were developed but are yet to be implemented.

3.1.1.4 National Policy on Wetlands, 2018

Zambia does not have a single, standalone "Wetlands Policy", but rather a strong framework guided by the Guidelines for the Sustainable Utilisation of Wetlands (2025), an Implementation Plan (2018-2028), and related national policies like the National Water Policy (2024), all focused on managing vast wetlands (19% of Zambia) for conservation and socio-economic benefits.

The key themes in the Zambian Wetland Policy are the following:

i) Integrated Management by bringing together water, land and biodiversity sectors
ii) Multi-Sectoral Approach involving government, private sector, NGOs and communities
iii) Economic Potential where wetlands are recognised for fisheries, tourism, agriculture and water supply.

Mining activities in Zambia pose significant threats to wetland ecosystems. Mining has been known to disrupt natural water flow patterns in wetlands by altering land use and increasing runoff while reducing groundwater recharge. Such changes can lead to the drying up of wetlands, severely impacting flora and fauna that depend on these ecosystems. A typical example is the Wieners Dam south east of Sino Metal's TD 15, which is now completely buried in historical tailings deposits.

The wetland south of TD 15, commonly known as the New Dam, demonstrates the ability to act as natural filters, mitigating the impacts of mining by sequestering and neutralising contaminants through processes like adsorption and co-precipitation. However, it must be known that extreme weather events, exacerbated by climate change, threaten to overwhelm such a natural system, mobilising pollutants during intense rainy seasons and reducing the wetland's resilience. The message here is that there should not be total dependency on such wetlands as pollution sinks, but rather development appropriate treatment facilities before the effluent is discharged into the "New Dam", for conservation and protection of the "New Dam".

3.1.1.5 National Resettlement Policy (2024)

The resettlement process in Zambia is regulated by a comprehensive legal and policy regime aimed at ensuring that displacement, compensation, and relocation activities are conducted in a lawful, fair, and sustainable manner that protects the rights and welfare of affected households and host communities.

The National Resettlement Policy governs all displacement and resettlement activities in Zambia. It emphasizes structured planning, meaningful stakeholder participation, livelihood restoration, integration with host communities, and compliance with the African Union Kampala Convention on Internally Displaced Persons. The Policy also mandates the preparation of a Resettlement Action Plan (RAP) supported by socio-economic surveys, spatial planning and fair compensation principles.

3.1.1.6 National Fisheries and Aquaculture Policy, 2023

The National Fisheries and Aquaculture Policy is the principal policy on fisheries and aquaculture development. The Policy was adopted in 2023. The vision of the policy is "an efficient, competitive, sustainable and export - led fisheries and aquaculture subsector."[5]. The overall objective of the policy is to transform the fisheries and aquaculture subsector in order to enhance sustainable fisheries and aquaculture development[6]. The specific objectives of the policy include:

(a) To promote sustainable fish production and productivity;

b) To strengthen fisheries and aquaculture extension service delivery;

c) To strengthen Research and Development (R&D) in Fisheries and Aquaculture;

d) To enhance market linkages for fish and fish products;

e) To improve and maintain Aquatic Animal Health;

f) To prevent and mitigate environmental degradation; and

g) To mainstream crosscutting issues in fisheries and aquaculture.

Considering the above objectives and the principles enunciated below, it will be noted that pollution from mining houses such as the February, 2025 tailings discharge incident is inimical to the realisation of the objections of the Fisheries and Aquaculture policy. Whenever there is a discharge of toxic waste, aquatic life is negatively impacted upon. The policy on aquaculture is an important tool in safeguarding this important natural resource.

3.1.2 Legal and Regulatory Framework

This subsection presents Zambia's legal and regulatory framework relevant to the Sino Metal incident, relating to pollution prevention, control and management. The legal and regulatory framework comprises the following instruments:

- The Constitution,
- Acts of Parliament,
- Delegated Legislation (Statutory Instruments), and
- By-laws.

In addition to the Constitution of Zambia, Chapter 1 of the Laws, the following Acts of Parliament have been reviewed under this Consultancy, in view of the Sino Metal incident that occurred on 18th February 2025:

1. The Environmental Management Act No. 12 of 2011 as amended by Act No. 8 of 2023;
2. The Local Government Act No. 2 of 2019;
3. The Public Health Act Chapter 295 of the Laws of Zambia;
4. The Water Resources Management Act No. 21 of 2011;
5. The Water Supply and Sanitation Act No. 28 of 1997;
6. The Disaster Management and Mitigation Act No. 13 of 2010.

[5] GRZ, 2023 National Fisheries and Aquaculture Policy, Lusaka at page 10
[6] Ibid page 11

7. The Minerals Regulation Commission Act No. 14 of 2024;

3.1.2.1 The Constitution of Zambia, Chapter 1 of the Laws of Zambia

The Constitution of Zambia, Chapter 1 of the Laws as amended by Act No. 2 of 2016 ("the Constitution") is the supreme law of the land. The Constitution has made provision for the protection and management of the environment and natural resources. Principles such as the polluter pays principle and the precautionary principle are expressly enunciated. Under Articles 256 and 257, the Constitution provides for the protection of the environment and natural resources and the sustainable utilisation of the environment and natural resources respectively.

The assessment of the post pollution incident by Sino Metals is being undertaken in compliance with the Polluter Pays principle enshrined in the Constitution.

3.1.2.2 Environmental Management Act No. 12 of 2011 as amended by Act No. 8 of 2023

An analysis of the environmental legal framework in Zambia will show that, subject to the Constitution, the EMA is the principal Act of Parliament on environmental management. The Act provides for environmental protection and pollution control as well as enshrining the polluter pays principle.

The EMA further provides for licensing of activities that have potential to impact the environment and natural resources. One of the key Licenses provided for under section 33 relevant to the assessment of the tailings discharge is the emission license and, in this respect, the Sino Metal effluent discharge license assigned to a discharge location downstream of the "New Dam, and before discharging into the Chambishi stream.

3.1.2.3 Local Government Act No. 2 of 2019

This is Zambia's main law, which established an integrated system for local governance, focusing on decentralization, democratic participation, revised functions for councils (like roads, fees, services), and incorporating traditional leadership roles, replacing the older 1991 Act. This Act facilitates an integrated, multi-tiered system for City, Municipal, and District Councils, aiming to empower local communities and manage public services, with amendments like the 2023 Act further refining local government operations.

Among other relevant provisions, this Act provides for the establishment of a Ward Development Committee in each ward, in the area of a local authority. The WDC, in view of their functions in a community, became important points of contact when reaching out to the affected communities, during the stakeholder engagement process. The stakeholder engagement process in this respect, was important to appreciate the socio-economic impact the incident had on those affected, thereby improving the decision-making process in the development of remediation and restoration strategies.

Going forward, Sino Metals is encouraged to hold regular community meetings to explain mining activities and risks, the associated environmental impacts and the safety and emergency procedures.

3.1.2.4 Public Health Act, Chapter 295 of the Laws of Zambia

The Public Health Act, Chapter 295 (Cap 295) of the Laws of Zambia, is the primary legislation for safeguarding public health, focusing on preventing and controlling diseases, ensuring sanitation, regulating food safety, managing water supply, and controlling vectors like mosquitoes, with provisions for infectious diseases, hygiene, and local authority responsibilities. Key aspects include notification of diseases, disinfection of premises, safe food handling (like ice-cream), waste management, and powers for health officers, with updates reflecting changes in public health needs and modern governance.

The primary purpose of the Public Health Act, with respect to the Sino Metal incident, is to safeguard the health of the population. Exposure to acidic substances and dissolved metals can cause skin irritation, gastrointestinal illness, respiratory problems, and long-term health risks, bringing the incident directly within the scope of public health law.

The Act places a duty on local authorities to investigate conditions that may be harmful to health. In this scenario, this supports, among others, the sampling and monitoring of water quality as well as the assessment of risks to residents and water users.

3.1.2.5 The Water Resources Management Act No. 21 of 2011

This is an Act to establish the Water Resources Management Authority and define its functions and powers; provide for the management, development, conservation, protection and preservation of the water resource and its ecosystems; provide for the equitable, reasonable and sustainable utilisation of the water resource; ensure the right to draw or take water for domestic and non-commercial purposes, and that the poor and vulnerable members of society have an adequate and sustainable source of water free from any charges; create an enabling environment for adaptation to climate change; provide for the constitution, functions and composition of catchment councils, sub-catchment councils and water users associations.

A core aim of water resource management is to protect rivers, streams, wetlands and groundwater from pollution. In the Sino Metal incident, the acidic tailings released into the environment lowered the pH of surface water and mobilized toxic metals. This occurrence directly undermines water resource protection objectives.

Some of the actions required to arrest the occurrence of the incident would include the treatment of acidic tailings through neutralisation (lime treatment) before it is stored at TD 15 and ensure installation of early warning systems to detect compromises to the integrity of the ponds at TD 15.

3.1.2.6 The Water Supply and Sanitation Act No. 28 of 1997

The Water Supply and Sanitation Act No. 28 of 1997 is a Zambian law that established the National Water Supply and Sanitation Council (NWASCO) to regulate water and sanitation services, mandate licensing for providers (Commercial Utilities/CUs), promote efficient service delivery, and define roles for local authorities, ensuring safe, sustainable water access through licensing, standard-setting, and enforcement.

The incident of February 2025 impacted negatively on the supply of clean and safe water to thousands of citizens serviced by some water utility firms who had to shut down their facilities in order to ensure that consumers are protected. Water utility companies need to have appropriate early warning systems and be able to switch to alternative safe water sources such as other reservoirs or treated water from unaffected sources.

3.1.2.7 The Disaster Management Act No. 13 of 2010

An Act to establish and provide for the maintenance and operation of a system for the anticipation, preparedness, prevention, coordination, mitigation and management of disaster situations and the organisation of relief and recovery from disasters. It is a key legal framework designed to prevent, reduce, manage, and respond to disasters, including environmental and industrial pollution incidents that threaten people, ecosystems, and livelihoods.

The Act defines a disaster as an event that causes or threatens loss of life, injury, or disease, a disaster that causes environmental damage, disrupts the ecosystem and livelihoods. The release of acidic pollution into the open environment met this definition because it threatened public health, water resources and the ecosystem and community livelihoods.

The Disaster Management Unit may need to activate an Emergency Response and Preparedness Plan for a better response encompassing strong coordination, transparent communication and long-term remediation, as may be supported by disaster management and environmental laws.

3.1.2.8 The Minerals Regulation Commission Act No. 14 of 2024

The Minerals Regulation Commission Act No. 14 of 2024 is Zambia's new primary mining law, replacing the 2015 Act, establishing the single, independent Minerals Regulation Commission (MRC) to centralize oversight, issue rights, manage mineral marketing, and enforce environmental standards, signalling a shift toward a more structured and compliance-driven mining sector with a focus on local beneficiation and citizen participation. Enacted in late 2024 and fully effective in mid-2025, the Act covers exploration, mining, licensing, health, safety, and environmental protection, consolidating regulatory power and introducing enhanced citizen empowerment requirements for mining operators.

The Act empowers the MRC to supervise all mining activities and ensure compliance with environmental, safety and operational standards and therefore relevant to Sino Metals' situation.

3.1.2.9 The Animal Health Act No. 27 of 2010

This Act was among others, created to provide for the prevention and control of animal diseases, as well as to control vectors that contribute to disease propagation in animals. The Act is of import to the February incident as animals were affected by the tailings dam failure.

3.1.2.10 Food Safety Act No. 7 of 2019

The Act provides for the protection of the public against health hazards and fraud in the manufacture, sale and use of food. The Act is relevant to the current assessment as people were exposed to contaminated food such as fish as a result of the February incident.

3.1.2.11 The Fisheries Act No 22 of 2011

The Fisheries Act No. 22 of 2011 provides inter alia for:

(a) the promotion of sustainable development of fisheries and a precautionary approach in fisheries management, conservation, utilisation and development;
(b) the establishment of fisheries management areas and fisheries management committees;
(c) the regulation of commercial fishing and aquaculture; and
(d) the establishment of the Fisheries and Aquaculture Development Fund.

In terms of Section 4(1) of the Fisheries Act, the functions of the Department of Fisheries are to—

(e) conserve, manage and develop fishery resources and waters in a sustainable manner;

(f) manage, develop and protect aquaculture, aquatic vegetation and fish habitats;

(g) take such measures as are necessary for the protection of fish stocks from the effects of pollution and from any other effects which are harmful or potentially harmful to fish stocks;

(h) regulate the conduct of fishing operations including aquaculture and operations ancillary thereto;

(i) manage, control and eliminate diseased fisheries resources;

(j) take appropriate measures, in consultation with ZEMA, for the safeguard against extinction of protected species;

(k) issue, vary, suspend and revoke any permits and licences for fishing, equipment used for fishing, aquaculture and other activities for which permits or licences are required under this Act;

(l) ensure the fair access to fisheries resources for commercial, recreational and indigenous use;

(m) conduct and support fisheries research and development;

(n) allocate money from the Fund;

(o) create an environment of cooperation and consultation with other public institutions so as to enable the other public institutions to perform their functions that impact on this Act, within the context of this Act and the ambit of their respective powers and functions;

(p) liaise or interface with similar organs in other countries or international institutions dealing with fisheries conservation and management.

The development of the fisheries sector inevitably requires an environment that is free from pollution. Pollution negatively affects aquatic life. The fisheries Act therefore becomes relevant , for reference, to the pollution incident of 18th February 2025.

3.1.3 Statutory Instruments

3.1.3.1 Environmental Management (Licensing) Regulation, 2013

The Environmental Management (Licensing) Regulations, Statutory Instrument No. 112 of 2013 ("the Licensing Regulations"), provides for the control and monitoring of pollution in the environment through the licensing tool. The Licensing Regulations provide a framework for licensing industry in the areas of air and water pollution, waste, chemicals and ozone depleting substances. These Regulations elaborate the general principles enunciated in the EMA providing detailed procedures for licensing.

These regulations are necessary for the licensing and management of Sino Metals operations, including the tailings dam's integrity and in the event that there is a discharge of effluent as it was recorded in the February 18th incident.

Some of the compliance requirements include the updating of the existing Environmental and Social Management Plan and thereafter carry out full implementation of the measures defined in the management tool, coupled with regular monitoring and reporting.

3.1.3.2 The Mines and Minerals (Environmental) Regulations Statutory Instrument No. 29 of 1997.

The Mines and Minerals (Environmental) Regulations, Statutory Instrument No. 29 of 1997 that governs environmental management in mining operations. It is designed to ensure that mining activities are conducted in a way that protects the environment, public health, and surrounding communities.

Key features of the Act include the requirements by the mining companies to submit and obtain approval for an Environmental & Social Impact Assessment of proposed mining project before commencing operations. The Act also requires, among others, that the mining companies prepare and implement an Environmental and Social Management Plan that outlines without fail, the following:

i) Measures to prevent environmental degradation
ii) Pollution control strategies
iii) Rehabilitation and closure plans

The regulations also discuss the handling, storage and disposal of mining waste, which includes tailings, under discussion in this assessment.

3.1.3.3 The Mines and Minerals (Environmental Protection Fund) Regulations Statutory Instrument No. 102 of 1998

The Mines and Minerals (Environmental Protection Fund) Regulations, Statutory Instrument No. 102 of 1998 is a Zambian legal instrument designed to ensure that mining companies set aside financial resources for environmental management, rehabilitation, and pollution mitigation. It complements other mining environmental regulations by making companies financially accountable for the environmental impacts of their operations.

One of the key features of this regulation is the establishment of the Environmental Protection Fund (EPF) where all mining companies are required to contribute a percentage of their revenues or production to a dedicated fund. The fund is used to finance environmental protection, rehabilitation and remediation activities associated with mining operations. The funds are meant to cover costs of environmental rehabilitation after mine closure. Additionally, the funds are also meant to address accident pollution or environmental damage during operations, such as the Sino Metals TD 15 acidic tailings discharge into the open environment.

For events like the Sino Metals acidic tailings release, the EPF regulations were to provide financial resources for emergency remediation and clean up of polluted water and soil. However, huge challenges being faced include inadequate funding levels, weak enforcement and compliance as well as limited transparency and accountability. Overdependency on government intervention could be one of the reasons these challenges have emerged, certainly other than poor enforcement. For a long time, the environmental risks and long term impacts have been poorly assessed. There is an urgent need to revisit this facility if the environment on the Copperbelt Province is to be salvaged.

3.2 International/regional legal framework and treaties

This sub-section presents international and regional instruments to which Zambia is a State Party and are relevant to the incident which is the subject of this assessment report.

3.2.1 The Agreement on the Establishment of the Zambezi Watercourse Commission

The Agreement on the Establishment of the Zambezi Watercourse Commission was adopted in 2004 by the Republics of Angola, Botswana, Malawi, Namibia, Tanzania, Zambia and Zimbabwe. The Agreement applies to the Zambezi Watercourse (Article 2). In terms of Article 4, the objective of the Commission is to promote the equitable and reasonable utilization of water resources of the Zambezi watercourse as well as the efficient management and sustainable use thereof. This also includes the protection of water quality, ecosystems and biodiversity as well as supporting sustainable development within the basin.

3.2.2 The Revised SADC Protocol on Shared Watercourses

The Revised SADC Protocol on Shared Watercourses (2000) is a regional legal instrument adopted by Southern African Development Community (SADC) member states, including Zambia, to promote the coordinated, sustainable, and equitable management of shared river systems. It aligns with international water law principles, particularly the UN Convention on the Law of the Non-Navigational Uses of International Watercourses.

The relevance that this protocol has required member states is to ensure they take appropriate measures to have all the activities within their territory do not cause significant harm to other states.

3.2.3 Ramsar Convention on Wetlands

The Ramsar Convention on Wetlands (1971) is an international environmental treaty that promotes the conservation and wise use of wetlands to protect biodiversity, water quality, and the livelihoods of people who depend on wetland ecosystems. Zambia is a Contracting Party to the Convention and has designated several Ramsar Sites of national and international importance.

The incident that occurred at Sino Metals of releasing acidic tailings, was a threat to rivers, streams and wetlands and this directly conflicts with Ramsar principles. Under this convention, Zambia is obligated to maintain the ecological character of its wetlands. Pollution incidents such as the one for Sino Metals may alter species composition and lead to long term ecosystem degradation. This places a responsibility on the state to prevent, mitigate and restore damage.

3.3 Plans and strategies

The development plans and strategies will have to focus on ensuring compliance, prevention of pollution and enforcement under the applicable laws discussed above. Some of the ingredients to this include the following:

1. Strengthening Regulatory Compliance, which includes regular compliance verifications.
2. Establishing clear liability frameworks for environmental pollution which include penalties for non-compliance or negligence and mandatory remediation obligations.
3. Legally mandating comprehensive environmental and social impact assessment for all mining activities before approval and conducting risk assessments for tailings, acidic waste and potential water contamination.
4. Strengthen coordination between environmental, health, water and disaster management agencies

3.4 Institutional arrangements

This subsection presents an analysis and assessment of the institutional arrangements relating to the structured coordination of government agencies, regulatory bodies, and stakeholders to manage, prevent, and respond to incidents such as industrial pollution. In the context of an acidic pollution event (e.g., Sino Metals tailings release), clear institutional arrangements ensure accountability, coordinated action, and effective protection of communities and the environment. Some of the key institutions identified are discussed below;

3.4.1 Environmental regulatory agencies

The Ministry of Green Economy and Environment, oversees environmental protection, pollution control and enforcement, and the Zambia Environmental Management Agency as a national environmental regulator, issues environmental permits and licenses and also monitors industrial activities which include tailings management, in coordination with Mines Safety Department.

3.4.2 Water and sanitation authority

The National Water Supply and Sanitation Council (NWASCO) regulates water utilities to ensure safe and sustainable water supply as well as monitor water quality and service provision, while the local water utilities companies provide safe drinking water and emergency supply during pollution incidents. The water utilities companies are expected to implement emergency response measures to prevent public health risks.

3.4.3 Public health authorities

The Ministry of Health's mandate includes the assessment and monitoring of health impacts of contaminated water and the environment as well as providing advice to the affected communities on safe water use and health precautions. The Zambia National Public Health Institute, working with the local Environmental Health Officers, conduct field inspections and community outreach.

3.4.4 Disaster management authority

The National Disaster Management and Mitigation Unit (DMMU) coordinates multi-agency disaster response and has the powers to declare disasters and mobilise emergency resources under the Disaster Management Act No. 13 of 20210. The DMMU has local disaster management committees who lead community level responses and provide early warning dissemination of relevant information.

3.4.5 Mines Safety Department

The Mines Safety Department (MSD) plays a critical role in ensuring the health, safety, and environmental protection of workers and communities in mining operations. Its functions extend beyond worker safety to include monitoring industrial practices, compliance with laws, and accident prevention. The department therefore has an obligation to oversee safe handling, storage and disposal of hazardous materials such as acidic tailings in this respect. It also has an obligation to investigate mine accidents such as the discharge of the acidic leach residue from TD 15 and the subsequent pollution events.

3.4.6 Local authorities

Local Authorities (district and municipal councils) play a critical frontline role in preventing, responding to, and mitigating environmental pollution arising from mining activities such as the

Sino Metals acidic pollution incident. The Local Authorities are expected to coordinate with the National Disaster Management and Mitigation Unit during environmental emergencies.

Considering that the Local Authorities are the closest government institutions to the affected communities and are legally mandated to protect public health, water resources, and the local environment, they are directly relevant to the incident. There is therefore a need to revisit and mend the gaps identified, to guarantee a swift response next time such an incident occurs.

3.4.7 Institutional challenges

Interviews with selected institutions and stakeholders listed below suggest a number of challenges that they generally face in the implementation of their various mandates. The table below shows the list of the institutions interviewed and the general challenges faced.

Table 3-1: Institutions and operational challenges

<table>
<tr><th>S/N</th><th>Institutions interviewed</th><th>Challenges cutting across listed institutions</th></tr>
<tr><td>1</td><td>Zambia Environmental Management Agency</td><td rowspan="9">i) Inadequate financial and human resources;
ii) Inadequate capacity to monitor pollution;
iii) Inadequate equipment for monitoring pollution from industry;
iv) Overlapping mandates with other institutions;
v) Weak legal and regulatory instruments (some legal instruments are outdated and as such do not cover current and emerging issues);
vi) A lack of an established coordination mechanism;
vii) Weak enforcement mechanisms;
viii) Inadequate data or monitoring systems;
ix) Absence of a defined national emergency response team/mechanism;</td></tr>
<tr><td>2</td><td>Zambia Institute for Agricultural Research Institute</td></tr>
<tr><td>3</td><td>National Water and Sanitation</td></tr>
<tr><td>4</td><td>Water Resources Management Authority</td></tr>
<tr><td>5</td><td>Mines Safety Department</td></tr>
<tr><td>6</td><td>Geological Survey Department</td></tr>
<tr><td>7</td><td>National Institute for Scientific & Industrial Research</td></tr>
<tr><td>8</td><td>National Science and Technological Council</td></tr>
<tr><td>9</td><td>Civil Society</td></tr>
</table>

3.5 Gaps and overlaps in the legal and regulatory framework

The assessment has shown that Zambia has in place a number of pieces of legislation which, if well implemented, the aspirations of the Constitution and the people of Zambia vis-à-vis sustainable development would be realized. However, the assessment of the legal and regulatory framework has also shown that there exist gaps and overlaps in the framework requiring attention. Table 3-2 below presents the legal instruments and highlights the existing gaps and/or overlaps therein. .

Table 3-2 Gaps in legal and regulatory framework

Legal Instrument	Area of coverage	Gaps/duplications Identified
Environmental Management Act, 2011	Environment and natural resources management; pollution prevention and control.	- The EMA overlaps with the Minerals Regulation Commission Act of 2024 as the two Acts provide for environmental protection. - A review of the Acts reveals that there is no specific provision on how the two entities implementing the Acts would collaborate to avoid duplicity. - Further, the EMA also overlaps with the Water Resources Management Act, 2011. Whilst the Water Resources Management Act provides for collaboration between WARMA[7]and ZEMA, there is no defined guidance on the collaboration. To this end, in practice, it is difficult to avert duplicity in the implementation of the two Acts of Parliament. - There is no specific provision for coordination of emergencies and pollution incidents.
The Environmental Impact Assessment Regulations SI 28 of 1997	Administration of the EIA process in Zambia and includes the mining sector	The EIA Regulations, 1997 do not provide for impact-based assessment as the assessment is based on lists. - Whilst Regulation 3(2)(c) grants discretion to ZEMA to determine that a project not listed in the First and Second Schedules, requires an environmental impact, there is no provision for guidance as to how the determination would be done. This leads to subjectivity in the work of Inspectors. - The regulations do not provide clear guidance on resettlement and compensation for loss as a result of a project, whether at preliminary, construction or operation levels or a pollution incident that would demand relocation of affected communities.
The Minerals Regulation Commission Act No. 14 of 2024	Provides for regulation of minerals development	- This Act overlaps with the EMA in the area of environmental protection. As indicated in this report, the functions of ZEMA and MSD overlap and create conflict and duplicity - There are no defined guidelines for tailings storage facility construction and monitoring - The Act does not provide for standards/grading of tailings storage facilities
The Mines and Minerals (Environmental) Regulations SI No. 29 of 1997	Environmental protection in the mining sector as well environmental impact assessment covering mining sector	- These Regulations directly overlap with the EIA Regulations SI 28 of 1997. The two sets of Regulations provide for environmental impact Assessment thereby creating duplicity. Need to provide distinct roles of each institution under the EIA regulations. - There are no defined guidelines and standards for construction and monitoring of Tailings Storage Facilities.

[7] Water Resources Management Authority

Legal Instrument	Area of coverage	Gaps/duplications Identified
The Disaster Management Act No. 13 of 2010	This Act provides for the maintenance and operation of a system for the anticipation, preparedness, prevention, coordination, mitigation and management of disaster situations and the organisation of relief and recovery from disasters.	The Act does not cross reference the EMA and the Mines and Minerals Development law when it comes to issues of environmental disasters. There is no defined mechanism for compensation of victims of pollution incidents.
The Public Health Act Cap 295 of the Laws	Regulates public health including pollution control.	Whilst this Act provides for public nuisance and pollution control, there is no provision for what happens to victims of public nuisance such as pollution of a water body and agricultural fields. Taking into account the above, there is no provision for coordination among stakeholders on issues to do with public health and in particular protection of victims of public health disasters.
The Water Supply and Sanitation Act, No. 28 of 1997	Provides for regulation of water supply and sanitation and creation of water utility companies.	There is no provision for emergency measures and what should be done in the event of a pollution incident. There is no provision for coordination with stakeholders with a view to averting pollution incidents.

3.6 Conclusion

This report has presented an analysis and assessment of policies, legal and regulatory instruments as well as the institutional arrangements for the sound management of the environment and natural resources. With regard to the policy framework, principally, most of the identified policies have made provision for prevention, control and management of pollution. What remains an issue is the implementation of the said policies as well as the implementation of the resultant legal instruments and guidelines. With regard to institutional framework, the assessment has shown that there are a number of weaknesses, amongst them being, lack of a defined coordination mechanism, overlapping mandates, inadequate financial and human resources as well as weak enforcement capacity.

With regard to the legal and regulatory framework, the assessment has shown that there are a number of laws and regulations in place. Some of the gaps identified include absence of provisions or guidance on management and control of TSFs; overlaps in mandates as well as absence of provisions on compensation and relocation of victims of pollution; absence of provisions on protection of community consumer rights.

3.7 Recommendations

The following are the recommendations emanating from the policy, legal and regulatory assessment component of the assignment:

1. Development of a framework and mechanism to respond to national emergencies.
2. Review of legislation to fill the identified gaps and removal of overlaps.
3. Development of a coordination mechanism amongst regulatory institutions. An example is an Inter-Agency Coordinating Committee which once existed. Such an arrangement could be revisited.
4. Development of a code which would bring together all environmental and natural resources laws into one Code. The Code when developed can also provide for a coordination mechanism.

4 ASSESSMENT OF THE IMPACT ON SURFACE WATER QUALITY

4.1 Introduction

4.1.1 Background to the assessment

Sino-Metals Leach Zambia Limited (Sino-Metals) is a mining company located in the Chambishi area of Kalulushi District, on the Copperbelt Province (Figure 4-1). The company was established in 2004 with the objective of producing copper cathodes and copper concentrates from copper ore obtained from its Mwambashi open pit mine which is under Mining License No. 18153-HQ-LML. Previously, Sino-Metals processed low grade copper oxide stockpiles and copper oxide tailings left behind by the previous mine operators, the Zambia Consolidated Copper Mines (ZCCM). Some of the processing facilities for Sino-Metals are situated within the mine license of NFC Africa Mining Plc (NFCA).

Figure 4- 1: Map of the Copperbelt province showing the location of Chambishi

The hydrometallurgical process adopted by Sino-Metals uses sulphuric acid to leach copper from low grade oxide ores and tailings and employs solvent extraction (SX) techniques to produce acidic leach liquor, followed by electro-winning (EW) of copper from the liquor. The solvent extraction process isolates copper from impurities in the original leach solutions and produces an electrolyte suitable for the direct electro-winning of high purity (99.9%) copper cathodes.

The leaching process generates large volumes of residue known as Leach Plant tailings as waste product. The tailings comprise a mixture of solids and liquid. The solids are made of milled rock or gangue minerals from the ore. The particle size of the solids typically ranges from silt-clay to sand. The liquid part of the tailings or liquor comprises water, sulphuric acid, dissolved metals and residues of solvent extraction reagents. Sino-Metals manages the tailings by storing them in a Tailings Storage Facility (TSF) known as Tailings Dam No. 15 (TD 15). The facility consists of a complex of seven paddocks labelled A-G as shown in Figure 4-2 below. The paddocks are lined with HDPE geomembrane to prevent seepage of pollutants into the environment.

Figure 4- 2: Satellite image of TD 15 showing the paddocks A-G

The tailings slurry, at a pH of about 2, consisting of 40-45% solids and 55-60% liquor, was pumped from the Leach Plant at an average rate of 1,200 m³ per day[8] via an HDPE pipeline and discharged to TD 15 by open end deposition. Upon deposition into the tailings dam, the solids settled to the bottom of the paddocks while the liquor was collected and pumped back to the Process Plant where it was reused in leaching of new copper oxide tailings from the copper sulphide flotation circuit. Due to these operational constraints, the TD 15 complex used to serve as both a tailings deposition facility and as a temporary storage facility for liquor.

On 18th February 2025, a breach occurred on the partition wall that demarcates the paddocks E and F in TD 15 resulting in an uncontrolled release of acidic tailings slurry from the impoundment into the open environment. At the time of the incident, tailings were being deposited into paddock F. Paddock G had been prepared to receive tailings but had not yet been commissioned. The tailings slurry exited TD 15 into the environment from the Paddocks A, B and C.

The discharge of tailings from TD 15 resulted in the following adverse impacts:

1. Pollution of Chambishi Stream, Mwambashi River and Kafue River.
2. Interruption of water supply in Kitwe as the water utility had to suspend its operations.
3. Soil contamination.
4. Death of aquatic flora and fauna.
5. Disruption to sources of livelihood for people who cultivate along the banks of the affected rivers.

[8] Sino-Metals

Following the accidental discharge of tailings from TD 15, Sino-Metals shut down the operations at the plant and repaired the breach in the embankments. The embankments have since been reinforced with soil and waste rock to enhance their stability and safety. Additionally, the paddocks A-D are being prepared for eventual closure by:

1. Capping them with compacted laterite to prevent infiltration of rainwater.
2. Constructing a system of drains to channel rainwater away from the facility.

4.1.2 Stakeholder interventions

Following the pollution incident, stakeholders tracked the migration of the pollution plume in the environment mostly by monitoring the pH of the water. Table 4-1 below lists the stakeholders who monitored the water quality of the various waterbodies and whose reports have been reviewed as part of this investigation.

In addition to monitoring the pollution plume, lime was applied on the drain transporting effluent, Chambishi Stream, Mwambashi River and Kafue River to neutralise the acid and raise the pH of the water. As of this assessment, Sino-Metals was still dosing the discharge from New Dam to Chambishi Stream with sodium hydroxide.

Table 4 - 1: Summary of water quality monitoring by stakeholders reviewed

No.	Institution	Area monitored	Parameters monitored	Period of monitoring
1	Sino-Metals	Chambishi Stream Mwambashi River Kafue River	pH Electrical conductivity Arsenic Boron Calcium Cobalt Copper Chromium Iron Lead Manganese Nickel Selenium Zinc	Feb – Oct 2025
2	Nkana Water and Sanitation Company (NWSC)	Mwambashi River Kafue River	pH Electrical conductivity Copper Cobalt Iron Manganese	May 2023 – Sep 2025
3	NFC Africa Mining PLC (NFCA)	Chambishi Stream (Discharge from New Dam)	Flow rate pH Electrical conductivity Total Dissolved Solids Cadmium Chloride Cobalt Copper Iron Lead Manganese Nitrates Sulphates	Jan 2021 – June 2024

No.	Institution	Area monitored	Parameters monitored	Period of monitoring
			Zinc	
4	Zambia Environmental Management Agency (ZEMA)	Chambishi Stream Mwambashi River Kafue River	pH Electrical conductivity Cadmium Cobalt Copper Manganese Nitrates Turbidity Zinc	Jun – Jul 2025
5	Water Resources Management Authority (WARMA)		pH Electrical conductivity Cadmium Cobalt Copper Manganese Nitrates Turbidity Zinc	Feb – July 2025
6	Department of Wildlife and National Parks (DWNP)	Ngabwe Luanshya Kitwe Mufulira	No water quality results Documented death of aquatic fauna	5 – 11 March 2025
7	The Fisheries Department	Mwambashi River Kafue River	pH Temp DO Conductivity Salinity TDS	Feb – Mar 2025
8	Ministry of Health	Chambishi Stream Mwambashi River Kafue River	Odour pH Electrical conductivity	12 August 2025

No.	Institution	Area monitored	Parameters monitored	Period of monitoring
			Arsenic Calcium Calcium (hardness) Cadmium Copper Cobalt Chloride Chromium Iron Turbidity Lead Nickel Magnesium Manganese Potassium Sodium Zinc	
9	Munshinganshi Conservancy	Kafue River (Mumbwa area)	pH	24 Feb – 10 Mar 2025

4.1.3 Objectives of the assessment

This section of the report discusses the impact of the tailings discharge on surface water quality and on the river sediment. The objectives for the hydrological study outlined below have been adapted from the overall objectives of the ESIIA.

1. To assess the impact of the tailings discharge on surface water. This objective involved the following:
   a. Identifying the pollutants present in the surface water and river sediment, including determining their concentrations.
   b. Assessing the spatial extent and magnitude of the contamination on surface water arising from the discharge of tailings into the aquatic environment.
   c. Identifying and assessing the immediate and future impacts and risks related to surface water and river sediment.
   d. Evaluating the impacts on the water quality of Chambishi Stream, Mwambashi River and Kafue River.
2. To recommend appropriate mitigation, remediation and restoration measures covering the following aspects:
   a. Remediation and restoration measures of streams and rivers.
   b. Estimating the time frame and financial resources required for remediation and restoration measures.
   c. Developing an implementation plan for remediation that will focus on reducing or eliminating contamination levels in the affected water bodies.
   d. Developing a comprehensive monitoring and evaluation for surface water.
   e. Developing and emergency preparedness and response plan to address similar future incidents.

4.1.4 Scope of the assessment

The scope of this assessment is limited to investigating the impact of the tailings discharge on Chambishi Stream, Mwambashi River and Kafue River down to Itezhi-Tezhi Dam, both water and sediment.

4.1.5 Limitations and challenges

The significant limitations and challenges encountered during the study are outlined below:

1. The study was conducted eight months after the incident, during which period the concentration of pollutants in the water from the incident had receded due to factors such as dilution and water flow. Consequently, the results do not represent the immediate and short-term impact of the incident on surface water quality.
2. Some areas of the Kafue River were inaccessible due to dense vegetation making passage difficult or low water levels preventing boat access.
3. The historical data collected by stakeholders and reviewed as part of this assignment was usually incomplete as described below:
   a. The lack of quality control (QC) information for historical data makes it hard to trace and verify its reliability. Existing records can only be accepted as is, thus presenting significant limitations when used as reference values.

b. In most cases, the water quality results lacked location data in the form of coordinates which meant that the sampling point could not be accurately placed or determine whether the sampling points were located in the same location to compare the changes.

c. In most cases, the water quality parameter monitored was limited to pH.

4.2 Description of the study area

4.2.1 Location

The study area for the Environmental and Social Incident Impact Assessment follows the three affected surface waterbodies, namely, Chambishi Stream, Mwambashi River and Kafue River. The area spans from Chambishi in Kalulushi District, on the Copperbelt Province where the incident occurred to Itezhi-Tezhi Dam in Southern Province. The assessment divided the streams impacted by the tailings discharge into three zones: primary, secondary and tertiary, depending on the hydrological connection to the source of the pollution. The streams that were not impacted by the tailings discharge from TD 15 have been added as additional zones to provide background water quality. The different zones are described in Table 4-2 and illustrated in the satellite image in Figure 4-3. The portion of the Kafue River that is covered by this report is shown on the map of Zambia in Figure 4-4.

Table 4-2: Description of the study zones

Zone	Description	Description	Distance (km)
Zone 1	Primary area impacted directly by tailings discharge from TD 15	The combined drain from TD 15 including Chambishi Stream up to the confluence with Mwambashi River	11
Zone 2	Secondary impact area, receiving pollution from Chambishi Stream	Mwambashi River from the confluence with Chambishi Stream to the confluence with Kafue River	27
Zone 3	Tertiary impact area receiving pollution from Mwambashi River	Kafue River from the confluence with Mwambashi River to Itezhi-Tezhi Dam	729
Zone 4	Mwambashi River unimpacted by tailings discharge from TD 15	Mwambashi River upstream of the confluence with Chambishi Stream including the tributaries of Mwambashi located in this area	7
Zone 5	Kafue River unimpacted by tailings discharge from TD 15	Kafue River upstream of the confluence with Kafue River	90

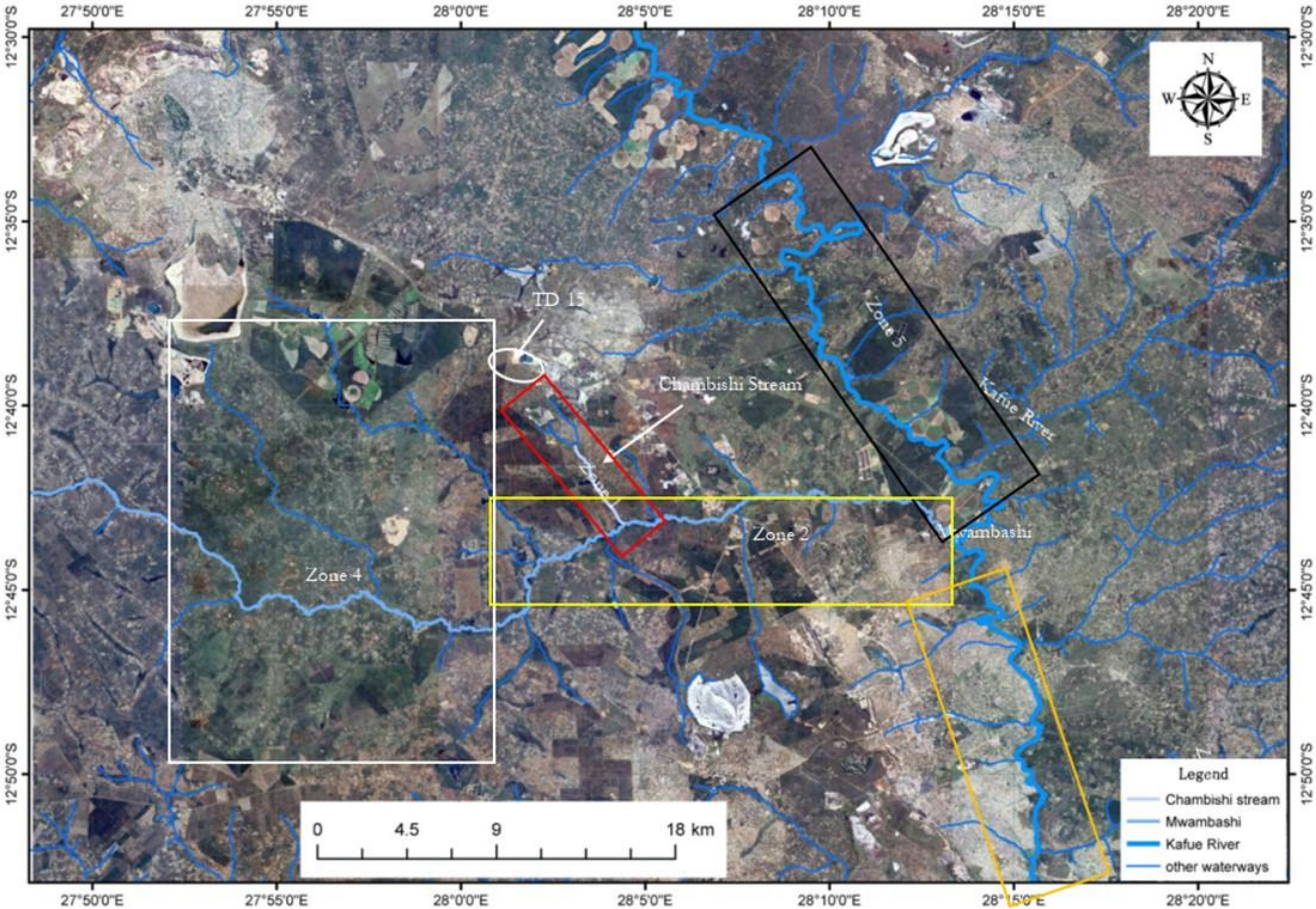


Figure 4- 3: Satellite image of the study area showing the study Zones 1-5

Figure 4- 4: Map of Zambia showing the portion of Kafue River covered by the study

4.2.2 Climate

The climate of the study area varies from Chambishi in the north to Itezhi-Tezhi in the south. The average annual rainfall in Chambishi is approximately 1,200 to 1,365 mm while the average annual rainfall in Itezhi-Tezhi is approximately between 535 and 687 mm. Chambishi is situated in the Copperbelt Province, which is on the central African plateau and has a higher elevation, typically ranging between 1000 and 1,300 meters. This higher elevation results in more moderate temperatures compared to the lower-lying southern areas. On the other hand, Itezhi-Tezhi, which is in the Southern Province, is generally one of the hotter and lower-lying regions of Zambia.

4.3 Catchment hydrology

4.3.1 Chambishi catchment

4.3.1.1 Topography

The topography and landscape of the Chambishi Stream and the surrounding area are illustrated in the relief map in Figure 4-5 below. The map shows that the Chambishi Stream has a southeast plunge and drains into the Mwambashi River.

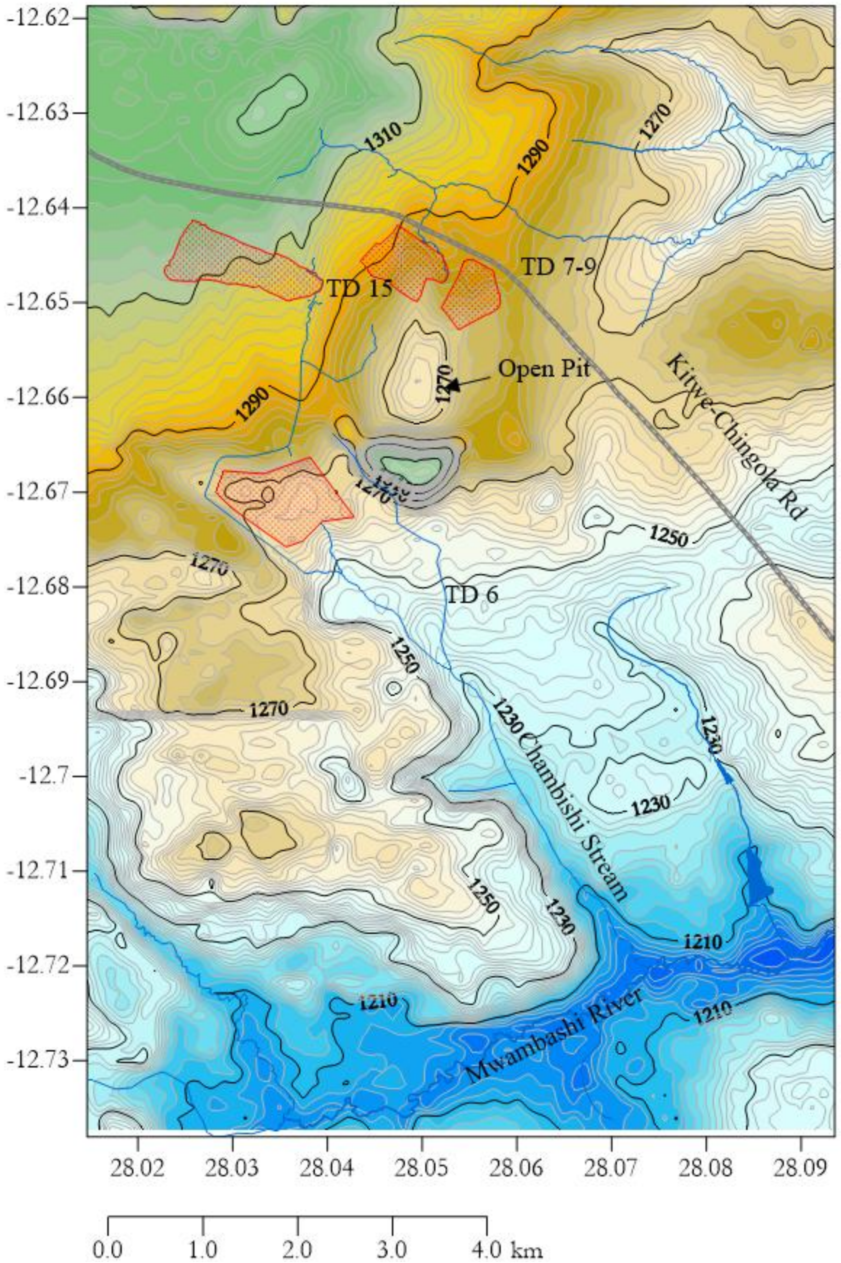


Figure 4- 5: Relief map of Chambishi Stream and the surrounding area

4.3.1.2 Catchment

The Chambishi Stream was the primary stream impacted by tailings discharge from TD 15. The catchment for the stream is shown on the satellite image in Figure 4-6. The catchment boundary was determined using Digital Elevation Model techniques with location and elevation data obtained from Google Earth®. The Chambishi catchment occupies an area of approximately 37 km^2.

The Chambishi catchment hosts three Tailings Storage Facilities (TSF), namely:

1. Tailings Dam No. 6 (TD 6) which was operated by ZCCM but is now licensed to NFCA as a Pollution Control Dam (PCD). At the time of the assessment, TD 6 was being reclaimed by a third party for reprocessing of tailings.
2. Werners Dam, a decommissioned tailings dam operated by ZCCM.
3. Tailings Dam No. 15 (TD 15) belonging to Sino-Metals which was the source of the pollution incident under investigation.

The source of Chambishi Stream is a wetland located downstream of TD 6. The wetland is currently overgrown with Typha. The local people refer to the stream as Kalusale. However, in this study, the entire stream is referred to as Chambishi Stream. The source of Chambishi Stream is vulnerable to pollution, including sedimentation as a result of effluent discharge from the mines and silt deposition from multiple tailings reclamation activities taking place in the area.

The map in Figure 4-6 shows the Chambishi catchment and other sub-catchments surrounding it.

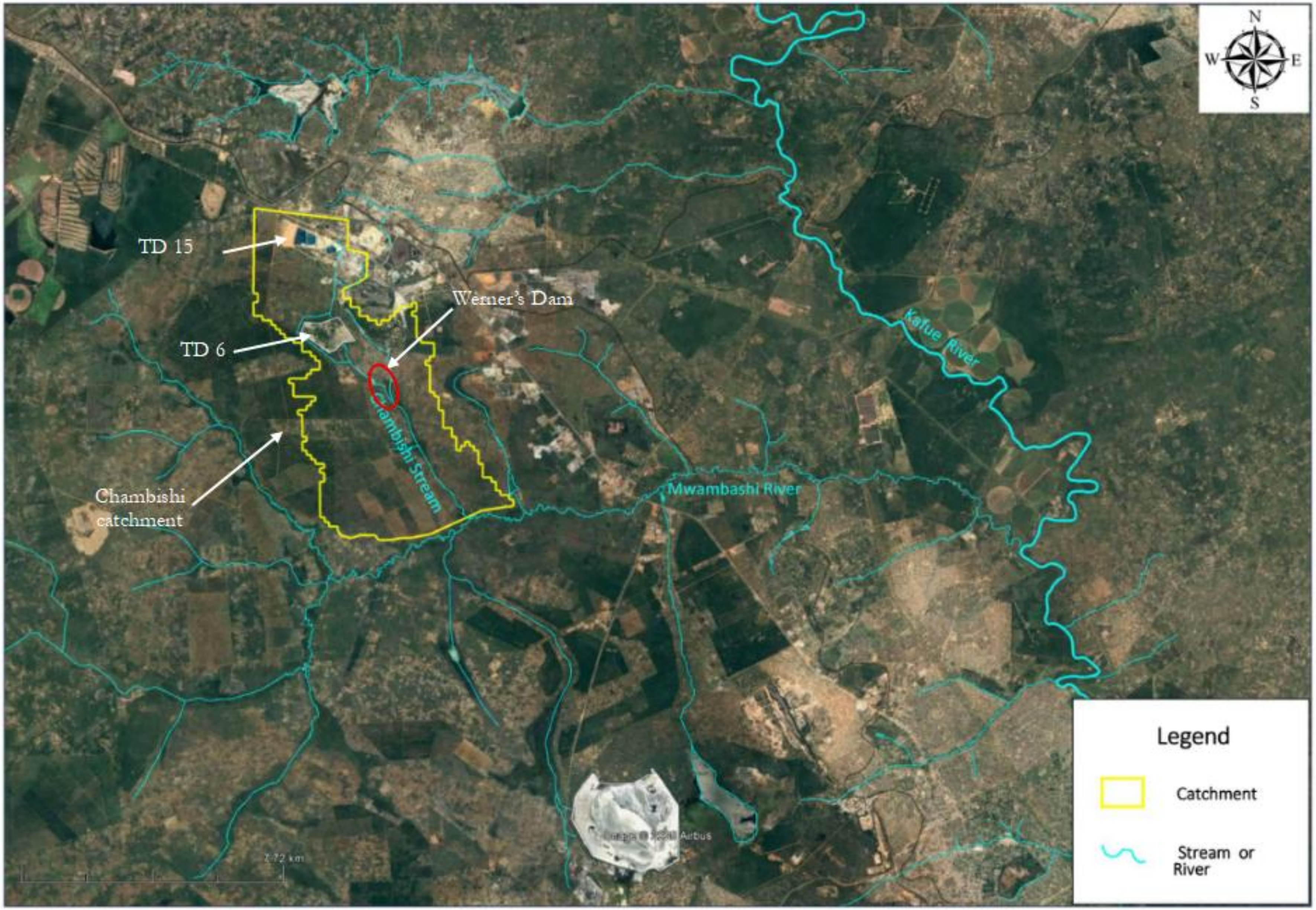


Figure 4- 6: Satellite image showing the of Chambishi catchment

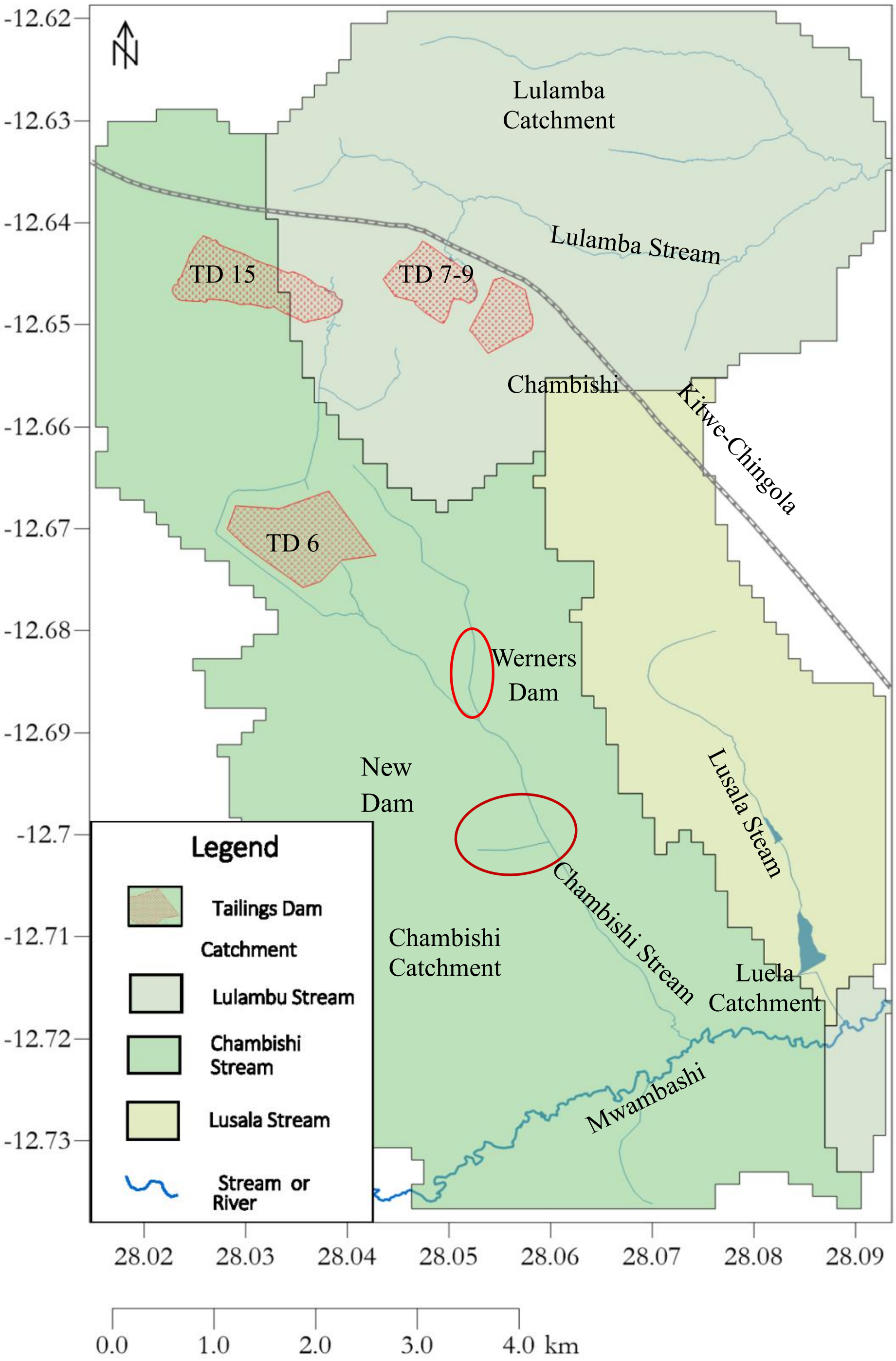


Figure 4- 7: Map showing the sub-catchments in the area

4.3.1.3 Chambishi Stream discharge rate

NFCA measures the discharge rate of Chambishi Stream at the v-notch weir located downstream of the wetland known as New Dam. The discharge rate measured at the site between January 2021 and June 2024 ranged between 3,104 and 14,795 m³/day and a mean of 6,403 m³/day for the period.

4.3.2 Mwambashi catchment

4.3.2.1 Topography and landscape

The Mwambashi River was the recipient of tailings flow from the Chambishi Stream. The topography of the Mwambashi catchment is illustrated in the relief map in Figure 4-8. The map was developed using Digital Elevation Model with location and elevation data obtained from Google Earth®. The map shows that the area has an overall easterly slope terminating into Kafue River. There are several hills and low-lying areas that form tributaries of Mwambashi River.

4.3.2.2 Catchment

The Mwambashi catchment is illustrated on the satellite image in Figure 4-9. It covers a surface area measuring 895 km². The catchment forms part of the upper Kafue River sub-basin. It spans portions of Kitwe, Kalulushi, Chambishi, and Chingola districts, encompassing both peri-urban and rural areas that are strongly influenced by mining, agriculture, and settlement expansion. The Mwambashi River and its tributaries, dominate the Kafue catchment in this region. The hydrology of the Mwambashi catchment is thus integral to the broader Kafue basin, one of Zambia's most economically and environmentally significant river systems.

The Mwambashi catchment hosts a number of mining related activities including the following:

1. Open pit and underground mining
2. Mineral processing facilities such as concentrators, smelters and leach plants
3. Many mining-waste stockpiles such as Tailings Storage Facilities, waste rock dumps, overburden dumps.

The catchment also hosts farming activities, both crops and livestock as well as fishing. The Mwambashi catchment hosts two water intakes for Nkana Water and Sanitation Company, one on Chati Stream and the other on Mwambashi River.

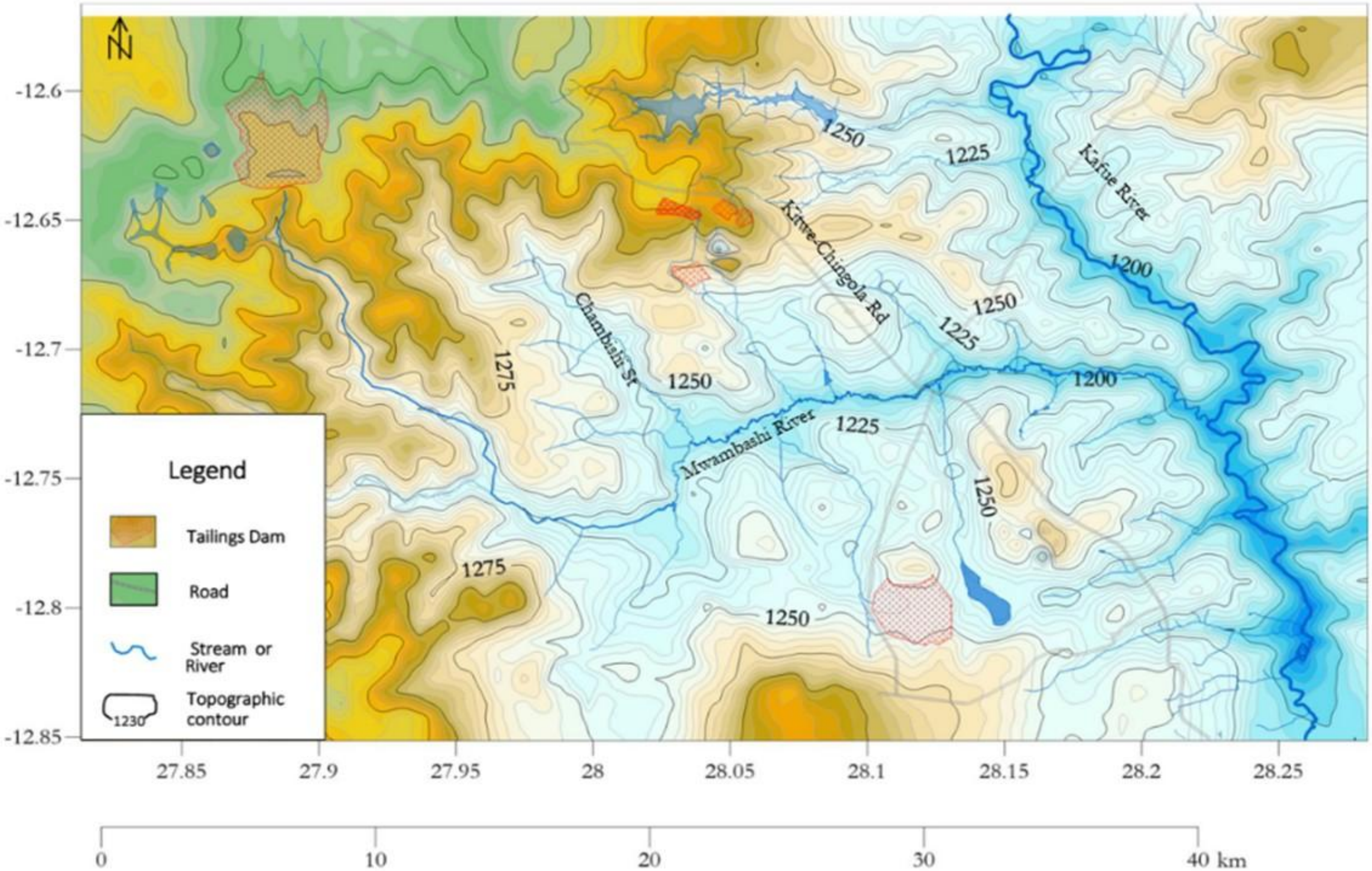


Figure 4- 8: Relief map of Mwambashi River and the surrounding area

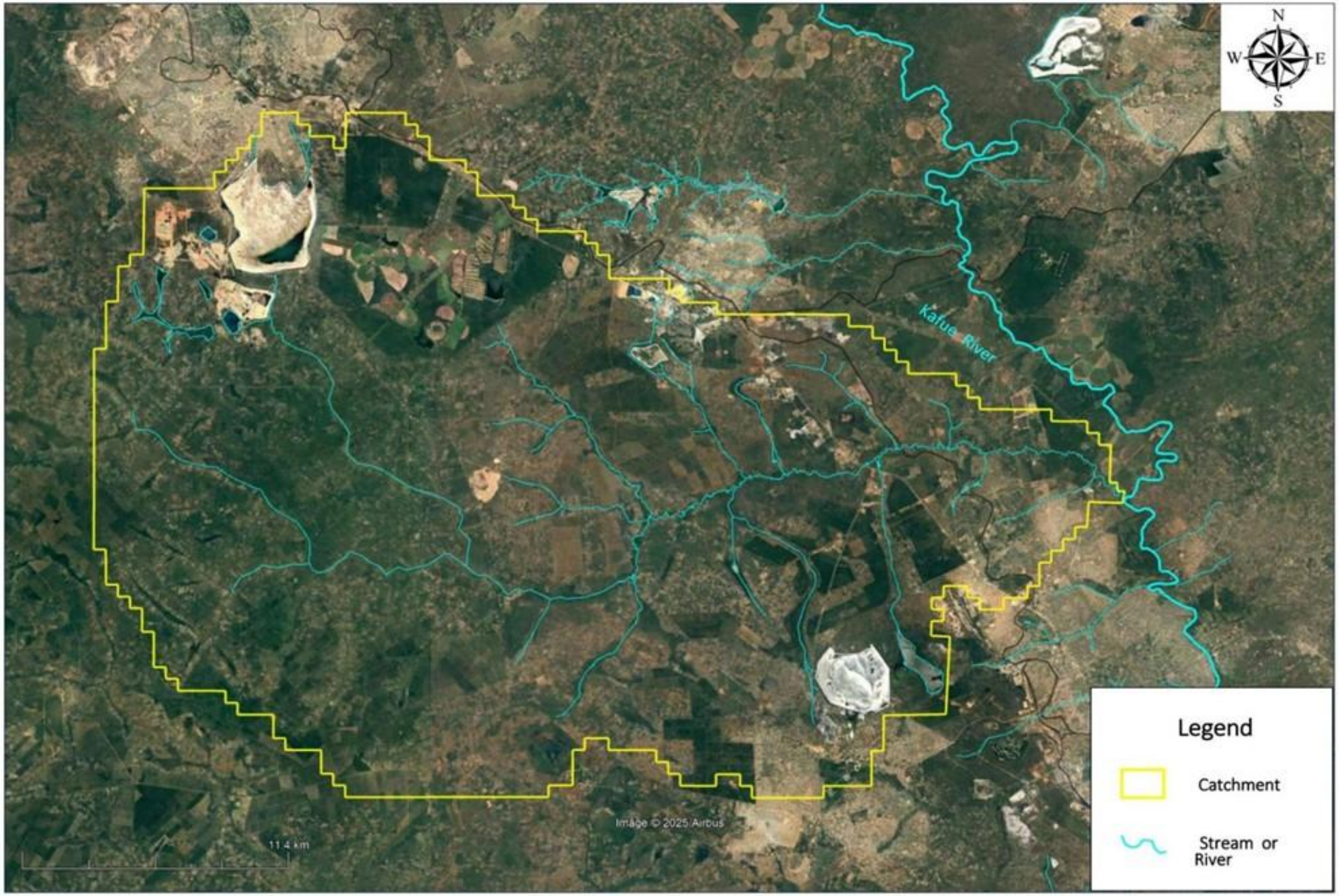


Figure 4- 9: Satellite image showing the Mwambashi catchment

4.3.2.3 River discharge rates

The discharge rate measured on Mwambashi River during the assessment ranged from 197,856 m³/day at Sabina to 254,707 m³/day before the confluence with Kafue River. Considering that the measurements were taken during the dry season, the flow rates could get significantly higher during the dry season. JICA puts the average discharge rate of Mwambashi River at 2,937,600 m³/day[9].

4.3.2.4 Velocities

The Mwambashi watershed has many sub-watersheds of which the Chambishi Stream is a part of. Mwambashi River in the watershed is 64 km long. It is shown highlighted in the map in Figure 4-10 below. This is the longest continuous flowline, hence the name of the catchment.

From an elevation point of view, Mwambashi River undulates between 1,347 meters above sea level (masl) at the source and 1,180 masl at its mouth into the Kafue River. The elevation profile along its drainage line is as shown in Figure 4-11. It has a gauge station which is rated by Water Resources Management Authority (WARMA) at 28.2173º longitude and -12.7232º latitude.

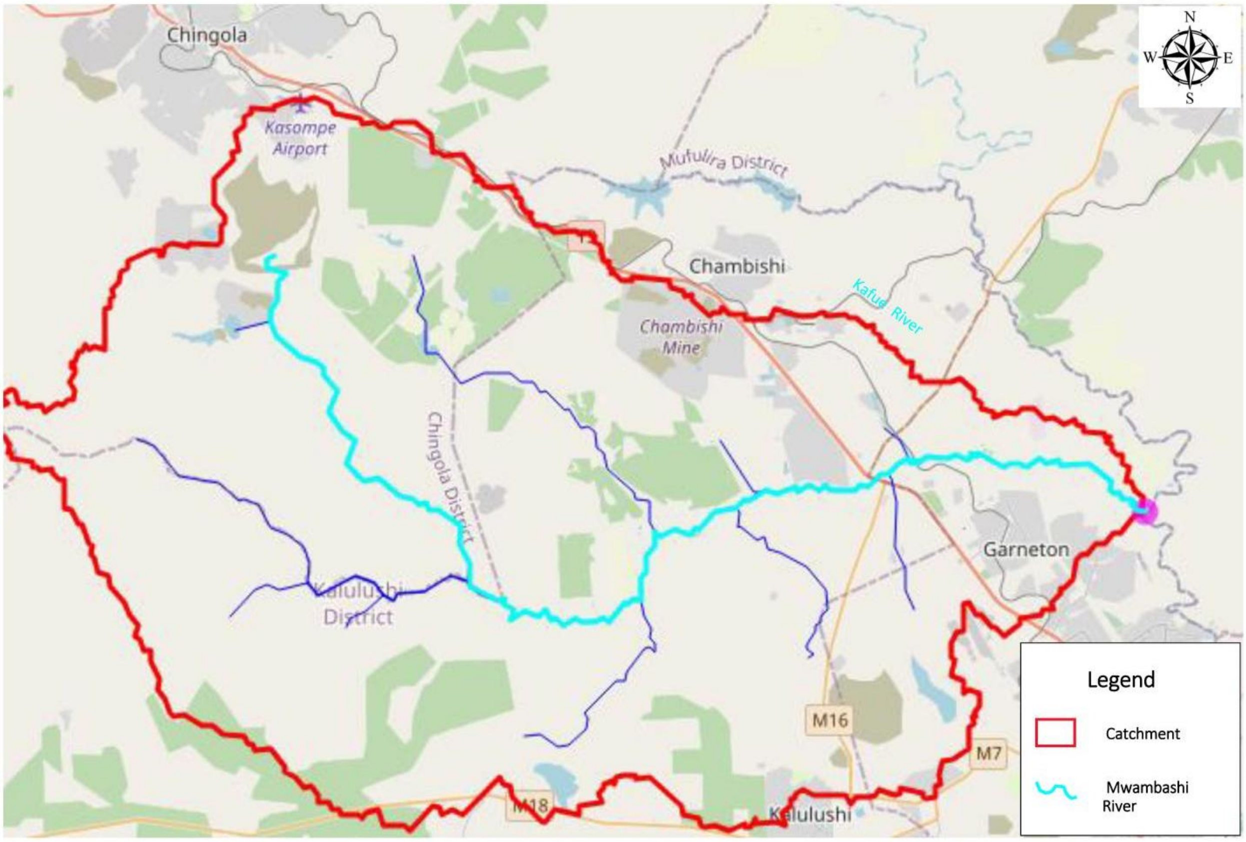


Figure 4-10: Map showing Mwambashi River

[9] https://openjicareport.jica.go.jp/pdf/11251634_06.pdf

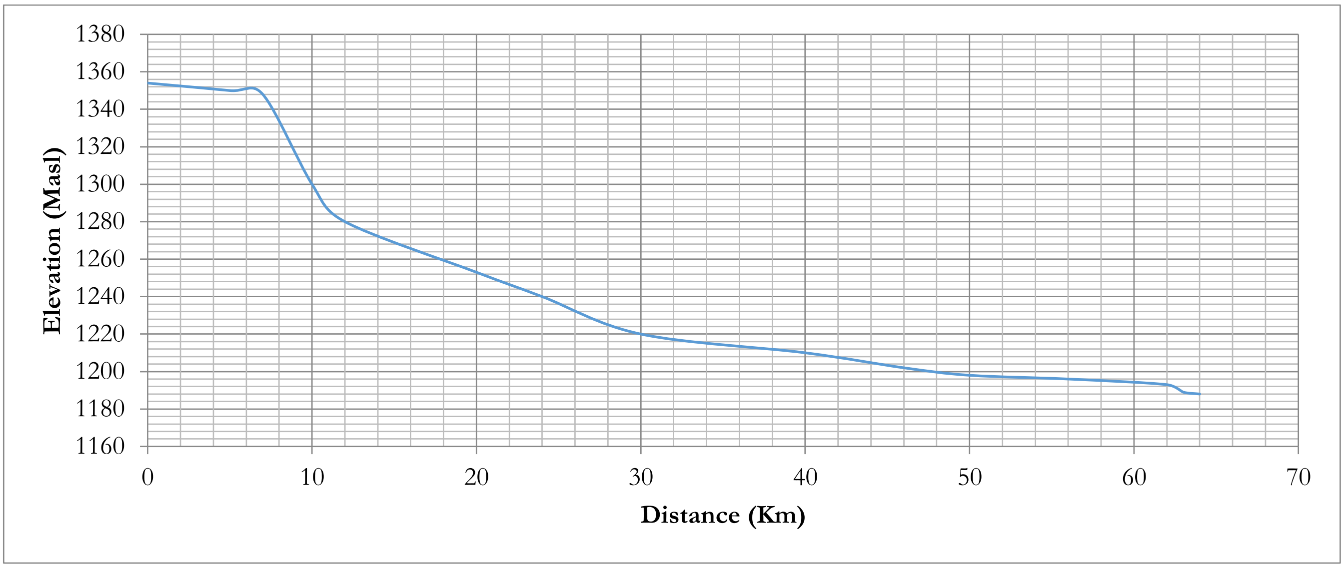


Figure 4-11: Elevation profile of Mwambashi River from the source to the confluence with Kafue River

4.3.3 Kafue River

4.3.3.1 Catchment

The Kafue catchment is divided into Upper and Lower catchments. The Upper Kafue catchment is the northern part of the Kafue River basin in Zambia, encompassing much of the Copperbelt Province. The Upper Kafue catchment is defined by the boundary from the upper parts of the Kafue River forming headwaters up to the Itezhi-Tezhi Dam with a total catchment area of 107,000 km². The catchment measures 99,361 km² from the confluence with Mwambashi River down to Itezhi-Tezhi Dam. Sub-basins include the Mwambashi, Kafulafuta, Kafubu, and Mpongwe catchments.

4.3.3.2 River discharge rates

The discharge rates of Kafue River were computed using flow measurements made by the Water Resources Management Authority. The discharge rates at selected gauging stations made in October 2025 are presented in Table 4-3 below.

Table 4 - 3: Discharge rates of Kafue River at gauging stations

Name of site on Kafue River	Location	Discharge rate (m^3/day)
Smith Bridge	Kitwe	934,243
Mpatamatu	Luanshya	1,766,189
Machiya	Mpongwe	2,261,520
Ndubeni		2,423,779
Chilenga	Mumbwa	2,891,203
Lubungu	Mumbwa	3,692,218
Hook Bridge	Mumbwa	7,127,050
Itezhi-Tezhi	Itezhi-Tezhi	6,322,493

4.3.3.3 Velocities

The Kafue River is the longest river in the watershed at 1,170 km long. It is shown highlighted in the map in Figure 4-12 below. However, Kafue River stretches about 822 km to Itezhi-Tezhi from its confluence with Mwambashi River in Kitwe while stretching around 348 km from its source in Northwestern Province/Congo up to the confluence with Mwambashi River.

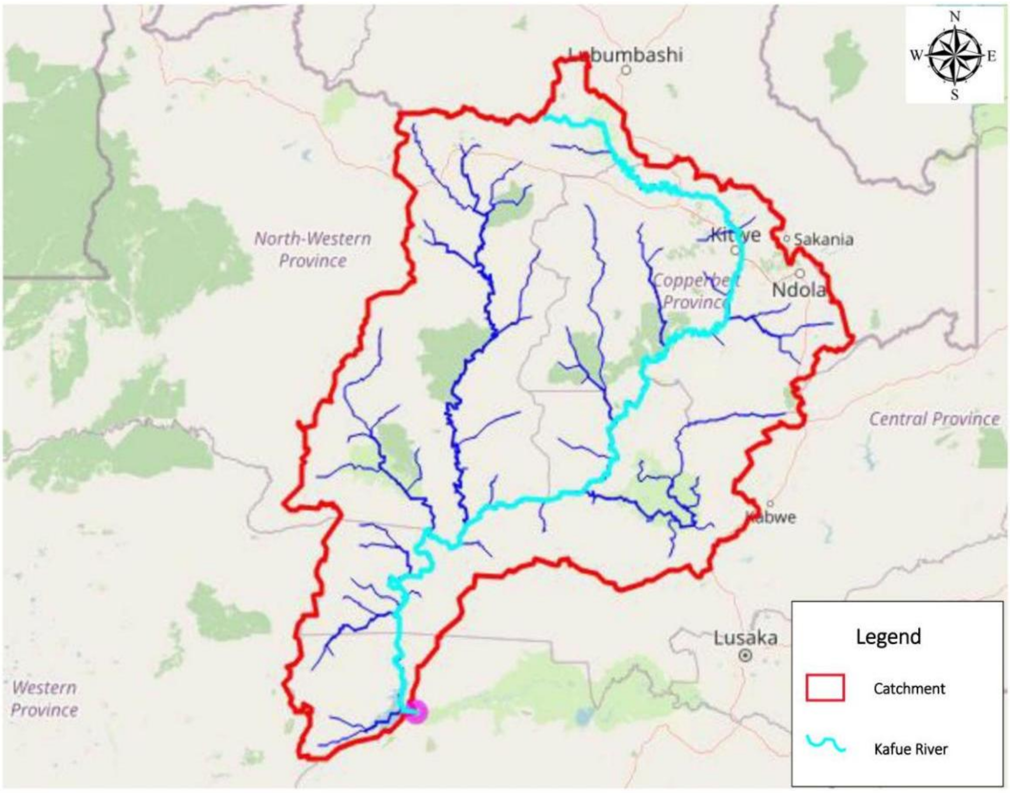


Figure 4-12: Map showing Kafue River

Figure 4-13 shows the elevation profile of the Kafue River. The river begins at 1,348 masl, and the outlet is at 983 masl.

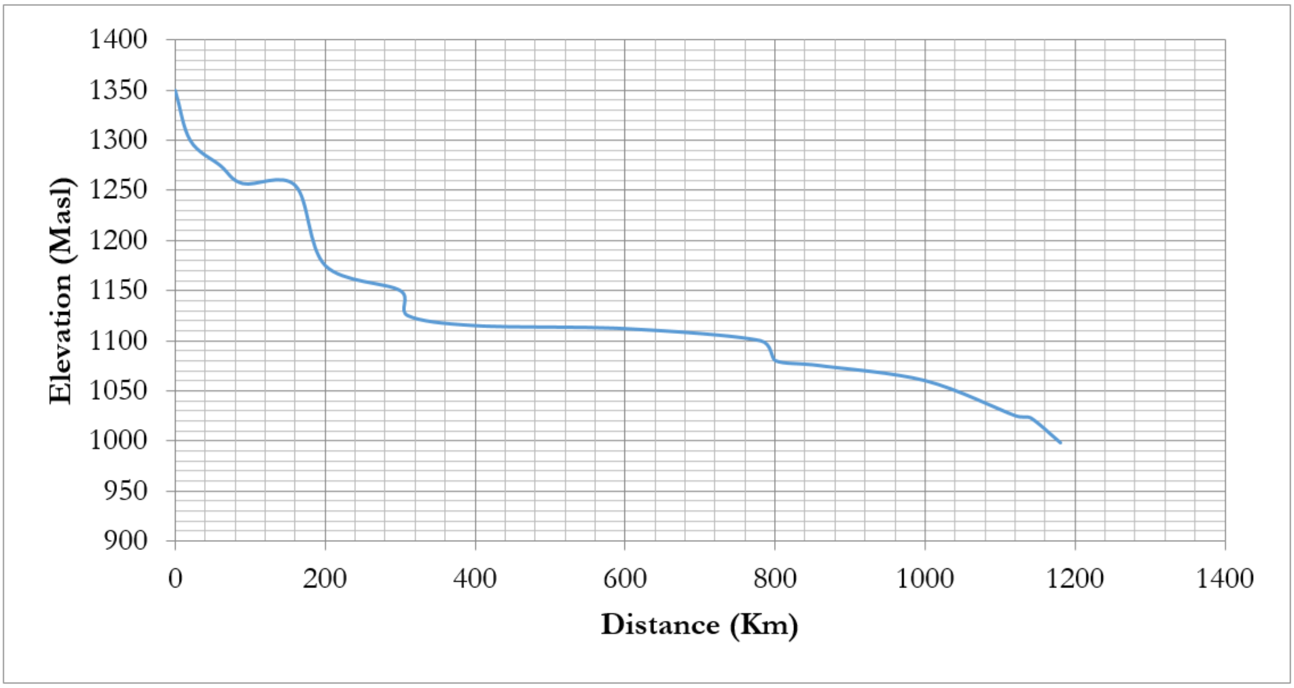


Figure 4-13: Elevation profile of the Kafue River

4.3.3.4 Land use and human activities

Land use and human activities in the study area vary from place to place. The activities include the following:

1. Settlements
2. Farming, both commercial and subsistence
3. Fishing
4. Mining and mineral processing

4.4 Methodology

This section outlines the methodology that was employed to assess the impact of the tailings discharge on the surface water.

4.4.1 Sampling procedures

4.4.1.1 Surface water

The detailed surface water sampling procedure is attached in Appendix II of this report. In principle, three water samples were collected at each site, one on the left bank of the river channel, one in the middle of the river and the third on the right bank of the river. The three samples were then composited into one sample. The samples were then stored in a cool box with ice packs.

Pertinent details at each site were recorded such as date and time, location, GPS coordinates, land use, activities, appearance and odour of the water.

4.4.1.2 River sediment

River sediments were collected from the same sites as surface water samples using a stainless-steel auger and double bagged and sealed with a cable tie. The samples were stored in cool boxes with ice packs.

4.4.1.3 Quality assurance/quality control

Strict quality assurance/quality control (QA/QC) measures were applied to surface water and sediment sampling. This included the following:

1. Training samplers before dispatching them to the field.
2. Using clean bottles to collect samples.
3. Triple rinsing the bottles with water before collecting the sample.
4. Ensuring that the samples get to the lab in the shortest period.
5. Maintaining the chain of custody.
6. Wearing a fresh pair of disposable latex gloves when handling bottles and collecting samples.
7. Rinsing the auger before collecting the sediment samples.
8. Collecting duplicate samples.
9. Sending the samples to the laboratory blind without identifying the source.

4.4.2 Sampling plan

The sampling work conducted by Applied Technology commenced in September 2025 and continued through mid-December. The sampling covered three waterbodies, they are Chambishi Stream, Mwambashi River, and Kafue River. All sampling personnel underwent professional training and are well-versed in standard operating procedures, ensuring that the samples collected are highly representative and reliable. Through this systematic sampling effort, it is possible to accurately assess the pollution extent of the incident and identify the distribution of potential pollution sources within the basin.

The distribution of sampling points is shown in Figure 4-14 to 4-18.

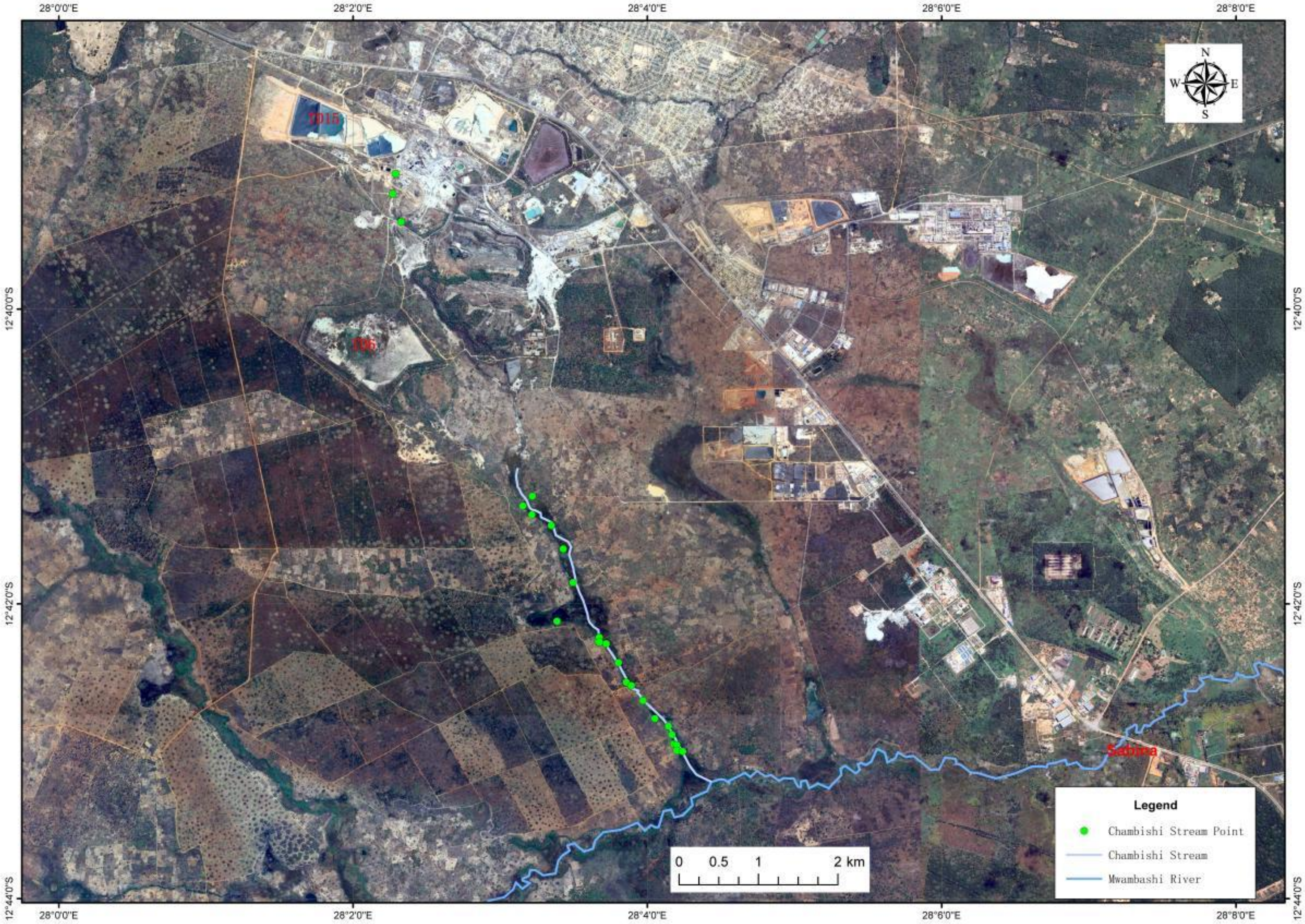


Figure 4-14: The distribution of sampling points in Chambishi Stream

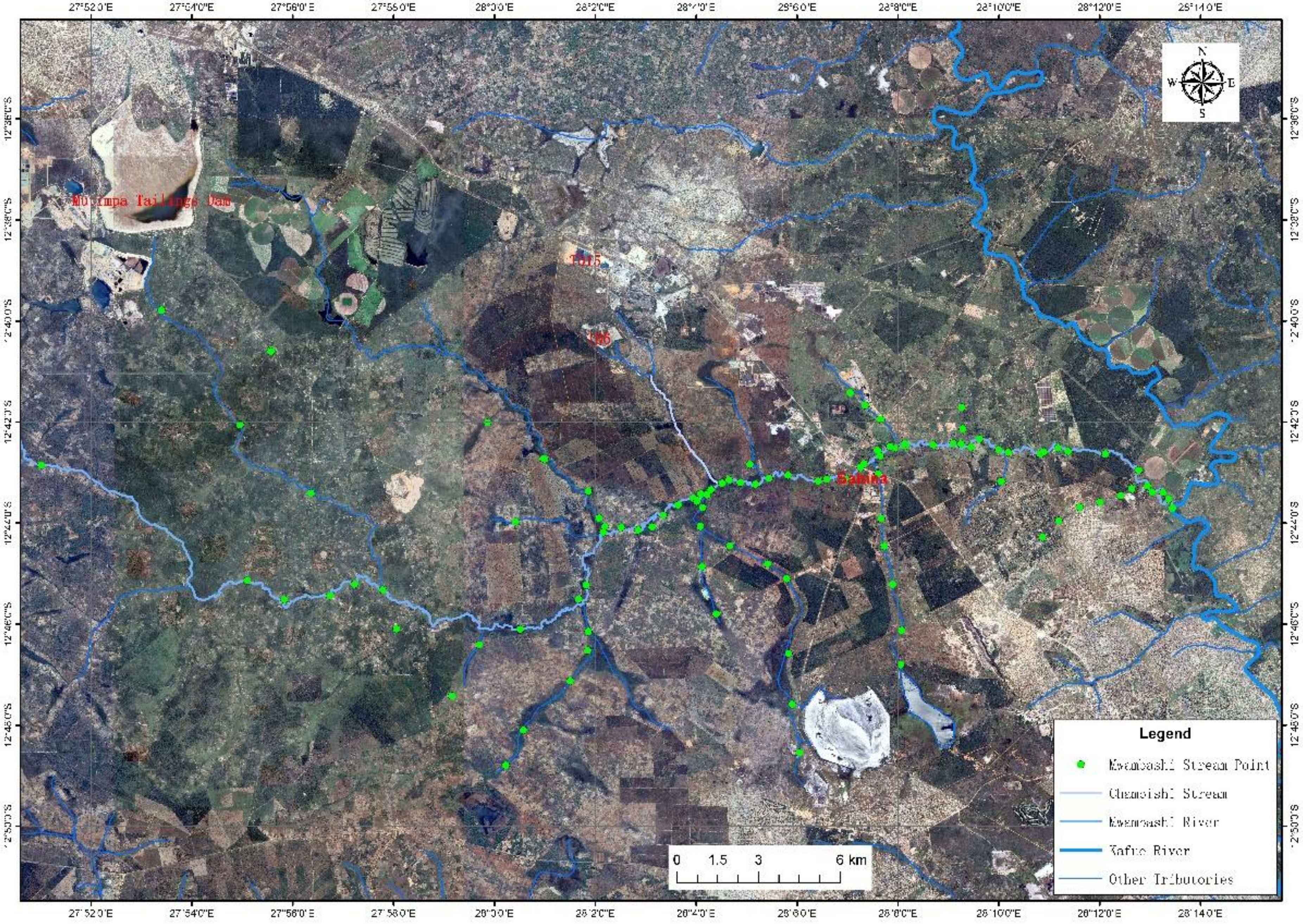


Figure 4-15: The distribution of sampling points in Mwambashi River

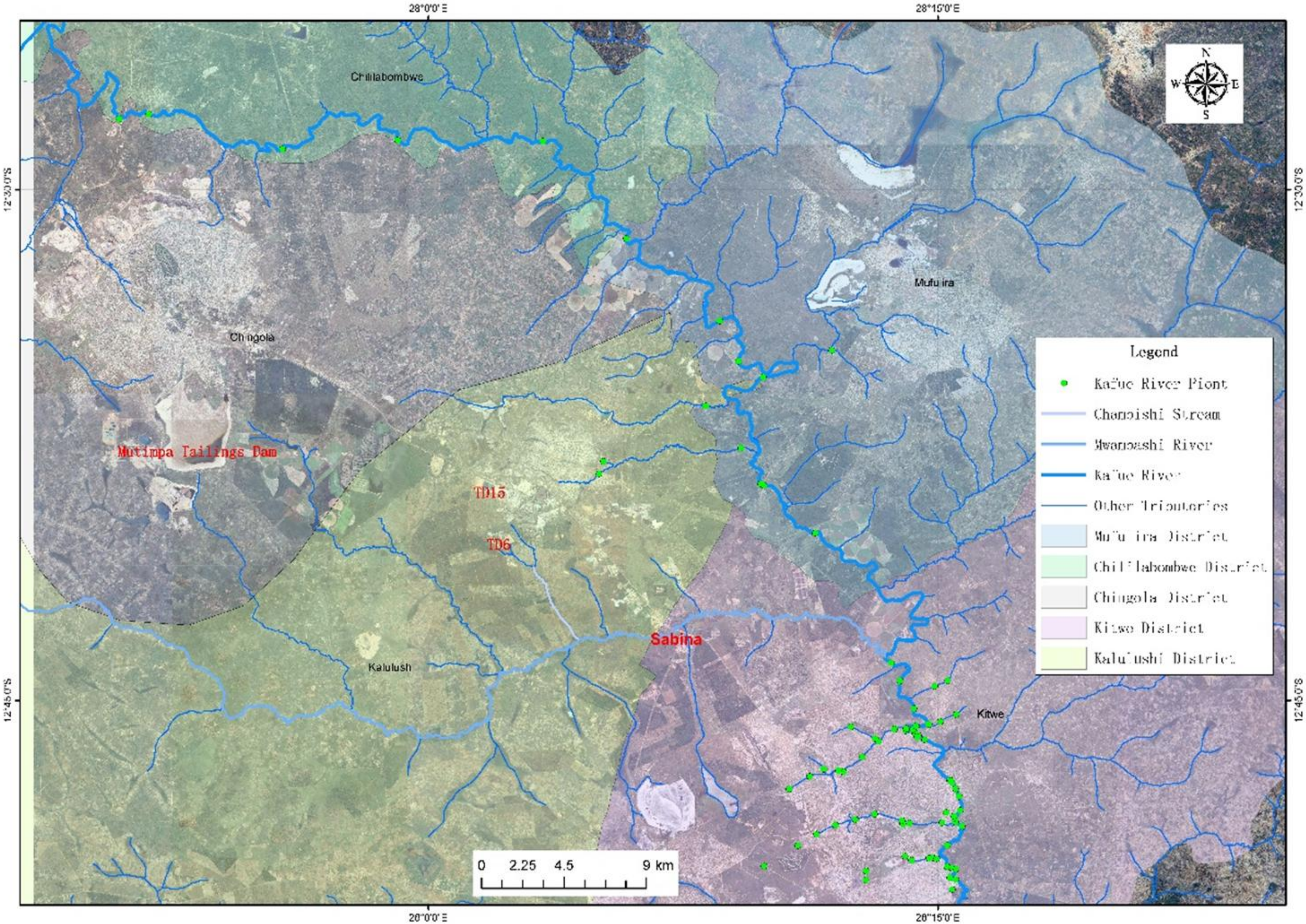


Figure 4-16: The distribution of sampling points in Kafue River (1)

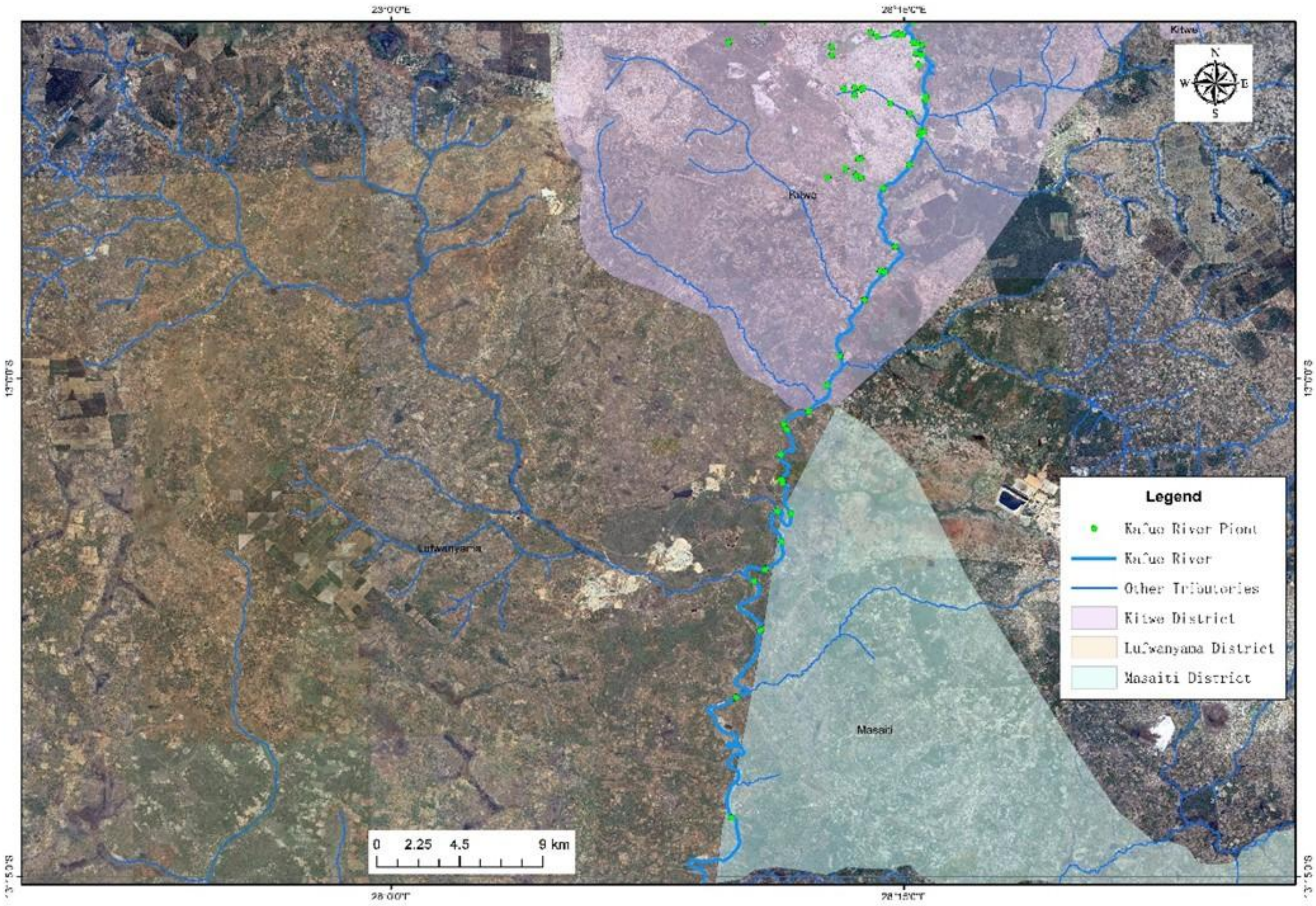


Figure 4-17: The distribution of sampling points in Kafue River (2)

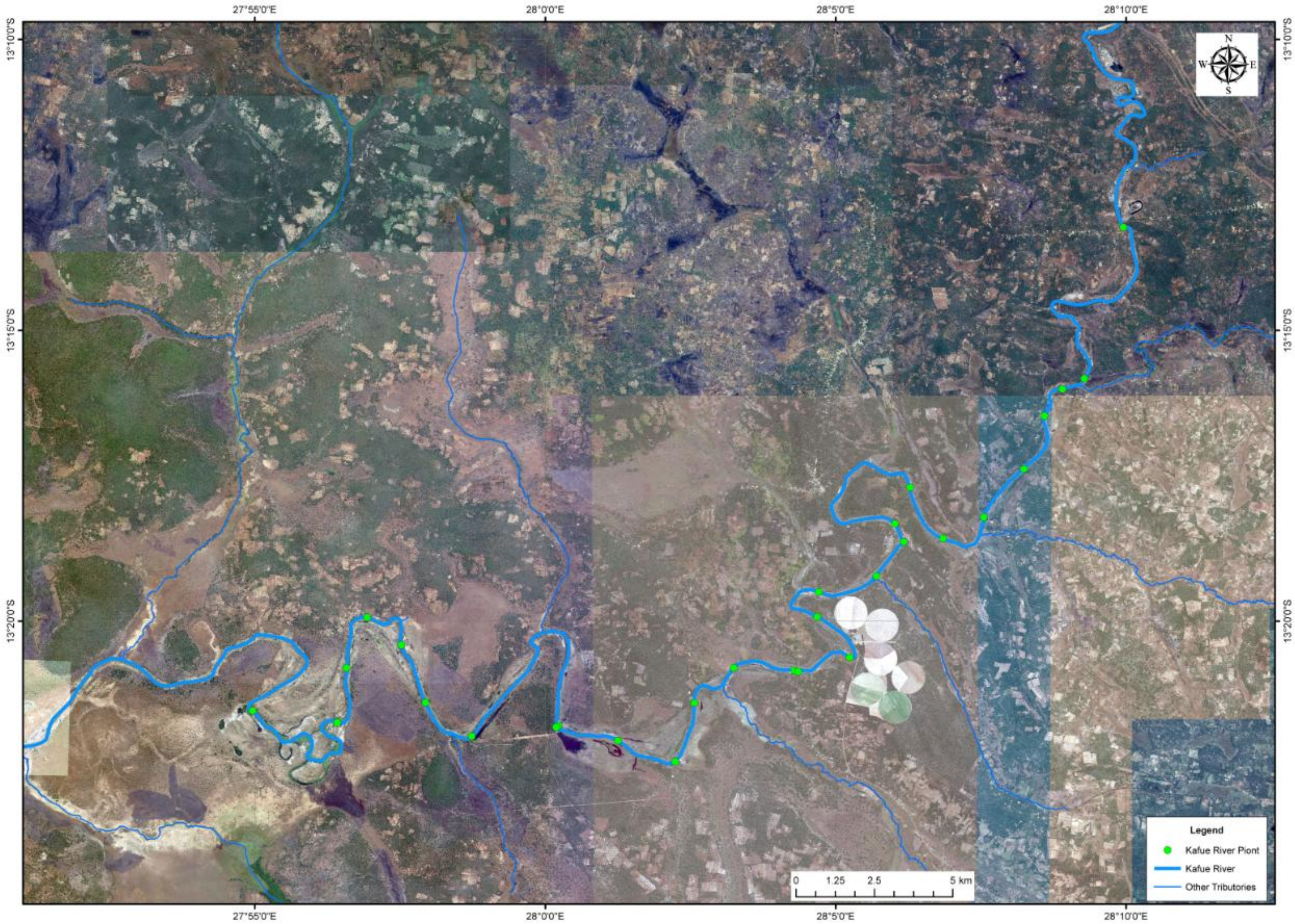


Figure 4-18: The distribution of sampling points in Kafue River (3)

4.4.3 Analytical plan

All the water samples collected were submitted to Alfred H. Knight laboratory in Kitwe. The list of analytical parameters was determined based on the composition of the tailings. The parameters analysed in the water samples are listed below.

Physical parameters

Parameter	Methodology	Lower Detection Limit
1. pH value at 21 °C & 25 °C	Potentiometric	0.2 pH value
2. Electrical Conductivity at 25 °C	Potentiometric	0.14 µS/cm
3. Total Suspended Solids	Gravimetric	4 mg/L
Cations		
1. Boron	ICP - OES	0.005 mg/L
2. Calcium	ICP - OES	0.2 mg/L
3. Magnesium	ICP – OES	0.02 mg/L
Anions		
Sulphates	ICP - OES	2.4 mg/L
Metals		
a. Arsenic	ICP – OES	0.01 mg/L
b. Aluminium	ICP – OES	0.1 mg/L
c. Cadmium	ICP – OES	0.001 mg/L
d. Chromium	ICP – OES	0.001 mg/L
e. Cobalt	ICP – OES	0.001 mg/L
f. Copper	ICP – OES	0.01 mg/L
g. Iron	ICP – OES	0.02 mg/L
h. Lead	ICP – OES	0.01 mg/L
i. Manganese	ICP – OES	0.01 mg/L
j. Nickel	ICP – OES	0.002 mg/L
k. Selenium	ICP – OES	0.01 mg/L
l. Zinc	ICP - OES	0.006 mg/L

4.5 Results and findings

4.5.1 Findings of the surface water

4.5.1.1 Presentation of analytical results

This report is based on all the results of surface water samples collected from September to December 2025. The summary of sites is presented in Table 4-4 below.

Table 4 - 4: Total number of sampling sites

Stream	No. of sites
Chambishi Stream	26
Mwambashi River	110
Kafue River	376
Total	**512**

The analytical results are presented in Appendix III of this report.

4.5.1.2 Statistical presentation of results

The statistical summaries of the analytical results are presented in Table 4-5 (Chambishi Stream), Table 4-6 (Mwambashi River) and Table 4-7 (Kafue River). Where the results are below the Method Detection Limit (MDL), the value of the MDL is used for calculation purposes.

Table 4 - 5: Statistical summary of analytical results of Chambishi Stream

Description	Al	As	B	Ca	Co	Cu	Mg	Ni	Se	Zn	Mn	SO_4^{2-}	pH	EC
Count	26	26	26	26	26	26	26	26	26	26	26	26	26	26
Minimum	0.1	0.01	0.005	9.6	0.004	0.01	3.88	0.002	0.01	0.006	0.04	8	4.51	62
Maximum	7.4	0.08	0.058	870.7	53.586	79.95	277.21	0.236	0.07	3.886	13.73	1586.4	9.92	3070
Mean	0.4	0.01	0.016	342.5	2.400	3.46	131.21	0.014	0.01	0.246	1.77	656.85	7.46	1441
Median	0.1	0.01	0.008	296.7	0.1035	0.105	134.64	0.002	0.01	0.006	0.56	567.7	7.55	1337
95%	0.98	0.01	0.043	748.63	3.083	5.275	233.86	0.037	0.03	1.526	9.90	1240.15	8.49	2069.5
Standard Deviation	1.44	0.01	0.02	246.53	10.47	15.66	71.16	0.05	0.01	0.84	3.42	384.46	0.99	600.16

The above statistical data includes the Upper Chambishi Stream, which is the area upstream of the New Dam discharging point.

The parameters cadmium, chromium and lead were not detected in Chambishi Stream samples at their respective Method Detection Limit.

Table 4 - 6: Statistical summary of analytical results of Mwambashi River

Description	pH	EC	Al	Ca	Co	Cu	Mg	Mn	Ni	Se	SO_4^{2-}	Zn
MDL	0.2	0.14	0.1	0.01	0.001	0.01	0.02	0.01	0.002	0.01	2.4	0.006
Count	110	110	110	110	110	110	110	110	110	110	110	110
Minimum	2.68	29	0.1	2.7	0.001	0.01	2.77	0.01	0.002	0.01	2.4	0.006
Maximum	8	5200	7	1617.5	2.926	0.51	1862.74	51.94	0.168	0.12	14214.18	0.055
Mean	6.96	1404.17	0.23	346.28	0.05	0.04	284.46	3.40	0.01	0.01	1502.62	0.01
Median	7.33	1572.00	0.1	365.30	0.00	0.01	262.72	0.18	0.00	0.01	918.85	0.01
95%-tile	7.84	3717.50	0.70	947.13	0.06	0.32	1136.47	13.01	0.05	0.03	8621.96	0.02
Standard Deviation	0.96	1129.08	0.689	303.377	0.327	0.097	337.241	7.835	0.023	0.012	2825.23	0.008

The above statistical data includes the Upper Mwambashi River and its tributaries.

The parameters arsenic, boron, lead and cadmium were not detected in Mwambashi River samples at their respective Method Detection Limit.

Table 4 - 7: Statistical summary of analytical results of Kafue River

Description	pH	EC	B	Ca	Co	Cu	Mg	Mn	Ni	Se	SO_4^{2-}	Zn
Count	375	376	376	376	376	376	376	376	376	376	376	376
Minimum	5.66	28.00	0.005	2.80	0.001	0.010	2.12	0.01	0.000	0.00	2.40	0.006
Maximum	9.92	2343.00	0.0510	1172.30	2.528	0.140	183.61	0.81	9.00	9.00	6157.20	0.02
Mean	7.41	738.37	0.0052	199.07	0.028	0.012	69.05	0.05	0.27	0.27	434.78	0.01
Median	7.33	717.50	0.005	176.25	0.001	0.010	59.24	0.01	0.002	0.01	243.25	0.006
95%-tile	8.19	1218.75	0.005	329.25	0.020	0.020	116.63	0.30	0.067	0.07	1564.15	0.006
Standard Deviation	0.46	282.34	0.003	134.14	0.19	0.01	29.44	0.10	0.001	0.004	663.74	0.001

The above statistical data includes the Upper Kafue River and its tributaries.

The parameters arsenic, aluminum, cadmium, chromium and lead were not detected in Kafue River samples at their respective Method Detection Limit.

4.5.1.3 Discussion on water results

This discussion is based on full water sampling data, covering a total of 512 samples from Chambishi Stream, Mwambashi River, Kafue River, and their tributaries, with all analysed parameters included.

In Chambishi Stream, copper (Cu, mean=3.46 mg/L) and cobalt (Co, mean=2.400 mg/L) show significantly higher concentrations compared to other water bodies, indicating potential sources of heavy metal pollution. Calcium (Ca, mean=342.504 mg/L), magnesium (Mg, mean=131.207 mg/L), and sulphate (SO_4, mean=656.85 mg/L) are the main ionic pollutants, with electrical conductivity (EC, mean=1441 µS/cm) at a moderate level and pH ranging from 4.51 to 9.92. aluminum (Al, mean=0.4 mg/L), boron (B, mean=0.016 mg/L), nickel (Ni, mean=0.014 mg/L), selenium (Se, mean=0.01 mg/L), and zinc (Zn, mean=0.246 mg/L) are present at low concentrations, while cadmium (Cd), chromium (Cr), and lead (Pb) were not detected, at their respective Method Detection Limits (MDL).

For Mwambashi River, EC (mean=1404.17 µS/cm) is the highest among the three water bodies, reflecting strong ionic pollution influence. Calcium (mean=346.28 mg/L), magnesium (mean=284.46 mg/L), manganese (Mn, mean=3.40 mg/L), and sulphate (mean=1502.62 mg/L) have prominent concentrations, with an acidic pH outlier (minimum 2.68). Aluminum (mean=0.23 mg/L), cobalt (mean=0.05 mg/L), copper (mean=0.04 mg/L), and other elements are at low levels, and As, B, Cd, Pb are not detected.

The Kafue River has the lowest levels of all parameters: calcium (mean= 199.07 mg/L), magnesium (mean=69.05 mg/L), and sulphate (mean= 434.78 mg/L) are the main ionic components, EC (mean=738.37 µS/cm) is the lowest, and pH is stable (mean=7.41, standard deviation=0.46). Boron (mean= 0.0052 mg/L), cobalt (mean= 0.028 mg/L), and all other elements are at very low concentrations, while As, Al, Cd, Cr, Pb are not detected. A common feature across all three water bodies is the non-detection of highly toxic metals such as As, Cd, and Pb. The major differences include higher ionic pollution risk in Mwambashi River, the need for focused monitoring of heavy metals in Chambishi Stream, and the most stable water quality in Kafue River.

4.5.2 Findings on the movement of tailings

The tailings slurry as it travelled from TD 15 consisted of the tailings solids, the liquor and soil particles eroded along its path. Based on the on-field observations and together with the records from the tailings cleanup of the site by Sino-Metals, it is determined that the movement of the solids component of the tailings, was as shown in Figure 4-19 below.

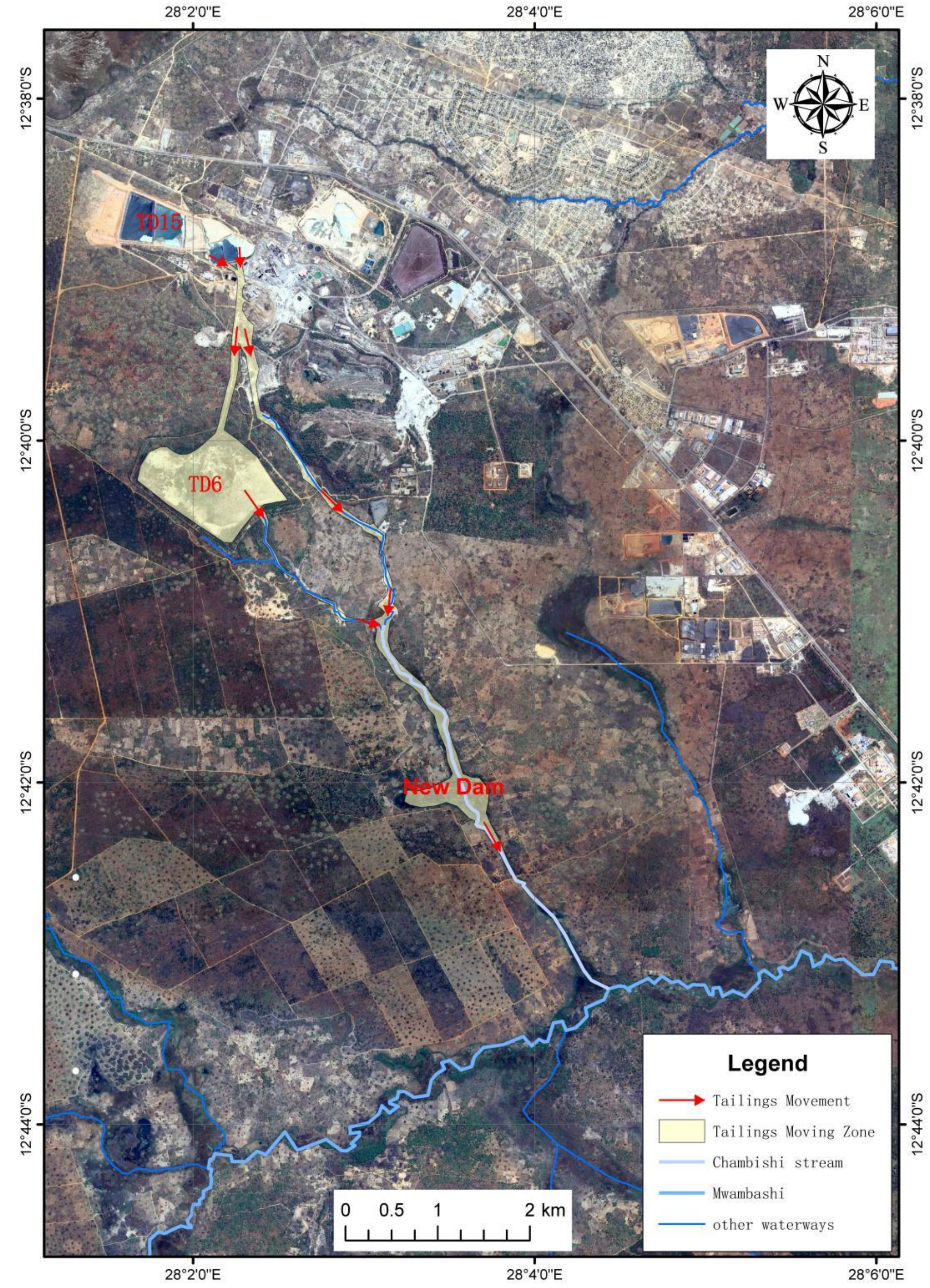


Figure 4-19: Path of tailings movement

Following the breach of Tailings Dam No. 15 (TD 15), the tailings slurry, comprising solids and liquor, flowed through the combined drainage channel before dividing into two streams. Once the stream continued with the drainage channel into Tailings Dam No. 6 (TD 6) which is designated as a Pollution Control Dam (PCD). The second stream travelled through the wetland area known as Werner's Dam, also a PCD. Some of the solids in the tailings slurry settled in TD 6, Werner's Dam, and the upstream combined drainage channel.

Subsequently, the tailings slurry from TD 6 and Werner's Dam converged and entered a downstream wetland area known as New Dam which also functions as a PCD, where further deposition of tailings solids from the slurry occurred.

Upon exiting New Dam, the tailings slurry travelled into Chambishi Stream where further deposition of tailings solids occurred. The sedimentation of the tailings solids out of the slurry was mostly due to the reduction of the velocity of Chambishi Stream as it approached the confluence with Mwambashi River. The reduction in the velocity of Chambishi Stream and the tailings slurry was a result of the following factors:

1. The earth embankment downstream of New Dam created a damming effect and slowed down the velocity of the tailings slurry exiting New Dam.
2. The widening of the stream channel together with the declining gradient of Chambishi Stream after New Dam, towards the confluence with Mwambashi River slowed down the velocity of the discharge.
3. The throwback of water in Chambishi Stream created by the smaller Chambishi Stream joining the larger Mwambashi River slowed down the velocity of water in Chambishi Stream.
4. Presence of overgrown weeds (Typha) in Chambishi Stream hindered the flow of water in the stream

The above factors ensured that tailings solids were deposited in Chambishi Stream. Field inspections during the assessment did not find verifiable tailings solids beyond the Chambishi Stream. However, there were deposits of very fine-grained sediments found along the Mwambashi River at several sites. The provenance of these fine-grained sediments deposited along Mwambashi River could not be ascertained beyond any reasonable doubt. This is especially so as visually similar sediments were found deposited along Mwambashi River upstream of the confluence with Chambishi Stream.

The liquid fraction of the tailings exited Chambishi Stream into the Mwambashi River and ultimately flowed into the Kafue River. These acidic leachates (tailings) caused severe adverse impacts on the ecological service functions of the affected areas and surrounding ecosystems. Affected water bodies include the Chambishi Stream, the Mwambashi River, and the Kafue River.

4.5.3 Findings on sediment quality

A total of 509 riverbed samples were collected for the project. A total of 25 samples were collected from Chambishi basin, 258 from Mwambashi basin and 226 from Kafue basin. The sediments were analysed for the same parameters as the water samples.

This section discusses the analytical results of sediment samples collected from Chambishi Stream, Mwambashi River and Kafue River.

4.5.3.1 Chambishi Stream

The location of sediment sampling sites on Chambishi Stream which have been used to discuss the quality of sediments along Chambishi Stream are illustrated on the map in the figure below. The key findings are discussed below. Sediment samples were collected at the sites along the Chambishi Stream and its tributaries.

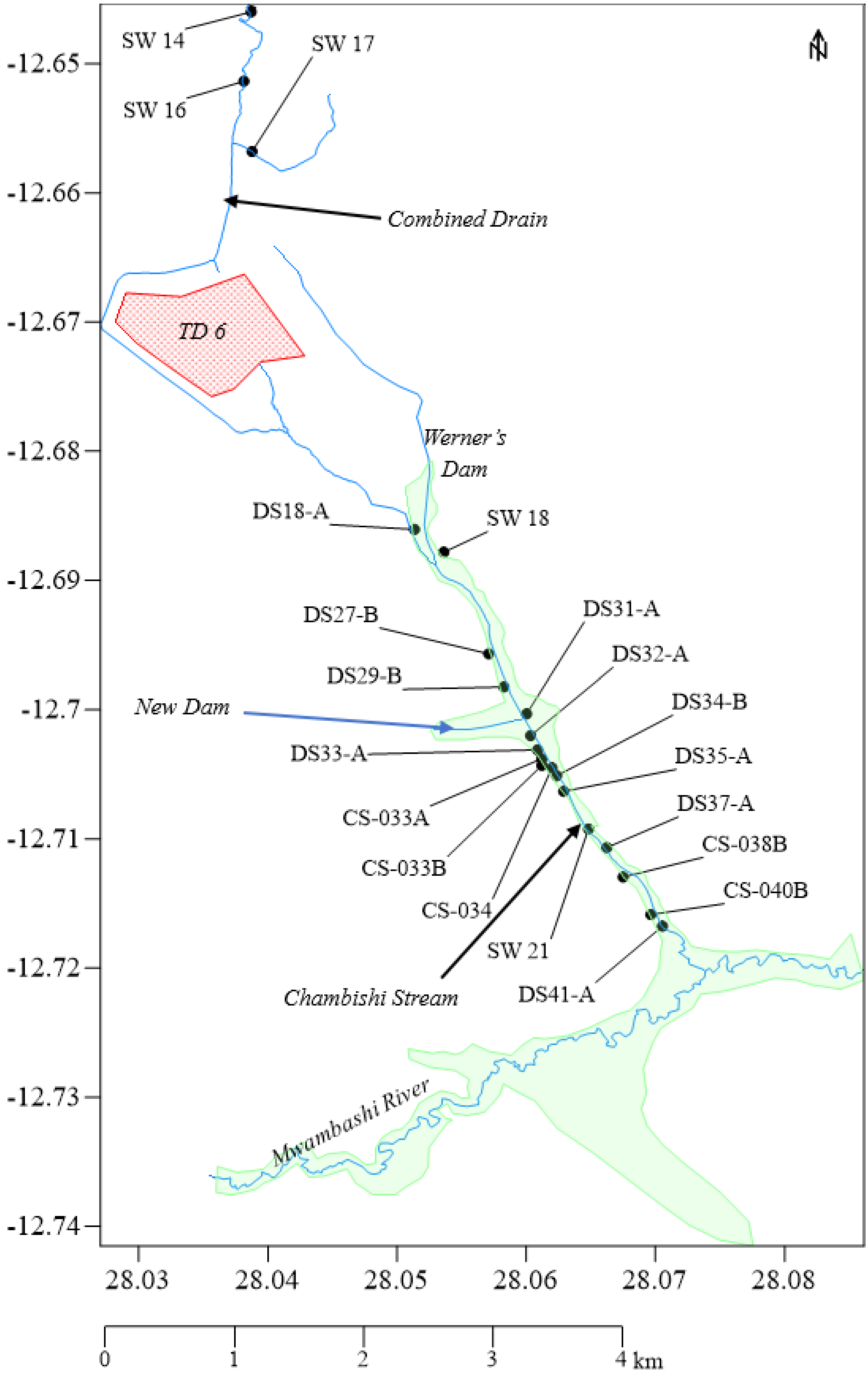


Figure 4-20: Map of Chambishi Stream showing the location of sediment sampling points

a. pH

The pH of sediment in Chambishi Stream is illustrated in the graph in the figure below. The graph shows the pH of sediment upstream of New Dam fell in a narrow range of between 6.14 and 6.5. However, upon exiting New Dam, the pH of the sediment jumped to 7.9. The rise in the pH after exiting New Dam has been attributed to dosing the discharge from New Dam with sodium hydroxide.

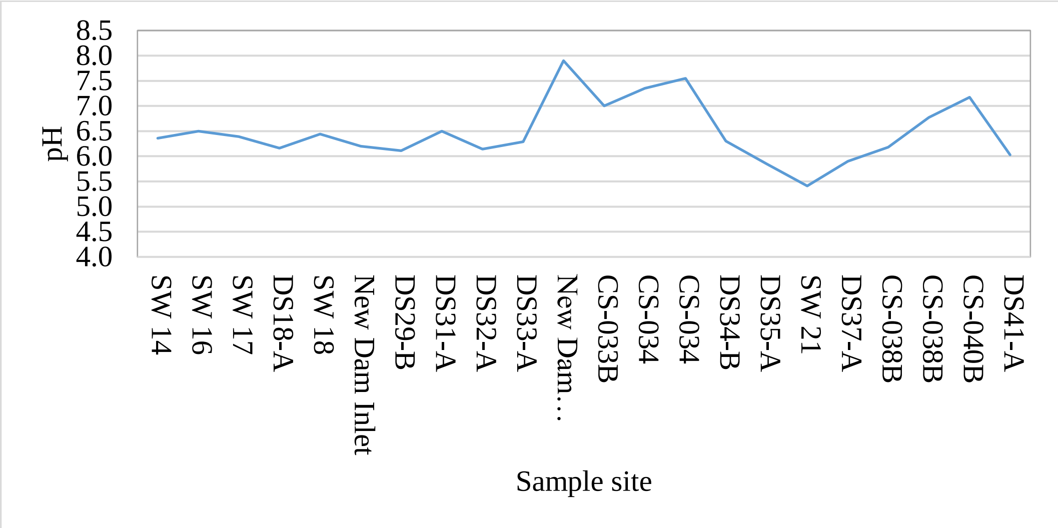


Figure 4-21: Graph showing the pH in sediment

b. Electrical conductivity

The electrical conductivity (EC) of the sediment in Chambishi Stream is presented in the figure below. The notable feature is that the EC jumped from 415 to 1,00 µS/cm towards the confluence with Mwambashi River and then declined again to 13 µS/cm at the confluence with Mwambashi River.

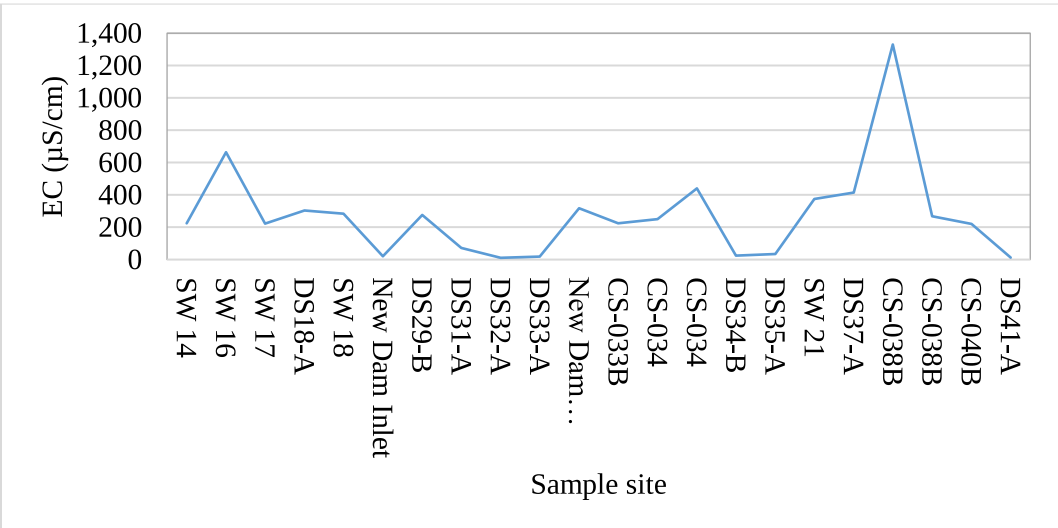


Figure 4-22: Graph showing EC in sediment

c. Copper

The concentration of copper in the sediments along Chambishi Stream is presented in the figure below. The figure shows the following:

- A site of elevated concentration of copper (31,266 mg/kg) in the combined drain
- A reduction in the concentration of copper in the sediments in New Dam to 133 mg/kg
- A short increase in the concentration of copper after New Dam to 6,030 mg/kg

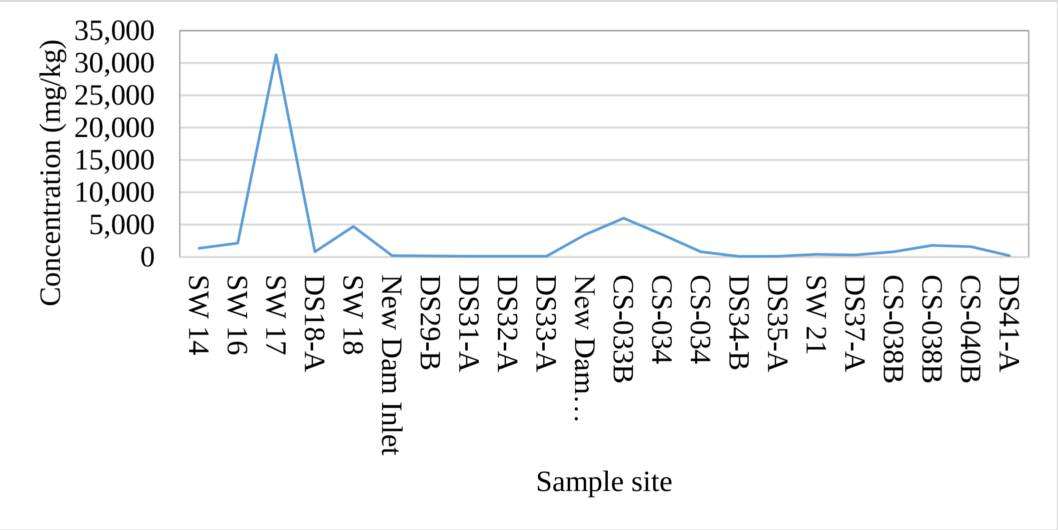


Figure 4-23: Graph showing the concentration of copper in sediment

d. Cobalt

The concentration of cobalt in the sediment in Chambishi Stream is shown in the figure below. The graph shows that the cobalt in the sediment was 624 mg/kg before New Dam and decreased to 5 mg/kg in New Dam. After New Dam, the concentration of cobalt had a short rise to 16,050 mg/kg after New Dam.

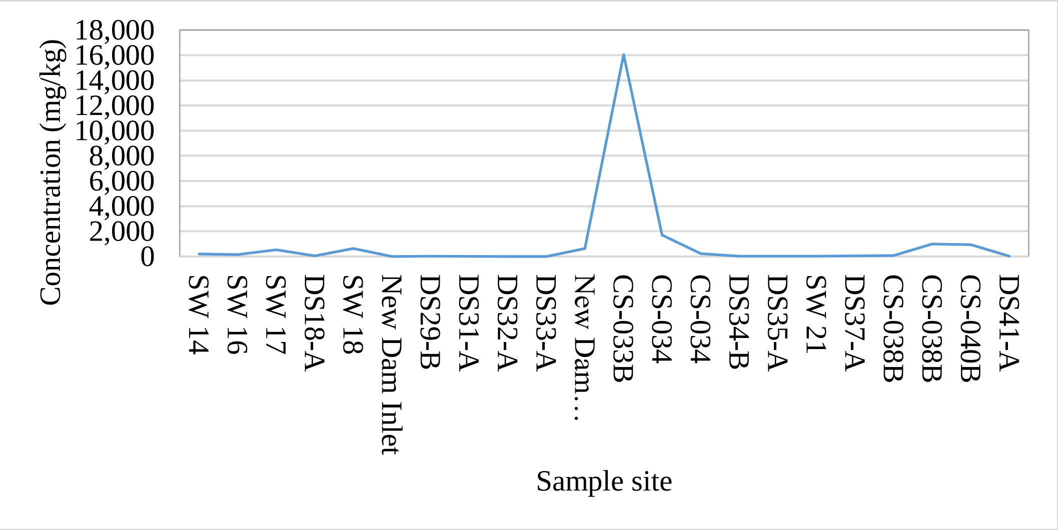


Figure 4-24 showing the concentration of Cobalt in sediment

e. Arsenic

The concentration of arsenic in Chambishi Stream showed a declining trend from 47.3 mg/kg in the combined drain to 0.01 mg/kg in New Dam. After New Dam, cobalt increased to 60.6 mg/kg before declining again towards the confluence with Mwambashi River.

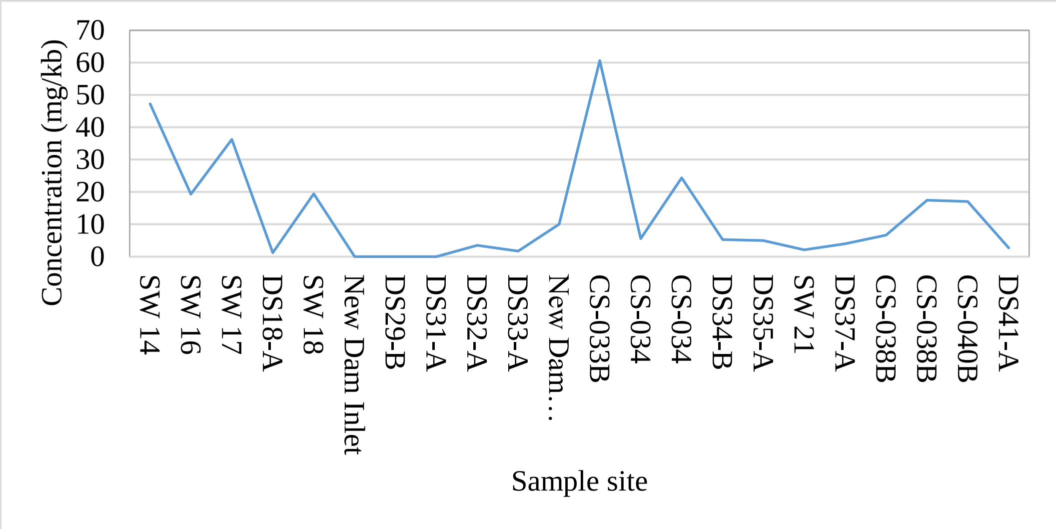


Figure 4-25: Graph showing the concentration of arsenic in sediment

f. Manganese

The figure illustrates the distribution of manganese in Chambishi River sediments. It briefly rises to 52,977 mg/kg downstream of the New Dam, then rapidly declines to approximately 500 mg/kg, followed by fluctuations before converging into the Mwambashi River.

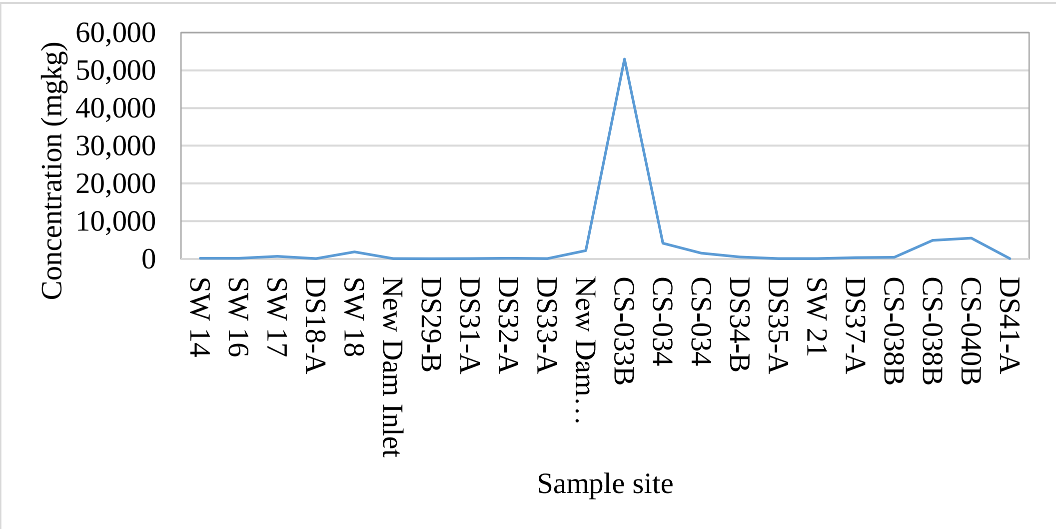


Figure 4-26: Graph showing the concentration of manganese in sediment

g. Sulphates

The concentration of sulphates in Chambishi Stream showed a declining trend from 47.3 mg/kg in the combined drain to 0.01 mg/kg in New Dam. After New Dam, cobalt increased to 60.6 mg/kg before declining again towards the confluence with Mwambashi River.

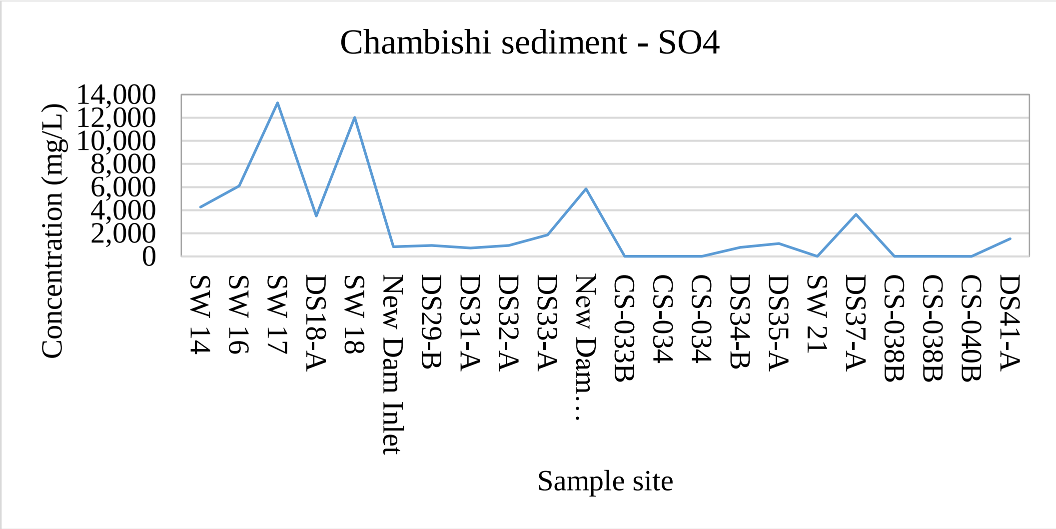


Figure 4-27: Graph showing the concentration of sulphates in sediment

The sulphate concentration in Chambishi River fluctuated at higher levels before entering the New Dam, with the maximum value recorded downstream of TD15 at 13,285 mg/kg. After entering the New Dam, the concentration showed a downward trend, but then increased again before merging into the Mwambashi River.

4.5.3.2 Mwambashi River

The location of sediment sampling sites on Mwambashi River which have been used to discuss the quality of sediments along Mwambashi River are illustrated on the map in Figure below. The key findings are discussed below. Sediment samples were collected along the Mwambashi River and its tributaries.

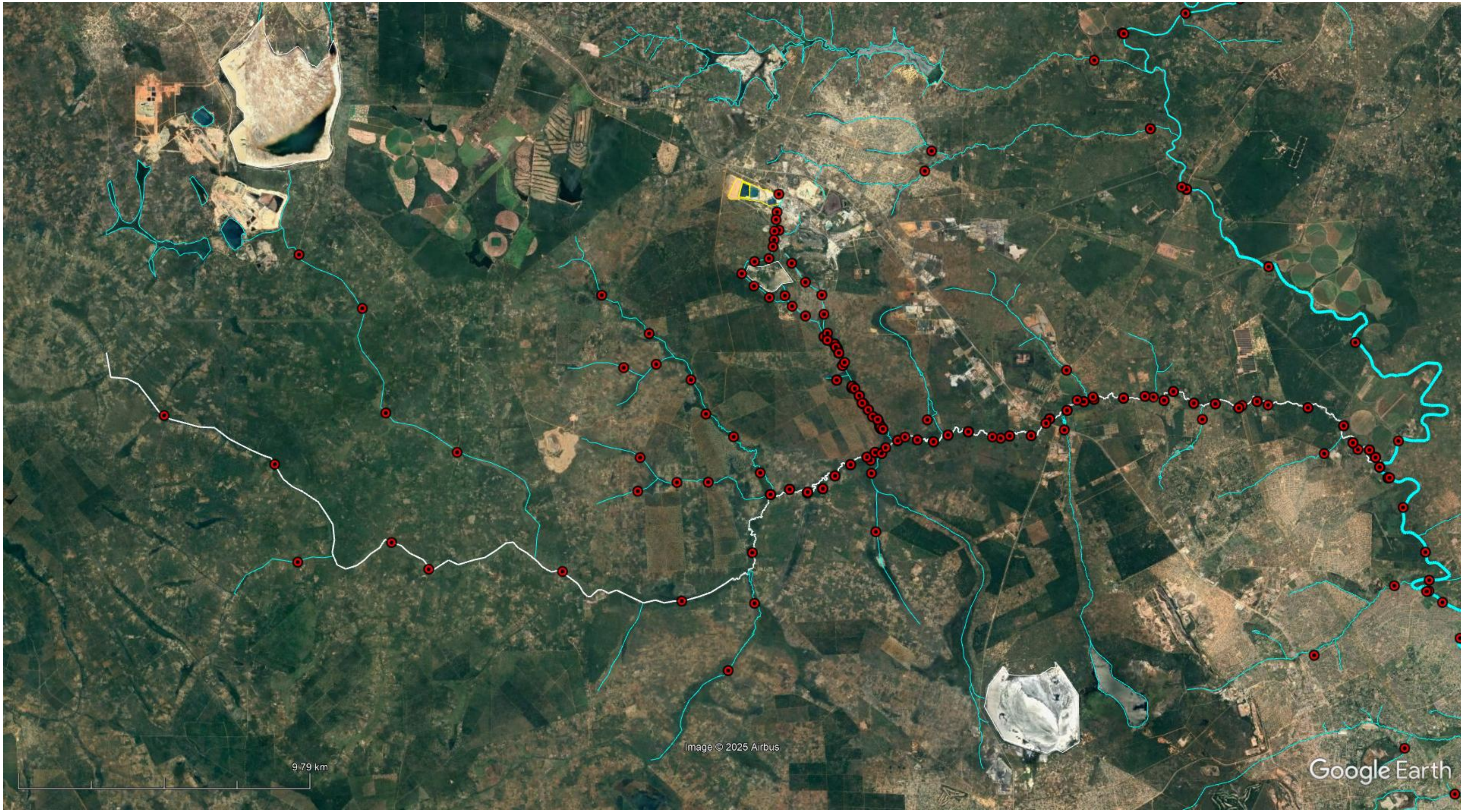


Figure 4-28: Satellite image showing location of sediment sampling points on Mwambashi River

a. pH

The pH of the sediment in the mainstream of the Mwambashi River is illustrated in the figure below. The sampling points to the left of and including MR-008 are located upstream of the confluence where the Chambishi Stream joins the Mwambashi River, while the sampling points to the right of and including MR-009 are downstream of this confluence. The figure indicates that the sediment pH values upstream of the Chambishi Stream's confluence are relatively low, with the lowest value reaching as low as 6.22. Near the confluence of the Chambishi Stream, the sediment pH values show little change, remaining around 7.5. The pH values of the sediments in the mainstream of the Mwambashi River all fall within the range of 6 to 8.

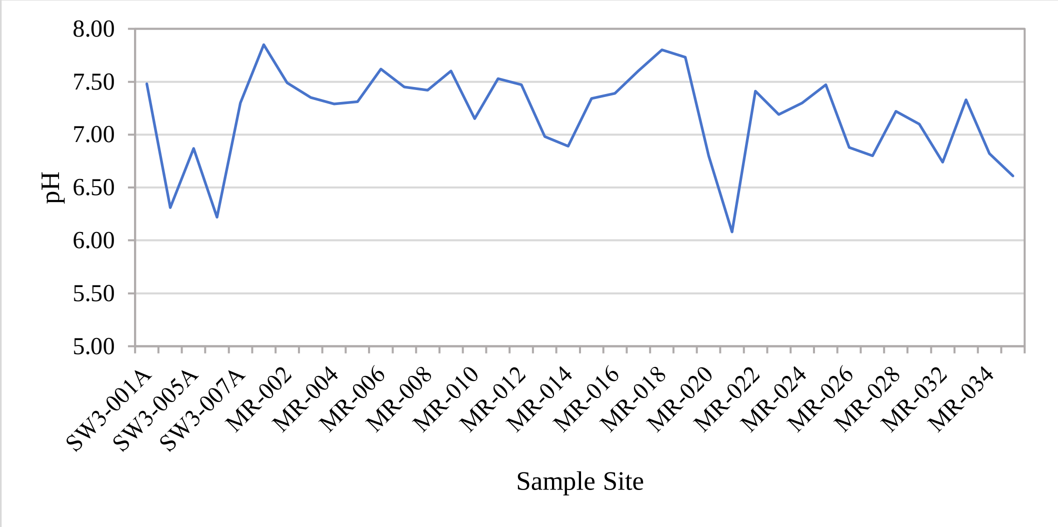


Figure 4-29: Graph showing the pH in sediment

b. Electrical conductivity

The EC of the sediment in the mainstream of the Mwambashi River is illustrated in the figure below. The sampling points to the left of and including MR-008 are located upstream of the confluence where the Chambishi Stream joins the Mwambashi River, while the sampling points to the right of and including MR-009 are downstream of this confluence. The figure shows that the point with the lowest EC of the sediments upstream of the confluence of the Chambishi Stream is SW3-005A, with an EC value of 6 µS/cm. The point with the highest EC is MR-002, with an EC value of 228 µS/cm. The EC of the sediments near the confluence of the Chambishi Stream shows little change, and the EC of the sediments in the mainstream of the Mwambashi River remains generally stable.

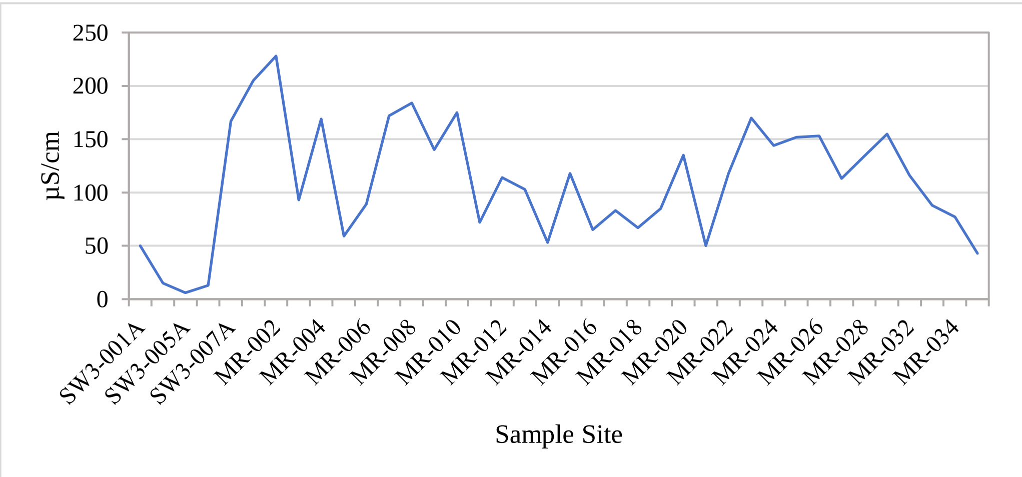


Figure 4-30: Graph showing EC in sediment

c. Copper

The copper concentration of the sediment in the mainstream of the Mwambashi River is illustrated in the figure below. The sampling points to the left of and including MR-008 are located upstream of the confluence where the Chambishi Stream joins the Mwambashi River, while the sampling points to the right of and including MR-009 are downstream of this confluence. The figure shows that the copper concentration in the sediments upstream of the Chambishi Stream's confluence reaches a maximum of 1894.60 mg/kg, with most points showing relatively low levels. Near the confluence of the Chambishi Stream, the copper concentration in the sediments exhibits minimal change. Downstream of MR-009, there is a slight increase in copper concentration, though it remains at a generally low level overall.

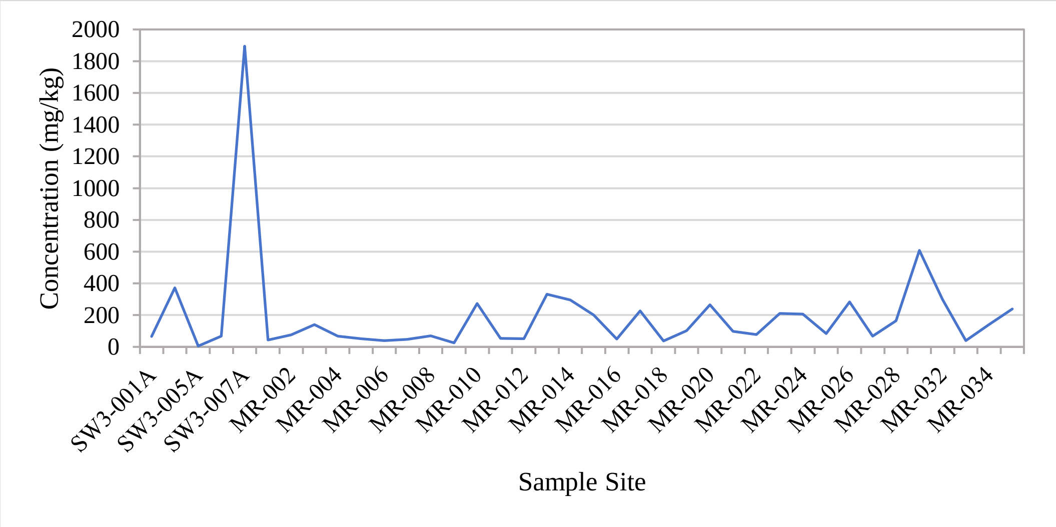


Figure 4-31: Graph showing the concentration of copper in sediment

d. Cobalt

The cobalt concentration of the sediment in the mainstream of the Mwambashi River is illustrated in the figure below. The sampling points to the left of and including MR-008 are located upstream of the confluence where the Chambishi Stream joins the Mwambashi River, while the sampling points to the right of and including MR-009 are downstream of this confluence. The figure shows that the cobalt concentration in the sediments upstream of the confluence of the Chambishi Stream reaches a maximum of 373.30 mg/kg, with most sampling points exhibiting relatively low levels. Compared to the upstream area, there is a slight increase in cobalt concentration downstream of the Chambishi Stream's confluence, followed by a subsequent decrease. However, some sampling points downstream still have relatively high cobalt concentrations in the sediments, around 300 mg/kg.

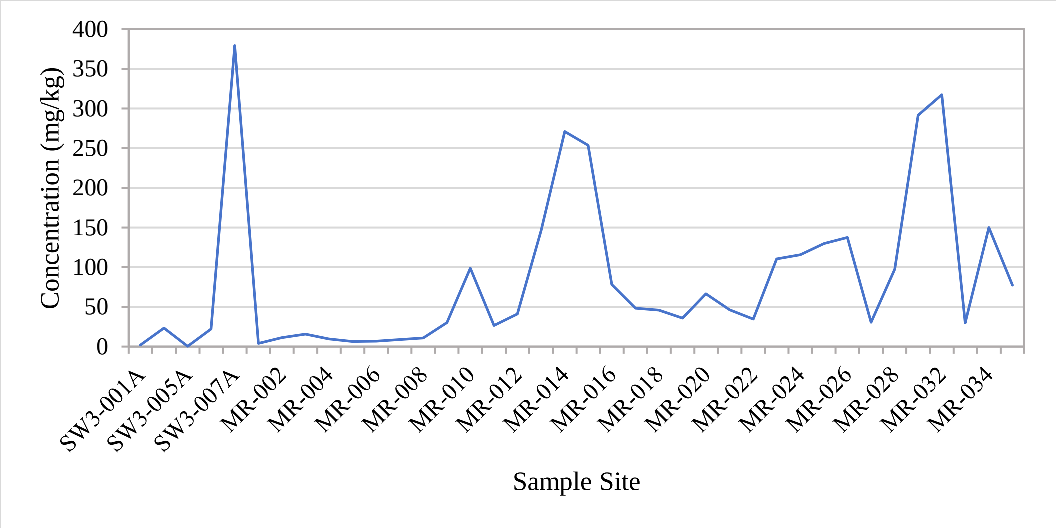


Figure 4-32 showing the concentration of Cobalt in sediment

e. Arsenic

The arsenic concentration of the sediment in the mainstream of the Mwambashi River is illustrated in the Figure below. The figure shows that the arsenic concentration in the sediments upstream of the confluence of the Chambishi Stream reaches a peak value of 47.75 mg/kg at sample site SW3-007A. Excluding this particular site, the arsenic concentrations in the sediments at all other points along the mainstream of the Mwambashi River stay at relatively low levels, all below 4 mg/kg.

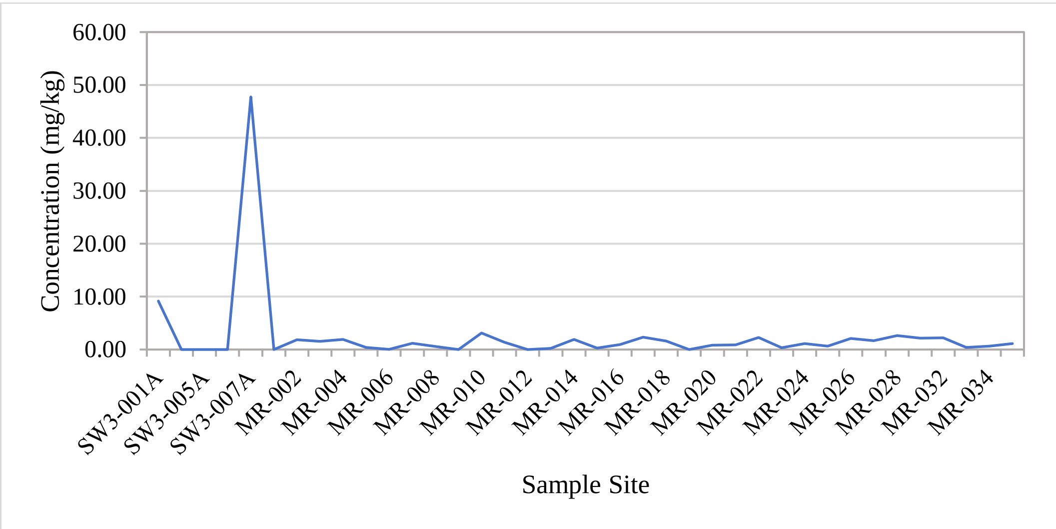


Figure 4-33: Graph showing the concentration of arsenic in sediment

f. Manganese

The manganese concentration of the sediment in the mainstream of the Mwambashi River is illustrated in the Figure below. The sampling points to the left of and including MR-008 are located upstream of the confluence where the Chambishi Stream joins the Mwambashi River, while the sampling points to the right of and including MR-009 are downstream of this confluence. The figure shows that the manganese concentration in the sediments upstream of the confluence of the Chambishi Stream is relatively high, reaching a maximum of 8,175.75 mg/kg. Near the confluence, the manganese concentration in the sediments drops sharply from 5,757.52 mg/kg at the upstream point MR-008 to 673.75 mg/kg at the downstream point MR-009. While the manganese concentrations in the sediments at most downstream points are not high, the concentration at point MR-015 is relatively elevated, measuring 5,548.64 mg/kg.

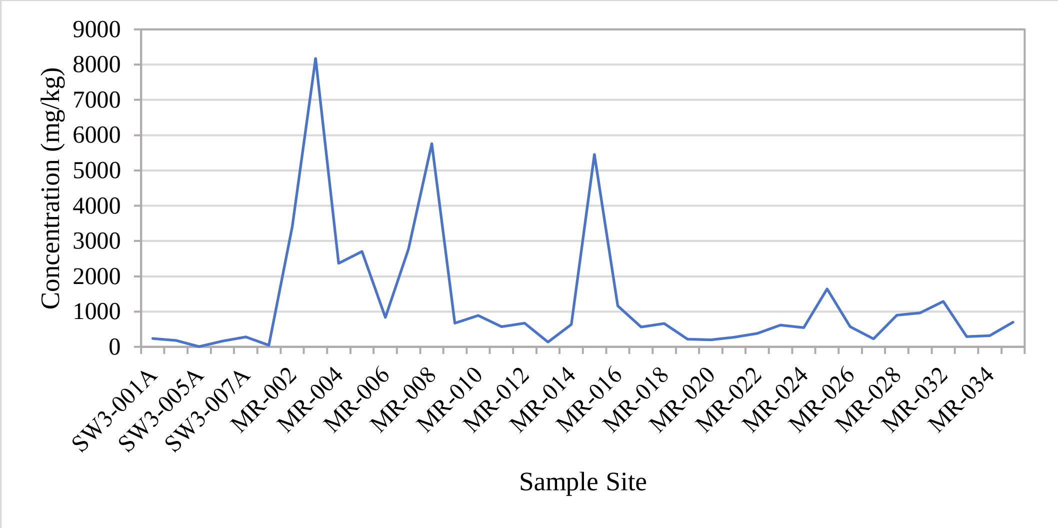


Figure 4-34: Graph showing the concentration of manganese in sediment

g. Sulphates

The sulphate concentration of the sediment in the mainstream of the Mwambashi River is illustrated in the Figure below. The sampling points to the left of and including MR-008 are located upstream of the confluence where the Chambishi Stream joins the Mwambashi River, while the sampling points to the right of and including MR-009 are downstream of this confluence. The figure shows that the sulphate concentration in the sediments of the mainstream of the Mwambashi River is generally at a relatively high level overall. Near the confluence of the Chambishi Stream, the sulphates concentration in the sediments shows little variation. However, at some points downstream of the Mwambashi River, there is a significant increase in sulphate concentration with the peak value reaching as high as 22,907.4 mg/kg at the sample site MR-032.

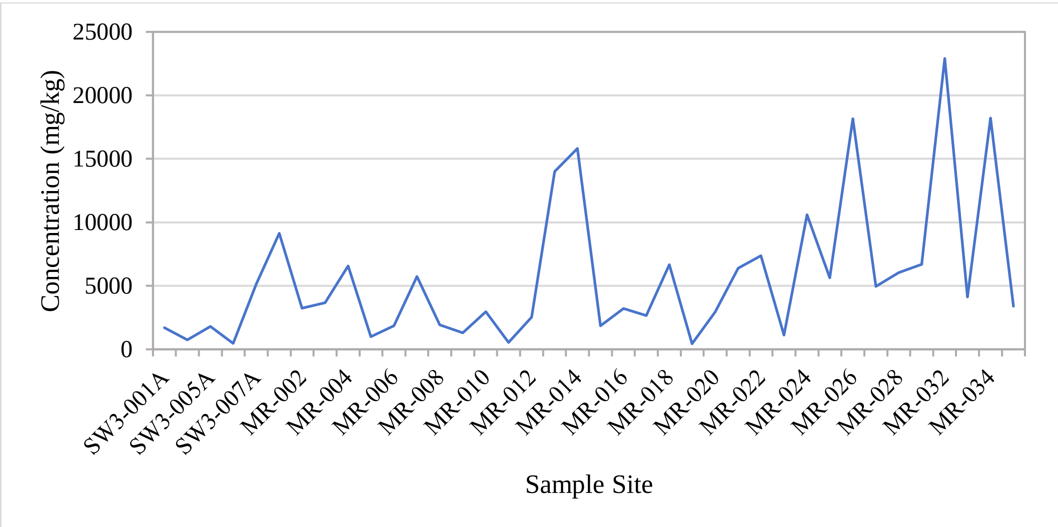


Figure 4-35: Graph showing the concentration of sulphates in sediment

4.5.3.3 Kafue River

The location of sediment sampling sites on Kafue River which have been used to discuss the quality of sediments along Kafue River are illustrated on the map in Figure below. The key findings are discussed below. Sediment samples were collected along the Kafue River and its tributaries.

Figure 4-36: Satellite image showing location of sediment sampling points on Kafue River

a. pH

The sediment pH values of the Kafue River are illustrated in the figure. The data indicates that the pH levels were generally below 7.5 before Ngabwe Pontoon, with the lowest recorded at approximately 6.3 at Kafironda Bridge, Bedrock Mine, and SW67. After Ngabwe Pontoon, the average pH value rose above 7.5.

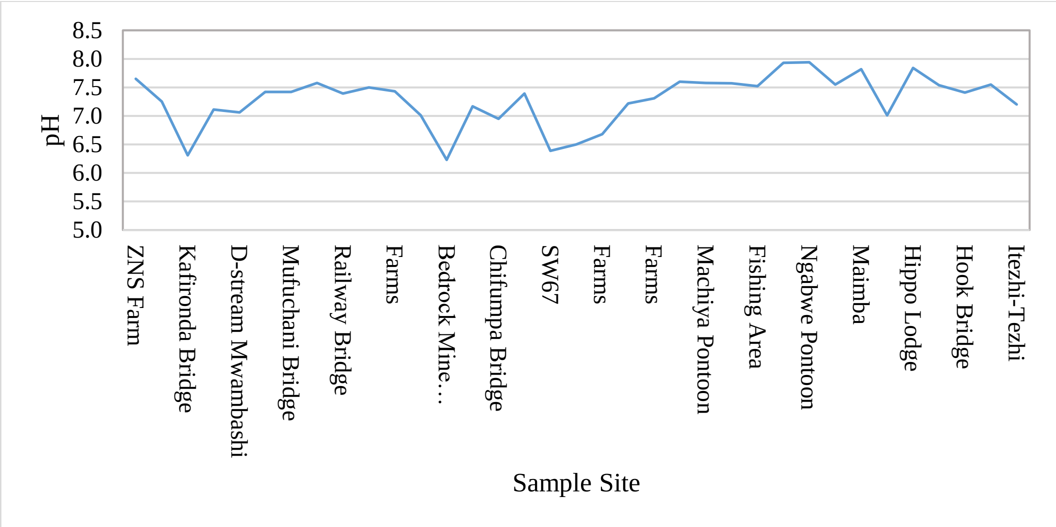


Figure 4-37: Graph showing the pH in sediment

b. Electrical conductivity

The figure illustrates the conductivity (EC) variations of Kafue River sediments. Notably, EC peaks at 457 µS/cm at the Mufuchani Bridge, followed by significant fluctuations over a distance. It then drops markedly after Kafue Lodge and further decreases to 66 µS/cm beyond Hook Bridge.

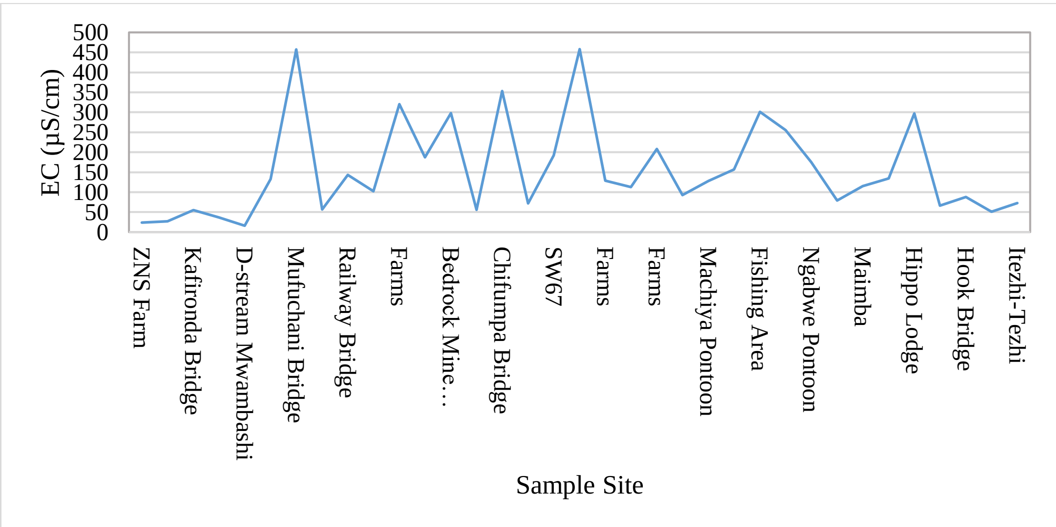


Figure 4-38: Graph showing EC in sediment

c. Copper

The figure illustrates the variation of copper (Cu) in Kafue River sediments. At ZNS Farm, the concentration decreases progressively from a peak value of 9,198.91 mg/kg, while at ZNS Area it shows a significant increase followed by a sharp decline. After Maimba, the concentration further drops below 100 mg/kg.

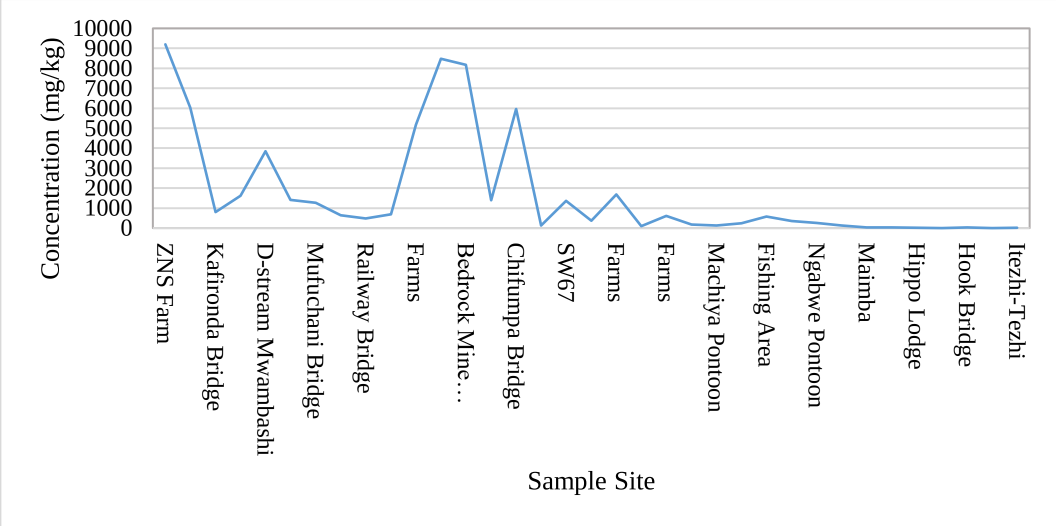


Figure 4-39: Graph showing the concentration of copper in sedimentt

d. Cobalt

The figure illustrates the variation of cobalt (Co) in Kafue River sediments. Significant elevation is observed between the Kitwe-Ndola Road Bridge and Kafulafuta, with a maximum value of 1,152 mg/kg, followed by a gradual decline from 259 mg/kg to below 10 mg/kg.

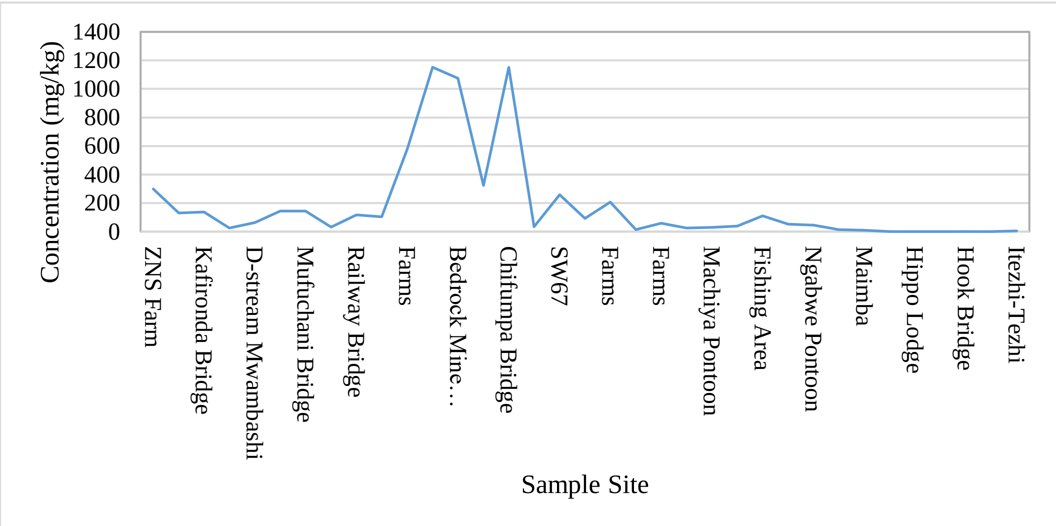


Figure 4-40 showing the concentration of Cobalt in sediment

e. Arsenic

Figure 4-41 illustrates the variation of arsenic (As) in Kafue River sediments. It shows a significant increase between Kitwe-Ndola Road Bridge and SW67, reaching a maximum of 30 mg/kg, followed by a steady downward fluctuation. At Maimba, the concentration abruptly rises to 26 mg/kg, then gradually decreases to below 5 mg/kg.

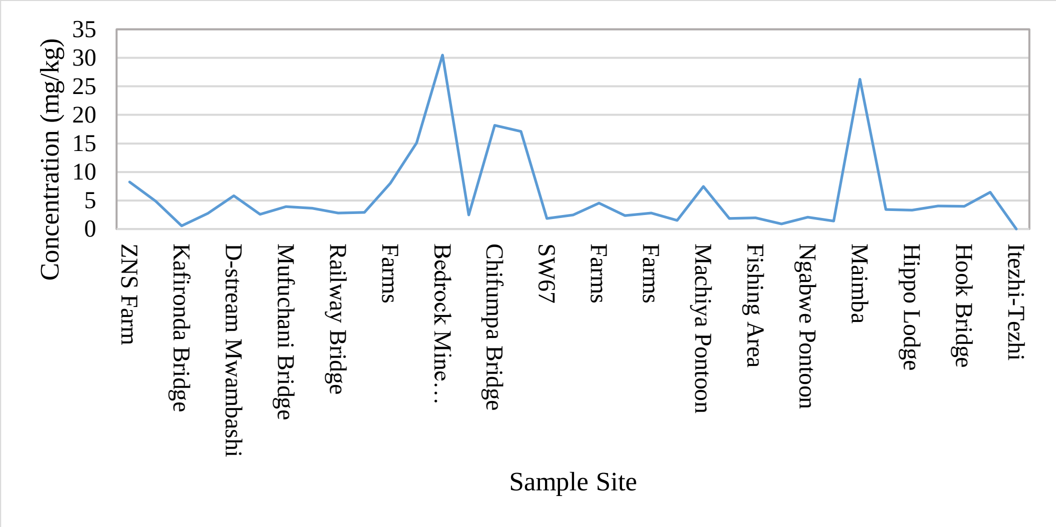


Figure 4-41: Graph showing the concentration of arsenic in sediment

f. Manganese

Figure 4.42 illustrates the variation of manganese (Mn) in Kafue River sediments, showing a gradual decreasing trend. The maximum value of 1896 mg/kg is observed at Kafronda Bridge, followed by a steady downward fluctuation. After the Fishing Area, the concentration stabilizes and decreases below 400 mg/kg.

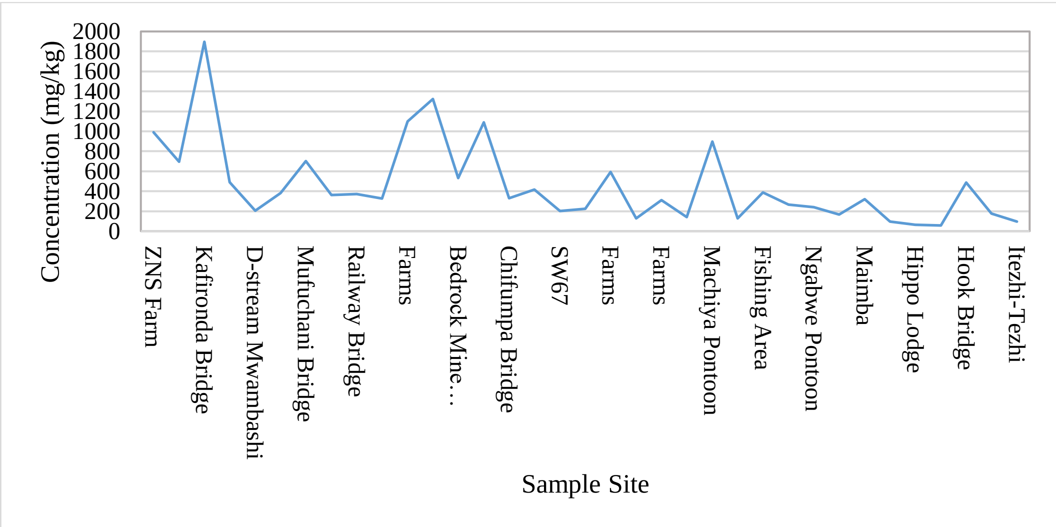


Figure 4-42: Graph showing the concentration of manganese in sediment

g. Sulphates

Figure 4-43 illustrates the variation of sulphate in Kafue River sediments. Following fluctuations after ZNS Farm, it reached a peak of 31,087 mg/kg at Chifumpa Bridge, then declined significantly. A subsequent rise was observed at the Fishing Area, after which it stabilized with downward fluctuations.

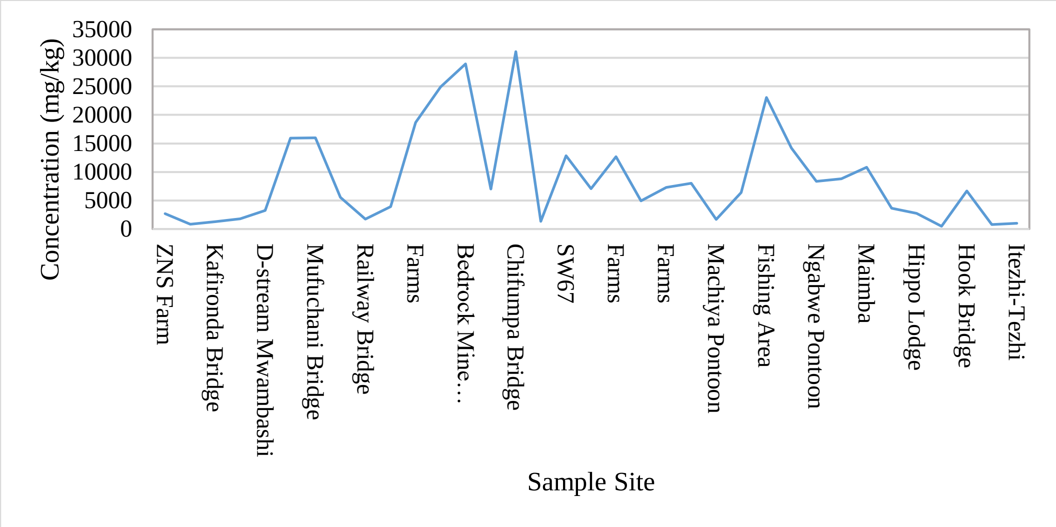


Figure 4-43: Graph showing the concentration of sulphates in sediment

h. Lead

The figure illustrates the variation of lead (Pb) in Kafue River sediments. Except for the highest value of 939 mg/kg recorded at the Bulangililo Bridge section, the concentrations fluctuated below 200 mg/kg in other areas.

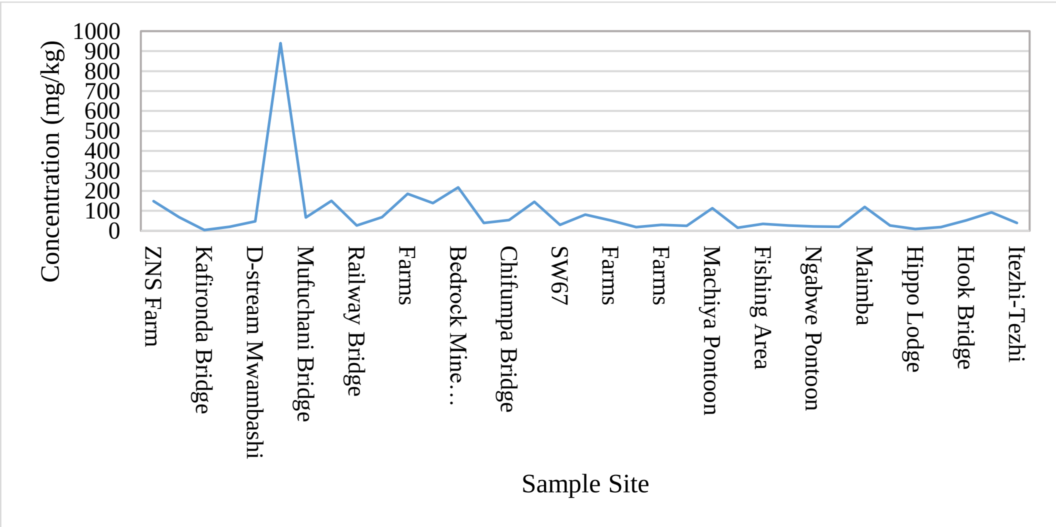


Figure 4-44: Graph showing the concentration of Lead in sediment

4.6 Assessment of the impact of the tailings discharge on surface water quality

This section conducts assessments cantered on the entire basin and on specific targeted areas. The basin-wide analysis is divided into three regions: the Chambishi Stream, the Mwambashi River, and the Kafue River. Eight pollution indicator parameters (electrical conductivity, pH, copper, cobalt, manganese, calcium, sulphates, magnesium, and calcium) are selected for analysis. The analysis of the targeted areas includes a comparative study of historical and current monitoring data for the Chambishi Stream, as well as a comparative analysis of two confluence points (Chambishi Stream confluences with Mwambashi River, and Mwambashi River confluences with Kafue River). Finally, the role of the New Dam in pollution control is outlined.

4.6.1 Assessment of the impact of the tailings discharge on the entire basin

4.6.1.1 Assessment of the impact on the Chambishi Stream

Figure 4-45 shows the profile of electrical conductivity along Chambishi Stream. The graph shows that the electrical conductivity of Chambishi Stream was mostly above the recommended value of Ambient Water Quality Standards (AWQS) of 800 µS/cm. The EC decreased from 2,070 µS/cm upstream of New Dam to 744 µS/cm at the discharge point. The decrease in the electrical conductivity is attributed to the uptake or settling of dissolved solids out of solution by the wetland. The graph also shows that electrical conductivity increased to 1,260 µS/cm upon leaving New Dam.

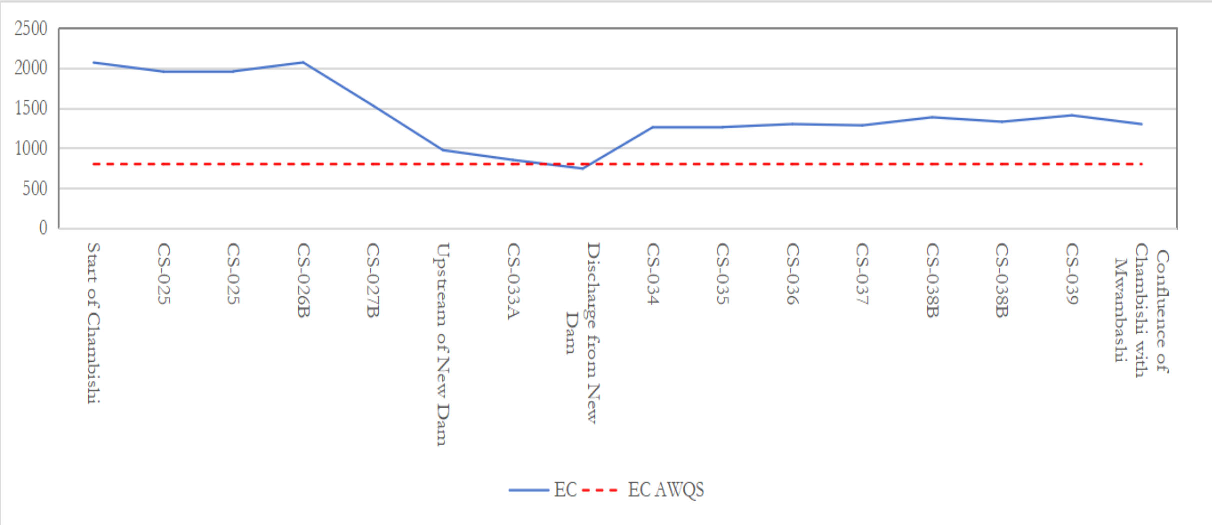


Figure 4-45: Electrical conductivity along Chambishi Stream

Figure 4-46 shows the pH profile of water along Chambishi Stream. The Figure shows the pH was within the recommended value of 6.0 to 9.0. The pH increased from 7.68 before New Dam to 8.5 at the discharge from New Dam. The increase in the pH of water has been attributed to the dosing of water coming out of New Dam with sodium Hydroxide (NaOH) by Sino-Metals. Dosing is carried out for the purpose of raising the pH of the water and precipitating the metal ions out of solution. The graph shows that the pH of Chambishi Stream returns to its pre-dosing level before the confluence with Mwambashi River.

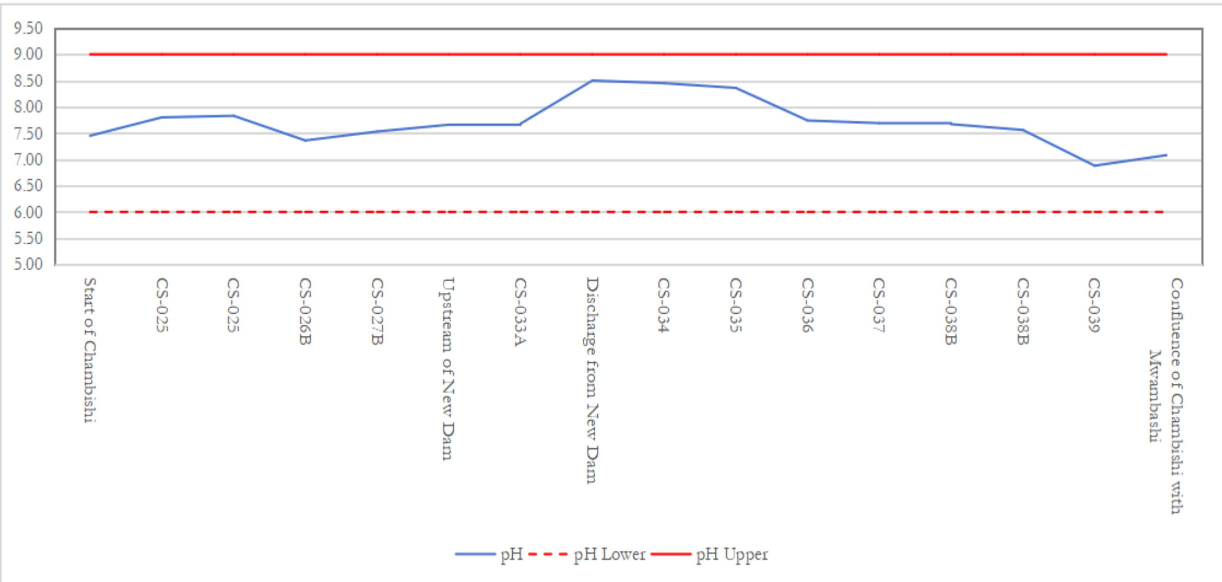


Figure 4-46: pH of water along Chambishi Stream

The concentration of copper in the Chambishi Stream is shown in Figure 4-47. The graph shows that the concentration of copper is below the recommended value of 1.5 mg/L according to the Ambient Water Quality Standards (AWQS) before entering the New Dam. It peaks at 6.87 mg/L at the New Dam, then decreases to below the recommended value of 1.5 mg/L after leaving the dam, and drops significantly below the recommended value before converging into the Mwambashi River.

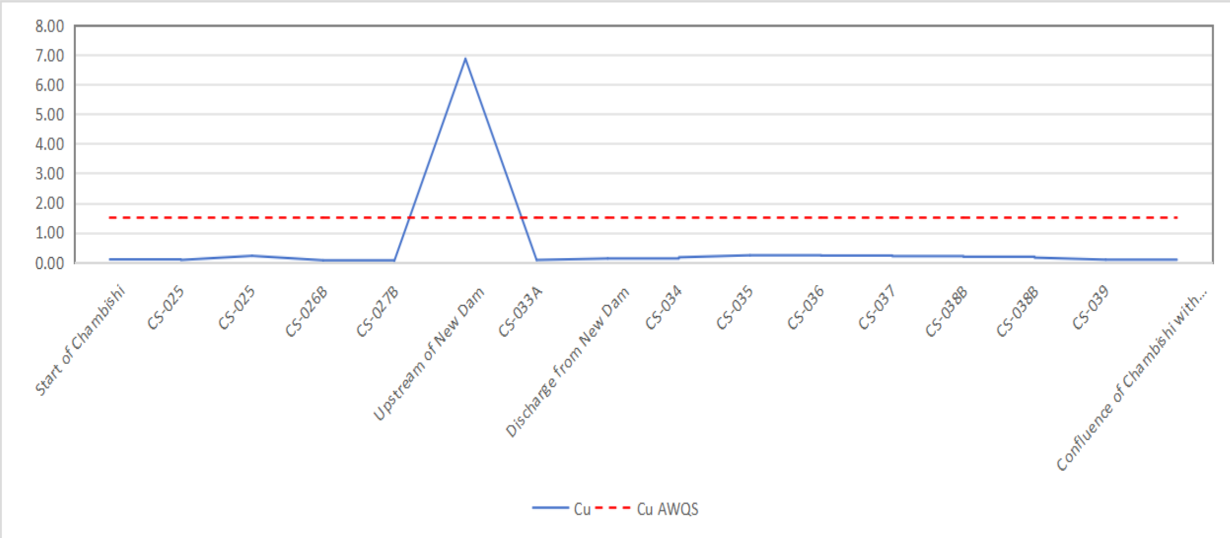


Figure 4-47: Concentration of copper in Chambishi Stream

The concentration of cobalt in the Chambishi Stream is shown in Figure 4-48. The graph shows that the concentration of cobalt is below the recommended value of 0.1 mg/L before entering the New Dam. It peaks at 3.512 mg/L at the New Dam, after leaving the New Dam, the concentration decreased significantly and fluctuated around the recommended value. It dropped notably below the recommended value before converging into the Mwambashi River.

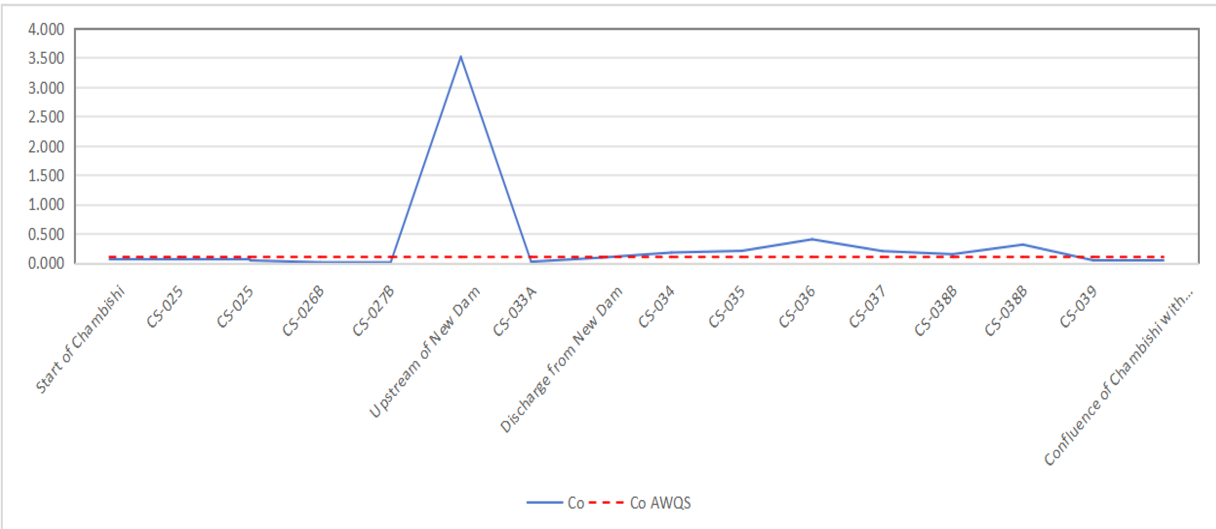


Figure 4-48: Concentration of cobalt in Chambishi Stream

The concentration of manganese in the Chambishi Stream is shown in Figure 4-49. The graph shows that the concentration of manganese fluctuated around the recommended value of 0.2 mg/L before entering the New Dam, reaching a peak of 12 mg/L just prior to the New Dam. After leaving the New Dam, the concentration decreased significantly, then showed a rising trend for a period before gradually declining again. It was notably lower than the recommended value before converging into the Mwambashi River.

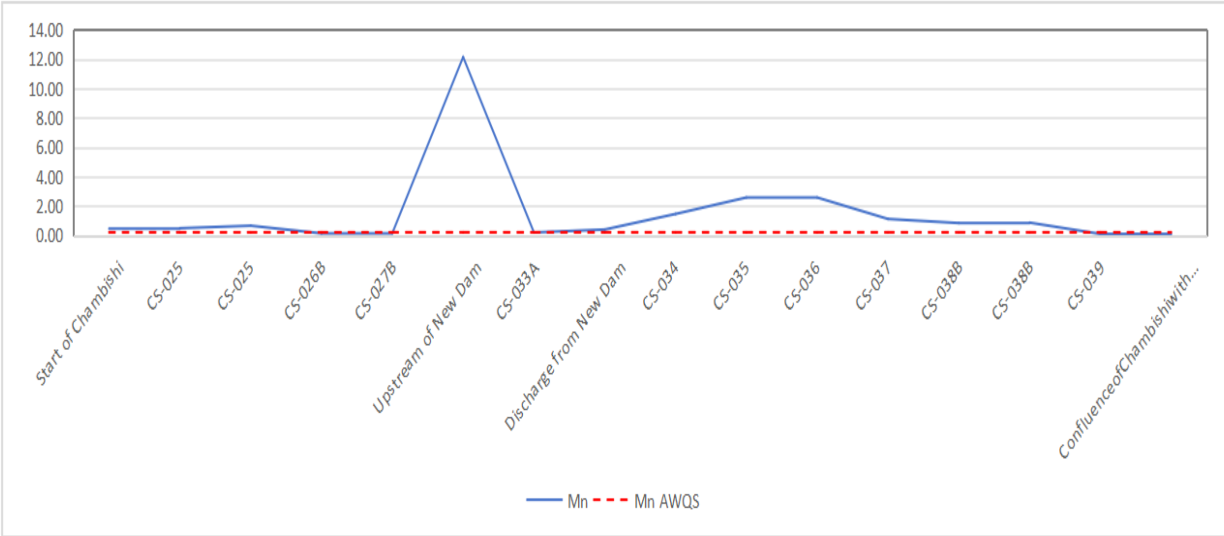


Figure 4-49: Concentration of manganese in Chambishi Stream

The concentration of sulphates in Chambishi Stream is shown in Figure 4-50. The graph shows that the concentration of sulphates in water was always above the recommended value of 60 mg/L. The concentration of sulphates decreased from 1,081 mg/L before New Dam to 213 mg/L at the discharge of New Dam. The graph illustrates the polishing effect of New Dam of effluent passing through the facility. The graph also shows that the concentration of sulphates increased to 528 mg/L after leaving New Dam.

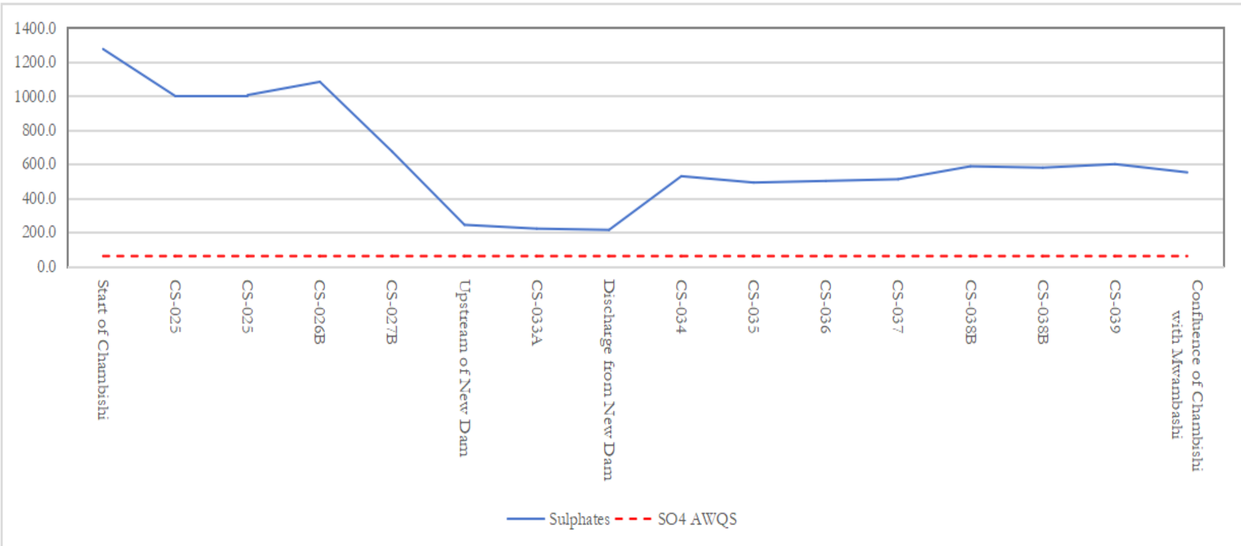


Figure 4-50: Concentration of sulphates in Chambishi Stream

The concentration of magnesium in the Chambishi Stream is shown in Figure 4-51. The graph shows that the magnesium concentration in the water consistently exceeds the recommended value of 40 mg/L under the Ambient Water Quality Standards (AWQS). The magnesium concentration decreases significantly after entering the wetland, dropping from 277.21 mg/L at the discharge of Wenners Dam to 91.80 mg/L at the discharge of the New Dam.

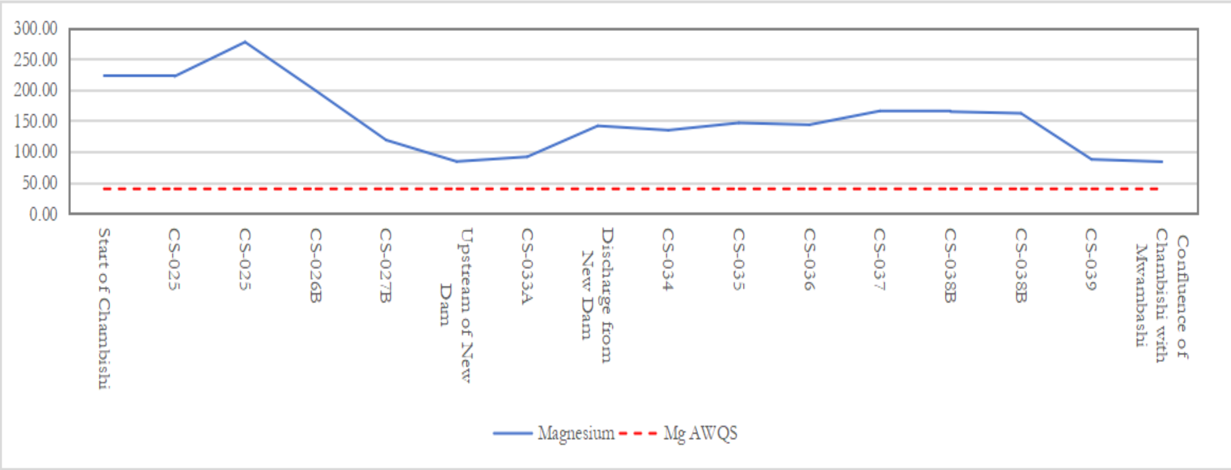


Figure 4-51: Concentration of magnesium in Chambishi Stream

The concentration of calcium in the Chambishi Stream is shown in Figure 4-52. The graph shows that the calcium concentration in the water consistently exceeds the recommended value of 60 mg/L. The concentration decreased significantly after entering the wetland, dropping from 662 mg/L at the discharge of Wenners Dam to 71.5 mg/L at the discharge of the New Dam.

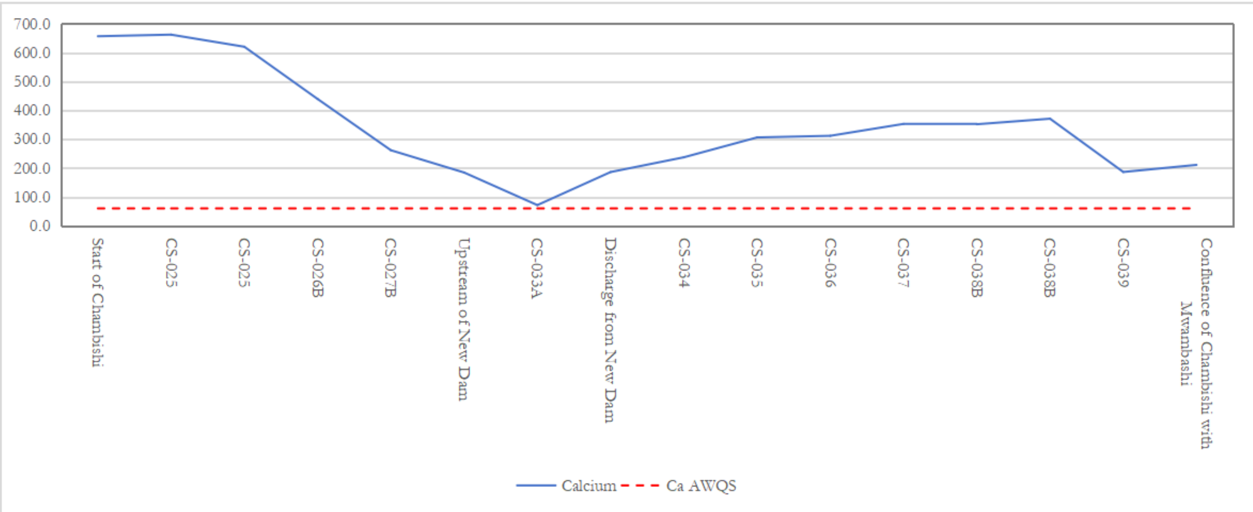


Figure 4-52: Concentration of calcium in Chambishi Stream

4.6.1.2 Assessment of the impact on the Mwambashi River

Figure 4-53 shows the profile of electrical conductivity along Mwambashi River. The average value of EC in the Mwambashi River was 1809 µS/cm, mostly above the Ambient Water Quality Standards (AWQS) of 800 µS/cm. The EC was at a low of 46 µS/cm upstream, near the source. But increased to 5200 µS/cm after the confluence with Mutimpa Stream and gradually decreased to 1567 µS/cm. The maximum value was found 30 km upstream of the confluence of the Chambishi Stream and Mwambashi Rivers. The graph shows that the electrical conductivity was no significant change at the confluence of Chambishi with Mwambashi.

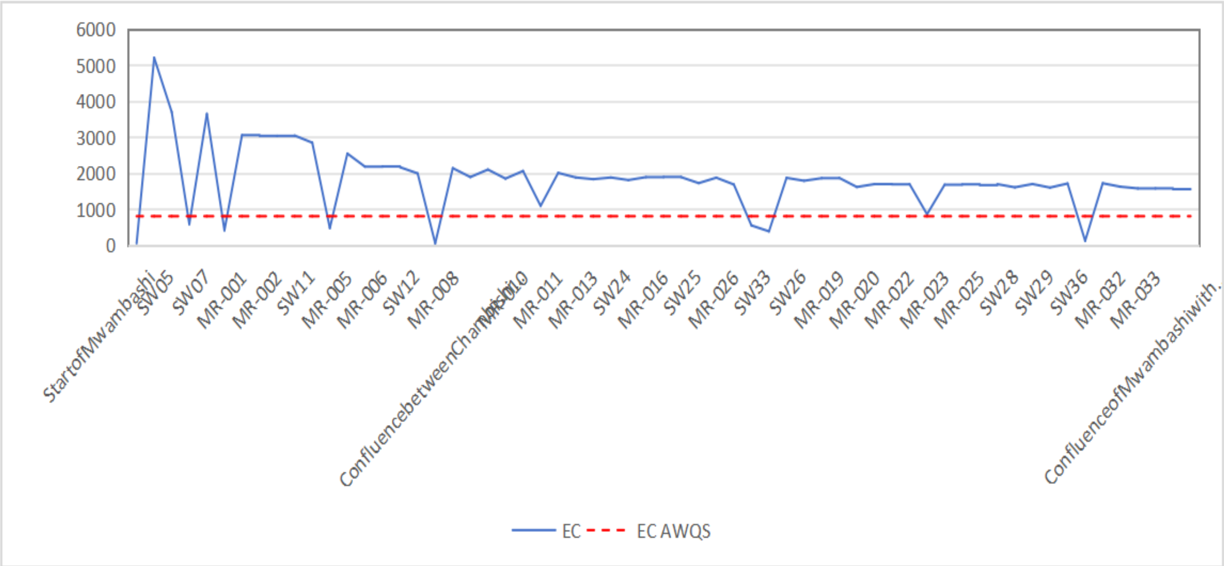


Figure 4-53: Electrical conductivity along Mwambashi River

Figure 4-54 presents the pH profile along the Mwambashi River, with an average pH of 7.35. The majority of the river's pH levels fall within the Ambient Water Quality Standards (AWQS) range of 6-9, though the upper reaches generally show lower values. The graph shows a gradual increase in pH after the confluence of Chambishi with Mwambashi River, with occasional drops caused by the lower pH of the merging tributaries. The lowest pH on Mwambashi River of 4.91 was recorded after the confluence with Mutimpa Stream, upstream of Chambishi Stream.

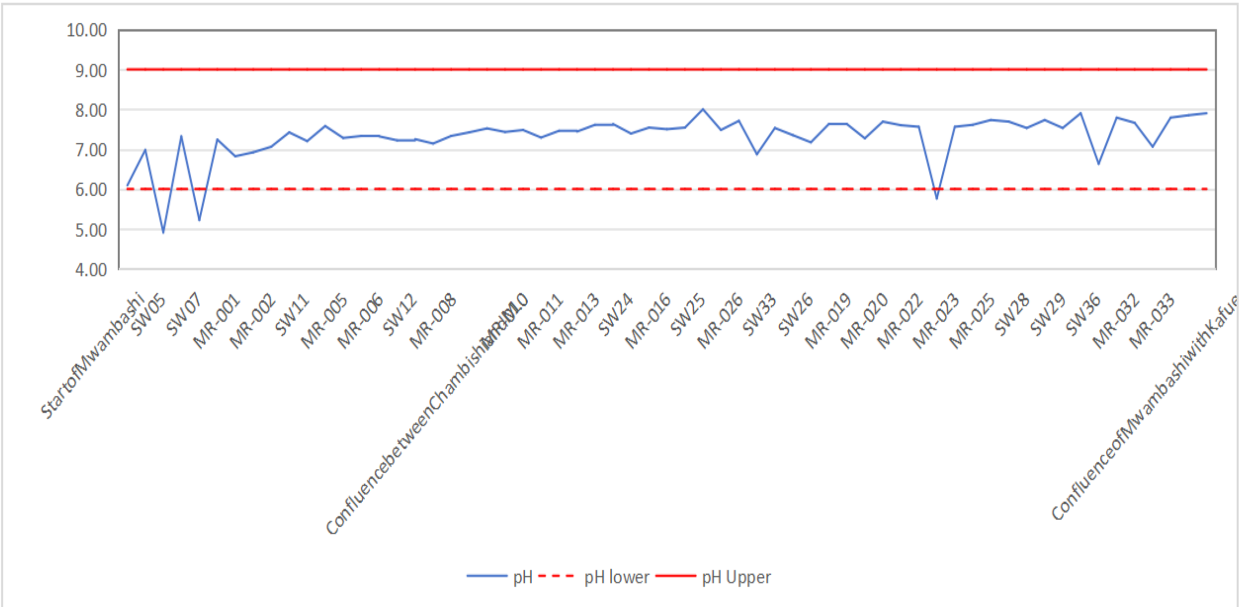


Figure 4-54: pH of water along Mwambashi River

Figure 4-55 shows the profile of Copper along Mwambashi River. With the exception of the upstream area where the maximum concentration reached 0.51 mg/L, the maximum value was found 30 km upstream of the confluence of the Chambishi Stream and Mwambashi Rivers. The average concentration at other locations was 0.014 mg/L, significantly below the Ambient Water Quality Standards (AWQS) recommended value of 1.5 mg/L. Copper was no significant change at the confluence of Chambishi with Mwambashi.

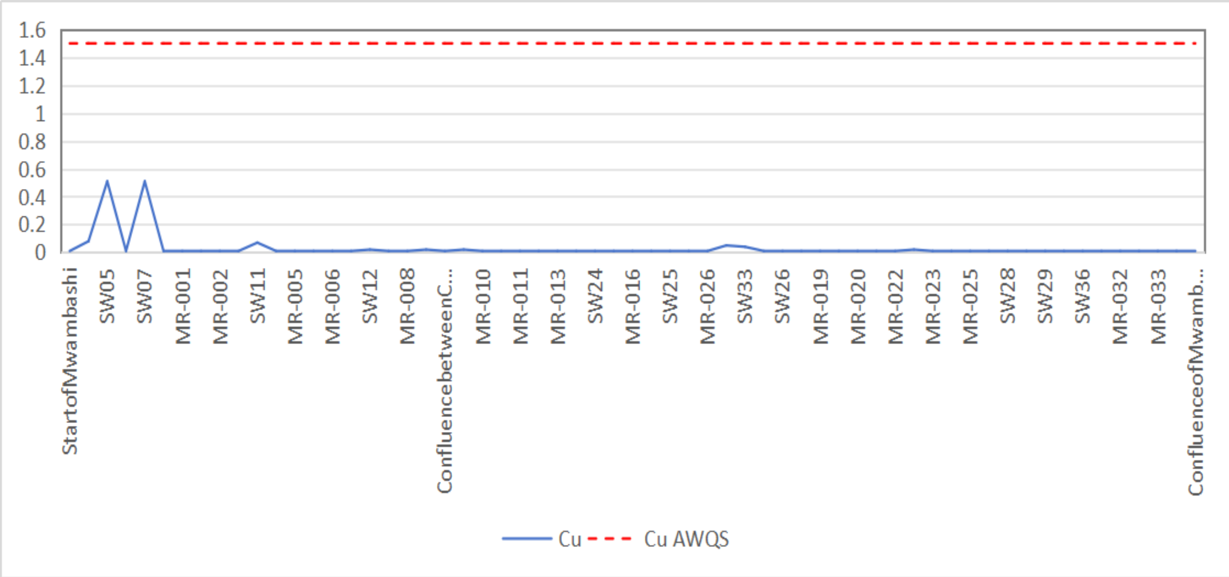


Figure 4-55: Concentration of Copper in Mwambashi River

Figure 4-56 shows the profile of Cobalt along Mwambashi River. With the exception of the upstream area where the maximum concentration reached 1.8 mg/L, the maximum value was found 30 km upstream of the confluence of the Chambishi Stream and Mwambashi Rivers. The average concentration at other locations was 0.0098 mg/L, significantly below the Ambient Water Quality Standards (AWQS) of 0.1 mg/L. Cobalt was no significant change at the confluence of Chambishi with Mwambashi.

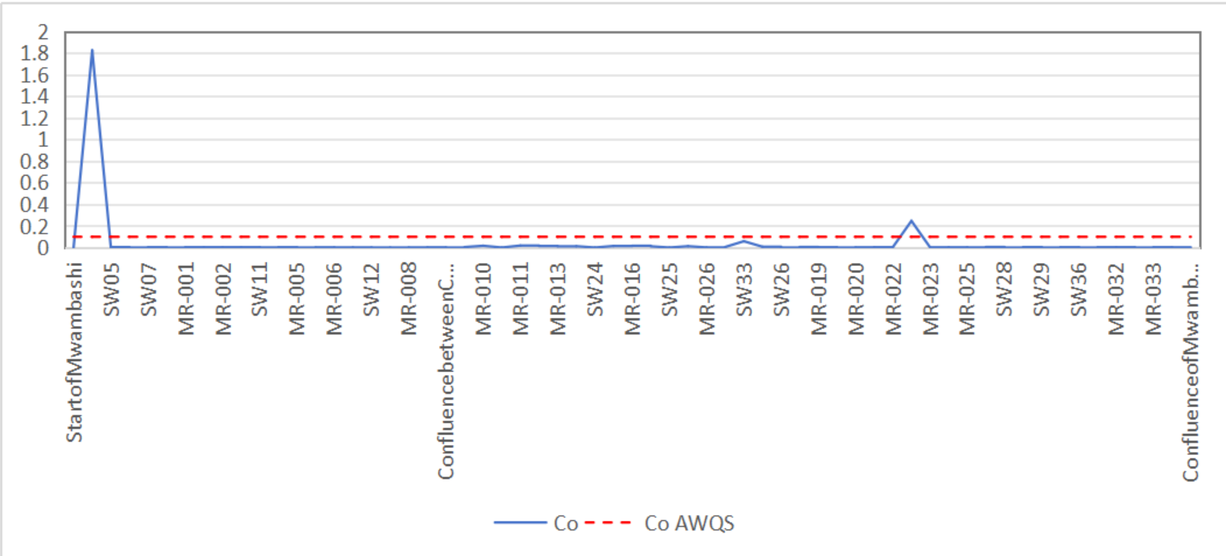


Figure 4-56: Concentration of Cobalt in Mwambashi River

Figure 4-57 illustrates the distribution of manganese concentration along the Mwambashi River, with the value decreasing from a maximum of 47.71 mg/L to 0.12 mg/L. The maximum value was found 30 km upstream of the confluence of the Chambishi Stream and Mwambashi Rivers. A clear downward trend in the concentration of manganese is observed from upstream to downstream. The average concentration in the river is 4.53 mg/L, significantly exceeding the Ambient Water Quality Standard (AWQS) recommended value of 0.2 mg/L. The average concentration between the upstream section and the confluence with the Chambishi Stream was 10.515 mg/L. After the confluence of the Chambishi Stream and the Mwambashi River, the concentration of manganese showed a significant declining trend.

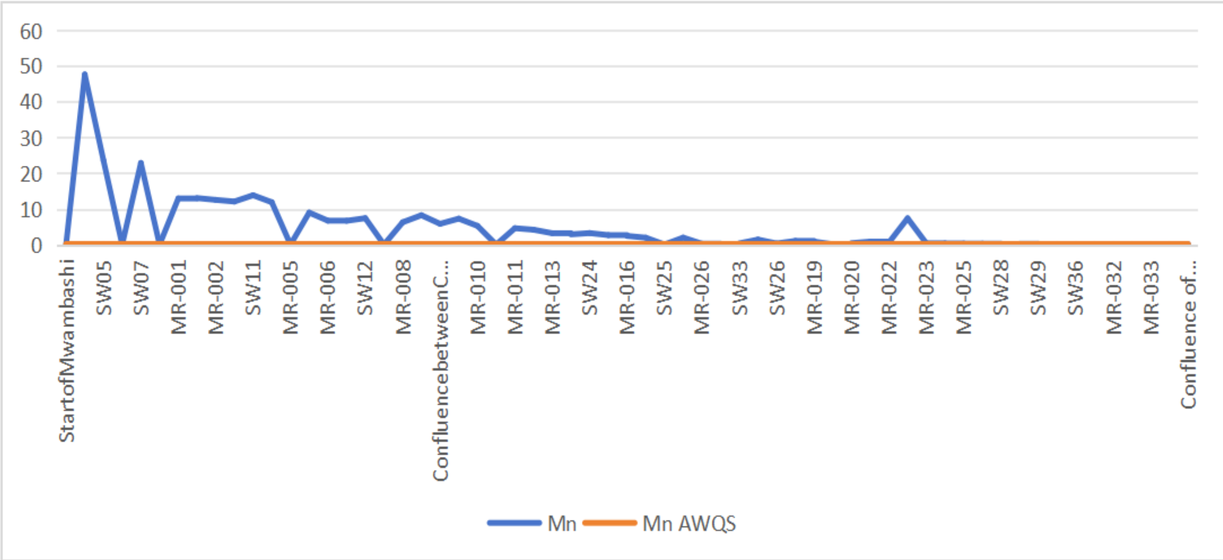


Figure 4-57: Concentration of Manganese in Mwambashi River

Figure 4-58 shows the profile of sulphates along Mwambashi River. The average value of sulphates in the Mwambashi River was 1,225 mg/L, significantly exceeding the Ambient Water Quality Standards (AWQS) recommended value of 60 mg/L. With the exception of the upstream area where the maximum concentration reached 3,920 mg/L, the maximum value was found 30 km upstream of the confluence of the Chambishi Stream and Mwambashi Rivers. Sulphates was no significant change at the confluence of Chambishi with Mwambashi.

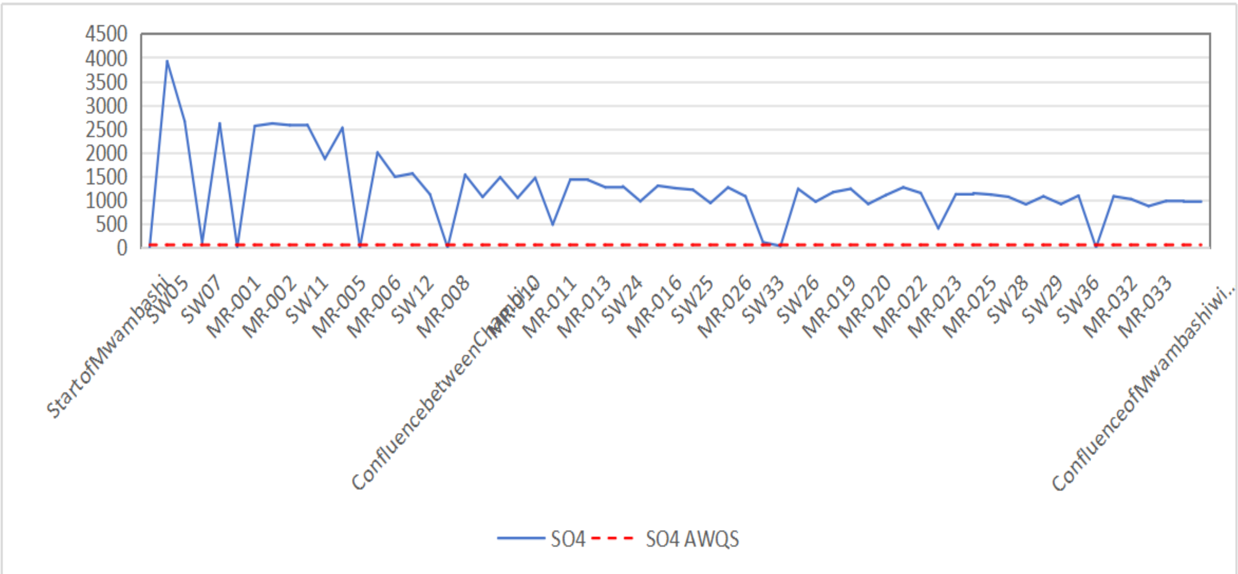


Figure 4-58: Concentration of sulphates in Mwambashi River

Figure 4-59 shows the profile of magnesium along Mwambashi River. The average value of magnesium in the Mwambashi River was 353 mg/L, significantly exceeding the Ambient Water Quality Standards (AWQS) recommended value of 40 mg/L. With the exception of the upstream area where the maximum concentration reached 1862 mg/L, the maximum value was found 30 km upstream of the confluence of the Chambishi Stream and Mwambashi Rivers. There was no significant change in the concentration of magnesium at the confluence of Chambishi Stream with Mwambashi River.

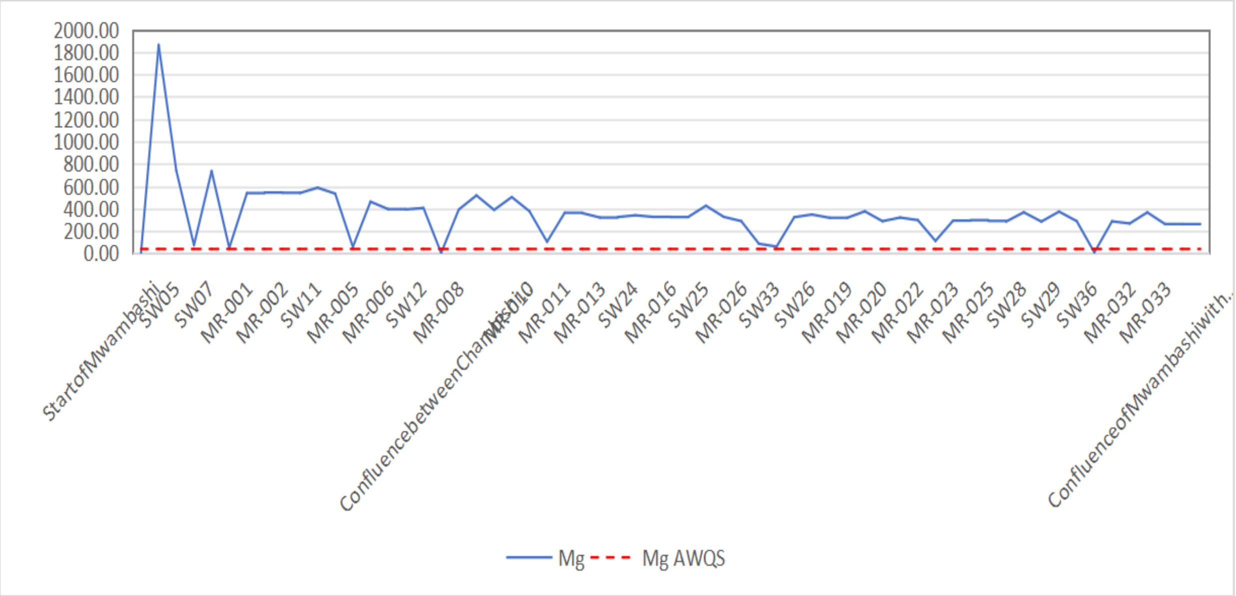


Figure 4-59: Concentration of Magnesium in Mwambashi River

Figure 4-60 shows the profile of calcium along Mwambashi River. The average value of calcium in the Mwambashi River is 337 mg/L, mostly above the Ambient Water Quality Standards (AWQS) of 60 mg/L. The calcium decreased from 1400 mg/L upstream of Mwambashi River to 186 mg/L, the maximum value was found 30 km upstream of the confluence of the Chambishi Stream and Mwambashi Rivers. The graph shows that Calcium was no significant change at the confluence of Chambishi with Mwambashi.

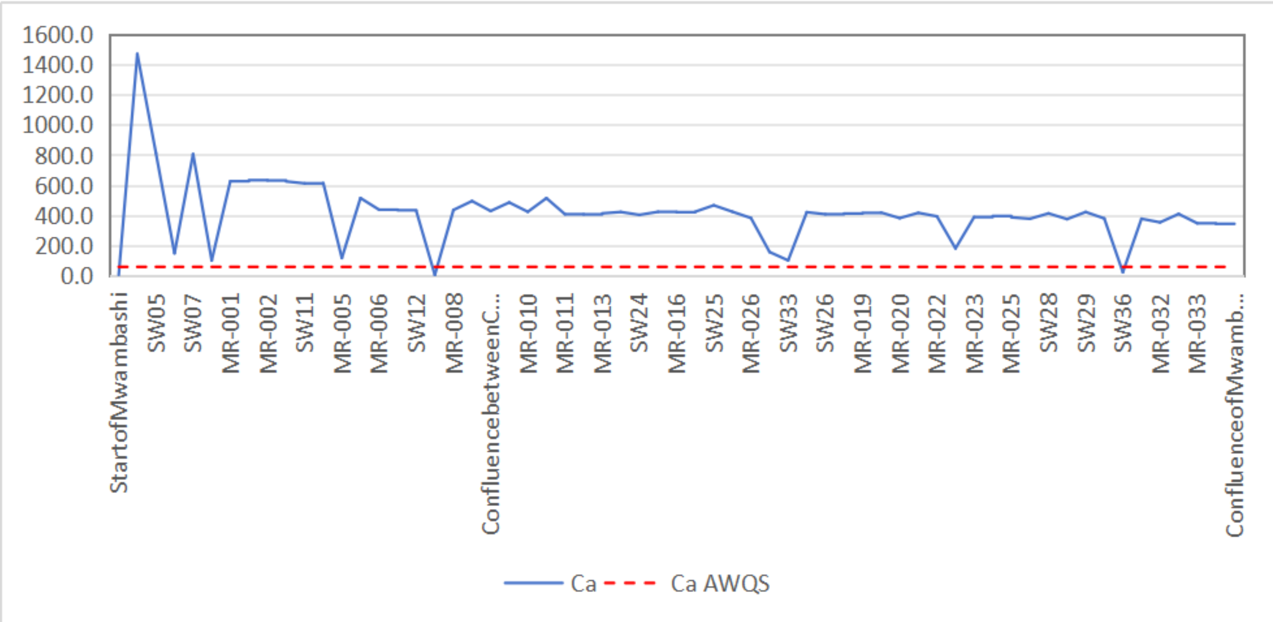


Figure 4-60: Concentration of calcium in Mwambashi River

4.6.1.3 Assessment of the impact on the Kafue River

Figure 4-61 shows the profile of electrical conductivity along the Kafue River. The overall trend along the Kafue River is a gradual decrease, with an average conductivity of 704 µS/cm, which is below the Ambient Water Quality Standards (AWQS) recommended value of 800 µS/cm. The average concentration reached 815 µS/cm from the confluence of the Mwambashi River and the Kafue River to 5 km downstream, with a maximum concentration of 2200 µS/cm located in the tributary flowing into the river at that point. A significant decreasing trend is observed downstream, with an average conductivity of approximately 694 µS/cm.

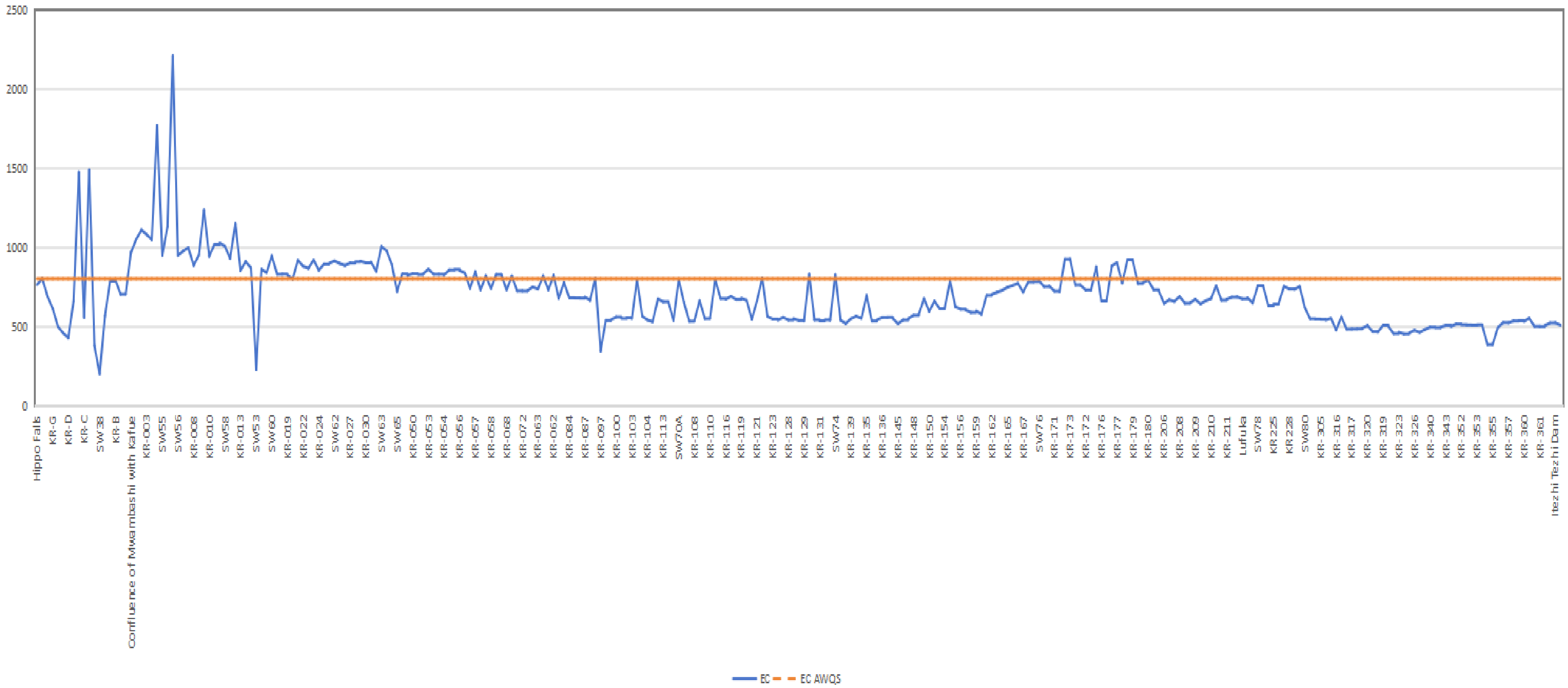


Figure 4-61: Electrical conductivity along Kafue River

Figure 4-62 shows the pH profile of water along the Kafue River, with an average pH of 7.45. Most pH levels in the river fell within the recommended value of 6–9 according to the Ambient Water Quality Standards (AWQS). However, the upstream section generally exhibited lower values. The graph shows that pH levels gradually increased overall, occasionally exceeding the recommended value due to inflows from tributaries with elevated pH (e.g., 9.92), located approximately 200 km downstream from the confluence of the Mwambashi River and the Kafue River.

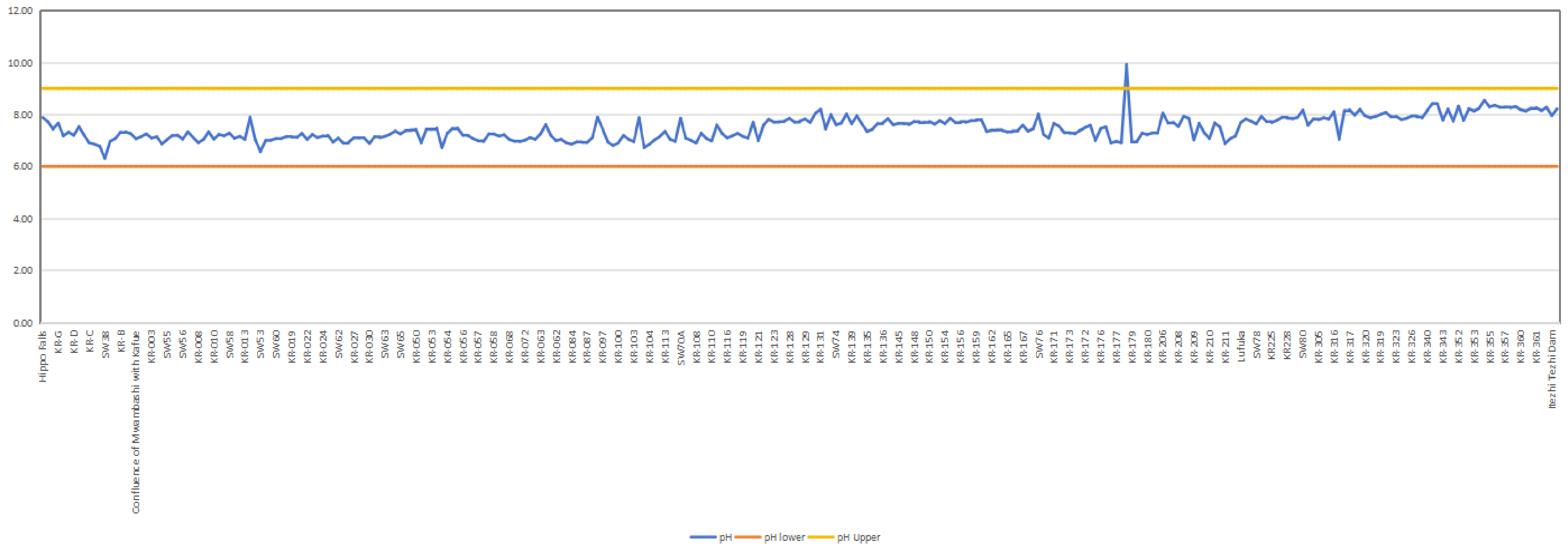


Figure 4-62: pH of water along Kafue River

Figure 4-63 shows the profile of copper concentration along the Kafue River. The average concentration is 0.012 mg/L, which is significantly lower than the Ambient Water Quality Standards (AWQS) recommended value of 1.5 mg/L. Except for the average concentration of 0.041 mg/L observed between the confluence of the Mwambashi River and the Kafue River and a point 5 km downstream, the concentrations at all other downstream sampling points were below the detection limit (0.01 mg/L).

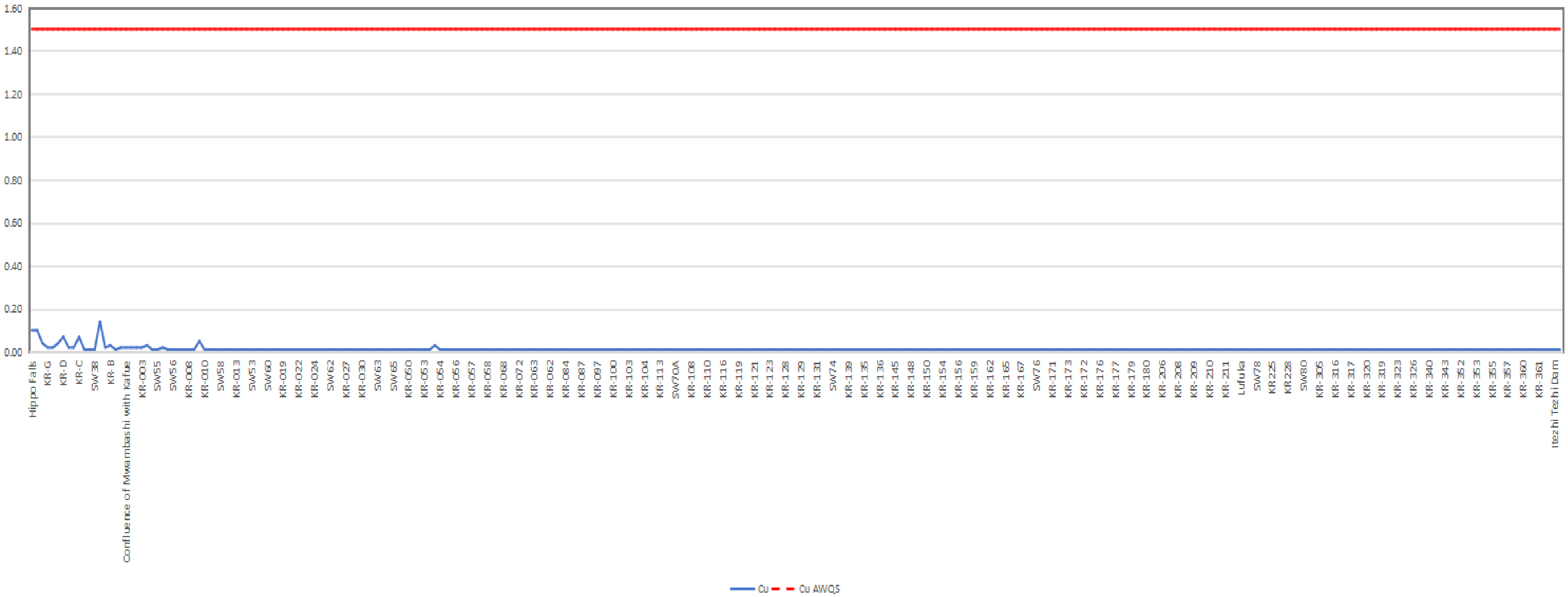


Figure 4-63: Concentration of copper in Kafue River

Figure 4-64 shows the profile of cobalt along Kafue River. Except for a maximum concentration of 0.906 mg/L recorded at the point 10 km downstream from the confluence of the Mwambashi River and the Kafue River, the concentration of cobalt in most areas of the river was below the detection limit (0.001 mg/L).

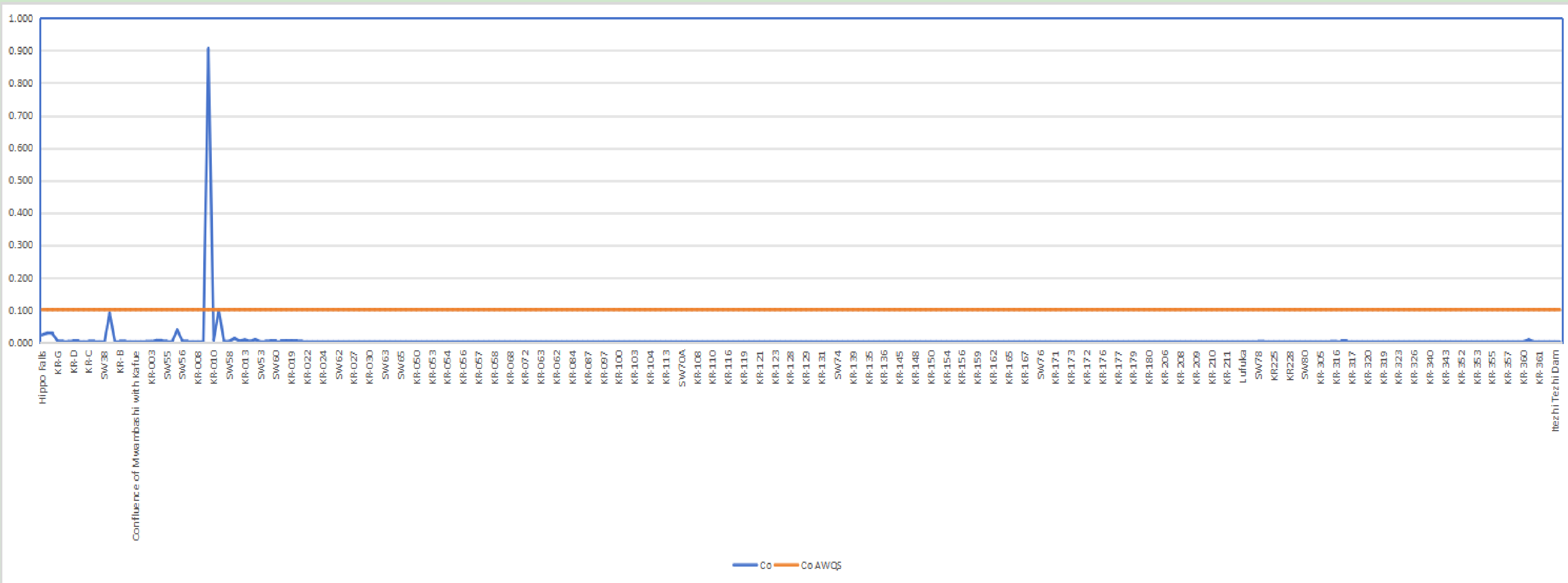


Figure 4-64: Concentration of cobalt in Kafue River

Figure 4-65 shows the profile of manganese concentration along the Kafue River. In the section from the confluence of the Mwambashi River and the Kafue River to a point 10 km downstream, the manganese concentration shows significant fluctuations, with an average concentration of 0.095 mg/L. However, the average value remains well below the Ambient Water Quality Standards (AWQS) recommended value of 0.2 mg/L, the maximum value of 0.81 mg/L was found in the Kafue tributary before the confluence. The concentrations at all other downstream sampling points are below the detection limit (0.01 mg/L).

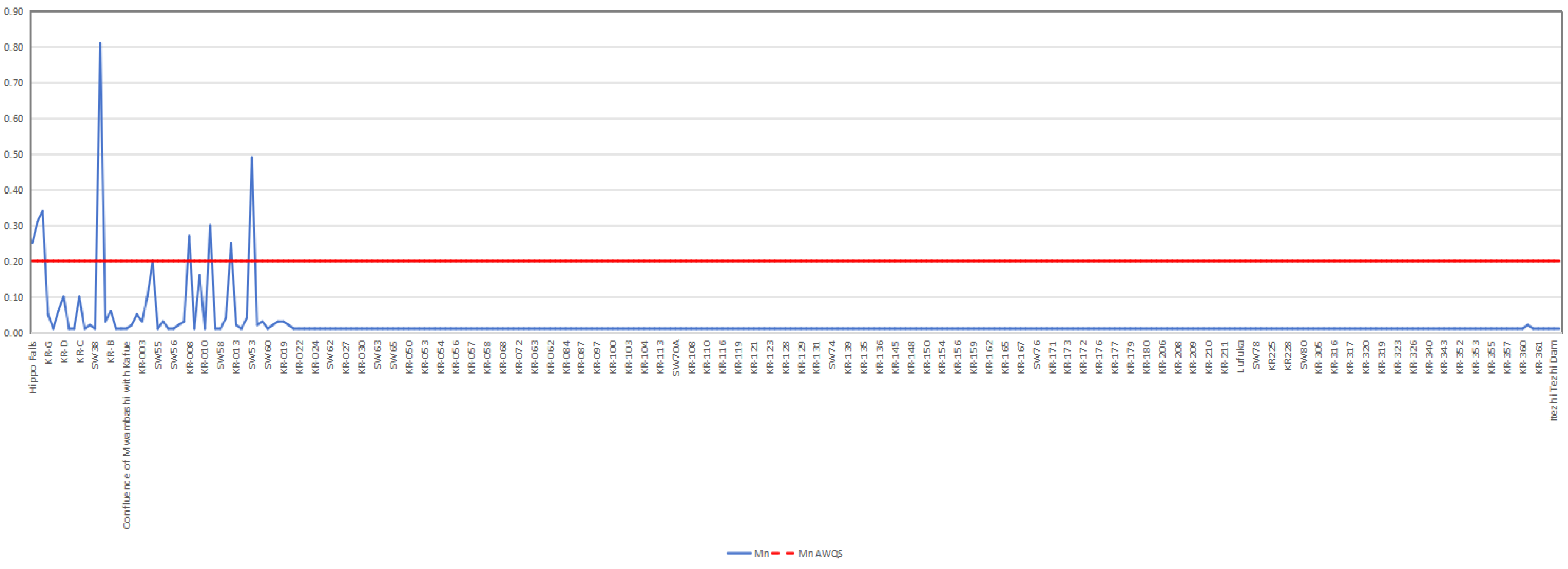


Figure 4-65: Concentration of manganese in Kafue River

Figure 4-66 shows the profile of sulphates along Kafue River. Overall, the concentration of sulphates exhibited a gradually decreasing trend. The concentration of sulphates in the Kafue River mostly exceeded the Ambient Water Quality Standards (AWQS) recommended value of 60 mg/L, with an average concentration being 229 mg/L. From the confluence of the Mwambashi River and the Kafue River to a point 20 km downstream, the concentrations fluctuated significantly, with an average reaching 363 mg/L. The highest concentration was located after the confluence with Mindolo Stream, some 5 km downstream of the confluence with Mwambashi River. Mindolo Stream carries both mine dewatering effluent and sewage effluent from several townships. A significant decrease to below 100 mg/L occurred only near the Belama area.

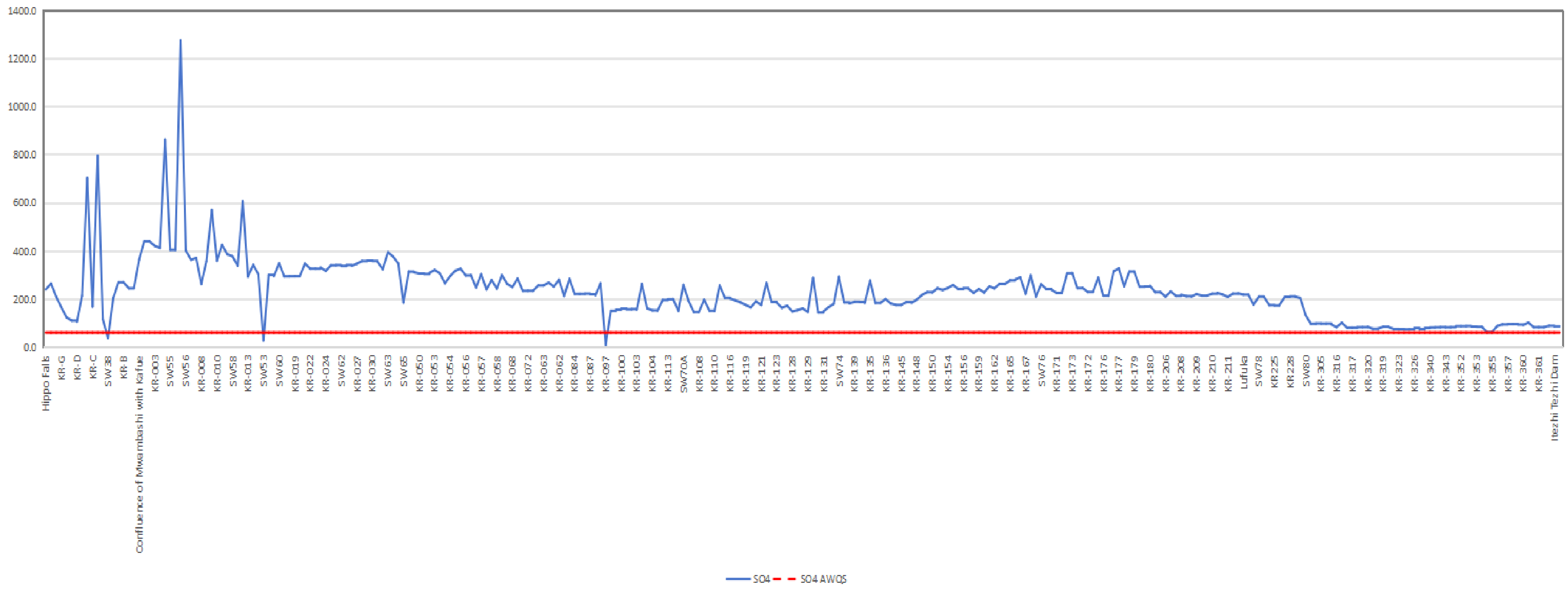


Figure 4-66: Concentration of sulphates in Kafue River

Figure 4-67 shows the profile of magnesium along the Kafue River. The concentrations were generally higher than the recommended value of 40 mg/L according to the Ambient Water Quality Standards (AWQS). The overall trend shows a gradual decrease, from a maximum of 180 mg/L to 47 mg/L. The maximum value was located after the confluence with Mindolo Stream, 5 kilometres downstream of the confluence with Mwambashi River.

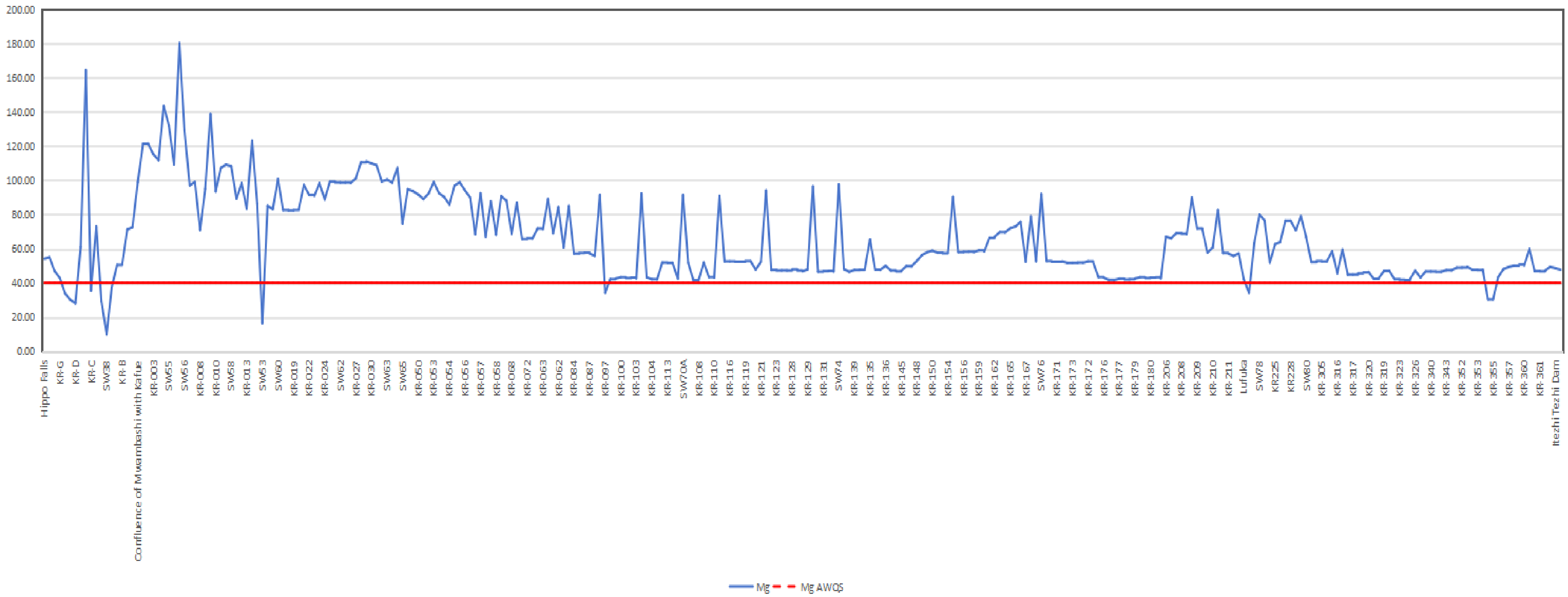


Figure 4-67: Concentration of magnesium in Kafue River

Figure 4-68 shows the profile of calcium along the Kafue River. The concentrations were generally higher than the recommended value of 60 mg/L according to the Ambient Water Quality Standards (AWQS). The overall trend shows a gradual decrease, from a maximum of 957 mg/L to 92 mg/L, the maximum value is located after the confluence with Mindolo Stream, 5 kilometres downstream of the confluence with Mwambashi River.

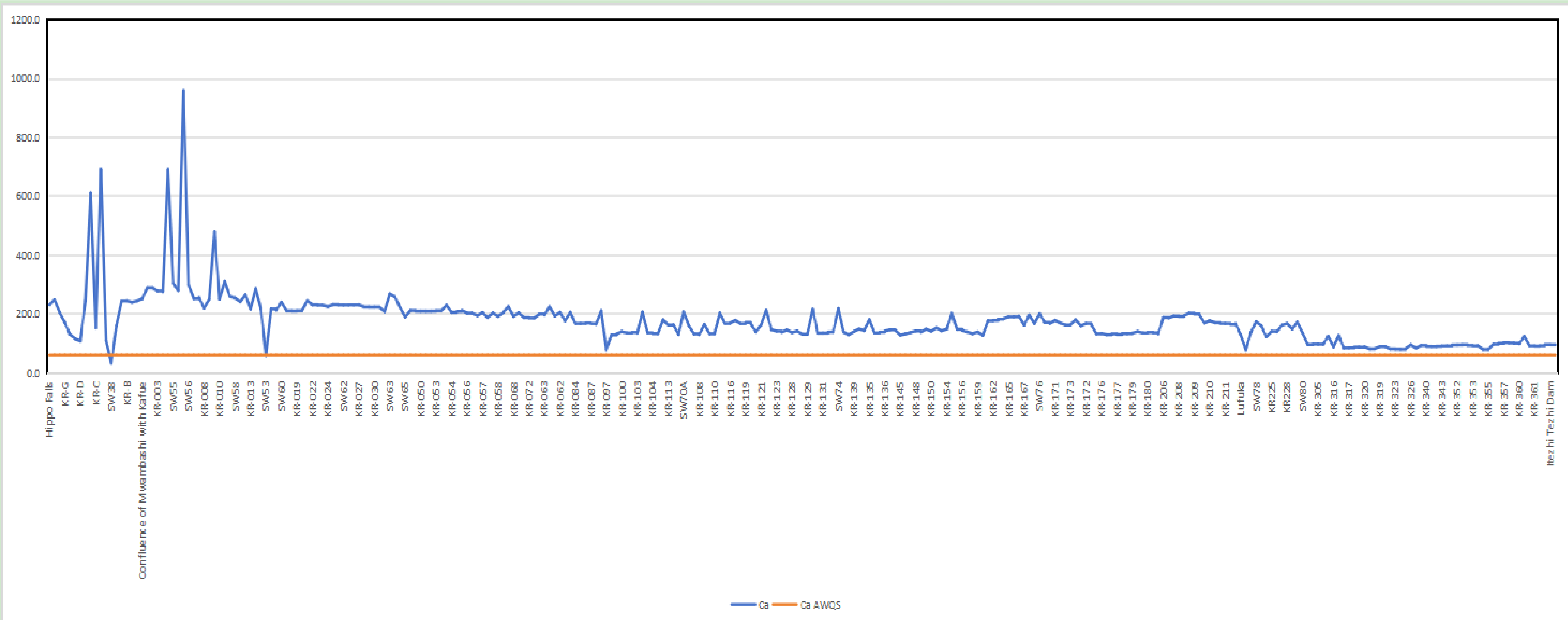


Figure 4-68: Concentration of calcium in Kafue River

4.6.1.4 Determination of the extent of the impact on surface water contamination

The analytical results of the water samples collected during the assignment show that there is no long-term impact on the water quality of Mwambashi River and consequently on Kafue River. This is observed by comparing the results of Mwambashi River immediately upstream and downstream of Chambishi Stream where it will be observed that there is no notable impact on water quality of Mwambashi River. Furthermore, the current analytical results do not show an area that is impacted by tailings discharge from TD 15.

Similarly, the historical results reviewed for this assignment do not indicate the spatial extent of the pollution. The on-site results by Nkana Water Supply and Sanitation Company (NWSC) shows that the water intake at Bulangililo on Kafue River recorded low pH three days after the incident occurred, a situation that lasted three more days before the pH returned to its pre-incident level. There were no other historical analytical results availed that show the downstream extent of the pollution. Claims to downstream pollution were mostly based on sightings of dead fish floating in the river.

The Environmental and Social Incident Impact Assessment (ESIIA) identified manganese (Mn) as the contaminant of concern associated with the incident. Based on systematic surface water sampling and analysis conducted throughout the Chambishi Stream, Mwambashi River, and Kafue River catchment, the assessment confirms that manganese concentration measured 0.3 mg/L at the designated monitoring point SW-57B, located 52.2 kilometres downstream of the TD 15. At the immediately subsequent monitoring point located 52.5 kilometres downstream of the TD 15, the concentration of Manganese dropped to 0.1 mg/L.

Critically, at all subsequent assessing points commencing with SW 57, manganese concentrations have been consistently recorded below Zambia's Ambient Water Quality Standard (AWQS) recommended value of 0.2 mg/L.

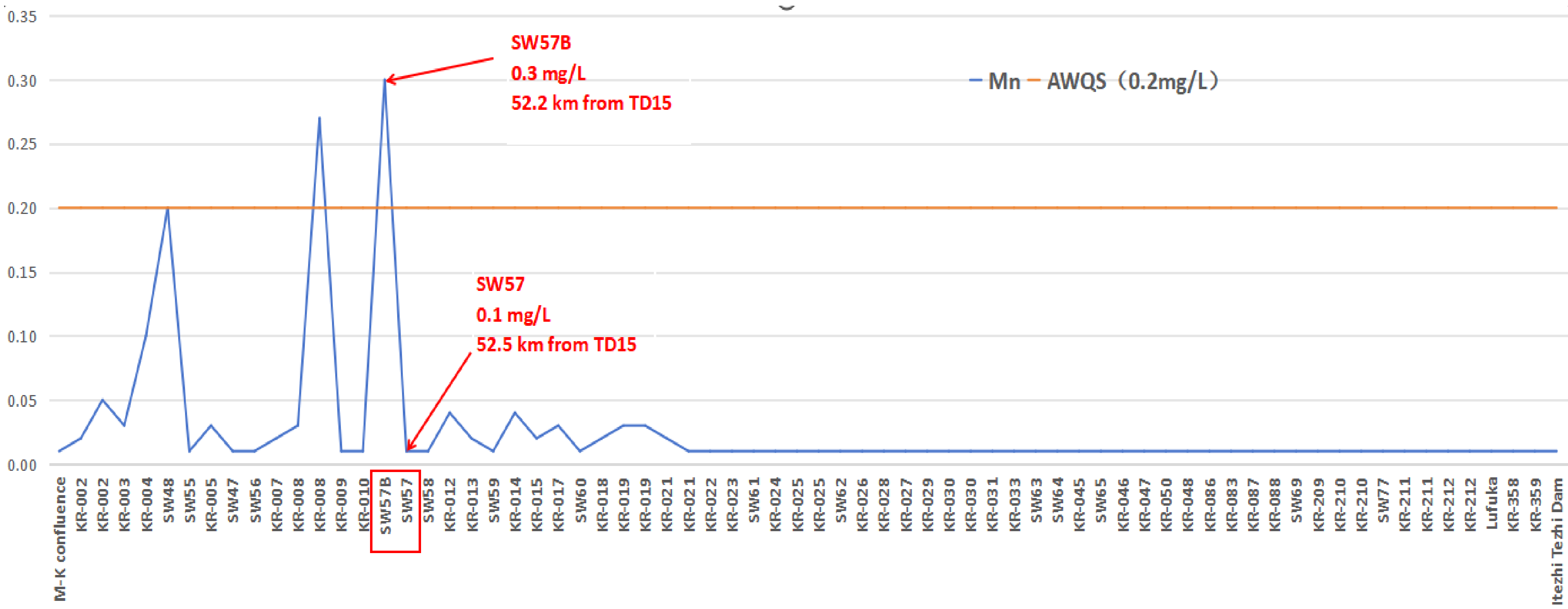


Figure 4-69: Distribution of Manganese Concentration along Kafue River

4.6.2 Assessment of the impact on targeted areas

4.6.2.1 Assessment of the impact on the Chambishi Stream

After the tailings escaped from TD 15, the material travelled through the combined drainage to TD 6 where some of the tailings were deposited. Upon leaving TD 6, the tailings entered a wetland known as New Dam, were, again, some of the tailings sedimented. The discharge from New Dam is into Chambishi Stream licensed to NFCA and Chambishi Metals as a compliant monitoring point. Consequently, NFCA monitors volume and quality of water discharged from New Dam into Chambishi Stream as a license condition.

NFCA provided the analytical results of water discharged from New Dam to Chambishi Stream between January 2021 and June 2024. The results are presented in Figure 4-70.

The pH values ranged from 6.61 to 8.29 and an average for the period of 7.64[6]. The pH value of 8.33 measured in Oct 2025 is comparable to the average pH for the period January 2021 to June 2024. Given that the tailings discharged from the Leach Plant to TD 15 had acidic pH, it can be concluded that the accidental release of tailings from TD 15 did not have a long-term impact on the pH of water discharged from New Dam to Chambishi Stream. However, it is noted that at the time of sampling, the discharge from New Dam to Chambishi Stream was being dosed with sodium hydroxide to raise the pH.

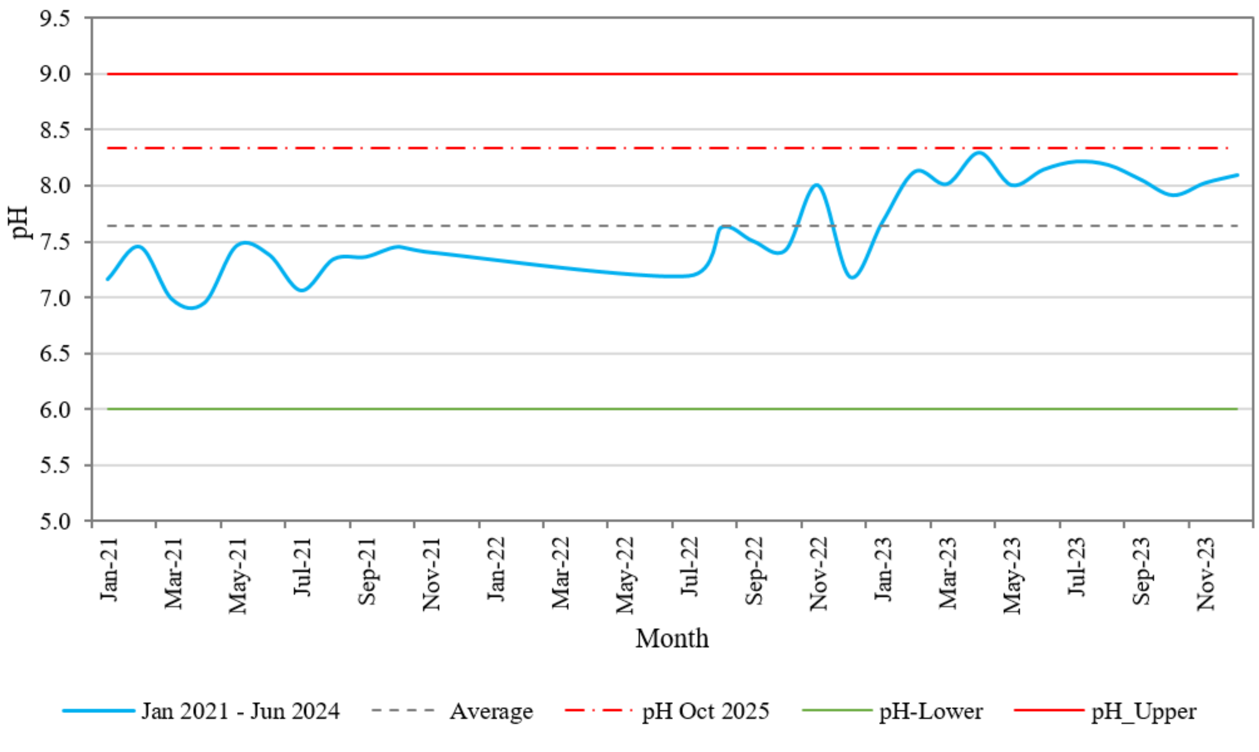


Figure 4-70: Graph of pH of water discharged from New Dam into Chambishi Stream from Jan 2021 to Jun 2024 and in Oct 2025

The electrical conductivity of 857 µS/cm recorded in Oct 2025 was below the average value for the period. Figure 4-71 shows a declining trend for TDS for the year 2024. The typical TDS value of liquor discharged from the Leach Plant to TD 15 was 11,630 mg/L. Based on the analytical results, it can be concluded that the accidental discharge of tailings from TD 15 did not have an adverse long-term impact on Chambishi Stream with regards to TDS.

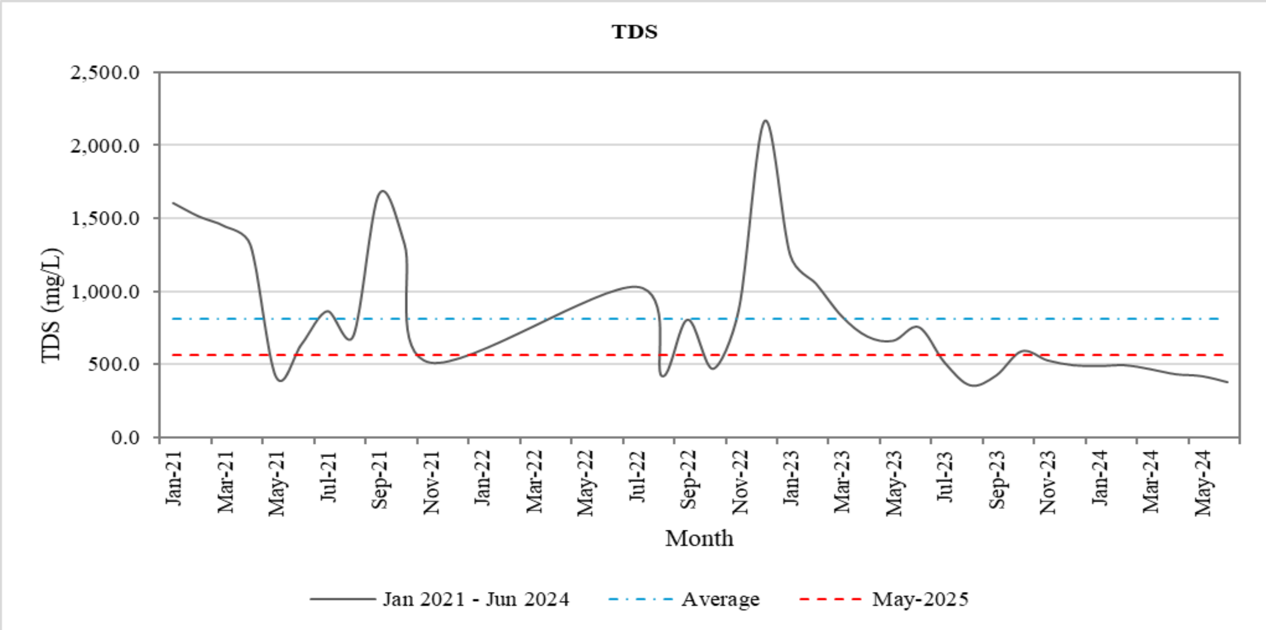


Figure 4-71: Graph of EC in the water discharged from New Dam into Chambishi Stream from Jan 2021 to Jun 2024 and in Oct 2025

The concentration of sulphates in the effluent discharged from New Dam to Chambishi Stream between January 2021 and December 2023 is presented in Figure 4-72. The concentration of sulphates ranged from 46 to 1,143 mg/L with an average value of 568 mg/L for the period. In comparison, the concentration of sulphates obtained in Oct 2025 of 319 mg/L was below the average for the period. The typical concentration of sulphates for liquor discharged from the Leach Plant to TD 15 was 17,012 mg/L. There was therefore a significant decrease in the concentration of sulphates in the discharge from New Dam.

It will be observed from Figure 4-72 that the concentration of sulphates in the discharge from New Dam shows a declining trend during the year 2023, from 906 mg/L in January to 159 mg/L in December. In contrast, the concentration of sulphates measured in Oct 2025 was 319 mg/L, which was below the average value of 568 mg/L for the period January 2021 to December 2023. Based on the analytical results, it can be concluded that the long-term impact of tailings spillage on Chambishi Stream with respect to sulphates is low, if any at all.

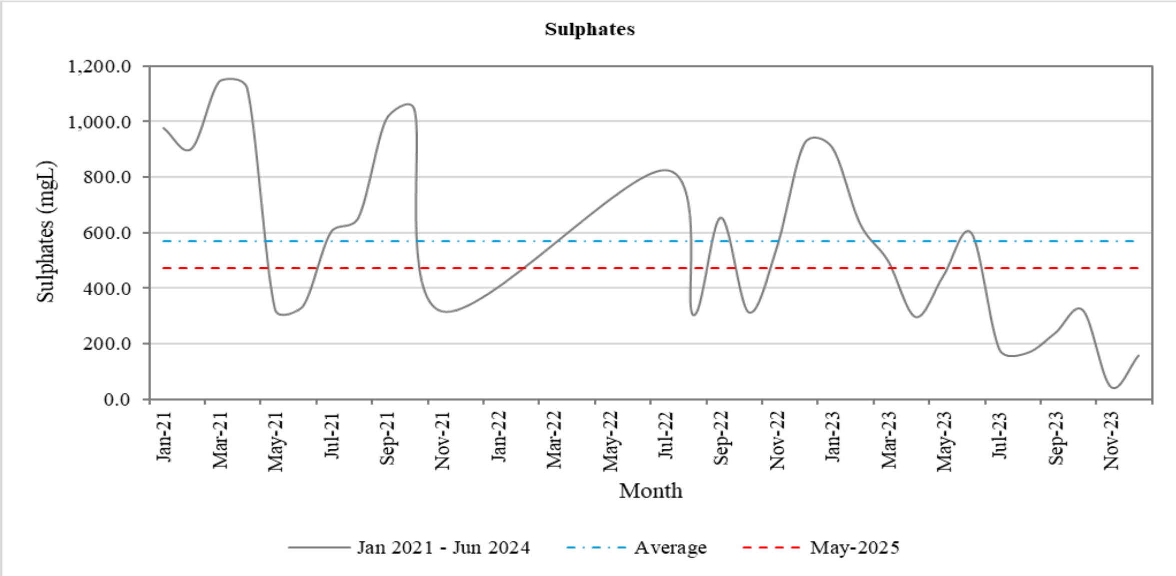


Figure 4-72: Graph of sulphates of discharged from New Dam into Chambishi Stream from Jan 2021 to Jun 2024 and Oct 2025

The assessment of the long-term impact of the tailings discharge from TD 15 on the water quality of Chambishi Stream is indicated by the following:

1. Sino-Metals sealed the breach in the tailings dam embankment approximately 14 hours after the discharge of tailings slurry from the facility started[10]. Upon sealing the breach on the embankment, the discharge of tailings from TD 15 ceased. This, therefore, means that the discharge of tailings from TD 15 was for a specific period rather than an ongoing occurrence. It is therefore expected that after some time, the discharge of tailings from TD 15 to the environment ceased.
2. During the period of sampling (October/November 2025) the combined drain which transports effluent from Chambishi Metals, NFCA and Sino-Metals was dry, confirming the position that there was no more effluent or tailings being discharged from TD 15 to the open environment. The water flowing in Chambishi Stream during this period was groundwater daylighting into the stream as surface water.
3. The quality of water discharged from New Dam to Chambishi Stream has returned to its pre-incident levels. This position is informed by the pH values which have recovered from the acidic state (pH 2) to mostly alkaline conditions (pH range from 6.88 to 8.50). The pH was found to be high in the upstream section of Chambishi Stream and therefore cannot be attributed to sodium hydroxide dosing at the exit from New Dam.

4.6.2.2 Assessment of the impact on the Mwambashi River

The analytical results show that the discharge of tailings from TD 15 did not have a long-term adverse impact on the water quality of Chambishi Stream based on the analysis of the key contamination indicator parameters, namely pH, TDS and sulphates. Since Chambishi Stream is

[10] Applied Science and Technology Associates, 2025. Incident Investigation Report Regarding the Breach of Tailings Dam No. 15 (TD 15) at Sino-Metals Leach Zambia Limited

a tributary of Mwambashi River, it follows that the tailings slurry released from TD 15 should equally not have a long-term adverse impact on Mwambashi River.

The schematic drawing in Figure 4-73 illustrates the quality of water in Chambishi Stream and its effect on Mwambashi River. The figure shows the pH, EC and sulphates of the water discharged from New Dam and that of Mwambashi River, both upstream and downstream of the confluence with Chambishi Stream. The analytical results show that there is no noticeable deterioration in the water quality of Mwambashi River with respect to the key contamination indicator parameters which can be attributed to Chambishi Stream. In other words, the inflow from Chambishi Stream, and hence, from TD 15 did not result in any noticeable deterioration in the water quality of Mwambashi River as a result of from Chambishi Stream.

Figure 4-73 shows that the pH before Chambishi Stream was 7.42 and after Chambishi Stream the pH showed an insignificant increase to 7.43. The EC was 1,887 µS/cm before Chambishi Stream and decreased to 1,884 µS/cm after Chambishi Stream. The concentration of sulphates was 1,066 mg/L before Chambishi Stream and decreased to 1,049 mg/L after Chambishi Stream.

In view of the above discussion, it is concluded that the discharge of tailings from TD 15 did not have long-term adverse impact on the water quality of Mwambashi River as indicated by the key water quality indicator parameters, i.e., pH, EC and sulphates.

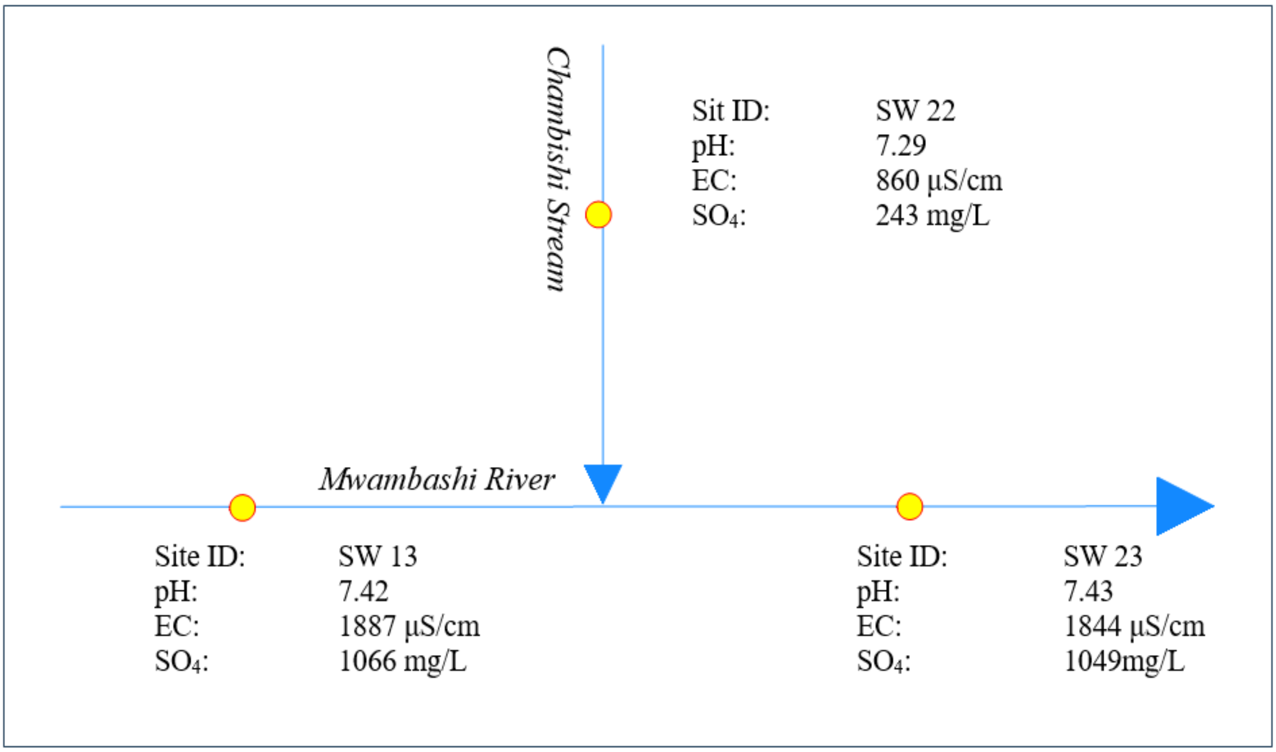


Figure 4-73: Schematic drawing illustrating the impact of Chambishi Stream on the water quality of Mwambashi River

4.6.2.3 Assessment of the impact of tailings discharge on Kafue River

It is concluded on the basis of the current results that the tailings discharge from TD 15 did not have long-term adverse impact on the water quality of Chambishi Stream and Mwambashi River. Since Chambishi and Mwambashi River were the transport routes for tailings from TD 15 to

Kafue River, it follows therefore that the tailings discharge similarly had no long-term adverse impact on Kafue River.

However, Mwambashi River does have an impact on Kafue River because of other sources of pollution not related to the 18th February incident. The impact of Mwambashi River on the water quality of Kafue River is illustrated in the schematic drawing in Figure 4-74 below. The Figure shows that there was an increase in EC from 705 µS/cm upstream of the confluence with Mwambashi River to 1129 µS/cm downstream of the confluence, while the concentration of sulphates increased from 247 mg/L to 404 mg/L. The increase in the EC and in the concentration of sulphates from the upstream site to the downstream site can be attributed to the inflow of Mwambashi River which had EC of 1571 µS/cm and sulphates of 875 mg/L.

It must be pointed out that, as shown in Figures 4-58 and 4-59, there are multiple potential contamination sources that are responsible for the elevated EC and sulphates in Mwambashi River. The potential contamination sources that have an impact on Kafue River have been identified and discussed.

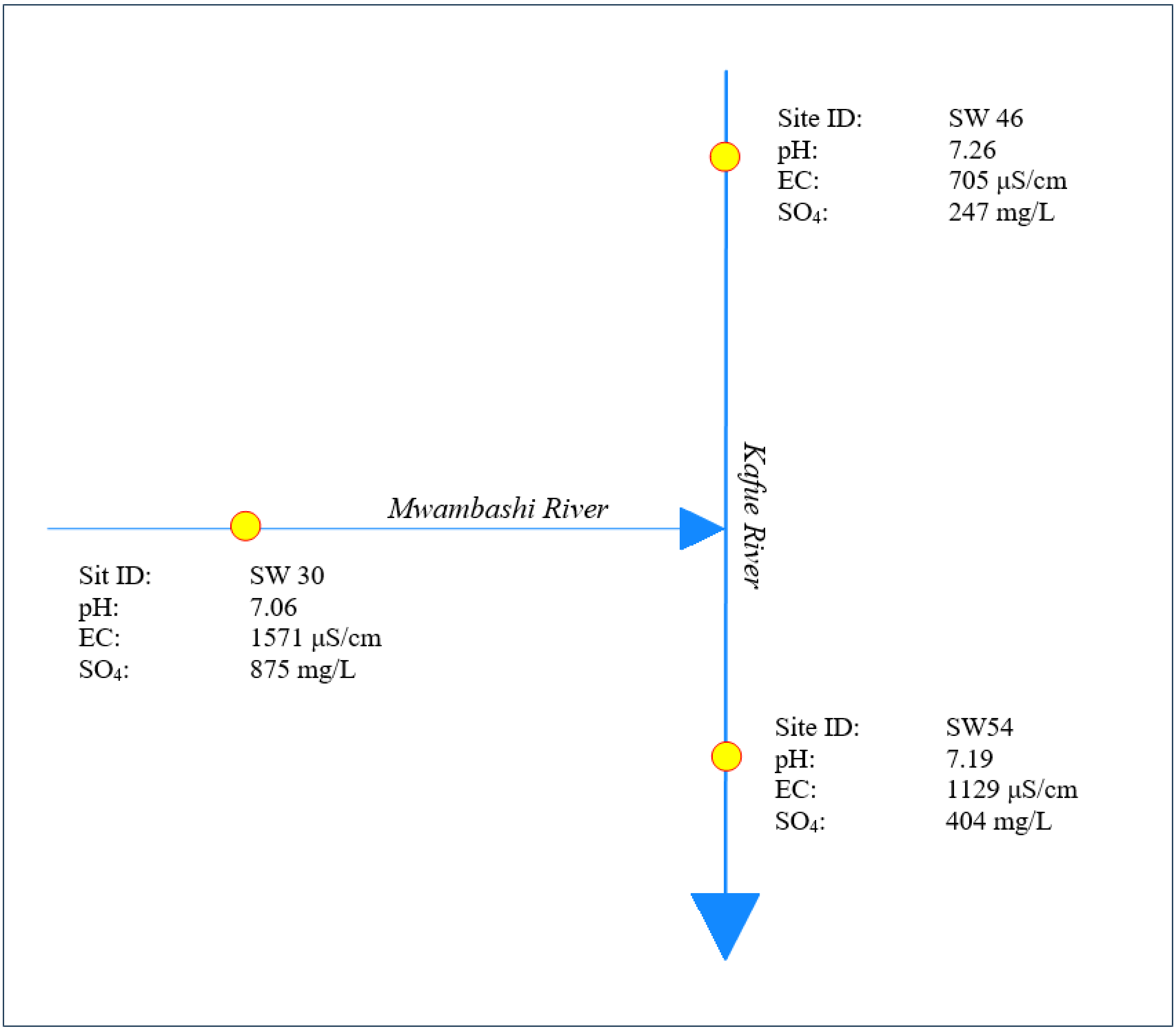


Figure 4-74: Schematic drawing illustrating the impact of Mwambashi River on the water quality of Kafue River

4.6.2.4 Role of New Dam in pollution control

The facility known as New Dam (shown on the satellite image in Figure above) is a low-lying wetland located on Chambishi Stream. The facility is completely covered with the aquatic weed Typha (Figure 4-75). New Dam has an inlet into the wetland and discharges to the environment through a v-notch weir (Figure 4-76). Effluent from Chambishi Metals, NFCA and Sino-Metals passes through New Dam before being discharged into Chambishi Stream through the v-notch weir. The New Dam functions as a Pollution Control Dam where contaminated water passing through the area is polished through sedimentation of particulates and uptake of dissolved minerals by weeds.

Figure 4-75: Photograph showing New Dam overgrown with Typha (left) and Typha flower11(right)

[11] https://en.wikipedia.org/wiki/Typha_%C3%97_glauca

Figure 4-76: Photograph showing v-notch weir at the discharge from New Dam to Chambishi Stream

The function of New Dam in polishing effluent is illustrated in the graphs in Figure 4-45 to 4-52. Figure 4-45 shows the profile of electrical conductivity along Chambishi Stream. The graph shows that the electrical conductivity of Chambishi Stream was mostly above the Ambient Water Quality Standards (AWQS) of 800 µS/cm. The EC decreased from 2,070 µS/cm upstream of New Dam to 744 µS/cm at the discharge point. The decrease in the electrical conductivity is attributed to the uptake or settling of dissolved solids out of solution by the wetland. The graph also shows that electrical conductivity increased to 1,260 µS/cm upon leaving New Dam.

Figure 4-46 shows the pH profile of water along Chambishi Stream. The Figure shows the pH was within the prescribed AWQS range of 6.0 to 9.0. The pH increased from 7.68 before New Dam to 8.5 at the discharge from Ned Dam. The increase in the pH of water has been attributed to the dosing of water coming out of New Dam with sodium Hydroxide (NaOH) by Sino-Metals. Dosing is carried out for the purpose of raising the pH of the water and precipitating the metal ions out of solution. The graph shows that the pH of Chambishi Stream returns to its pre-dosing level before the confluence with Mwambashi River.

The concentration of sulphates in Chambishi Stream is shown in Figure 4-50. The graph shows that the concentration of sulphates in water was always above the prescribed standard of 60 mg/L. The concentration of sulphates decreased from 1,081 mg/L before New Dam to 213 mg/L at the discharge from New Dam. The graph illustrates the polishing effect of New Dam of effluent passing through the facility. The graph also shows that the concentration of sulphates increased to 528 mg/L after leaving New Dam.

4.6.3 Assessment of sediment contamination

Based on the assessment of sediment pollution in the basin, localised areas of the Chambishi Stream and Mwambashi River are heavily polluted. This is primarily caused by the precipitation of high-concentration wastewater discharged upstream. Peak sediment concentrations occur at key downstream locations: Below the New Dam on the Chambishi Stream, below the confluence of the Chambishi and Mwambashi Rivers, and below the confluence of the Mwambashi and Kafue Rivers, though the overall spatial impact remains limited.

Spatial analysis of pollutants in the basin's main rivers indicates that contamination patterns are influenced by hydrological conditions, proximity to mining areas, and sediment dynamics. Tributaries in the upper reaches (flowing through mining areas) carry water with higher heavy metal concentrations, while downstream sites show cumulative pollution effects in sediments. The results show that manganese pollution in the basin's sediments is widespread but not continuous, exhibiting clear spatial clustering with significant pollution hotspots formed downstream of major mining tailings discharge areas.

Analysis of the distribution and variation of manganese in river sediments indicates that sediment pollution is primarily caused by the input of upstream water soluble pollutants precipitating downstream. The spatial relationship between the locations of maximum manganese concentrations in surface water and sediments suggests that the range of impact from short-term inputs is relatively limited.

Figure 4-77 and 4-78 show the distribution of sediment samples and the distribution of the points exceeding the standard for the soil based on the FAO and WHO standards.

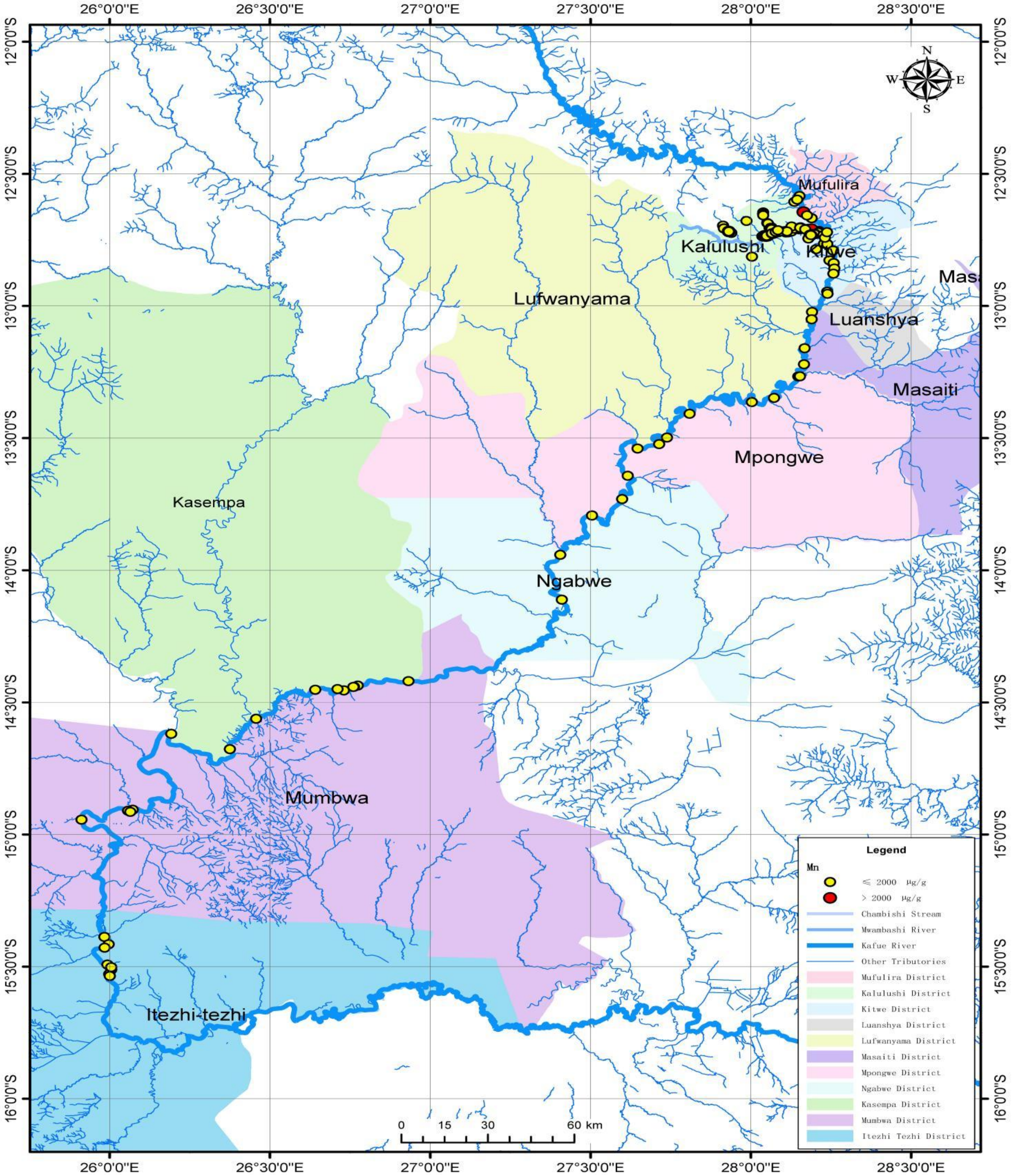


Figure 4-77: The distribution of sediment samples

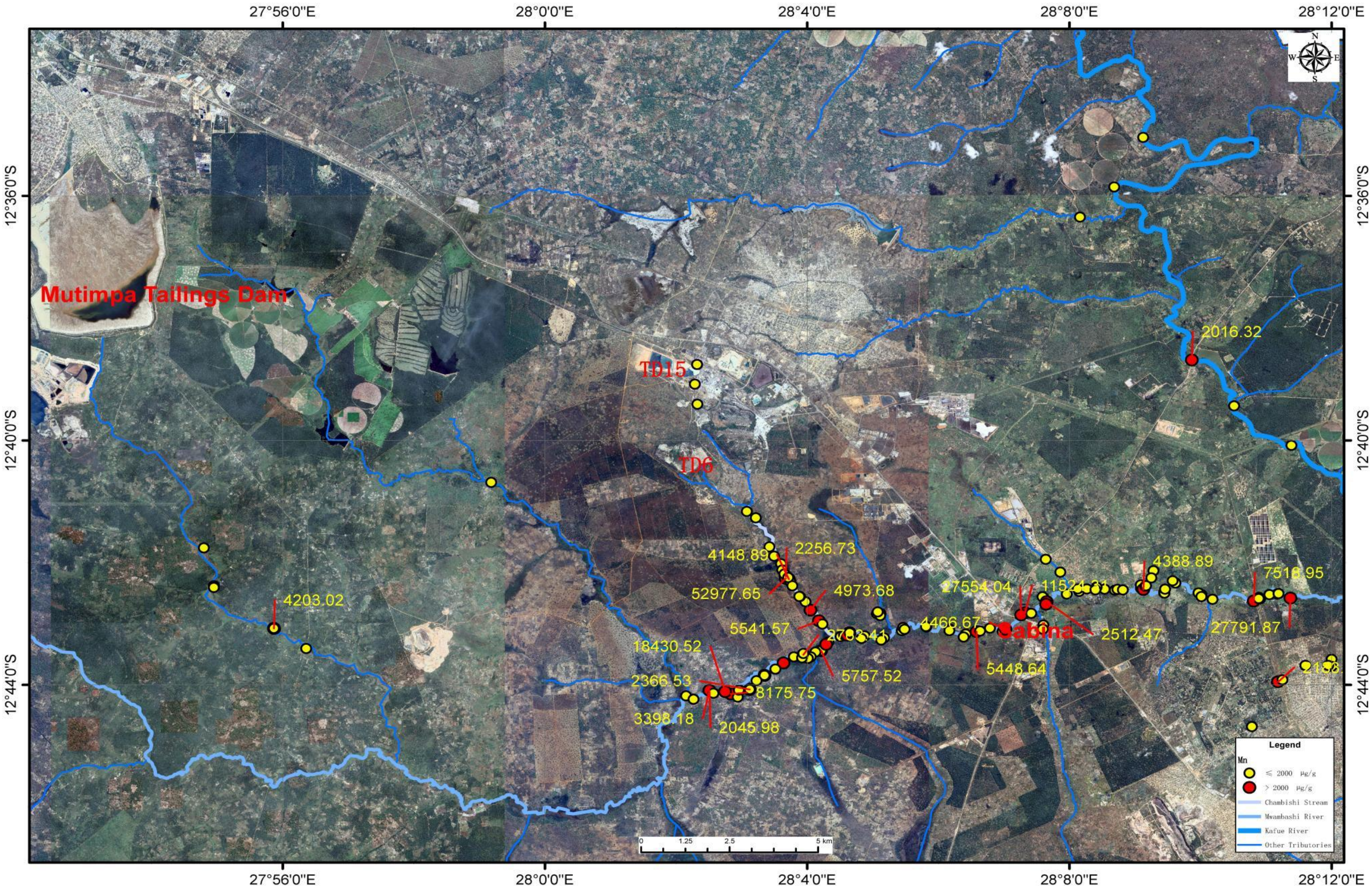


Figure 4-78: The distribution of the points exceeding the standard (soil, FAO/WHO, Mn)

4.7 Identification potential contamination sources to Kafue River

This section examines the origins and pathways of mining-related contamination affecting the Kafue River, with a focus on key pollutants, spatial impacts, and compliance with ambient water quality standards.

4.7.1 Justification for identifying potential contamination sources to Kafue River

The analytical results show elevated concentration of sulphates in Mwambashi River to the extent of adversely impacting the water quality of Kafue River. It was therefore necessary to identify the potential sources of mining-related contamination to Mwambashi River and Kafue River.

4.7.2 Identification of potential contamination sources from mining activities

The area under consideration has multiple mining and mineral processing facilities that have the potential to contaminate both surface water and groundwater. Some of the facilities are historical dating back to the previous mine operators, Zambia Consolidated Copper Mines (ZCCM) while others are current. The major potential contamination sources related to mining and mineral processing are listed in Table 4-8 below.

Table 4 - 8: List of potential contamination sources and the impacted streams

Facility	Ownership	Potential impacted streams
1. Mutimpa Tailings Dam	Konkola Copper Mines	1. Mwambashi River 2. Kafue River
2. Luano Tailings Dam	NFCA	1. Musakashi Stream 2. Kafue River
3. TD 15 Tailings Dam	Sino-Metals Leach Zambia	1. Chambishi Stream 2. Mwambashi River 3. Kafue River
4. TD 7 – 9 Tailings Dam	Sino-Metals Leach Zambia	1. Lulamba Stream 2. Lukoshi Stream 3. Kafue River
5. Chambishi Metals Tailings Dam	Chambishi Metals	1. Lulamba Stream 2. Lukoshi Stream 3. Kafue River
6. Pollution Control Dam (TD 6), Tailings Dam	Chambishi Metals	1. Chambishi Stream 2. Mwambashi River 3. Kafue River
7. Mineral processing facilities	Nkana Mining and Mineral Processing Ltd	1. Lula Stream 2. Mwambashi River 3. Kafue River
8. Tailings Dam and stockpiles	Chambishi Copper Smelter	1. Lula Stream 2. Mwambashi River 3. Kafue River
9. Tailings Dam	Metro Mining	1. Lusala Stream 2. Mwambashi River 3. Kafue River
10. Tailings Dam	Rong Xing	1. Lula Stream 2. Mwambashi River 3. Kafue River
11. TD 11	Mopani Copper Mines	4. Mufulira Stream 5. Kafue River

Facility	Ownership	Potential impacted streams
12. TD 15A	Mopani Copper Mines	1. Ichimpe Stream 2. Mwambashi River 3. Kafue River
13. TD 15	Mopani Copper Mines	1. Ichimpe Stream 2. Mwambashi River 3. Kafue River
14. TD 25	Jubilee Metals?	1. Kitwe Stream 2. Kafue River
15. TD 26	Jubilee Metals?	1. Uchi Stream 2. Kafue River
16. Old Musakshi	NFCA	1. Musakashi Stream 2. Kafue River
17. New Musakashi	NFCA	1. Musakashi Stream 2. Kafue River
18. Minbula Minerals	Mimbula Minerals	3. Mutimpa Stream? 1. Mwambashi River 2. Kafue River
19. Butingwa Resources	Butingwa Resources	1. Mwambashi River 2. Kafue River
20. Chambishi Metals stockpiles	Chambishi Metals	1. Chambishi Stream 2. Mwambashi River 3. Kafue River
21. Mwambashi Mine	Sino-Metals	3. Mupitanshi 4. Mwambashi River 5. Kafue River
22. Mineral processing plants on Kalulushi-Sabina Road	Multiple operators	6. Ichimpe Stream
23. Sewer effluent from Mindolo and Chimwemwe, Buchi, and Kwacha townships	Residential areas	1. Mindolo Stream 2. Kafue River

4.7.3 Impact of mining and minerals processing operations on local streams

The impact of mining and mineral processing facilities is indicated on the maps in Figures 4-79, 4-80, 4-81. Figure 4-79 shows the pH of local streams, Figure 4-80 the TDS and Figure 4-81 the concentration of sulphates. The maps also show how the results on Kafue River increase progressively from upstream to downstream. In other words, the water quality of Kafue River deteriorates progressively downstream.

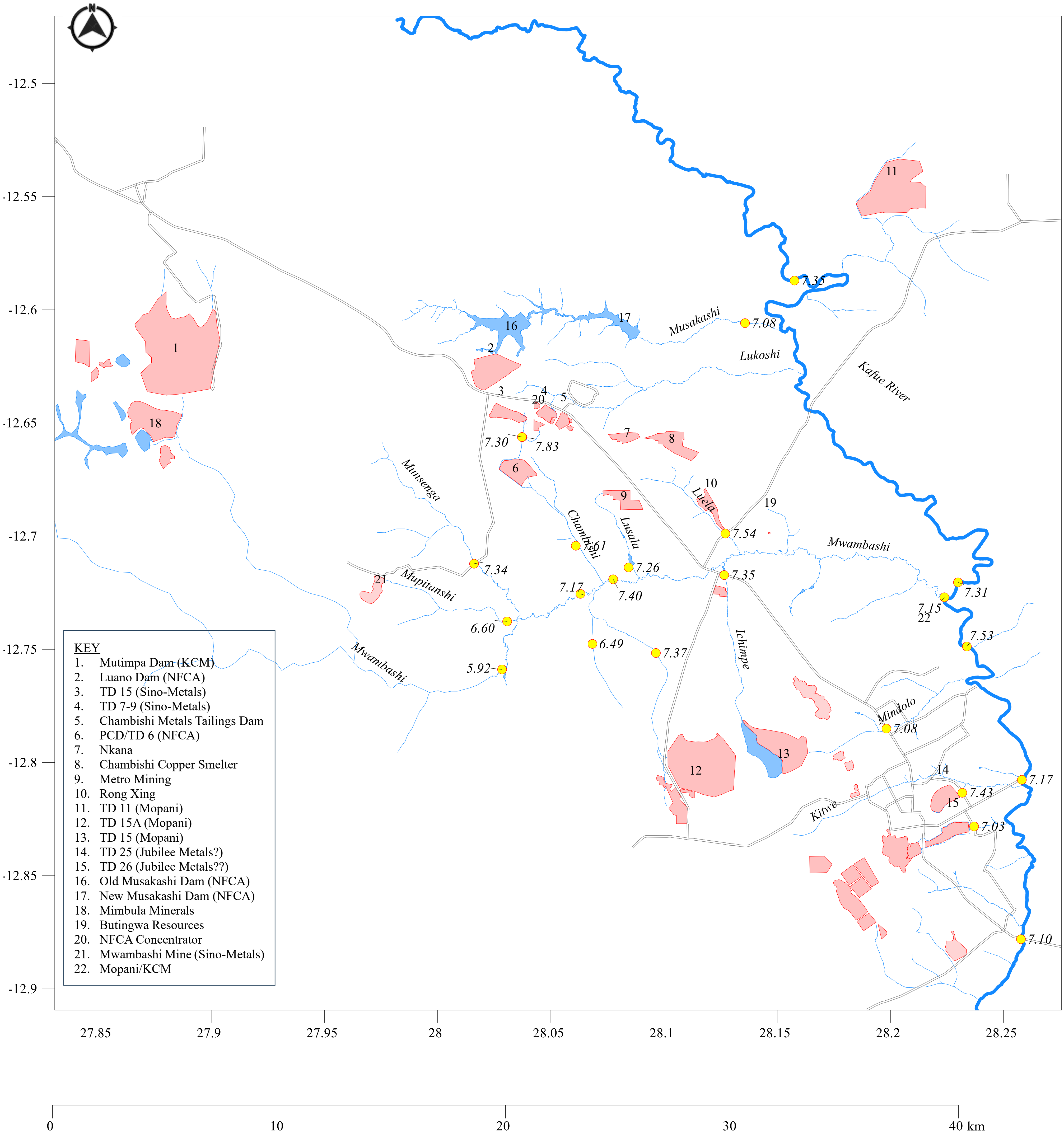


Figure 4-79: Map showing pH of streams in the area

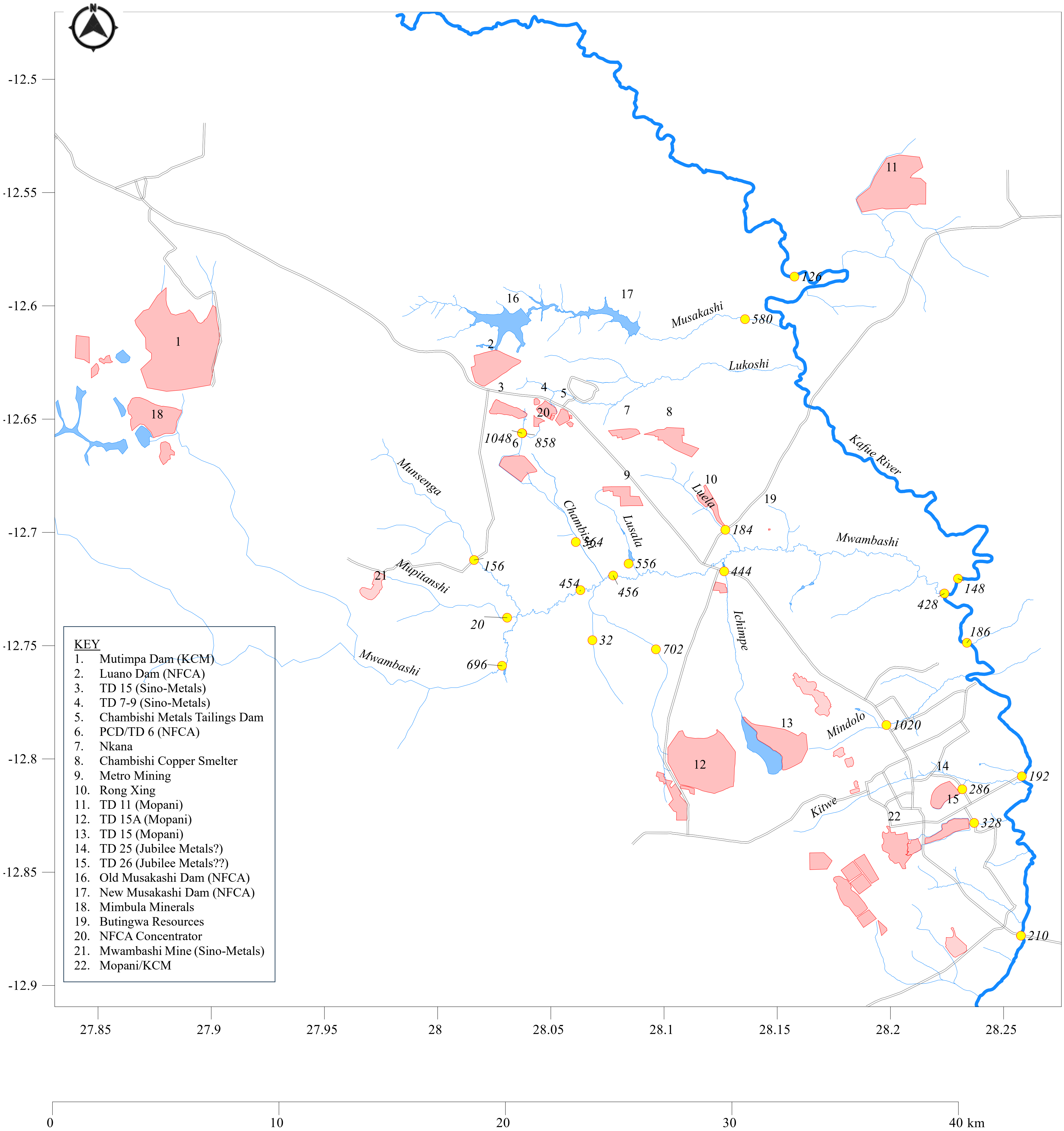


Figure 4-80: Map showing TDS of streams in the area

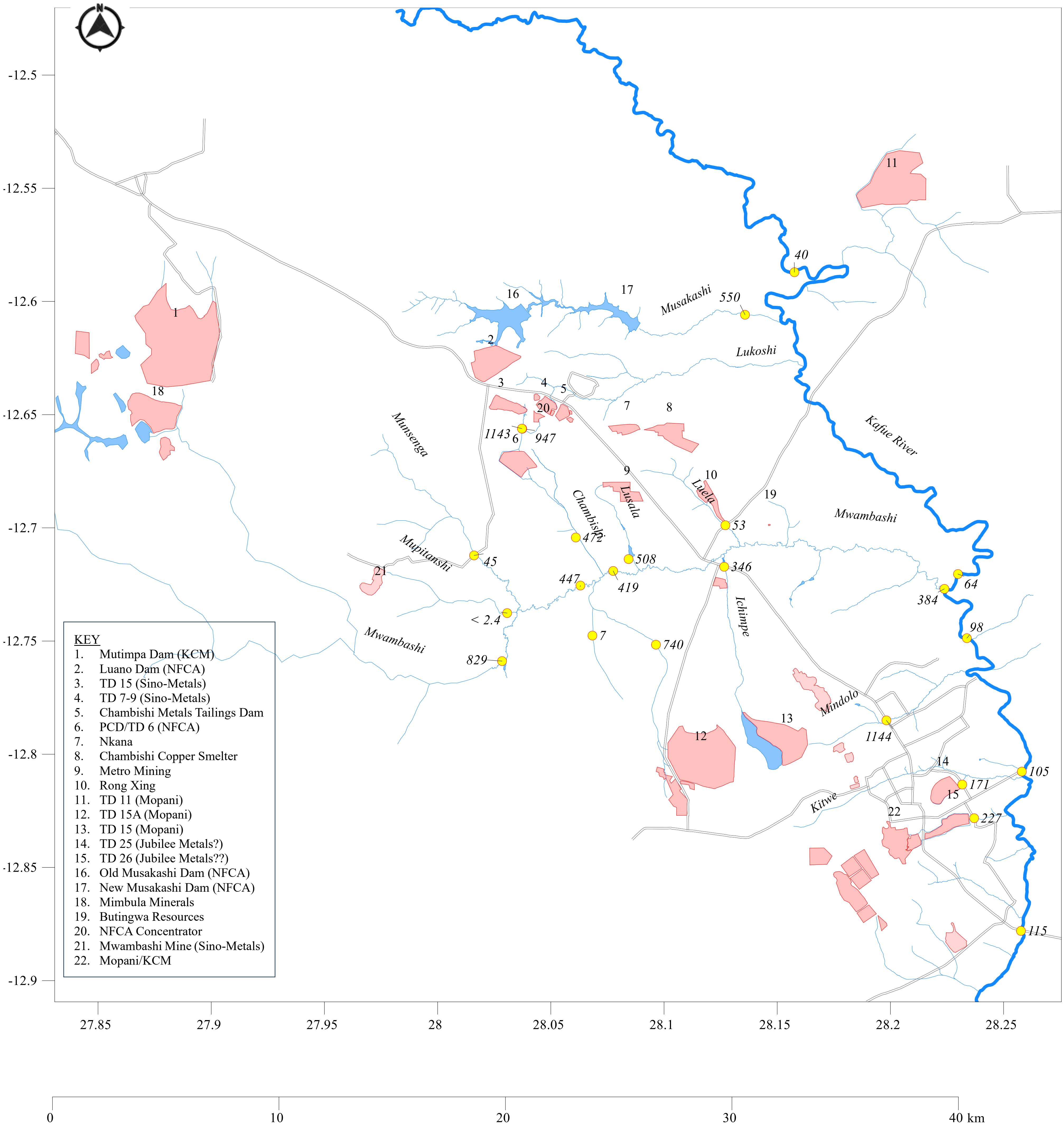


Figure 4-81: Map showing concentration of sulphates in streams in the area

4.7.4 Impact of mining and minerals processing operations on Kafue River

The adverse impact of the various tributaries on the water quality of Kafue River is illustrated in the schematic drawing in Figure 4-82 below. The figure shows that the key contamination indicators increased along the river. EC increased from 659 µS/cm upstream to 908 659 µS/cm while the concentration of sulphates increased from 213 mg/L to 341 mg/L. This shows that there is loading of contaminants to Kafue River from mining and mineral processing facilities, and from industrial and sewage effluent through the various tributaries to Kafue River.

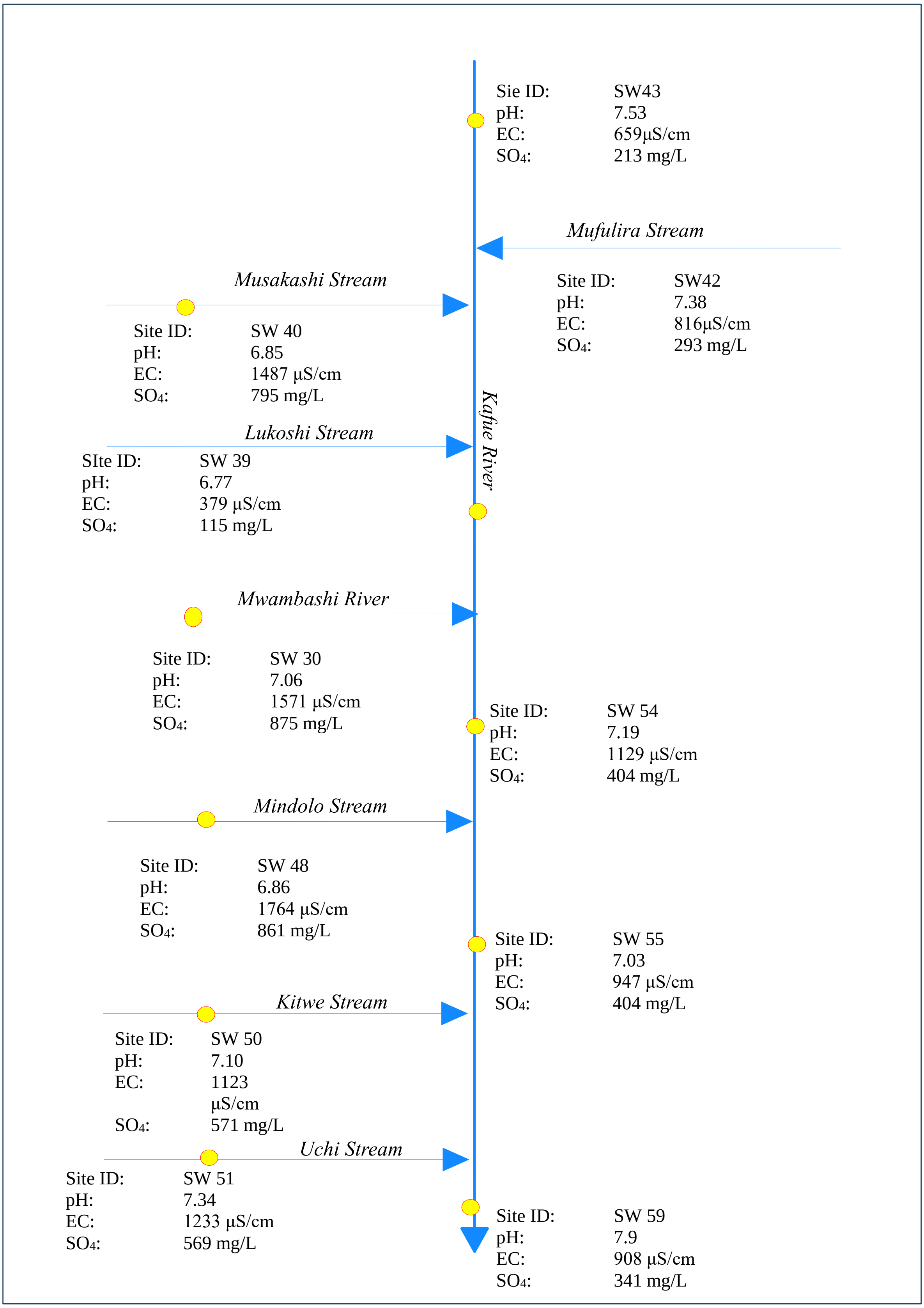


Figure 4-82: Schematic drawing illustrating impact of tributaries on Kafue River

4.7.5 Comparison of Kafue River to ambient water standards

The Zambian Ambient Water Quality Standard (AWQS) (ZS 1182: 2021, ICS 13.060.10) specifies the water quality criteria for different parameters in water. The current project has used the specifications for the Kafue catchment. The standards for Kafue catchment were developed with the aim of protecting the water sources for domestic use.

The guideline values for Kafue catchment are presented in Table 4-9 below. The table also includes the range of results obtained from Kafue River. The concentration of sulphates, calcium and magnesium in Kafue River exceeded the guidelines downstream of the confluence with Mwambashi River.

Table 4 - 9: Ambient water quality standards for the Kafue catchment and the range of analytical results obtained from the river

Parameter	Catchment mean value	Catchment highest value	Recommended value	Reference Point	Range of Kafue River results	
					Minimum	Maximum
pH	7.9	9.05	6.0 – 9.0	6.73	5.66	9.92
Electrical Conductivity	297	771	800	165	28	2343
Calcium	41	77	60	1078.3	2.8	1172.3
Cobalt	0.03	0.22	0.1	2.840	0.001	2.528
Copper	0.1	1.5	1.5	43.24	0.01	0.14
Magnesium	27	61	40	692.76	2.12	183.61
Manganese	0.18	0.23	0.20	168.32	0.01	0.81
Sulphates	36	53	60	3295.4	2.4	6157.2

All units are in mg/L except pH in pH units and electrical conductivity in µS/cm

4.8 Conclusion

The historical water quality data monitored by the stakeholders show that the three surface water sources, namely, Chambishi Stream, Mwambashi River and Kafue River, were significantly impacted by the tailings slurry discharged from TD 15 at Sino-Metals. The impact was indicated by low pH, elevated metals and sulphates in the water.

The current analytical results show that the water quality has returned to its pre-incident levels. This may be attributed to the following:

1. Dosing of the water with lime and sodium hydroxide at strategic sites in the days immediately following the incident most likely assisted to raise the pH of the water.
2. Dilution due to inflow of streams from tributaries and runoff from precipitation

4.9 Recommendations

This section outlines key proposed measures to address water pollution and improve long-term water resource management in the study area. The recommendations are structured into two focus areas: pollution mitigation strategies, monitoring and management.

4.9.1 Pollution mitigation strategies

The following recommendations are made to prevent pollution of surface water sources:

1. The wetland known as New Dam has demonstrated to be effective at removing pollutants from water, both suspended particulates and dissolved metals. It is therefore recommended that the use of wetlands to clean up water be utilised before the effluent is discharged to the environment.
2. There is uncontrolled reclamation of TD 6 in the area. This activity is destroying the function of TD 6 as a Pollution Control Dam as well as generating fine particulates which will be washed into the rivers where it will cause water pollution. This activity needs to be stopped and the facility rehabilitated.
3. There are multiple sources of pollution to Mwambashi and Kafue Rivers. There is a need to take an inventory of pollution sources and their impact on surface water quality.

4.9.2 Monitoring and management

The following recommendations are made regarding ongoing monitoring of water quality.

1. It is recommended that follow up monitoring be conducted during the rainy season at strategic points to assess the impact of the rainy season on water quality and especially secondary pollution.
2. The Zambia Bureau of Standards should establish a standard or procedure to standardise water quality monitoring by different stakeholders.
3. The government through ZEMA should limit the number of mineral processing facilities in the Mwambashi catchment to prevent further deterioration of the River.

4.10 Appendix

Appendix 4-1: Certificate of analysis for tailings

Appendix 4-2: Surface water sampling procedures

Appendix 4-3: Analytical results for surface water

Appendix 4-4: Analytical results for sediment

5 ASSESSMENT OF IMPACT ON GROUNDWATER

5.1 Objectives of the assessment

This Groundwater Contamination Assessment investigated the impact of the tailings discharge on groundwater quality. The specific objectives of the study were to:

1. Assess the impact of the tailings discharge on groundwater. This objective involved the following:
    a. Conducting a hydrocensus of groundwater sources in the area such as boreholes, shallow wells and springs.
    b. Determining the flow direction of groundwater in the affected area and hence the flow direction of pollutants.
    c. Determining the background water quality
    d. Identifying key pollutant indicator parameters in groundwater
    e. Assessing the spatial extent and magnitude of groundwater contamination.
    f. Assessing the risk of contamination to shallow wells.
2. Recommend groundwater remediation measures involving:
    a. Clean up strategies for contaminated groundwater.
    b. Estimating the time frame and financial resources required for remediation measures.
    c. Developing a comprehensive monitoring and evaluation for groundwater.

5.2 Scope of the assessment

The study investigated the contamination of the shallow groundwater and not the deep aquifers. This was done primarily for two reasons outlined below:

1. The shallow subsurface aquifer is more prone to be impacted by surface contaminants compared to the deep aquifers. In this case, the pollutants from the tailings will have to pass through the sub-surface aquifer before impacting the deep aquifers. It was, therefore, necessary to investigate the shallow sub-surface aquifer before extending the investigation to the deep aquifers.
2. The available groundwater sources for the purpose of collecting samples were shallow wells and scoop wells, which are indicative of shallow groundwater.

5.3 Methodology and limitations

5.3.1 Methodology

This section outlines the activities that were conducted to determine the impact of the tailings discharge on groundwater in the area.

5.3.1.1 Hydrocensus

An inventory of groundwater sources was carried out in the affected areas from Kalusale, immediately downstream of TD 6 to Luangwa township in Kitwe. The hydrocensus mapped groundwater sources that were within the expected influence of the tailings flow.

The information record about each groundwater source mapped included:

1. Type of groundwater source (e.g. shallow wells, springs, boreholes).
2. Depth to the groundwater level.
3. Coordinates of the groundwater source.
4. Ownership.
5. Usage of the water.

6. Water quality issues noted by the users.

The groundwater sources identified were mostly shallow wells and a few scoop wells.

5.3.1.2 Surveying

Selected shallow wells were surveyed to obtain their collar coordinates and elevations. The information was used to contour the elevations of the groundwater levels and hence to determine the groundwater.

5.3.1.3 Groundwater sampling

Groundwater samples were collected from groundwater sources and submitted to Alred H. Knight Laboratory for analysis. Groundwater samples were collected using the same containers used by the local people to abstract groundwater. The list of groundwater sources sampled is presented in Table 5-1 below.

Table 5-1: Types and numbers of groundwater sources sampled

No.	Type of groundwater source	No. identified	No. sampled
1	Boreholes	1	1
2	Shallow wells	75	42
3	Scoop wells	5	2
4	Springs	0	0
Total		81	45

5.3.1.4 Quality assurance/Quality control

To ensure data reliability, reproducibility, and compliance with international standards, a rigorous quality assurance (QA) and quality control (QC) framework has been implemented throughout the sampling and analysis process. QA/QC measures have been employed both in the field and in laboratory analysis.

1. Field Quality Control:
    a. All equipment calibrated before and after each sampling campaign.
    b. Field blanks, duplicates, and trip blanks used for water and biological tissue samples to detect contamination.
    c. Sample bottles were triple rinsed with water from the groundwater sources to be sampled before collecting the sample.
    d. Duplicate samples were collected at multiple groundwater sources.
    e. Standard operating procedures (SOPs) followed by all field personnel; staff trained and certified in sampling techniques.
    f. GPS coordinates and timestamps recorded for all samples; Digital data sheets used to minimize transcription errors.
2. Laboratory Quality Control:
    Chain-of-custody documentation maintained for all samples.
3. Data management:
    a. All data entered into a centralized database.
    b. Data validation checks (range, consistency missing values) performed prior to analysis.

5.3.1.5 Groundwater chemical analysis

The choice of parameters analysed in groundwater samples was based on the parameters identified as being of concern from the analysis of tailings. At the beginning of the investigations, tailings samples were collected from TD 15 and analysed to identify contaminants of concern. The analytical results of the tailings are attached in Appendix IIA (tailings liquor) and Appendix II-B (tailings solids). Going by the analytical results of the tailings, parameters such as uranium, cyanide and mercury were excluded because they were not present in the material. The chemical analysis therefore excluded uranium, cyanide and mercury as parameters of concern. Groundwater samples were analysed at Alfred H. Knight Laboratory for the parameters listed below.

<u>Physical parameters</u>

1. pH
2. Electrical Conductivity

<u>Cations</u>

1. Boron
2. Calcium

<u>Anions</u>

Sulphates

<u>Metals</u>

1. Arsenic
2. Aluminium
3. Cadmium
4. Chromium
5. Cobalt
6. Copper
7. Lead
8. Magnesium
9. Manganese
10. Nickel
11. Selenium
12. Zinc

5.3.2. Limitations

The significant limitations regarding the study are outlined below:

1. Groundwater sources for the study were restricted to existing groundwater sources (boreholes, wells and springs) located within the influence of the tailings flow, up to about 250 metres from the banks of the affected stream and rivers. There were therefore no new groundwater monitoring boreholes drilled for the purpose of the investigations.
2. The existing shallow wells in the areas of interest are prone to contamination from multiple contamination sources such as containers used for drawing water, farming activities and from historical contamination that is unrelated to the tailings discharge from Sino-Metals.

However, based on the methodology described above, the assessment yielded scientific subject to informative results, while these limitations were acknowledged.

5.4 Description of the study area

5.4.1 Location

This study to investigate contamination of groundwater from the tailings spillage was conducted in the following locations:

1. Kalusale settlement

Kalusale settlement is in the Chambishi area of Kalulushi District between TD 15 and Mwambashi River. Kalusale was the primary area of impact by tailings flow from TD 15. The impacted surface water is Chambishi Stream which flows in the middle of the settlement and discharges into Mwambashi River.

2. Mwambashi River

Mwambashi River is the receiving environment of Chambishi Stream. Groundwater contamination along Mwambashi River was investigated near the confluence with Chambishi Stream.

3. Bulangililo/Ipusukilo/Chipata settlements

The Bulangililo/Ipusukilo/Chipata settlements are located on the eastern side of Kitwe along the Kafue River. The Kafue River received tailings contamination from Mwambashi River.

4. Luangwa township

Luangwa Township is located on the southern part of Kitwe, along the Kafue River. The settlement is located downstream of the Bulangililo/Ipusukilo/Chipata settlements.

These locations were selected because of their proximity to the tailings flow path.

5.4.2 Land use

The land use in the areas where groundwater was investigated is mixed. Kalusale is an illegal settlement located on a mining land. According to the Zambia Mining Cadastre Map Portal, part of the Kalusale settlement sits on mining license number 7069-HQ-LML belonging to NFC Africa Mining PLC (NFCA) and another part sits on exploration license number 41019-HQ-LEL belonging to Copperzam Limited. The settlement is therefore wholly located on mining land.

The people who have settled in the Kalusale area are engaged in subsistence farming, growing especially rainfed maize. There was limited cultivation of vegetables along Chambishi Stream and Mwambashi River. Some people are engaged in fishing and trading.

Bulangililo, Ipusukilo, Chipata and Luangwa are peri-urban settlements located along the Kafue River on the eastern side of Kitwe. The livelihood activities in the area include cultivation of vegetables along the Kafue River, fishing, trading and both formal and informal employment.

5.4.3 Groundwater sources and groundwater usage

Groundwater is the primary source of potable water in the areas investigated. This is because the areas are not supplied with piped water by the local water utility, Nkana Water Supply and Sanitation Company (NWSC). Groundwater abstraction is mostly through shallow hand-dug wells, both protected well (Figure 5- 1 and Figure 5- 2) and unprotected (Figure 5- 3 and Figure 5- 4). Other groundwater sources identified in the area, especially in Kalusale, are what are known as scoop wells. Scoop wells are shallow excavations made near the streams, in the dambo areas where groundwater is shallow (Figure 5-5 and Figure 5-6. There is one borehole fitted with a hand-pump in Kalusale.

Figure 5-1: Photograph of a protected well in Luangwa Township

Figure 5-2: Photograph of a protected well in Luangwa Township

Figure 5-3: Photograph of an unprotected well in Luangwa Township

Figure 5-4: Photograph of an unprotected well in Kalusale

Figure 5-5: Photograph of a scoop well in the Kalusale area

Figure 5-6: Photograph of a scoop well in the Kalusale area

The water from the wells is used for all domestic purposes, including drinking, cooking, bathing, washing and for irrigation of small gardens located near the streams. Water is abstracted from the wells using different kinds of containers.

5.4.4 Topography

The topography of the Kalusale area is illustrated in the relief map in Figure 5-7 below. The map shows that the Chambishi Stream has a southeasterly plunge and drains into the Mwambashi River. The significant observation from the topographic map is that it shows the flow direction, which is expected to be taken by the tailings both through surface flow and groundwater flow. Transport of pollutants from tailings through surface and groundwater moves by gravity from areas of higher elevations to areas of lower elevations.

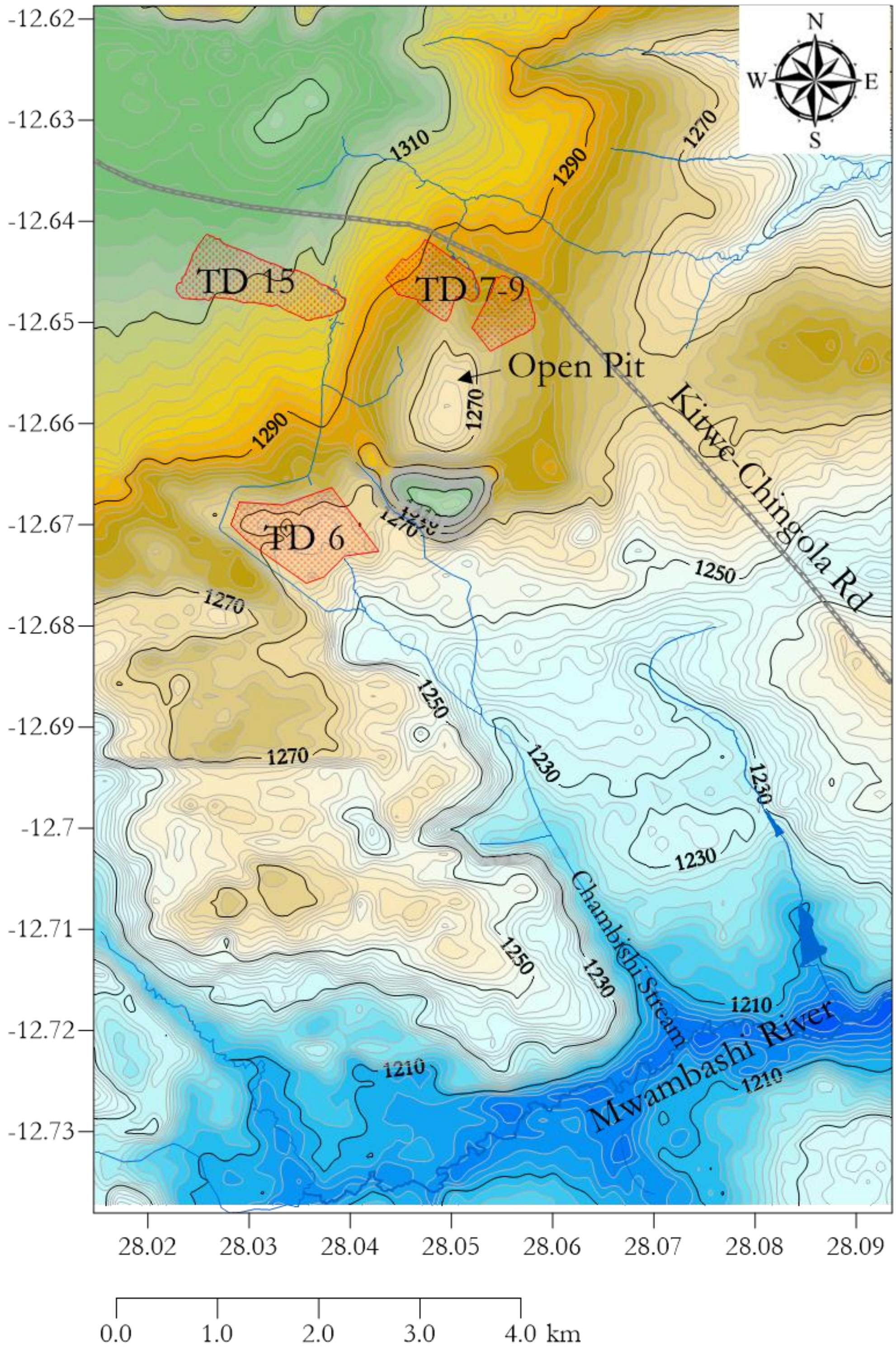


Figure 5-7: Relief map of Chambishi Stream and the surrounding area

5.4.5 Identification of potential groundwater contamination sources

Multiple sources of potential groundwater contamination sources were identified in the study area and are listed in Table 5-2 below. These sources have the potential to impact the shallow groundwater and ultimately daylight in Chambishi Stream or Mwambashi River.

Table 5-2: Types and numbers of groundwater sources sampled

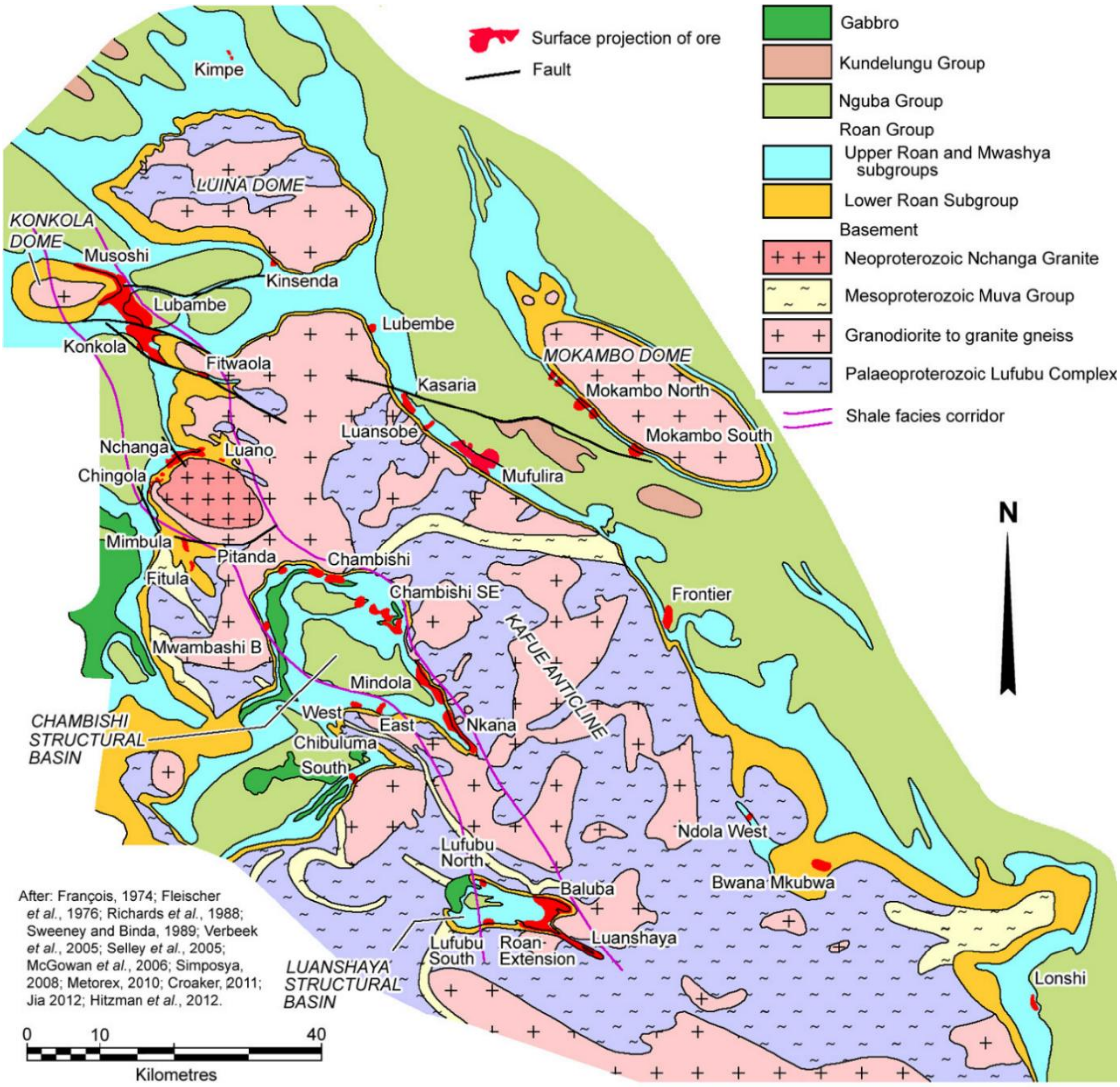
Area	Potential source of groundwater contamination	Expected contaminants in groundwater
Kalusale	Tailings Dam No. 6 (TD 6)	• Metals • Sulphates
	Historical tailings spill	• Metals • Sulphates
	Gardens	• Nutrients • Sulphates
	Decomposition of organic matter	Weak acid
	Tailings deposits	• Metals • Sulphates • Acidic contaminants
	Geology	• Metals
Bulangililo Ipusukilo Chipata Luangwa	Gardens	• Nutrients • Sulphates
	Septic tanks/soak aways & pit latrines	• Nutrients • Metals • Sulphates
	Decomposition of organic matter	• Weak acid
	Geology	Metals

The contamination sources listed in Table 5-2 above have the potential to impact groundwater sources of interest, i.e. (shallow wells, scoop wells, boreholes) and through groundwater flow, affect the water quality of the streams and rivers.

5.4.6 Geological setting

5.4.6.1 Regional geology

The regional geology of the Zambian Copperbelt (Figure 5-8) lies at the south-eastern end of the 800 km long Lufilian fold belt. It comprises deformed sedimentary rocks of the Late Precambrian Katanga System draped around the flanks of the Kafue Anticline, a major northwest trending late-tectonic structural feature.



Geological setting of the Zambian Copperbelt and the distribution of stratabound sediment hosted copper deposits

Figure 5-8: Geological setting of the Zambian Copperbelt[12]

5.4.6.2 Local geology

The Chambishi deposits are hosted by the Neoproterozoic Lower Roan Group Ore Formation of the Katanga Supergroup, within the Chambishi-Nkana basin, located on the mid-southwestern flank of the 'Kafue Anticline'. The 'Kafue Anticline' is a late-tectonic structural feature within the Dome's Region of the Lufilian Arc, centred on a basement high of Palaeo- and Mesoproterozoic gneisses and schists, over which the Katangan sedimentary rocks were draped. The Chambishi-Nkana basin is essentially a NW-SE elongated, doubly plunging, structural basin, predominantly surrounded by pre-Katangan basement. The basinal structure cuts across the generally NW-SE trending facies boundaries within the Lower Roan Group.

The Chambishi deposits lie on the northeastern and northern margins of the Chambishi-Nkana structural basin. The stratigraphy of the Lower Roan Group at Chambishi can be summarised as follows, from the base, where it unconformably overlies the Palaeo- to Mesoproterozoic basement complex, which is predominantly a grey, microcline-biotite-granite and numerous aplite dykes, with a few Lufubu schist xenoliths, overlain by Mesoproterozoic Muva conglomerate, quartzite and quartz-schist. The geology map of the Chambishi basin is presented in Figure 5-9 below.

[12] https://portergeo.com.au/database/mineinfo.php?mineid=mn126

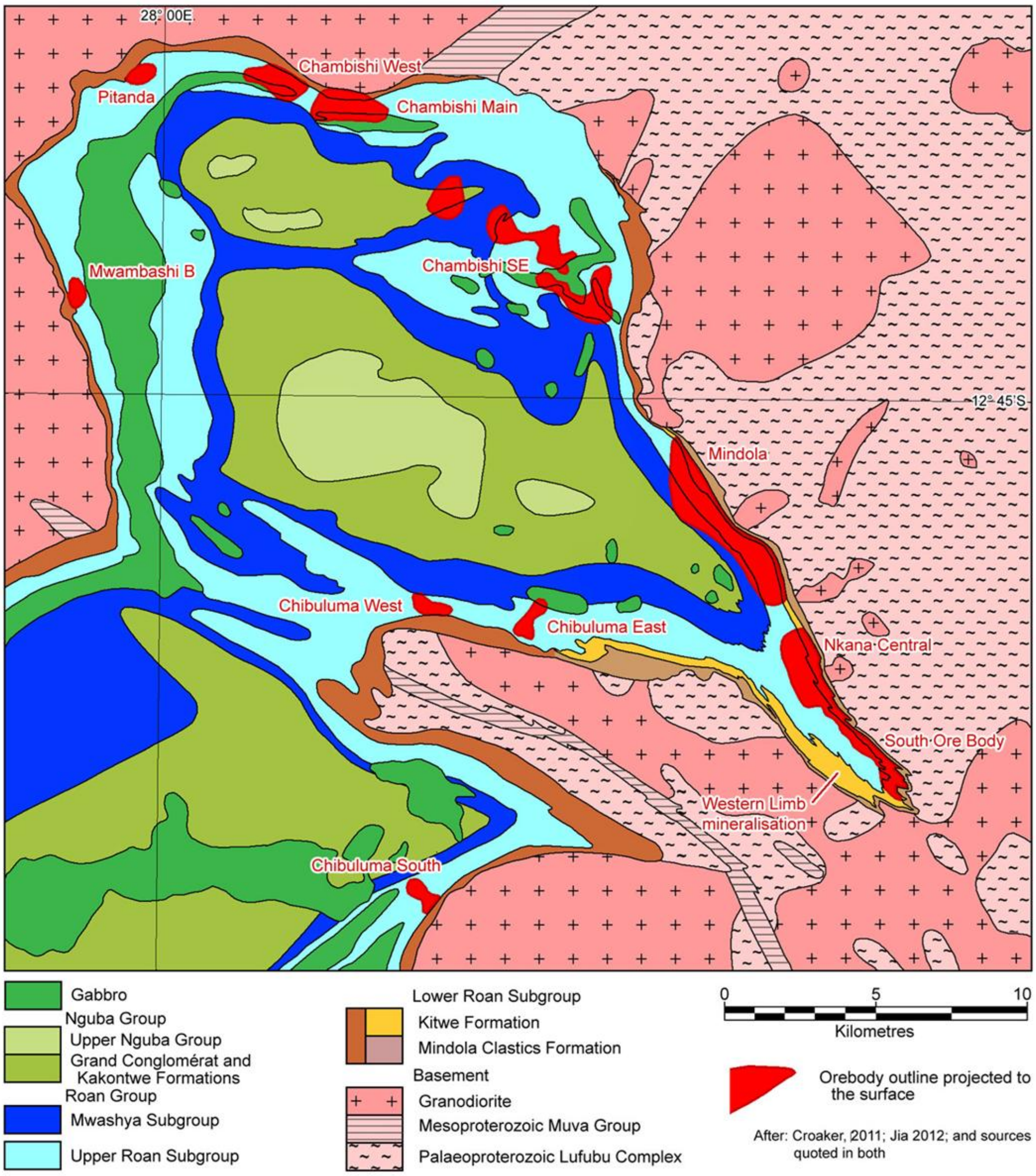


Figure 5-9: Geological setting of the Chambishi basin[13]

5.4.7 Hydrogeological setting

5.4.7.1 Local hydrogeology

This study investigated the contamination of the shallow or groundwater from the tailings discharged from TD 15. accessed through shallow wells and scoop wells.

5.4.7.2 Depth to the groundwater

The depth of groundwater in the wells below the ground level varied from site to site. The groundwater depth ranged from 0 to 10.9 metres below the ground level (mbgl). The mean depth to the groundwater level was 5.4 mbgl. This means that the groundwater level is relatively shallow and therefore prone to contamination from activities on the surface.

5.4.7.3 Groundwater flow direction

Establishing the flow direction of groundwater in the Kalusale area involved the following steps:

1. Surveying the collar coordinates (x, y) and elevations (z) of the shallow wells
2. Measuring the depth of groundwater from the collar of the well (d)
3. Calculating the elevation of groundwater using the formula:

[13] https://portergeo.com.au/database/mineinfo.php?mineid=mn013

4. Groundwater elevation
5. =
6. Collar elevation (E) – depth to the water level (d)
7. Contouring the groundwater elevations using Surfer® software to establish the groundwater flow direction.

The coordinates and elevations of the shallow wells, their respective water levels and groundwater elevations are presented in Appendix I. The flow direction of groundwater in the Kalusale is determined from the groundwater elevations in the shallow wells is shown on the satellite image in Figure 5-10.

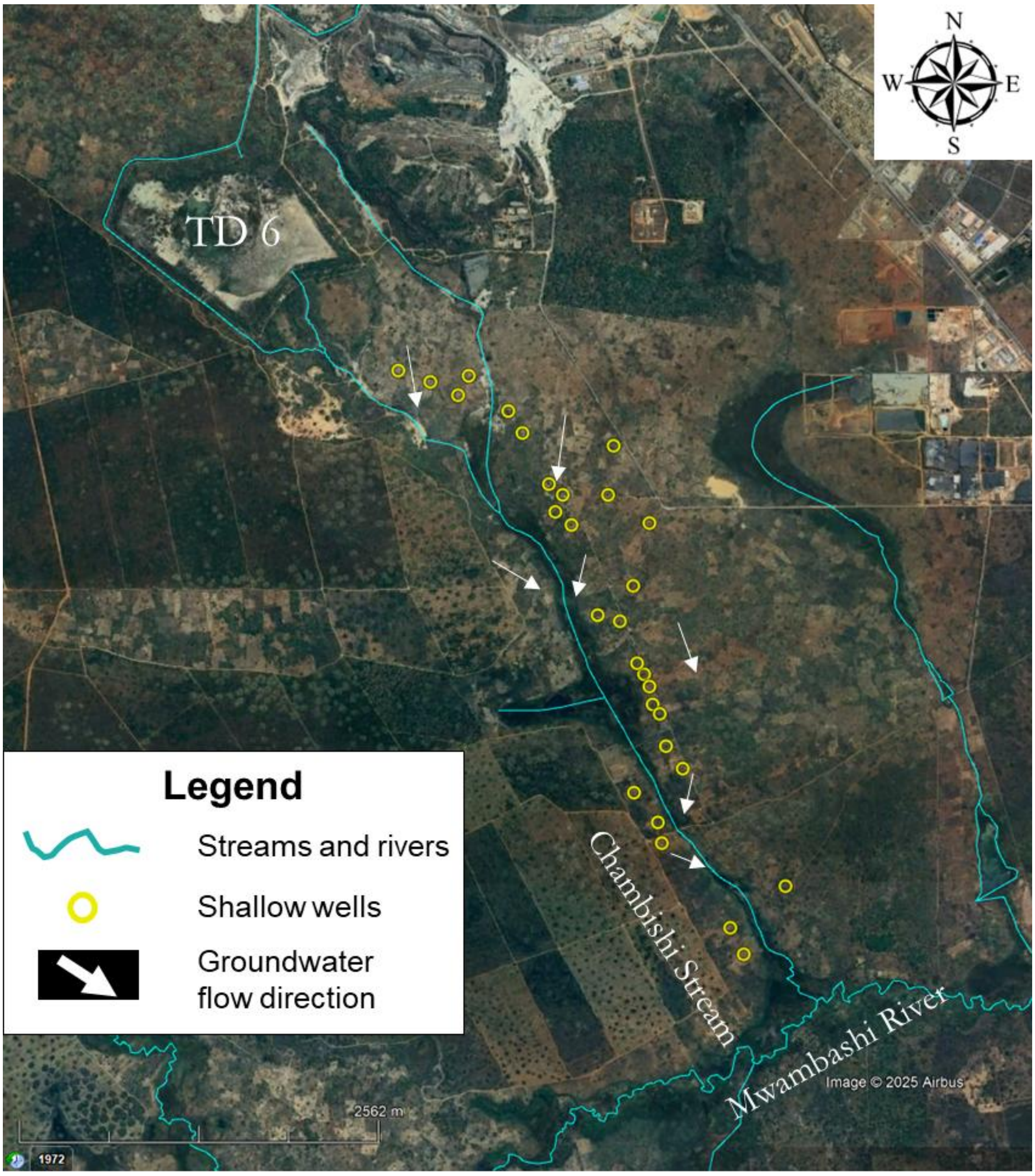


Figure 5-10: Satellite image showing the location of shallow wells and groundwater flow direction

Based on the analysis of groundwater elevations, two flow directions of the groundwater were identified at Kalusale. There is a regional flow in the southeasterly direction and a localised flow towards Chambishi Stream from both sides of the stream. The two flow directions are discussed in detail below, including the implications on groundwater contamination.

1. **Regional groundwater flow direction**

   The regional or overall flow direction of groundwater in the Kalusale area is in the southeasterly direction, following the flow direction of Chambishi Stream. This implies that the Pollution Control Dam, TD 6, is upstream of the shallow wells while Mwambashi River is downstream. In fact, the southeasterly regional flow terminates into Mwambashi River. This flow is expected to transport pollutants from TD 6 to the shallow wells located downstream of the facility.

2. **Local groundwater flow direction**

   The local groundwater flow direction is a result of the recharge of Chambishi Stream from both sides of the stream. This flow direction entails groundwater flowing from upland and daylighting at the stream. This is illustrated in the drawing in Figure 5-11 below. It will be observed that groundwater in the shallow wells is at a higher elevation compared to Chambishi Stream. Consequently, groundwater flows from the wells to Chambishi Stream.

   The local groundwater flow direction has implications on the transport of pollutants from the tailings discharge into groundwater. Based on this analysis, pollutants are not expected to travel from Chambishi Stream and contaminate the shallow wells as this would require the pollutants to travel upgradient.

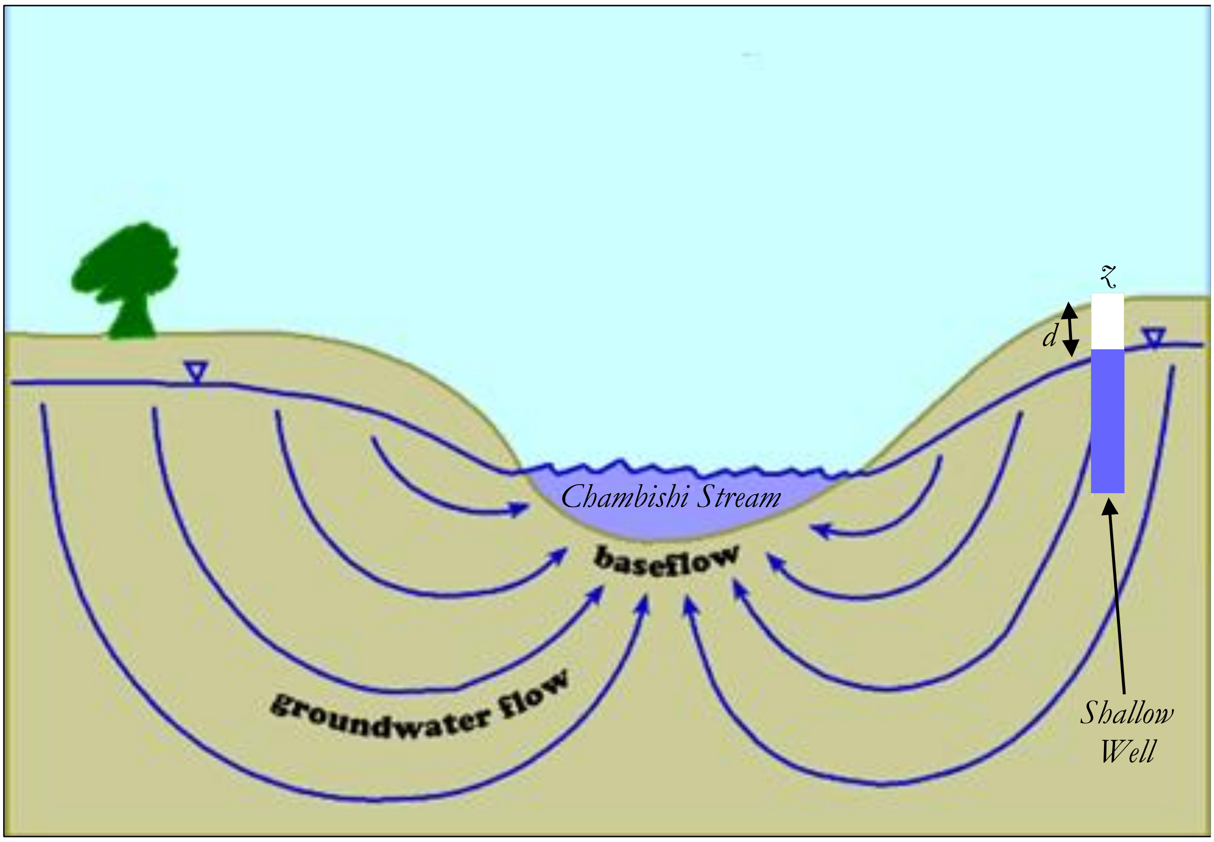


Figure 5-11: Drawing illustrating groundwater flow direction to Chambishi Stream

5.5 Results and findings

5.5.1 Presentation of analytical results

The analytical results of groundwater are presented in Appendix III. Table 5-3 below presents the summary of selected parameters and the comparison of the water quality results with the drinking water guidelines. Where the results were below the Method Detection Limit (MDL), a figure of 0 has been used for statistical analysis. The concentrations of cadmium, cobalt, copper, chromium, lead, nickel, selenium in groundwater were mostly below their respective detection limits.

The shallow wells from which groundwater samples were obtained are used as sources of potable water by the local communities. It is for this reason that the analytical results of groundwater samples have been compared to the World Health Organization (WHO) guidelines for drinking-water quality. The number of results exceeding the guidelines for the specified parameters are listed in Table 5-3.

Although multiple parameters are compliant with the WHO guidelines for drinking-water quality, it must be pointed out that shallow wells and scoop wells are not the best sources of potable water for the following reasons:

1. The wells are open and unprotected and prone to contamination
2. The shallow wells in Kalusale by virtue of being located downstream of TD 6 are prone to contamination by leachate from the facility.
3. The shallow wells in Bulangililo, Ipusukilo, Chipata and Luangwa are prone to contamination from seepage from pit latrines, septic tanks and soak aways.

Table 5-3: Summary of groundwater results

Parameter	Units	WHO guidelines for drinking-water quality	Number of results. exceeding the guidelines	Drinking water quality of Zambian Standard	Statistical summary of analytical results					
					Count	Minimum	Maximum	Mean	Median	Standard Deviation
pH	pH units	6.5-8.5	41	6.5-8.0	44	4.49	7.33	5.8020	6.0350	0.6896
Electrical conductivity	µS/cm	500-1500	2	1500	44	19.00	2949.00	510.6136	409.5000	574.6689
Aluminium	mg/L	0.2	6	0.2	44	0	6.30	0.3114	0	1.0504
Arsenic	mg/L	0.01	2	0.01	44	0	0.02	0.0009	0	0.0042
Boron	mg/L	0.5	0	-	44	0	0	0	0	0.0000
Calcium	mg/L	-	-	200	44	1.50	927.80	91.5932	64.8500	145.8604
Cadmium	mg/L	0.003	0	0.003	44	0	0	0	0	0.0003
Cobalt	mg/L	-	-	0.5*	44	0	2.01	0.0494	0	0.3031
Chromium	mg/L	0.05	0	0.05	44	0	0	0	0	0.0000
Copper	mg/L	2	1	1	44	0	13.95	0.3198	0	2.1027
Magnesium	mg/L	-	-	150	44	0.43	395.79	38.1293	28.1700	62.2794
Manganese	mg/L	0.08	14	0.1	44	0	6.58	0.2705	0.0100	1.0076
Nickel	mg/L	0.07	0	-	44	0	0.05	0.0015	0	0.0072
Lead	mg/L	0.01	0	0.01	44	0	0	0	0	0.0000
Selenium	mg/L	0.04	0	0.01	44	0	0.03	0.0030	0	0.0079
Sulphates	mg/L	250	7	400	44	0	1953.40	154.0409	57.5000	313.8957
Zinc	mg/L	-	-	3	44	0	0.12	0.0034	0	0.0180

* Note: the toxicological analysis standard for Cobalt is 0.003 mg/L.

5.5.1.1 Normality tests

The normality test, which assesses whether there is a significant difference between the population level represented by a sample and the theoretical normal distribution, is of paramount importance and is the most widely used method in parametric statistical analysis. Key methods include the Kolmogorov-Smirnov test and its modified version, the Lilliefors test, based on empirical distribution function comparisons; the Anderson-Darling test, based on quadratic form statistics; and the Shapiro-Wilk test.

The Shapiro-Wilk normal distribution test and the Kolmogorov-Smirnov normal distribution test were used to test the original detection data with SPSS Statistics 17.0. When the test results show that p value>0.05, it shall be considered that the data are close to normal distribution; otherwise, it is considered that the data do not conform to normal distribution.

Table 5-4: Normality tests statistics

Parameter	Kolmogorov-Smirnov			Shapiro-Wilk		
	Statistic	df	P	Statistic	df	P
pH	0.159	44	0.007	0.934	44	0.015
EC	0.196	44	0.000	0.779	44	0.000
Al	0.412	44	0.000	0.337	44	0.000
As	0.540	44	0.000	0.216	44	0.000
Ca	0.268	44	0.000	0.532	44	0.000
Cd	0.537	44	0.000	0.137	44	0.000
Co	0.501	44	0.000	0.152	44	0.000
Cu	0.515	44	0.000	0.139	44	0.000
Mg	0.272	44	0.000	0.523	44	0.000
Mn	0.394	44	0.000	0.271	44	0.000
Ni	0.471	44	0.000	0.223	44	0.000
Se	0.509	44	0.000	0.419	44	0.000
SO_4^{2-}	0.312	44	0.000	0.485	44	0.000
Zn	0.462	44	0.000	0.188	44	0.000

Note: B, Cr, and Pb are constant across all samples and have been omitted.

5.5.1.2 Spatial distribution of analytical results

1. pH

The pH of groundwater in all the areas investigated was generally low, being less than 7. The pH values of groundwater are indicated on the satellite images in Figure 5-12 (Kalusale area), Figure 5-13 (Mwambashi River), Figure 5-14 (Bulangililo/Ipusukilo area) and Figure 5-15 (Chipata compound area).

Based on the research findings regarding groundwater quality in the Kitwe District area, it has been observed that the pH of groundwater in this region is generally low, with the groundwater being slightly acidic. This widespread low-pH characteristic of the groundwater is likely caused by other factors, such as natural geological conditions and the carbon dioxide produced by the decomposition of organic matter. Therefore, the low pH of groundwater is not from tailings discharge when the totality of the results is considered.

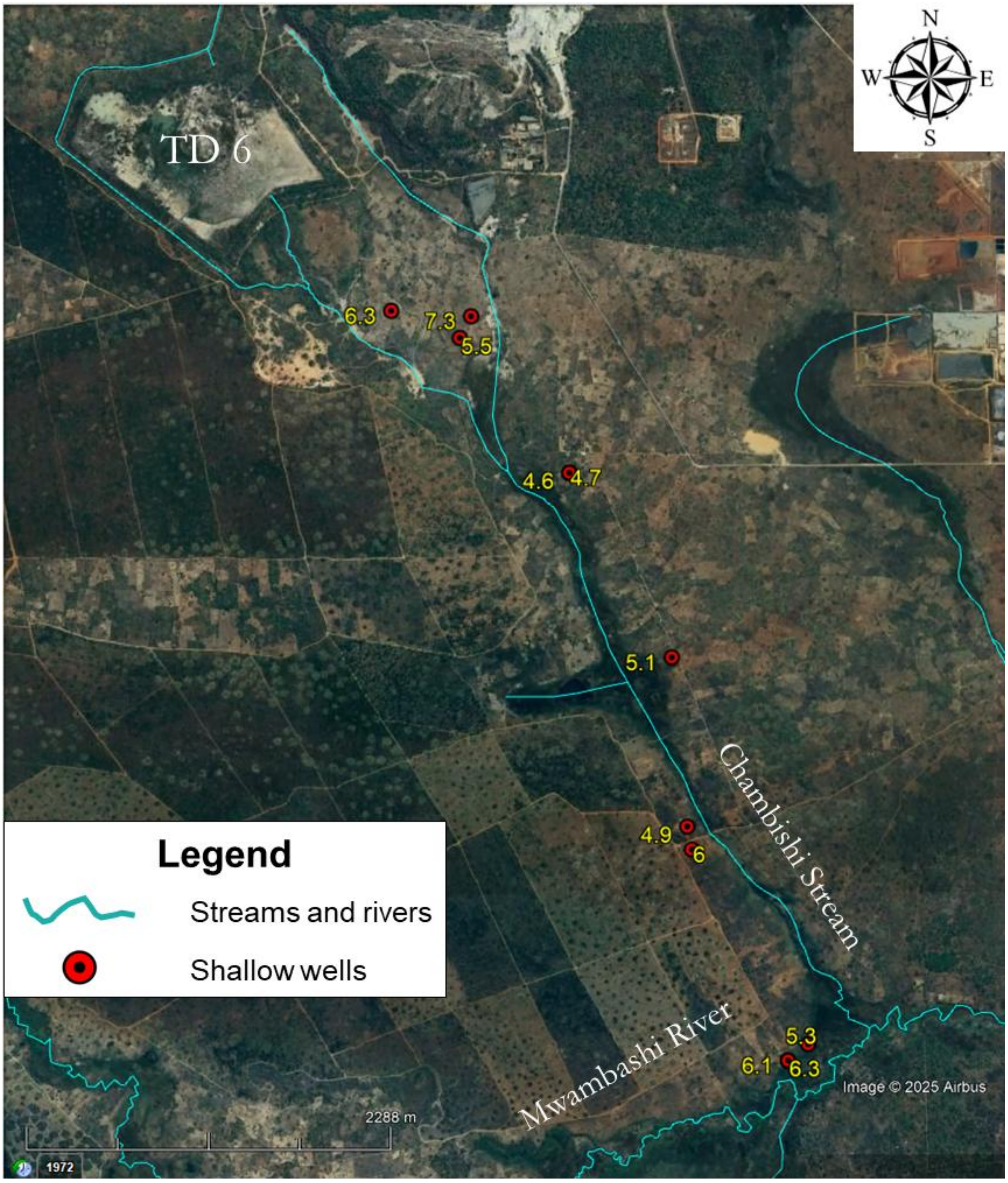


Figure 5-12: Satellite image showing the pH of shallow wells in the Kalusale area

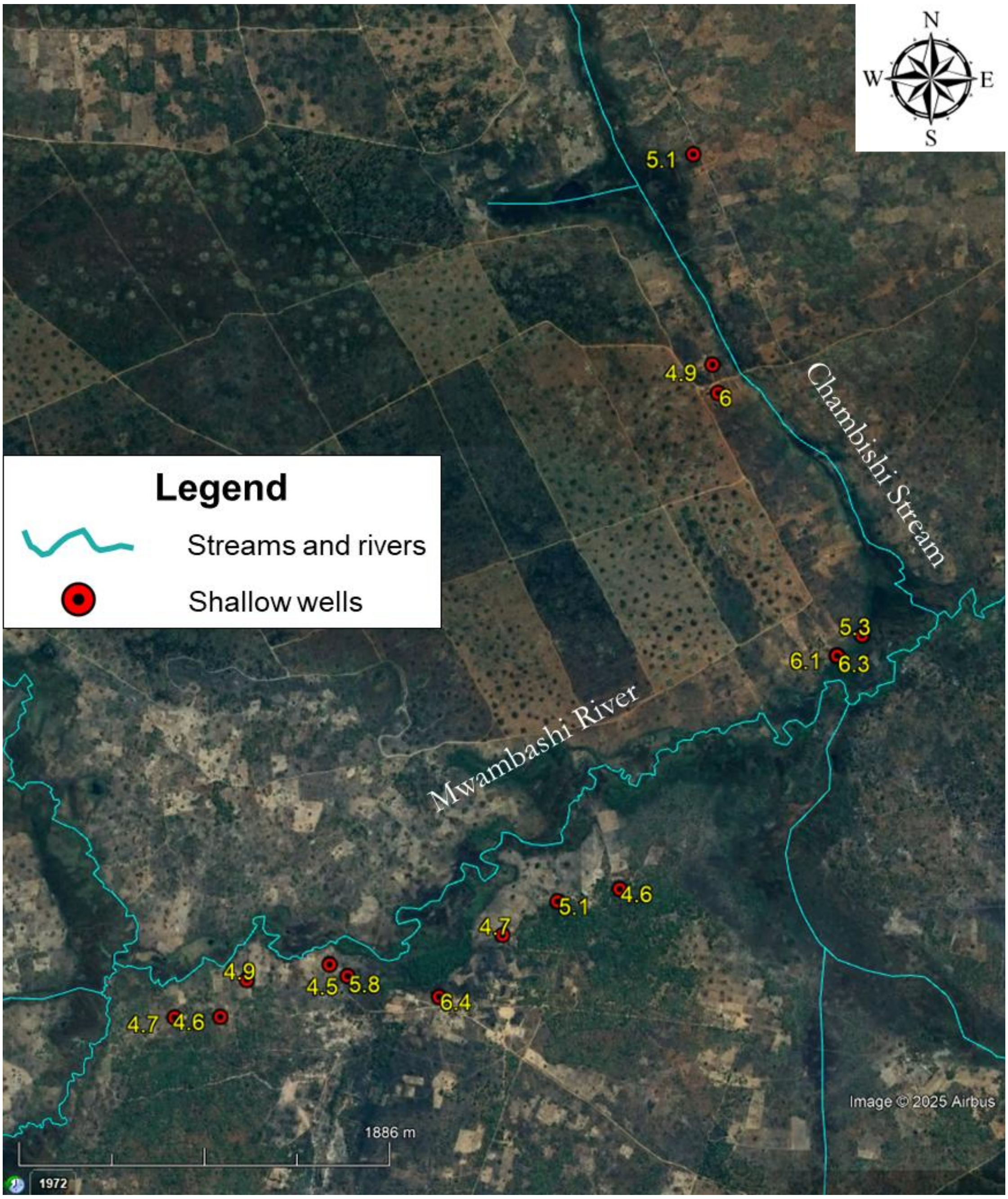


Figure 5-13: Satellite image showing the pH of shallow wells in the Mwambashi area

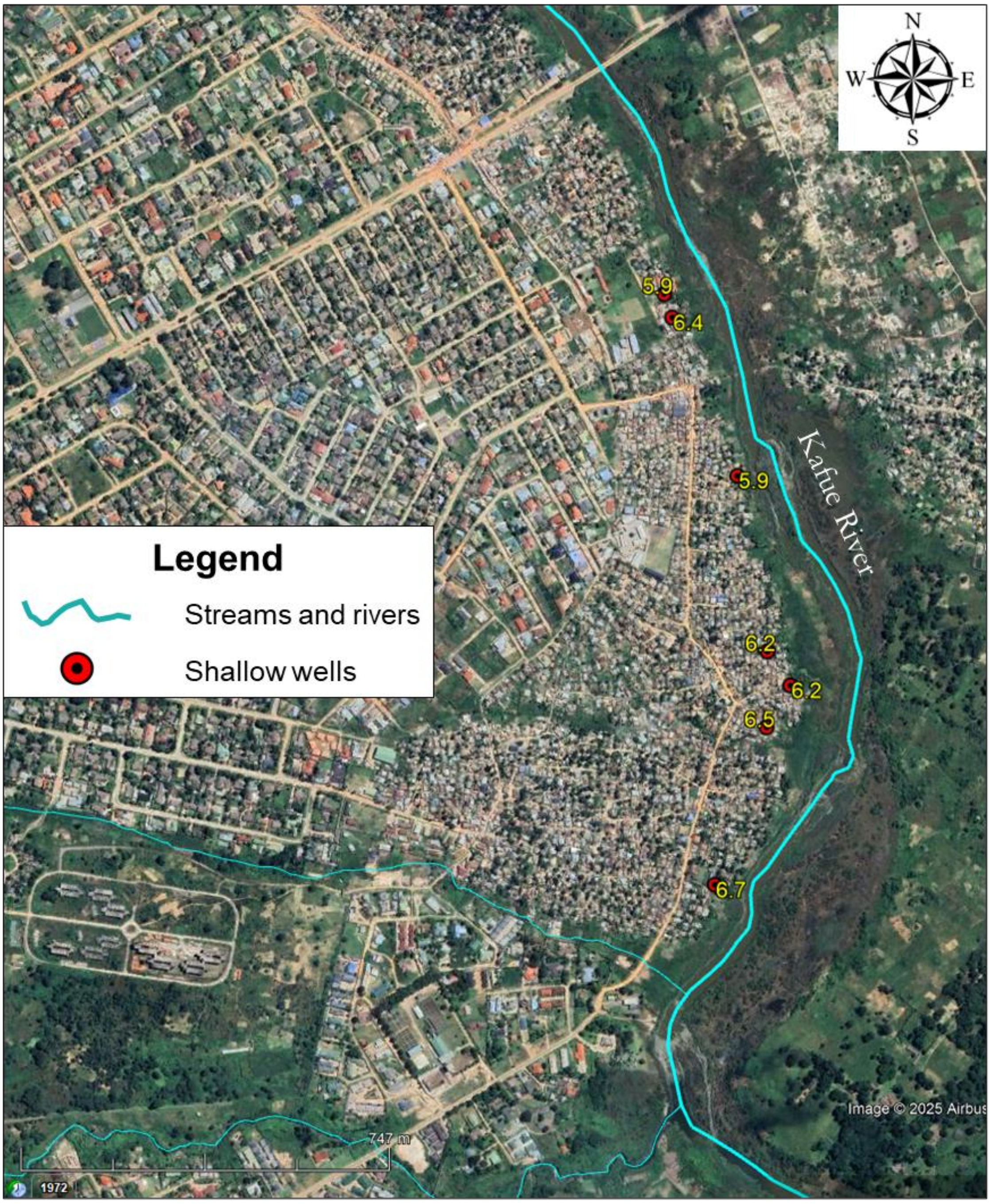


Figure 5-14: Satellite image showing the pH of shallow wells in the Chipata compound area

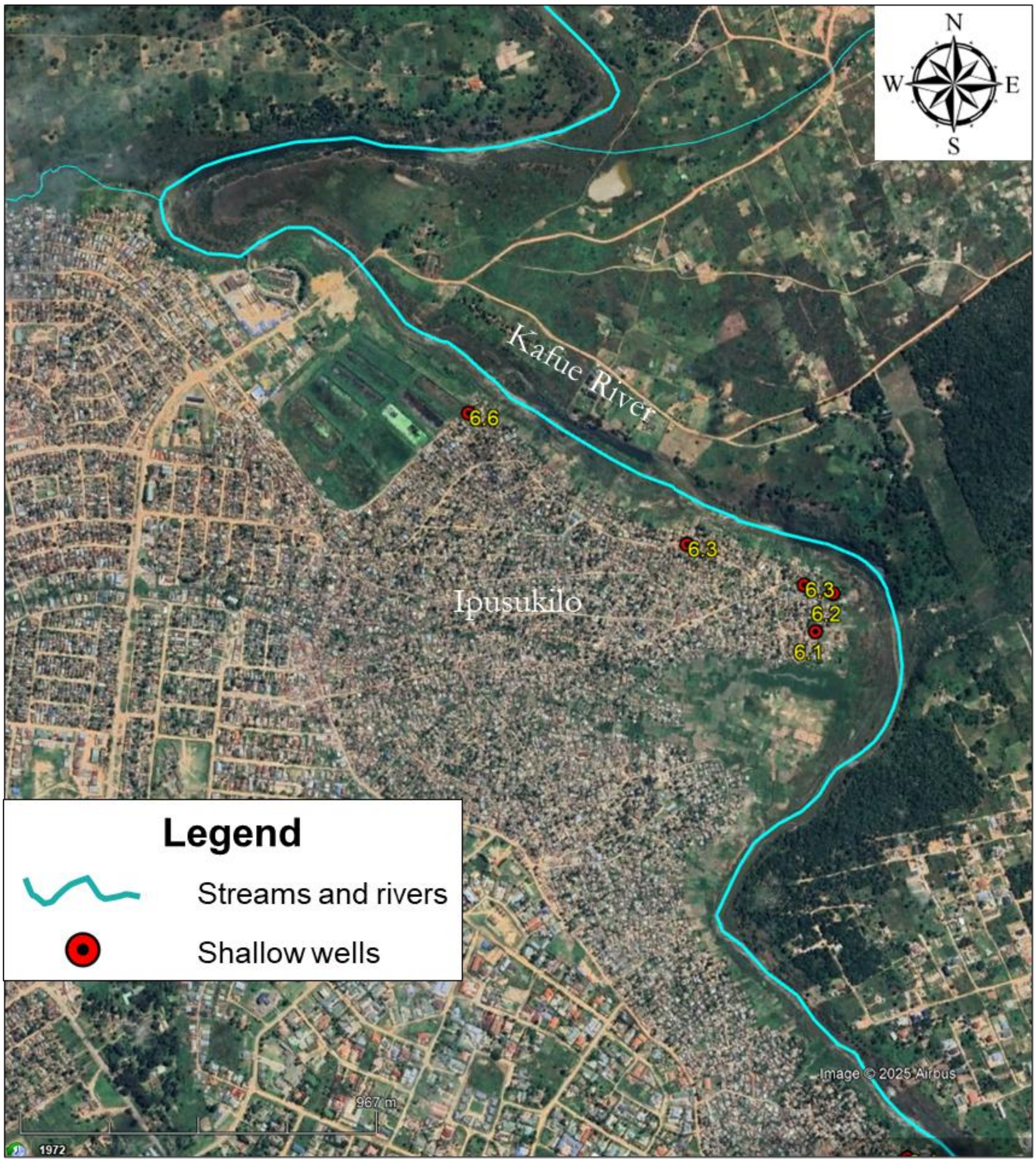


Figure 5-15: Satellite image showing the pH of shallow wells Ipusukilo area

2. Electrical conductivity

Historical monitoring results indicate that uncontaminated groundwater on the Copperbelt has relatively low electrical conductivity (EC) of less than 100 µS/cm. Consequently, EC exceeding 100 µS/cm is indicative of groundwater contamination.

The above criteria when applied to the groundwater results shows that the shallow wells located immediately downstream of the Pollution Control Dam TD 6, with EC ranging from 510-2,949 (Figure 5-16), are potentially contaminated and require further verification. The shallow wells are likely contaminated by the third-party's mining activities from TD 6 and the downstream channel. The rest of the wells monitored in the Kalusale area, including the wells along Mwambashi Stream, have low EC ranging from 26-44 µS/cm (Figure 5-17), and are therefore unimpacted by leachate from TD 6.

The elevated EC of the shallow wells located in the Ipusukilo area of 1,072-1,36 µS/cm (Figure 5-18) and in the Luangwa area of 112-632 µS/cm (Figure 5-19) may be attributed to groundwater contamination from on-site sewer treatment facilities in the form of pit latrines and septic tanks/soak away.

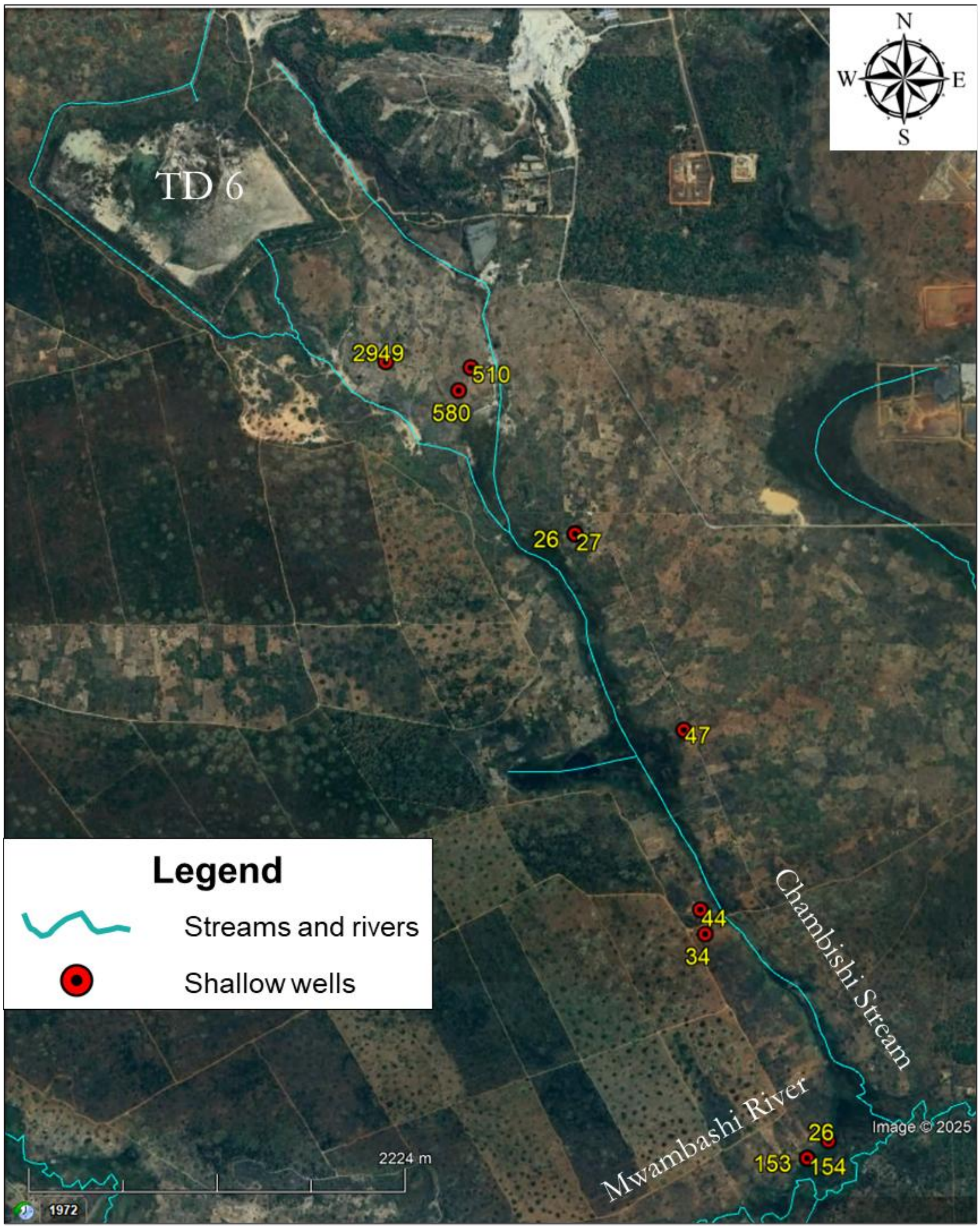


Figure 5-16: Satellite image showing the EC of shallow wells in the Kalusale area

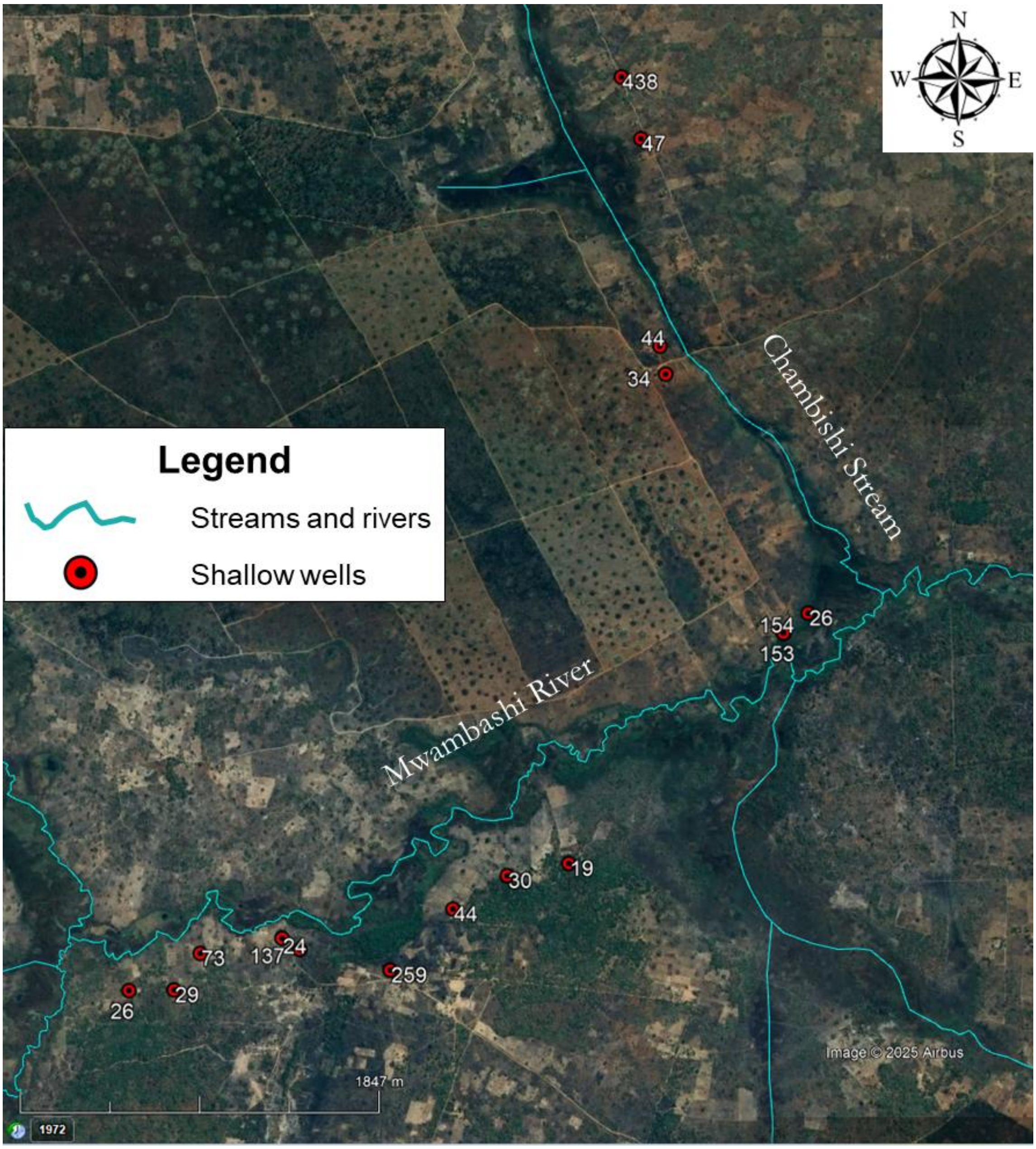


Figure 5-17: Satellite image showing the EC of shallow wells in the Mwambashi area

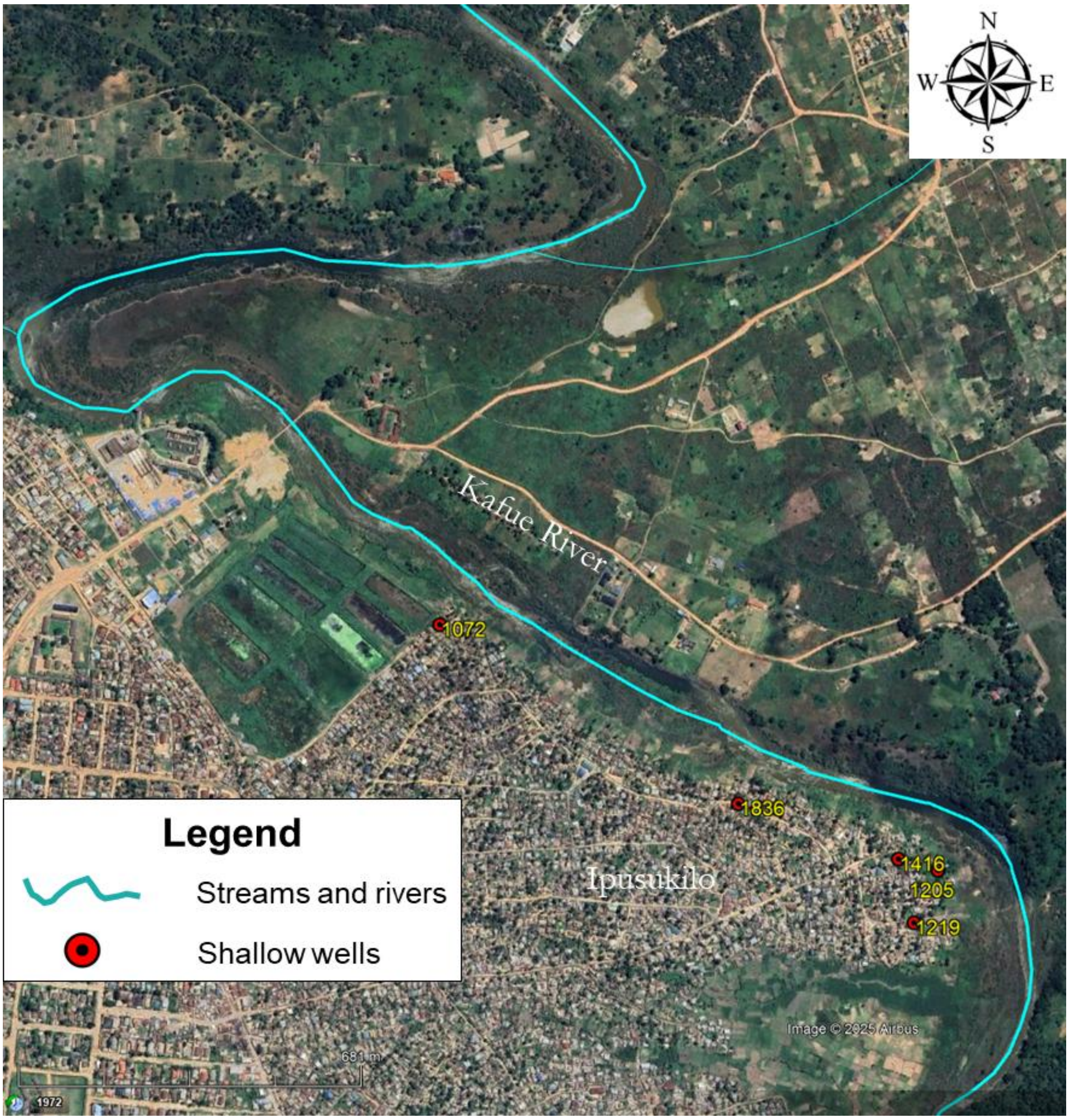


Figure 5-18: Satellite image showing the EC of shallow wells in the Ipusukilo area

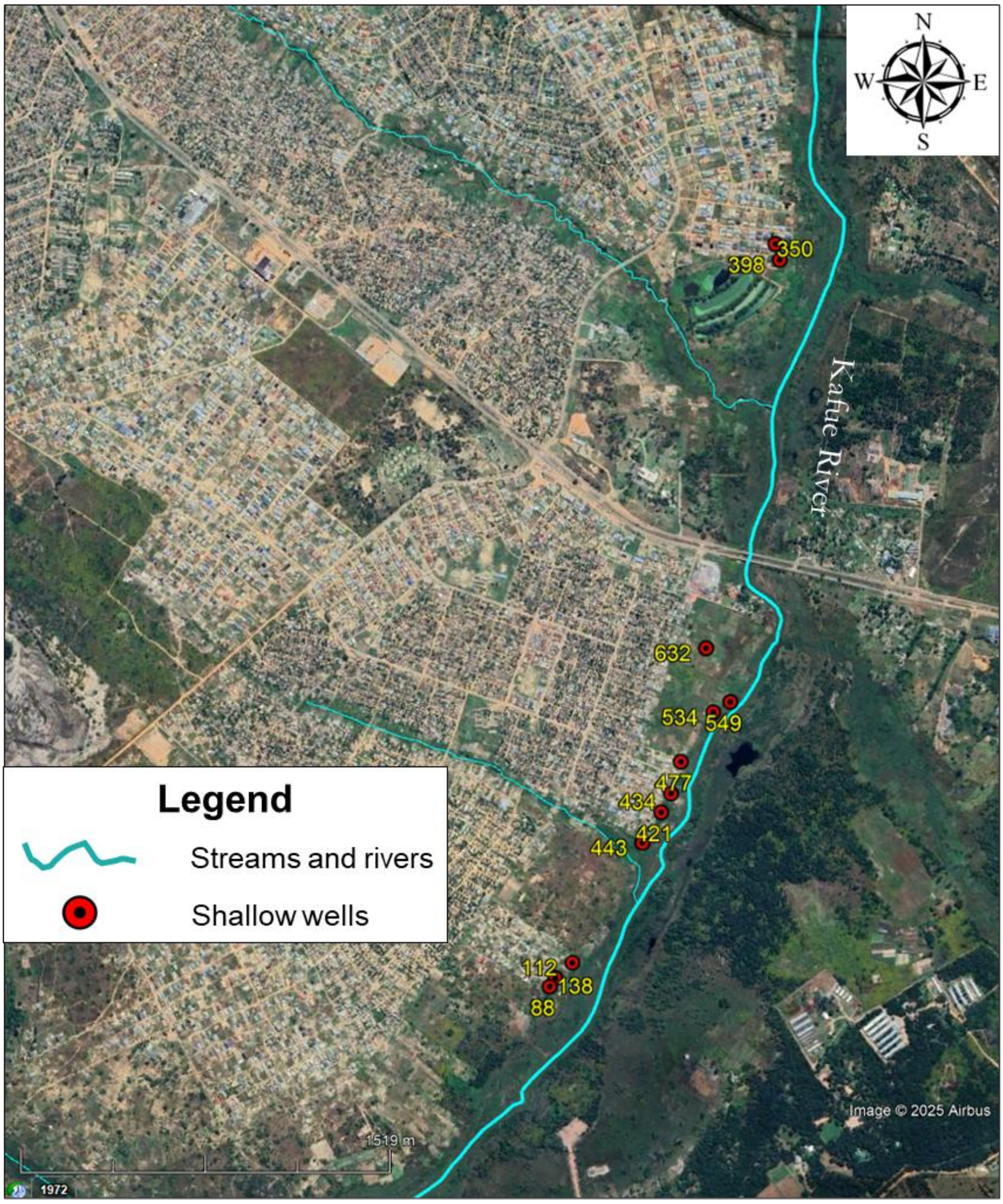


Figure 5-19: Satellite image showing the EC of shallow wells in the Luangwa Township area

3. Sulphates

The concentration of sulphates in the shallow wells in the Kalusale area is illustrated on the satellite image in Figure 5-20. The figure shows that the wells immediately downstream of TD 6 had relatively high concentrations of sulphates (67.3-1,953 mg/L)., indicating groundwater contamination by leachate from TD 6 or Werners Dam. There were no sulphates detected in the wells close to Chambishi Stream (2.4 mg/L) indicating uncontaminated shallow wells.

Figure 5-21 shows that there were no sulphates detected in the shallow wells in the Mwambashi River (2.4 mg/L)

The Ipusukulo/Chiapata compound area (Figure 5-22) shows elevated concentrations of sulphates in shallow wells (107-548 mg/L) while Luangwa Township area (Figure 5-23) shows reduced concentrations of sulphates.

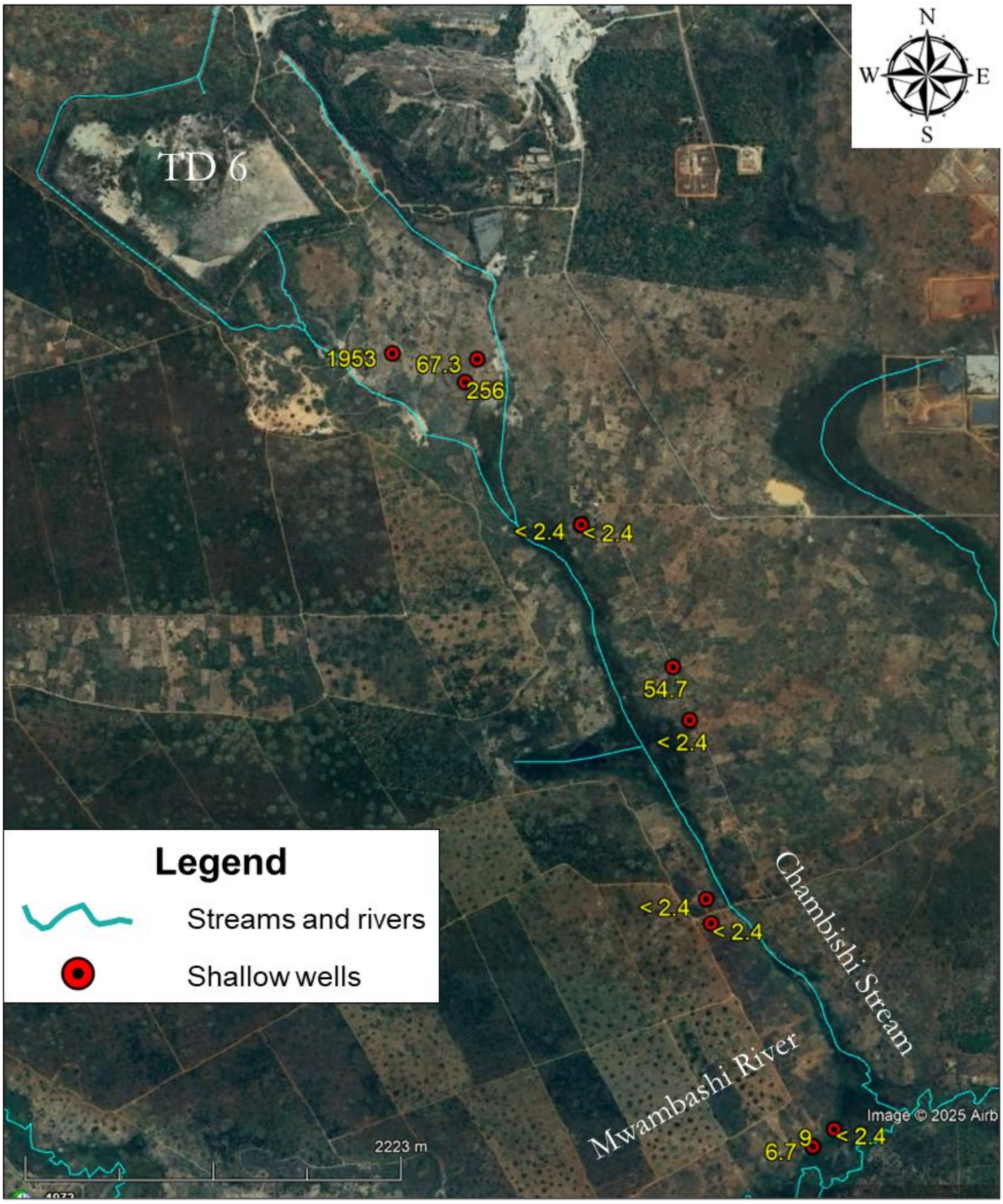


Figure 5-20: Satellite image showing the sulphates in shallow wells in the Kalusale area

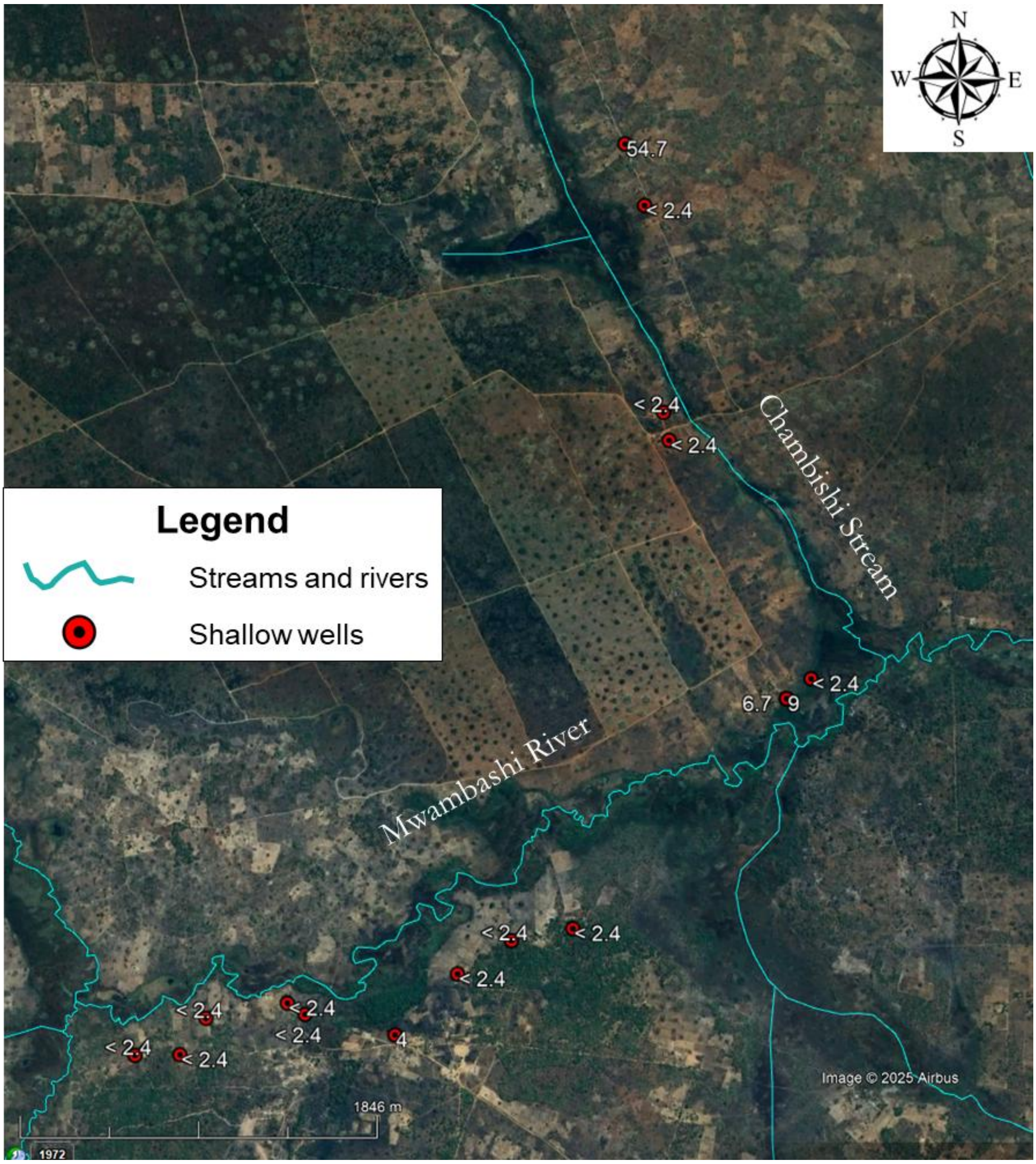


Figure 5-21: Satellite image showing the sulphates in shallow wells in the Mwambashi area

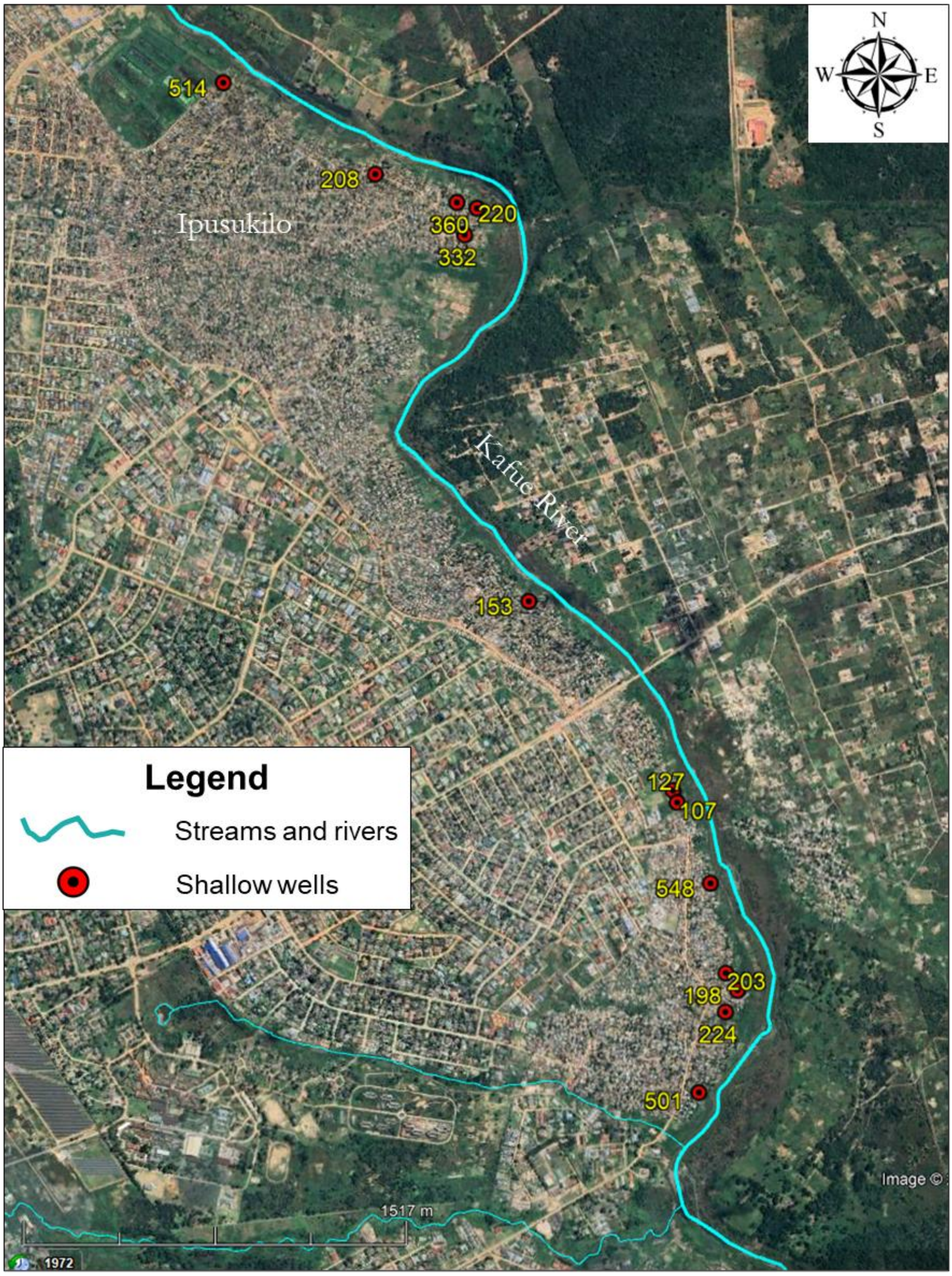


Figure 5-22: Satellite image showing the sulphates in shallow wells in the Ipusukilo/Chipata areas

Figure 5-23: Satellite image showing the concentration of sulphates in shallow wells in the Luangwa Township area

4. Metals

The concentration of metals in groundwater (chromium, copper, nickel, lead, and selenium) was mostly not detected in the shallow wells. Aluminium, cobalt and manganese were detected in some of the shallow wells slightly above the MDL.

5.5.2 Assessment of the impact of the tailings discharge on groundwater water quality

5.5.2.1 Identification of pollution indicator parameters

Based on the analytical results, the key groundwater contamination indicator parameters for the shallow wells are:

1. Electrical conductivity exceeding 100 µS/cm.
2. Sulphate concentration above the Method Detection Limit of 2.4 mg/L.
3. Metals

The pH of groundwater in the shallow wells was generally low even in areas that were far away from the impact zone. Therefore, pH may not be used as an indicator of groundwater pollution in this particular case.

The concentration of metals in groundwater was generally low, i.e., below the Method Detection Limit. Consequently, the presence of metals is an indicator of groundwater pollution.

5.5.2.2 Spatial extent of groundwater contamination

The analytical results show that none of the shallow wells monitored were impacted by the tailings discharge. The conclusion is based on the analysis of the key groundwater pollution indicators and is supported by groundwater flow direction. It has been determined that the flow of groundwater, and hence the transport of pollutants, is from the direction of the shallow wells to the streams and rivers. The presence of metals in some of the wells in the Kalusale area has been attributed to the leaching of the subsoil by the low pH groundwater.

Contamination of groundwater was identified in the shallow wells immediately downstream of TD 6. The contamination was indicated by elevated EC and sulphates in the affected shallow wells. The flow direction of groundwater indicates that the contamination detected in the shallow wells immediately downstream of the TD 6 is a result of leachate from either TD 6 or the nearby Werners Dam.

A study by von der Heyden14of groundwater pollution from Werner's Dam, a decommissioned tailings impoundment which is adjacent to TD 6, found evidence of groundwater pollution from the facility. The groundwater pollution was in the form of a high-solute groundwater plume extending downgradient from Werner's Dam. The study found elevated concentrations of iron, manganese, cobalt, nickel and zinc in the plume background groundwater concentrations.

The presence of sulphates in the shallow wells in Bulangilio/Ipusukilo and Luangwa areas above the Method Detection Limit of 2.4 mg/L has been attributed to sewage contamination from pit latrines, septic tanks and soak aways.

5.5.2.3 Impact on surface water

The analytical results of Chambishi Stream show elevated electrical conductivity (2,068 µS/cm) and sulphates (1,274 mg/L) at the source of the stream. These elevated results point to a polluted groundwater source recharging the stream. The hydrogeological analysis shows that the Chambishi Stream is influenced by groundwater from Werner’s Dam. Consequently, it is determined that the groundwater discharged from Werner’s Dam was responsible for the high sulphates and electrical conductivity measured in Chambishi Stream. Werner’s Dam, in turn, contains historical tailings and possibly liquor from the incident under investigation. The hypothesis is that when the tailings slurry that was deposited in Werner’s Dam, some liquor infiltrated the ground and is now being discharged to the surface as Chambishi Stream.

5.6 Appendix

Appendix 5-1: Groundwater coordinates and elevations of shallow wells in the Kalusale area

Appendix 5-2: Analytical results of tailings solids

Appendix 5-3: Analytical results of shallow wells groundwater

[14] von der Heyden C.J., New M.G., 2003. Groundwater pollution on the Zambian Copperbelt: deciphering the source and the risk

6 ASSESSMENT OF THE IMPACT ON SOIL

6.1 Assessment context

This soil assessment component of the ESIIA, focuses on defining the spatial extent, concentration, and behaviour of contaminants within soils surrounding TD 15 and along the downstream transport corridors. The assessment recognizes soil as a critical subordinated reservoir and transmission medium for contaminants due to sedimentation, overbank flooding, infiltration, and wind dispersal processes. By characterizing both vertical and lateral contaminant distributions, this component provides essential evidence for remediation planning, risk assessment, and ecological restoration of affected landscapes.

6.1.1 Site location and setting

The Sino-Metals Leach Zambia Limited (Sino-Metals) tailings management complex, including Tailings Dam No. 15 (TD 15), is situated in the Chambishi area of Kalulushi District, within Zambia's Copper-belt Province. The site lies approximately 15 km south-west of Kitwe and is positioned within the upper catchments of the Mwambashi River, a key tributary of the Kafue River. The broader area is defined by the geographical coordinate; Latitude, 12.64° S – 12.67° S and Longitude, 28.02° E – 28.05 °E. The dam forms part of an industrial landscape historically associated with metallurgical operations under the former Zambia Consolidated Copper Mines (ZCCM). Adjacent facilities include Chambishi Metals, NFCA Mining PLC, and several legacy tailings and pollution control dams (TD 6, Werner's Dam, and New Dam), all connected through a complex hydrological network.

6.1.2 Topography and drainage

The terrain is characterised by gently undulating slopes that facilitate drainage eastward toward the **Chambishi Stream**, which merges with the **Mwambashi River** before entering the **Kafue River**. The average elevation of the area ranges between 1,250 and 1,280 metres above sea level, with local relief shaped by historical mining and tailings deposition.

The principal flow path of the 18 February 2025 tailings discharge followed this sequence:

1. **Tailings Dam No. 15 (TD 15)** – the point of breach and primary release of acidic tailings.
2. **Tailings Dam No. 6 (TD 6)** – acted as the first sedimentation basin, intercepting coarse tailings material.
3. **Werner's Dam** – a low-lying depression and former wetland where significant sediment deposition occurred.
4. **New Dam** – a regulated discharge point licensed by ZEMA to NFCA and Chambishi Metals, from which effluent enters **Chambishi Stream**.
5. **Chambishi Stream** – the main channel transporting contaminants downstream to the Mwambashi River.
6. **Mwambashi River** – receives contamination from Chambishi Stream, flowing south-eastward into the **Kafue River**.
7. **Kafue River** – contaminants transported from Mwambashi River to Kafue River.
8. **Itezhi-Tezhi Dam** – designated as the most distal assessing sector to facilitate a comprehensive assessment of the Kafue River.

This network defines the natural and anthropogenic drainage corridor along which soil and sediment sampling zones (Areas of Interest – AOIs) were delineated for the soil characterization component.

6.1.3 Climate and hydrological conditions

The area experiences a humid subtropical climate, with a pronounced wet season **from** November to April and a dry season from May to October. Annual rainfall averages between 1,000 and 1,200 mm, while mean annual temperatures range from 17° C to 25 °C**.** Rainfall intensity and seasonal runoff play a key role in contaminant transport through surface flow, infiltration, and bank overflow**,** making hydrological timing a critical factor in assessing contaminant redistribution in soils and sediments.

6.1.4 Soils and land use

The soils of the Chambishi–Mwambashi basin are predominantly Ferralsols and Acrisols, characterized by moderate to low natural fertility and high iron and aluminum oxides. The soils' clayey texture and cation exchange capacity influence their potential to adsorb and retain heavy metals from tailings discharge. Land use is mixed, comprising industrial mining operations, subsistence and commercial agriculture, and riparian vegetation zones. Many communities depend on the Mwambashi and Kafue River systems for water supply, irrigation, and fishing—activities that have been adversely affected by the spill.

6.1.5 Defined Areas of Interest (AOIs) for soil sampling

To capture the spatial variability of contamination, four Areas of Interest (AOIs) were delineated based on hydrological connectivity, drainage flow, and land use (Table 6-1).

Table 6-1: Summary of AOIs, approximate size km^2 and key characteristics

AOI Code	Description	Approx. area (km^2)	Key characteristics
AOI-TD	Zone surrounding Tailings Dam 15 (primary contamination source)	7.5	High-intensity sampling zone to determine pollutant profile at source.
AOI-CW	Chambishi Stream sub-catchment	31.9	Captures transport and lateral diffusion of contaminants in the stream corridor.
AOI-MW	Mwambashi River watershed	181	Defines subordinated dispersion zone with agricultural and ecological exposure.
AOI-KF	Kafue River buffer zone (up to Itezhi-Tezhi Dam)	4341	Represents potential far-field deposition and cumulative contaminant impacts.

These AOIs collectively provide a spatially representative framework for evaluating contaminant transport, deposition, and persistence within the terrestrial environment.

6.1.6 Environmental Sensitivity and Receptors

Sensitive receptors within and downstream of the AOIs include:

1. Surface water bodies supporting domestic, industrial, and agricultural use.
2. Soil systems acting as both sinks and potential sources of contamination.
3. Aquatic ecosystems (Chambishi Stream, Mwambashi and Kafue Rivers).
4. Riparian agriculture and household gardens dependent on streambank soils and water.
5. Human populations utilizing water and land resources within the impacted corridor.

The interplay between hydrology, land use, and pollutant behavior underscores the need for integrated soil–water–ecosystem assessment to guide remediation and restoration strategies.

6.2 Methodology

6.2.1 Desk review

The predominant soil type in the Chambishi and Mwambashi water is the Ferralsols and Acrisols that are predominately high in Aluminium (Al) and Iron (Fe) oxide content. These soils are inherently having a low pH and making them acidic and this may cause mobilization of the heavy metals. Both the Ferralsols and Acrisols have low fertility levels making them unable to support plant growth when affected by pollutants.

The main land use type for the Chambishi and Mwambashi catchment is scale farming and commercial activities mainly in mining. Most smallholder farmers cultivate rain fed crops such as maize, groundnuts, sweet potatoes and sugar cane, while a number of them also established small irrigation areas using diesel or electric powered pumps to abstract water from Chambishi and Mwambashi streams that traverse the area joining Kafue River. Mostly, vegetables are grown under irrigation in the dry season. It is therefore important to understand that any human activity upstream has a significant impact on the Kafue River ecosystems and the food chain.

The Ministry of agriculture working with other government agencies conducted an environmental input assessment in the first quarter of 2025. Their main findings were that soils are generally acidic in the farmlands along the Chambishi Stream. There was an acidifying effect resulting from the effluent from the dam. Some heavy metals found in soil samples were higher than the allowable limits, hence indicating a possible pollution of Copper (822/mg/kg) and Cobalt (302 mg/kg) on average, while the permissible levels by WHO/FAO are respectively Copper (100 mg/kg), and Cobalt (50 mg/kg).dry season. Whereas the Ministry of agriculture used a random sampling method in their study, the current study used a Purposive grid sample in order to come up with an in depth understanding of the effect of the discharge on the soils and the environment. The report by the Ministry of agriculture recommended that Sino-Metals conduct neutralization of the fields affected by the discharge and undertake the restoration of the ecosystems.

6.2.2 Study design and sampling framework

The soil assessment was guided by a structured Design and Sampling Framework developed to characterize contamination levels and establish a scientifically defensible basis for land restoration interventions. The framework centered on four Areas of Interest (AOIs) identified as priority zones based on their proximity to pollution sources, potential contamination pathways, and ecological sensitivity. These AOIs included Tailings Dam 15 (TD 15)**,** the Chambishi Watershed, the Mwambashi Watershed, and the Kafue River Buffer Zone**.**

6.2.2.1 Conceptual Basis and Objectives

The design was informed by a conceptual site model (CSM) that considered contaminant transport pathways (surface runoff, wind dispersion, seepage), exposure receptors, and land-use characteristics within the AOIs. The primary objectives of the design were to:

1. Establish the spatial distribution and concentration gradients of contaminants in soils.
2. Identify hotspots of contamination and potential zones of ecological impairment.
3. Generate baseline data for comparison with reference/background conditions.
4. Provide empirical evidence to guide remediation, restoration, and long-term monitoring.

6.2.2.2 Sampling Strategy and Layout

A stratified, georeferenced sampling approach was adopted to ensure representativeness of soil conditions within each AOI. The AOIs were divided into sampling strata based on landform, hydrological flow direction, and vegetation cover. Within each stratum, sampling locations were selected using a combination of:

1. Grid-based sampling for uniform spatial coverage,
2. Purposive sampling at suspected hotspot areas (e.g., tailings footprints, drainage channels),
3. Transect-based sampling across contamination pathways within the watersheds and towards the Kafue River.

All sampling points were recorded using GPS to facilitate mapping, repeatability, and integration into the GIS-based ESIIA spatial analysis system.

6.2.2.3 Sampling Depths and Soil properties

To capture vertical contaminant distribution, soil samples were collected at standard depths of 0–10 cm and 10–30 cm. Soil properties of interest included soil texture, soil pH, and electrical conductivity.

6.2.2.4 Quality Assurance and Control

The sampling framework incorporated strict QA/QC measures including:

1. Decontamination of tools between sampling points,
2. Chain-of-custody documentation,
3. Use of certified sample containers and appropriate preservation methods.

6.2.2.5 Coverage of the four AOIs

1. AOI 1: Tailings Dam 15 (TD 15)

The TD 15 AREA focused on areas with direct deposition, flow and seepage pathways. Dense sampling grids were placed around the dam zone and downstream drainage lines.

2. AOI 2: Chambishi Watershed

The sampling followed surface water flow paths downstream of TD 15 to capture potential transport of contaminants through soils in agricultural and semi-natural landscapes.

3. AOI 3: Mwambashi Watershed

The soil sampling was designed to assess cross-basin contaminant influence, with transects positioned perpendicular to flow paths and in zones of sediment accumulation.

4. AOI 4: Kafue River Buffer Zone (KRBZ)

Targeted to understand the terminal deposition of transported sediments and potential risks to riparian ecosystems and aquatic-reliant livelihoods.

6.2.3 Soil sampling plan and georeferencing

The soil sampling plan for the soil assessment was developed to ensure systematic, spatially representative, and scientifically unassailable characterization of soil conditions across the four Areas of Interest (AOIs): TD 15, the Chambishi Watershed, the Mwambashi Watershed, and the Kafue River Buffer Zone. For each AOI, georeferenced sampling points were established using handheld GPS units support accurate mapping, and spatial analysis of contamination patterns. The Chambishi catchment (Figure 6-1) shows the source of contamination of the 18 February incident.

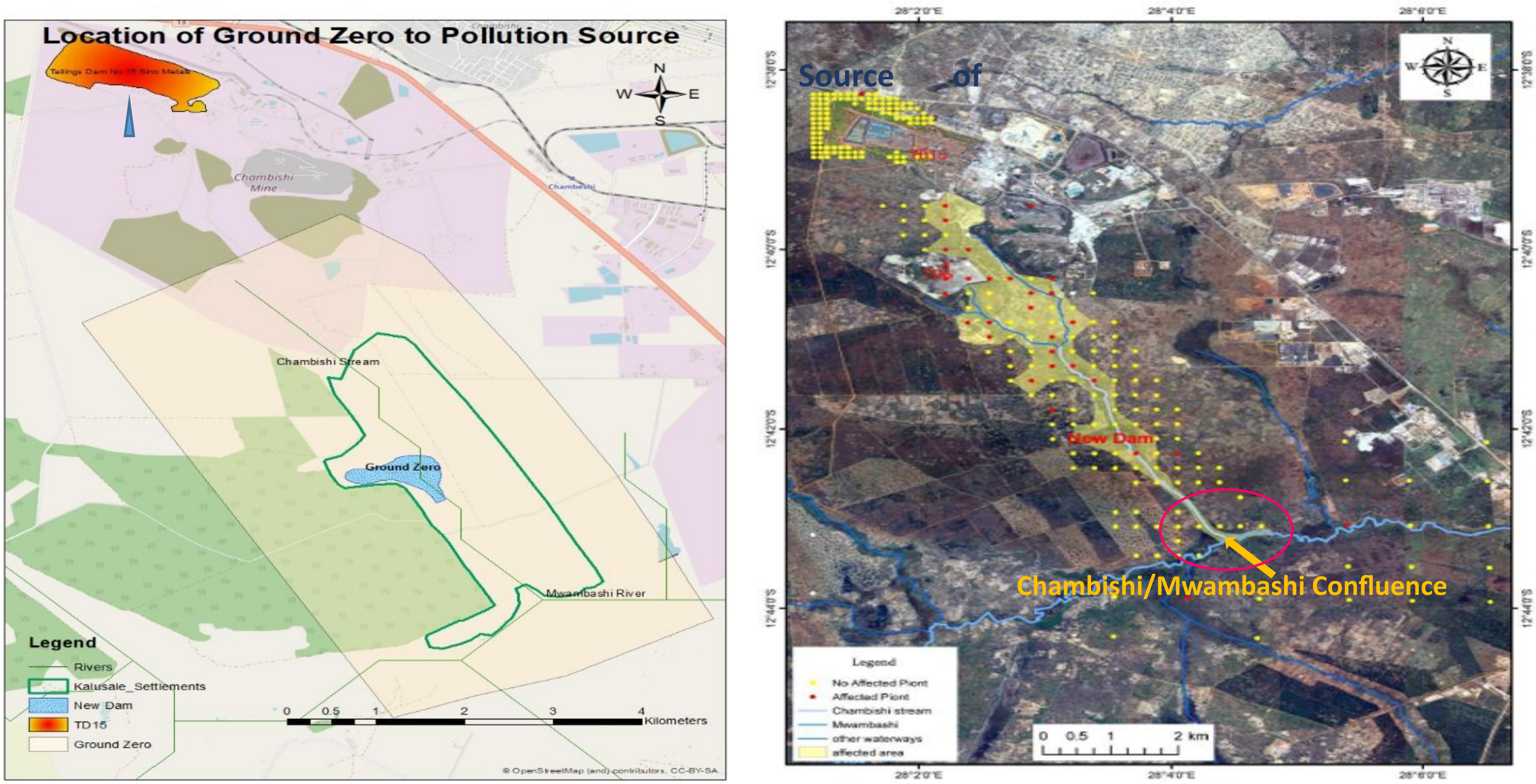


Figure 6-1 TD-15 and Chambishi /Mwambashi Confluence

The sampling plan for each AOI reflects a combination of grid-based**,** transect-based, and targeted hotspot sampling approaches, depending on the geomorphology, land use, hydrological pathways, and the likelihood of tailings dispersion. The maps presented in this section illustrate the spatial distribution of all sampling locations, their georeferenced coordinates, and the major environmental features influencing sampling design (e.g., drainage lines, depressions, access routes, and tailings infrastructure).

All sampling locations were assigned unique identification codes and recorded in a GIS database to ensure consistent tracking of samples from field collection through laboratory analysis. These geospatial datasets provide the foundation for subsequent contamination mapping, interpolation, and risk interpretation under the ESIIA.

The sampling method used was essentially a mix of fixed predetermined grid and random selection of points according to the specific target area of assessment. These areas specific areas were categorised by the deemed potential or vulnerability to the contamination of the incident.

6.2.3.1 The tailings dam 15 potential pollution assessment area

This is the area around the tailings dam which was the point source of the run off; the surrounding environment was sampled to assess the likely affect to the surrounding environment. This area was deemed to be the likely source of contamination to the downstream as well as the lower ground areas by water and wind.

ESIIA sampling: this area was thoroughly sampled at a fixed grid of 100 x 100 meters. Note that some sampling points were in inappropriate sites and as such the surveyors assessed the inability of such site to contribute to the targeted objective and therefore were not sampled.

Control sampling: further sample sites were allocated around the tailings dam but further away from the dam to assess the like contents of the soils around the tailings dam without the incident of the pollution. This would allow the understanding of the would be content of the soils in the natural environment either without human intervention related to the current mine incident or with previous and historical mine activities.

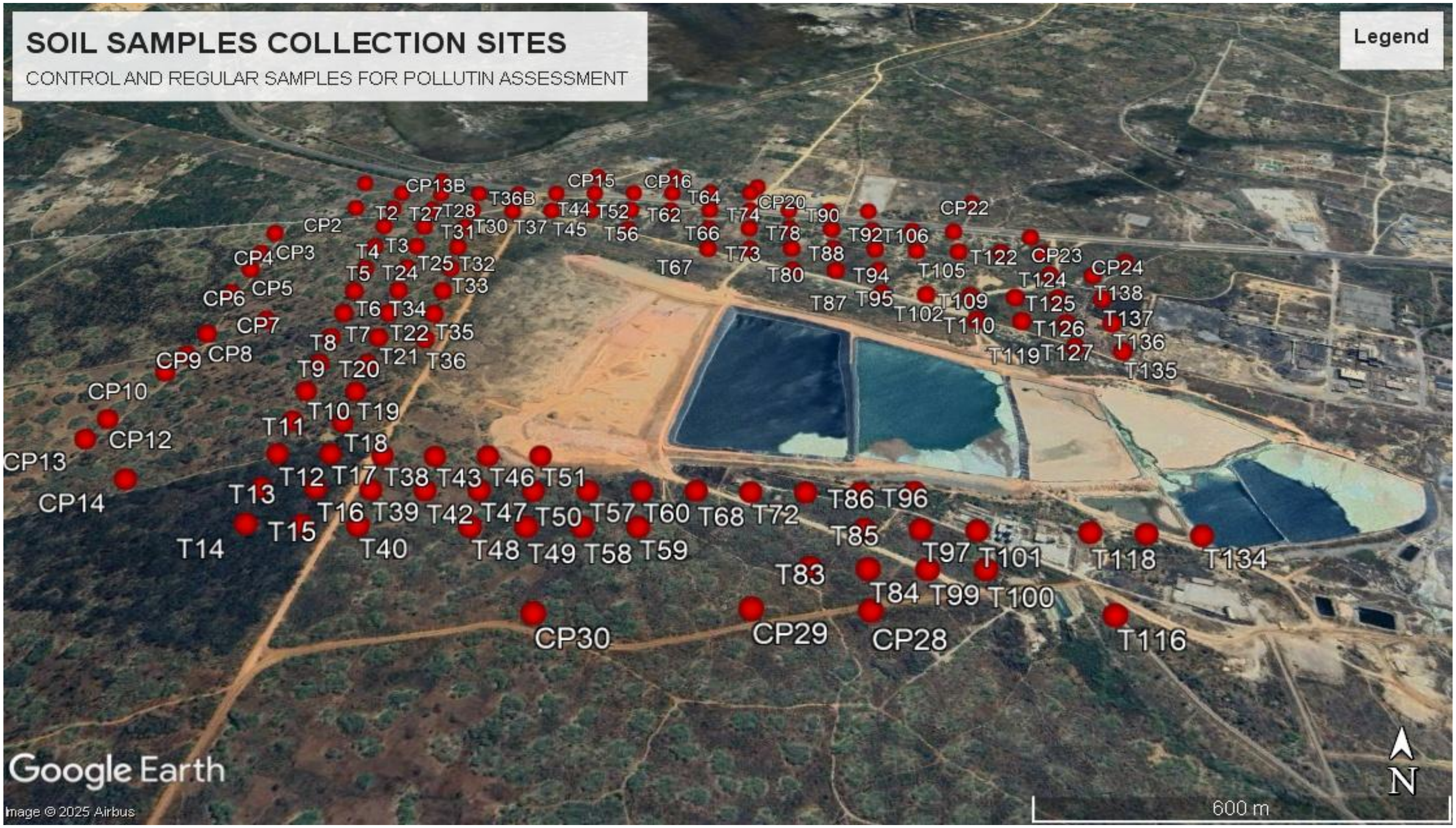


Figure 6.2 Soil Samples Collection Site

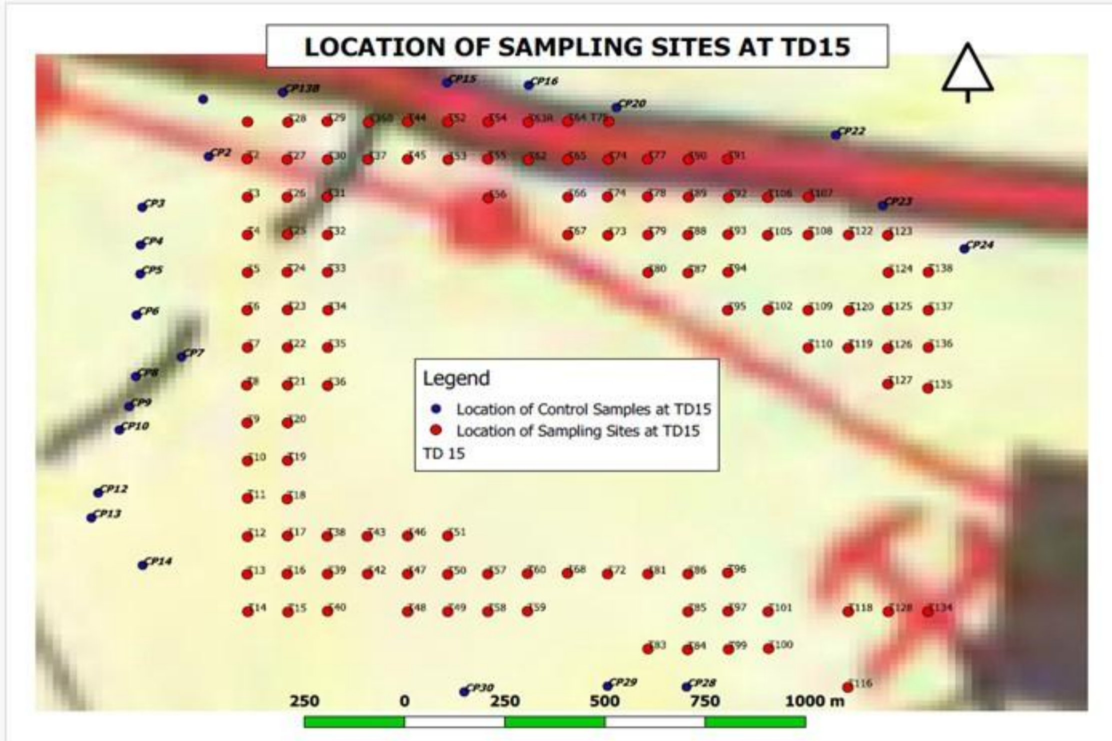


Figure 6-3: Georeferenced Soil Sampling Plan for Tailings Dam 15 (TD 15)

6.2.3.2 Chambishi catchment area

This was the area around the drain from the below tailings dam to the Chambishi and Mwambashi confluence. This catchment area was the immediate recipient of the overflow which directly affected the people residing and farming in the area.

In this area, three categories of samples were collected to answer specific environmental queries.

ESIIA sampling: sample sites were predetermined in a fixed grid system of 300 x 300m spatial spacing to thoroughly assess the current impact of the contamination in the catchment area.

Control sampling: samples were collected further away from the impact or active passage zone of the contamination flow to assess the inherent or natural content of the soils without the impact of the current incident. This would also suggest the potential impact from previous and historical influence of the mining activities.

Targeted sampling: these sites were included to first of all assess the trends of contamination along the stream from the time the incident happened in February to the current status over the period of time. This area was deemed to be the epicenter of the runoff from the tailings dam and therefore needed to be assessed in great detail. Sites were earlier sampled a few days after the incidents and analysed to be contaminated with some heavy metal elements. The purpose of this current survey was to compare in the same sites the current status of the soils. In addition, some special sites were randomly targeted in the field either because of the extra observed impacts and due to their strategic location in relation to the significant impacted areas.

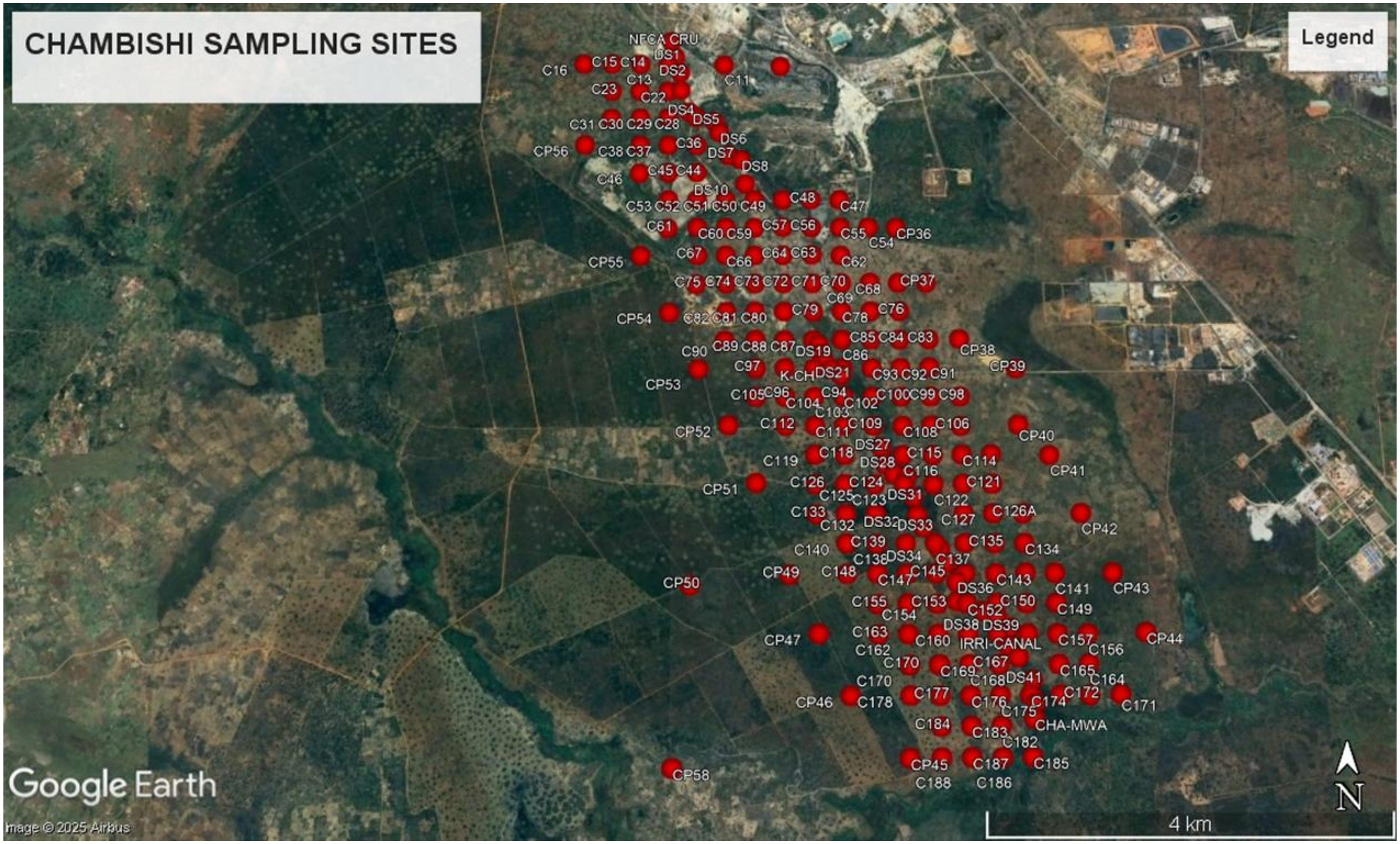


Figure 6–4: Georeferenced Soil Sampling Plan for the Chambishi Watershed

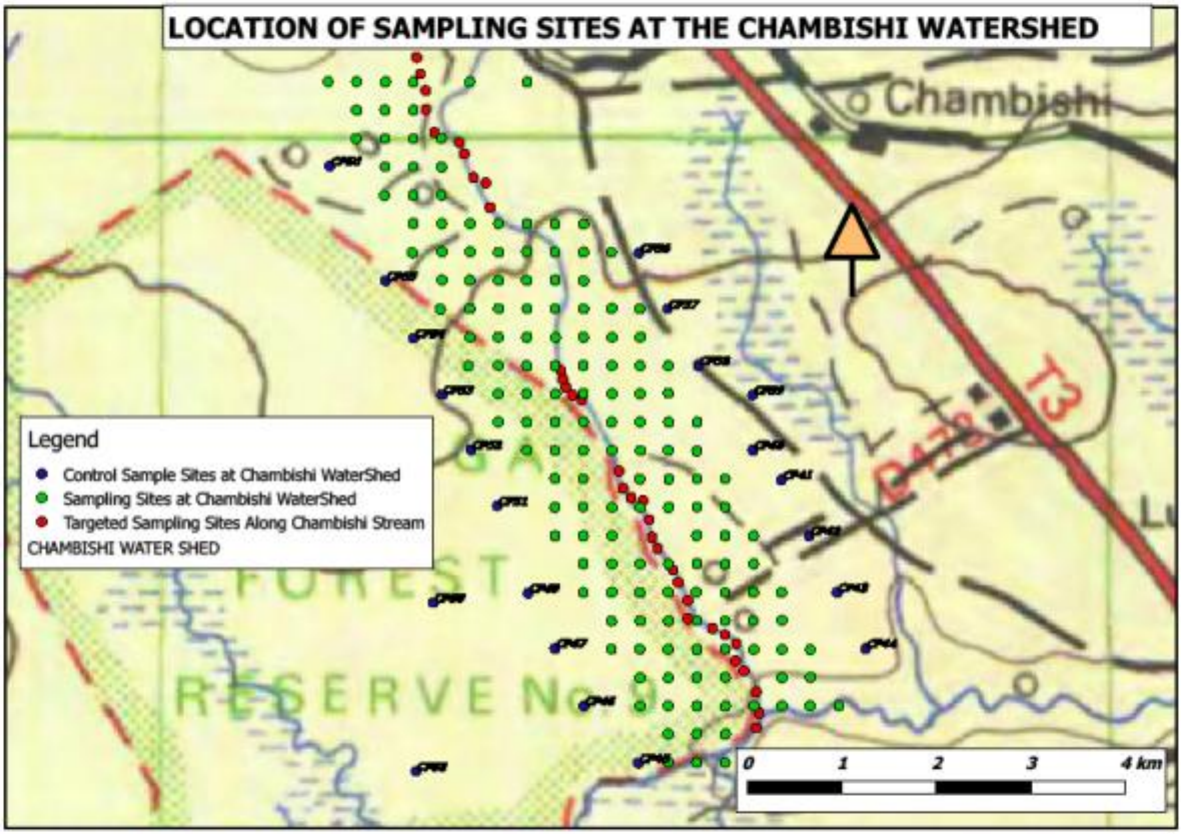


Figure 6–5: Georeferenced Soil Sampling Plan for the Chambishi Watershed

6.2.3.3 Mwambashi to Kafue River catchment area

This is the 2 kilometer wide on either side of the Mwambashi Stream up to the confluence with the Kafue River. In this area are a number of farms legally settled in this area and using the water from the Mwambashi Stream for irrigation of crops by pumps and hand methods. The soils around this area were to be assessed and determine their status as regards the likely effect from the incident as well as their inherent conditions. Therefore, three categories of samples were collected, which included:

1. ESIIA samples spaced at 750 x 750 m
2. Control samples randomly selected further away from the catchment are
3. Verification samples: these samples were collected in the upstream of the Chambishi-Mwambashi confluence and the upstream of an unmarked stream from active industrial sites unrelated to the Sino-Metals mining activities but are in contact with the Mwambashi Stream. This would allow assessing whether there are other potential sources of pollution.

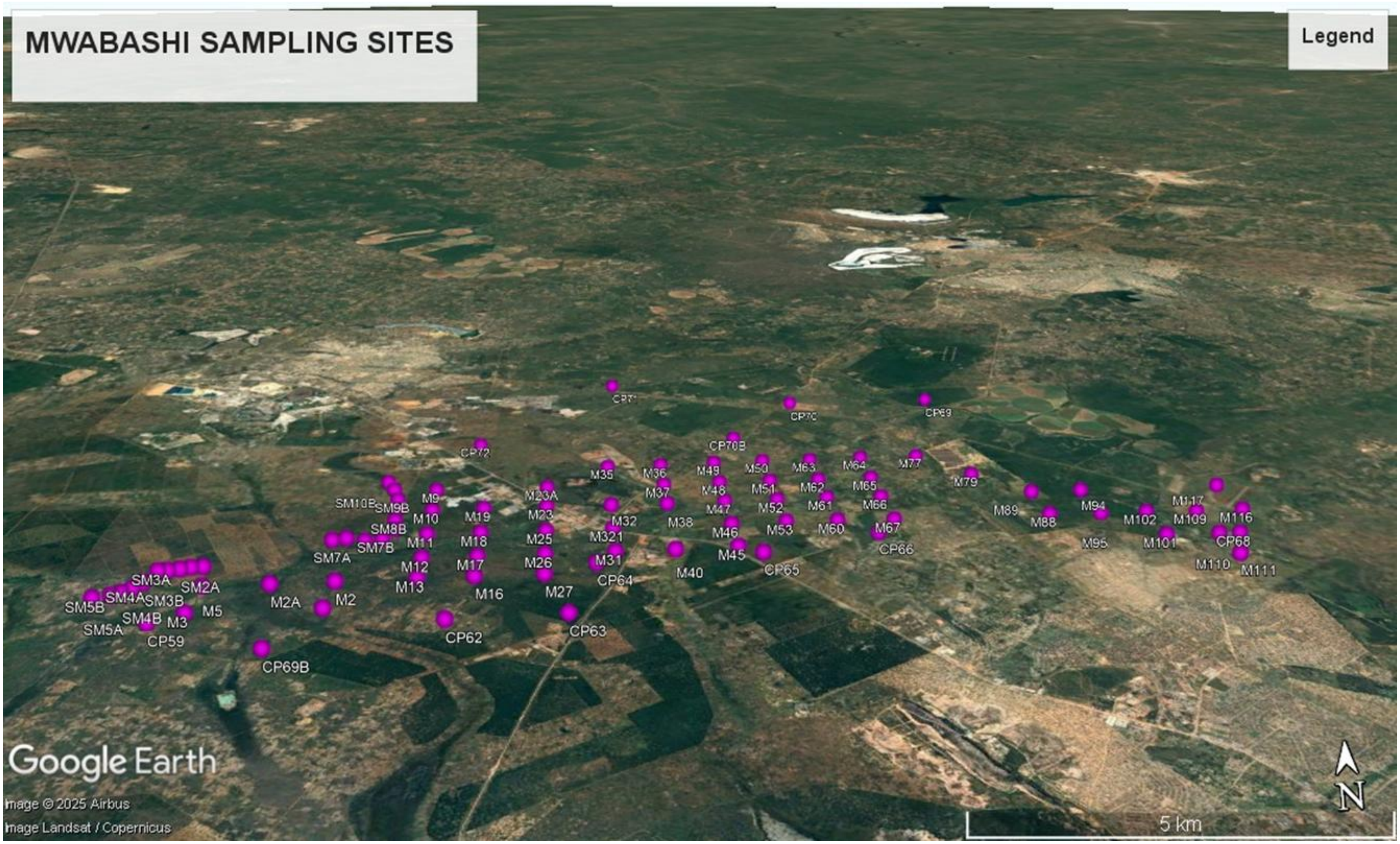


Figure 6–6: Georeferenced Soil Sampling Plan for the Chambishi Watershed

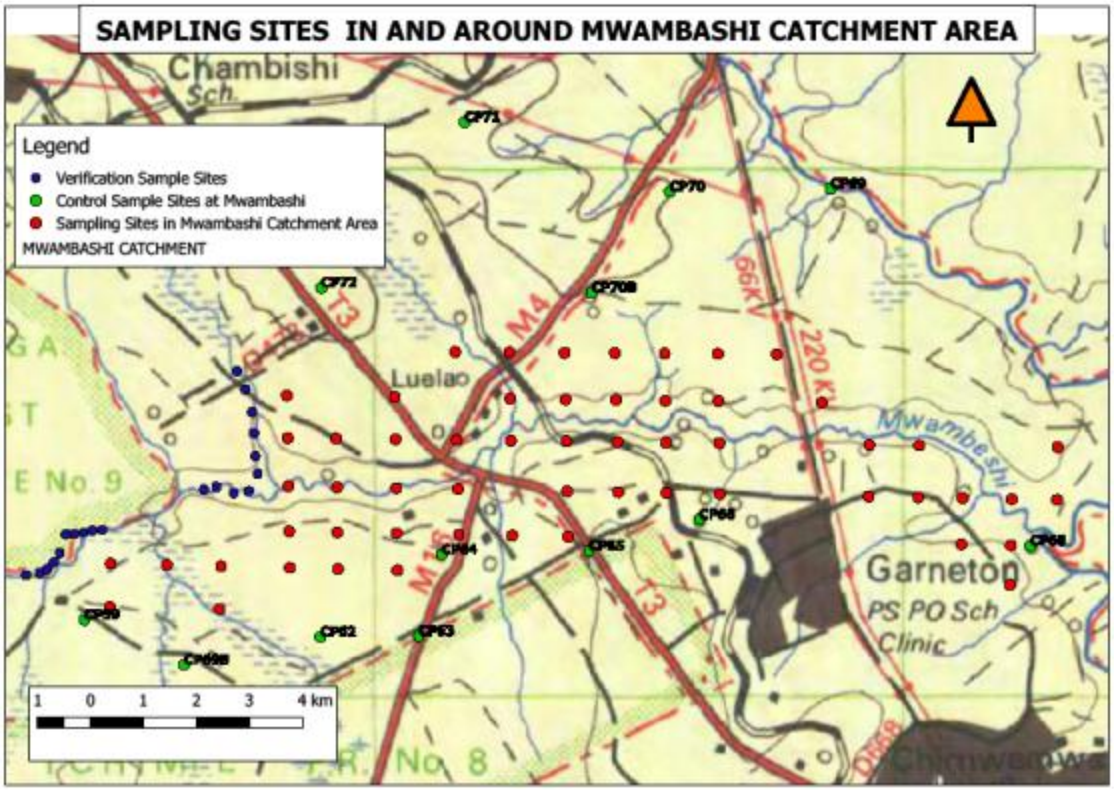


Figure 6–7: Georeferenced Soil Sampling Plan for the Mwambashi Watershed

6.2.3.4 Kafue buffer zone

The Kafue buffer zone is the area from the Mwambashi river-Kafue River confluence to lake Itezhi-Tezhi in Itezhi-Tezhi district. This sampling would enable stakeholders to assess if there has been any wide effect in the long term to the catchment area. The sampling points were randomly selected with close spacing in Kitwe which is nearer to the source of pollution and wider spacing were used as you go further to Itezhi-Tezhi. The total sampling sites were 19 in total and each district where the Kafue River passes had at least two sites thoroughly sampled, one before the Kafue passes the Town and another after the town. This would enable us to check if there is any potential pollution coming from within a particular town.

At each site, seven sub sites were chosen across the river where these sites were spaced in a stretch of at least 1.5 kilometers from one end to the other. The further most sites from the river acted as control samples.

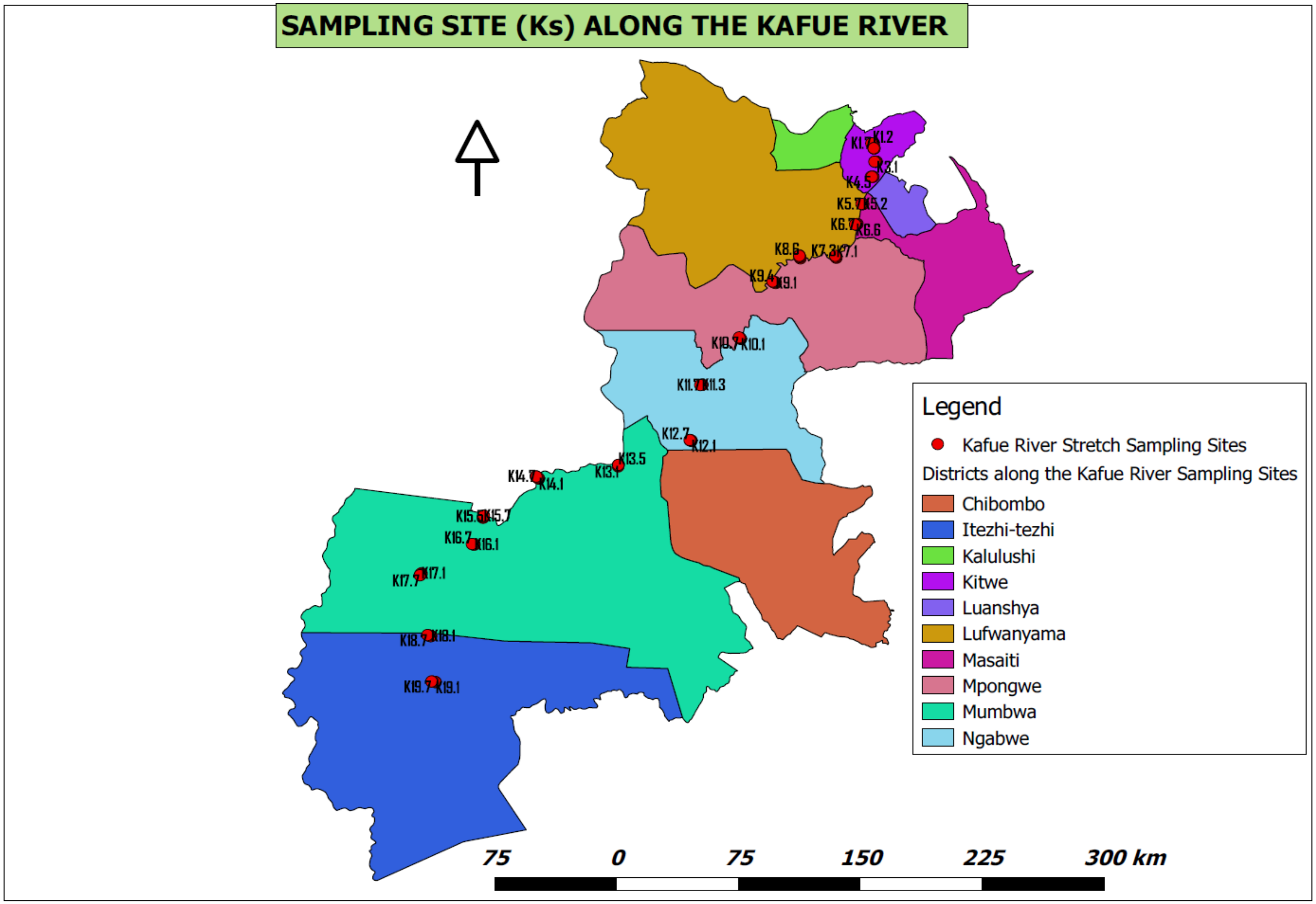


Figure 6–8: Georeferenced Soil Sampling Plan for the Kafue Buffer Zone,

6.2.3.5 Sampling summary

Summary of the distribution of the actual samples collected during the sampling exercise and analysed at Alfred Knight Laboratory as shown in Table 6-2 below.

Table 6-2: Summary of the soil samples distribution

No.	Sampling site	Number of samples
1	TD 15	221
2	TD 15 control samples	41
3	Chambishi Stream samples (c)	302
4	Chambishi Stream control samples	31
5	Targeted samples	121
6	Mwambashi catchment samples (m)	100
7	Mwambashi control samples (sm)	21
8	Verification sample	39
9	Kafue buffer zone samples (k)	241
10	Kafue control samples	71
Total number of soil samples collected		**1,188**

6.2.4 Field sampling procedures

A sampling plot covering 5 m^2, in which soil samples were taken at *at least two sub-locations*. The central location acts as the reference point (R_0) based on allocated GPS coordinates (e.g., T1) and serves as the 1st sub-location. The other sub-location was positioned randomly and within a 5 m^2. Using auger samples were collected from the two sub locations and mixed thoroughly in a bucket to gather a 500-gram composite sample.

6.2.4.1 General precautions

a. Safety and health

The team observed safety precautions when collecting soil samples to ensure the health and safety of individual members of the teams and to prevent introducing any contamination to members of the public. This included the following precautions:

- A comprehensive safety and health training was provided to all team members and other auxiliary staff. The training covered hazard identification, control measures, and proper use of PPE.
- A clean and organised work environment was established while sampling to minimise the risk of accidents and contamination.

- Proper procedures for collecting, storing, and disposing of contaminated materials and waste were implemented.
- Conduct hazard identification and assessment - the team undertook a thorough identification of potential hazards that could have emanated from the breach of the tailings dam and the environmental screening process.
- Evaluated the severity and likelihood of each hazard to determine appropriate control measures.

b. Procedural precautions

The following precautions were taken when collecting soil samples:

- Special care was taken not to contaminate samples which involved storing samples in a secure location to preclude conditions which could alter the properties of the sample. Samples were custody sealed during storage or transportation.
- Protocols were established for safety and traceability of sample movement. Samples were in the custody of the sample custodian until they were relinquished to another party.
- International standards were applied for transportation of hazardous materials when any samples need shipment.
- Documentation of field sampling was done in a traceable field logbook.
- Chain-of-custody documents were filled out and remained with the samples until custody was relinquished.
- All shipping documents, such as air bills, bills of lading, etc., were retained by the project leader in the project files.
- When sampling in landscaped areas, cuttings were placed on plastic sheeting and returned to the borehole upon completion of the sample collection. All 'turf plug' generated during the sampling process was returned to the borehole.
- In non-landscaped areas, unused sample material was returned to the auger, drill or push hole from which the sample was collected.

6.2.4.2 Sampling depth

The depth for the soil samples was 0 - 10 cm and 10 - 30 cm. The depth 0 - 30 cm is the plough depth for agricultural crop lands. This depth has deliberately been chosen to be able to assess contamination in the plough layer. Furthermore, most of the heavy metals are cations as a result they tend to be bound on the cation exchange capacity (CEC) complex on clay particles or soil colloids in the organic matter. On the other hand, most organic contaminants are hydrophobic, tend to be slightly soluble in fatty acids from complexes with organic matter (OM). In most soils in the sub humid tropics, OM is usually rich in the top 0 - 10 cm. Thus, the sampling depth has been split to avoid averaging the concentration of organic contaminants from surface soil which might have higher ranges than those in the lower layers of soil.

6.2.4.3 Records

Field notes were recorded in a bound field logbook, as well as chain-of-custody documentation for the soil samples was generated. Digital field forms were considered to eliminate transcribing errors and for purposes of online data storage.

6.2.4.4 Sample labelling

All sampling points were geo-referenced. The coordinates for the sampling points were uploaded onto GPS devices. Furthermore, bar-codes were generated for labelling all the soil samples. The bar-code bore the critical information for distinguishing each sample, including the coordinates, area, time of sampling, depth, surveyors name etc.

6.2.5 Sample handling, preservation and transport

a. Special precautions for trace contaminant soil sampling

- A clean pair of new, non-powdered, disposable gloves were worn each time a different sample was collected, and the gloves were donned immediately prior to sampling. The gloves did not come in contact with the media being sampled and changed any time during sample collection when their cleanliness was compromised.
- Sample containers with samples suspected of containing high concentrations of contaminants were handled and stored separately.
- All background samples were segregated from obvious high-concentration or waste samples. Sample collection activities were proceeded progressively from the least suspected contaminated area to the most suspected contaminated area. Samples of waste or highly contaminated media were forbidden to be placed in the same ice chest as background samples.
- A specific member of the field sampling team was assigned to take all the notes and photographs, fill out tags, etc., while the other member(s) collected the samples.
- New verified/certified-clean disposable or non-disposable equipment was used when sampling. Sampling tools were cleaned according to procedures contained in the LSASD Operating Procedure for Field Equipment Cleaning and Decontamination (SESDPROC - 205), for collection of samples for trace metals or organic compound analyses (USEPA, 2023).

b. Sample homogenisation

When compositing multiple primary samples in the field, the samples were placed in glass or stainless-steel homogenization containers and mixed thoroughly. An appropriate size aliquot of a composite was obtained for laboratory analysis.

Except for samples for volatile organic compound (VOC) analysis, all other soil samples were thoroughly mixed to ensure that the sample is representative of the sample media. Samples were placed into appropriate, labelled containers (s) by using the alternate shovelling method and secure the seal tightly.

c. Dressing soil surfaces

Any time a vertical or near vertical surface is sampled, such as achieved when shovels or similar devices were used for subsurface sampling, the surface was dressed (scraped) to remove smeared soil. This is necessary to minimize the effects of contaminant migration interference due to smearing of material from other levels.

6.2.6 Laboratory Analytical Plan and Parameters Tested

All the soil samples were submitted to Alfred H. Knight laboratory in Kitwe for analysis. The detailed analytical program is presented in Table 6-3 below.

Table 6-3: List of analytical parameters on the soil samples

Parameter	Full name	Chemical symbol
Physical parameters	pH	pH
	Electrical Conductivity	EC
Heavy Metals	Aluminium	Al
	Arsenic	As
	Cadmium	Cd
	Cobalt	Co
	Chromium	Cr
	Copper	Cu
	Manganese	Mn
	Nickel	Ni
	Lead	Pb
	Zinc	Zn
Cations	Boron	B
	Calcium	Ca
	Magnesium	Mg
	Selenium	Se
Anions	Sulphates	SO_4^{2-}

6.2.7 Quality Assurance and Quality Control (QA/QC) procedures

To ensure data reliability, reproducibility, and compliance with international standards, a rigorous quality control (QC) and quality assurance (QA) framework WAS implemented throughout the sampling and analysis process.

6.2.7.1 Field Quality Control

All equipment calibrated before and after each sampling campaign.

Field blanks, duplicates, and trip blanks used for water and biological tissue samples to detect contamination.

Standard operating procedures (SOPs) followed by all field personnel; staff trained and certified in sampling techniques.

GPS coordinates and timestamps recorded for all samples; digital data sheets used to minimize transcription errors.

6.2.7.2 Laboratory Quality Control:

Samples processed in accredited laboratories with ISO 17025 certification where applicable.

Use of reference materials and participation in inter-laboratory proficiency testing.

Chain-of-custody documentation maintained for all samples

6.2.8 Data management

All data entered into a centralized database (e.g., using PostgreSQL or specialized soil software like SIS or EQuIS).

Data validation checks (range, consistency, missing values) performed prior to analysis.

Metadata fully documented using ISO 28258:2013.

6.3 Soil Texture Desk Review and Analysis

Soil texture is a fundamental control on the spatial distribution, retention, transport, and ecological significance of contaminants in terrestrial environments. Textural properties—defined by the relative proportions of sand, silt, and clay—not only govern the adsorption and desorption dynamics of metals, metalloids, and anions (e.g., sulphates), but also critically influence soil pH buffering capacity, hydraulic conductivity, water retention, preferential flow pathways, plant root accessibility, and the long-term sequestration or mobilization of pollutants. As such, soil texture serves as a primary determinant of contaminant fate and bioavailability across diverse landscapes and land-use contexts.

6.3.1 Soil Texture Desk Review

6.3.1.1 Soil texture and contamination implications – TD 15

6.3.1.1.1 Overview of Soil Textures around TD 15

The TD 15 area, located within the Sino-Metals tailings complex in Chambishi, lies on a gently undulating plateau underlain by quartzite–shale–dolomite sequences characteristic of the Zambian Copperbelt. The natural soils surrounding TD 15 are primarily weathered ferralsols and acrisols, with depositional influences from tailings runoff, aeolian dust, and historical seepage. The predominant textures around TD 15 are:

a. Sandy loam and loamy sand (upland and inter-dam areas)

These textures dominate the natural undisturbed soils surrounding the engineered tailings platforms.

Key characteristics:

- High sand fraction (55–75%)
- Low silt–clay content (10–25%)
- Low organic matter and weak structural stability
- High infiltration rates but low water-holding capacity
- Very low cation exchange capacity (CEC)
- These soils are highly vulnerable to contaminant mobility, particularly for Cu, Co, Zn, Ni, and SO_4^{2-}.

b. Sandy clay loam and clay loam (depressions, runoff concentration zones, and foot slopes)

These occur where tailings effluent, runoff, or sediment deposition have modified natural soils.

Key characteristics:

- Moderate clay (20–35%)
- Higher silt content than uplands
- Greater adsorption capacity
- Greater retention of metals such as Cu, Pb, As, and Mn
- These soils typically form contaminant accumulation zones.

Silt Loam and silty clay loam (drainage channels and riparian areas downstream of TD 15)

Observed around seepage channels, drainage pathways, and sediment traps.

Kay characteristics:

- Higher fine fractions (silt 35–50%; clay 20–30%)
- High Fe-Mn oxide content
- Strong affinity for trace metals

These areas behave as geochemical sinks for pollutants mobilized from the tailings facility.

6.3.1.1.2 Implications of soil texture for contamination dynamics around TD 15

The texture distribution around TD 15 strongly influences the behaviour of contaminants derived from:

1. Tailings dust
2. Seepage water
3. Acidic drainage
4. Storm water runoff carrying particulates

Below are the principal contamination implications associated with each dominant texture.

1. Sandy Loam/loamy sand: High mobility zone

Processes:

- Metals leach rapidly through the soil profile
- Acidic conditions (low pH) increase solubility of Cu, Co, Zn
- SO_4^{2-} is minimally retained → leads to deeper percolation

Implications:

- Risk of groundwater contamination, especially for dissolved metals
- Wider dispersion of contaminants beyond TD 15 footprint
- Low natural attenuation, requiring engineered remediation (liming, organic amendments)

Land use sensitivity:

Any agriculture in these zones is highly vulnerable to metal uptake by crops, particularly leafy vegetables

Settlement areas may face contaminated shallow wells

2. Sandy Clay Loam / Clay Loam: Accumulation and Immobilization Zones

Processes:

- Greater adsorption of Pb, As, Cu, Mn
- Metals accumulate in the top 0–20 cm layer
- Precipitation of metal hydroxides under neutral-to-alkaline micro-environments

Implications:

- Formation of contamination hotspots near runoff channels and foot slopes
- Slow natural recovery due to strong metal retention
- Soil pH modifications can remobilize previously adsorbed metals

Land use sensitivity:

- High-risk soils for livelihoods using irrigation water
- Livestock exposure through grazing is elevated due to surface adherence of metal-rich particles

3. Silt loam/silty clay loam: Riparian sinks and long-term reservoirs

Processes:

- Very high metal adsorption due to fine particles and Fe/Mn oxides
- Preferential trapping of Cu, Co, Pb, Zn, As in suspended sediments

- Periodic remobilization during high-flow events

Implications:

- Downstream ecological impacts through benthic toxicity
- Persistent contamination of wetlands
- Incremental build-up of metals in gardens and smallholder agricultural plots near streams

Land use sensitivity:

- Irrigated fields along these channels show consistently elevated risk
- Water quality impacts persist long after improvements in tailings management

6.3.1.1.3 Integrated land-use and Environmental Risk Assessment for TD 15

Groundwater Vulnerability

- High in sandy loam zones due to:
- Low clay fraction
- Rapid percolation
- Low retention of metals and sulphates

Agricultural Risk

- Moderate to high across all zones, but especially where:
- Sandy soils → high metal mobility
- Clayey depressions → high total metal concentration
- Crop uptake risks are greatest for: Cu, Co, Zn, Mn.

Human Exposure Pathways

- Dust inhalation near tailings
- Consumption of contaminated vegetables
- Use of contaminated shallow groundwater
- Livestock ingestion of contaminated forage

Ecosystem Health

- Riparian soils act as long-term sinks for Cu, Co, Pb, and Zn
- Seasonal remobilization can repeatedly contaminate downstream wetlands
- Soil fauna and microbial functions are impaired by acidity and metal loading

6.3.1.1.4 Conclusions

Table 6-4: Soil texture and contamination implications around TD 15

Dominant Texture	Behaviour	Contaminant impacts	Land use implications
Sandy loam/loamy sand	Low retention; high mobility	Cu, Co, Zn, SO_4 leach downward; acidification	Groundwater contamination; high crop uptake risk
Sandy clay loam/clay loam	Moderate–high adsorption	Contaminant hotspots; persistent elevated metals	Grazing risk; food chain contamination
Silt loam/ Silty Clay Loam	Very high adsorption	Long-term sinks for Cu, Pb, As, Mn	Irrigation water contamination; ecological impacts

The TD 15 environment is characterized by a mosaic of sandy to clayey textures, each presenting different contamination pathways and risks. Sandy textures promote high contaminant mobility, while fine-textured soils act as accumulation zones, creating persistent contamination hotspots. Such spatial patterns require texture-specific remediation, including:

- Liming and organic amendments in sandy zones
- Physical containment or phyto-stabilization in clayey hotspots
- Riparian buffer rehabilitation
- Controlled land-use planning around contaminated footprints

This textural–contamination interaction forms a critical basis for designing effective land restoration, risk mitigation, and community safety interventions around TD 15.

6.3.1.2 Soil texture and contamination implications – Chambishi catchment area

The Chambishi–Mwambashi system is underlain by soils derived from shale–quartzite–dolomite lithological sequences typical of the Copperbelt and exhibits a mosaic of sandy loam, loamy sand, silt loam, silty clay loam, and clay loam textures depending on the landscape position (UNZA Soil Survey, 1974; JICA, 1995; Musonda et al., 2020).

6.3.1.2.1 Predominant Soil Textures in the Chambishi Watershed

1. Upland and interfluve areas — sandy loam/loamy sand

These soils are dominated by quartz-rich sand fractions and exhibit:

- Low cation exchange capacity (CEC)

- High permeability
- Weak structure and low organic matter

Such characteristics predispose upland soils to rapid downward leaching of Cu, Co, Zn, SO_4^{2-} and associated acidity, reducing their ability to immobilize contaminants (Kabata-Pendias & Pendias, 2011).

2. Mid-slope and pediment zones — sandy clay loam

Intermediate textures with moderate clay content show:

- Improved metal adsorption capacity
- Greater resistance to contaminant mobility compared to sandy soils
- Potential for mixed responses depending on pH and redox state

3. Riparian corridors — silt loam to silty clay loam

Riverine and floodplain soils accumulate fine particles enriched with Fe-Mn oxides, resulting in:

- High metal adsorption potential
- Long-term storage of Cu, Co, Pb, Zn, and As
- Formation of contaminant hotspots along the Mwambashi and Chambishi Rivers

These act as natural geochemical sinks, trapping sediments transported from upstream tailings infrastructure and smelter-related dust fallout (ZEMA, 2021; Mwitwa et al., 2019).

4. Wetlands and depressions — clay loam to clay

Fine-textured soils exhibit:

- Highest adsorption of metals
- Lowest permeability
- Potential for metal remobilisation under reducing (anaerobic) conditions, particularly Mn, Fe, and sorbed trace elements (Alloway, 2013)

6.3.1.2.2 Relation between soil texture and contaminant distribution

1. Sandy Loam / Loamy Sand Zones

- Exhibit lower absolute metal concentrations but higher mobility.
- Tend to show acidic pH, enhancing metal solubility.

- Elevated SO_4^{2-} concentrations in these textures suggest ongoing sulphide oxidation and leaching.

Implication:

Increased risk of **groundwater contamination**, wider dispersion of metals, and lower capacity for natural attenuation.

2. Silt Loam to Silty Clay Loam (Riparian Zones)

- Show highest Cu, Co, Pb, Zn, and As accumulation, consistent with sediment deposition and high clay plus Fe/Mn oxide content.
- Elevated EC reflects concentration of dissolved salts associated with AMD-impacted waters.

Implication:

Riparian zones serve as long-term contaminant reservoirs, creating ecological exposure risks for benthic organisms, livestock watering areas, and gardens irrigated with river water.

3. **Clay and Clay Loam (Wetlands)**

- Metals strongly adsorb to clays, but redox-driven remobilization may occur seasonally.
- Mn and Fe often peak in these areas, reflecting reductive dissolution.

Implication:

Potential episodic release of metals into wetland waters, affecting downstream aquatic systems.

6.3.1.2.3 Implications for Land Use and Environmental Risk

1. **Agriculture**

Sandy loam soils widely used for crop production around Chambishi show:

- Increased metal bioavailability due to low CEC and acidic conditions
- Potential for plant uptake of Cu, Co, Zn, and transfer into the food chain (FAO, 2017)
- Riparian vegetable gardens on silty/clayey soils face:
- Risk of high metal loading in soils and irrigation water
- Chronic crop contamination where Cu and Pb exceed international guidelines

2. **Water resources**

Sandy textures: rapid leaching → shallow aquifers vulnerable

Clay/silt textures: bank storage of metals → long-term secondary pollution source

3. **Ecosystem health**

- Sediment-bound Cu, Co, Pb accumulate in fine-textured riparian soils → effects on microbial activity, invertebrates, and riparian vegetation
- Acidic, sulphate-rich sandy soils impair soil fauna and slow natural rehabilitation processes

6.3.1.2.4 Management implications

Table 6-5: Summary of predominant textures and associated contamination risk

Landscape position	Dominant texture	Contaminant behaviour	Risk level

Uplands	Sandy loam / loamy sand	Low adsorption; high mobility	High (Groundwater)
Mid-slopes	Sandy clay loam	Moderate adsorption	Moderate
Riparian zones	Silt loam / silty clay loam	High adsorption; metal sinks	High (Ecological + food chain)
Wetlands	Clay loam / clay	Strong adsorption; redox remobilization	Moderate–High

Based on texture–contamination interactions, the watershed requires:

Targeted remediation

Sandy zones → liming, organic amendments

Riparian clay-rich hotspots → containment, phyto-stabilization

Land-use zoning based on contamination risk maps

Protection of groundwater abstraction zones in sandy landscapes

Rehabilitation of contaminated riparian corridors to reduce sediment-bound pollutant fluxes

6.3.1.3 Soil texture and contamination implications – Mwambashi Watershed

6.3.1.3.1 Overview of soils in the Mwambashi Watershed

The Mwambashi Watershed lies within the Chambishi-Kalulushi copper mining zone of the Zambian Copperbelt. The terrain consists of gently dissected plateaus, lower pediplains, and riparian floodplains, underlain by quartzite-shale-dolomite and schistose formations. These parent materials, coupled with prolonged tropical weathering, give rise to ferralsols, acrisols, and fluvisols, exhibiting distinct textural patterns across the watershed.

Regional soil surveys (UNZA Soil Mapping Unit, 1974; JICA 1995; Copperbelt ESIAs 2010–2023) indicate that soil texture in the Mwambashi drainage basin is largely controlled by:

- Degree of weathering
- Topographic position
- Hydrological processes (runoff, sediment deposition, flooding)
- Inputs from mining operations (windblown tailings, smelter dust, runoff-borne particulates)

6.3.1.3.2 Predominant soil textural classes in the Mwambashi Watershed

Based on typical Copperbelt soil characteristics and previous ESIA work:

1. Sandy loam and loamy sand – plateau and upland zones

These textures dominate the upper slopes and interfluves surrounding the watershed.

Characteristics:

- Sand ≈ 55–75%
- Silt ≈ 10–20%
- Clay ≈ 10–25%
- Weak structure, low organic matter, low CEC
- Rapid infiltration and low water-holding capacity

These soils form the background sediment source for much of the Mwambashi River catchment.

2. Sandy clay loam – mid-slope and pediment areas

Intermediate textures occur where erosion and deposition balance.

Characteristics:

- Clay ≈ 20–35%
- Silt ≈ 15–30%
- Improved nutrient retention
- Higher metal adsorption capacity

Such soils often show higher contaminant accumulation than plateau soils.

3. Silt loam and silty clay loam – riparian corridors and floodplains

These fine-textured soils dominate the Mwambashi Riverbanks, tributary valleys, and seasonal wetlands.

Characteristics:

- Silt 30–50%
- Clay 15–30%
- High Fe–Mn oxide content
- Excellent capacity to adsorb trace metals
- Prone to sedimentation from upstream erosion and mining-related particulates
- Riparian soils form natural geochemical sinks for metals mobilised from mining areas.

4. Clay loam and clay – wetland pockets and depressions

Occur in backswamps, depressions, and drainage accumulation zones.

Characteristics:

- Clay > 35%
- Very slow permeability
- Strong sorption capacity
- High potential for redox-driven remobilisation

These are the highest-risk contamination retention zones in the watershed.

6.3.1.3.3 Implications of soil texture for contaminant distribution

Sandy loam / loamy sand (uplands): high-mobility zones

Processes:

- Low adsorption → metals readily leach
- Acidic micro-environments increase solubility of Cu, Co, Zn
- SO_4^{2-} moves freely through these profiles

Implications:

- Risk of groundwater contamination
- Wider dispersion of contamination plumes, especially during rainfall
- Minimal natural attenuation

Land use sensitivity:

- Crops grown here (maize, groundnuts, vegetables) are vulnerable to metal uptake
- Shallow wells are at risk from dissolved Cu, Co, Mn
- Sandy Clay Loam (Mid-slopes): Accumulation and Transition Zones

Processes:

- Improved adsorption slows contaminant migration
- Moderate accumulation of Cu, Pb, Mn, Zn
- Clay minerals and Fe/Mn oxides bind metals effectively

Implications:

Formation of secondary contamination hotspots, especially in erosion–deposition interfaces

Strong interaction between pH, EC, and metal solubility

Land use sensitivity:

- Livestock may be exposed through contaminated grazing
- Gardens irrigated with river water accumulate metals in topsoil
- Silt Loam / Silty Clay Loam (Riparian Zones): Geochemical Sinks

Processes:

- High trapping of suspended sediments carrying Cu, Co, Pb, Zn, Mn, As
- Metals bind strongly to fine particles and Fe–Mn oxides
- Seasonal flooding enhances deposition

Implications:

- Persistent contamination hotspots along the Mwambashi River
- Long-term ecological toxicity risks (macroinvertebrates, fish)
- Contaminant buildup in community gardens along streams

Land Use Sensitivity:

- Irrigation with contaminated river water increases food-chain exposure
- Heavy metal accumulation threatens household vegetable plots
- Clay and Clay Loam (Wetlands): High Retention but Redox-Sensitive Zones

Processes:

- Metals are strongly sorbed in toxic conditions
- Under waterlogging, reductive dissolution of Fe/Mn oxides releases Mn, Zn, Co

Implications:

- Potential for seasonal spikes in dissolved metal concentrations
- Wetland degradation from chronic contamination
- Downstream transport during heavy flows

Land use sensitivity:

- Not ideal for crop production due to high metal loads

- Livestock watering points may become contaminated seasonally

6.3.1.3.4 Integrated land use and environmental risk assessment

1. Groundwater vulnerability

High in sandy-textured uplands due to rapid percolation and low adsorption.

2. Agricultural exposure

Occurs primarily where:

- Sandy soils → metal mobility is high
- Riparian silty soils → metal accumulation is high
- Irrigation uses contaminated surface water

Crops like leafy vegetables, pumpkins, beans, and maize show elevated metal uptake risks.

- Human health pathways
- Consumption of contaminated crops
- Drinking shallow groundwater
- Direct soil ingestion (children)
- Contact with contaminated sediments in riparian gardens
- Livestock-based transfer (milk, meat)

3. Ecological impacts

- Chronic Cu, Co, Pb loading in fine-textured riparian soils affects benthic diversity
- Altered soil microbial activity reduces natural soil fertility
- pH and EC changes stress aquatic biota and riparian vegetation

6.3.1.3.5 Conclusion

Table 6-6: Soil texture and contamination implications in the Mwambashi Watershed

Texture	Behaviour	Contaminant risk	Land use implications
Sandy loam / loamy sand	Low retention; high mobility	Leaching of Cu, Co, Zn, SO_4	Groundwater contamination; high crop uptake

Sandy clay loam	Moderate retention	Hotspots for Cu, Pb, Mn	Grazing and crop contamination
Silt loam / silty clay loam	High adsorption; sediment sinks	Persistent hotspots for Cu, Pb, Zn, As	Irrigated gardens at high risk; ecological impacts
Clay / clay loam	Very high retention; redox-sensitive	Seasonal remobilization	Wetland contamination; livestock water risk

The Mwambashi Watershed exhibits a soil-texture gradient that strongly governs contaminant behaviour. Sandy uplands promote metal mobility, while riparian silt and clay deposits act as persistent sinks for Cu, Co, Pb, Zn, Mn, and As. These patterns present significant implications for:

- Agricultural safety
- Groundwater protection
- Community health
- Ecological integrity
- Land-use planning around mining infrastructure

Targeted remediation and land-use zoning should therefore reflect the textural–contamination interactions mapped in this ESIIA.

6.3.1.4 Soil texture and contamination implications – Kafue River Buffer Zone (KRBZ)

6.3.1.4.1 Overview of soil textures in the KRBZ

The Kafue River Basin Buffer Zone (KRBZ) extends across a diverse geomorphic landscape including alluvial plains, river terraces, gently undulating uplands, and wetlands. These landscapes are underlain by mixed parent materials, alluvium, lacustrine deposits, clay-rich floodplain sediments, and weathered lithosols, resulting in a mosaic of soil textures.

Across the KRBZ sampling sites, the predominant soil textures fall within three broad groups:

1. Sandy Loam and Loamy Sand (Upland and levee zones)

These soils dominate the slightly elevated areas away from the active floodplain.

Characteristics:

- High sand fraction (50–70%)
- Low clay (5–20%)

- Weak structure and low organic matter
- Rapid infiltration and low water-holding capacity

These textures are typical of reworked alluvial and colluvial deposits along the edges of the Kafue basin.

2. Silt loam and silty clay loam (floodplain and lower terrace zones)

These dominate the riverine floodplain, where finer suspended particles settle during seasonal flooding.

Characteristics:

- High silt content (30–50%)
- Moderate clay content (15–30%)
- High moisture-holding capacity
- High nutrient content due to periodic sediment deposition

These soils form the principal agricultural zone of the basin.

3. Clay Loam and Clay (Backswamps, depressions, and wetland areas)

These occur in poorly drained depressions and oxbow systems.

Characteristics:

- Clay content ≥30%
- High shrink–swell potential
- Slow permeability
- High cation exchange capacity (CEC)
- Prone to prolonged waterlogging

These fine-textured soils accumulate both natural and anthropogenic contaminants.

6.3.1.4.2 Implications of soil texture for contaminant behaviour in the KRBZ

The textural variations across the basin directly influence the mobility, retention, and distribution of contaminants identified in the KRBZ analysis (Cu, Co, Mn, Pb, Zn, Cr, As, B, Cd, Ni, Se, SO_4^{2-}, pH, EC).

Below is the contamination behaviour associated with each dominant texture.

1. Sandy loam / loamy sand: high contaminant mobility zone

These textures adsorb contaminants poorly, especially metals and sulphates, due to:

- Low clay and organic matter
- Low CEC
- High hydraulic conductivity

Contaminant behaviour:

- Metals such as Cu, Zn, Ni, and Co leach downward quickly, especially under acidic conditions
- SO_4^{2-} shows very high mobility
- pH tends to drop faster, increasing metal solubility

Implications:

- Potential contamination of groundwater sources used for domestic supply
- Wider dispersion of contamination beyond the immediate source
- Increased crop uptake risk in sandy cultivated areas

This aligns with observed elevated variability and outliers parameters (Cu, Mn, SO_4) seen in KRBZ boxplots.

2. Silt loam / silty clay loam: contaminant accumulation zones (floodplains)

Fine alluvial soils along the Kafue floodplain show:

- High adsorption of Cu, Pb, Zn, Mn, As
- High water-holding capacity
- Strong interactions with Fe/Mn oxide coatings

Contaminant behaviour:

- Floodplain soils act as sinks, accumulating metals transported by river sediments
- Elevated Mn, Cu, and Co concentrations in these soils reflect river borne contamination
- EC elevates due to dissolved ions retained in floodplain sediments

Implications:

- Long-term contamination hotspots in agricultural zones

- Elevated risk of food-chain transfer through vegetables and maize grown along the floodplain
- Metal build-up contributes to soil degradation and reduced microbial activity

3. Clay loam / clay: strong adsorption but high ecological risk under redox fluctuations

These fine-textured soils retain most contaminants due to high CEC and clay activity.

Contaminant behaviour:

- Pb, Cu, As, Mn, Zn, and Cd adsorb strongly
- Under waterlogged or reducing conditions (common in wetlands), Fe–Mn oxides dissolve, releasing previously bound metals
- pH shifts during wet–dry cycles intensify metal mobility

Implications:

- Risk of episodic metal pulses into surface and shallow groundwater
- Wetland vegetation and aquatic life are exposed to fluctuating toxic metal levels
- Persistent long-term contamination even after source reduction
- High-risk grazing areas due to metal-rich sediment accumulation
- Contaminants (B, Cd, Ni, and Se) often show greatest instability in clay-rich wetland soils due to redox-driven transformations.

6.3.1.4.3 Implications for land use in the KRBZ

The interaction between soil texture and contamination has significant implications for agriculture, human health, ecological integrity, and development planning.

1. Agriculture

- Floodplain silt loams support most cropping but also show high metal accumulation.
- Sandy soils allow greater metal uptake by crops due to low adsorption and acidic conditions.
- Clayey wetland soils may cause increased plant stress due to toxicity and poor aeration.

Key risks:

- Cu, Mn, Zn phyto-toxicity in sensitive crops
- Pb and As entering food chains

- Reduced microbial activity and nutrient cycling

2. Human settlements and water use

- Sandy aquifers in the basin margins are highly vulnerable to leachate contamination.
- Communities using shallow wells near wetlands risk exposure to remobilized metals.
- Floodplain gardens irrigated with river water accumulate metals in edible vegetables.

3. Ecosystem Health

- Fine-textured floodplain soils behave as persistent pollutant sinks, altering ecological function.
- Wetlands face redox-driven metal shocks, impacting fish and benthic organisms.
- Riparian vegetation may show die-back in heavily contaminated patches.

4. Land-use planning and risk management

Understanding soil texture enables targeted interventions:

Table 6-7: Targeted interventions based on soil texture enables

Texture zone	Recommended management action
Sandy loam	Liming, organic amendments, groundwater protection
Silt loam	Monitoring of agricultural produce, erosion management
Clay / wetlands	Riparian buffer restoration, hydrological regulation

Summary

- The KRBZ presents a complex soil–contaminant landscape shaped by natural sedimentation and anthropogenic pressures.
- Sandy textures → high mobility, groundwater risk
- Silt loams → floodplain sinks with food-chain implications
- Clay-rich soils → strong adsorption but high ecological vulnerability due to redox processes
- These texture–contamination interactions help explain the spatial patterns and guide evidence-based land management and remediation planning.

6.3.1.5 Water and soil quality for crop irrigation in Chambishi, Mwambashi, and Kafue Agricultural Zones

This assessment evaluates the suitability of water and soil conditions for crop irrigation across Chambishi, Mwambashi, and Kafue agricultural zones. It is a synthesis integrating soil chemistry indicators, inferred water-quality parameters, and internationally recognized guidelines (FAO, USSL, and boron toxicity thresholds). The objective is to provide a unified interpretation of salinity, sodicity, acidity, ion toxicity, and related agronomic constraints that may affect irrigation performance and long-term soil productivity.

6.3.1.5.1 Key issues influencing irrigation sustainability

Across all three zones, soil and inferred water-quality indicators demonstrate generally moderate suitability for irrigation, with localized zones of concern requiring targeted management. Key issues influencing irrigation sustainability include:

Salinity Risk (EC):

Chambishi shows variable salinity with topsoil EC generally <10 dS/m but subsoil hotspots reaching extremely high values.

Mwambashi has low EC in most topsoil samples but several subsoil readings >3 dS/m, indicating potential salinity buildup.

Kafue displays predominantly non-saline conditions (2 dS/m) with isolated topsoil peaks (up to 1.89 dS/m) related to evaporation or fertilizer residues. Salinity is not widespread but hotspots will require leaching and drainage interventions.

Acidity and Aluminium Toxicity:

Most soils range from slightly to moderately acidic (pH 5.1–7.7), but pockets of high acidity (pH 4.3–4.8) in Kafue indicate potential Al^{3+} toxicity which restricts root growth.

Acidic locations require lime application.

Boron Toxicity:

Boron is a major constraint, particularly in Kafue where concentrations exceed 10–25 mg/kg, posing significant risks for boron-sensitive crops (beans, citrus, groundnuts). Chambishi and Mwambashi display moderate B levels with occasional spikes.

Crop selection must prioritize B-tolerant species, and leaching or gypsum amendments may be necessary.

Major Ions (Ca, Mg, SO_4):

All regions show high Ca and Mg concentrations—especially extreme values in Kafue's topsoil—indicating strong buffering capacity and minimal sodicity risk. Sulphate levels are elevated in places but not harmful to crops.

Depth Profile Insights:

EC and sulphate values typically decrease with depth, indicating effective leaching.

Boron accumulates deeper in some profiles, confirming its mobility.

Local surface accumulations suggest evaporation or fertilizer deposition.

Irrigation Suitability Rating (Across All Three Sites)

Table 6-8: Irrigation Suitability Rating (Across All Three Sites)

Parameter	General Rating	Implications /Action
Salinity	Low–Moderate	Monitor and manage hotspots
Sodicity	Low	High Ca–Mg prevents structural degradation
Acidity	Moderate	Lime required in low-pH zones
Boron Toxicity	Moderate–High (Site-dependent)	Biggest constraint; requires crop screening
Aluminium Toxicity	Localized	Present in strongly acidic soils
Overall Suitability	**Moderate**	Suitable with site-specific mitigation

6.3.1.5.2 Strategic Recommendations

Expand Irrigation Water Testing: Collect full ionic profiles (Na^+, Cl^-, HCO_3^-, CO_3^{2-}) to compute SAR, RSC, and chloride hazard.

Manage Salinity: Implement leaching fractions, improve field drainage, and adjust irrigation scheduling in high-EC zones.

Mitigate Acidity & Al Toxicity: They will need to apply agricultural lime in plots with pH < 5.5.

Address Boron Hazards: Consider gypsum, deep irrigation, and selection of B-tolerant crops (maize, sorghum, barley).

Crop Planning: Avoid B-sensitive crops in high-boron zones; design nutrient management programs that prevent salt accumulation.

Routine Monitoring: Quarterly testing of both soils and irrigation water to track changes in salinity, pH, and toxicity parameters.

6.3.1.5.3Conclusion

Chambishi, Mwambashi, and Kafue agricultural soils remain viable for irrigation, but localized salinity, acidity, and boron hazards require targeted intervention. Adoption of site-specific soil amendments, improved irrigation management, and strategic crop selection will ensure sustainable water use and maintain long-term soil productivity for agricultural investments in these regions.

6.3.2 Soil Texture Data from the Chambishi, Mwambashi, Kafue–Transect

6.3.2.1 Chambishi–Mwambashi–Kafue Transect

6.3.2.1.1 Introduction and Methodological Context

A total of 70 soil samples were evaluated to characterize the textural composition of topsoils (0–10 cm or 0–15 cm) and subsoils (10–30 cm or deeper) across agricultural, hydrological, and irrigation monitoring points within the Kafue River basin and associated command areas.

While laboratory-based Particle Size Distribution (PSD) analysis (e.g., hydrometer or laser diffraction) is often regarded as the reference method, field-based hand texturing is a globally accepted, scientifically grounded soil survey method, especially when conducted by trained and experienced soil scientists. Hand texturing is explicitly recognized and institutionalized by:

- USDA Soil Survey Manual
- FAO Guidelines for Soil Description
- WRB (World Reference Base) field protocols
- ISO 18400 series (site reconnaissance and preliminary characterization)

The hand-texture method was therefore legitimately applied as a corrective, field-based determination following the omission of PSD requests, ensuring that soil functional interpretation, classification inference, and land-use suitability analysis could still be conducted reliably.

Importantly, soil texture is a class variable**,** not a continuous variable. The objective of texture determination is correct class assignment within the USDA textural triangle**,** not exact percentage replication. Numerous comparative studies demonstrate that experienced field estimations typically fall within ±5–10% of laboratory PSD**,** rarely crossing class boundaries in a meaningful way.

6.3.2.2 Scientific Validity of Hand-Texturing

6.3.2.2.1 Hand-Texturing as a Scientific Method

Hand texturing is not subjective guesswork**.** It is a standardized tactile-mechanical assessment based on:

- Plasticity
- Cohesion
- Ribbon length
- Grittiness (sand fraction)
- Smoothness (silt fraction)
- Stickiness and resistance to deformation (clay fraction)

These properties directly reflect particle size dominance and mineralogical behaviour**,** particularly of clay fractions. Crucially, soil texture classes are defined by behavior, not merely by numerical percentages.

6.3.2.2.2 Empirical Accuracy Relative to Laboratory Methods

Peer-reviewed studies consistently show that:

- Trained soil scientists correctly classify texture 70–90% of the time,
- Misclassification usually occurs between adjacent classes (e.g., sandy loam vs sandy clay loam),
- Errors rarely exceed one textural class, and
- Functional interpretations (hydrology, rootability, nutrient retention) remain valid.

Thus, field-determined textures remain scientifically acceptable**,** particularly for:

- Soil survey
- ESIA baseline studies
- Irrigation suitability
- Contaminant mobility interpretation
- Pedogenic interpretation

6.3.2.3 Results (Field-Determined Texture Distribution)

6.3.2.3.1 Overall Texture Distribution

In assessment, the soil texture frequency distribution (Figure 6-9) indicates that:

- Sandy clay loam dominates (40%; n≈27)
- Loamy sand (n≈10) and Sandy clay (n≈9) are secondary
- Fine-textured classes (Silty clay, Silty clay loam, Clay, Silty loam) collectively comprise <15%

- Sand occurs rarely (3%)

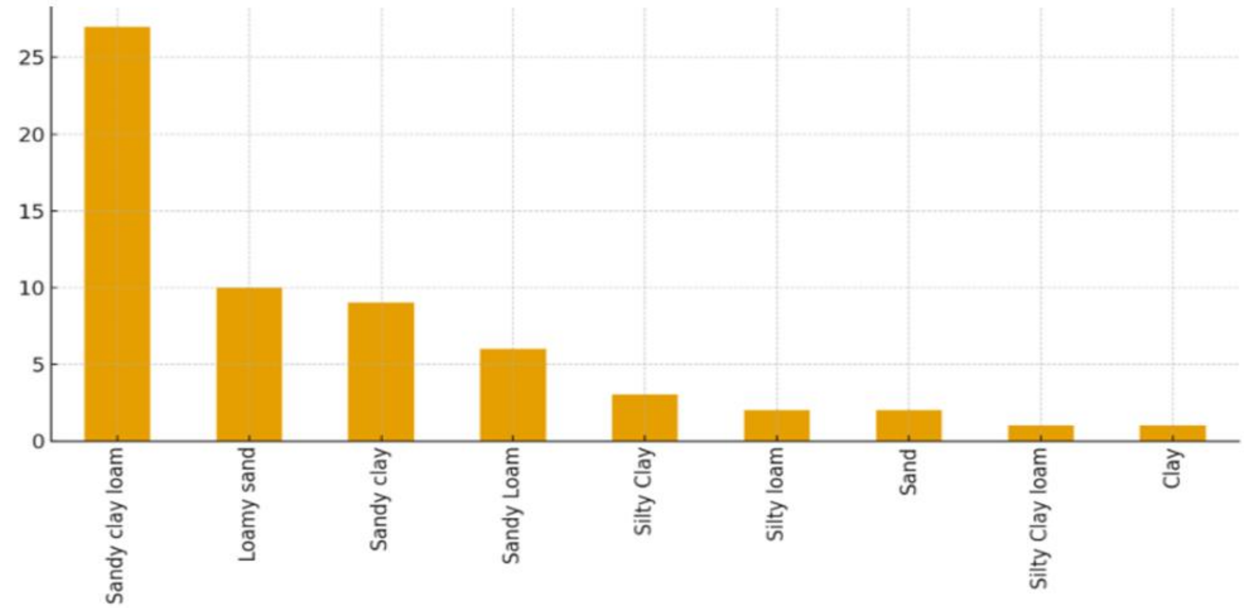


Figure 6–9: Frequency of Soil Texture Classes

This distribution reflects a coarse-textured depositional landscape with localized fine-textured inclusions**,** typical of alluvial–colluvial geomorphic systems such as the Kafue basin.

6.3.2.3.2 Topsoil vs Subsoil Textural Trends

Topsoil (n≈30):

- Dominance of sandy clay loam and loamy sand
- Frequent gravelly/gritty modifiers
- Indicative of **surface reworking, erosion, and redeposition**

Subsoils (n≈40):

- Greater textural uniformity
- Increased sandy clay and clay loam occurrence
- Reflects **clay illuviation (argillation)**

6.3.2.3.3 Quantitative implication:

Clay-rich classes constitute:

- ~30% of subsoil
- ~12% of topsoil

This vertical differentiation is pedogenetically meaningful**,** not an artefact of method.

6.3.2.4 Texture Triangle Projection and Error Margins

Using class centroids**,** textures cluster into three coherent domains:

- High sand / low clay → Loamy sands
- Intermediate sand / moderate clay → Sandy loams & sandy clay loams
- Low sand / high clay → Clayey classes

Even allowing for ±5–10% estimation error, class movement remains within functional and pedological coherence, confirming that interpretive conclusions are robust.

6.3.2.5 Pedogenic Interpretation (Method-Independent)

6.3.2.5.1 Argilluviation

The systematic clay increase with depth strongly supports:

- Downward translocation of clay
- Formation of incipient argic (Bt) horizons
- Compatibility with Luvisols (WRB) **or** Alfisols (USDA)

Such interpretations rely on relative texture change**,** not absolute PSD values.

6.3.2.5.2 Alluvial and Colluvial Influence

Surface gravel, grit, and sandy textures reflect:

- Flood deposition
- Canal overflow
- Sheetwash and slope processes

These geomorphic signals are of course usually diagnostic in the field and often masked in homogenized laboratory samples**.**

6.3.2.6 Soil Classification Validity

6.3.2.6.1 USDA Soil Taxonomy (Field-Texture Basis)

Texture Pattern	Likely Order	Rationale
Sandy clay loam over sandy clay	Alfisols	Argillic horizon probable
Weakly developed sandy profiles	Entisols	Young depositional soils

Clay pockets	Ultisols (localized)	If base saturation is low

6.3.2.6.2 WRB Correlation

Dominant: Luvisols
Secondary: Cambisols
Localized: Arenosols**,** Fluvisols

These classifications are explicitly allowed using field texturing under WRB guidelines.

6.3.2.7 Implications for Soil Function (Method-Robust)

6.3.2.7.1 Hydrology

- Sandy clay loams: balanced infiltration & storage
- Loamy sands: rapid drainage → higher irrigation frequency

6.3.2.7.2 Agronomy

- Clay-enriched subsoils improve nutrient retention
- Sandy topsoils benefit from organic matter amendments

6.3.2.8. Conclusion: Scientific Defense Statement

Hand-texturing, when conducted by a trained soil scientist, is a scientifically valid, internationally recognized, and professionally admissible method of soil texture determination.

The textures reported here:

- Are consistent internally
- Align with geomorphic and pedogenic expectations
- Support robust soil classification
- Fall within accepted margins of error relative to laboratory PSD

Accordingly, the soil assessment conclusions remain valid, defensible, and fit-for-purpose**,** particularly for land evaluation, irrigation planning, and environmental assessment**.**

6.3.2.8.1 Land Management

- Gravel limits tillage depth
- Textural heterogeneity demands site-specific management

These conclusions are functionally invariant to minor PSD deviations.

6.3.2.9. Key References (Authoritative)

6.3.2.9.1 Core Soil Survey Manuals

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6.3.2.9.2 Scientific Validation of Hand-Texturing

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6.3.2.9.3 Applied and ESIA Context

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- Add a formal "Methodological Limitation and Uncertainty Statement" for ESIA/ZEMA submissions.
- DISCLAIMER: However, it would have been more plausible to have included laboratory-based particle-size distribution analysis of at least 25% of the 1,1,88 collected soil samples to enhance the quality of this assessment.

6.4 Assessment of Soil Contamination and Pollution Status

6.4.1 Overview

In this study, assessment of soil contamination and the associated toxicity hazard was based on the assessment of the soil concentration levels of several contaminants which included aluminum (Al), Arsenic (As), Boron, cadmium (Cd), cobalt (Co), chromium (Cr), copper (Cu), manganese (Mn), Nickel (Ni), lead (Pb), selenium (Se), zinc (Zn) and sulphate (SO_4^{2-}).

6.4.2 Characterisation and Baseline Soil Conditions

A meaningful interpretation of the soil assessment findings for the Sino-Metal tailings dam breach requires an understanding of the **baseline soil conditions** in the wider project area. Baseline conditions represent the state of soils *prior to* the breach event and, as much as possible, independent of mining-related influences. Establishing these conditions is essential for distinguishing impact-related contamination from natural background variability, guiding **risk assessment**, and informing **appropriate remediation and restoration measures**.

Given that historical, undisturbed soil data for the area are limited, the establishment of a defensible baseline mainly relied on **field-based reference sampling**, and **analytical and statistical approaches** designed to approximate natural geochemical conditions. The selected methodological options aim to identify soils that are comparable in geology, landform and land use but clearly outside the influence of the tailings spillage; and apply depth profiling and statistical screening to separate geogenic signatures from contamination introduced by the breach.

This integrated approach ensures that the baseline values derived are scientifically credible, spatially representative, and suitable for subsequent comparison with impacted soils. The following subsections outline the methodological options considered for establishing the baseline soil conditions and the rationale for their application within the Sino Metal project area.

6.4.3 Assessment of Contaminants in Soils

The assessment of contaminant concentrations in surface soils represents a central component of the soil assessment, providing the empirical evidence required to understand the magnitude, spatial distribution, and potential risks associated with tailings-derived pollutants. Surface soils, typically defined as the upper 0–10 cm, serve as the primary interface between deposited contaminants, ecological receptors, agricultural activities, and human exposure pathways. As such, quantifying contaminant levels within this zone is essential for evaluating both immediate and long-term environmental and public health implications.

This section presents the analytical results for key contaminants of concern identified during the ESIIA scoping process and informed by the conceptual site model. The results are organized according to the four Areas of Interest (AOIs), enabling comparison across different hydrological and land-use settings influenced by the tailings dam breach. Summary statistics, concentration ranges, and spatial patterns are provided to highlight contaminant hotspots, gradients, and deviations from background or reference levels. These findings form the basis for subsequent interpretations on soil quality status, ecological risks, and the development of targeted remediation and restoration recommendations.

In light of the absence of officially introduced soil standards in Zambia from Zambia Bureau of Standards (ZABS) and Zambia Compulsory Standards Agency (ZCSA), the FAO/WHO international guidelines have been adopted in this assessment to ensure a scientifically rigorous and precise evaluation of the incident's impacts on soil.

Table 6-9: FAO/WHO Limit

Statistics	Cd	Co	Cu	Ni	Pb	Zn	Mn
	µg/g	µg/g	µg/g	µg/g	µg/g	µg/g	µg/g
Thresholds	<3	<50	<100	<50	<100	<300	<2000

Assessment of Heavy Metal Contamination Using Integrated Indices

To quantitatively evaluate the extent and potential ecological risks of heavy metal contamination in soils, this study employs a suite of widely recognized geochemical assessment indices: the Exceedance Ratio (ER), the Average Pollution Index (CF), and the Pollution Load Index (PLI). These complementary metrics together form a hierarchical evaluation framework—progressing from assessing the compliance of individual pollutants with regulatory standards, to characterizing the overall pollution level within a region, and finally to evaluating the total cumulative pollution load.

The Exceedance Ratio (ER) directly reflects the compliance of a pollutant with regulatory limits by comparing its measured concentration against established environmental quality benchmarks. Its calculation formula is:

$$ER = C_i / C_s$$

where C_i is the measured concentration of pollutant "i" and C_s is the corresponding benchmark value. An $ER > 1$ indicates that the pollutant concentration exceeds the regulatory threshold, signaling potential ecological or health risks and necessitating prioritized control measures.

The Average Pollution Index (CF) characterizes the average pollution level of contaminants within a defined study area. It is defined as the arithmetic mean of the ratios of measured pollutant concentrations to their respective benchmark values. Its calculation formula is:

$$CF = (1/n) \times \Sigma (C_{i,j} / C_{s,i})$$

where $C_{i,j}$ is the measured concentration of pollutant "i" at sampling point "j", $C_{s,i}$ is the benchmark value for pollutant "i", and "n" is the total number of sampling points. This index effectively represents the overall average pollution level of contaminants within the region and can be used for pollution classification (e.g., clean, low, moderate, or high degree of contamination).

The Pollution Load Index (PLI) builds upon the Average Pollution Index by integrating information from multiple pollutants into a single composite indicator that reflects the overall contamination status. Its calculation formula is:

$$PLI = (CF_1 \times CF_2 \times \ldots \times CF_m)^{(1/m)}$$

where "m" is the number of pollutant types assessed. A $PLI > 1$ indicates that the study area is subject to the combined influence of multiple pollutants, with environmental quality showing a trend of cumulative deterioration. This index is particularly suitable for comprehensive regional pollution assessment, determining remediation priorities, and analyzing spatiotemporal trends of contamination.

In summary, the progressive indicator system of 'Exceedance Ratio — Average Pollution Index — Pollution Load Index' enables a systematic assessment from single-point, single-pollutant analysis to regional, multi-pollutant evaluation. This framework effectively links pollution identification, severity judgment, and integrated management, thereby providing a scientific basis for risk assessment and decision-making in the management of soil heavy metal contamination.

6.4.3.1 Tailings dam 15

The results from the Laboratory were subjected to basic statistical analysis based on the objectives of the study and the following section reviews the contents of the soils in terms of pH, heavy metals and other elements considered in the assessment.

a) ESIIA Results Analysis

Soil concentrations of elements exceeding FAO/WHO thresholds in potential impact zones around the tailings dam are summarized in the table below. As shown, the primary contaminants in both surface and subsurface soils are copper and cobalt, with levels reaching up to 4.5 times the World Health Organization/Food and Agriculture Organization (WHO/FAO) threshold values. Elevated concentrations of cobalt and lead are also present in localized areas. The pollution load index (PLI) for surface soils is 0.42, while that for subsurface soils is 0.796. Both values are below 1.0. This indicates that, from the perspective of the integrated load of multiple heavy metals, the soil environment in this area has not yet reached a level of systemic contamination, and the overall cumulative risk remains within a manageable range.

Table 6-10: Top soil (0-10 cm)

DESCRIPTION	Cd	Co	Cu	Pb
	µg/g	µg/g	µg/g	µg/g
WHO/FAO Thresholds	3	50	100	100
Sample Size	107	107	107	107
Minimum	0.001	3.714	66.21	2.12
Maximum	6.07	114.80	2531.80	185.73
Average	0.38	27.49	457.68	9.94
Exceedance Ratio	1%	12%	97%	1%
Average Contamination Index	0.13	0.55	4.58	0.10
Pollution Load Index	0.42			

Table 6-11: Subsoil (10-30 cm)

DESCRIPTION	Co	Cu
	µg/g	µg/g
WHO/FAO Thresholds	50	100
Sample Size	116	116
Minimum	0.022	19.03
Maximum	202.367	3994.16
Average	14.26	219.50
Exceedance Ratio	3%	59%
Average Contamination Index	0.29	2.21
Pollution Load Index	0.796	

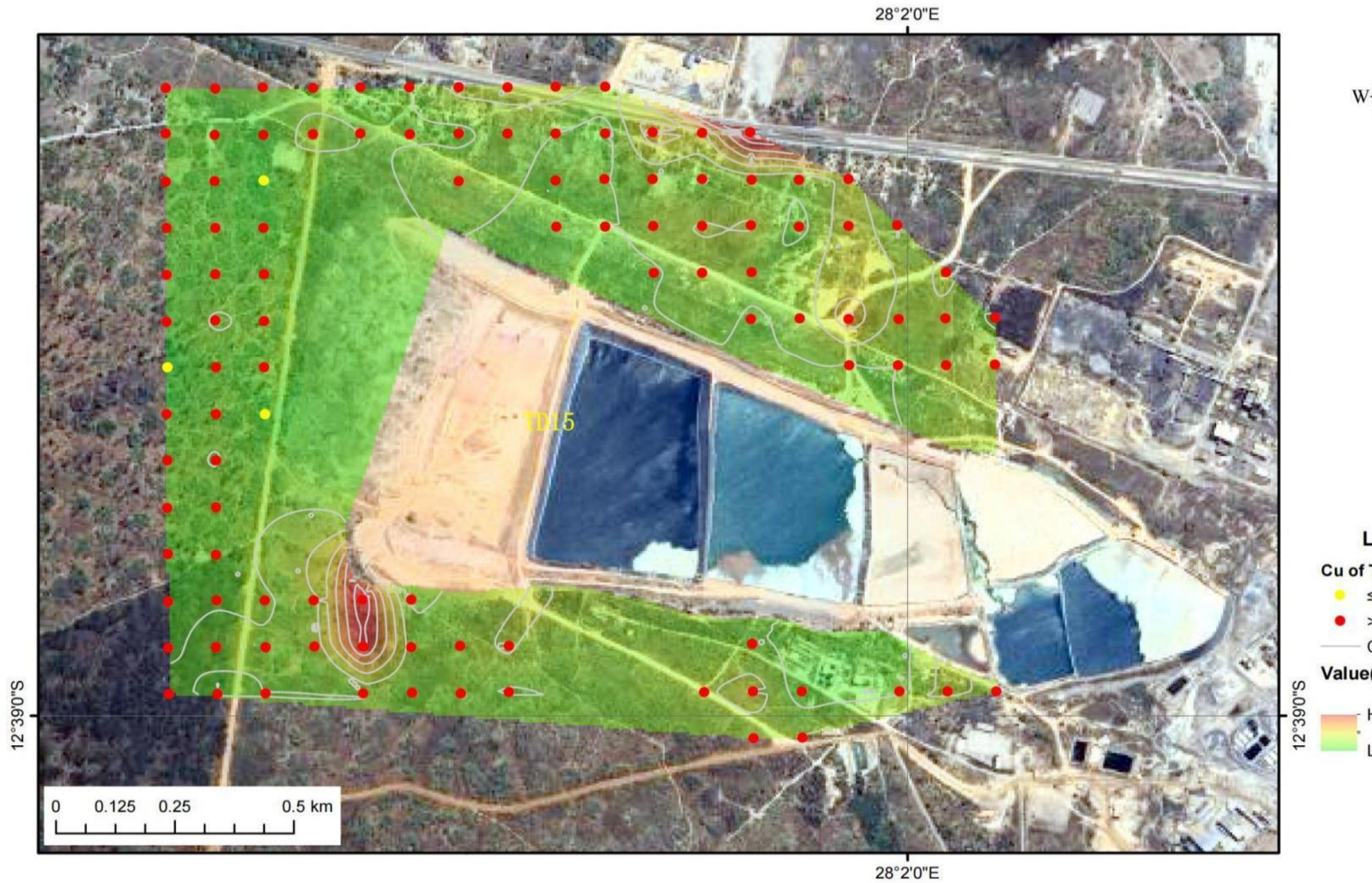


Figure 6–10: Distribution of Copper in TD 15

Figure 6–11: Distribution of Lead in TD 15

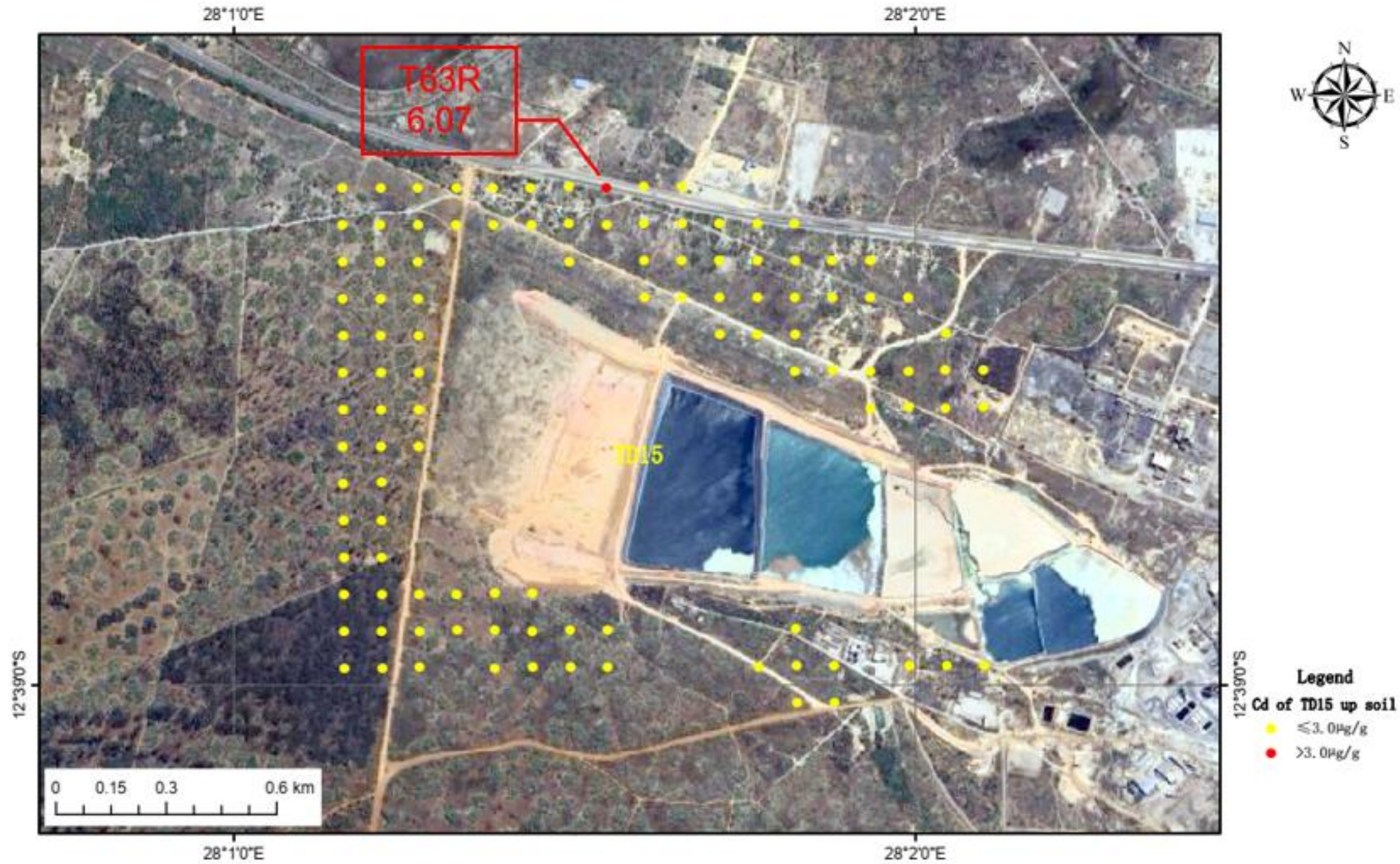


Figure 6–12: Distribution of Cadmium in TD 15

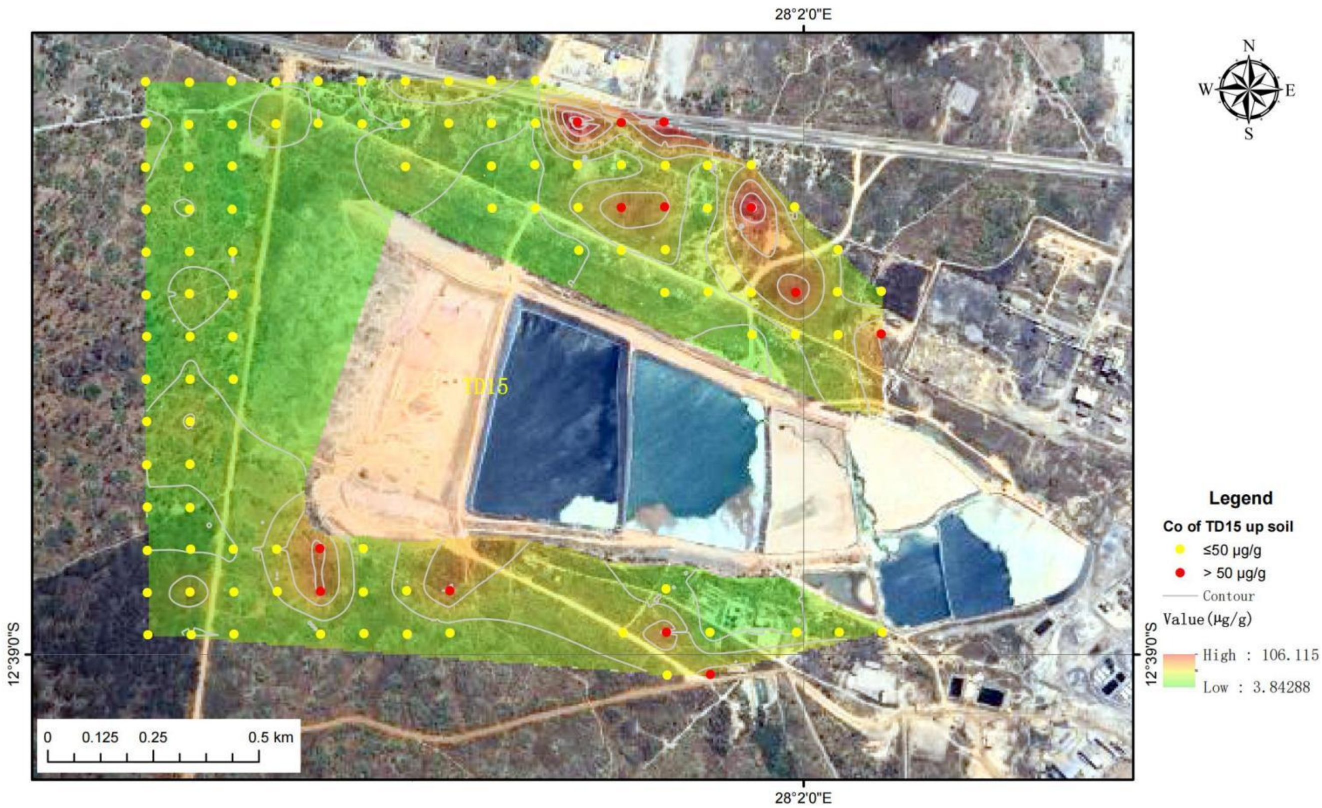


Figure 6. 13: Distribution of Cobalt in TD 15

b) Control Sample Results Analysis

Soil concentrations of elements exceeding FAO/WHO thresholds in the control zones around the tailings dam are summarized in the table below. As shown in the table, copper is the primary contaminant in both surface and subsurface soils. The pollution load index (PLI) for surface soil is 1.07, while that for subsurface soil is 1.22. Both values exceed 1.0, indicating a certain degree of contamination in the control areas surrounding the tailings dam.

Table 6-12: Top soil (0-10 cm)

DESCRIPTION	Cd	Co	Cu	Ni	Pb	Zn
	µg/g	µg/g	µg/g	µg/g	µg/g	µg/g
WHO/FAO Thresholds	3	50	100	50	100	300
Sample Size	20	20	20	20	20	20
Minimum	0.648	1.262	49.75	0.002	15.48	5.165
Maximum	12.44	2127.46	12001.15	74.19	523.17	1275.55
Average	2.26	145.03	1463.01	10.26	81.59	84.39
Exceedance Ratio	15%	15%	95%	10%	10%	5%
Average Contamination Index	0.75	2.90	14.63	0.21	0.82	0.28
Pollution Load Index	1.07					

Table 6-13: Subsoil (10-30cm)

DESCRIPTION	Co	Cu	Pb
	µg/g	µg/g	µg/g
WHO/FAO Thresholds	50	100	100
Sample Size	16	16	16
Minimum	1.825	49.74	13.56
Maximum	517.199	2169.87	371.26
Average	41.94	348.30	61.89
Exceedance Ratio	13%	63%	6%
Average Contamination Index	0.84	3.48	0.62
Pollution Load Index	1.22		

Copper and cobalt are the primary elements of concern. Even in control areas located far from known pollution sources, concentrations of copper and cobalt in both topsoil and subsoil significantly exceed established safety thresholds. Specifically. The presence of elevated copper and cobalt concentrations even in the control area indicates that the contamination cannot be entirely attributed to recent incidents.

Other heavy metals remain within acceptable levels. Elements such as Cd, Ni, and zinc Zn all fall below regulatory thresholds, suggesting they are not major risk factors in this area. Lead approaches the threshold but remains within safe limits; continued monitoring is recommended. pH and EC values are within normal ranges.

6.4.3.2 Chambishi catchment area

a) ESIIA Results Analysis

Statistical data on soil elements exceeding FAO/WHO limits in the potential impact zones around the Chambishi Stream catchment are presented in the table below. As shown in the table, copper levels are notably high in the Chambishi catchment, with significant accumulations of cadmium, nickel, lead, and zinc observed in localized areas. This indicates long-term accumulation of these elements in the environment, reflecting a slightly higher degree of contamination compared to the upstream tailings dam area. The pollution load index (PLI) for surface soil is 0.73, and for subsurface soil, it is 0.68—both values below 1.0.

The Chambishi Stream catchment has developed a contamination pattern dominated by copper with co-accumulation of multiple heavy metals. However, the overall pollution load remains within a controllable range. Although localized exceedances and accumulation exist, the Pollution Load Index (PLI) for both surface and subsurface soils is below 1.0. This indicates that, from a multi-element integrated load perspective, the area has not yet reached a level of systemic contamination, and the overall environmental risk remains relatively low.

Table 6-14: Top soil (0-10 cm)

DESCRIPTION	Cu	Co	Cd	Ni	Pb	Zn	Mn
	µg/g	µg/g	µg/g	µg/g	µg/g	µg/g	µg/g
WHO/FAO Thresholds	100	50	3	50	100	300	2000
Sample Size	137	137	137	137	137	137	137
Minimum	0.01	0.001	0.001	0.002	0.58	0.006	0.01
Maximum	15220.12	15215.522	13.032	292.14	1108.17	2179.913	15664.97
Average	1296.20	292.47	0.78	12.01	35.22	80.76	507.07
Exceedance Ratio	94%	18%	12%	4%	4%	4%	2%
Average Contamination Index	12.96	5.85	0.26	0.24	0.35	0.27	0.25
Pollution Load Index	0.73						

Table 6-15: Subsoil (10-30cm)

DESCRIPTION	Cu	Co	Cd	Ni	Pb	Zn	Mn
	µg/g	µg/g	µg/g	µg/g	µg/g	µg/g	µg/g
WHO/FAO Thresholds	100	50	3	50	100	300	2000
Sample Size	166	166	166	166	166	166	166
Minimum	0.01	0.001	0.001	0.002	1.72	0.006	0.006
Maximum	20701.46	10046.95	19.57	385.11	1017.38	411.41	2611.25
Average	1266.18	171.81	1.32	12.83	48.00	51.79	347.39
Exceedance Ratio	67%	11%	17%	4%	7%	2%	1%
Average Contamination Index	12.66	3.44	0.44	0.26	0.48	0.17	0.17
Pollution Load Index	0.68						

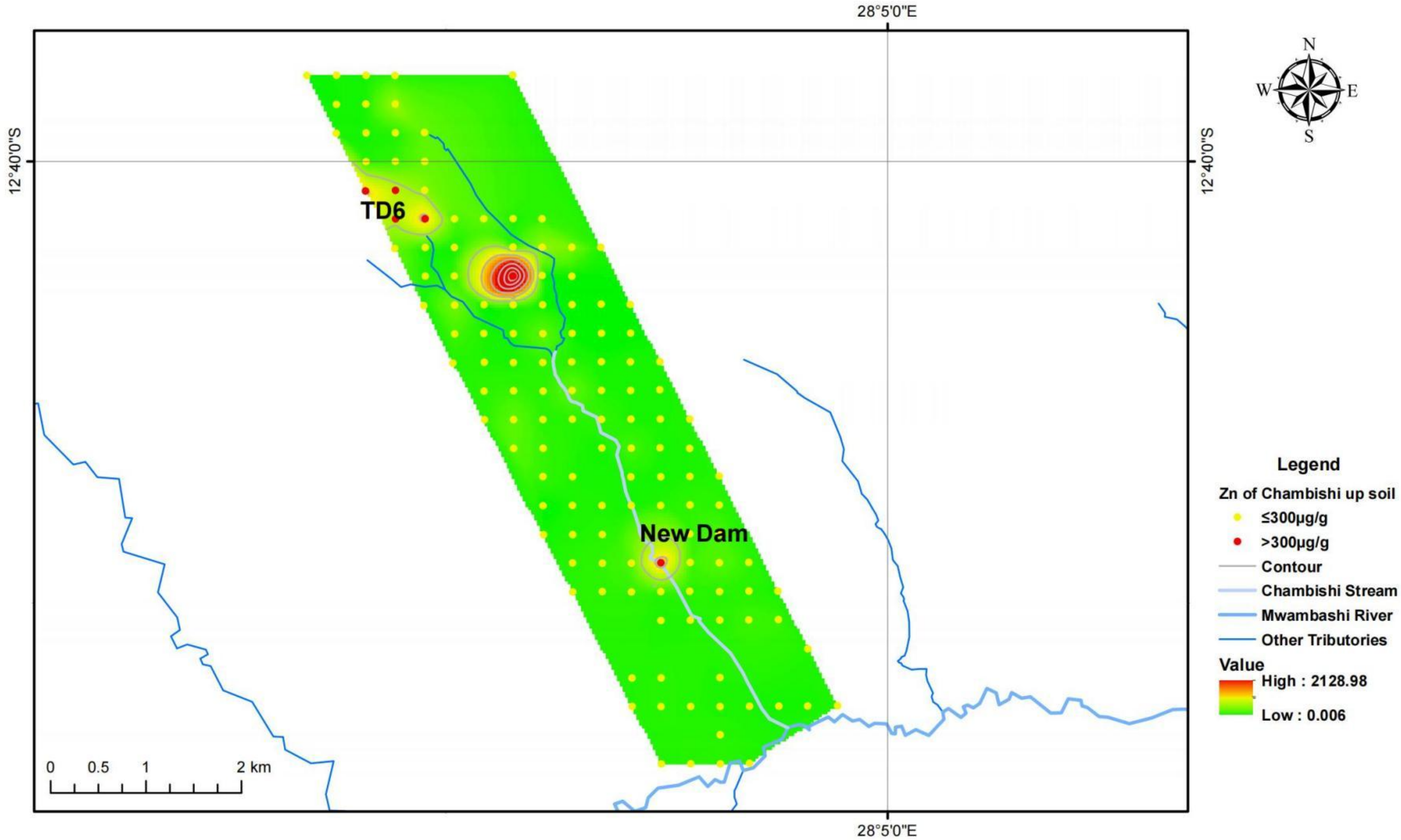


Figure 6–1: Distribution of Zinc in Chambishi Stream

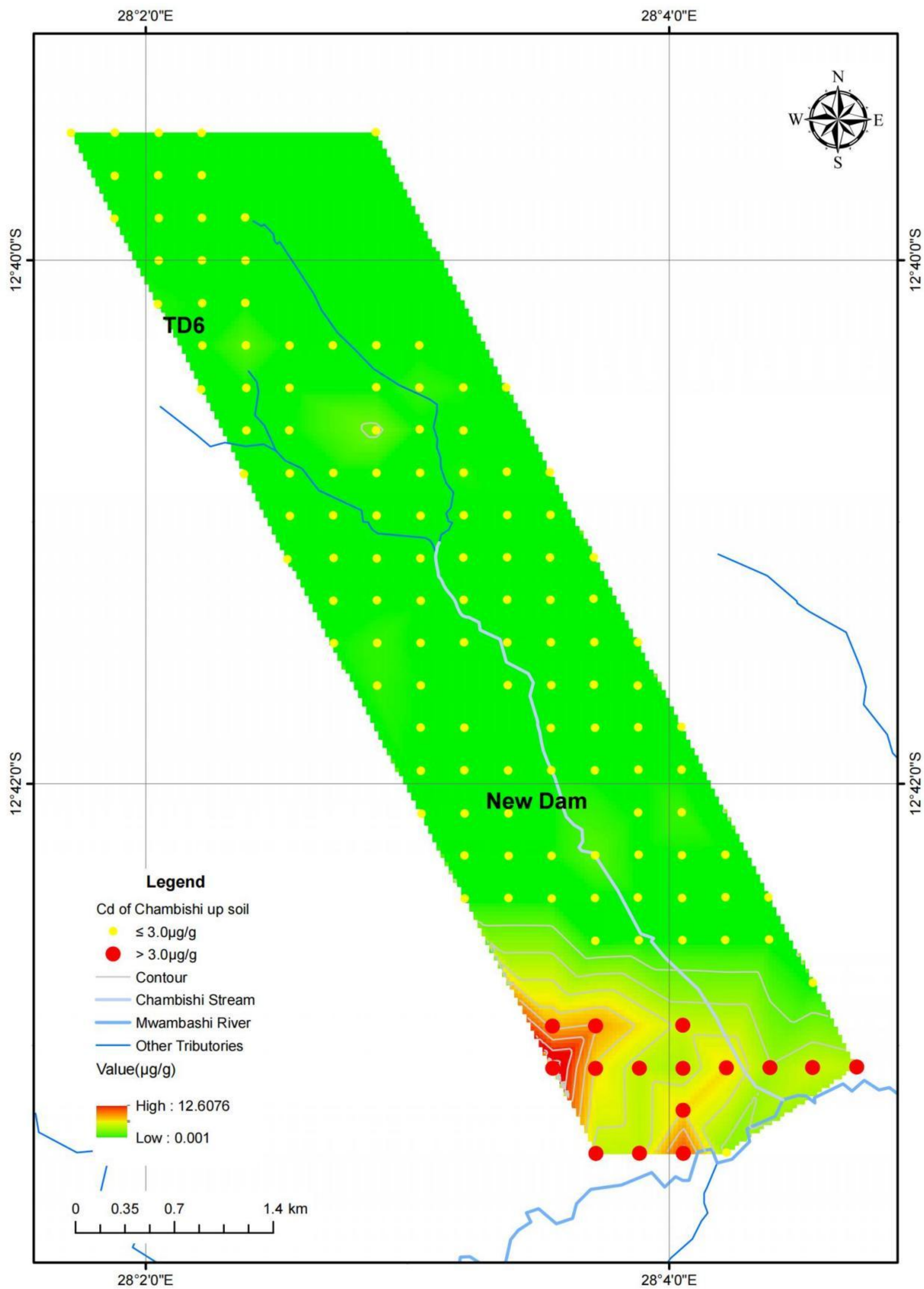


Figure 6-15: Distribution of Cadmium in Chambishi Stream

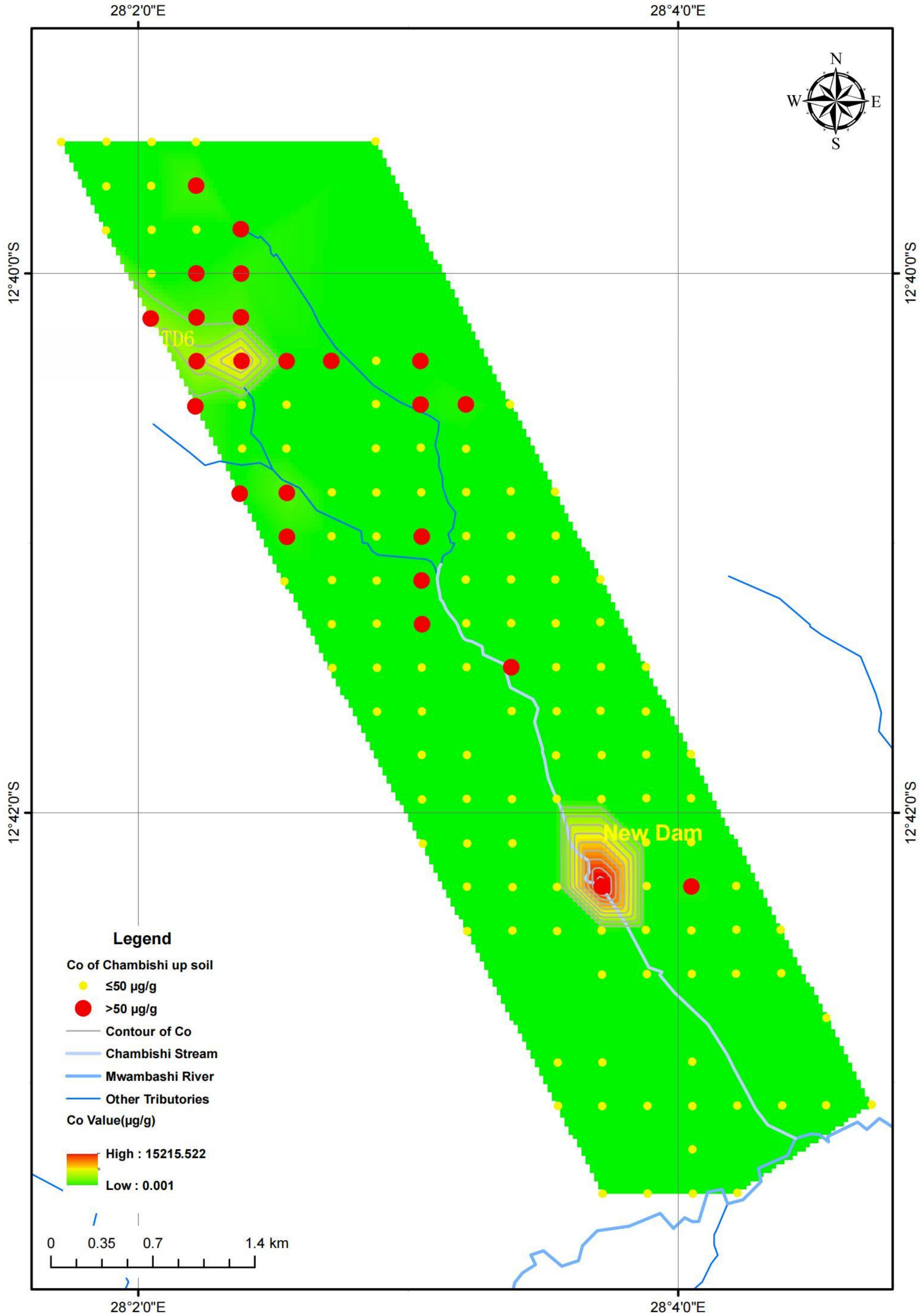


Figure 6-2: Distribution of Cobalt in Chambishi Stream

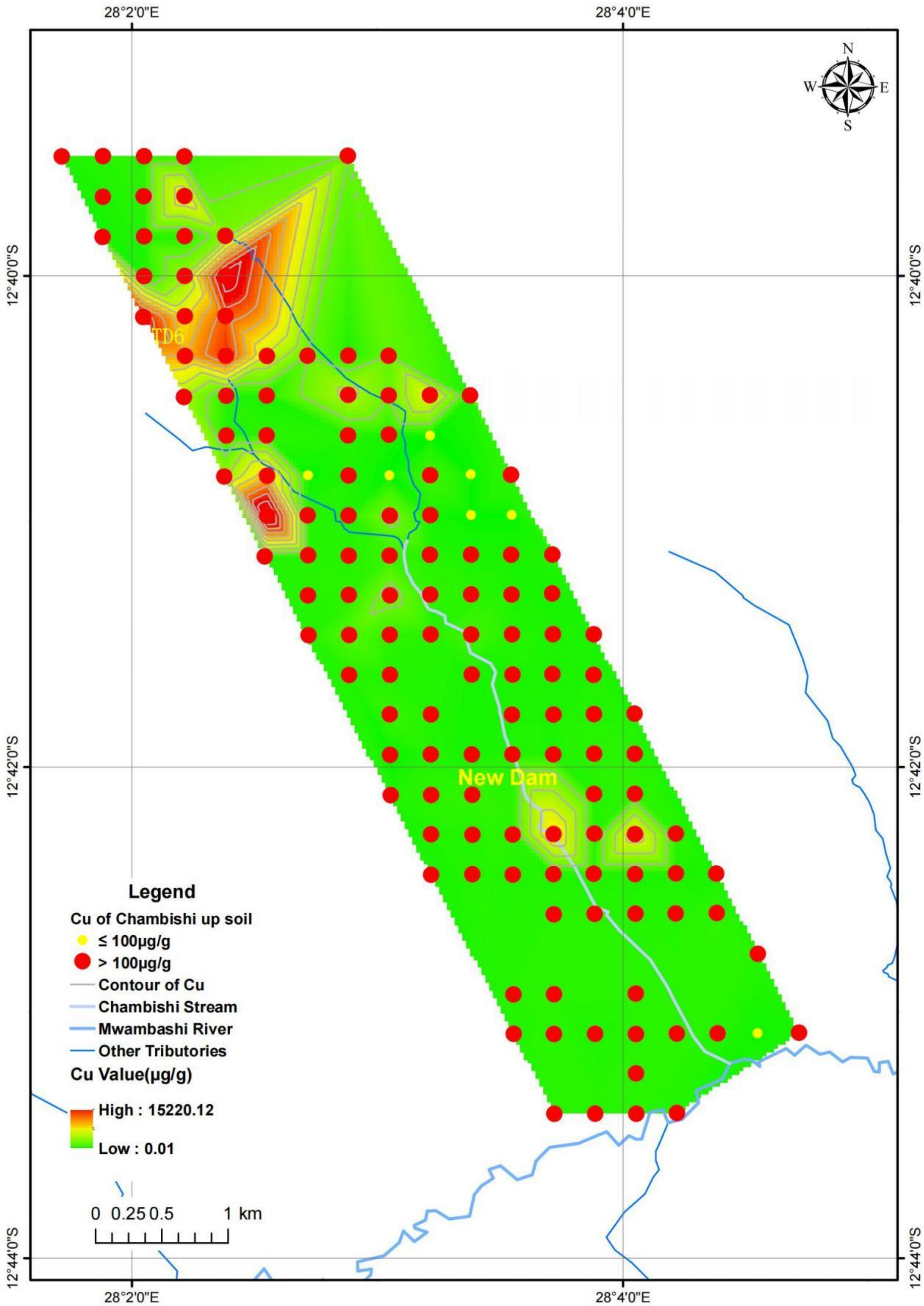


Figure 6-3: Distribution of Copper in Chambishi Stream

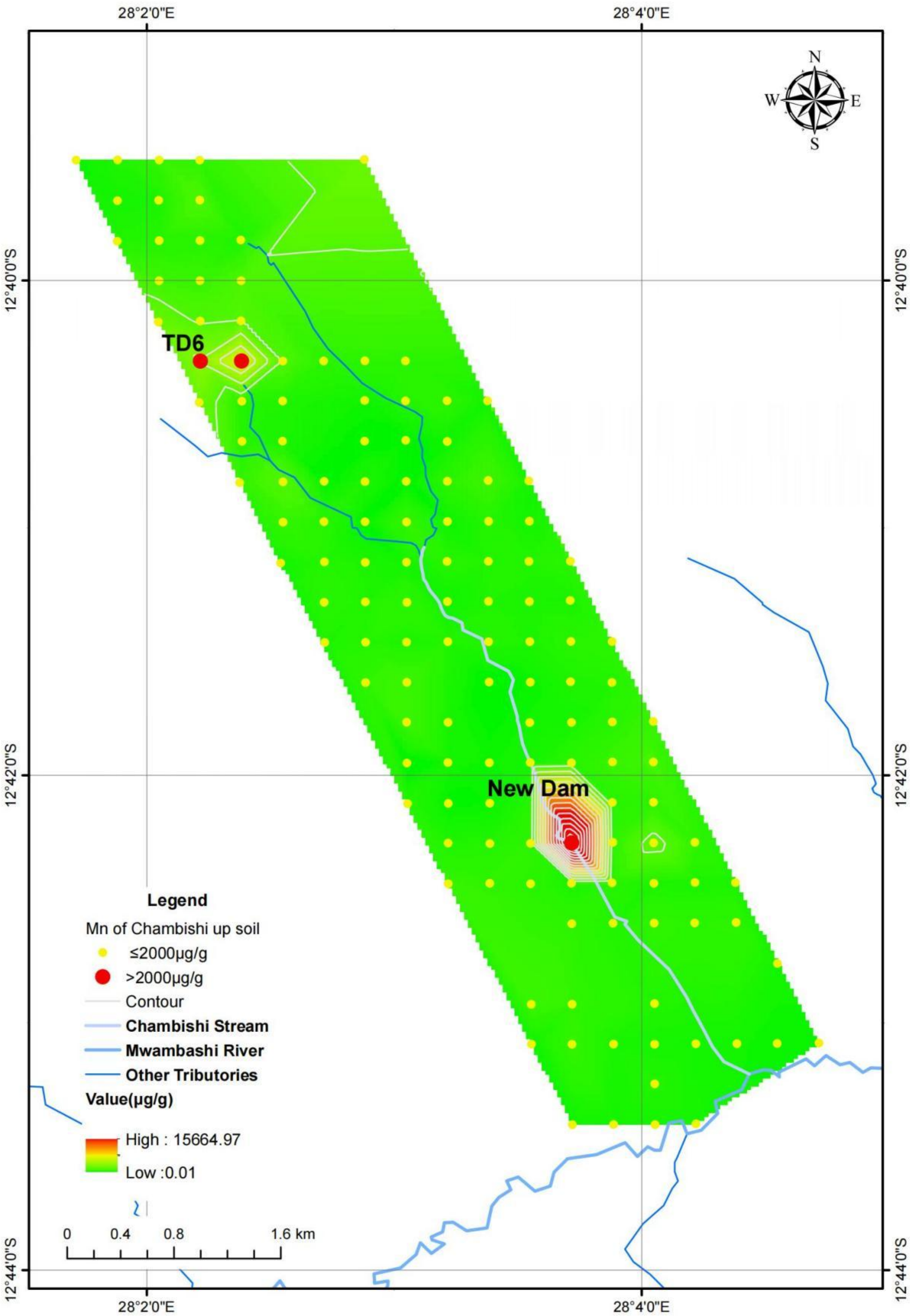


Figure 6-4: Distribution of Manganese in Chambishi Stream

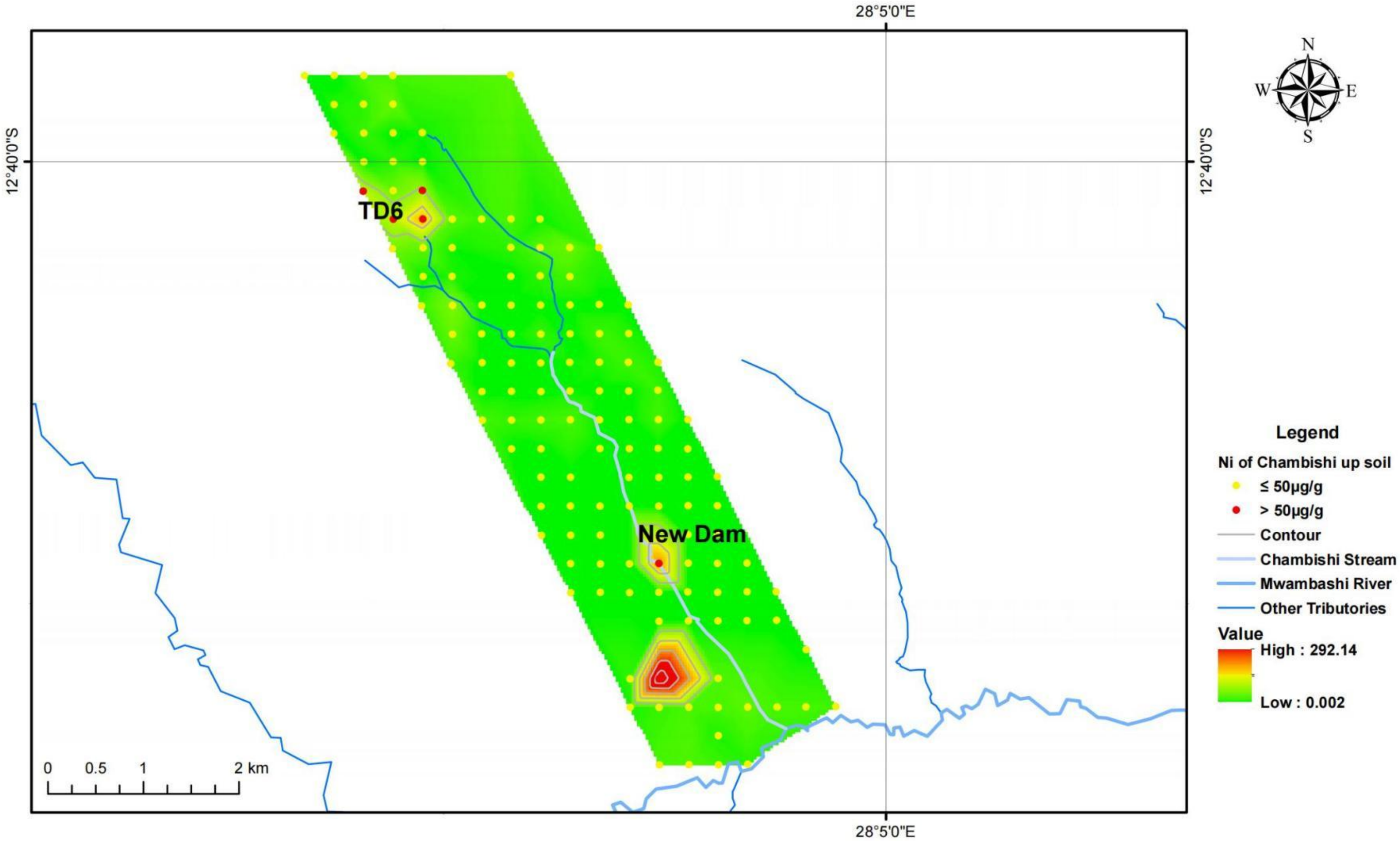


Figure 6-5: Distribution of Nickel in Chambishi Stream

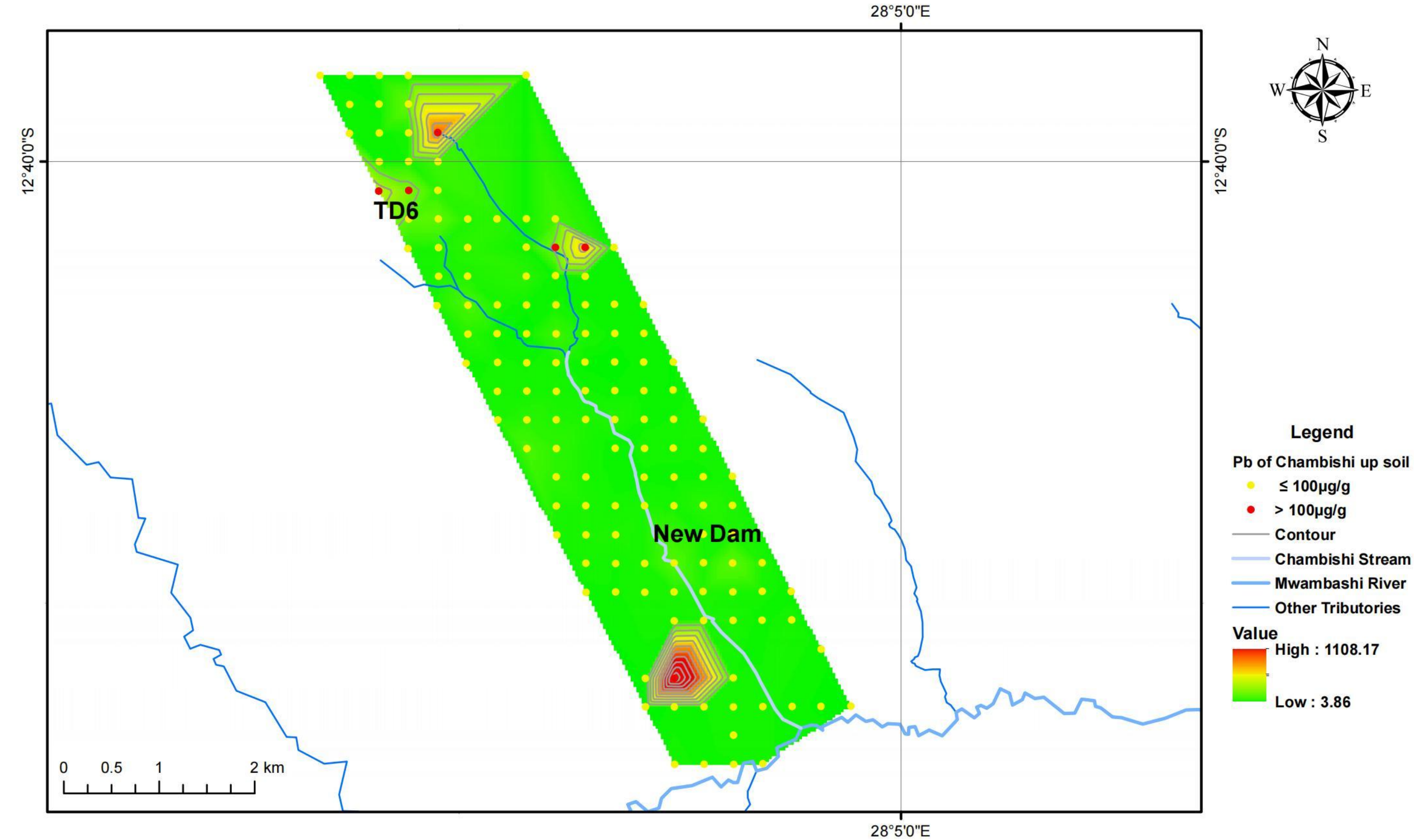


Figure 6-21: Distribution of Lead in Chambishi Stream

b) Control Sample Results Analysis

Soil concentrations of elements exceeding FAO/WHO limits in the control zone of the Chambishi Stream catchment are summarized in the table below. As shown in the table, copper and lead are the primary contaminant in both surface and subsurface soils. The pollution load index (PLI) for surface soil is 0.72, while that for subsurface soil is 0.76. Both values are below 1, indicating an overall low level of contamination in the Chambishi Stream catchment and minimal influence from anthropogenic pollution.

Table 6-16: Top soil (0-10 cm)

DESCRIPTION	Cd	Co	Cu	Pb
	µg/g	µg/g	µg/g	µg/g
WHO/FAO Thresholds	3	50	100	100
Sample Size	18	18	18	18
Minimum	0.001	4.066	191.33	62.27
Maximum	4.947	59.078	666.04	297.16
Average	0.79	12.96	311.25	127.17
Exceedance Ratio	6%	6%	100%	50%
Average Contamination Index	0.26	0.26	3.11	1.27
Pollution Load Index	0.72			

Table 6-17: Subsoil (10-30 cm)

DESCRIPTION	Cd µg/g	Cu µg/g	Pb µg/g
WHO/FAO Thresholds	3	100	100
Sample Size	18	18	18
Minimum	0.001	46.16	60.46
Maximum	4.733	395.49	528.04
Average	0.78	116.64	147.60
Exceedance Ratio	11%	50%	61%
Average Contamination Index	0.26	1.17	1.48
Pollution Load Index	0.76		

Copper concentrations significantly exceed safety thresholds in both topsoil and subsoil, particularly in the topsoil. The presence of elevated copper levels even in the control area suggests that its source is likely attributable to long-term geological enrichment or residual contamination from historical mining activities, rather than solely to recent incidents.

6.4.3.3 Mwambashi to Kafue River catchment area

a) ESIIA Results Analysis

The soil element concentrations exceeding FAO/WHO limits in the potential impact zones around the Mwambashi River catchment are summarized in the table below. As shown in the table, copper levels are elevated within the catchment, with locally increased concentrations of cobalt and nickel also observed. The Pollution Load Index (PLI) values are 0.48 for both surface and subsurface soils—both below 1.00. From the perspective of the integrated load of multiple heavy metals (PLI), the overall cumulative contamination level in the soils of this catchment remains low and has not yet developed into a systemic or widespread pollution condition. The PLI value is well below the threshold of 1.00, indicating that, in terms of the combined multi-element effects, the regional environmental risk is currently within a relatively safe and manageable range.

Table 6-18: Top soil (0-10 cm)

DESCRIPTION	Co	Cu	Ni
	µg/g	µg/g	µg/g
WHO/FAO Thresholds	50	100	50
Sample Size	54	54	54
Minimum	0.61	53.06	0.002
Maximum	128.3	800.38	65.17
Average	12.9	177.67	12.24
Exceedance Ratio	6%	74%	2%
Average Contamination Index	0.26	1.78	0.24
Pollution Load Index	0.48		

Table 6-19: Subsoil (10-30 cm)

DESCRIPTION	Co	Cu	Ni
	µg/g	µg/g	µg/g
WHO/FAO Thresholds	50	100	50
Sample Size	47	47	47
Minimum	0.001	0.01	0.002
Maximum	66.429	153.89	1015.44
Average	7.91	64.92	53.81
Exceedance Ratio	2%	13%	9%
Average Contamination Index	0.16	0.65	1.08
Pollution Load Index	0.48		

Copper is slightly higher but not to alarming levels as in Chambishi and the tailings dam and in exceptional cases Nickel and Cobalt have shown some elevated levels in 10 percent of the samples.

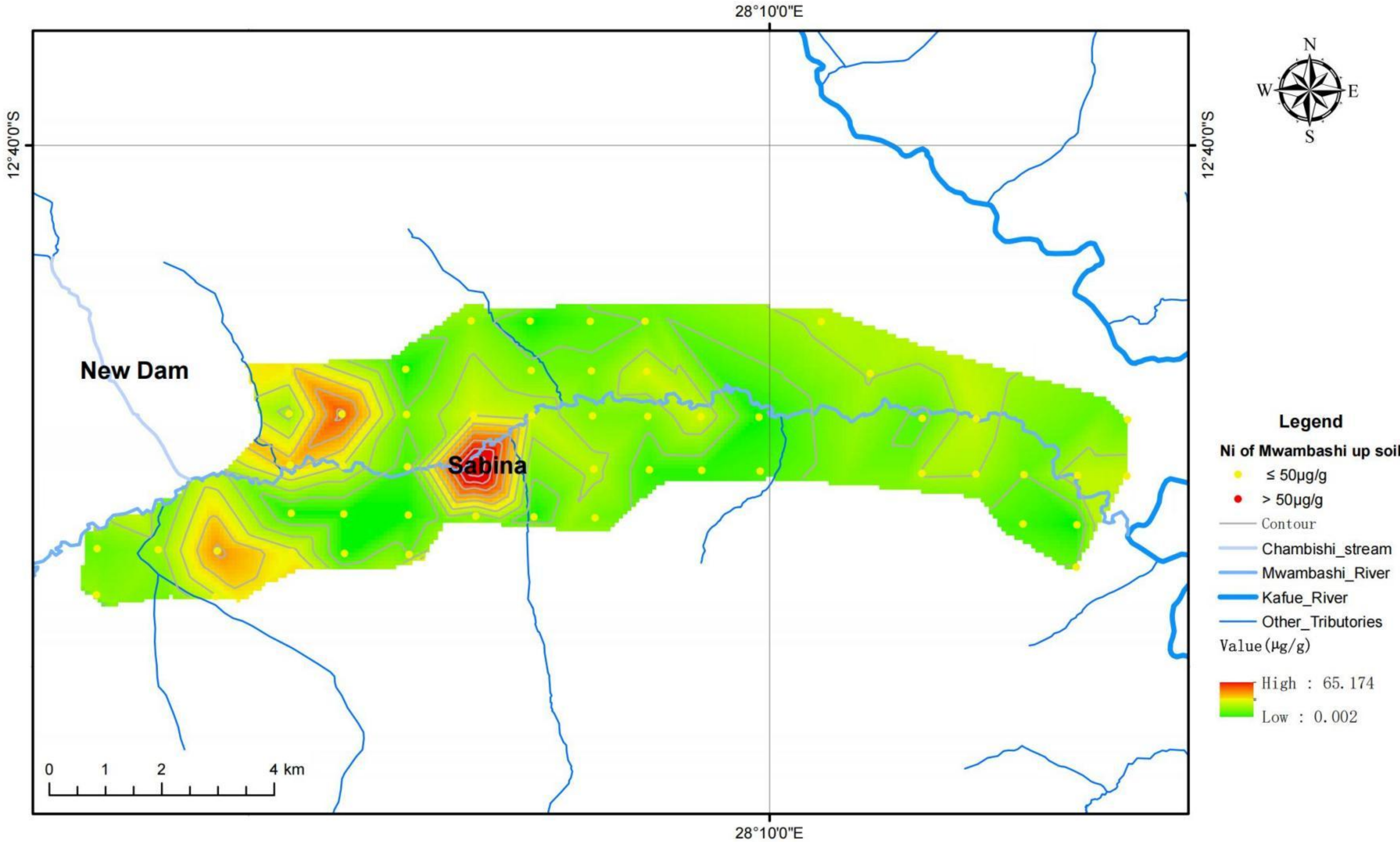


Figure 6-22: Distribution of Nickel in Mwambashi River

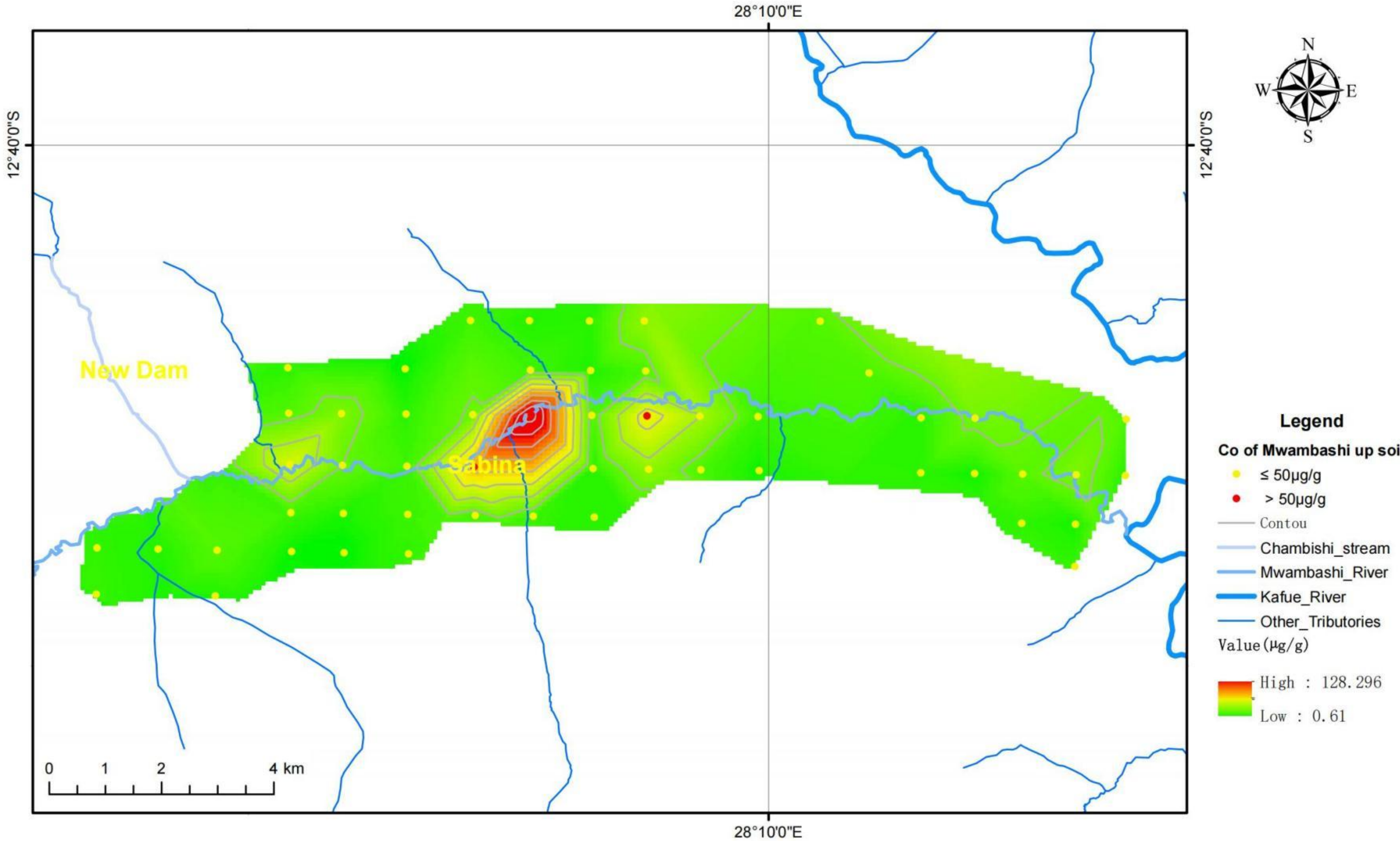


Figure 6-23: Mwambashi Topsoil Cobalt Spatial Distribution

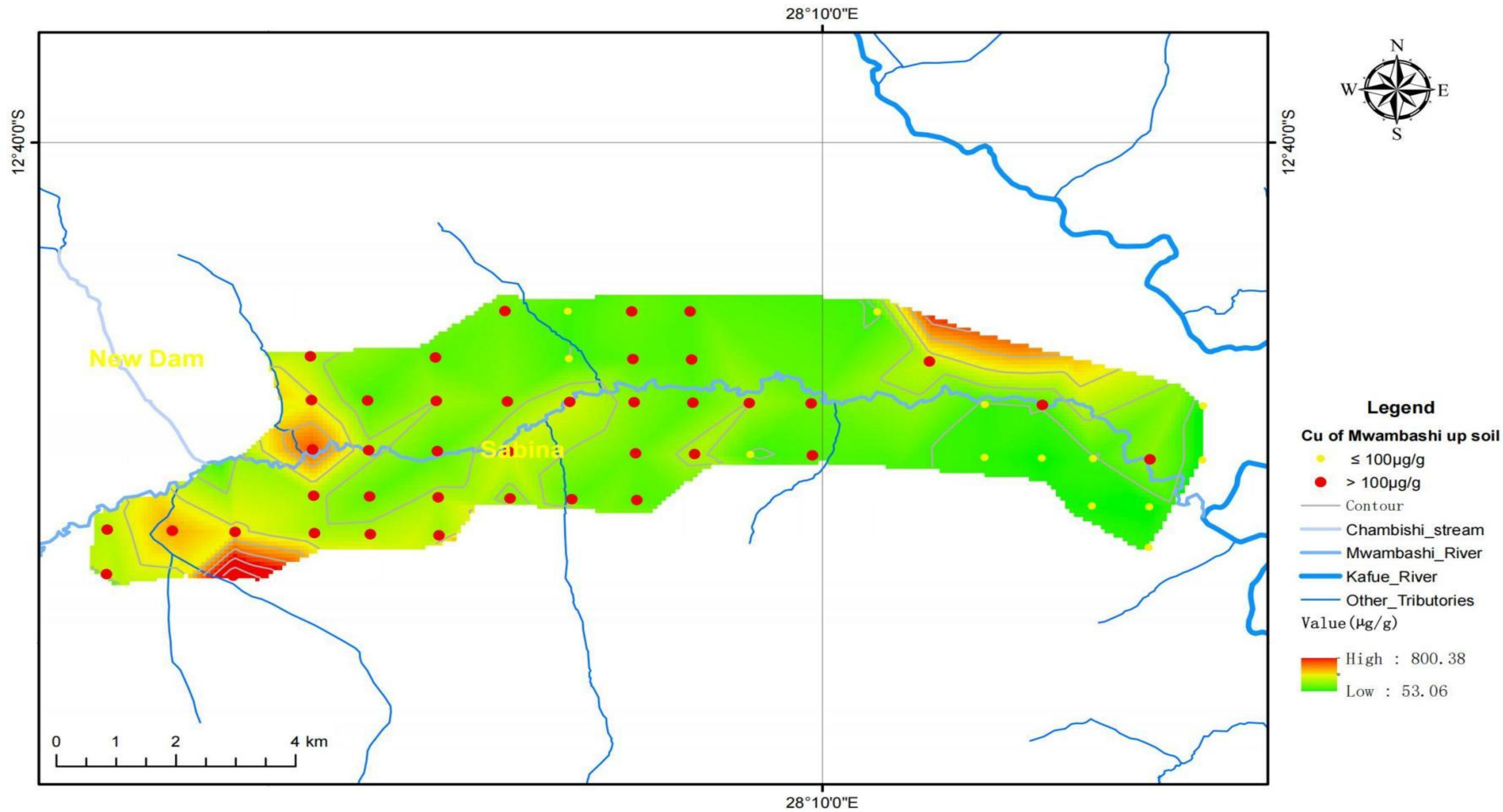


Figure 6-6: Distribution of Copper in Mwambashi River

b) Control Sample Results Analysis

The soil element concentrations exceeding FAO/WHO limits in the control zone of the Mwambashi River catchment are summarized in the table below. As shown in the table, copper is the primary contaminant in both surface and subsurface soils, followed by cadmium and lead. The pollution load index (PLI) for surface soil is 0.57, while that for subsurface soil is 1.67. Although both values exceed 1.00, the higher contamination level in subsurface soil compared to surface soil suggests that the source may be attributed to long-term geological enrichment or residual pollution from historical mining activities, rather than solely from recent events.

Table 6-20: Top soil (0-10 cm)

DESCRIPTION	Cd	Co	Cu	Pb
	µg/g	µg/g	µg/g	µg/g
WHO/FAO Thresholds	3	50	100	100
Sample Size	29	29	29	29
Minimum	0	0.936	90.4	6.97
Maximum	6.653	53.811	1741.64	430.93
Average	1.18	5.94	243.15	65.51
Exceedance Ratio	14%	3%	90%	14%
Average Contamination Index	0.39	0.12	2.43	0.66
Pollution Load Index	0.57			

Table 6-21: Subsoil (10-30cm)

DESCRIPTION	Cu	Pb
	µg/g	**µg/g**
WHO/FAO Thresholds	100	100
Sample Size	22	22
Minimum	33.6	18.51
Maximum	2012.62	485.37
Average	218.25	127.53
Exceedance Ratio	59%	36%
Average Contamination Index	2.18	1.28
Pollution Load Index	1.67	

In Mwambashi area, the control sample sites sampled showed that there is still an elevated amount of copper in 90 percent of the cases and this seems to be the inherent property of the soils around this region. Also note that the average variance above the threshold in the top soil, which is the most affected, is 1.75, slightly lower than the samples collected from near the river, which is 1.77. This shows that the soils around the Mwambashi catchment are not really polluted from the incidence alone but there could be other sources.

6.4.3.4 The Kafue buffer zone

a) ESIIA Results Analysis

The soil element concentrations exceeding FAO/WHO limits in the potential impact zone of the Kafue Buffer Zone are summarized in the table below. As shown in the table, cobalt and copper exhibit the highest exceedance rates within the buffer zone. The coefficient of variation for copper is 1.96, indicating that the elevated concentrations of these elements in the soil cannot be attributed solely to geological characteristics. Locally elevated levels of lead and manganese are also observed. The pollution load index (PLI) is 1.11 for surface soil and 0.75 for subsurface soil, suggesting an overall low to moderate contamination level.

Copper concentrations in surface soil are significantly elevated, far exceeding the prescribed limits. Although cobalt levels slightly surpass the threshold, they generally remain low. Lead concentrations are higher than those in the reference area but still below the regulatory limits.

Table 6-22: Top soil (0-10 cm)

DESCRIPTION	Cd	Co	Cu	Pb	Mn
	µg/g	µg/g	µg/g	µg/g	µg/g
WHO/FAO Thresholds	3	50	100	100	2000
Sample Size	85	85	85	85	85
Minimum	0.001	0.42	2.97	3.67	31.89
Maximum	5.30	1371.02	9708.12	105.84	5806.66
Average	1.14	139.51	1520.93	35.78	577.75
Exceedance Ratio	15%	28%	53%	1%	4%
Average Contamination Index	0.38	2.79	15.21	0.36	0.29
Pollution Load Index	1.11				

Table 6-23: Subsoil (10-30cm)

DESCRIPTION	Cd	Co	Cu	Ni	Pb	Mn
	µg/g	µg/g	µg/g	µg/g	µg/g	µg/g
WHO/FAO Thresholds	3	50	100	50	100	2000
Sample Size	92	92	92	92	92	92
Minimum	0.001	0.307	3.12	0.002	3.7	14.22
Maximum	10.212	1112.543	9762.21	58.771	100.52	3824.59
Average	1.01	96.17	1195.66	13.02	33.86	420.18
Exceedance Ratio	15%	22%	41%	2%	1%	3%
Average Contamination Index	0.34	1.92	11.96	0.32	0.34	0.21
Pollution Load Index	0.75					

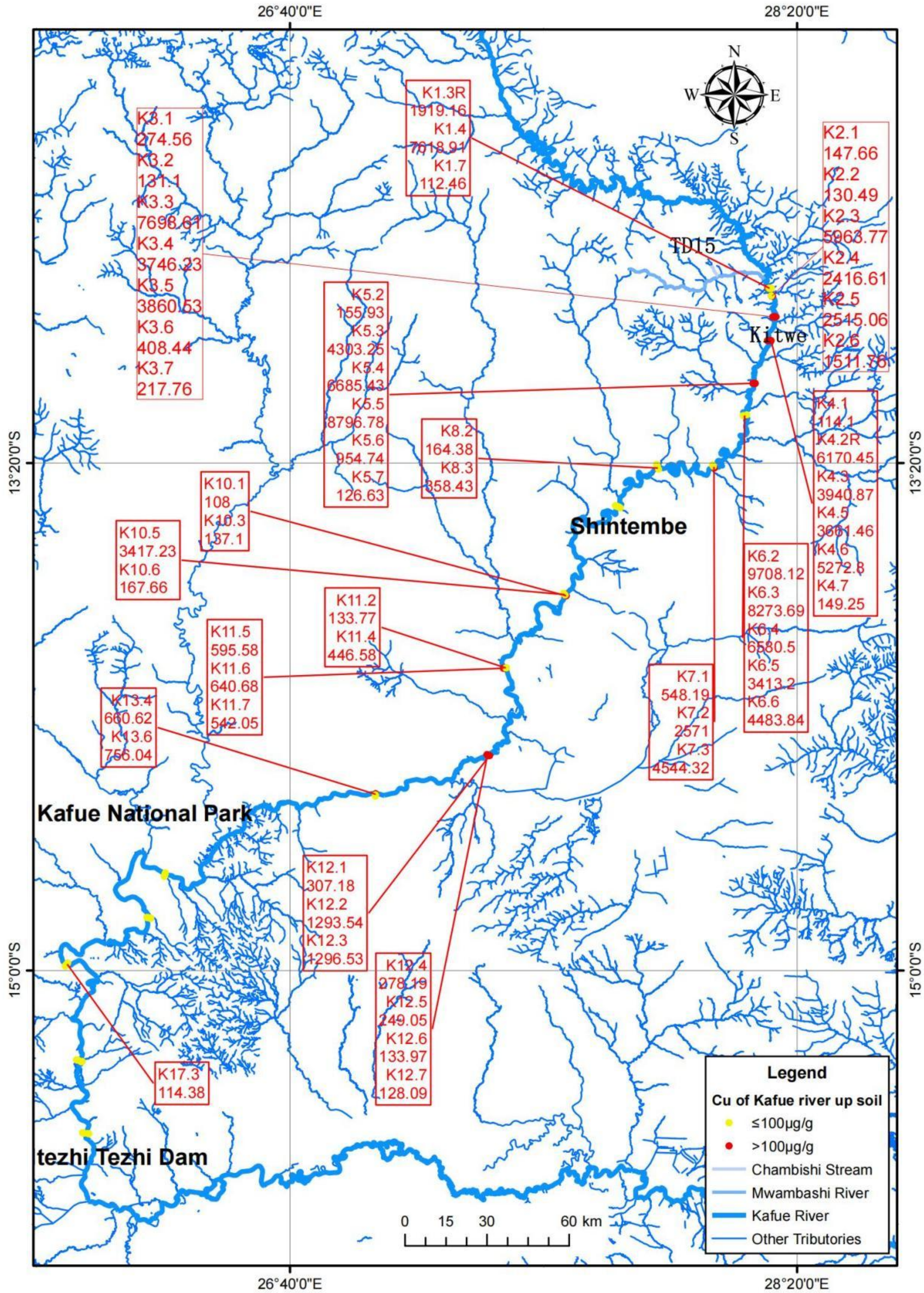


Figure 6-7: Distribution of Copper in Kafue River

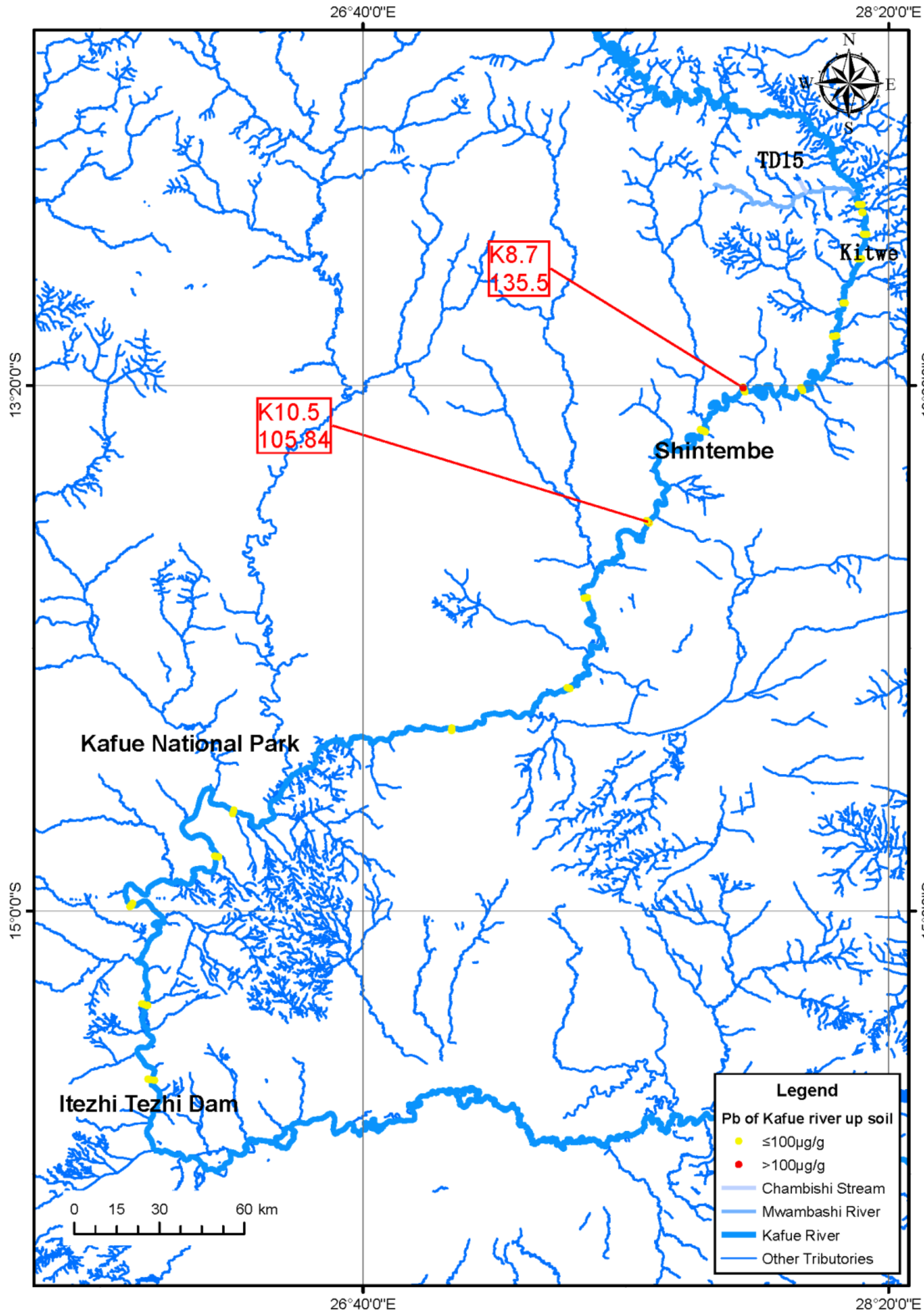


Figure 6-8: Distribution of Lead in Kafue River

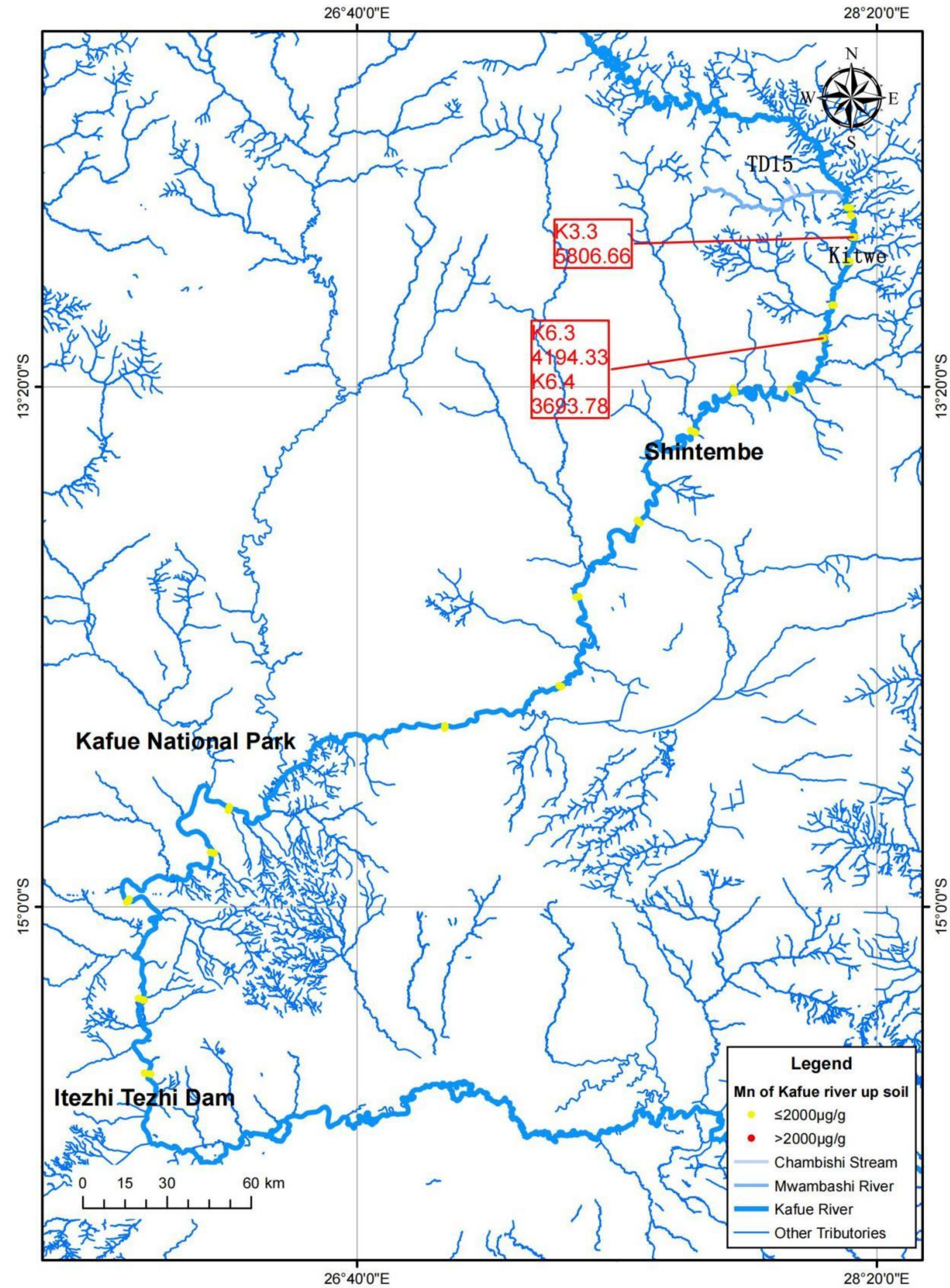


Figure 6-9: Distribution of Manganese in Kafue River

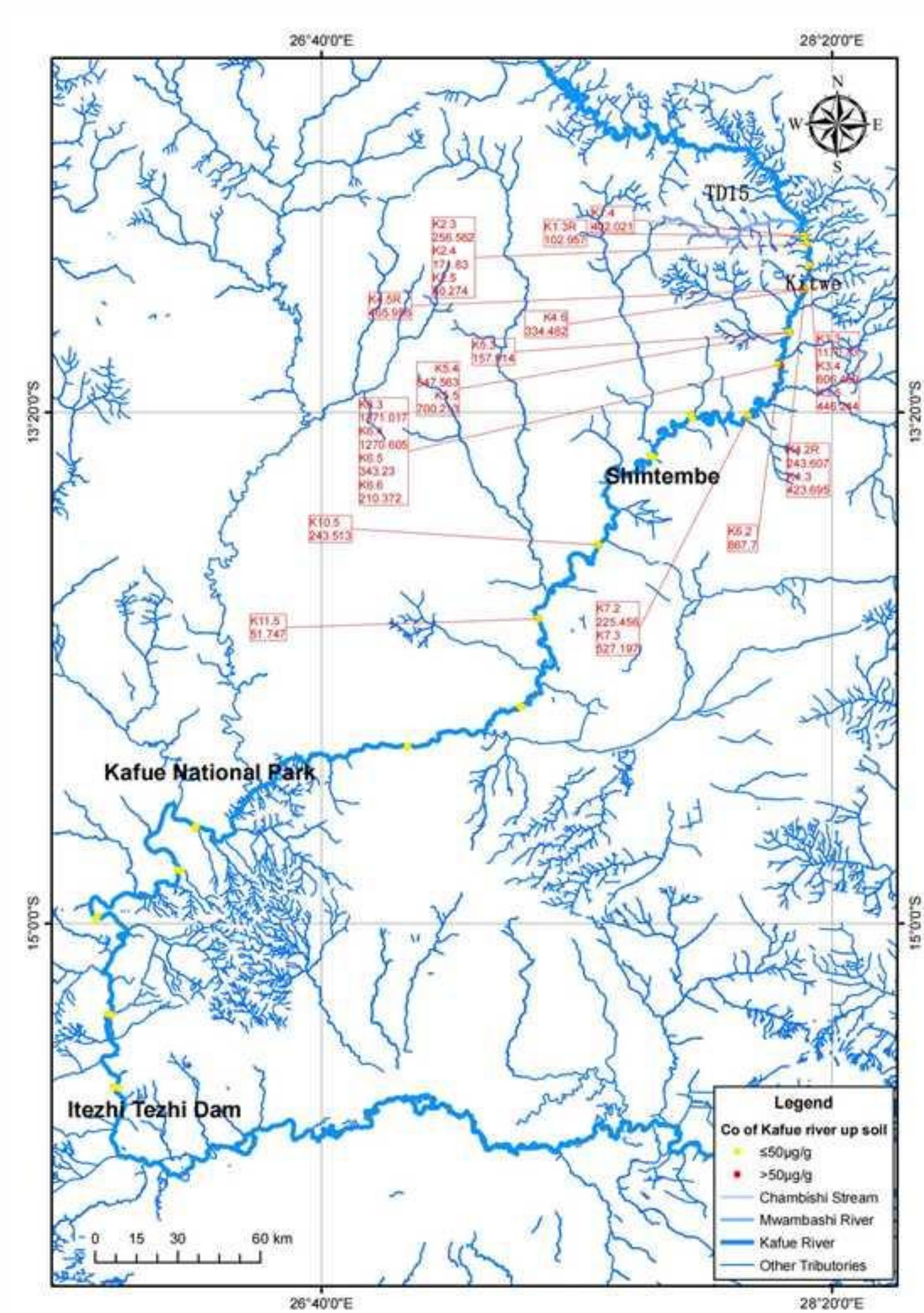


Figure 6-27: Distribution of Cobalt in Kafue River

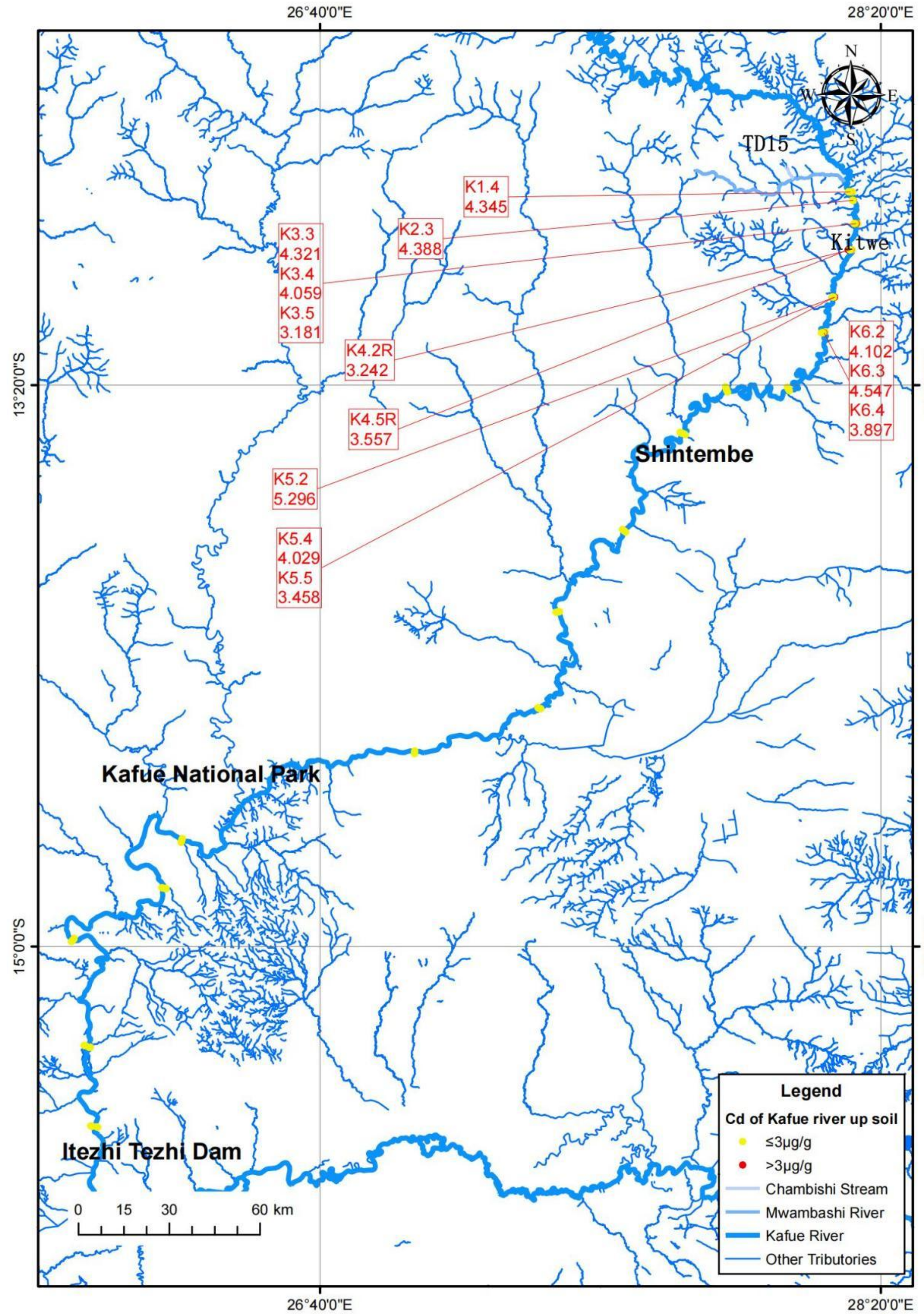


Figure 6-108: Distribution of Cadmium in Kafue River

b) Control Sample Results Analysis

At sampling sites located away from the Kafue River (control samples), some areas still exhibited relatively high copper concentrations in the surface layer, with average levels exceeding the WHO/FAO limits, while the average copper concentration in the subsurface layer was markedly lower than that of the surface. The pollution load index for the surface layer was 0.54, and 0.29 for the subsurface layer, indicating that the soils in this area are relatively clean but have been affected to some extent by input-related contamination.

Table 6-24: Top soil (0-10 cm)

DESCRIPTION	Cu	Pb
	µg/g	**µg/g**
WHO/FAO Thresholds	100	100
Sample Size	37	37
Minimum	4.55	3.18
Maximum	756.04	135.5
Average	112.69	25.87
Exceedance Ratio	35%	3%
Average Contamination Index	1.13	0.26
Pollution Load Index	0.54	

Table 6-25: Subsoil (10-30cm)

DESCRIPTION	Cu	Pb	Mn
	µg/g	µg/g	µg/g
WHO/FAO Thresholds	100	100	2000
Sample Size	32	32	32
Minimum	4.75	2.47	16.02
Maximum	554.67	351.72	2121.06
Average	69.90	34.26	242.59
Exceedance Ratio	20%	3%	6%
Average Contamination Index	0.70	0.34	0.10
Pollution Load Index	0.29		

6.4.3.5 Verification Sample Results

As stated in the sampling criteria; these samples were collected from areas which have little or no interaction with the Sino-Metals waste water. They were collected from the upstream of the Mwambashi before the confluence with Chambishi and others from a stream area whose source is near neighboring industries. As shown in the table, there is also an elevation of Copper, Lead and cadmium; this indicates a possible source of the pollution in the area.

Table 6-26: Top soil (0-10 cm)

STATS	Al (µg/g)	As (µg/g)	B (µg/g)	Ca (µg/g)	Cd (µg/g)	Co (µg/g)	Cr (µg/g)	Cu (µg/g)	Mg (µg/g)	Ni (µg/g)	Pb (µg/g)	Se (µg/g)	Zn (µg/g)	Mn (µg/g)	SO_4^{2-} (µg/g)	pH	EC (µS/cm)
Mean	14895.2	2.1	10.9	1430.5	1.7	3.4	20.0	175.8	724.2	5.8	41.5	9.0	7.4	91.4	805.2	6.2	20.4
Min	7991.3	0.3	2.6	417.6	0.3	1.1	4.1	90.4	474.9	0.0	7.0	0.1	0.6	19.3	163.7	5.8	12.0
Max	33081.5	6.9	40.8	4078.0	6.7	6.1	67.3	350.8	1193.7	22.9	165.1	40.3	20.4	332.9	3055.4	6.6	32.0
Heavy Metal threshold				200	<3	**<50**		<100	50	**<50**	<100		**<300**	**<2000**			

Table 6-27: Subsoil (10-30cm)

STATS	Al (µg/g)	As (µg/g)	B (µg/g)	Ca (µg/g)	Cd (µg/g)	Co (µg/g)	Cr (µg/g)	Cu (µg/g)	Mg (µg/g)	Ni (µg/g)	Pb (µg/g)	Se (µg/g)	Zn (µg/g)	Mn (µg/g)	SO_4^{2-} (µg/g)	pH	EC (µS/cm)
Mean	15868.6	2.0	12.5	1159.8	1.9	2.0	21.5	68.4	688.1	8.0	45.2	7.0	6.4	76.7	836.3	6.3	12.7
Min	7991.3	0.4	3.2	217.0	0.3	0.9	4.1	25.2	399.0	1.1	9.7	0.4	0.2	13.8	212.2	5.8	6.0
Max	33352.2	6.1	52.6	2659.0	8.8	4.9	80.9	160.4	1541.4	14.9	213.5	34.4	20.4	362.9	2359.0	6.6	20.0
WHO/FAO Thresholds				200	<3	**<50**		<100	50	**<50**	<100		**<300**	**<2000**			

6.4.3.6 Summary on the Assessment of Polluting Parameters in The Environment

Copper and Cobalt are present in excess amounts than the thresholds in all the sites; in the top soil copper is higher at the tailings dam and reduces according to distance up to Itezhi-tezhi. The other elements vary from site to site, indicating the influence of geological factors, soil characteristics and other sources of the elements. The graphs and maps in the following sections show the location and levels of contamination of each of the parameters in each of the catchment areas. Comparison has also been made to the results of control sites in each of the areas.

The red cells in the table represent the percentage of sampling sites where elemental concentrations exceeded the FAO/WHO standard thresholds, while blank cells indicate no exceedance. Although the tailings dam shows high contamination levels, it exhibits fewer types of exceeding elements compared to the Chambishi catchment. The Mwambashi catchment has even fewer contaminated elements, suggesting a dilution or attenuation effect downstream. However, the Kafue buffer zone shows a resurgence in the number of elements exceeding thresholds—particularly for metals such as manganese, lead, and cadmium—which are not dominant at the tailings dam site.

This pattern indicates that the contamination in the Kafue buffer zone is not solely attributable to direct discharge from the upstream tailings dam. Instead, it suggests the influence of additional local sources, such as geological background enrichment, historical mining activities, or other anthropogenic inputs within the Kafue area. Therefore, pollution assessment should consider both regional geology and localized factors, rather than assuming a simple downstream propagation from the tailings dam.

Table 6-28: Percentage of the sites with more elements than the standard thresholds (FAO/WHO)

Site		Al	As	B	Ca	Cd	Co	Cr	Cu	Mg	Ni	Pb	Se	Zn	Mn	SO_4^{2-}	pH	EC
Tailings Dam	Top Soil					0.9	12.1		97.2			0.9						
	Sub Soil						3.4		58.6									
Chambishi Catchment	Top Soil					11.7	17.5		94.2		4.4	4.4		4.4	2.2			
	Sub Soil					17.5	11.4		67.5		3.6	6.6		2.4	1.2			
Mwambashi Catchment	Top Soil						5.6		70.4		1.9							
	Sub Soil						2.1		12.8		8.5							
Kafue Buffer Zone	Top Soil					15.3	28.2		52.9			1.2			3.5			
	Sub Soil					15.2	21.7		41.3		2.2	1.1			3.3			

Table 6-29: Summary of Average Results

Assessment Area	Depth of Sample	**Al (µg/g)**	**As (µg/g)**	**B (µg/g)**	**Ca (µg/g)**	**Cd (µg/g)**	**Co (µg/g)**	**Cr (µg/g)**	**Cu (µg/g)**	**Mg (µg/g)**	**Ni (µg/g)**	**Pb (µg/g)**	**Se (µg/g)**	**Zn (µg/g)**	**Mn (µg/g)**	**SO_4^{2-} (µg/g)**	**pH**	**EC (µS/cm)**
TD 15	ESIIA Top	11463.3	0.9	0.4	2477.3	0.4	27.5	26.9	457.7	1434.7	3.6	9.9	9.4	19.0	131.3	770.0	6.4	29.5
	ESIIA Sub	11969.2	0.7	1.1	2101.5	0.4	14.3	24.1	219.5	1311.9	4.3	9.0	8.4	12.0	102.2	711.5	6.4	21.0
	Control Top	11249.8	9.2	16.1	5906.7	2.3	145.0	24.1	1463.0	1838.3	10.3	81.6	8.7	84.4	158.0	2082.6	6.4	128.5
	Control Sub	12056.2	3.9	12.1	2842.8	1.5	41.9	16.8	348.3	856.4	3.2	61.9	4.9	18.7	93.1	1268.7	6.5	113.3
Chambishi Watershed	ESIIA Top	18704.8	7.5	44.8	8574.3	0.8	292.5	62.0	1296.2	6218.4	12.0	35.2	15.8	80.8	507.1	8924.1	6.4	170.7
	ESIIA Sub	20343.4	12.6	32.6	7085.0	1.3	171.8	72.6	1266.2	4565.4	12.8	48.0	20.7	51.8	347.4	8685.2	6.4	115.3
	Control Top	24383.1	5.6	4.7	3062.5	0.8	13.0	82.7	311.2	2060.0	19.7	127.2	10.6	32.6	353.5	1478.6	6.2	16.3
	Control Sub	26286.6	6.7	4.9	2569.5	0.8	9.0	103.2	116.6	1680.3	20.6	147.6	9.5	26.1	290.8	1471.7	6.2	11.0
	Verification Sub	15687.9	11.2	25.5	5276.6	4.2	99.3	51.2	1116.3	8067.9	17.4	119.3	10.0	92.3	276.9	4371.0	6.2	402.8
	Comparison Sub	15883.5	10.7	24.6	6395.2	3.8	168.1	72.0	1217.3	7676.1	17.5	119.2	13.6	79.7	291.9	3805.8	6.3	330.9
Mwambashi Watershed	ESIIA Top	12121.2		9.4	2300.1	0.1	12.9	56.0	177.7	1234.2	12.2	6.2	4.9	21.0	236.4	706.1	6.4	
	ESIIA Sub	14562.9		45.6	1422.3	0.2	7.9	48.1	64.9	970.3	53.8	5.5	10.2	15.5	176.0	658.7	6.4	
	Control Top	15613.1	2.3	7.5	2296.9	1.2	5.9	34.8	243.2	1078.5	8.6	65.5	8.5	14.4	158.6	1092.9	6.3	22.4
	Control Sub	18440.0	5.5	3.4	2452.6	0.5	8.2	101.0	218.3	1275.8	16.2	127.5	10.8	23.5	257.0	1750.6	6.4	13.1

	Verification Top	14895.2	2.1	10.9	1430.5	1.7	3.4	20.0	175.8	724.2	5.8	41.5	9.0	7.4	91.4	805.2	6.2	20.4
	Verification Sub	15868.6	2.0	12.5	1159.8	1.9	2.0	21.5	68.4	688.1	8.0	45.2	7.0	6.4	76.7	836.3	6.3	12.7
Kafue Buffer Zone	ESIIA Top	10867.5	4.2	4.1	7076.9	1.1	139.5	37.9	1520.9	5746.7	13.9	35.8	13.0	48.5	577.8	1926.6	6.4	97.8
	ESIIA Sub	11310.6	3.9	5.5	7639.9	1.0	96.2	37.3	1195.7	5646.5	13.0	33.9	10.4	39.6	420.2	1460.7	6.5	54.5
	Control Top	7741.8	3.2	2.0	3405.4	0.6	6.7	37.1	124.2	1548.0	6.5	23.3	12.2	19.0	183.4	1451.1	6.6	54.7
	Control Sub	9576.9	6.0	5.2	13037.5	0.6	6.8	41.8	69.9	2473.9	6.9	34.3	11.2	18.8	202.8	1241.0	6.6	42.9
WHO/FAO Thresh holds					200	**<3**	**<50**		**<100**	50	**<50**	**<100**		**<300**	**<2000**			

6.4.4 Determination of baseline value of soil environment

6.4.4.1 Methodology

Control areas were established beyond the impacted perimeter of the Zone surrounding TD 15, the Chambishi Stream Sub-Catchment, and the Mwambashi River Watershed, positioned at optimal proximity to pollution assessment sectors. These designated zones functioned as reference points for establishing soil quality baselines from where a total of 67 surface soil samples (0-10 cm depth) were collected for the purpose of calculating the regional baseline value. Comprehensive statistical analysis of the baseline datasets enabled the determination of environmental baseline values for principal contaminants across the three monitored sectors: Zone Surrounding TD 15, Chambishi Stream Sub-Catchment, and Mwambashi River Watershed. The methodology is as follows:

a) For data which follows a normal distribution, when contamination or damage leads to an increase in the evaluation index, the baseline is set at the upper 90% reference value of the control data (arithmetic mean + 1.65 * standard deviation). When contamination or damage results in a decrease in the evaluation index, the baseline for soil environmental conditions is set at the lower 90% reference value of the control data (arithmetic mean-1.65 * standard deviation).

b) For data which does not follow a normal distribution, when contamination or damage leads to the increase of evaluation indicators, the 90th percentile of the control data is used as the baseline; when contamination or damage leads to the decrease of evaluation indicators, the 10th percentile of the control data is used as the baseline value of soil environment.

6.4.4.2 Normality Test and T-Test

The normality test is used to evaluate whether there is a statistically significant difference between the population represented by a sample and the theoretical normal distribution. It is a fundamental and widely applied assumption in parametric statistical analysis. Commonly used normality tests include: the Kolmogorov-Smirnov test and its modified version, the Lilliefors test, both based on comparisons of the empirical distribution function; the Anderson-Darling test, which uses a quadratic-form statistic and is particularly sensitive to deviations in the tails of the distribution; and the Shapiro-Wilk test, often interpreted alongside Q-Q plots and generally considered to have high statistical power for small to moderate sample sizes.

In this study, the Kolmogorov-Smirnov test was performed on the original measurement data using SPSS Statistics 17.0 to assess normality. If the resulting p-value was greater than 0.05, the data were considered approximately normally distributed; otherwise, they were deemed to deviate significantly from normality.

The t-test is a commonly used hypothesis testing method designed to determine whether there is a statistically significant difference between the means of two groups. Following the assessment of normality, an independent samples t-test was conducted to compare the mean concentrations of heavy metals between two groups (e.g., Background Reference Area versus affected area). When the assumption of homogeneity of variances was violated—as determined by Levene's test—the Welch-corrected t-test was applied to improve the reliability of inference under conditions of heteroscedasticity.

a) Zone Surrounding TD 15

i) Normality Test

The primary soil contaminants in the TD 15 areas are Cd, Co, Cu, and Pb. The Kolmogorov-Smirnov normality test results for baseline soil data indicate that none of the sample results ($p<0.05$) follow a normal distribution. The frequency histograms and standard Q-Q plots for each contaminant are presented in Figures 6-29 to 32.

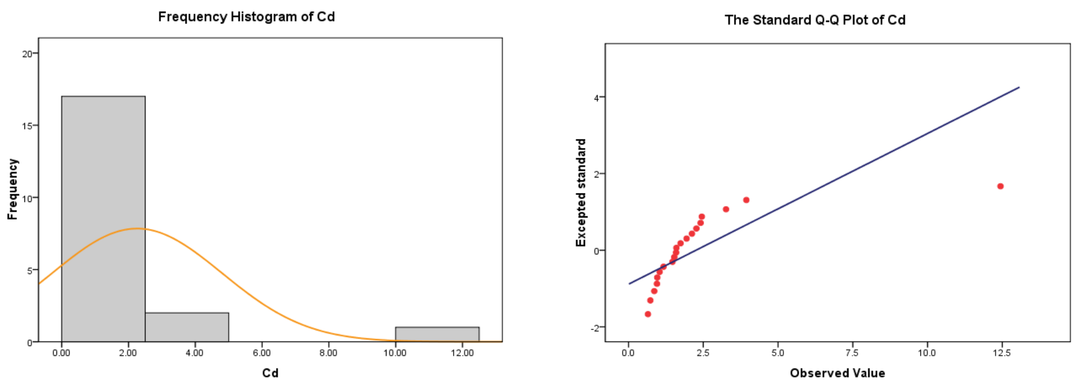


Figure 6-11: Frequency histogram and Q-Q diagram of Cd

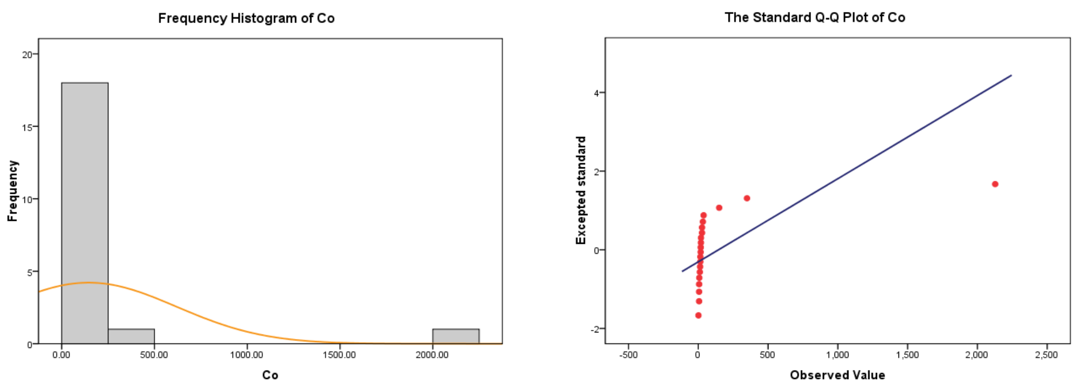


Figure 6-12: Frequency histogram and Q-Q diagram of Co

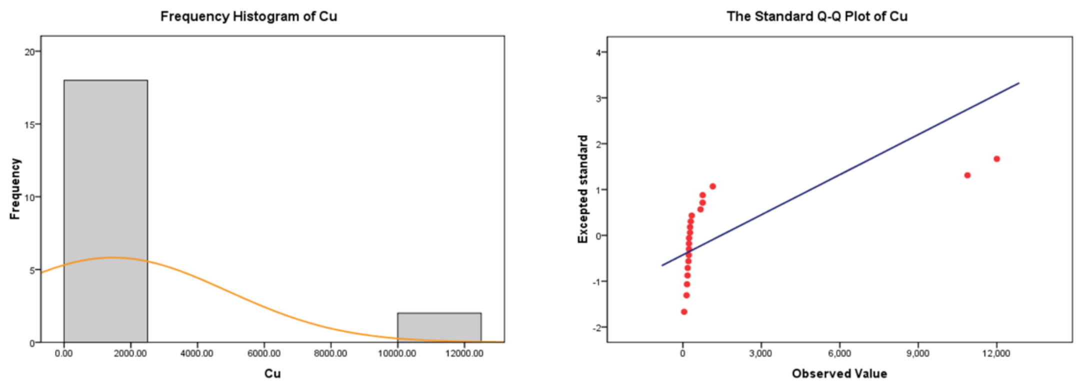


Figure 6-13: Frequency histogram and Q-Q diagram of Cu

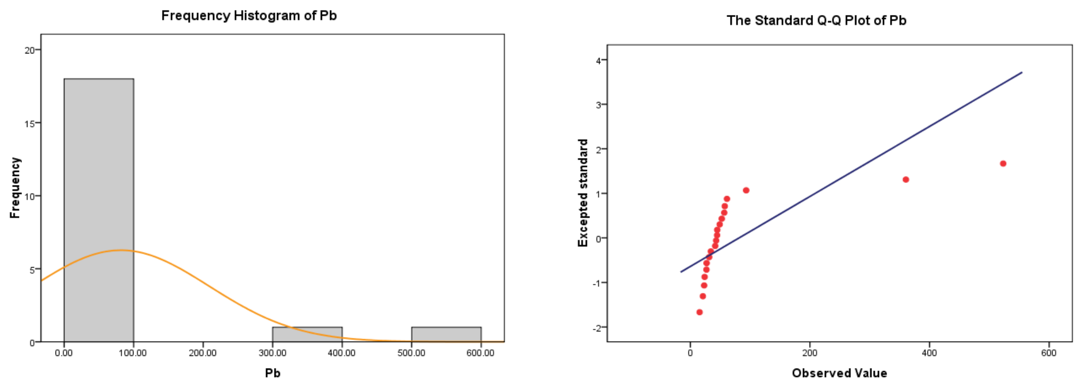


Figure 6-14: Frequency histogram and Q-Q diagram of Pd

ii) T-Test (independent 2-Sample test)

To evaluate the characteristics of heavy metal contamination in soils between the Background Reference Area (n = 20) and the surrounding area of TD 15 (n = 107), an independent samples t-test was conducted for four elements: Cd, Co, Cu, and Pb. Levene's test for equality of variances indicated significant heterogeneity of variances for all factors ($p < 0.05$); therefore, Welch's t-test was applied for analysis.

Results showed statistically significant differences between the two groups for Cd and Pb (Cd: $t = 6.308$, $df = 125$, $p < 0.001$; Pb: $t = 5.619$, $df = 125$, $p < 0.001$). The mean Cd concentration in the TD 15 surrounding area (0.37 mg/kg) was approximately one-sixth that of the Background Reference Area (2.26 mg/kg), while Pb concentration (9.94 mg/kg) was about one-eighth of that in the background area (81.59 mg/kg). The 95% confidence intervals for both mean differences excluded zero, confirming statistical significance.

Although the average concentrations of Co (27.49 mg/kg) and Cu (457.68 mg/kg) in the TD 15 surrounding area were markedly lower than those in the Background Reference Area (145.03 mg/kg and 1463.01 mg/kg, respectively), the t-tests did not reach conventional levels of significance (Co: $p = 0.010$; Cu: $p = 0.004$)—likely due to extremely high data dispersion (e.g., the standard deviation of Cu in the background area reached 3427.50), suggesting the presence of localized extreme outliers.

In summary, Cd and Pb are the key pollutants distinguishing the TD 15 surrounding area from the Background Reference Area, with significantly higher concentrations observed in the Background Reference Area.

Table 6-30: Comparison of Heavy Metal Concentrations and T-test Results Between the Background Reference Area and the Surrounding Area of TD 15

Factor	Levene's Test for Equality of Variances (F, p)	t-value	Degrees of Freedom (df)	p-value	Mean Difference (Group 1 – Group 2)	95% Confidence Interval	Interpretation
Cd	F = 11.682, p = 0.001	3.275	19.667	0.004	+1.879	[0.681, 3.077]	Group 1 is significantly higher than Group 2; the difference is highly significant (p < 0.01).
Co	F = 26.249, p < 0.001	1.111	19.015	0.281	+117.542	[–103.983, 339.067]	No significant difference (p > 0.05); insufficient evidence to conclude a difference between groups.
Cu	F = 41.413, p < 0.001	1.310	19.099	0.206	+1005.333	[–600.318, 2610.983]	No significant difference (p > 0.05); although the mean is higher in Group 1, variability is large.
Pb	F = 40.976, p < 0.001	2.513	19.144	0.021	+71.643	[12.001, 131.286]	Group 1 is significantly higher than Group 2 (p < 0.05); the difference is statistically significant.

Note: Levene's test indicated significant heterogeneity of variances for all factors ($p < 0.05$); therefore, the results from the 'unequal variances assumed' row—corresponding to Welch's t-test—were consistently applied.

b) Chambishi Stream Sub-Catchment

i) Normality Test

The primary soil contaminants in the Chambishi Stream Sub-Catchment are Cd, Co, Cu, Ni, Pb, Zn, and Mn. The Kolmogorov-Smirnov normality test results for baseline soil data indicate that the sample results of Cd, Co, and Zn are normally distributed ($p>0.05$), while those of Cu, Ni, Pb, and Mn do not conform to a normal distribution ($p<0.05$). The frequency histograms and standard Q-Q plots for each contaminant are presented in Figures 6-33 to 39.

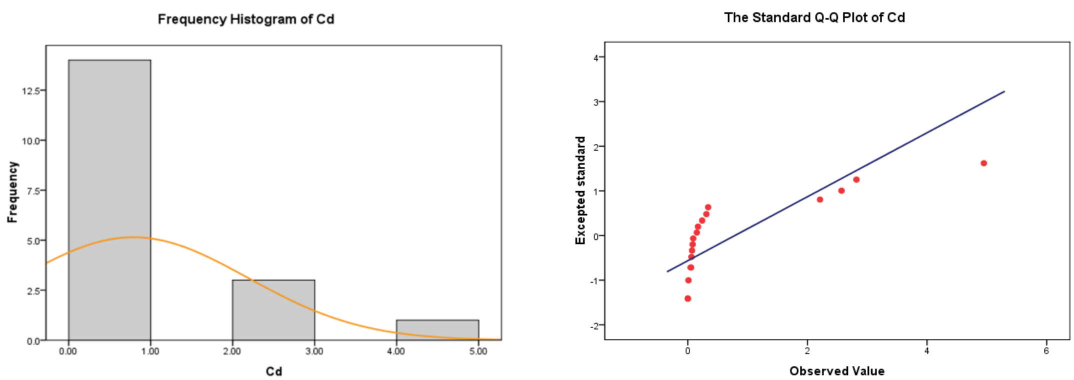


Figure 6-15: Frequency histogram and Q-Q diagram of Cd

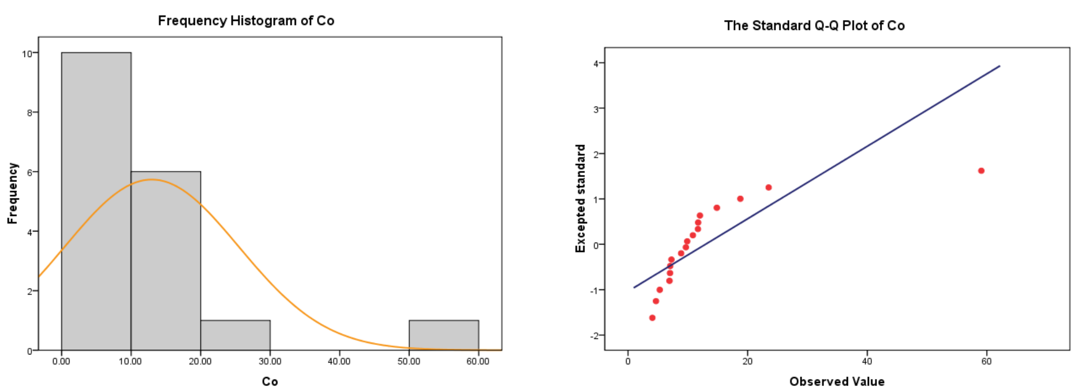


Figure 6-34: Frequency histogram and Q-Q diagram of Co

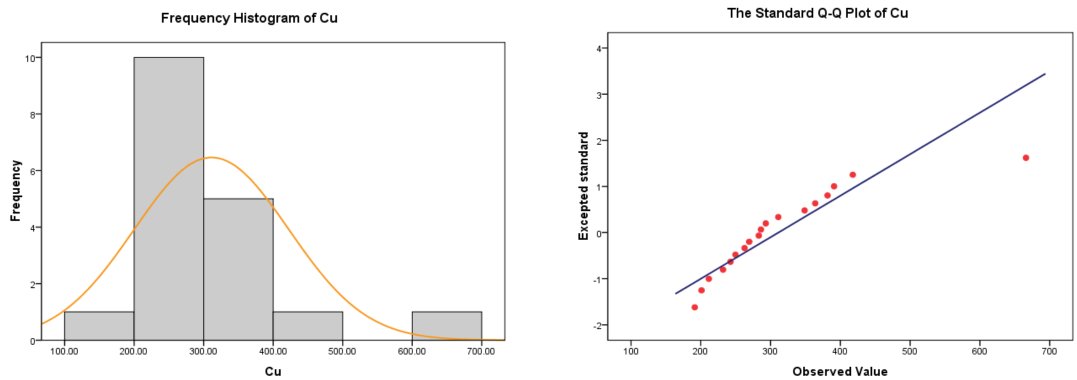


Figure 6-16: Frequency histogram and Q-Q diagram of Cu

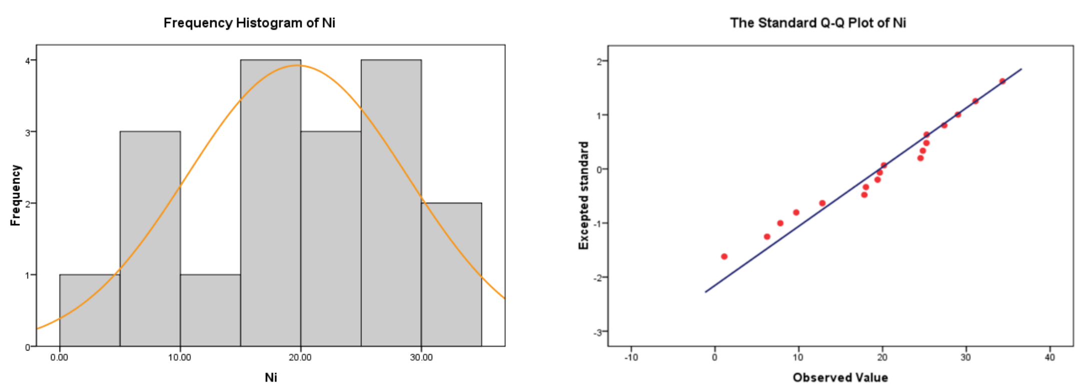


Figure 6-17: Frequency histogram and Q-Q diagram of Ni

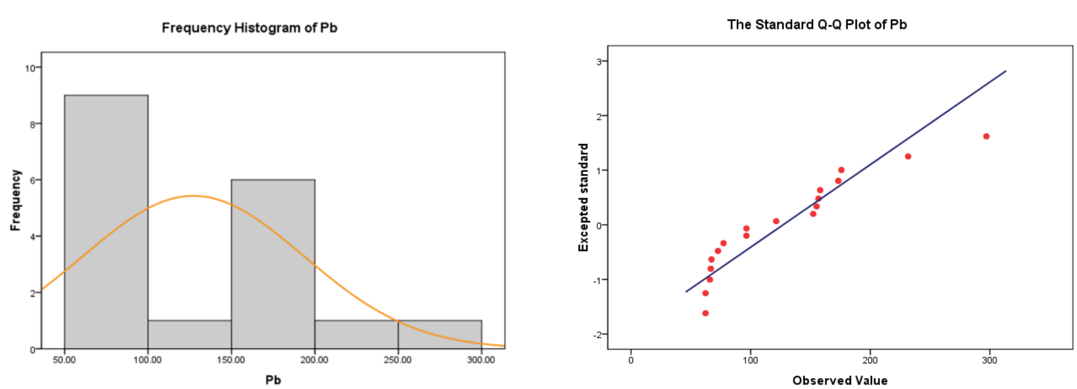


Figure 6-18: Frequency histogram and Q-Q diagram of Pd

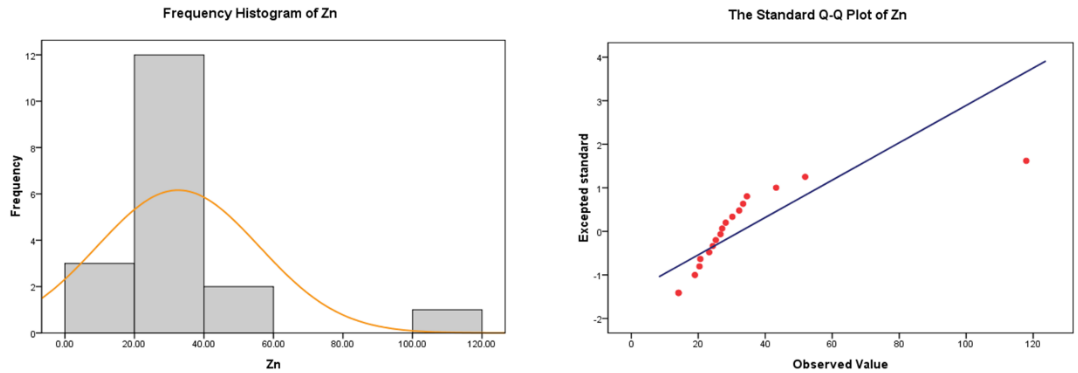


Figure 6-19: Frequency histogram and Q-Q diagram of Zn

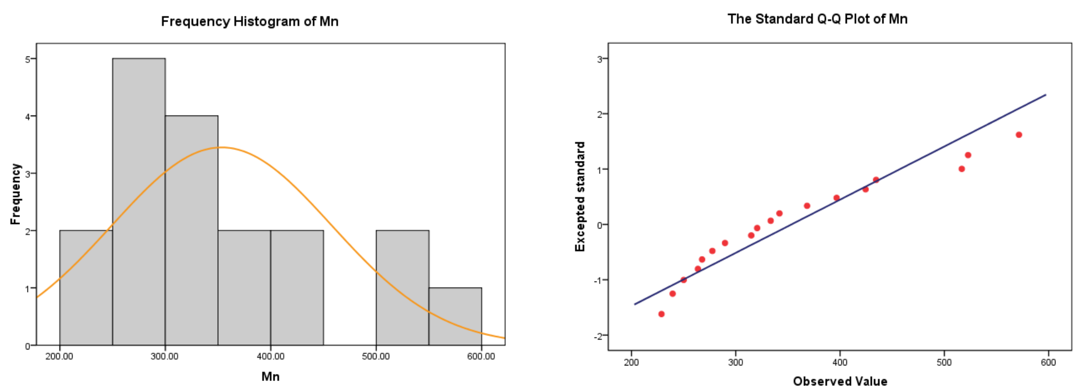


Figure 6-20: Frequency histogram and Q-Q diagram of Mn

ii) T-Test (independent 2-Sample test)

This study conducted independent samples t-tests to analyze the concentration differences of seven heavy metals (Cd, Co, Cu, Ni, Pb, Zn, and Mn) between the 'Background Reference Area' (Group 1, $n = 18$) and the 'affected area' (Group 2, $n = 137$). Levene's test for equality of variances indicated significant heterogeneity for most factors ($p < 0.05$), except for Cd ($p = 0.633$) and Pb ($p = 0.624$). Therefore, results from either the 'equal variances assumed' or Welch's t-test ('unequal variances assumed') were interpreted based on these premises.

The findings reveal that concentrations of Cu, Co, Zn, and Mn in the affected area (Group 2) are significantly higher than those in the Background Reference Area (Group 1). Specifically:

The mean Cu concentration in the affected area is as high as 1,296.20 mg/kg (vs. 311.25 mg/kg in the background), with Welch's $t = -4.038$ and $p < 0.001$;

Co shows a mean concentration of 292.47 mg/kg (vs. 12.96 mg/kg in the background), $p = 0.035$;

Zn has a mean concentration of 80.76 mg/kg (vs. 32.58 mg/kg in the background), $p = 0.012$;

Although Mn does not show a statistically significant difference ($p = 0.205$), the trend is consistent with the other elements.

In contrast, Pb and Ni exhibit opposite patterns, with significantly higher concentrations in the Background Reference Area compared to the affected area. Specifically:

Pb has a mean concentration of 127.17 mg/kg (vs. 35.22 mg/kg in the affected area), $p = 0.001$;

Ni shows a mean concentration of 19.68 mg/kg (vs. 12.01 mg/kg in the affected area), $p = 0.030$.

Cd shows no significant difference between the two groups ($p = 0.994$).

It is noteworthy that the affected area exhibits extremely high variability in Co and Cu concentrations (Co SD = 1534.75; Cu SD = 2838.65), indicating localized hotspots or geological heterogeneity. However, the differences between groups remain statistically significant.

In conclusion, Cu, Co, and Zn are the characteristic pollutants in the affected area around Chambishi Stream, showing significant accumulation in this region. Conversely, Pb and Ni are predominantly found at higher levels in the Background Reference Area, possibly due to local bedrock composition or historical land use.

Table 6-31: Comparison of Heavy Metal Concentrations and T-test Results Between the Background Reference Area and the affected area around Chambishi Stream

Factor	Levene's Test for Equality of Variances (F, p)	t-value	Degrees of Freedom (df)	p-value	Mean Difference (Background – Affected Area)	95% Confidence Interval	Interpretation
Cd	F = 0.229, p = 0.633	0.007	153	0.994	+0.004	[–1.00, 1.00]	No significant difference between groups (p > 0.05).
Co	F = 1.984, p = 0.161	–2.131	136.14	0.035	–279.52	[–538.88, –20.15]	Concentration significantly higher in the affected area (p < 0.05).
Cu	F = 8.640, p = 0.004	–4.038	139.04	<0.001	–984.95	[–1467.25, –502.66]	Concentration significantly higher in the affected area (p < 0.001).
Ni	F = 1.151, p = 0.285	2.205	87.09	0.030	+7.669	[0.755, 14.583]	Concentration significantly higher in the background area (p < 0.05).
Pb	F = 0.241, p = 0.624	3.308	153	0.001	+91.95	[37.03, 146.86]	Concentration significantly higher in the background area (p < 0.001).

Factor	Levene's Test for Equality of Variances (F, p)	t-value	Degrees of Freedom (df)	p-value	Mean Difference (Background – Affected Area)	95% Confidence Interval	Interpretation
Zn	F = 2.431, p = 0.121	–2.529	151.80	0.012	–48.18	[–85.83, –10.54]	Concentration significantly higher in the affected area (p < 0.05).
Mn	F = 1.044, p = 0.309	–0.470	153	0.639	–153.58	[–798.65, 491.49]	No significant difference between groups (p > 0.05).

Note: Levene's test indicated significant heterogeneity of variances for most factors ($p < 0.05$); therefore, results from the 'unequal variances assumed' row (i.e., Welch's t-test) were used where appropriate. Mean difference is calculated as Background (Group 1) minus Affected Area (Group 2). A negative value indicates higher concentration in the affected area; a positive value indicates higher concentration in the background.

c) Mwambashi River Watershed

i) Normality Test

The primary soil contaminants in the Mwambashi River Watershed are Co, Cu, Ni. The Kolmogorov-Smirnov normality test results for baseline soil data indicate that none of the sample results ($p<0.05$) follow a normal distribution. The frequency histograms and standard Q-Q plots for each contaminant are presented in Figures 6-40 to 41.

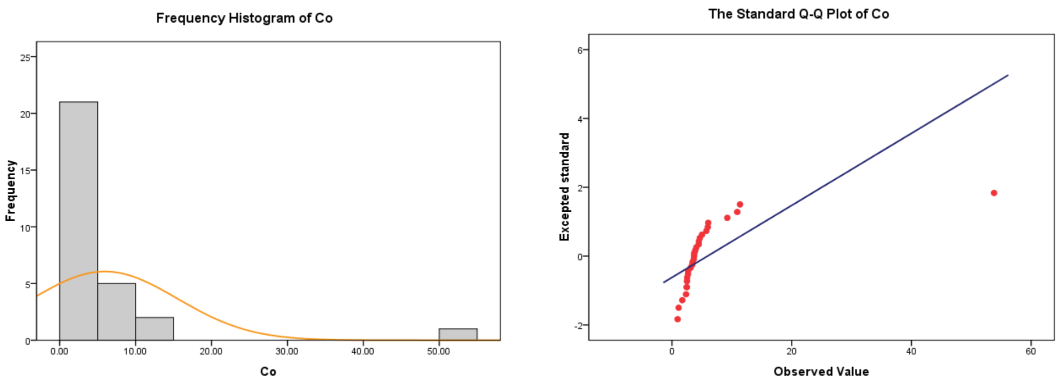


Figure 6-21: Frequency histogram and Q-Q diagram of Co

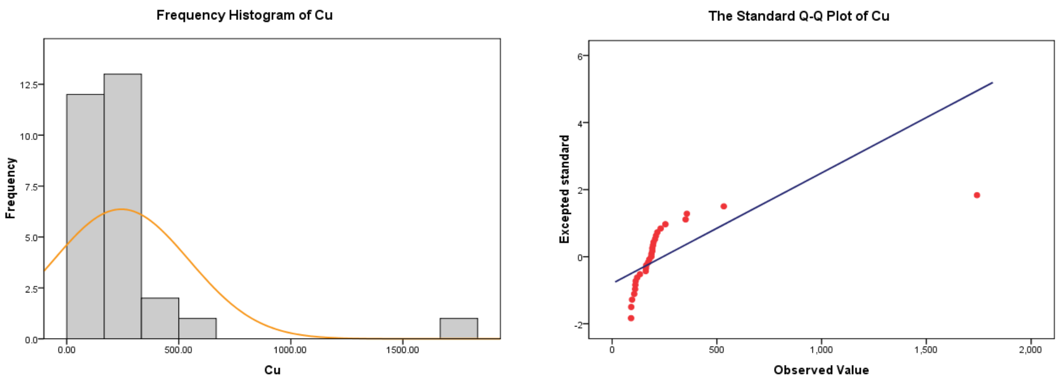


Figure 6-22: Frequency histogram and Q-Q diagram of Cu

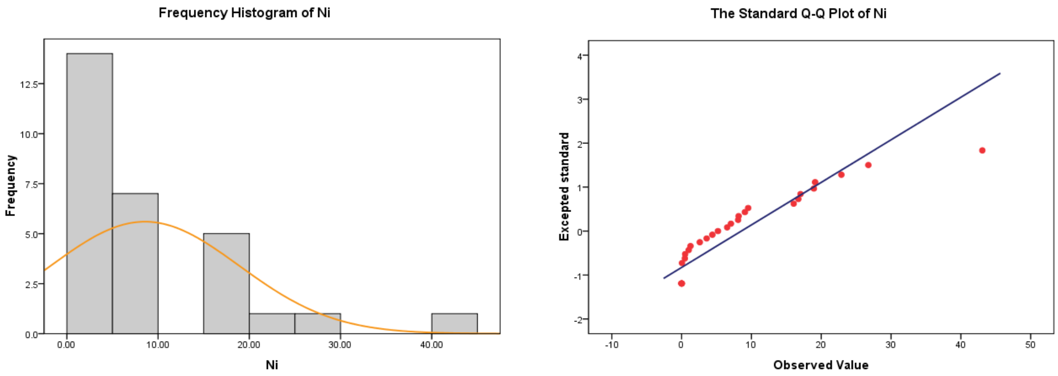


Figure 6-42: Frequency histogram and Q-Q diagram of Ni

ii) T-Test (independent 2-Sample test)

This study conducted independent samples t-tests to examine the concentration differences of five heavy metals—Co, Cu, Ni, Cd, and Pb—in soils around the Mwambashi River between the 'Background Reference Area' (Group 1, n = 29) and the 'affected area' (Group 2, n = 54). Levene's test for equality of variances indicated significant heterogeneity only for Co (p = 0.037), while the assumption of homogeneity was met for the other elements. Accordingly, interpretations were based on either the 'equal variances assumed' or Welch's t-test ('unequal variances assumed') results, as appropriate.

The results show that Cd and Pb concentrations were significantly higher in the Background Reference Area than in the affected area. The mean Cd concentration in the background area was 1.182 mg/kg—substantially greater than the 0.055 mg/kg observed in the affected area (Welch's t = –3.495, df ≈ 28.1, p = 0.002). Similarly, Pb averaged 65.51 mg/kg in the background area—approximately 10.6 times higher than the 6.16 mg/kg in the affected area (Welch's t = –3.470, df ≈ 28.0, p = 0.002). The 95% confidence intervals for both mean differences excluded zero, confirming highly significant differences.

In contrast, Co, Cu, and Ni showed no statistically significant differences between the two groups (p > 0.05).

Notably, the unusually elevated levels of Cd and Pb in the Background Reference Area may indicate that this zone coincides with a historical pollution hotspot, tailings deposit, or a geological unit with naturally high metal background values. Conversely, the affected area along the Mwambashi River exhibits lower concentrations, possibly due to dilution, erosion, or flushing effects from riverine processes. This pattern suggests that the primary pollution source is unlikely to originate from the river itself, but rather from specific upstream or adjacent land-based sources.

Table 6-32: Comparison of Heavy Metal Concentrations and t-test Results Between the Background Reference Area and the affected area along the Mwambashi River

Factor	Levene's Test (p)	t-value	df	p-value	Mean Diff (Affected – Background)	95% CI	Interpretation
Cd	<0.001	3.495	28.06	0.002	+1.126	[0.466, 1.787]	Significantly higher in affected area*
Co	0.037	–2.113	79.88	0.038	–6.966	[–13.527, –0.405]	Slightly lower (marginal)
Cu	0.174	1.388	81	0.169	+65.481	[–28.414, 159.376]	Not significant
Ni	0.671	–1.392	81	0.168	–3.688	[–8.959, 1.584]	Not significant
Pb	<0.001	3.470	28.02	0.002	+59.347	[24.315, 94.380]	Much higher in affected area*
Zn	0.125	–2.167	81	0.033	–6.590	[–12.640, –0.539]	Lower in affected area*
Mn	0.504	–1.829	81	0.071	–77.761	[–162.361, 6.839]	Trend: lower in affected

Note: Mean Difference = Affected Area (Group 1) – Background (Group 2). Positive values indicate enrichment in the affected area. $^{*}p < 0.05$.

6.4.4.3 Determination of Baseline Values

a) Calculation of Baseline Value of Zone Surrounding TD 15

The raw data for Cd, Co, Cu, Ni, Pb, Zn, and Mn in soil samples from baseline monitoring points all deviated from a normal distribution. Consequently, the 90th percentile of the dataset was adopted to establish baseline values for each element, with results presented in Table 6-33.

Table 6-33: Baseline values in the soil of Zone surrounding TD 15 (ug/g)

	Kolmogorov-Smirnov			Shapiro-Wilk			Distribution	Baseline value	remarks
	Statistic	df	P	Statistic	df	P			
Cd	0.320	20	0.000	0.532	20	0.000	Non-Normal	3.87	90th percentile
Co	0.439	20	0.000	0.321	20	0.000	Non-Normal	328.92	90th percentile
Cu	0.437	20	0.000	0.418	20	0.000	Non-Normal	9905.25	90th percentile
Ni	0.346	20	0.000	0.509	20	0.000	Non-Normal	65.88	90th percentile
Pb	0.414	20	0.000	0.489	20	0.000	Non-Normal	333.78	90th percentile
Zn	0.469	20	0.000	0.292	20	0.000	Non-Normal	149.18	90th percentile
Mn	0.239	20	0.004	0.699	20	0.000	Non-Normal	301.08	90th percentile

b) Calculation of Baseline Value of Chambishi Stream Sub-Catchment

The raw data for Cu, Ni, Pb, and Mn in soil samples from baseline monitoring points all deviated from a normal distribution, and thus the 90th percentile of the data set was adopted to establish baseline values for these elements. In contrast, the raw data for Cd, Co, and Zn followed a normal distribution, and therefore the upper 90% reference limit (arithmetic mean + 1.65 × standard deviation) was used to determine their baseline values. The results are presented in Table 6-34.

Table 6-34: Baseline values in the soil of Chambishi Stream sub-catchment (ug/g)

	Kolmogorov-Smirnov			Shapiro-Wilk			Distribution	Baseline value	remarks
	Statistic	df	P	Statistic	df	P			
Cd	0.403	18	0.000	0.617	18	0.000	Non-Normal	3.03	90th percentile
Co	0.308	18	0.000	0.596	18	0.000	Non-Normal	27.07	90th percentile
Cu	0.176	18	0.145	0.821	18	0.003	Normal	494.60	upper 90% reference limit
Ni	0.146	18	0.200	0.962	18	0.644	Normal	34.78	upper 90% reference limit
Pb	0.179	18	0.134	0.866	18	0.015	Normal	236.29	upper 90% reference limit
Zn	0.300	18	0.000	0.623	18	0.000	Non-Normal	58.52	90th percentile
Mn	0.155	18	0.200	0.911	18	0.089	Normal	525.24	upper 90% reference limit

c) Calculation of Baseline Value of Mwambashi River Watershed

The raw data for Co, Cu, and Ni in soil samples from baseline monitoring points all deviated from a normal distribution. Consequently, the 90th percentile of the dataset was adopted to establish baseline values for these elements, with the results presented in Table 6-35.

Table 6-35: Baseline values in the soil of Mwambashi River Watershed (ug/g)

	Kolmogorov-Smirnov			Shapiro-Wilk			Distribution	Baseline value	remarks
	Statistic	df	P	Statistic	df	P			
Co	0.357	29	0.000	0.392	29	0.000	Non-Normal	10.90	90th percentile
Cu	0.347	29	0.000	0.417	29	0.000	Non-Normal	356.70	90th percentile
Ni	0.204	29	0.003	0.807	29	0.000	Non-Normal	22.88	90th percentile

d) Determination of Baseline Values

A comparative analysis between the calculated baseline values from each area and the FAO/WHO standard limits revealed that the former were substantially lower. Applying these significantly underestimated values for soil pollution investigation and assessment would fail to accurately represent the actual environmental quality conditions. To ensure objective and truthful characterization of soil quality, the FAO/WHO standard limits shall be adopted as baseline values for evaluation purposes whenever calculated baselines are substantially lower than these international standards.

Table 6-36: Baseline values in areas (ug/g)

Areas	Description	Cd	Co	Cu	Ni	Pb	Zn	Mn
Zone surrounding TD 15	FAO/WHO limits	3	50	100	/	100	/	/
	Calculated Baseline Value	3.87	328.92	9905.25	/	333.78	/	/
	Baseline Value	3.87	328.92	9905.25	/	333.78	/	/
Chambishi Stream Sub-Catchment	FAO/WHO limits	3	50	100	50	100	300	2000
	Calculated Baseline Value	3.03	27.07	494.6	34.78	236.29	58.52	525.24
	Baseline Value	3.03	50	494.6	50	236.29	300	2000
Mwambashi River Watershed	FAO/WHO limits	3	50	100	50	100	300	2000
	Calculated Baseline Value	3.36	10.9	356.7	22.88	165.1	35.88	439.51
	Baseline Value	3.36	50	356.7	50	165.1	300	2000

6.4.4.4 Soil Pollution Analysis

Al, Ca, Mn, and related elements are fundamental constituents of the Earth's soil matrix and typically occur at high background concentrations. As these elements are not associated with raw materials, processing streams, or characteristic emissions from local mining and mineral processing activities, they are excluded from the present environmental impact assessment and analytical framework.

a) Zone surrounding TD 15

Analysis of 107 surface soil samples from the Zone surrounding TD 15 confirmed that pH, Pb, Zn, Mn, and SO_4^{2-}, did not exceed FAO/WHO standard limits and were therefore excluded from statistical analysis.

However, elevated concentrations of Co, Cu, Cd, and Pb were detected, exceeding FAO/WHO guideline values. This suggests potential exogenous input of these heavy metals into the local soil environment.

To assess the extent of external contamination, a comparative analysis was conducted between baseline values and measured concentrations in the impacted zones. The exceedance status of each key element is summarized in the table below, while the spatial distribution of sampling points exceeding baseline values is presented in the accompanying figure.

Table 6-37: Exceedances in Soil in Zone surrounding TD 15 (ug/g)

DESCRIPTION	Cd	Co	Cu	Pb
Maximum	6.07	114.804	2531.8	185.73
Calculated Baseline Value	3.87	328.92	9905.25	333.78
FAO/WHO limits	3	50	100	100
Count of Exceedances	1	0	0	0
Percentage of Exceedances	1%	0%	0%	0%
Count of Samples Exceeding FAO/WHO Limits	1	13	104	1
Percentage of Samples Exceeding FAO/WHO Limits	1%	12%	97%	1%

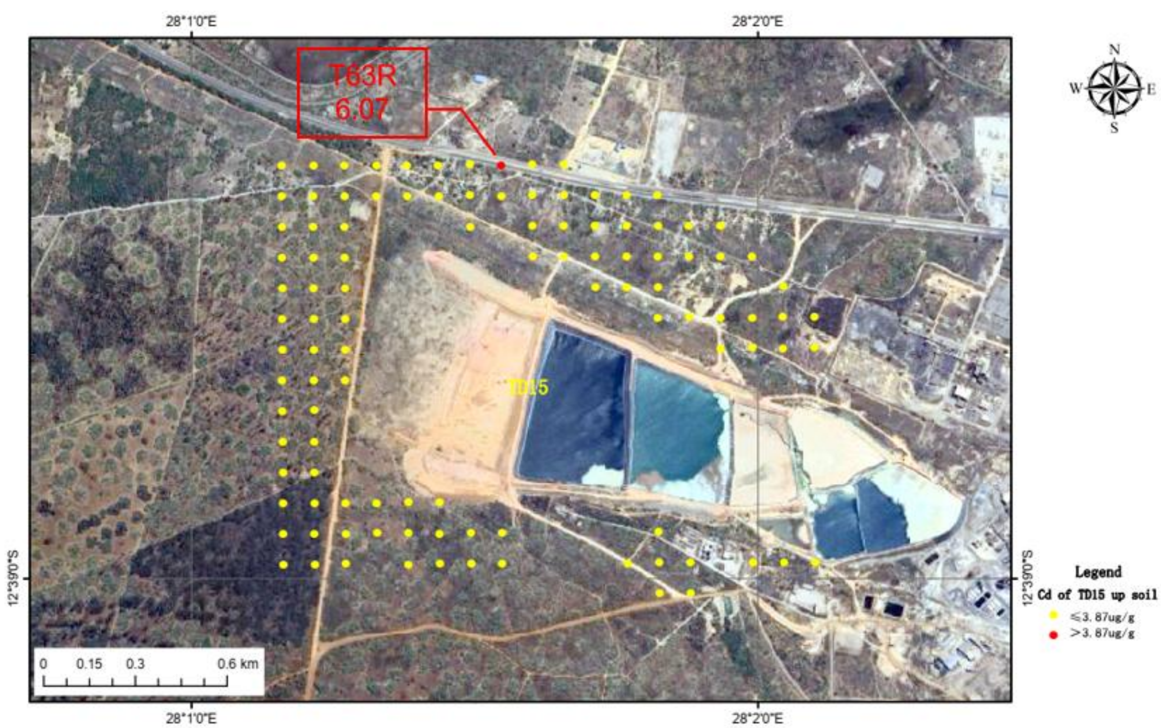


Figure 6-23: Distribution of Cd Exceeding Baseline Value

The figure indicates that Cd levels exceeded the baseline value at only a single sampling point in the area, with no exceedances detected in the surrounding locations, demonstrating a relatively isolated pattern. Comprehensive analysis suggests that this phenomenon exhibits characteristic features of 'point source pollution.' The primary reasons for this include:

Historical human activities: The area may contain a concealed historical pollution source, such as localized waste burial or material leakage, which has limited contaminant migration and dispersion.

Spatial variability in soil properties: The physicochemical characteristics of the soil at this specific point (e.g., clay content, pH) may differ significantly from the surrounding soils, resulting in a markedly higher capacity for Cd accumulation.

b) Chambishi Stream Sub-Catchment

Analysis of 137 soil samples from the Chambishi Stream Sub-Catchment confirmed that pH, Cd, Pb, Zn, Mn, and SO_4^{2-}, did not exceed FAO/WHO standard limits and were therefore excluded from statistical evaluation.

Elevated concentrations of Co, Cu, Ni, Cd, Pb, Zn and Mn were detected, exceeding FAO/WHO guideline values, indicating potential exogenous input of these heavy metals into the local soil environment.

To evaluate the magnitude of exogenous influence, a comparative assessment was performed between established regional baseline concentrations and measured values in affected zones. Among all monitored elements, Co demonstrated the highest frequency of baseline exceedances. The exceedance profile of key heavy metals is summarized in the Table below, with spatial distributions of sampling locations surpassing baseline thresholds illustrated in the Figure below.

Table 6-38: Exceedances in Soil in Chambishi Stream Sub-Catchment (ug/g)

DESCRIPTION	Cu	Co	Cd	Ni	Pb	Zn	Mn
Calculated Baseline Value	494.60	27.07	3.03	34.78	236.29	58.52	525.24
Count of Exceedances	33.0	30.0	16.0	8.0	4.0	28.0	23.0
Percentage of Exceedances	24%	22%	12%	6%	3%	20%	17%
Maximum Exceedance Multiple	28.92	562.14	4.30	8.40	4.69	12.94	29.82
Maximum	14305.90	15215.52	13.03	292.14	1108.17	757.07	15664.97
FAO/WHO limits	100	50	3	50	100	300	2000
Count of Samples Exceeding FAO/WHO Limits	129	24	16	6	6	6	3
Percentage of Samples Exceeding FAO/WHO Limits	94%	18%	12%	4%	4%	4%	2%

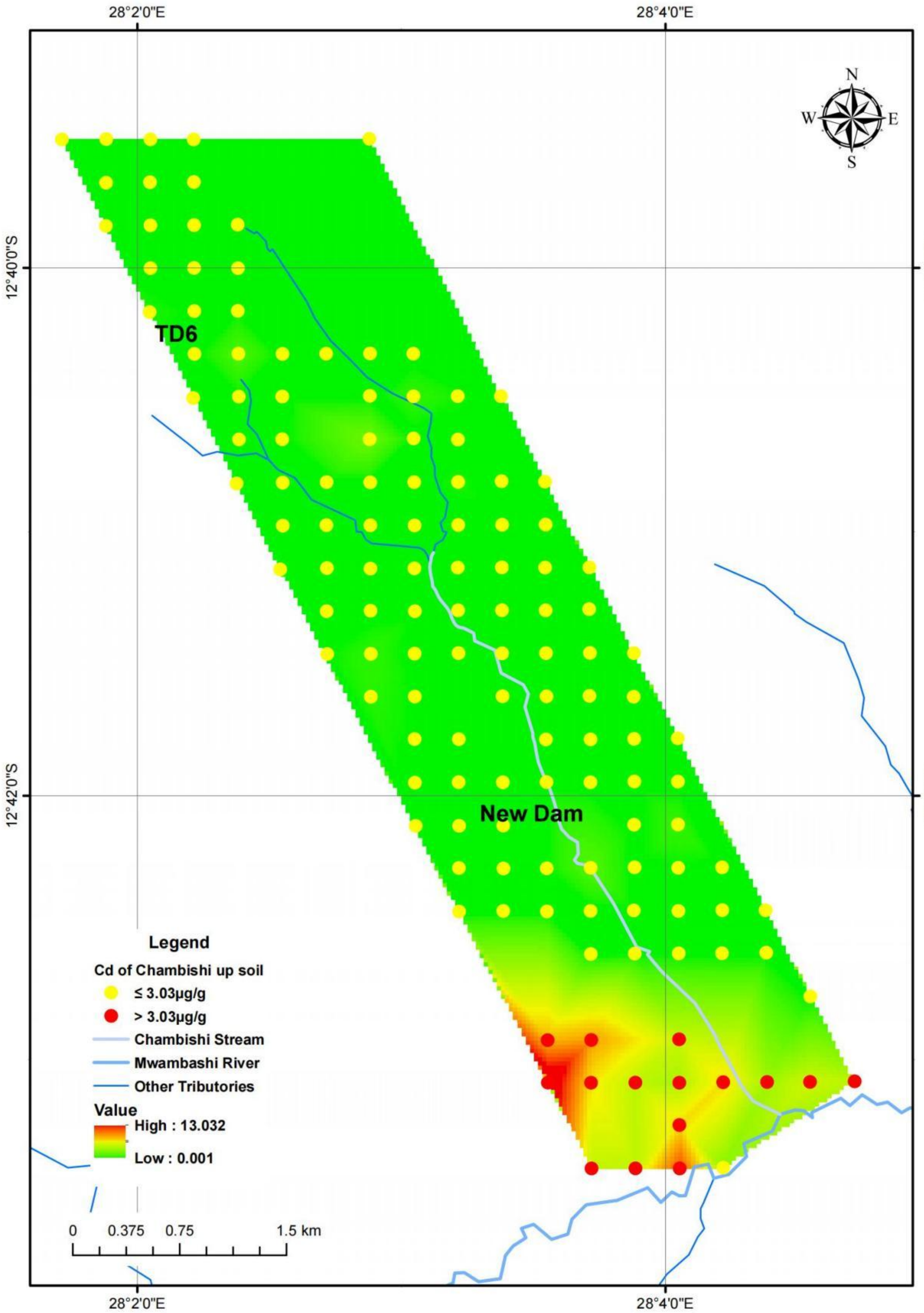


Figure 6-24: Distribution of Cd Exceeding Baseline Value

The figure 6.44 reveals that the Cd-exceeding zone is primarily located at the confluence of the Chambishi Stream and Mwambashi River, with no detected exceedances in adjacent upstream or downstream areas, demonstrating a distinct isolation pattern. The concentration of cadmium (Cd) was insignificant to be considered further downstream as hotspots. Therefore, the exceedance of Cd levels should be interpreted solely as a characterization of current conditions and is not attributable to the incident.

Comprehensive analysis suggests this pattern aligns with characteristic point-source contamination, attributable to the following mechanisms:

Historical Human Activities: The areas may contain localized legacy pollution sources, such as undocumented waste disposal or contained material spills, where limited contaminant migration has occurred.

Pedogeochemical Heterogeneity: Distinct physicochemical properties (e.g., elevated clay content, differential pH) at these specific locations likely enhanced Cd sorption capacity compared to surrounding soils, creating localized accumulation zones.

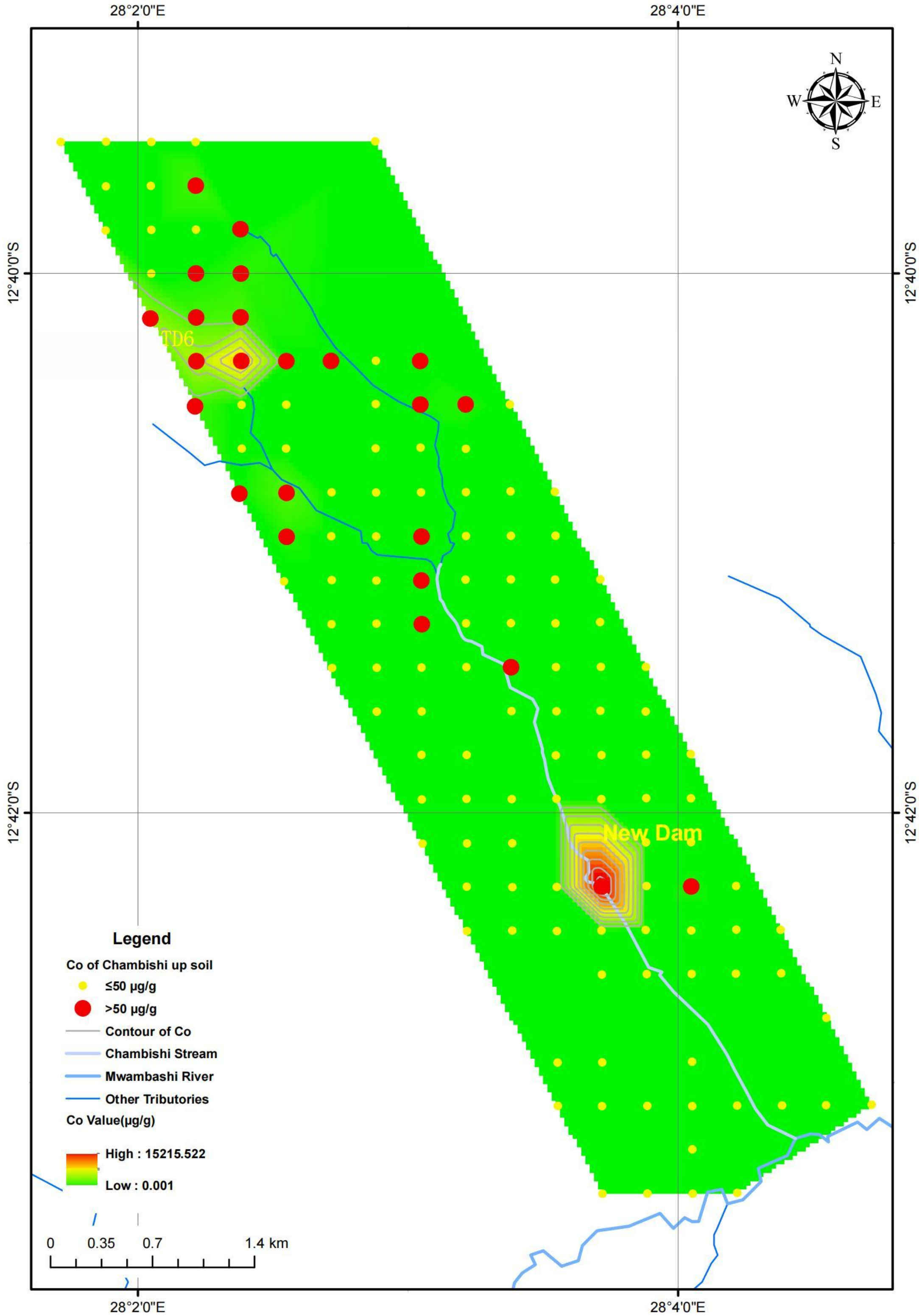


Figure 6-25: Distribution of Co Exceeding Baseline Value

The Figure indicates that Co exceedances are primarily concentrated in and downstream of the TD 6 and waste rock site. This spatial pattern correlates strongly with the naturally elevated background levels of Co in the local soil. Through leaching and hydrological transport processes, Co has been mobilized and subsequently deposited in adjacent areas, resulting in elevated concentrations that reflect the region's inherent geochemical conditions.

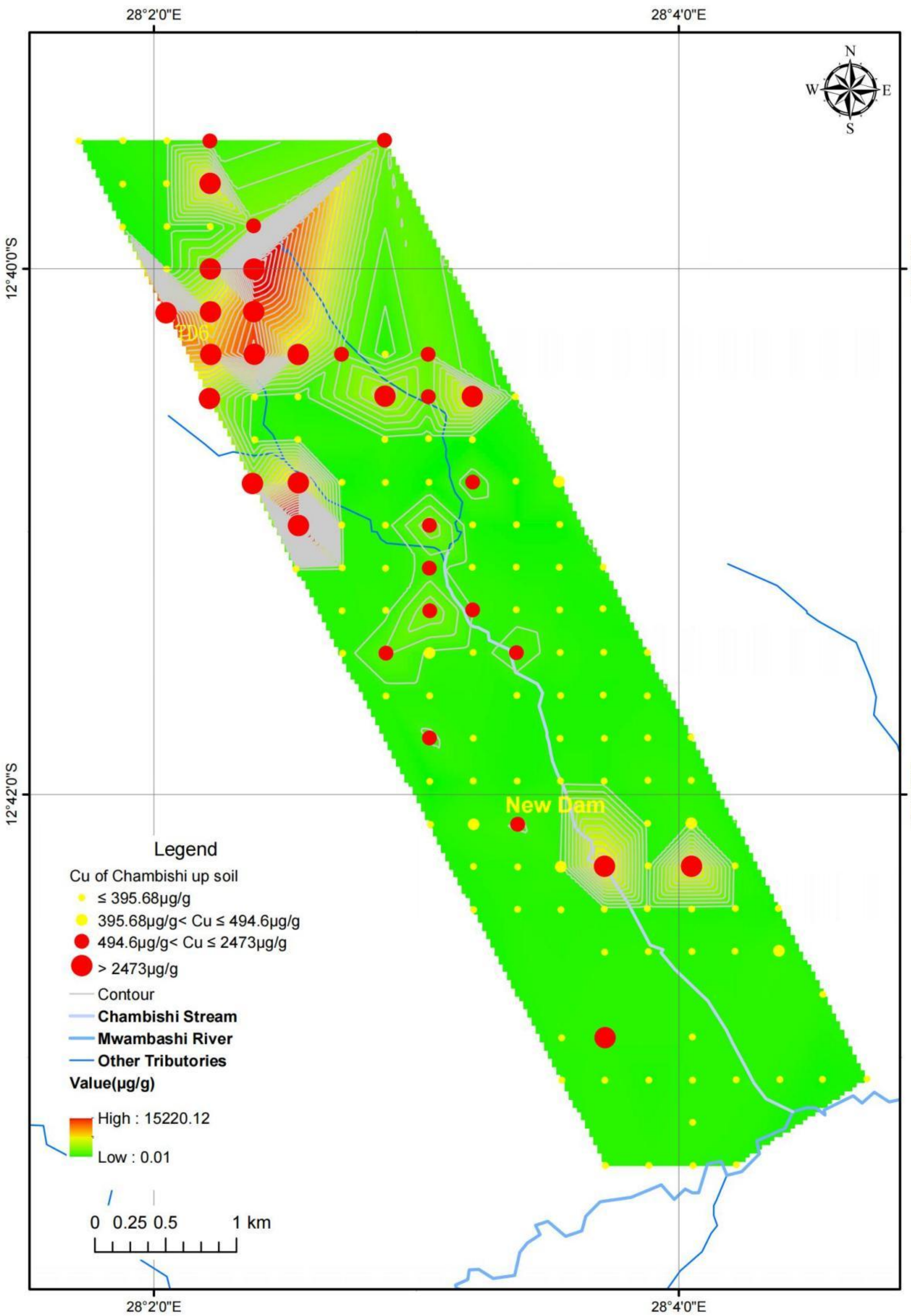


Figure 6-26: Distribution of Cu Exceeding Baseline Value

The spatial distribution of copper exceedances, as shown in the Figure, is primarily concentrated in and downstream of the TD 6 and waste rock site. While this pattern may be partially influenced by naturally elevated background levels of Cu in the area, suggesting possible geochemical associations, it is also consistent with inadequate management of tailings and waste rock. Under rainfall leaching and transport processes, copper has been mobilized and subsequently deposited in nearby soils, leading to elevated concentrations that align with expected contamination pathways in such operational contexts.

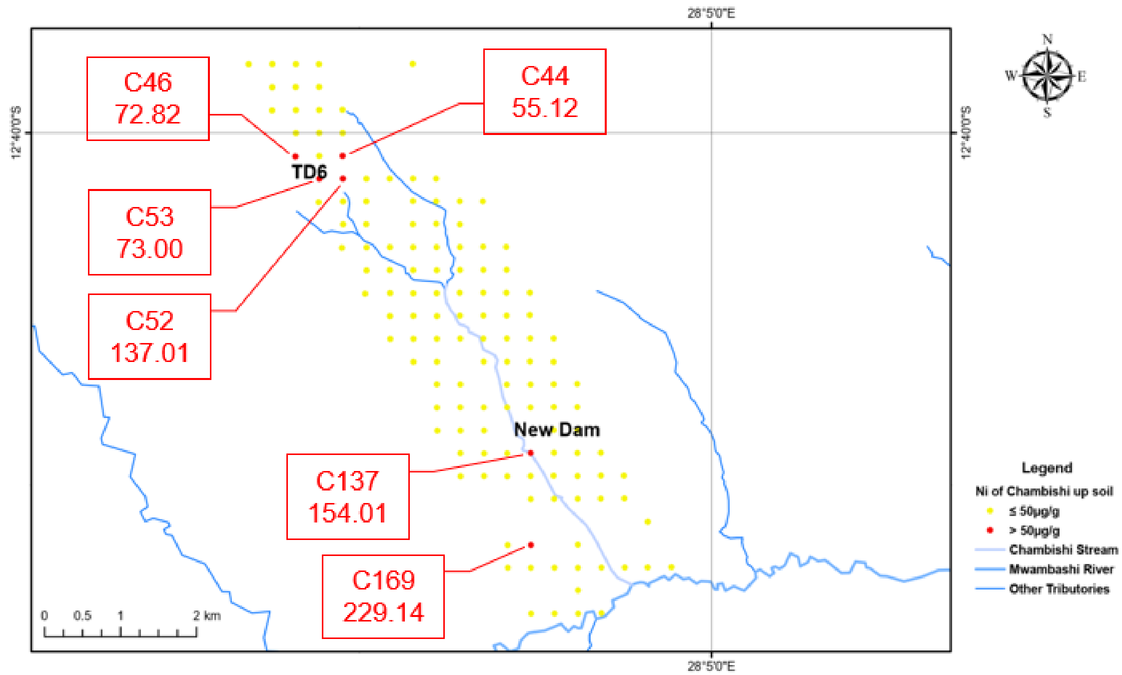


Figure 6-27: Distribution of Ni Exceeding Baseline Value

Figure 6-28 indicates

the observed Ni exceedances are exclusively localized within the TD 6 boundary. It should be noted that these sampling points represent tailings materials derived from underground mining operations, rather than natural soil samples. Consequently, elevated Ni concentrations in these tailings relative to surrounding soils constitute an expected characteristic of the deposited material. Furthermore, the absence of exceedances in all surrounding soil samples indicates effective environmental containment practices at the tailings facility, demonstrating no significant adverse impact on the adjacent terrestrial environment.

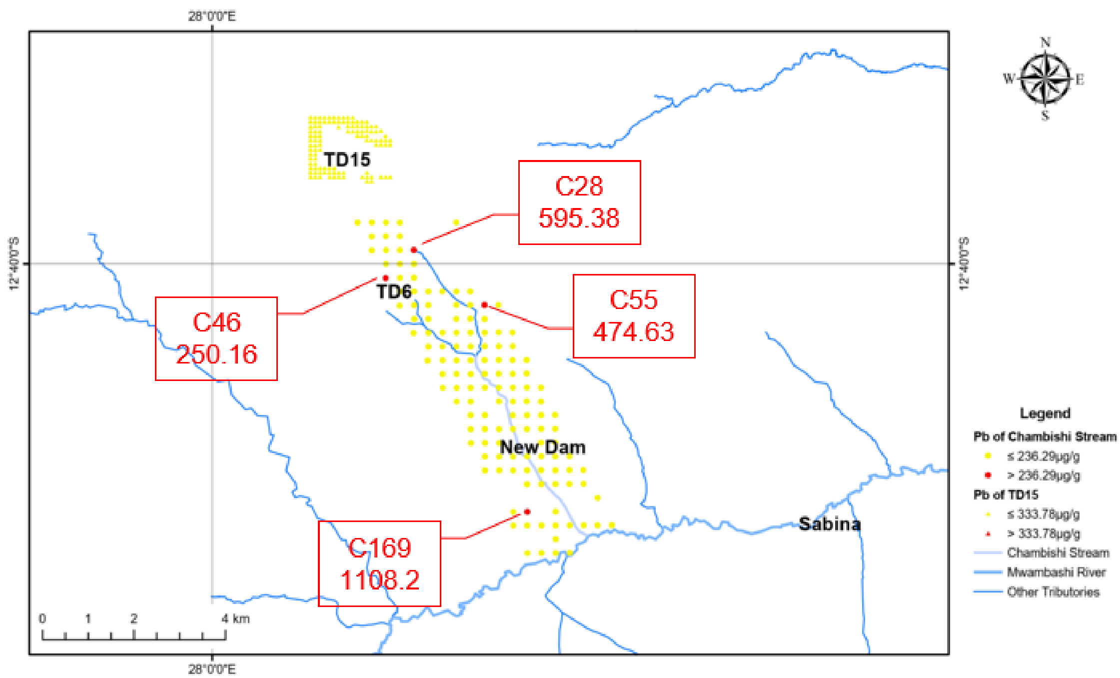


Figure 6-29: Distribution of Pb Exceeding Baseline Value

As shown in the figure 6-48, Pb exceedances demonstrate a distinct isolated distribution pattern, with no elevated concentrations detected in adjacent upstream or downstream areas. Comprehensive analysis indicates that this spatial profile reflects typical point-source contamination characteristics. The observed pattern can be attributed to two primary mechanisms:

Historical human activities: The area may contain localized, historical pollution sources such as unrecorded waste disposal or small-scale material leakage events. These sources have not undergone significant migration or dispersion, resulting in confined contaminant distribution.

Spatial variability in soil properties: Distinct physicochemical characteristics (e.g., clay content, pH levels) at the exceedance locations may enhance lead retention capacity compared to surrounding soils, creating localized accumulation hotspots.

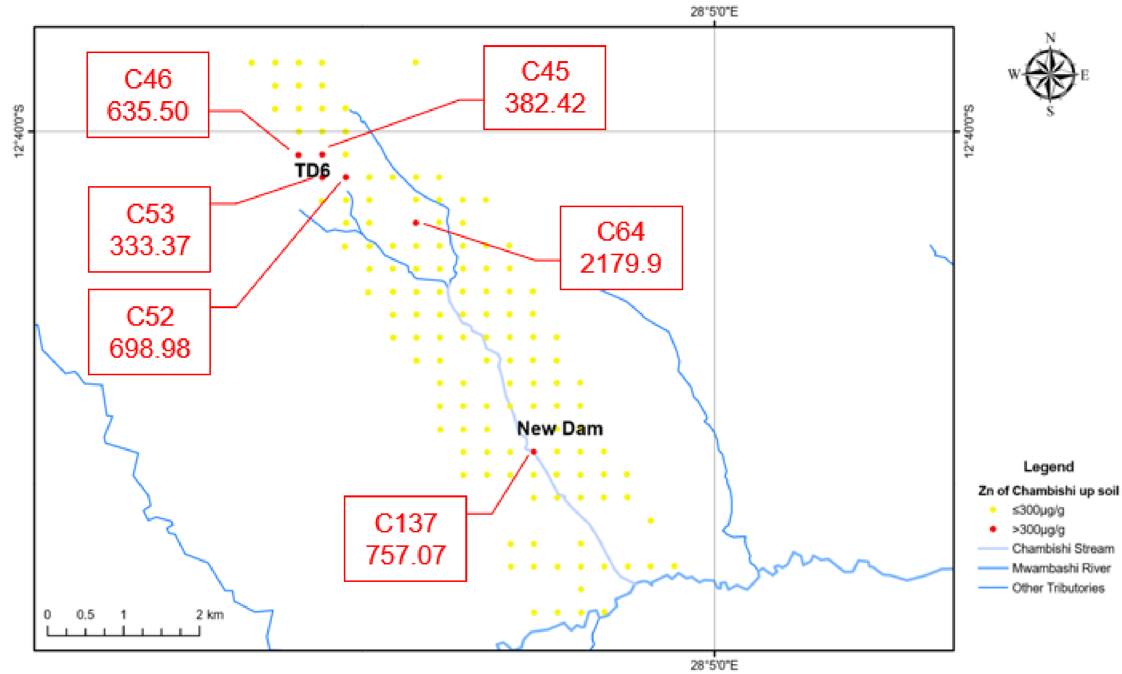


Figure 6-30: Distribution of Zn Exceeding Baseline Value

As indicated in the figure 6-49, Zn exceedances are predominantly located within the confines of the TD 6. It is important to note that the sampled media at these locations consist of tailings derived from underground mining operations, rather than in-situ natural soils. Consequently, elevated zinc concentrations in these tailings relative to surrounding natural soils represent an expected characteristic of the deposited industrial material. Furthermore, the absence of exceedances in all adjacent soil samples suggests that current environmental management measures at the tailings facility are effectively containing the material, with no significant off-site impact observed in the surrounding terrestrial environment.

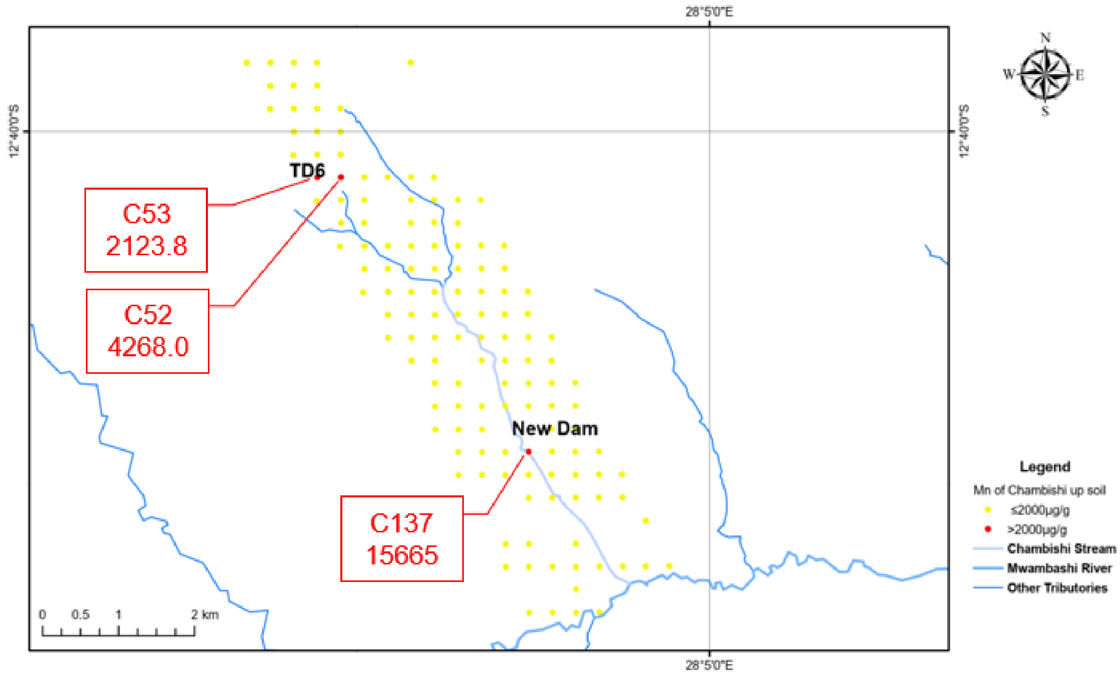


Figure 6-50: Distribution of Mn Exceeding Baseline Value

As illustrated in figure 6-50, Mn exceedances are predominantly confined within the TD 6. The materials sampled within this area consist of processed tailings generated from underground mining operations, rather than natural soil profiles. Consequently, elevated Mn concentrations observed in these tailings, compared to surrounding natural soils, represent expected geochemical characteristics of the deposited industrial material. Furthermore, the absence of exceedances in all peripheral soil samples demonstrates effective environmental containment at the tailings facility, indicating no significant migration of contaminants to adjacent ecosystems.

c) Mwambashi River Watershed

Analysis of 54 soil samples from the Mwambashi River Watershed confirmed that pH, Cd, Pb, Zn, Mn, and SO_4^{2-}, did not exceed FAO/WHO standard limits and were therefore excluded from statistical analysis.

Elevated concentrations of Co, Cu, and Ni, exceeding FAO/WHO guideline values, were detected, indicating potential exogenous input of these heavy metals into the local soil environment.

To assess the extent of external influence, a comparative analysis was conducted between regional baseline values and concentrations measured in the impacted areas. Co exhibited the most frequent exceedances above the baseline among all monitored elements. A summary of exceedance status for key heavy metals is provided in the table below, while spatial distributions of sampling points exceeding baseline values are presented in figure 6-51 below.

Table 6-39: Exceedances in Soil in Mwambashi River Watershed (µg/g)

	Cd	Co	Cu	Ni	Pb	Zn	Mn
Maximum	0.26	128.30	800.38	65.17	12.45	64.30	1148.59
Baseline Value	3.36	10.90	356.70	22.88	165.10	35.88	439.51
FAO/WHO limits	3	50	100	50	100	300	2000
Count of Exceedances	0.0	15.0	3.0	6.0	0.0	7.0	8.0
Percentage of Exceedances	0%	28%	6%	11%	0%	13%	15%
Count of Samples Exceeding FAO/WHO Limits	0.0	3.0	38.0	1.0	0.0	0.0	0.0
Percentage of Samples Exceeding FAO/WHO Limits	0%	6%	38%	2%	0%	0%	0%

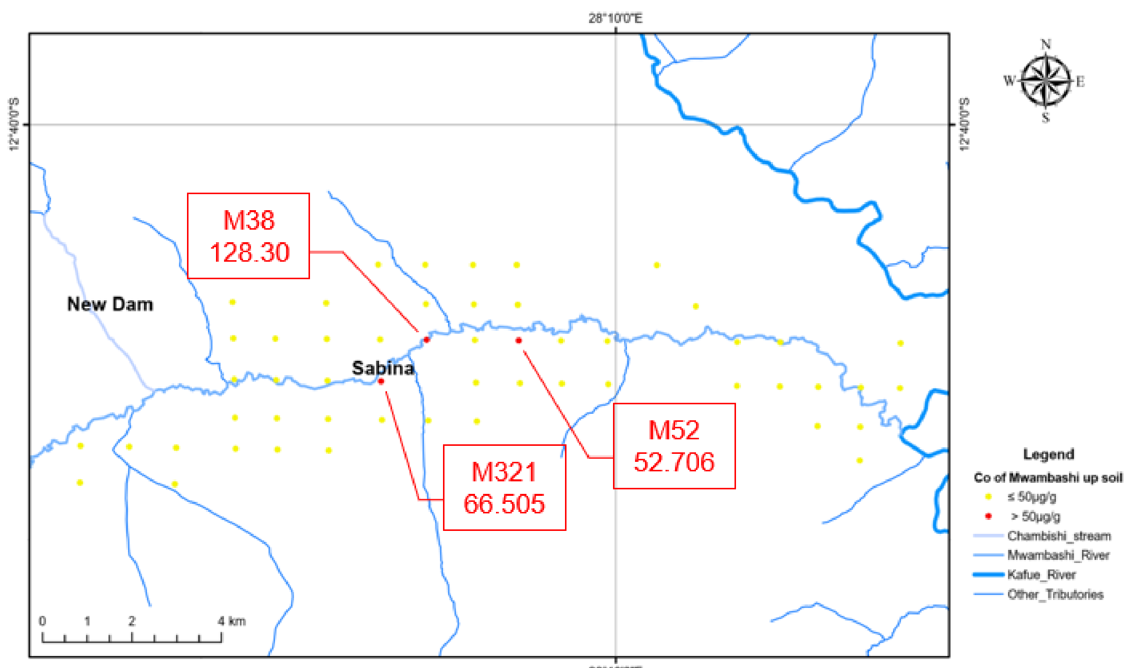


Figure 6-51: Distribution of Co Exceeding Baseline Value

The survey results indicate a coefficient of variation of 150% for cobalt concentrations in soil samples collected along and adjacent to the Mwambashi River basin, reflecting pronounced spatial heterogeneity with extreme unevenness in distribution. Data analysis reveals that the area consists predominantly of soils at background concentration levels interspersed with localized anomalies (contamination hotspots).

Comparison with baseline values shows that only three sampling points along the Mwambashi River Watershed exceeded the reference thresholds. Among these, two points marginally exceeded the standard, while a single location (M38) exhibited a concentration 2.5 times the baseline value, demonstrating a typical 'point-source pollution' pattern. This spatial distribution can be attributed to two primary factors:

Historical human activities: The area may contain concealed historical pollution sources, such as small-scale waste burial or localized material leakage, which have not undergone extensive migration or dispersion.

Spatial variability in soil properties: Distinct physicochemical characteristics (e.g., clay content, pH) at specific locations may significantly enhance the soil's capacity for Co retention compared to surrounding areas, resulting in localized accumulation hotspots.

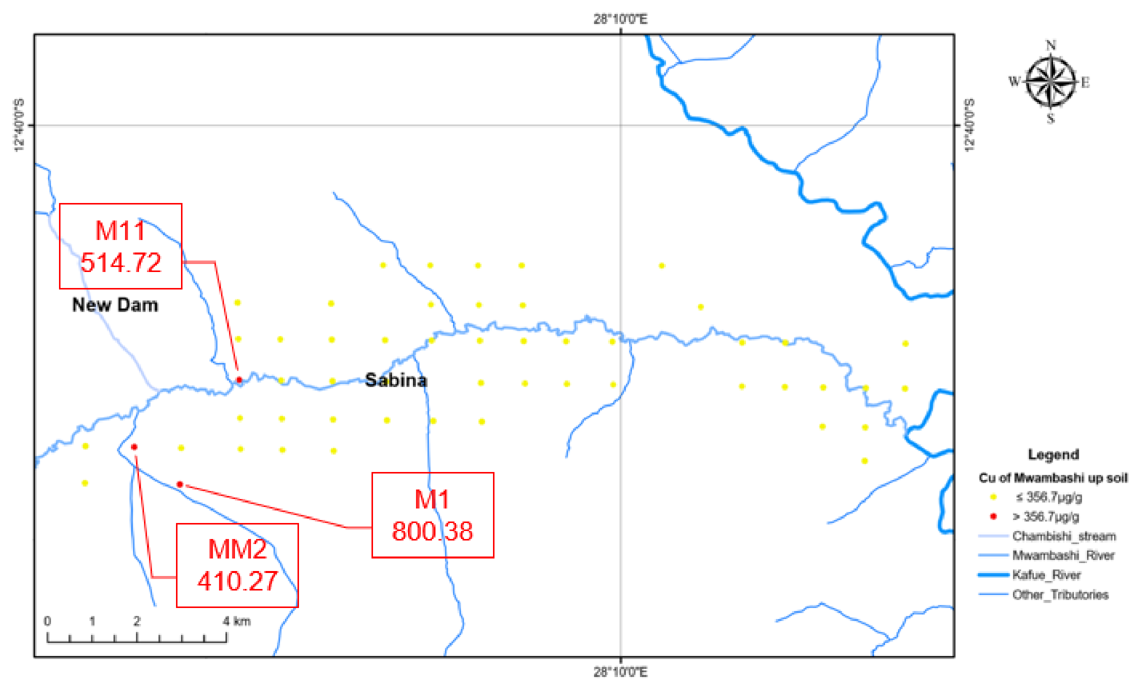


Figure 6-52: Distribution of Cu Exceeding Baseline Value

The Figure indicates that Cu concentrations exceeded regulatory thresholds at only two sampling points within the Watershed, both situated near tributary confluences of the Mwambashi River. No adjacent upstream or downstream locations exhibited similar exceedances, demonstrating a distinct spatial isolation.

Comprehensive analysis suggests this pattern aligns with characteristic point-source contamination, attributable to the following mechanisms:

Historical Human Activities: The areas may contain localized legacy pollution sources, such as undocumented waste disposal or contained material spills, where limited contaminant migration has occurred.

Pedogeochemical Heterogeneity: Distinct physicochemical properties (e.g., elevated clay content, differential pH) at these specific locations likely enhanced Cu sorption capacity compared to surrounding soils, creating localized accumulation zones.

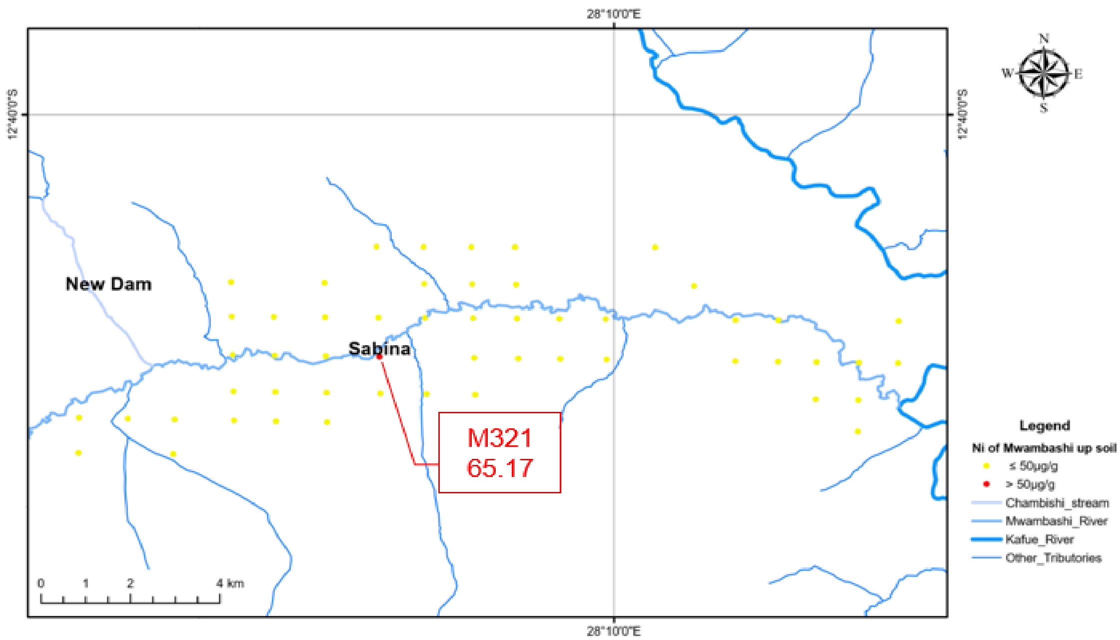


Figure 6-31: Distribution of Ni Exceeding Baseline Value

The observed Ni exceedances are located discontinuously along both banks of the Mwambashi River downstream of its confluence with the Chambishi Stream, exhibiting a characteristic point-source contamination pattern. This spatial distribution can be attributed to two primary mechanisms:

Historical Human Activities: The area likely contains localized legacy pollution sources, such as unrecorded waste disposal incidents or contained material leakage, where limited hydrological transport has prevented widespread contaminant migration.

Pedological Heterogeneity: Significant differences in physicochemical properties (particularly clay content and pH variations) at these specific locations have potentially created enhanced Ni retention capacity compared to adjacent soils, resulting in isolated accumulation zones.

6.4.4.5 Determination of the Extent of Impact

A comparative assessment of all measured parameters at sampling locations within the incident-affected area was performed against both international regulatory standards (FAO/WHO) and established regional baseline concentrations. Exceedance status for individual elements was quantified using the single-factor pollution index methodology. Spatial delineation of the impacted boundary was achieved through the non-polluted nodal linkage approach, which synthesized uncontaminated peripheral sampling data with hydrographic networks (including mining-affected tributaries) and verified field observations. The resultant impact zone, illustrated in Figure 6-54, demonstrates a primary distribution within the Chambishi Stream and its confluence with the Mwambashi River, encompassing a total area of 5.35 km^2 (535 hectares).

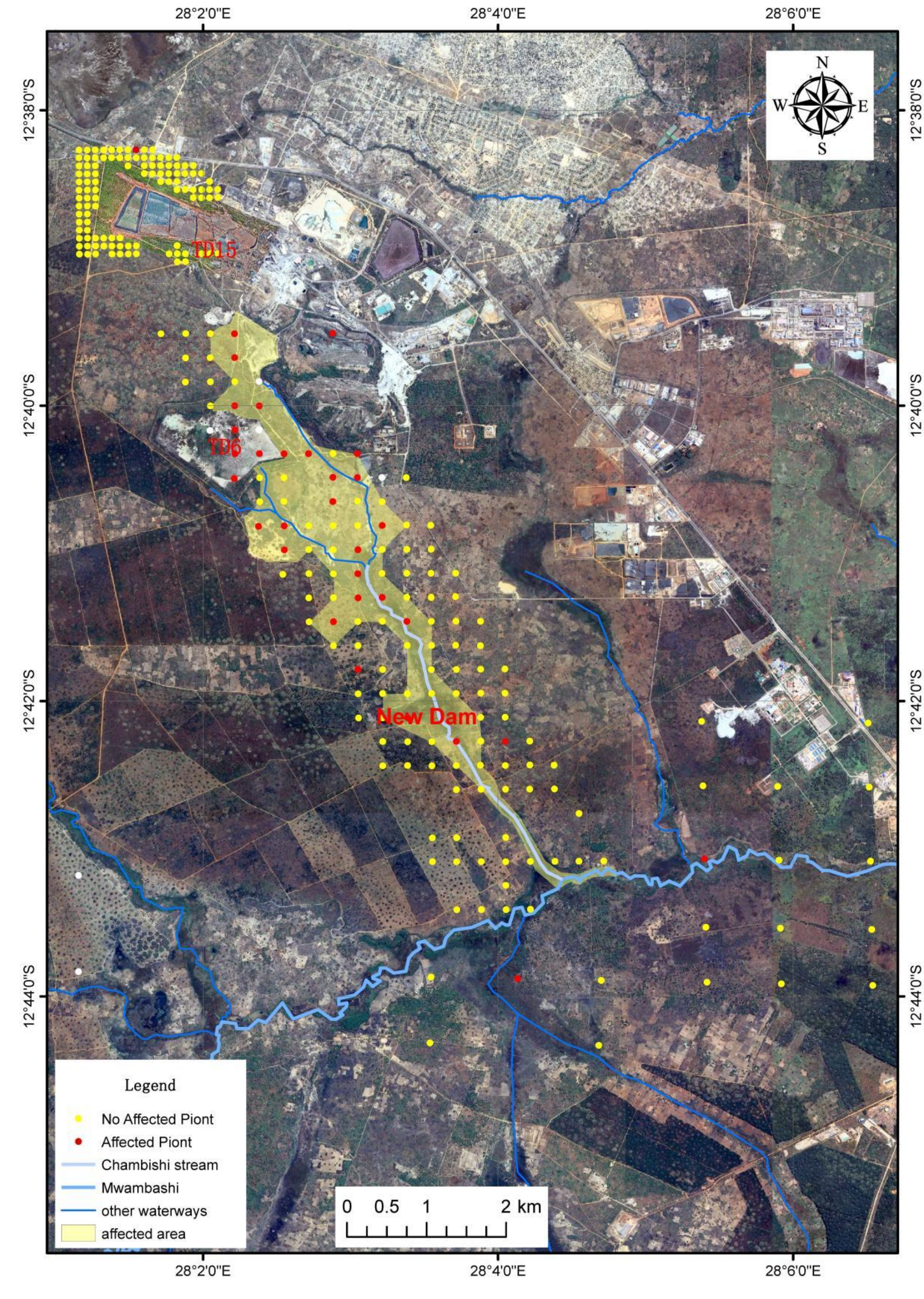


Figure 6-32: Heavy Metals Distribution within Chambishi Stream and Confluence of Mwambashi

6.5 Key Findings

Soil pH Characteristics

Soils within the assessed area, including both subsoil and topsoil, are predominantly acidic, with pH values typically ranging between 5.0 and 6.0.

Heavy Metal Exceedance

Across all assessment zones, Cu and Co concentrations in soils exceeding the guideline limits established by the Food and Agriculture Organization/World Health Organization (FAO/WHO) were detected.

Spatial Distribution Pattern of Pollutants

The concentrations of major heavy metals (such as Cu, Co, Pb, As, Mn, Cd, Zn) and sulphate ions (SO_4^{2-}) display an 'N'-shaped spatial trend along the watercourse from TD 15 to the Chambishi Stream, the Mwambashi River, and the Kafue River: increasing from TD 15 to the Chambishi Stream, decreasing toward the Mwambashi River, and rising again at the Kafue River.

Pollution Characteristics of the Chambishi Stream Sub-catchment

Soil concentrations of Co, Cu, and Mn in the Chambishi Stream Sub-catchment are significantly elevated, indicating a direct link to contamination originating from upstream and surrounding mining activities. The contribution from long-term metal accumulation through aeolian and hydraulic erosion, likely associated with the region's well-developed Cu mineralization, should also be considered.

Pollution Status in the Mwambashi River Catchment

Although Cu concentrations in the Mwambashi River catchment are elevated compared to background levels, they remain lower than those observed in the Chambishi Stream Sub-catchment and the areas adjacent to TD 15. These Cu levels are comparable to those in surface and subsurface soils of control samples. For other elements, Co and Ni exceed threshold limits but are detected only in a few localized sites.

Pollution Features along the Kafue River Section

Along the Kafue River section, exceedances of Cd, Co, Cu, Pb, and Mn have increased relative to the surrounding Mwambashi River catchment, suggesting that additional pollution sources.

Radiological Monitoring Results

No localized hotspots indicating elevated radioactivity were identified in the TD 15 area. Neutron dose rates at all monitoring points were below the detection limit, confirming the absence of neutron-emitting sources within the assessed zone.

6.6 Appendix

Appendix 6-1: Soil Results and Raw Data Tables

Appendix 6-2: Photographic records of field sampling activities

Appendix 6-3: Preliminary radiological assessment report of TD 15 at Sino-Metals

7 ECOLOGICAL IMPACT ASSESSMENT

7.1 Introduction

On 18th February 2025, a structural failure at tailings dam TD 15, operated by Sino-Metals Leach Zambia Limited (SMLZ) in Chambishi, Copperbelt province, released acidic, metal-laden tailings slurry into the Chambishi Stream. The plume rapidly propagated downstream, entering the Mwambashi River and ultimately the Kafue River, one of Zambia's most ecologically and socio-economically vital river systems. The Kafue supports over 2 million people through irrigated agriculture, domestic water supply, and biodiversity conservation, including the ecologically sensitive Lukanga Swamps, a Ramsar-designated wetland of international importance.

The incident triggered an immediate regulatory response from the Zambia Environmental Management Agency (ZEMA) and the Water Resources Management Authority (WARMA), resulting in an Environmental Restoration Order mandating a comprehensive Biodiversity Impact Assessment (BIA). This report fulfills that mandate, presenting the partial findings of a multidisciplinary ecological assessment conducted between September and October 2025.

The assessment was designed to:

a) Characterize the spatial and temporal extent of contamination across water, sediment, and soil

b) Evaluate ecological recovery trajectories and resilience mechanisms

c) Identify key stressors and exposure pathways for aquatic and terrestrial organisms

d) Inform science-based, community-informed restoration and long-term governance strategies.

A strategically designed network of 35 sampling sites was established along the Chambishi Stream, Mwambashi and Kafue River continuum, capturing the full gradient of contamination from the point of discharge to the far-field reaches downstream of the Lukanga Swamps. Sites were categorized as impacted (n=12), intermediary (n=15), and reference (n=8), enabling robust comparative analysis of contamination dynamics and ecological response.

Riparian and aquatic ecosystem health was assessed through a combination of field-based biological surveys (focusing on macroinvertebrates and vegetation) and high-resolution remote sensing. Concurrently, riparian vegetation health was evaluated using Sentinel-2 satellite imagery to detect landscape-scale changes in vegetation cover, indicative of phytotoxic stress, erosion, or recovery.

Findings reveal a distinct spatial pattern; acute contamination is confined to the upper Chambishi Stream. Moderate, patchy recovery is underway in the Mwambashi River, and the Kafue River while the downstream of the Lukanga Swamps shows negligible impact, reinforcing the wetland's role as a natural attenuation zone. Although water chemistry has stabilized following emergency liming and operational shutdowns, persistent metal accumulation in sediments, particularly copper, manganese, and cobalt, continues to threaten benthic invertebrates and riparian soil health, with potential implications for agricultural use and ecosystem function.

This report synthesizes field observations, laboratory analyses, and community knowledge into a cohesive diagnostic of current ecological status. It concludes that while natural recovery is beginning, it remains incomplete, uneven, and vulnerable to reversal without sustained, coordinated, and accountable remediation. The path forward requires integrated management that bridges science, policy, and community stewardship to restore ecosystem function and safeguard livelihoods.

7.2 Methodology & Sampling Design

The assessment addressed the four key objectives outlined in the Terms of Reference (TORs):

a) Characterize the spatial and temporal extent of contamination across water, sediment, and soil media.

b) Evaluate ecological recovery trajectories and resilience mechanisms in aquatic and riparian ecosystems;

c) Identify key stressors and exposure pathways for aquatic and terrestrial organisms;

d) Inform science-based, community-informed restoration and long-term governance strategies.

A total of 35 sampling sites were established along the Chambishi, Mwambashi and Kafue River continuum, stratified into impacted (n=12), intermediary (n=15), and reference (n=8) zones. Sampling included:

SAMPLE TYPE	NUMBER OF SAMPLES	NOTES
Water	25	Includes surface water from sites like KAF-01, MWB-02, CHM-01, DWS series, etc. Some duplicates across analyte sheets; 25 unique water sample IDs.
Soil / Sediment	32	Includes both dry soil and wet soil/sediment samples (e.g., KAF-04 DRY SOIL, CHM-02 WET SOIL, DWS-01 S).
Vegetation	16	Riparian plant samples (e.g., KAF-03 V, CHM-02 V, MWB-01 V). Some sites have duplicate analyses (e.g., KAF-08 V appears twice).
Other Biota	8	Includes: rats (2), frogs (2), bees (1), locust (1), insect (1), bat droppings (1).
Quality Control (QC)	14	Blanks, calibration standards (e.g., Co 2ppm, Zn 0.5ppm, Cr 6ppm, BLANK, 2%HNO_3, etc.). Not environmental samples.

7.2.1 Field-Based Biological Survey Methods

Field assessments followed standardized, replicable protocols:

a) **Macroinvertebrates**: Sampled using the **South African Scoring System Version 5 (SASS5)**, involving kick-net sampling (300-µm mesh) in riffle-pool sequences over 3 minutes per site. Taxa were identified to family level in the field using the SASS5 key, and **Average Score Per Taxon (ASPT)** was calculated as a metric of ecological integrity.

b) **Riparian vegetation**: Within each site, **three 1 m² quadrats** were established along a transect perpendicular to the bank. Species identity, percent cover, height, and visible stress symptoms (e.g., chlorosis, necrosis) were recorded.

7.2.2 In-Situ Water Quality Parameters

In-situ measurements were taken using a calibrated Hanna HI 9,813-6 multi-parameter probe and Hach DR2800 spectrophotometer

a) pH (range: 3.2–7.1; impacted sites <5.0)

b) Dissolved oxygen (DO): 1.8–8.4 mg/L (hypoxic at CHM-02)

c) Conductivity: 420–1,850 µS/cm (elevated in impacted zones)

d) Turbidity: 15–210 NTU

These parameters indicate persistent acidification, metal solubility, and oxygen depletion in the Chambishi, consistent with sulfide oxidation from tailings.

7.2.3 Remote Sensing and Ground Truthing

a) Remote Sensing: Sentinel-2 Level-2A imagery (10 m resolution) was processed in QGIS to compute NDVI = (NIR – Red) / (NIR + Red) using Band 8 (NIR) and Band 4 (Red).

b) Classification Scheme

   i. Class 1: Barren land / open water (NDVI ≤ threshold)

   ii. Class 2: Sparse or degraded vegetation

   iii. Class 3: Moderate vegetation

   iv. Class 4: Dense vegetation

   v. Class 5: Very dense, healthy vegetation (e.g., riparian forest or grassland)

Thresholds were calibrated per observation period to reflect dynamic vegetation responses. Ground validation used DJI Matrice 3M drone surveys (±3 cm accuracy) and on-site vegetation quadrats.

7.2.3.1 Temporal NDVI Analysis and Interpretation

7.2.3.1.1 January 2025 – Baseline (Pre-Incident)

a) NDVI Thresholds:

i. Class 1: ≤ 0.0301

ii. Class 2: 0.0301 – 0.1917

iii. Class 3: 0.1917 – 0.3531

iv. Class 4: 0.3531 – 0.5146

v. Class 5: > 0.5146

b) Interpretation: A healthy, stratified riparian ecosystem with extensive high-performing vegetation (Class 5), consistent with undisturbed Copperbelt riparian corridors.

7.2.3.1.2 March 2025 – Immediate Post-Incident Impact

a) NDVI Thresholds:

vi. Class 1: ≤ 0.1269

vii. Class 2: –0.1269 – 0.0828

viii. Class 3: 0.0828 – 0.2925

ix. Class 4: 0.2925 – 0.5022

x. Class 5: > 0.5022

b) Key Changes:

i. 4.2-fold expansion of barren/Class 1 areas (threshold rose from 0.0301 to 0.1269), indicating widespread vegetation dieback.

ii. Emergence of negative NDVI values in Class 2, characteristic of exposed toxic soils or surface water with high turbidity.

iii. Compression of dense vegetation classes, confirming loss of canopy cover and photosynthetic capacity—aligned with field-observed chlorosis and necrosis in *Setaria* and *Cyperus* spp. at CHM-02.

7.2.3.1.3 October 2025 – Recovery Phase (8 Months Post-Accident)

a) NDVI Thresholds:

i. Class 1: ≤ 0.079

ii. Class 2: –0.079 – 0.2167

iii. Class 3: 0.2167 – 0.3356

iv. Class 4: 0.3356 – 0.4544

v. Class 5: > 0.4544

b) Key Changes:

i. 38% reduction in barren land threshold compared to March (0.1269 → 0.079), signaling initial stabilization.

ii. Expansion of Class 2 and 3 ranges, consistent with pioneer species colonization (e.g., annual grasses) observed in drone and quadrat surveys along mid-reach Mwambashi sites (MWB-02 to MWB-04).

iii. However, Class 5 still 11.6% below baseline (0.4544 vs. 0.5146), confirming incomplete recovery of mature riparian woodland—particularly in high-metal sediment zones.

7.2.3.2 Integrated Ecological Diagnosis

The NDVI trajectory aligns with biological and chemical data across the contamination gradient:

ZONE	NDVI RANGE (OCT 2025)	FIELD OBSERVATIONS	INTERPRETATION
Chambishi (CHM-02)	0.18–0.22	Extensive plant scorching, sediment Cu = 1,240 mg/kg, pH < 5.0	Acute phytotoxicity; minimal recovery
Mwambashi (MWB-03)	0.28–0.34	Pioneer grasses, reduced macro invertebrate diversity (ASPT = 4.8), episodic metal remobilization	Moderate, fragile recovery
Kafue (KAF-10)	0.42–0.61	Diverse riparian woodland, NDVI > 0.5, no metal exceedances	Unimpacted; natural attenuation by Lukanga Swamps

7.3 Key Findings By Media And Zone

7.3.1 Source Attribution of Metals

Metals detected (Cu, Mn, Co) match the geochemical fingerprint of SMLZ tailings. Background levels in reference tributaries are <50 mg/kg Cu, versus >1,200 mg/kg at CHM-02, suggesting the spill as the primary contamination source.

7.3.2 Nature of Disruption in Mwambashi River

The "moderate disruption" includes:

a) Reduced EPT (Ephemeroptera, Plecoptera, Trichoptera) taxa richness (only 2 families vs. 7 at reference sites),

b) Intermittent sediment resuspension during rainfall, elevating turbidity and metal flux,

c) Patchy riparian dieback, particularly of *Phragmites australis*,

d) Elevated sediment Co (85 mg/kg) exceeding Zambian soil screening levels (50 mg/kg).

7.4 Integrated Interpretation: Gradient of Impact and Recovery

NDVI values provide a spatially explicit indicator of ecosystem stress:

a) CHM-02 (0.18–0.22): Reflects extensive plant scorching, consistent with Cu-induced chlorosis and root necrosis observed in *Setaria* and *Cyperus* spp.

b) MWB-03 (0.28–0.34): Indicates partial recovery, with pioneer grasses stabilizing banks but lacking canopy closure.

c) KAF-10 (0.42–0.61): Represents healthy, diverse riparian woodland, with NDVI>0.5 confirming absence of phytotoxic influence.

This gradient corroborates biological and chemical data, confirming contamination attenuation enhanced by wetland filtration.

7.5 Appendix

Appendix 7-1: General Maps

Appendix 7-2: Sampling Sites Maps

Appendix 7-3: Field Pictures

Appendix 7-4: Biota Sampling Sites

Appendix 7-5: Activities Implemented In The Field

Appendix 7-6: Baseline Conditions (The Ecological "Snapshot")

Appendix 7-1: General Maps

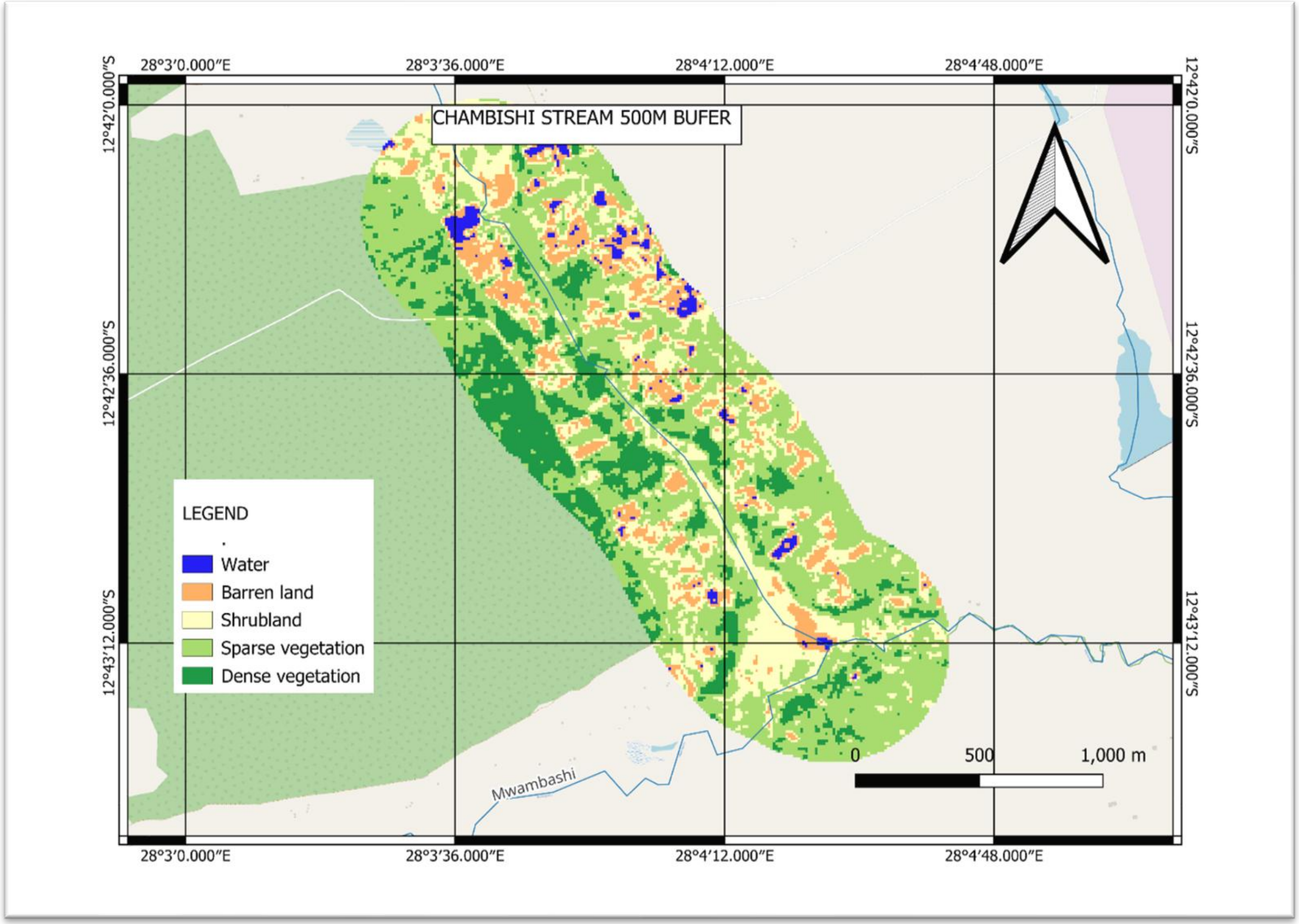


Figure 7-1: Chambishi Stream Study Area 500-Meter "Buffer"

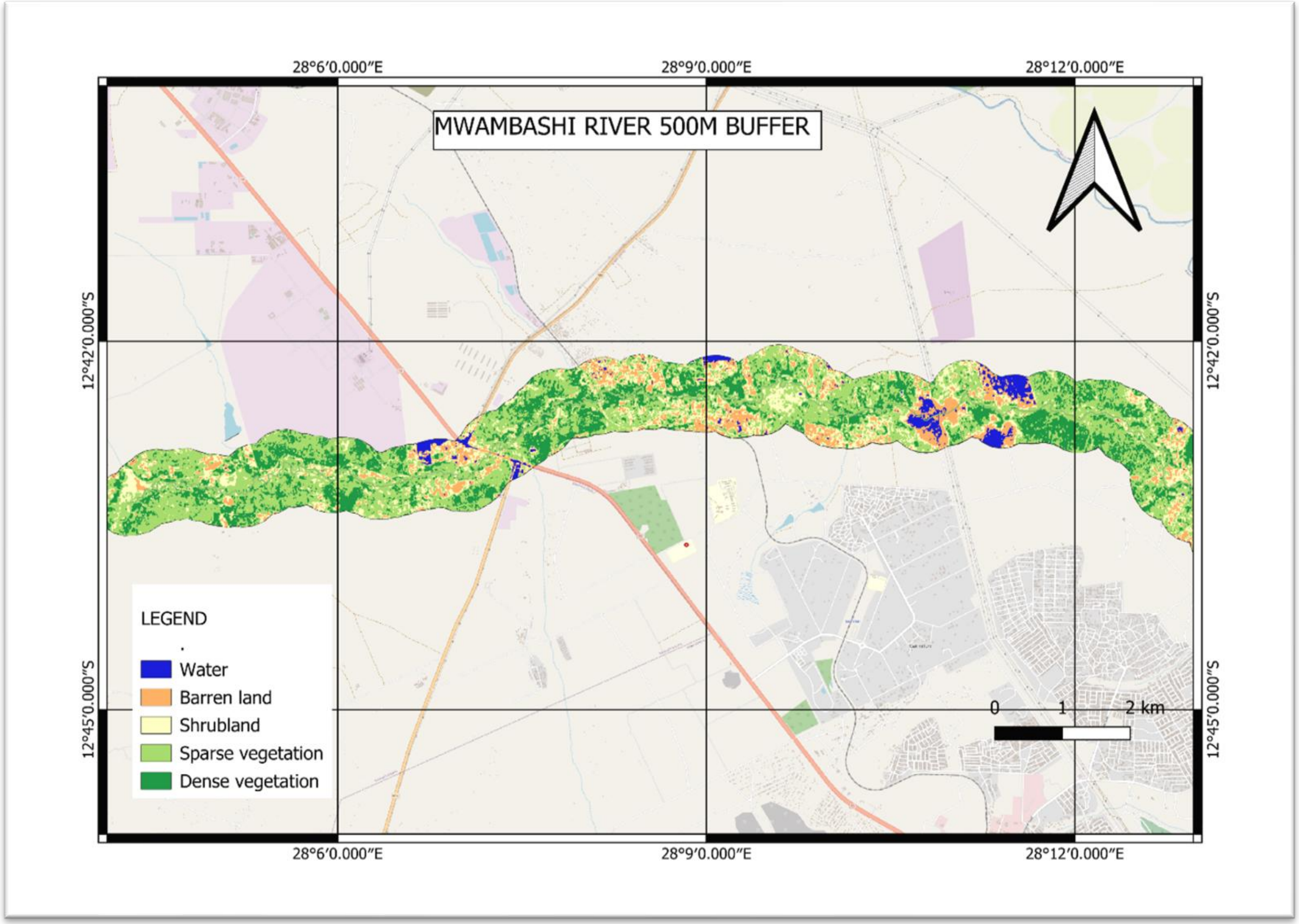


Figure 7-2: Mwambashi River Study Area 500-Meter "Buffer"

Appendix 7-2: Sampling Site Maps

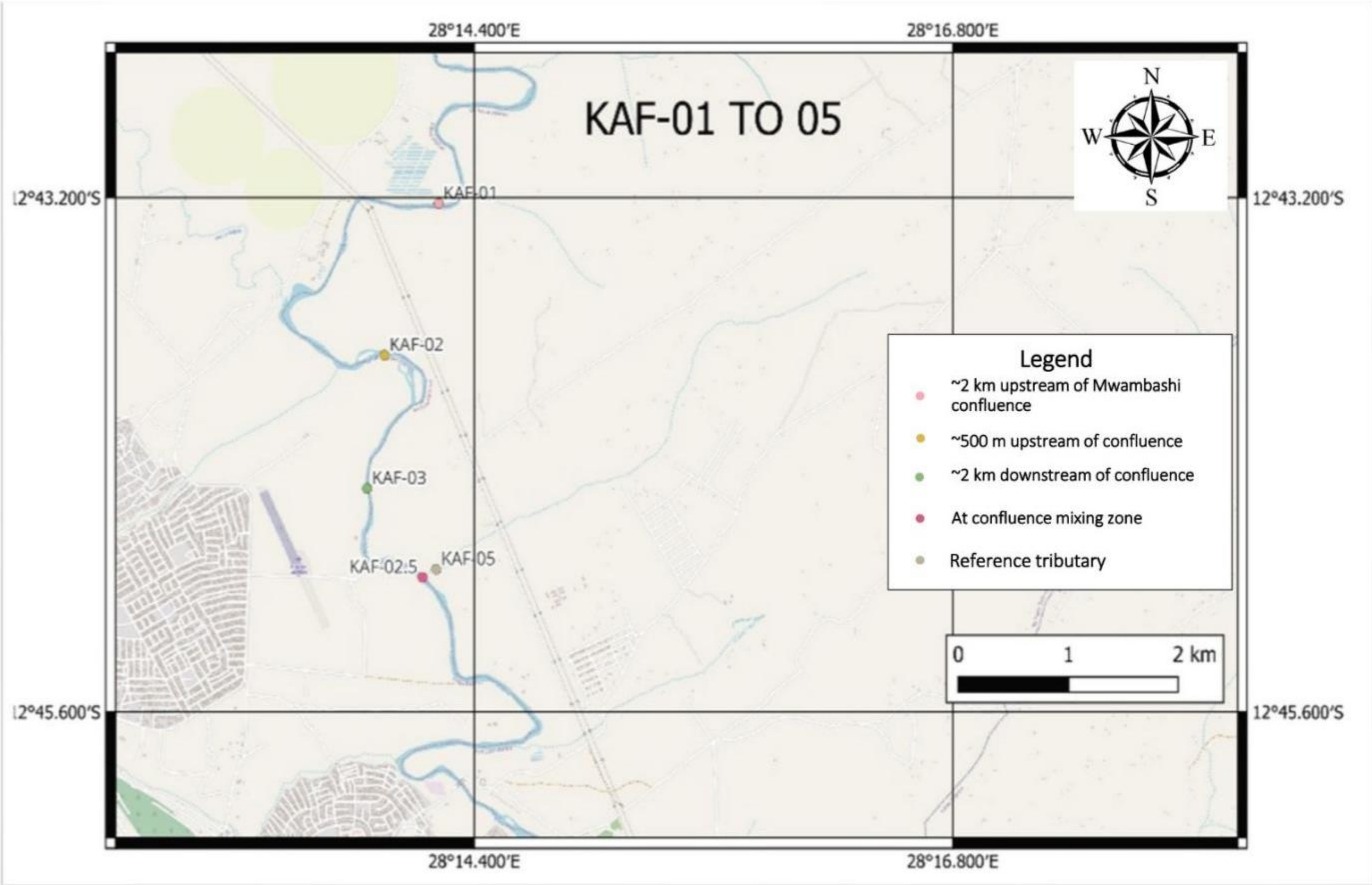


Figure 7-3: Sampling Site Map (KAF-01 TO 05)

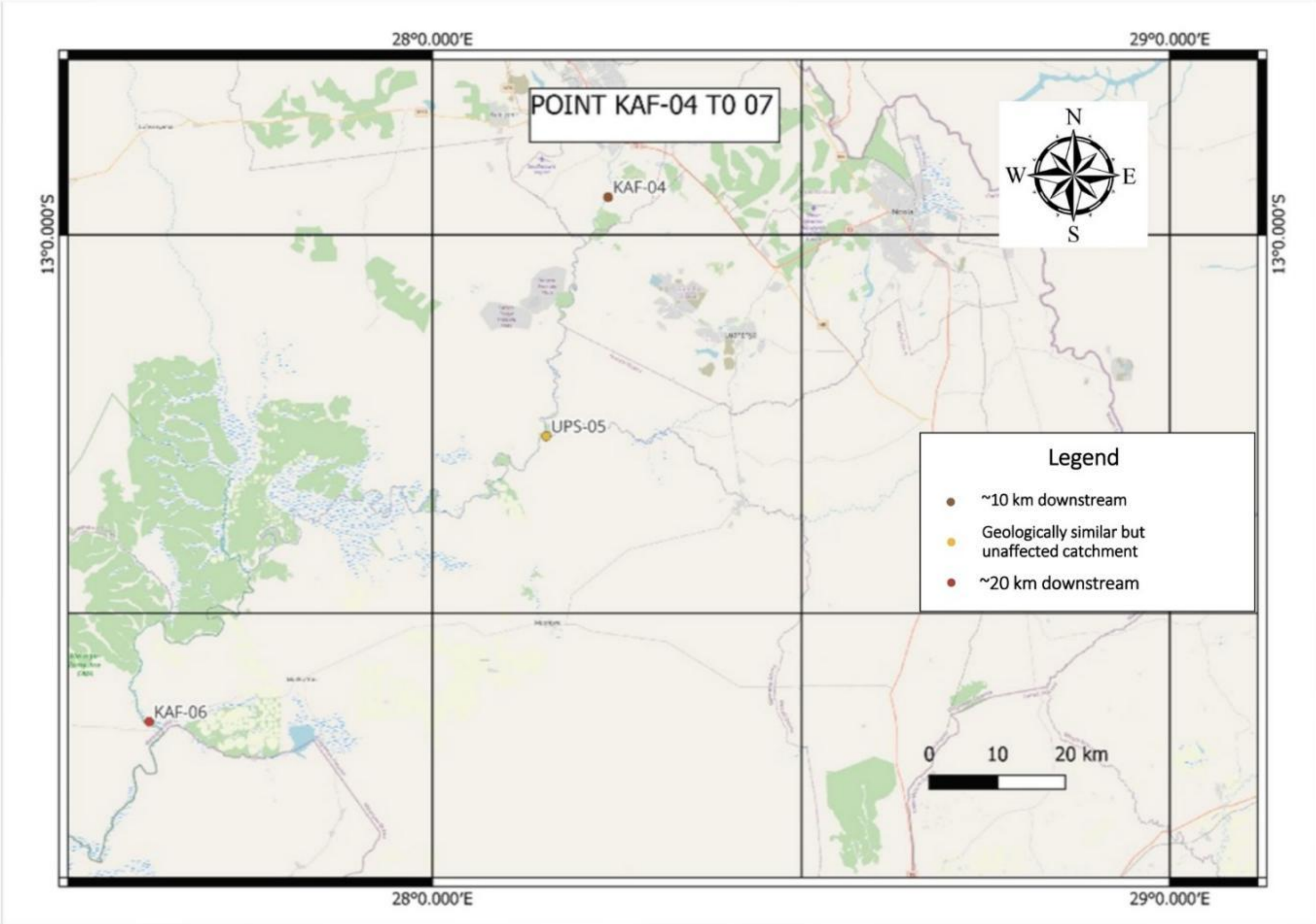


Figure 7-4: Sampling Site Map (KAF-04 TO 07)

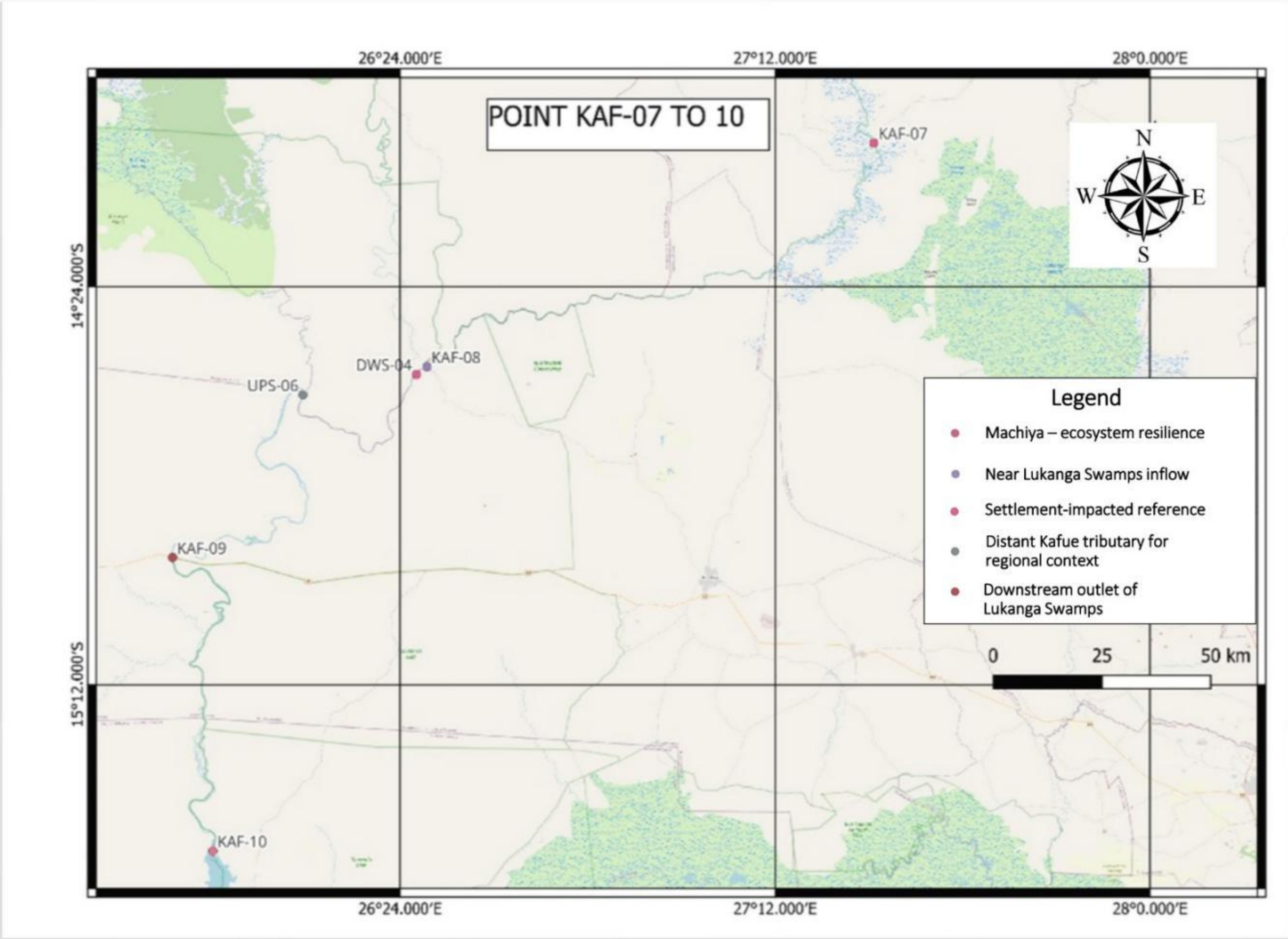


Figure 7-5: Sampling Site Map (KAF-07 TO 10)

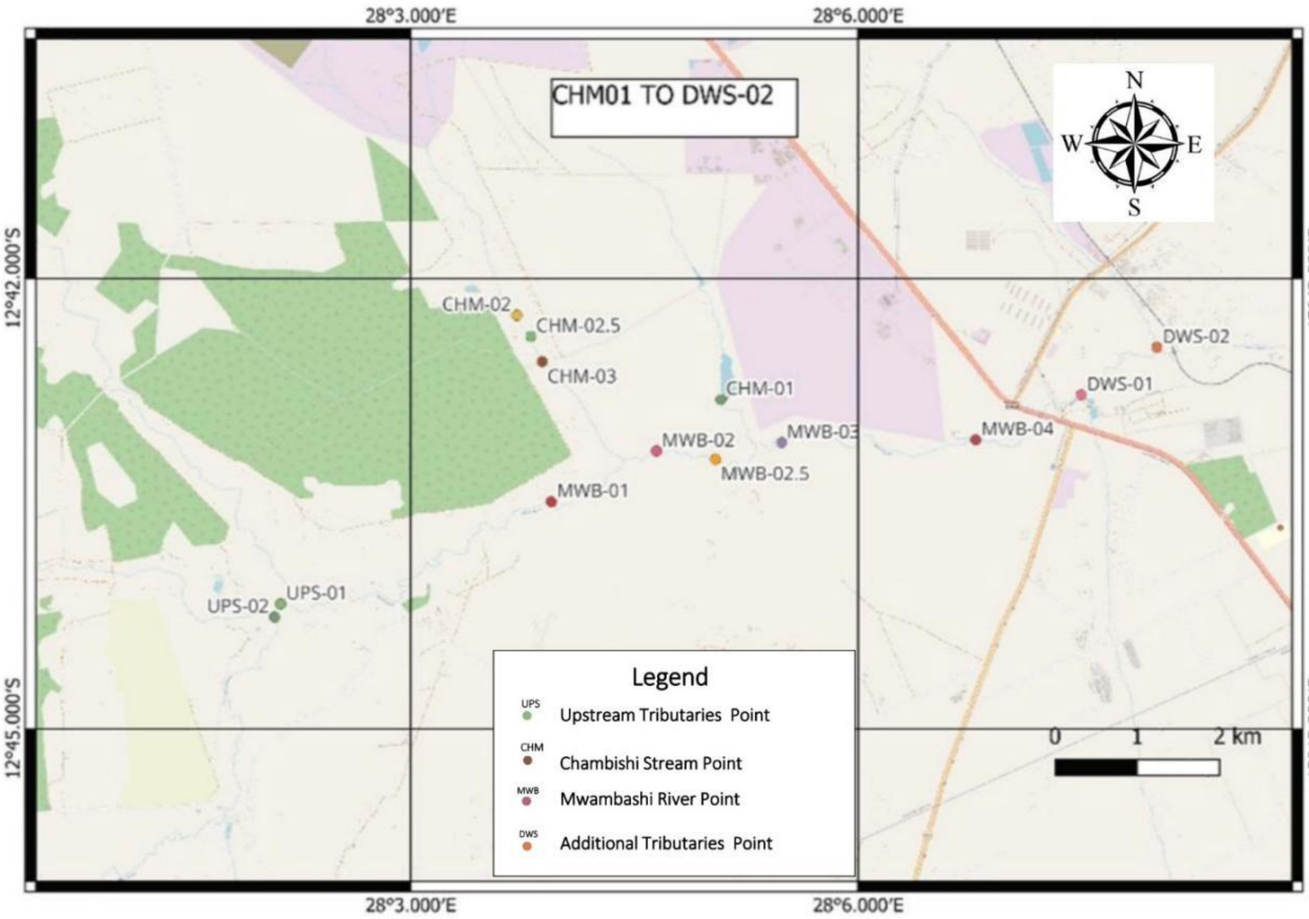


Figure 7-6: Sampling Site Map (CHM-01 TO DWS-02)

Appendix 7-3: Field Pictures

Figure 7-7: Mwambashi Kafue River Confluence (Mavic 3M drone picture)

Figure 7-8: Mwambashi Kafue River Confluence (Mavic 3M drone picture)

Appendix 7-4: Biota Sampling Sites (35 Total Points)

Table 7 - 1: Biota Sampling Sites (35 Total Points)

ZONE	RIVER SYSTEM	SAMPLING SITE	JUSTIFICATION
1	Chambishi Stream	CHM-01	Upstream reference (pre-discharge)
		CHM-01.5	~200 m upstream of T15 outfall (pre-impact signal)
		CHM-02	~500 m downstream of discharge (acute impact)
		CHM-02.5	~1,000 m downstream (early recovery zone)
		CHM-03	~1,500 m downstream, pre-confluence with Mwambashi (dilution/recovery assessment)
2	Mwambashi River	MWB-00	Headwater reference (10 km upstream of confluence) – pristine baseline
		MWB-01	Upstream of Chambishi confluence (semi-reference)
		MWB-02	Immediately downstream of confluence (mixing zone impact)
		MWB-02.5	~1 km downstream (short-term response)
		MWB-03	~2 km downstream (recovery gradient)
		MWB-04	~5 km downstream, near Musakashi confluence (cumulative stressors)
3	Kafue River	KAF-00	Upper Kafue headwaters (regional pristine reference)
		KAF-01	~2 km upstream of Mwambashi confluence
		KAF-02	~500 m upstream of confluence
		KAF-02.5	At confluence mixing zone – critical for plume tracking
		KAF-03	~2 km downstream of confluence (chronic effects)
		KAF-04	~10 km downstream (Ndola Road Bridge) – mid-basin response
		KAF-05	Reference tributary (upper Ichimpe Stream) – biodiversity benchmark
4	Upstream Tributaries (Minimal/no mining influence)	Chati Stream (upper) UPS-02	Pristine background system
		Mupitanshi Stream (upper) UPS-01	Natural variability baseline
		Lulamba Stream (upper) UPS-03	Differentiates mining vs. natural sources
		Kasaba Stream UPS-04	Additional headwater reference
		Kafubu Upper Tributary UPS-05	Geologically similar but unaffected catchment
		Lufupa Headwaters UPS-06	Distant Kafue tributary for regional context
5	Additional Tributaries (Non-mining stressors)	Luela Stream (upper) DWS-02	Agricultural/domestic influence
		Ichimpe Stream (upper) DWS-01	Basin-wide stressor reference
		Kulusale Stream (upper) CHM-01	Ecological risk mapping
		Musakashi Stream (upper) DWS-03	Key tributary baseline
		Lunga Stream DWS-04	Settlement-impacted reference
6	Kafue River (Mid–Lower Reaches)	KAF-06	Ndola Road Bridge (20 km downstream)
		KAF-07	Machiya – ecosystem resilience
		KAF-07.5	Midway to Lukanga Swamps – transitional zone
		KAF-08	Near Lukanga Swamps inflow – wetland risk
		KAF-09.5	Downstream outlet of Lukanga Swamps – filtration assessment
		KAF-10	Upstream of Itezhi-Tezhi Dam – cumulative basin impact

Appendix 7-5: Activities Implemented in the Field

ACTIVITY	METHODOLOGY	OUTPUT PER SITE	TOTAL OUTPUT	FIELD PICTURES
1. Macrophyte Quadrats	Three 1m² quadrats randomly placed per site; species identified, % cover estimated, and voucher specimens archived (non-lethal where possible).	3 quadrats	9 quadrats	 
2. Sediment Cores	Triplicate 15-cm cores collected using stainless steel corers; subsampled for metals (Pb, Cd, As, Cu, Zn, Fe, Mn) and grain size analysis.	3 cores	9 cores	 

3. Periphyton Scrapes	Scraped from 3 stable substrates (rocks, wood) per site using sterile brushes; preserved in ethanol for diatom and algal analysis.	3 scrapes	9 scrapes	 

5. Riparian Transects	50m x 5m belt transects perpendicular to stream; woody vegetation (1.3m height) recorded for species, DBH, and canopy cover.	1 transect	3 transects	

6. Abiotic Parameters	In-situ measurements using calibrated multi-parameter probe: pH, dissolved oxygen (DO), temperature, conductivity, turbidity, and redox potential.	Full suite recorded	18 parameter readings	 

Appendix 7-6: Baseline Conditions (The Ecological "Snapshot")

This section provides a comprehensive ecological baseline, representing the state of biodiversity and ecosystem structure. This "snapshot" serves as the benchmark against which impact severity and recovery are measured.

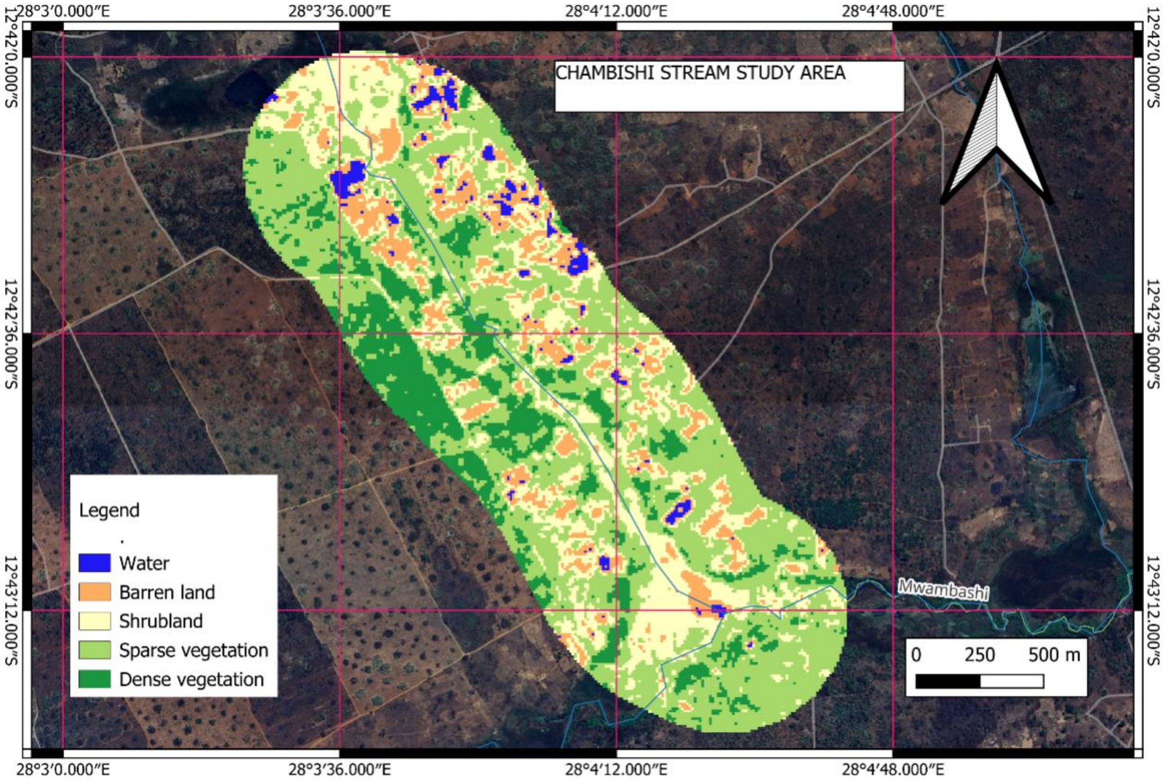


Figure 7-9: Chambishi Stream Study Area

HABITATS

Using the Zambian National Habitat Classification System (aligned with the IUCN Ecosystem Typology), the study area encompasses the following habitat types:

Figure 7-10: Showing Kafue river at Machiya Pontoon (source Marvic 3M multi spectral drone)

AQUATIC HABITATS

PERMANENT HEADWATER STREAMS

Clear, rocky-bottomed tributaries of the Kafue River system with moderate flow; dominated by riffle-pool sequences.

Figure 7-11: Showing the confluence of the Mwambashi Kafue river (source Marvic 3M multi spectral drone)

SEASONAL WETLANDS (DAMBOS)

Perennially moist grass-sedge systems acting as groundwater discharge zones; critical for dry-season water retention.

Figure 7-12: Showing Chambishi Mwambashi confluence (source Marvic 3M multi spectral drone)

RIPARIAN CORRIDORS

Narrow (10–30 m wide) gallery forests and shrub thickets lining watercourses, dominated by *Ficus sycomorus*, *Phoenix reclinata*, and *Phragmites australis*.

Figure 7-13: Showing Chambishi Mwambashi confluence (source Marvic 3M multi spectral drone)

TERRESTRIAL HABITATS:

MIOMBO WOODLAND

Open-canopy, Brachystegia-dominated woodland covering ~65% of the upland study area; rich in understory herbs and seasonal fungi.

Figure 7-14: Showing riparian corridors of the Kafue river (source Marvic 3M multi spectral drone)

GRASSLAND PATCHES

Fire-maintained open areas used for grazing and smallholder farming; interspersed with termite mounds supporting localized biodiversity hotspots.

Figure 7-15: Showing Open-canopy, Brachystegia-dominated woodland (source Marvic 3M multi spectral drone)

ANTHROPOGENIC ZONES

Smallholder agricultural plots (maize, cassava), rural homesteads, and degraded roadside verges; low native biodiversity but high livelihood value. No urban habitats are present within the assessment corridor; land use is predominantly rural-agricultural with embedded natural ecosystems except for the corridor that traverses the Kitwe District.

Figure 7-16: Showing Fire-maintained open areas used for grazing and smallholder farming (source Marvic 3M multi spectral drone)

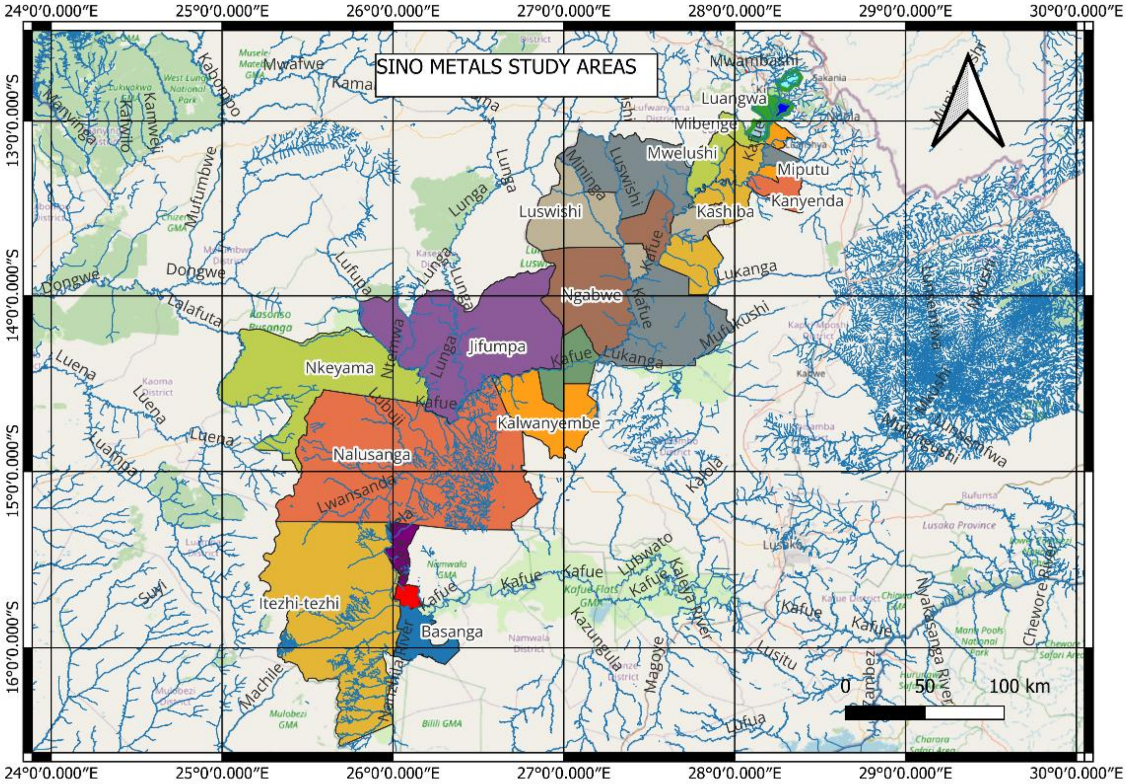


Figure 7-17: Anthropogenic Zones

PROTECTED/SIGNIFICANT SITES

While the study area does not contain formally gazetted national parks, it overlaps with ecologically and culturally significant zones.

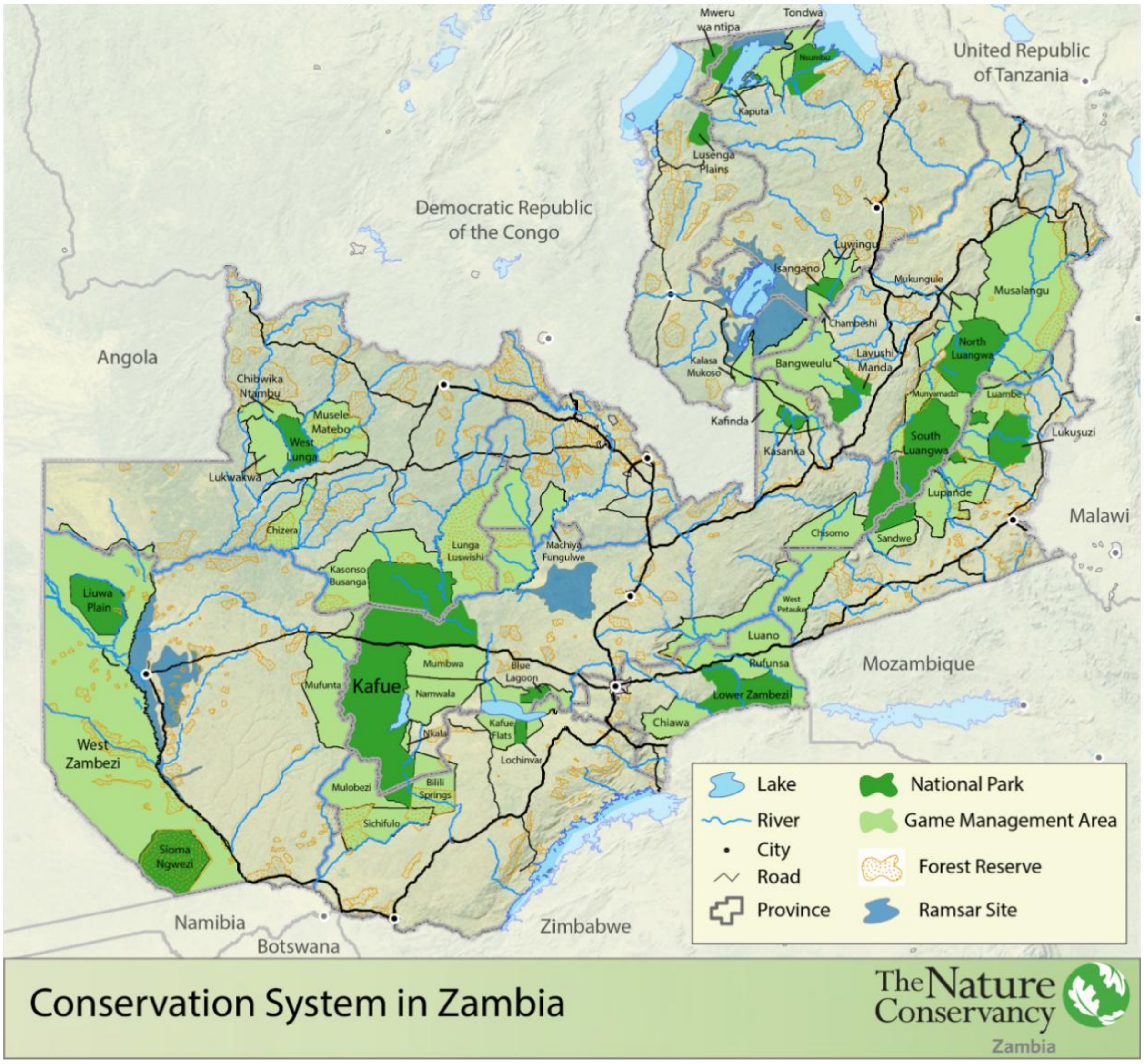


Figure 7-18: Conservation System in Zambia

KEY BIODIVERSITY AREA (KBA) ZM028 (UPPER KAFUE HEADWATERS)

Recognized by BirdLife International for its populations of *Grus carunculata* (Wattled Crane, Vulnerable) and endemic amphibians. The impacted tributaries form part of this KBA's hydrological network.

RAMSAR SITE PROXIMITY

The study area lies within the upstream catchment of the Lukanga Swamp Ramsar Site (85 km downstream), highlighting its role in maintaining water quality for a wetland of international importance.

Figure 7-19: Lukanga Swamp Ramsar Site

8 ASSESSMENT OF IMPACT ON AGRONOMY

8.1 Introduction

8.1.1 Background and context

Agriculture in Zambia's Copperbelt province sustains rural and peri-urban households, cultivating maize (*Zea mays*), cassava (*Manihot esculenta*), common beans (*Phaseolus vulgaris*), and horticultural crops within smallholder systems. These farming practices depend on soil quality, water availability, and micro-ecological balance, all of which are vulnerable to industrial effluent discharges and tailings spillages (Phiri et al., 2019; Sinkala et al., 2021).

Following the Sino-Metals Leach Zambia (SMLZ) tailings spillage into the Chambishi Stream and the downstream Mwambashi-Kafue River corridor, concerns have emerged about contamination of arable lands and their effects on crop growth, soil fertility, and irrigation water quality. Unlike general environmental contamination, agronomic impacts directly influence soil fertility indicators, nutrient cycles, and the physiological performance of crops that support local communities (FAO, 2017). The spillage introduced potentially toxic elements (PTEs), notably copper (Cu), cobalt (Co), lead (Pb), zinc (Zn), cadmium (Cd), and arsenic (As), into farmers' fields, which could disrupt key soil-plant interactions (Kabata-Pendias, 2011) and crop yield.

Heavy metals in soils can reduce soil cation exchange capacity (CEC), decrease soil microbial biomass, inhibit enzymatic activity, and cause nutrient antagonism, particularly decreasing nitrogen and phosphorus uptake in plants (Alloway, 2013). Elevated metal concentrations can also alter soil pH and electrical conductivity (EC), interfering with the chemical balance required for optimal plant growth. These conditions result in visible crop stress symptoms such as chlorosis, stunting, leaf necrosis, and lower grain or tuber yield. The effects of agriculture are often long-lasting because metals accumulate in the topsoil (0-30 cm), where root systems are most active (FAO, 2020).

The Chambishi-Mwambashi-Kafue corridor consists of ferralsols and acrisols, which are typically acidic (pH 5.0-6.0) and have low organic matter (3%). These soils have limited buffering capacity against contamination and poor nutrient retention (ZEMA, 2019). Even small amounts of tailings effluent can cause significant changes in soil chemistry and biological fertility. The local farming communities, whose fields are situated within 30-100 metresof the riverbanks, depend heavily on surface and residual moisture for irrigation, making them directly susceptible to contamination through both soil deposition and irrigation water uptake pathways.

8.1.2 Objectives of the agronomic assessment

Given these risks, the agronomic component of this Environmental and Social Incident Impact Assessment (ESIIA) was designed to assess the impact of the tailings discharge on agronomy. Specifically, we aimed to:

- Assess the impact of the tailings discharge on soil chemical properties and potential crop performance.
- Evaluate the extent of heavy metal build-up in agricultural soils and crops.
- Recommend locally feasible and environmentally sustainable agronomic restoration and remediation strategies.

8.1.3 Scope and alignment with overall environmental and Social Incident Impact assessment

This assessment recognises that agronomic degradation affects health and socio-economic outcomes. Crops grown on contaminated soil can absorb and translocate these toxic elements into their edible tissues. Consuming contaminated produce exposes people to harmful levels of heavy metals, posing significant long-term health risks. Furthermore, reduced soil fertility and crop yields lead to income losses, food insecurity, and lower land values. These are important issues for rural households that rely on smallholder farming. The results of this assessment will inform targeted remediation strategies, including soil amendment, phytoremediation, and farmer capacity-building programmes, ensuring that agricultural productivity and environmental integrity are both restored. The study aligns with Zambia's Environmental Management Act (2011) and the National Agricultural Policy (NAP, 2016–2030), as well as global soil protection frameworks established by the FAO (2017) and UNEP (2020) for the rehabilitation of contaminated sites. It represents a crucial step in safeguarding soil resources and promoting agricultural sustainability following industrial contamination.

8.1.4 Study Justification and Relevance to Agricultural Productivity

This agronomic assessment aims to quantify, understand, and minimise the potential impacts of the Sino-Metals Leach Zambia (SMLZ) tailings spill on agricultural productivity and soil health within the Chambishi-Mwambashi-Kafue River corridor. Agriculture in this region supports both subsistence and commercial livelihoods, and its success depends directly on the chemical, physical, and biological integrity of soils, as well as the quality of irrigation water (FAO, 2020; ZEMA, 2019).

Mining-related effluents frequently contain elevated levels of copper (Cu), cobalt (Co), zinc (Zn), lead (Pb), and cadmium (Cd). When these metals enter arable soils, they can accumulate in the topsoil layers, disrupting soil nutrient cycles, microbial activity, and enzymatic processes essential for plant growth (Alloway, 2013; Kabata-Pendias, 2011). As a result, the capacity of soils to support crop production diminishes due to reduced cation exchange capacity (CEC), slower decomposition of organic matter, and decreased nutrient bioavailability, leading to lower yields and weaker crop health (Phiri et al., 2019).

In the Copperbelt region, soils are already moderately acidic and nutrient-poor, with limited ability to buffer against contamination. Additional pollutant loads from industrial discharges can accelerate soil acidification, induce nutrient antagonism (e.g., between Zn and Fe or between Cu and P), and reduce root uptake efficiency (FAO, 2017; UNEP, 2020). The impact on agricultural productivity is significant, as reduced nutrient cycling and interference from toxic elements lead to lower yields of maize, beans, and vegetables, the main food and cash crops in the area.

The agronomic assessment is therefore justified on several interrelated grounds:

Evidence-based Remediation- Measuring contamination levels offers the empirical basis for targeted soil and crop remediation actions (biochar application, liming, organic amendments, or phytoremediation).

Food Safety Assurance- Heavy metals absorbed by crops pose potential risks to consumers through dietary exposure. Understanding metal accumulation in edible plant parts is essential to safeguard public health and maintain agricultural trade standards (WHO, 2011).

Sustainable Land Use Planning- The results endorse land-use zoning and soil rehabilitation efforts that prevent long-term loss of productive farmland.

Policy and Institutional Strengthening - Findings guide regulatory bodies like ZEMA, the Ministry of Agriculture, and local councils on setting monitoring thresholds, enhancing effluent discharge compliance, and incorporating agronomic resilience into environmental management plans.

Livelihood Restoration- By assessing the extent of productivity loss and degradation, the study supports compensation, livelihood recovery, and sustainable farming interventions for affected households

8.2 Literature review

8.2.1 Review of agronomic and soil impact studies

Agronomic impact research in mining areas has shown the link between industrial effluent contamination and declining soil productivity. In Zambia's Copperbelt Province, studies have indicated elevated levels of copper (Cu), cobalt (Co), and lead (Pb) in agricultural soils near mine tailings and smelter sites (Phiri et al., 2019; Sinkala et al., 2021). These contaminants originate from tailings seepage, waste dumps, and atmospheric deposition, collectively disturbing the soil's chemical and biological balance.

Research by Chirwa et al. (2020) revealed that agricultural soils near the Chambishi and Kitwe industrial zones contained Cu concentrations exceeding 200 mg/kg. This was more than double the FAO-permissible limit for agricultural soils (FAO, 2017). Similarly, Mulenga et al. (2022) found that maize cultivated within 2 km of Tailings Storage Facilities exhibited significant reductions in chlorophyll content and grain yield compared to control sites, primarily due to metal-induced physiological stress.

Soil health parameters such as pH, cation exchange capacity (CEC), and microbial biomass, among others, act as sensitive indicators of contamination (Alloway, 2013). Decreases in microbial respiration and enzyme activity (notably dehydrogenase and phosphatase) are often seen in contaminated farmland (Kabata-Pendias, 2011). These findings emphasise the importance of agronomic impact assessments that use chemical, biological, and remote-sensing indicators to evaluate the full extent of soil degradation in areas affected by mining.

8.2.2 Impacts of contamination on crop and soil health

Heavy metal contamination affects both soil fertility and crop physiological performance, thereby lowering agricultural productivity. In contaminated soils, metals such as Cu, Pb, and Cd bind to soil colloids and organic matter, reducing nutrient availability and disrupting ion exchange processes (FAO, 2020). High levels of Cu and Co inhibit root elongation and reduce seed germination rates, while Pb interferes with photosynthesis and chlorophyll synthesis in crops such as maize, cassava, and vegetables (Kabata-Pendias, 2011; Alloway, 2013). According to Sinkala et al. (2021), increased metal concentrations in Zambian agricultural soils are linked to lower maize biomass and reduced nitrogen use efficiency. Physiological stress from metal toxicity manifests as leaf chlorosis, necrosis, and stunted growth, often accompanied by nutrient imbalances, such as reduced Ca and Mg uptake (Phiri et al., 2019).

Furthermore, soil contamination indirectly affects soil microbial communities responsible for nutrient cycling. Reduced microbial diversity leads to slower organic matter decomposition and lower enzyme activity (e.g., urease and phosphatase), resulting in long-term declines in soil fertility and productivity

(FAO, 2017). This cumulative impact reduces both crop quality and yield, threatening food security and the sustainability of smallholder farmers' livelihoods.

8.2.3 Review of heavy metals and nutrient imbalances in agricultural systems

Heavy metals such as Cu, Zn, Co, Pb, Cd, and As are naturally occurring elements, but their elevated levels in soils resulting from human activities can be toxic to plants and soil microorganisms (Kabata-Pendias, 2011; UNEP, 2020). When concentrations exceed critical thresholds, they interfere with the uptake of essential nutrients, leading to antagonistic or synergistic interactions that disrupt plant nutrition. For example, excess copper can inhibit the absorption of iron (Fe) and zinc (Zn), causing micronutrient deficiencies despite adequate soil reserves (Alloway, 2013). Similarly, cadmium (Cd) competes with zinc (Zn) and calcium (Ca) for uptake sites in plants, affecting cell wall formation and membrane integrity. Studies by Tembo et al. (2020) on the Copperbelt showed that high concentrations of Cu and Co in soils were associated with a 25–40% reduction in available phosphorus (P) due to fixation reactions and microbial inhibition.

Nutrient imbalances also influence soil acidity regulation, as metal-rich soils tend to become more acidic over time, reducing base saturation and buffering capacity (FAO, 2020). In Zambia's ferralsols and acrisols, this process is accelerated by naturally low pH and low organic matter content (ZEMA, 2019). The persistence of heavy metals in the topsoil layer (0–30 cm) means that, without remediation, contamination effects can persist for decades, decreasing land productivity and increasing the risk of exposure through the food chain (WHO, 2011).

8.2.4 Review of Zambian agricultural and environmental policies

Zambia's policy framework emphasises sustainable agricultural productivity and environmental protection, recognising soil as a crucial natural resource. The National Agriculture Policy (NAP) 2016–2030 promotes conservation agriculture, soil fertility enhancement, and integrated nutrient management to improve resilience and productivity (Ministry of Agriculture, 2016). Similarly, the National Environmental Policy (NEP, 2007) and the Environmental Management Act (EMA No. 12 of 2011) provide the legal basis for regulating pollution and enforcing environmental standards through the Zambia Environmental Management Agency (ZEMA). Regarding soil contamination, the ZEMA Environmental Management (Licensing) Regulations, 2013, specify acceptable limits for effluent discharges and require environmental monitoring for all mining activities. The National Climate Change Policy (2016) and the Eighth National Development Plan (8NDP) further underscore the importance of climate-smart, sustainable land management practices for maintaining ecosystem integrity and securing food security.

However, enforcement gaps and limited soil-monitoring capacity have constrained the effectiveness of these policies (ZEMA, 2019). The current agronomic assessment directly helps to fill this knowledge and regulatory gap by providing site-specific empirical data to inform policy implementation and guide soil rehabilitation strategies in contaminated agricultural zones.

8.2.5 International standards and guidelines (FAO, WHO, UNEP)

Internationally, several agencies set benchmarks for assessing and managing soil and crop contamination. The Food and Agriculture Organisation (FAO) establishes guidelines on acceptable levels of trace metals in agricultural soils and irrigation water, highlighting safe thresholds for plant growth and food quality

(FAO, 2017). The FAO's 2020 Framework on Sustainable Soil Management promotes integrated soil monitoring, remediation, and nutrient restoration as part of sustainable agricultural practices.

The World Health Organiation (WHO, 2011) provides supplementary standards for heavy metals in food and drinking water, setting maximum permissible levels for Pb (0.1 mg/L), Cd (0.01 mg/L), and As (0.05 mg/L). These guidelines act as international benchmarks for food safety risk evaluations.

The United Nations Environment Programme (UNEP, 2020) further provides technical guidance on soil contamination and remediation, emphasising risk-based management, phytoremediation, and community involvement in contaminated-site recovery. Collectively, these frameworks create a harmonised approach that combines scientific monitoring, policy regulation, and community resilience, offering a model that the current study adapts to Zambia's agronomic context. In line with these standards, the current assessment applies FAO and UNEP field protocols, adopts WHO permissible limits for crop safety, and aligns its remediation recommendations with global best practices for contaminated agricultural ecosystems.

8.3 Baseline agronomic conditions

8.3.1 Description of the Study Area

The study area covers the Chambishi, Mwambashi, and Kafue River catchments, specifically parts of Kalulushi, Kitwe, Luanshya, Mpongwe, Ngabwe, and Itezhi-Tezhi Districts. The contamination pathway extended from the Chambishi Stream through Musakashi camp in Kalulushi District, where the three directly affected areas were Kalusale, Mukulumpe, and Sabina. Along the Mwambashi River, the impacted site was Luongo Camp in Kitwe District. Further downstream on the Kafue River, the assessment focused on several agricultural communities, specifically Milyashi Camp in Luanshya, Machiya Camp in Mpongwe, Chisangwe–Peshelungu Camp in Ngabwe, and Banamwaze Camp in Itezhi-Tezhi. These locations collectively represent the full upstream–midstream–downstream gradient of the spill-affected agricultural corridor. They form a north–south transect across Zambia's Agro-Ecological Regions III and II, with the Copperbelt districts situated within the high-rainfall AER III zone, Ngabwe in a transitional IIb–III belt, and Itezhi-Tezhi within the medium-rainfall AER IIa zone (MoA, 2016; FAO, 2020).

8.3.1.1 Rainfall

Rainfall patterns differ along the corridor. The northern part (Kalulushi, Kitwe, Luanshya, Mpongwe) usually receives 1,200–1,400 mm each year, while Ngabwe averages 1,000-1,200 mm. Itezhi-Tezhi, situated in the Kafue Basin, receives 800-1,000 mm annually. Rainfall is unimodal, mainly falling between November and April, followed by a clear dry season from May to September. Localised flooding happens along the Kafue Flats and Itezhi-Tezhi floodplain, whereas the Copperbelt plateau experiences regular, evenly spread rainfall.

8.3.1.2 Temperature

The average annual temperature ranges from 18°C to 26°C, with daily highs reaching 32°C in October and lows near 12°C in June. The northern highlands around Kalulushi and Kitwe experience cooler microclimates, while Itezhi-Tezhi is considerably warmer due to its lower elevation and open savannah landscape.

8.3.1.3 Soil types

Soils across the study area are diverse, mainly comprising ferralsols, acrisols, and luvisols, which are generally acidic (pH 5.0-6.0) with low cation exchange capacity (CEC) and moderate to low organic matter content (1.5-2.5%). The alluvial soils along the Chambishi, Mwambashi, and Kafue riverbanks are relatively more fertile and retain higher moisture levels, supporting horticultural activities. Conversely, upland ferralsols in Mpongwe and Luanshya are more leached, requiring organic or lime amendments to sustain productivity. The Kafue floodplain soils in Itezhi-Tezhi are hydromorphic, consisting of sandy loams enriched with clay and silt deposits, but they are prone to seasonal waterlogging.

8.3.1.4 Topography and drainage

The terrain is mainly gentle, with slope gradients of 3-5%, leading to moderate runoff and occasional erosion during heavy rainfall. The Chambishi and Mwambashi tributaries drain from the Copperbelt plateau into the Kafue River, which eventually flows into the Itezhi-Tezhi reservoir downstream. This drainage system supports both rainfed and irrigated agriculture, with several wetlands and dambos used for dry-season cultivation.

8.3.1.5 Vegetation

The area's vegetation transitions from Miombo woodland in the north to savanna and open grassland ecosystems in the south. The Copperbelt and Mpongwe regions are characterised by the dominance of Brachystegia, Julbernardia, and Isoberlinia species, interspersed with fallows and grazing lands. Ngabwe features a mosaic of secondary woodland and cultivated grasslands, while Itezhi-Tezhi supports mixed savanna vegetation influenced by the hydrology of the Kafue Flats. These ecosystems are vital for soil protection, biodiversity, and traditional resource uses such as charcoal production, grazing, and harvesting wild foods.

8.3.2 Dominant cropping systems

8.3.2.1 Copperbelt plateau (Kalulushi, Kitwe, Luanshya, Mpongwe)- high rainfall mixed Crop System

Agro-Ecological Region III is characterised by a rainfed maize–legume farming system, complemented by interspersed horticultural activities and dairy-livestock integration. The main crops grown in this region include maize, beans, soybeans, groundnuts, sweet potatoes, cassava, and vegetables such as rape, cabbage, tomato, and onion. Farming is primarily done by smallholder and emerging farmers, who manage between 1 and 5 hectares of land, often using ox-drawn or minimal-tillage techniques. A few commercial farms, especially in the Mpongwe area, operate mechanised maize-soybean rotations that improve productivity and market supply. Livestock plays an important role in the farming system, with dairy and beef cattle being predominant in Mpongwe. Goats, pigs, and poultry are also kept, providing manure that boosts soil fertility and supports integrated crop–livestock production. Horticultural production thrives along the Chambishi and Mwambashi streams, where farmers use treadle pumps and shallow wells to irrigate their crops, particularly during the dry season from July to October. However, the region faces several challenges, including soil acidity, nutrient depletion, and high input costs. Additionally, agricultural activities are increasingly threatened by exposure to metal-rich sediments from upstream mining operations, posing risks to both soil health and crop productivity.

8.3.2.2 Ngabwe District-Mixed crop-livestock/ fisheries-based system

This area lies within the transitional zone between Agro-Ecological Regions IIb and III, characterised by a mixed crop-livestock/ fisheries farming system complemented by emerging groundnut and horticultural enterprises. The major crops cultivated include maize, groundnuts, beans, soybeans, and sweet potatoes, reflecting a diversified yet subsistence-oriented agricultural structure. In some rural zones, traditional slash-and-burn (chitemene) shifting cultivation practices are still observed. However, non-governmental organisations promote a gradual shift towards conservation agriculture (CA) methods to enhance soil health and sustainability.

Horticultural activities are expanding around small dams and along seasonal streams, where farmers focus on vegetables and bananas for both household consumption and local markets. Livestock rearing, mainly goats, chickens, and village pigs, is integrated into the cropping systems, providing manure to improve soil fertility and supporting household food security. The area also offers seasonal fishing, with many fishing camps.

Despite these adaptive practices, the region continues to face persistent constraints, including poor soil fertility, limited access to agricultural inputs and extension services, and high post-harvest losses. These challenges continue to affect productivity and profitability, underscoring the need for targeted interventions to strengthen sustainable farming systems in this transitional agro-ecological zone.

8.3.2.3 Agronomic implications

The agro-ecological diversity across the corridor supports a wide variety of crops. Rainfed maize, cassava, and legumes are dominant in the northern and central regions. At the same time, irrigated horticulture (tomatoes, cabbage, onions, leafy vegetables) is common along the riverbanks and dambos (low-lying wet areas) during the dry season. However, the same river systems that sustain agricultural production also increase vulnerability to contaminants and heavy metals transferred through irrigation water and sediment deposition, especially downstream of mining and industrial zones in the Copperbelt (Phiri et al., 2019; Sinkala et al., 2021).

8.3.2.4 Itezhi-Tezhi District-Kafue basin floodplain and irrigated agro-pastoral system

Agro-Ecological Region IIa features an agro-pastoral farming system that combines maize and vegetables, with flood-recession farming along the Kafue Flats. The main crops include maize, sweet potatoes, sorghum, and various vegetables, such as tomatoes, cabbage, onions, and okra. Farmers also grow green maize for sale, providing a significant source of cash income during the growing season.

Cropping follows a clear seasonal cycle. During the rainy season, from November to April, rainfed upland maize dominates the landscape. In contrast, the dry season, from May to October, features flood-recession farming, in which vegetables are grown along the edges of the Kafue Flats as the floodwaters recede. This dual system enables year-round farming, supporting both food security and household incomes.

Livestock, particularly cattle, play a crucial role in the region's agro-economy. They are important assets, offering draft power for ploughing, manure for soil enrichment, and a form of financial reserve. Seasonal movement of livestock to graze is a common practice, with herds migrating along the Kafue Flats in response to changes in water levels and pasture availability. Irrigation for crops mainly comes from the

Kafue River and nearby low-lying areas, using buckets, canals, or small pump systems, often managed collectively within farmer groups.

Most farmers in this region are smallholders, although a few organised cooperatives operate under the Farmer Input Support Program (FISP) or NGO-supported irrigation schemes. Despite the productive potential of this mixed system, farmers face several constraints, including seasonal flooding and waterlogging, wildlife-livestock conflicts, and inadequate storage and marketing infrastructure. These challenges limit productivity and profitability, underscoring the need for enhanced water management, value chain development, and resilient farming practices.

8.4 Methodology

8.4.1 Study design and site stratification

The study employed a stratified impact-based approach to evaluate the agronomic effects of the Sino-Metals Leach Zambia (SMLZ) tailings spillage on agricultural soils and crops. The method combines field surveys and laboratory analysis to assess contamination levels and their impact on soil and potential crop productivity. This stratification enables a comparative analysis of spatial contamination gradients, providing an empirical basis for correlating proximity to contamination with soil and crop health parameters.

8.4.1.1 High impact zone

This refers to farmers' fields directly affected by the spill, where the discharged material physically flowed through and across the cultivated land. This area is primarily around the Chambishi River. These zones experienced the most immediate and severe impact, as the contaminants came into direct contact with crops, soil, and irrigation channels. The spillage likely disrupted farming activities, damaged standing crops, and altered soil quality, thereby posing a potential risk to productivity. Musakashi camp falls into this category.

8.4.1.2 Medium impact zone

This includes farmers' fields located downstream of the Mwambashi River. These areas were not directly affected by the spillage but were exposed to secondary contamination routes, such as runoff, seepage, or sediment deposition from the affected river system. While the impact level is lower than in the high-impact zone, these fields remain at risk of soil and water contamination, especially during flooding or irrigation, when pollutants can spread. Luongo Camp falls into this category.

8.4.1.3 Low impact zone

This includes agricultural fields along the Kafue River and those that use river water for irrigation. These areas are mainly affected by diluted downstream flows, where contaminant levels have fallen significantly due to dispersion and natural dilution. Although the direct impact is minor compared to the high and medium zones, there remains a possibility of low-level contamination through irrigation water or sediment build-up over time, highlighting the need for regular monitoring of soil and water quality to protect crop yields and environmental health. Milyashi, Machiya, Ngabwe and Banamwaze Camps are part of this category.

8.4.1.4 Control sites

The agricultural fields are situated more than 50 metres away from any contaminated watercourse and lie outside the designated contamination corridor, which runs parallel to the contamination zones. These sites also include locations that depend on rainwater for irrigation and do not utilise contaminated water.

8.4.2 Sampling framework

A proportionate stratified random sampling framework was used to ensure representative coverage across all impact zones. This method meant that more fields were sampled from high-impact areas than from low-impact zones. It was also based on the total number of affected fields. From each field, a composite soil sample was gathered. Each composite consisted of five subsamples, which were thoroughly mixed to create a representative sample for laboratory analysis. From the same fields, plant samples were collected. Sampling points were georeferenced using GPS, and their coordinates were recorded in the GIS database for spatial mapping. The sampling density and replication were determined in accordance with the FAO (2020) and ZEMA (2019) guidelines for environmental soil sampling, ensuring statistical validity and repeatability. A questionnaire was also administered to the field owner to gain additional insights into crop performance.

8.4.3 Soil sampling and laboratory analysis

Soil samples were taken from the 0-20 cm depth, which represents the main root zone most vulnerable to contamination and nutrient exchange. This layer was selected because it serves as the primary interface for plant uptake, microbial activity, and chemical interactions. The analyses focused on a broad range of parameters to evaluate the soil's chemical properties. The chemical properties tested included pH and electrical conductivity (EC). Additionally, trace and heavy metals such as copper (Cu), cobalt (Co), lead (Pb), zinc (Zn), cadmium (Cd), arsenic (As), selenium (Se), manganese (Mn), iron (Fe), and aluminium (Al) were measured to detect possible contamination from tailing dam spillage. All laboratory analyses were performed in ISO/IEC 17025-certified laboratories, following standard procedures recommended by the FAO (2017) and UNEP (2020).

8.4.4 Plant tissue sampling and crop condition assessment

Where crops or natural vegetation were present, plant tissue samples were collected from farmers' fields. The samples included both edible and leaf components. Crops sampled comprised maize (*Zea mays*) grains and leaves, as well as leafy vegetables and their fruits. The analysis focused on trace and heavy metals such as copper (Cu), cobalt (Co), lead (Pb), zinc (Zn), cadmium (Cd), arsenic (As), selenium (Se), manganese (Mn), iron (Fe), and aluminium (Al). Field assessments identified visual indicators, including chlorosis, necrosis, stunting, and leaf curling, which were later compared with laboratory data to examine the relationship between contamination levels and crop stress. This combined approach of visual observation and chemical analysis provides a thorough evaluation of both visible and hidden contamination effects on plant health.

The wet digestion method was employed to extract the elements. 5.0 g of the homogenised sample was placed into a labelled 250 mL beaker. This mass served as the key reference point for calculating the final concentration. A mixture of 10 ml of 1:1 hydrochloric acid and 30 ml of concentrated nitric acid was then added to the sample. The nitric acid acted as a strong oxidising agent, breaking down the organic components, while the hydrochloric acid helped keep the metal ions soluble and prevent precipitation. The sample was then placed on a heated plate and brought to a boil under a fume hood. Boiling continued until the reaction was complete, as confirmed visually when the volatile brown nitrogen oxide fumes were fully driven off, and the remaining solution became clear or pale yellow, indicating the successful destruction of the organic matter.

After cooling, the solution was diluted with 100 ml of distilled water. The resulting solution was then filtered, if necessary, to remove any insoluble residual particles, such as silica or undigested matter, ensuring that only the dissolved metal ions were carried forward. The filtered solution was transferred accurately into a 100 ml volumetric flask. The flask was then filled to the calibration mark with distilled water, establishing the final, precise volume. After thorough mixing to ensure homogeneity, the solution was ready for analysis by inductively coupled plasma.

8.4.5 Data management and quality assurance

All quality assurance and quality control (QA/QC) measures strictly adhered to the FAO (2020) and UNEP (2020) data quality frameworks, thereby ensuring that the compiled datasets were consistent, reproducible, and scientifically robust for subsequent analysis and interpretation.

8.4.6 Statistical and spatial data analysis

Statistical analysis was conducted to detect significant differences and patterns in soil and plant parameters within impact zones and between the control sites. Key analyses included descriptive and inferential statistics. Mean, standard deviation, and coefficient of variation.

8.4.7 Ethical considerations

The study was conducted in strict accordance with ethical standards for environmental and social research. All participating farmers were informed of the purpose, objectives, and scope of the assessment, and verbal consent was obtained before entering their fields or collecting samples. The research team ensured that no destructive sampling was conducted outside the designated small-plot sampling zones and that all collected data were anonymised to protect the privacy and confidentiality of the participating farmers.

To promote transparency and inclusivity, engagements were held with local agricultural officers and community leaders, fostering community trust and ownership of the research process. The study adhered to the ethical provisions of the Environmental Management Act (2011). The University of Zambia granted ethical clearance through the Research and Innovation hub.

8.5 Results and discussion

8.5.1 Soil heavy metal concentration and contamination trends

8.5.1.1 Kalusale- Chambishi Stream

The soil assessment for Kalusale showed varied suitable farming conditions and high contamination risks. Table 8-1 presents the mean values, soil threshold limits, coefficient of variation (CV%), and risk classifications for each parameter. The results reveal that while some elements are within normal agricultural ranges, several toxic elements exceed safe limits, posing challenges for crop production and potential threats to environmental and human health.

The traffic light system used in this study provides a clear visual representation of soil quality and contamination risk across the assessed parameters. Each element was evaluated against internationally recognised threshold limits and assigned a colour-coded symbol indicating its risk level. Green (●) signifies normal or safe conditions, showing that the parameter is within acceptable agronomic ranges and poses no immediate concern. Yellow (●) indicates a medium or cautionary risk, meaning the values are slightly outside optimal levels and could begin to affect plant performance if not managed. Single red (●) denotes a high-risk condition, suggesting the parameter exceeds permissible limits and may harm soil health, crop productivity, or microbial activity. The double red symbol (● ●) represents a very high or critical risk level, where values are well above safe thresholds and urgent action is necessary to prevent toxicity or environmental damage. This system enhances interpretation by distinguishing safe soil conditions from areas requiring targeted intervention, thereby supporting informed decisions on crop zoning, soil remediation, and sustainable land management. A score ranging from 0 to 3 is also assigned for the traffic light, with 0 indicating safety and 3 indicating very high risk.

Table 8 - 1: Kalusale Soil parameters

Parameter	Mean	Threshold	CV (%)	Risk	Traffic Light	Score (0–3)
pH	6.29	6.0–7.5	8.85	Medium		1
EC	379.78	< 400	89.04	Medium		1
Al	21119.89	5,000–10,000 (toxic if pH<5)	28.03	High		2
As	4.87	<20	108.01	Low		0
B	< 0.005	1.0 – 2.0	-	Low		-
Ca	2979.108	2000 – 20,000	62.31	Low		0
Cd	0.3625	<1	396.47	Low		0
Co	34.49	5-20	90.86	High		1
Cr	43.87	< 100	61.11	Low		0
Cu	342.25	20 – 100	194.93	Very high		3
Mg	2519.87	-	-	-	-	
Mn	288.34	50 – 300	85.73	Medium		1
Ni	14.50	10-50	89	Low		0
Se	9.69	0.5 – 2.0	96.07	High		2
SO_4^{2-}	4395.133	200 – 1500	63.09	Very high		3
Pb	85.55	30-50	65.47	High		1
Zn	36.52	10 – 200	89.6	Low		0

Note: all elements are in mg/kg, except for pH (no units) and EC (µS/cm).

General soil conditions

Ng ba

Spatial Variability- Moderate variability (CV = 8.85%) suggests localised acidic zones, which may increase the mobility and toxicity of metals such as aluminium (Al) and cobalt (Co).

Electrical Conductivity (EC)- Mean EC of 379.78 µS/cm is below the salinity threshold; however, very high variability (CV = 89.04%) indicates the presence of localised salinity hotspots.

Agronomic Implication- Areas with elevated EC may experience reduced water and nutrient uptake, resulting in crop stress, stunted growth, leaf burn, and yield reduction. Findings support the need for site-specific soil management, rather than uniform interventions across Kalusale.

Macronutrients and beneficial elements

Adequate Nutrient Levels- Calcium (Ca), Chromium (Cr), Zinc (Zn), Nickel (Ni), Selenium (Se), and Magnesium (Mg) were within agronomic limits and classified as low risk, indicating generally favourable conditions for crop establishment.

Spatial Variability- Magnesium (CV = 83.96%) and Zinc (CV = 89.6%) show high variability, suggesting uneven nutrient distribution that may affect uptake efficiency in some fields.

Boron Deficiency- (B < 0.005 mg/Kg) was below detection limits, indicating severe deficiency. Unrelated to spillage.

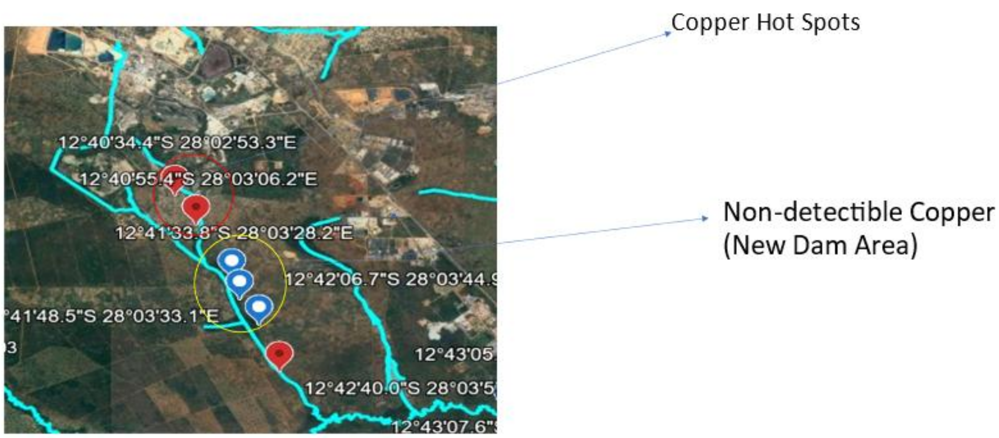
Trace elements and contamination risks

Soil analysis at Kalusale identified elevated concentrations of several trace elements of agronomic and environmental concern. Aluminium (Al = 21,119.89 mg/Kg) and cobalt (Co = 34.49 mg/Kg) exceed recommended agronomic thresholds and are classified as high risk, with potential to restrict root development, nutrient uptake, and crop establishment. Cadmium (Cd) shows extremely high spatial variability (CV ≈ 396%), indicating isolated hotspots despite generally low background levels.

Copper (Cu = 342.25 mg/Kg) and sulphate (SO_4^{2-} = 4,395.13 mg/Kg) are present at very high-risk levels, consistent with mining-related influence. The figure below shows that along the Chambishi River, there are areas with elevated Cu levels, whereas a few meters downstream, the Cu levels are undetectable. These concentrations pose risks to soil microbial activity, nutrient cycling, and sensitive crop species. Lead (Pb

= 85.55 mg/Kg) also exceeds safe limits and presents a potential food safety concern, particularly for crops with high uptake capacity such as leafy vegetables.

Agronomic Implication- Soils retain baseline fertility; however, contamination is spatially heterogeneous, with distinct hotspots rather than uniform distribution. Observations along the Chambishi Stream show sharp contrasts over short distances, where elevated copper levels occur adjacent to areas with non-detectable concentrations. This pattern confirms the need for site-specific management, crop zoning, and risk-based land-use controls rather than blanket agronomic interventions.



8.5.1.2 Luongo camp- Mwambashi River

The soil analysis conducted in Luongo camp reveals a complex mixture of favourable agronomic conditions and high contamination risk elements. Table 8-2 shows the mean values, threshold limits, coefficient of variation (CV%), and associated risk levels for soil parameters. The results indicate that while several nutrients fall within normal agricultural ranges, there are critical hotspots of contamination that may impact crop production, soil functionality, and potential environmental health.

Table 8 - 2: Luongo Camp soil parameters

Element	Mean	Threshold	CV (%)	Risk	Traffic Light	Score (0–3)
pH	6.49	6.0–7.5	9.61	Medium	●	1
EC	366.76	< 400	88.02	Medium	●	1
Al	16729.58	5,000–10,000 (toxic if pH<5)	23.76	Medium	●	1
As	7.72	<20	104.34	Low	●	0
B	18.23	1.0 – 2.0	109.64	Very high	● ●	3
Ca	8161.59	2000 – 20,000	139.2	Low	●	0
Cd	1.54	<1	108.15	Medium	●	1
Co	144.27	5-20	71.61	Very high	● ●	3
Cr	36.24	< 100	68.09	Low	●	0
Cu	970.21	20 – 100	84.99	Very high	● ●	3
Mg	3627.89	-	-	-	-	-
Mn	277.66	50 – 300	67.71	Medium	●	1
Ni	21.11	10-50	137.58	Low	●	0
Se	8.29	0.5 – 2.0	151.45	Very high	● ●	3
SO_4^{2-}	4395.13	200 – 1500	78.97	Very high	● ●	3
Pb	80.08	30-50	44.22	High	●	2
Zn	122.48	10 – 200	76.34	Low	●	0

Note: all elements are in mg/Kg, except for pH (no units) and EC (µS/cm).

General soil conditions

Soil Reaction (pH)- The mean soil pH of **6.49** indicates slightly acidic to near-neutral conditions, which are generally suitable for most arable crops. There are localised acidic zones that may enhance the solubility and bioavailability of certain metals, increasing potential phytotoxicity.

Electrical Conductivity (EC)- The average EC value of 366.76 µS/cm is below the salinity threshold for agricultural soils, indicating that soils are broadly non-saline. Nonetheless, the high coefficient of variation (CV = 88.02%) points to uneven salt distribution, with some sampling points likely approaching or exceeding salinity stress levels.

Agronomic Implication- These results indicate that while overall soil conditions remain suitable for crop production, salinity and acidity risks are localised rather than uniform**.** A blanket soil management approach is therefore not recommended. Instead, site-specific interventions, including targeted soil amendments and crop zoning, are necessary to prevent yield losses and manage emerging stress conditions.

Macronutrients and beneficial elements

Calcium (Ca)- Within acceptable agronomic ranges, supporting soil structural stability, pH buffering, and efficient nutrient uptake.

Manganese (Mn)- Concentrations fall within safe limits; however, moderate spatial variability indicates the need for routine monitoring to prevent localised imbalances.

Magnesium (Mg)- Elevated above typical agronomic ranges. While essential for chlorophyll formation and enzymatic processes, excessive Mg may antagonise calcium (Ca) and potassium (K) uptake, potentially affecting crop growth and yield.

Agronomic Implication- The nutrient status supports crop production, but nutrient imbalances pose risks in areas with high Mg. Targeted soil nutrient management and balancing interventions are recommended to maintain optimal crop performance.

Trace elements and contamination risks

A significant concern from the Luongo Camp soils is the presence of toxic trace elements that exceed international safety limits, particularly cobalt (Co), copper (Cu), selenium (Se), lead (Pb), sulfur (SO_4^{2-}), and boron (B). High concentrations of these elements may affect crop metabolism, reduce germination, or pose long-term environmental health risks.

8.5.1.3 Machiya Camp- Kafue River

The soil results from the Machiya Camp indicate generally favourable agronomic conditions, with most parameters falling within acceptable limits for crop production (Table 8-3). The findings suggest that this area has good potential for agricultural use. However, certain elements, particularly cobalt (Co), copper (Cu), selenium (Se), and manganese (Mn), require close monitoring due to elevated concentrations and spatial variability.

Table 8 - 3: Machiya Camp soil Characteristics

Element	**Mean**	**Threshold**	**CV (%)**	**Risk**	**Traffic Light**	**Score (0–3)**
pH	6.71	6.0–7.5	3.24	Low	◍	0
EC	103	< 400	30.24	Low	◍	0
Al	11,306.14	5,000–10,000 (toxic if pH<5)	23.78	Low	◍	0
As	2.88	<20	32.04	Low	◍	0
B	<0.005	1.0 – 2.0	-	Low	●	0
Ca	6128.5	2000 – 20,000	19.56	Low	◍	0
Cd	<0.001	<1	-	Low	◍	0
Co	62.70	5-20	135.44	Very high	◍ ◍	3
Cr	32.83	< 100	20.11	Low	◍	0
Cu	392.65	20 – 100	176.92	Very high	◍ ◍	3
Mg	982.22		111.82			
Mn	466.80	50 – 300	51.44	High	◍	2
Ni	17.74	10-50	45.19	Low	◍	0
Se	10.91	0.5 – 2.0	42.54	Very high	◍ ◍	3
SO_4^{2-}	885.06	200 – 1500	31.05	Low	◍	0
Pb	41.59	30-50	29.46	Low	◍	0
Zn	21.02	10 – 200	38.21	Low	◍	0

Note: all elements are in mg/Kg, except for pH (no units) and EC (µS/cm).

General soil conditions

Soil Reaction (pH)- Mean pH of 6.71 falls within the optimal agronomic range (6.0–7.5), supporting nutrient availability and root development. Low variability (CV = 3.24%) indicates uniform soil reaction across the site.

Electrical Conductivity (EC)- Mean EC of 103 µS/cm is well below the salinity threshold (<400 µS/cm), confirming non-saline conditions and suitability for crop growth and water uptake.

Macronutrients and agronomic elements

Calcium (Ca), Zinc (Zn), Nickel (Ni), and Chromium (Cr)- within acceptable agronomic limits and classified as low risk, indicating favourable nutrient balance and soil biological activity.

Cadmium (Cd)- below detection limits, posing no immediate contamination concern.

Boron Status- (B < 0.005 mg/Kg) is deficient, which may limit flowering and reproductive performance in legumes, vegetables, and oilseed crops. This is not related to the spillage.

Trace Elements and Contamination Risks

Copper (Cu)- mean concentration (392.65 mg/Kg) far exceeds the recommended agronomic threshold (20-100 mg/Kg) and shows very high spatial variability (CV = 176.92%), indicating severe contamination hotspots likely linked to mining or industrial inputs.

Cobalt (Co)- mean value of 62.70 mg/Kg against a safe range of 5–20 mg/Kg and extremely high variability (CV = 135.44%), cobalt presents a critical contamination risk and is unevenly distributed across the site.

Sulphates (SO_4^{2-}) - mean sulphate level (885.06 mg/Kg) falls within acceptable limits (200- 500 mg/Kg) and is classified as low risk, suggesting no immediate sulphate-related constraint on crop growth.

Agronomic Implications- While sulphate levels are generally suitable for crop production, the exceptionally high concentrations and variability of copper and cobalt significantly restrict crop choice and productivity in affected zones, making site-specific management, crop zoning, and remediation essential before safe agricultural use.

8.5.1.4 Milyashi camp- Kafue River

The soil assessment for Milyashi Camp indicates generally favourable conditions for agricultural production, with most parameters falling within acceptable limits for crop growth (Table 8-4). The overall results suggest low contamination risk, good soil stability, and suitability for a wide range of crops. However, specific parameters still require attention for long-term soil management and sustainable farming practices.

General Soil Conditions

Soil pH - (Av = 6.54; CV = 3.27%) lies within the optimal agronomic range (6.0- 7.5), indicating stable soil chemistry and favourable nutrient availability.

Electrical conductivity (EC = 189.33 µS/cm) is well below salinity thresholds, confirming non-saline conditions suitable for root growth and water uptake.

Aluminium, arsenic, chromium, nickel, calcium, and manganese occur within safe agronomic limits, reflecting stable base saturation and generally healthy soil structure.

Table 8 - 4: Milyashi camp soil parameters

Element	Mean	Threshold	CV (%)	Risk	Traffic Light	Score (0–3)
pH	6.54	6.0–7.5	3.27	Low		0
EC	189.33	< 400	68.40	Low		0
Al	7,344.27	5,000–10,000 (toxic if pH<5)	36.88	Low		0
As	1.73	<20	46.66	Low		0
B	<0.005	1.0 – 2.0	–	Low		0
Ca	4,177.90	2000 – 20,000	12.26	Low		0
Cd	<0.001	<1	–	Low		0
Co	4.20	5-20	87.84	Low		0
Cr	14.36	< 100	27.58	Low		0
Cu	136.71	20 – 100	61.55	Medium		1
Mg	<0.02 –					
Mn	127.44	50 – 300	43.23	Low		0
Ni	8.59	10-50	29.20	Low		0
Se	14.14	0.5 – 2.0	44.98	Very high		3
SO_4^{2-}	1004.30	200 – 1500	23.59	Low		0
Pb	17.68	30-50	40.95	Low		0
Zn	4.10	10 – 200	105.96	Low		0

Note: all elements are in mg/Kg, except for pH (no units) and EC (µS/cm).

Nutrient availability and micronutrient stability

Calcium shows low spatial variability, supporting uniform root development and nutrient uptake.

Most trace elements (As, Cr, Ni, Mn, Pb, Zn) remain within acceptable limits with no immediate toxicity risk.

Boron levels were below detection (<0.005 mg/kg), and this deficiency is not related to the spillage.

Trace elements and contamination risks

Copper (136.71 mg/kg) exceeds recommended agronomic thresholds and may suppress microbial activity and nutrient cycling in sensitive crops.

Selenium (14.14 mg/kg) is significantly above permissible limits (0.5–2.0 mg/kg) and represents a very high risk due to potential phytotoxicity and food-chain accumulation.

These exceedances are localised rather than uniform, highlighting the need for site-specific monitoring and management.

Agronomic Implication- Soil conditions support crop production; however, elevated copper and selenium levels in specific zones necessitate targeted monitoring and management to protect crop performance, soil biological function, and long-term food safety.

8.5.1.5 Chisangwe peshelungu camp- Kafue River

The soil assessment for Chisangwe Peshelungu camp indicates generally favourable conditions for crop production, with most parameters within acceptable agronomic limits. However, some elements show high spatial variability, suggesting localised hotspots and the need for site-specific soil management. While overall soil quality supports agriculture, certain areas may require closer monitoring to guarantee long-term productivity and environmental sustainability.

Table 8 - 5: Chisangwe Peshelungu Camp Soil Parameters

Element	Mean	Threshold	CV (%)	Risk	Traffic Light	Score (0–3)
pH	6.13	6.0–7.5	8.80	Medium		1
EC	314.30	< 400	63.45	Low		0
Al	8,509.38	5,000–10,000 (toxic if pH<5)	38.43	Low		0
As	1.31	<20	53.54	Low		0
B	4.35	1.0 – 2.0	50.15	Low		1
Ca	4,112.56	2000 – 20,000	39.34	Low		0
Cd	0.67	<1	65.18	Low		1
Co	7.64	5-20	142.88	Low		0
Cr	28.87	< 100	49.54	Low		0
Cu	125.61	20 – 100	231.86	Medium		1
Mg	1,063.27		55.10			
Mn	92.63	50 – 300	76.67	Low		0
Ni	13.27	10-50	72.43	Low		0
Se	5.71	0.5 – 2.0	81.61	High		2
SO_4^{2-}	1521.07	200 – 1500	76.89	Medium		0
Pb	23.67	30-50	48.82	Low		0
Zn	12.36	10 – 200	89.69	Low		0

Note: all elements are in mg/Kg, except for pH (no units) and EC (µS/cm).

General soil conditions

Soil pH- The mean soil pH (Av = 6.13) falls within the optimal range for crop growth (6.0–7.5), though it is close to the lower threshold and therefore classified as medium risk.

Electrical conductivity (EC = 314.30 µS/cm) is below the salinity limit (<400 µS/cm), confirming non-saline conditions that support root development, water uptake, and nutrient availability.

Macronutrients and agronomic elements

Calcium (Ca), manganese (Mn), nickel (Ni), chromium (Cr), and zinc (Zn) occur within safe agronomic limits and are classified as low risk, indicating a generally adequate nutrient base for cereals, legumes, and tuber crops.

Boron (B = 4.35 mg/kg) exceeds the optimal agronomic range and is classified as medium risk, which may cause toxicity in boron-sensitive crops if unmanaged.

Cadmium (Cd = 0.67 mg/kg) remains within acceptable limits but shows notable spatial variability, justifying periodic monitoring.

Trace elements and contamination risks

Selenium (Se = 5.71 mg/kg) exceeds the FAO guideline range (0.5- 2.0 mg/kg) and is classified as high risk, likely reflecting geogenic or groundwater influences.

Copper (Cu = 125.61 mg/kg) also exceeds recommended agronomic thresholds and is classified as medium risk, with potential to affect soil microbial activity and sensitive crops.

Agronomic Implication- The soils remain suitable for agriculture. However, elevated boron, copper, and selenium require site-specific management, crop selection, and ongoing monitoring to prevent yield losses and food safety risks.

8.5.1.6 Banamwaze camp- Kafue River

The soil analysis for Banamwaze Camp shows generally favourable agronomic conditions with minimal concerns about contamination. Most parameters are within acceptable ranges for plant growth, indicating that the soil has strong potential for agricultural use. However, the variability (CV%) across several elements suggests that site-specific monitoring might be necessary, especially in areas with higher variability or potential trace-element build-up.

Table 8 - 6: Banamwaze Camp Soil Parameters

Element	Mean	Threshold	CV (%)	Risk	Traffic Light	Score (0–3)
pH	6.89	6.0–7.5	8.34	Low	●	0
EC	228	< 400	45.90	Low	●	0
Al	21,098.19	5,000–10,000 (toxic if pH<5)	21.41	Low	●	0
As	3.81	<20	41.05	Low	●	0
B	1.10	1.0 – 2.0	266.44	Low	●	0
Ca	18,879.18	2000 – 20,000	64.78	Low	●	0
Cd	0.00	<1	-	Low	●	0
Co	0.048	5-20	387.30	Low	●	0
Cr	29.48	< 100	37.55	Low	●	0
Cu	34.12	20 – 100	31.23	Low	●	0
Mg	7,880.03		55.14			
Mn	325.25	50 – 300	56.51	Medium	●	1
Ni	15.84	10-50	47.86	Low	●	0
Se	15.40	0.5 – 2.0	34.66	Very high	● ●	2
SO_4^{2-}	3594.9	200 – 1500	68.72	Very high	● ●	2
Pb	52.68	30-50	25.89	Medium	●	1
Zn	46.77	10 – 200	64.06	Low	●	0

Note: all elements are in mg/Kg, except for pH (no units) and EC (µS/cm).

General Soil Conditions

Soil pH- The mean soil pH (Av = 6.89) falls within the optimal agronomic range (6.0- 7.5) and is classified as low risk. The low coefficient of variation (CV = 8.34%) indicates stable soil reaction across the site, reducing the likelihood of metal mobilisation or nutrient lock-up.

Electrical conductivity (EC = 228 µS/cm) remains below the salinity threshold (<400 µS/cm) and is classified as low risk.

Macronutrients and agronomic elements

Calcium (Ca) and magnesium (Mg) occur at favourable levels and support adequate cation exchange capacity, root development, and nutrient uptake. Zinc (Zn), chromium (Cr), and nickel (Ni) are within acceptable agronomic limits and are classified as low risk.

Manganese (Mn=325.25 mg/kg) slightly exceeds the recommended upper threshold and is classified as medium risk, indicating the need for monitoring in areas where sensitive crops are grown.

Trace elements and contamination risks

Most trace elements are within safe limits; however, selenium (Se=15.40 mg/kg) exceeds FAO guideline values and is classified as very high risk.

Sulphate (SO_4^{2-}=3594.9 mg/kg) is also classified as very high risk. Geogenic or groundwater-related factors likely influence these concentrations.

Lead (Pb=52.68 mg/kg) slightly exceeds recommended thresholds and is classified as medium risk.

Agronomic Implication- The soils remain conditionally suitable for agriculture; however, elevated selenium, sulphates, manganese, and lead necessitate site-specific management, crop zoning, and continued monitoring to safeguard crop performance and food safety.

8.5.1.7 Overview of spatial soil variability across sites

The six study sites showed clear differences in soil chemistry and contaminant levels, forming a distinct contamination gradient from unpolluted agricultural areas to heavily impacted mining zones (Table 8-7). Although the fields in Kalusale were expected to record the highest metal concentrations due to direct effluent passage, this was not the case. Instead, lower soil concentrations were observed in Kalusale, while downstream areas such as Luongo exhibited elevated contamination levels. This spatial pattern indicates that direct soil deposition was not the primary mechanism of contamination.

The effluent passing through Kalusale was highly acidic (approximately pH 3), a condition known to increase metal solubility and reduce metal retention in soils. Under these conditions, metals were mobilised rather than deposited, resulting in their transport away from the point of discharge. The mobilised metals subsequently entered the Mwambashi Stream, from which water was later used for irrigation by downstream farmers.

Based on the soil parameters measured, the sites can be divided into three separate zones. These classifications differ from the initial grouping, which only included Musakashi camp in zone one as a high-impact area.

Table 8 - 7: Overview of the spatial variability across sites

Zone	Sites	Characteristics
1 (Clean Reference)	Banamwaze Camp	Lowest contamination; ideal for agriculture
2 (Transitional Zones)	Milyashi and Chisangwe Peshelungu camps	Moderately impacted; pockets of risk
3 (High-Risk Contamination Zones)	Luongo, Musakashi, and Machiya camps	Mining-dominated signatures and metal hotspots

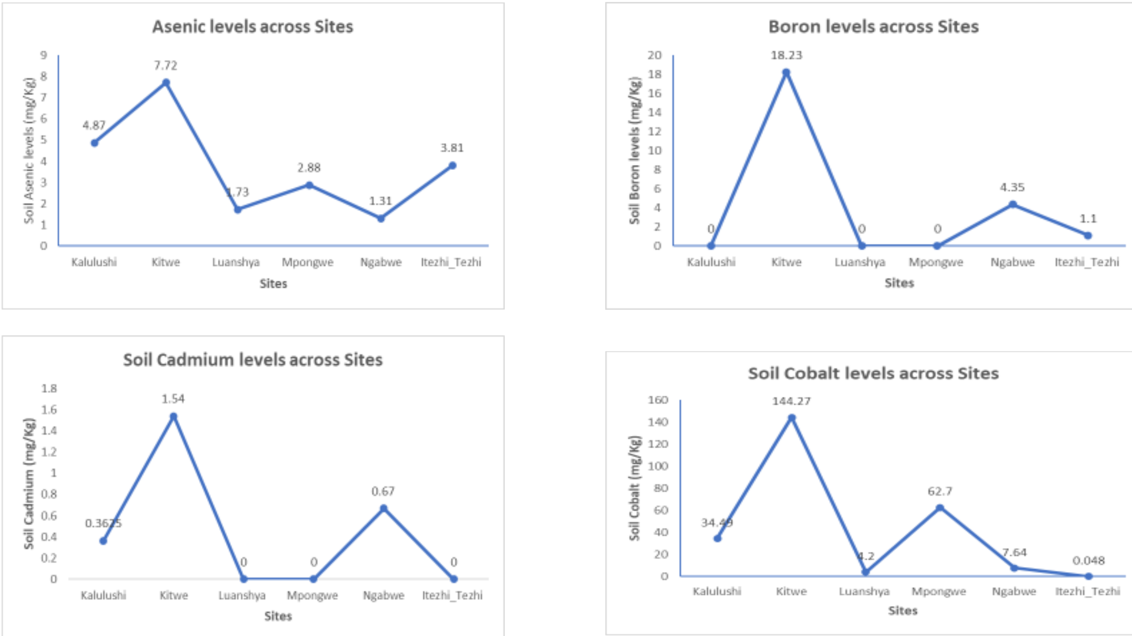


Figure 8 - 1: Selected soil chemical elements across the different sites

Building on evidence of acid-driven metal mobilisation and downstream transport, the spatial distribution of arsenic, boron, cadmium, and cobalt indicates that elevated concentrations downstream result from deposition of dissolved metals transported from upstream. However, we cannot rule out independent background or legacy sources. Metal concentrations do not peak at Kalusale, the point of direct spill influence, because the highly acidic effluent promoted metal solubilisation rather than soil deposition (Figure 8-1). Instead, metals remained dissolved and were transported downstream until conditions became more favourable for deposition. Consequently, Luongo Camp records the highest concentrations, reflecting a downstream accumulation zone where dissolved metals settled from irrigation and surface waters.

Boron shows highly localised levels at Luongo, with non-detectable levels at Kalusale, Milyashi, and Machiya, consistent with downstream deposition rather than localised source inputs. Cadmium follows the same pattern, with Luongo emerging as the primary hotspot while upstream locations remain comparatively low. Cobalt concentrations are highest at Luongo and Machiya, moderate at Kalulushi, and low elsewhere, reflecting progressive downstream deposition along the hydrological pathway.

Within-site variability and hotspot behaviour

The Coefficients of Variation (CV%) revealed important within-site patterns.

- Banamwaze Camp showed low metal concentrations with moderate CV values, indicating relatively uniform and uncontaminated soils.
- Milyashi and Chisangwe Peshelungu camps contained fluctuating soil chemistry, but means largely remained within tolerable limits. These locations represent buffer zones, where early warning monitoring is possible before risk levels escalate.
- Machiya, Luongo, and Kalusale showed high mean values with very high CVs (100%) for Cu, Co, Mn, and SO_4^{2-}, indicating strong hotspot behaviour. In these locations, contamination is not uniform, but concentrated in specific fields or low-lying catchment zones where mine runoff and seepage accumulate.

This pattern suggests that site-level averages alone may be misleading and that field-scale stratification is necessary to inform agricultural decisions. Thus, targeted sampling, rather than uniform fertiliser or lime application, is essential for effective management.

The figure below shows clear and uneven cobalt contamination across the study area. Severe hotspots (200–800 mg/kg), marked in red, are mainly concentrated along the Mwambashi River and are unsuitable for agricultural production, indicating influences from long-term mining activity or inherent geochemical conditions rather than the recent Chambishi spill. Along the Chambishi Stream, cobalt levels are elevated but lower (100–200 mg/kg), with no extreme hotspots observed. From an agronomic perspective, green areas indicate soils suitable for cropping without remediation, while blue areas require close monitoring and controlled crop selection. Orange and red zones are not recommended for agriculture and would require remediation or natural attenuation before safe use.

Chambishi Stream/ Mwambashi River- Musakashi Camp

Mwambashi River- Luongo Camp

Legend

- Acceptable soil Cobalt levels (0- 20mg/Kg)
- Slightly elevated Soil Cobalt levels (20 100 mg/Kg)
- Elevated Soil Cobalt levels (100 200mg/Kg)
- Extremely elevated Soil Cobalt levels (200- 800mg/Kg)

Map Showing the Cobalt levels from Farmers' Fields along the Chambishi Stream and Mwambashi River.

Cross-variable relationships and contamination sources

Strong positive correlations were observed among Cu, Co, Zn, Mn, and SO_4^{2-}, indicating that these elements co-occur and originate from a common source (Figure 8-2). The Cu-Co-Zn-Mn grouping aligns with typical Copperbelt ore geochemistry, while SO_4^{2-} is linked to sulphide oxidation and mine drainage. Based on the observed chemical relationships, the soils exhibit a combination of geogenic and anthropogenic contamination influences. The strong Cu-Co correlation reflects mineralised parent material typical of the Copperbelt Extension, placing affected areas within moderate to high environmental risk categories under ZEMA classification, where concentrations exceed agronomic thresholds. The association between As and sulphates indicates possible mine drainage or sulphide oxidation processes, elevating environmental and food-chain risk in susceptible zones. Although soil pH remains within acceptable limits, its weak inverse relationship with metal concentrations suggests that contamination is primarily source-driven rather than pH-induced.

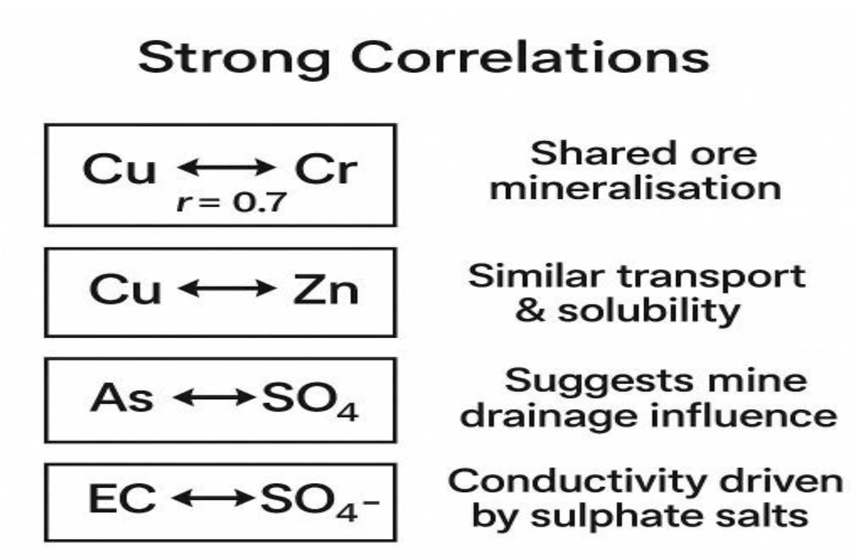


Figure 8 -2: Relationships between elements

Figure 8-2 presents a visual summary of the key chemical relationships observed in the soil samples. The Cu ↔ Co (r = 0.7) relationship indicates a significant correlation, suggesting that copper and cobalt originate from a shared ore mineralisation source. This aligns with the geological history of the Copperbelt Extension zone, where cobalt frequently co-occurs with copper in sulphide-rich mineral formations. Consequently, this correlation emphasises the influence of the parent geological material on soil chemistry.

Similarly, the positive relationship between Cu and Zn suggests similar transport mechanisms and solubility behaviour within the soil system. These elements are known to be mobilised under slightly acidic to neutral pH conditions, which aligns with the pH values observed in the soils. Their co-movement indicates that the soils may have pathways that allow for simultaneous release and potential bioavailability.

The link between As and SO_4^{2-} is particularly important from an environmental risk perspective. This pattern suggests possible mine drainage or sulphide mineral oxidation processes, which can mobilise arsenic along with sulphate. Arsenic is typically released during the oxidation of arsenopyrite or similar minerals, and its association with sulphate further supports the potential for mine-related geochemical inputs in the area. This may indicate human influence, especially in zones where hydrological flow paths could carry contaminants.

Additionally, a weak negative correlation between pH and metal concentration suggests that metal solubility may increase in slightly acidic soils. However, the pH remained within 6.1–6.7, indicating that external contamination sources are more influential than pH-driven mechanisms alone.

8.5.1.8 Paired assessment of the affected versus unaffected fields

A paired t-test comparison between affected fields and intended control sites (Table 8-8) found no statistically significant differences across analysed soil parameters ($p > 0.05$). This outcome is constrained by a small sample size, which limits statistical power. The results indicate that the paired controls do not represent uncontaminated baseline conditions but share similar chemical characteristics with affected fields.

Although not statistically significant, observed trends show slightly higher mean concentrations of Pb, Zn, and Co in some control sites. The findings further support the view of element dissolution along the flow pathway. On the other hand, electrical conductivity was marginally higher in affected fields. These patterns suggest that contamination may be spatially diffuse rather than confined to identified spill points.

Table 8 - 8: Paired t-test of the contaminated sites versus the uncontaminated sites

Element	npairs	tstat	p value	Mean contaminated	Mean control
Al	5	-1.1985223 NS	0.296	16701.3	22874.18
As	5	-0.8476046 NS	0.444	1.808	3.588
Ca	5	-0.0198744 NS	0.985	1979.36	2001.52
Cd	5	0.92357366 NS	0.4079	0.3772	0.0266
Co	5	-0.5424993 NS	0.6162	16.4334	24.2238
Cr	5	-1.9673444 NS	0.1205	30.417	63.2686
Cu	5	-0.8957200 NS	0.4210	5.064	61.028
Mg	5	-0.0773874 NS	0.9420	1806.822	1882.98
Ni	5	-0.76625902 NS	0.4862	9.2518	13.582
Pb	5	-2.240927648 NS	0.0885	66.878	111.842
Se	5	-1.499298898 NS	0.2081	6.3600	12.634
Zn	5	-1.230970129 NS	0.2857	14.3562	29.8776
Mn	5	-1.542440497 NS	0.1978	191.714	269.254
SO4	5	-0.541024900 NS	0.6172	2944.62	3494.44
pH	5	-0.361885796 NS	0.7357	6.300	6.356
EC	5	2.4330028287 NS	0.0717	355.4	104.8

Note: all elements are in µg/g, except for pH (no units) and EC (µS/cm). NS = Not significant (P>0.05)

8.5.2 Plant tissue analysis

The analysis of plant tissue samples shows apparent differences in how crops absorb nutrients and trace elements. Sulphates were the most abundant element in plant tissues, reflecting their high mobility in soils and their essential role in plant growth and protein formation. Aluminium was also detected at elevated levels in some crops; although it is not a plant nutrient, its presence may indicate soil stress or interactions with other elements. Zinc and manganese were found at moderate levels and are essential micronutrients that support normal plant development, though their uptake varied depending on crop type and local soil conditions. In contrast, cadmium, chromium, and cobalt were generally present at low levels, suggesting that most crops limit the uptake of potentially harmful metals. The results show that while essential nutrients are readily absorbed, some non-essential elements signal underlying soil stress, underscoring the need for site-specific crop selection and routine monitoring to ensure safe and sustainable agricultural production.

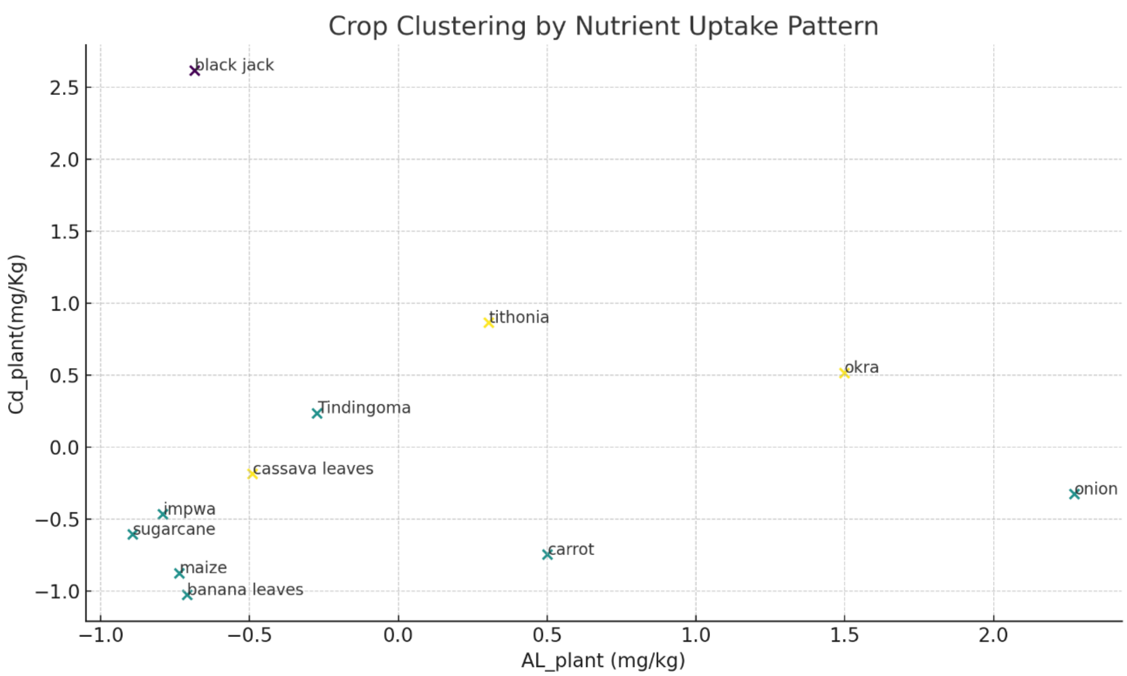


Figure 8 - 2: Crop clustering by nutrient uptake pattern

The cluster analysis revealed clear distinctions in nutrient uptake behaviour among different crops (Figure 8-3), indicating that plant species play a crucial role in determining metal absorption patterns. Three distinct clusters emerged. The first group, comprising black jack, tithonia, okra, and onion, exhibited elevated concentrations of several nutrients and trace metals, suggesting that these species may function as bioindicators or potential phytoremediators in contaminated environments. The second cluster, which included cassava leaves, tindingoma (leafy okra), and carrot, showed moderate uptake levels, indicating that these crops could be suitable for monitoring soil nutrient dynamics while remaining within acceptable safety ranges. The third cluster, consisting of maize, impwa (African eggplant), sugarcane, and banana leaves, displayed low nutrient uptake, implying that these crops possess exclusion mechanisms and may therefore be more suitable for cultivation in mildly contaminated soils intended for food production. Overall, the clustering analysis confirms that nutrient uptake is species-specific rather than solely dependent on soil concentration, and highlights the need for crop-based management strategies in agricultural planning, food safety assessment, and environmental restoration.

8.5.3 Comparative analysis – soils vs. crops

8.5.3.1 Musakashi camp

The results show apparent differences in how various elements transfer from the soil into plant tissues, highlighting important implications for crop safety and soil management (Table 8-9). Some elements, particularly cadmium (Cd), cobalt (Co), and zinc (Zn), showed high positive correlations between soil concentration and plant uptake, meaning that when these metals increase in the soil, the plants also absorb more of them. Cadmium showed a strong correlation ($r = 0.79$), which is concerning because even small amounts in soil can easily enter the food chain and pose significant health risks. Cobalt showed an even stronger relationship with uptake ($r = 0.86$), suggesting that certain crops may act as hyperaccumulators, storing this element in large quantities. Zinc also exhibited a strong correlation ($r = 0.76$); this is expected, as zinc is an essential nutrient for plant growth. However, excessive soil zinc could lead to nutrient imbalances or mild toxicity, depending on the crop type.

Table 8 - 9: Relationship between soil nutrients and plant uptake for Musakashi camp

Element	Correlation (r)	Interpretation
Zn	0.76	Strong uptake – zinc mobility is high
Cd	0.79	Strong uptake – cadmium is highly bioavailable
Co	0.86	Very strong uptake – possible hyperaccumulation
Mn	0.56	Moderate uptake
Cr	0.09	Very weak uptake
Cu	0.13	Weak uptake (possible exclusion)
Al	-0.05	No uptake / possible root exclusion

In contrast, other elements, such as copper (Cu), aluminium (Al), and chromium (Cr), showed very weak or negligible uptake, suggesting that plants may actively resist their absorption. Copper showed limited movement from soil to plant tissues, suggesting the presence of root-level exclusion mechanisms. Aluminium showed almost no correlation, suggesting that although it might be present in the soil, it is likely blocked by plant roots, consistent with known strategies to avoid toxicity. Similarly, chromium showed very low uptake, suggesting it may be poorly bioavailable or bound in forms that plants cannot readily absorb.

The results suggest that while some parts of the soil may be contaminated, not all contaminants are entering the food chain. This is significant because it indicates that certain crops can be safely grown on soils with specific metal concentrations, provided that metal uptake remains low. Understanding these patterns aids in crop selection, the design of phytoremediation strategies, and the development of soil–plant management plans for both agricultural productivity and food safety.

Soil -Plant Uptake Ratio

The soil–plant uptake ratios for chromium (Cr), copper (Cu), zinc (Zn), and manganese (Mn) varied considerably across crop species and sampling locations (Table 8-10). The results show that zinc (Zn) was the most actively absorbed element, with uptake ratios exceeding 5.0 in several samples, especially in cassava leaves, maize, and tithonia. This indicates high zinc mobility within the soil–plant system and suggests that these crops could act as bioindicators of zinc availability. Cobalt and cadmium, identified earlier through correlation analysis as highly bioavailable, further support the possibility of hyperaccumulation, particularly in cassava and tithonia. In contrast, chromium (Cr) and manganese (Mn) exhibited consistently low uptake, implying either limited bioavailability or biological exclusion mechanisms by the plants. Copper uptake was minimal across all samples, with several ratios approaching zero, suggesting most crops demonstrate copper exclusion behaviour, possibly as a protective physiological response.

Table 8 - 10: Soil-plant uptake ratios for heavy metals (Cr, Cu, Zn, Mn) for Musakashi camp

Sample ID	**Crop Type**	**Cr Uptake Ratio**	**Cu Uptake Ratio**	**Zn Uptake Ratio**	**Mn Uptake Ratio**
1.1	Maize	0.156	–	5.13	0.027
1.2	Maize	0.207	0.00	6.56	0.336
1.2A	Tithonia	0.202	0.584	2.90	0.637
1.2B	Tindingoma	0.178	0.00	2.29	0.221
1.3	Cassava leaves	0.073	∞	12.34	0.673
1.5	Maize	0.069	0.00	3.41	0.222
1.7	Cassava tuber	0.027	0.00	5.01	0.105
1.9	Maize	0.183	0.00	2.77	0.344
1.11	Tithonia	0.322	0.612	3.88	0.847

1.13	Beans	0.091	–	4.22	0.539
1.15	Cassava leaves	0.141	∞	10.22	0.899
1.18	Maize	0.164	0.00	3.35	0.468
1.24	Maize	0.121	0.00	2.38	0.451
1.31	Cassava tuber	0.055	0.00	5.66	0.689
1.38	Tithonia	0.198	0.401	3.22	0.902

Note: Ratios above 1 indicate potential hyperaccumulation; values below 1 suggest limited uptake.

∞ (infinity) indicates very high plant uptake despite very low soil concentration (possible hyperaccumulator behaviour).

– indicates missing values or non-detected levels.

Notably, infinite uptake ratios (∞) were observed in some cassava samples, indicating extremely high metal absorption even at very low soil concentrations. This phenomenon reflects strong root absorption capacity and suggests that cassava leaves may serve as phytoremediators in metal-contaminated environments. These findings highlight the importance of species-specific responses in soil–plant interactions and demonstrate that crop type significantly influences the risk of metal accumulation, with implications for food safety, crop selection, and phytoremediation potential in polluted landscapes.

Table 8 - 11: Soil-Plant nutrient uptake prediction for Musakashi camp

Element	Regression Equation	R^2 Value	Interpretation
Cr	Plant Cr = 2.02 + 0.0069 × Soil Cr	0.02	Extremely weak prediction – uptake is independent of soil levels
Cu	Plant Cu = 9.45 + 0.0024 × Soil Cu	0.00	No predictive relationship – strong exclusion by plants
Zn	Plant Zn = 49.84 − 0.329 × Soil Zn	0.12	Weak negative effect – possible competition/saturation
Mn	Plant Mn = 106.54 − 0.0826 × Soil Mn	0.02	Very weak uptake trend – soil Mn barely influences plant Mn

The regression analysis showed weak predictive links between soil concentrations and plant uptake for all elements studied (Cr, Cu, Zn, Mn) (Table 8-11). This indicates that soil metal levels alone do not strongly drive plant absorption, which is likely affected by other factors such as:

Soil pH and redox potential
Organic matter content

Soil texture and metal binding capacity
Competition or antagonism between nutrients
Crop-specific physiological mechanisms (excluder vs. accumulator traits)

The low R^2 values across all metals confirm that plant uptake cannot be reliably predicted based solely on soil levels. Instead, metals like Cu and Cr seem to be poorly bioavailable, while Zn and Mn show limited to moderate absorption, potentially influenced by nutrient interactions or root-level regulation. The negative regression slopes seen for Zn and Mn suggest that higher soil concentrations might actually reduce uptake, implying saturation, root regulation, or antagonism from other elements. This pattern is typical of metal-sensitive or metal-excluding crops and reflects biological defence mechanisms aimed at maintaining internal nutrient balance.

8.5.3.2 Luongo camp

The correlation results indicate that sulphate (SO_4^{2-}) is the most mobile and bioavailable nutrient in the soil–plant system, with a moderate positive correlation (r = 0.55) (Table 8-12). This suggests that as soil sulphate levels increase, plant tissue concentrations also tend to rise, implying active uptake and high mobility within the soil profile. Chromium and zinc show weak-to-moderate correlations (r ≈ 0.30), indicating that their uptake is partly affected by soil concentration but is also likely influenced by other factors such as pH, organic matter, and crop physiology.

Table 8 - 12: Relationship between soil nutrients and Plant Uptake for Luongo camp

Element	**Correlation (r)**	**Interpretation**
SO_4^{2-}	**0.55**	Moderate positive uptake – mobile & bioavailable
Cr	0.31	Weak–moderate uptake
Zn	0.30	Weak–moderate uptake
Cd	0.19	Weak correlation
Cu	0.15	Very weak uptake
Co	0.12	Very weak uptake
Mn	**–0.06**	Slight negative relationship (possible exclusion)

Other elements, such as Cd, Cu, and Co, show **very weak correlations,** suggesting possible regulation of uptake, exclusion mechanisms, or low soil bioavailability. Manganese (Mn) even shows a slight negative relationship (r = –0.06), suggesting that increased soil Mn **does not result in higher plant uptake** and may reflect **nutrient antagonism or root-level regulation.**

Table 8 - 13: Soil-Plant uptake ratios for heavy metals (Cd, Co, Cr, Cu, Zn) for Luongo camp

Site ID	Crop	Cd	Co	Cr	Cu	Zn

2.1	Fresh maize leaves	2.68	1.12	0.14	0.00	1.09
2.2	Bean leaves	0.36	0.02	0.04	0.02	0.22
2.5	Impwa	0.19	0.02	0.05	0.02	0.86
2.6	Onion	0.74	0.24	0.07	0.00	0.64
2.6 P	Pumpkin leaves	0.31	0.01	0.05	0.00	0.24

The uptake ratio analysis revealed that nutrient absorption varied significantly across crops, indicating differences in physiological response and metal mobility within the soil–plant system. Sulphates (SO_4^{2-}) consistently showed high uptake across all sampled crop species, with ratios ranging from 1.87 to 5.15, suggesting strong mobility and potential influence from water movement, drainage patterns, or external environmental factors such as mining activity. Additionally, cadmium (Cd) and cobalt (Co) exhibited notably high uptake in maize and onion, implying that these crops may serve as bioindicators of trace metal presence in the soil. Zinc (Zn) also displayed strong uptake, particularly in maize and impwa, further indicating that these species could act as useful indicator crops for monitoring nutrient availability and potential contamination.

In contrast, bean leaves and pumpkin leaves showed low uptake of Cd, Cr, Cu, and Mn, suggesting that these crops may be suitable for food production in areas with mild contamination. The uptake of copper (Cu) was particularly low across all crops, with some values approaching zero, indicating exclusion behaviour, possibly due to physiological regulation by plant roots. These results imply that certain crops actively limit heavy metal absorption and might be safer options for agriculture in affected regions.

8.5.4 Agronomic Meaning of the Patterns

The observed trends in plant tissue data reveal important agronomic implications for how different crops and plant types interact with heavy metals under varying environmental conditions. Notably, **tithonia and tindingoma (leafy okra) exhibit strong metal-accumulation characteristics.** These leafy, fast-growing plants consistently show elevated concentrations of cobalt, zinc, and copper compared with maize. Such uptake behaviour is typical of biomass species with high nutrient demand and rapid metabolic rates. Their ability to accumulate metals to a greater extent than food crops positions them as useful **phytoremediation indicators**, capable of signalling the presence and potential mobility of contaminants in agricultural soils and irrigation water.

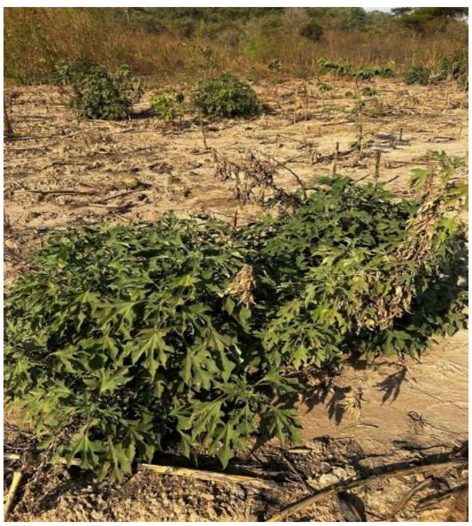
In contrast, the data clearly show that leafy crops such as rape and spinach accumulate significantly higher levels of heavy metals than maize grain. This pattern aligns with established physiological principles: metals tend to accumulate in actively growing vegetative tissues, such as leaves and stems, rather than being transported into the grain. During grain filling, physiological barriers limit the movement of metals into the kernel, ensuring that maize grain often remains relatively protected from contamination even when grown under stressful conditions. From an agronomic perspective, this indicates that grain crops may stay safe for consumption despite contamination events, whereas leafy vegetables are much more vulnerable, especially when exposed to polluted water through ongoing irrigation.

Finally, the timing of the liquor spillage clearly explains the differences observed between maize grain and fresh maize samples. The mature grain had already finished filling before the spillage happened, resulting in minimal uptake and thus low measured concentrations. However, the fresh maize, which continued to grow and was irrigated after the contamination event, experienced prolonged exposure to potentially contaminated water. This led to higher recorded levels of metals in the fresh tissue. The dataset therefore demonstrates a strong temporal effect, where the stage of crop development at the time of contamination directly affects the degree of metal accumulation.

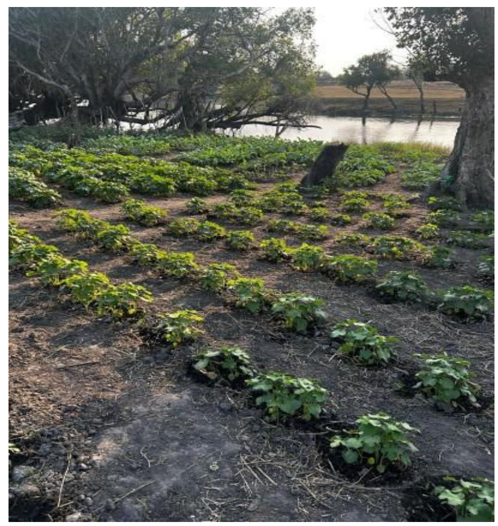
8.6 Agronomic impact assessment

8.6.1 Short-term impacts on agronomy and crop production

In the short term, heavy metal and sulphate contamination in agricultural soils generally causes physiological stress, uneven crop performance, and local yield reductions, which matches the patterns observed in the fields in Musakashi camp and Luongo Camp. Experimental and field studies indicate that high levels of Cd, Zn, Cu, and other metals can reduce germination, hinder root and shoot growth, and cause chlorosis and reduced biomass in cereals and root crops (Vasilachi et al., 2023; Shahriar et al., 2024). For instance, cassava grown in metal-contaminated soils in Nigeria experienced significant reductions in stem girth and dry matter yield even within a single season (Mmekam et al., 2025). Figure 8-4 shows that Tithonia can grow in areas directly affected by liquor in Musakashi camp. Figure 8-4b depicts a garden along the Kafue River in Ngabwe District where the farmer has been irrigating using water from the river.



a) Tithonia thriving in a farmer's field where the tailings liquor passed Kalulushi



b) An okra field irrigated with water from the Kafue River- Ngabwe

Figure 8 - 3: Response of different plants after the tailings spillage

Reviews of heavy metal contamination in agricultural soils consistently highlight short-term declines in soil quality and crop performance, driven by toxicity to root systems and disruption of photosynthesis and enzyme function (Wan et al., 2024; Rashid et al., 2023; Angon et al., 2024). These mechanisms align with this study's results: some crops, such as maize, beans, and pumpkin, show relatively low uptake and therefore milder stress, whereas tithonia, black jack, okra, and some cassava leaves accumulate more metals and sulphates, acting as bioindicators or hyperaccumulators. This is consistent with research showing that Bidens pilosa and Tithonia diversifolia accumulate high levels of Pb, Cd, and As in contaminated soils, making them ideal for phytoremediation but unsuitable as food crops (Adejumo & Togun, n.d.; Shah et al., 2024). Taken together, these findings offer a reasonable indication of contamination effects on the local agro-ecosystem, although continued monitoring and further sampling are advisable to fully confirm long-term trends and potential risks.

In Zambia, Mulonga (2017) reported that soils and crops around Chililabombwe mining areas accumulate Cu and Co to concerning levels, impacting food safety and crop growth. The findings for Musakashi camp and Luongo Camp align with established trends, showing visible stress in sensitive crops, significant crop-to-crop variation, and early appearance of indicator species in contaminated fields.

8.6.2 Long-Term Impacts on Soil Health and Food Systems

In the long run, the literature shows that chronic metal contamination can damage soil function and threaten food security, even when initial yield losses seem minor. Studies show that heavy metals gradually reduce soil fertility by disrupting microbial activity, slowing organic matter decomposition, and altering key soil properties, such as pH and C: N: P ratios (Wan et al., 2024; Hou et al., 2025). The long-term accumulation of non-degradable metals such as Cd, Pb, Ni, and Cu leads to persistent declines in crop productivity and increased reliance on external inputs, especially fertilisers and amendments (Rashid et al., 2023; Alengebawy et al., 2021).

Further research shows that cassava and vegetables grown on soils contaminated with crude oil and metals absorb As, Cr, and Cd at levels above food safety limits (Mmekam et al., 2025). In our case in Zambia, if contamination in Musakashi and Luongo camps continues unchecked, the region could face reduced crop productivity, declining soil health, and the potential transfer of toxic metals through the food chain. The consistently high sulphate and aluminium readings in the samples align with findings from mine-affected or acidifying soils, where long-term effects include acidification, metal mobilisation, and the eventual loss of arable land (Nyiramigisha et al., 2021). Meanwhile, bioremediation studies have demonstrated that species such as Tithonia diversifolia and Bidens pilosa can be employed to extract metals from soils when combined with composts, biochar, or organic amendments (Shah et al., 2024; Adejumo & Togun, n.d.). This supports a dual-monitoring approach: Low-uptake crops (such as maize, beans, and pumpkin) for safe food production, and Hyperaccumulator species for controlled phytoremediation zones.

8.7 Mitigation and remediation measures

The findings from Musakashi camp and Luongo camp reveal varying levels of metal mobility and plant uptake, indicating that remediation should be tailored to specific sites and crops. The immediate priority is to ensure that safe crops continue to be produced, while areas with high metal accumulation are monitored and managed through phytoremediation strategies or alternative land uses. Based on these results and international experiences from similar mining–agriculture interfaces, mitigation and remediation should be guided by four key principles: crop selection, soil amendment, water management, and long-term monitoring.

8.7.1 Crop selection

To begin, land can be classified into zones based on contamination severity. Fields with low metal uptake, especially those growing maize, beans, or pumpkins, can continue to be used for food production, provided farmers adhere to good agronomic practices and maintain soil organic matter. Areas with moderate levels of soil contamination should be restricted from growing leafy vegetables and root crops intended for direct consumption. These fields may instead be used for grain crops, fibre crops, seed production, or as temporary phytoremediation sites. Where contamination is high, cultivation of food crops is not recommended until remediation has taken place. Such areas can be planted with hyperaccumulator species such as Tithonia diversifolia, Bidens pilosa, black jack, or fast-growing grasses, which have already shown strong bioaccumulation tendencies in this study. These species should be grown for several cycles, fully harvested, and disposed of safely to reduce soil metal availability gradually.

8.7.2 Soil amendment

Soil amendments can significantly reduce metal toxicity and improve soil health. Using agricultural lime is recommended in acidic soils to lower metal solubility. At the same time, organic materials, such as compost, manure, or biochar, can enhance soil structure, increase microbial activity, and immobilise metals. When used together, lime and compost treatments have proven effective in mine-affected areas in South Africa, India, and China. Raised beds, drainage channels, and proper water management are also vital, as sulphate mobility appears closely connected to water movement in these regions. Preventing waterlogging and maintaining stable drainage will help stop further spread of metals through runoff or subsurface flows.

8.7.3 Policy

At the policy level, mining regulation and agricultural management need to be more closely linked. Environmental Impact Assessments should include soil and crop contamination baselines, and mine closure plans should incorporate agricultural remediation as part of community restoration. Supporting farmers with lime, compost, biochar, and locally adapted phytoremediation packages would be far more cost-effective than addressing long-term declines in food quality, land abandonment, or health-related impacts. If these principles are adopted, the Musakashi camp and Luongo camp can prevent the irreversible soil degradation seen in other mining regions. They might even become a model for sustainable mining–agriculture coexistence in Zambia and beyond.

8.7.4 Long-term management

Long-term management must extend beyond individual farms. A coordinated monitoring programme, led by extension officers, research institutions, and relevant ministries, would enable soil and crop testing to be integrated into routine agricultural assessments. Land-use guidelines could then be established to categorise fields into zones for safe food production, controlled phytoremediation, or alternative uses such as biomass, fodder, or fibre production. Farmer training is vital to help communities interpret laboratory results, understand crop suitability, and recognise early signs of contamination stress.

8.8 Monitoring and evaluation framework work for agronomic restoration

This framework outlines the essential Monitoring and Evaluation (M&E) programme designed to track the performance of remediation and restoration measures implemented after the recent tailings discharge incident. The M&E plan is organised around four key areas: Soil Contamination and Remediation Effectiveness, Water Quality, Crop Safety and Bioaccumulation, and Remediation Intervention Effectiveness and Social Adoption. The aim is to ensure that heavy metal and contaminant levels return to safe, permissible limits across the affected camps (Musakashi, Luongo, Machiya, Milyashi, Chisangwe Peshelungu, and Banamwaze Camps) and that sustainable agricultural practices are fully re-established in specified areas where farming is allowed to continue.

Table 8 - 14: Soil contamination and remediation effectiveness monitoring

Monitoring Indicator	**Metric / Parameter**	**Location / Sampling Point**	**Frequency**	**Success Criteria / Target**
Heavy Metal Reduction	Concentration (mg/kg) Cu, Co, Cd, Pb in topsoil (0–20 cm depth).	Designated contaminated zones in Musakashi, Luongo, and Machiya camps (worst-hit areas).	Baseline (Pre-remediation), Annually (for 5 years), then Biennially.	Concentration levels fall below **ZEMA/FAO/WHO maximum permissible limits** for agricultural soil for two consecutive years.
Soil pH **Correction**	Soil reaction (pH value) in contaminated fields.	All fields where liming or acid-neutralising amendments were applied	Quarterly (Year 1), Semi-annually (Year 2-5).	pH stabilizes within the target range of 6.0 - 6.5 to reduce heavy metal mobility and maximize nutrient availability.
Essential Nutrient Recovery	Concentration of essential nutrients (Mn, Ca, Zn, Ni in soil.	All monitoring sites.	Annually	Nutrient levels are maintained within the optimal productive ranges specified by the Ministry of agriculture soil test guidelines.

Table 8 - 15: Water quality monitoring

Monitoring Indicator	Metric / Parameter	Location / Sampling Point	Frequency	Success Criteria / Target
Sulphate Concentration	Concentration of Sulphate ($SO4^{2-}$mg/L) in surface water	Upstream, point-of-impact, and downstream transects along the **Chambishi Stream, Mwambashi River, and Kafue River.**	Monthly (Year 1), Quarterly (Year 2-5).	$SO4^{2-}$ concentrations stabilize and fall below the **WHO guidelines for surface water** used for irrigation and livestock.
Dissolved Heavy Metals	Concentration (mg/L) of dissolved Cu, Co, Cd, Pb in river water.	Same water quality transects as above.	Quarterly	Metal concentrations remain below the **ZEMA Effluent Discharge Standards** and safe limits for irrigation.

Table 8 - 16: Crop safety and bioaccumulation monitoring

Monitoring Indicator	Metric / Parameter	Location / Sampling Point	Frequency	Success Criteria / Target
Food Safety Validation	Concentration (mg/kg dry weight) Co, Cd, Zn, $SO4^{2-}$ in the **harvested edible portion** of high-uptake crops (Impwa/African Eggplant, Onion).	Fields identified as high-risk but still cultivated.	At Harvest (annually).	Crop metal concentrations remain below the **Codex Alimentarius/National Food Safety Standards** for edible produce.

Recommended Crop Adoption	Concentration (mg/kg dry weight) of Cu, Co, Cd and Pb in low-uptake crops (Common Beans, Pumpkin Leaves).	Fields planted with recommended low-uptake crops	At Harvest (annually).	Confirm that low-uptake species maintain metal concentrations significantly lower (e.g., 50% less) than high-uptake species in the same soil, validating the crop substitution strategy.

Table 8 -17: Remediation intervention effectiveness and social adoption

Monitoring Indicator	**Metric / Parameter**	**Location / Sampling Point**	**Frequency**	**Success Criteria / Target**
Farmer Adoption Rate	Percentage of target farmers implementing specific recommended agronomic interventions (e.g., liming, crop rotation, switching to low-uptake crops).	Survey of farming communities in the six affected districts.	Biennially	80% **or greater** adoption rate of key recommended agronomic measures
Land Restoration	Total hectares of previously contaminated land certified as agriculturally safe by ZEMA/Ministry of Agriculture standards.	Mapping data and land certification records.	Annually.	Annual increase in certified safe hectarage until 100% **of the initially affected farmland** is restored to safe use

8.9 Appendix

Appendix 8-1: Results of parameter trends across sites

Appendix 8-2: Sampling maps and coordinates

Appendix 8-3: Field photographs

Appendix 8-4: Farmer Interview Tools and Data Sheets

9 ASSESSMENT OF IMPACT ON AIR QUALITY

9.1 Introduction

Following the failure of the Tailings Storage Facility (TSF) at Sino-Metals Leach Zambia Limited that occurred on 18th February, 2025 in Chambishi, some of the residents of Kalusale area complained of unpleasant smells in their dwellinghouses as well as surroundings.

In accordance with the Environmental Management Act (No. 12 of 2011) which provides for the health and welfare of people, animals, plants and the environment in general, Acid mist sampling and gaseous monitoring was done in the area.

9.2 Monitoring Methodology

Baseline Acid mist and gaseous sampling are a systematic procedure to identify the possibility of acid mist and gaseous pollutants which are potential health hazards, in order to quantitatively evaluate their existence and to establish the most efficient and cost-effective control measures.

9.2.1 Approach

The Acid mist sampling survey approach consisted of selection of appropriate sampling points prior to sampling. Eleven sampling points were picked for both acid mists and gas sampling.

9.2.2 Acid Mist

Use charged Gilair advanced air sampling pump (Pre-calibrated to flow rate 1.9 Liters per minute), attached to a Dreschel sampling bottle via a sampling train.

Add 20 mls of sodium hydroxide solution to the Dreschel sampling bottle then add 3 drops of methyl red indicator to attain a visible yellow color of the sampling solution

At the sampling site, select the worst exposed area to the fumes and position the sampling train. Start the sampling pump and record the start time while noting prevailing general air

Look out for any color change in the Dreschel bottle solution. The sodium hydroxide solution doped with methyl red indicator (yellowish) coloration turns red to indicate the presence of acid mists in ambient air. At this point, time should be noted and the sampling pump stopped.

9.2.3 Gases

The ambient air quality parameters monitored include; Carbon Monoxide (CO), Carbon Dioxide (CO2), Sulphur Dioxide (SO2), Methane (CH4), Oxygen (O2) and Hydrogen Sulphide (H2S).

A total of eleven (11) gas samples were collected. The gasses were monitored using Drager X-am 5600, Multi gas detector which gives instantaneous results and uses a combination of infrared technology electrochemical dragger's miniature sensors. The device measures up to 6 gases as highlighted above.

9.3 Monitoring Results

9.3.1 Gas Sampling

Eleven (11) gas samples were collected using the Drager X– am 5,600 multi gas detector. All the samples collected showed only trace amounts of gases in the air at time of sampling.

ZEMA statutory limits which are available are included in the tables. Some prominent international best practices from reputable organizations are also included in the tables.

Table 9 - 1: Gas sampling day 1

Date: 22.11.2025															
Equipment: Gas Detector: Drager X - am 5600			**Target Gases**												**Calibration:** √Passed Not passed
Sampling Point Number	Geographical Coordinates		Carbon Dioxide (CO_2) [vol%]		Oxygen (O_2) [vol%]		Methane (CH_4)[%LEL]	Sulphur Dioxide (SO_2)		Carbon Monoxide (CO) [ppm]		Hydrogen Sulphide (H_2S) [vol%]			Comments
	Easting's	Northing's	ZEMA	OSHA 5000 (PPM)	ZEMA	OSHA 19.5 (%)	No recommender exposure limit for explosion hazards	ZEMA 0.13 (PPM)	OSHA 2 (PPM)	ZEMA 26.19 (PPM)	OSHA 50 (PPM)	ZEMA	ACGIH1 (PPM)		
1	613752.4	8598404.1	0.04		20.9		0	0		0		0.0			Normal air conditions during sampling
2	613767.4	8598373.3	0.17		20.9		0	0		0		0.0			Normal air conditions during sampling

3	613761.4	8598373.4	0.04	20.9	0	0	0	0.0	Normal air conditions during sampling
4	614070.3	8598679.4	0.04	20.9	0	0	**0**	0.0	Normal air conditions during sampling
5	614030.1	8598640	0.04	20.9	0	0	0	0.0	Normal air conditions during sampling
6	614075	8598635	0.03	20.9	0	0	0	0.0	Normal air conditions during sampling
7	613960	8598650	0.04	20.9	0	0	0	0.0	Normal air conditions during sampling

Table 9 - 2: Gas sampling day 2

Date: 23.11.2025														**Phase**
Equipment: Gas **Detector**: Drager X - am 5600			**Target Gases**											**Calibration:** √Passed Not passed
Sampling Point Number	Geographical Coordinates		Carbon Dioxide (CO_2) [vol%]		Oxygen (O_2) [vol%]		Methane (CH_4)[%LEL]	Sulphur Dioxide (SO_2)		Carbon Monoxide (CO) [ppm]		Hydrogen Sulphide ((H_2S) [vol%]		Comments
	Easting's	Northing's	ZEMA	OSHA 5000 (PPM)	ZEMA	OSHA 19.5 (%)	No recommended exposure limit for explosion hazards	ZEMA 0.13 (PPM)	OSHA 2 (PPM)	ZEMA 26.19 (PPM)	OSHA50(PPM)	ZEMA	ACGIH1 (PPM)	
1	614120	8598570	0.04		20.9		0	0		0		0.0		Normal air conditions during sampling
2	614115	8598567	0.05		20.9		0	0		0		0.0		Normal air conditions during sampling
3	614125	8598590	0.04		20.9		0	0		0		0.0		Normal air conditions during sampling
4	614070	8598585	0.04		20.9		0	0		0		0.0		Normal air conditions during sampling

Results Discussion:

The sample results indicated in the tables9-1 and 9-2 above show insignificant traces of target parameters while others are not even traceable. These trace gases are insignificant and are unlikely to cause negative health impact as a result of exposure either accidental or by intentional means.

9.3.2 Acid Mist Sampling

A total of eleven (11) acid mist samples were collected and the results were as shown in tables9-3 and 9-4 below. All the results show that there were very low to no concentrations of acid mist in the air.

Table 9 - 3: Acid mist day 1

Date: 22.11.2025					
Equipment: GilarPlus					**Calibration:** □√Passed □Not Passed
Sampling Point Number	Geographical Coordinates		Location Description		Comments No ZEMA Limit (ILO/WHO OEL <**1mg/m³**)
	Easting's	Northing's			
1	613752.4	8598404.1	Outside Mr. Dine Bidwell's House – Kalusale Ward	0	Normal air conditions during sampling
2	613767.4	8598373.3	Inside Mr. Dine Bidwell's House – Kalusale Ward	0	Normal air conditions during sampling
3	613761.4	8598373.4	Inside Mr. Dine Bidwell's grandson's house – Kalusale Ward	0	Normal air conditions during sampling
4	614070.3	8598679.4	Inside Mr. Isaac Siyapona's House – Kalusale Ward	0	Normal air conditions during sampling
5	614030.1	8598640	Outside Mr. Elias Mulenga's House – Kalusale Ward	0	Normal air conditions during sampling
6	614075	8598635	Mainstream (Main Drainage) – Kalusale Ward	0	Normal air conditions during sampling
7	613960	8598650	House near the steam – Kalusale Ward	0	Normal air conditions during sampling

Table 9 - 4: Acid mist day 2

Date: 23.11.2025					
Equipment: GilarPlus					**Calibration:** ☐√Passed ☐Not Passed
Sampling Point Number	Geographical Coordinates		Location Description		Comments No ZEMA Limit (ILO/WHO OEL <**1mg/m^3**)
	Easting's	Northing's			
1	614120	8598570	Outside Mr. Sakala's House – Kalusale Ward	0	Normal air conditions during sampling
2	614115	8598567	Down the stream opposite Mr. Sakala's house – Kalusale Ward	0	Normal air conditions during sampling
3	614125	8598590	Down the stream outside at Chapu Elizabeth's house –Kalusale Ward	0	Normal air conditions during sampling
4	614070	8598585	Down the stream outside Shula Peter's house –Kalusale Ward	0	Normal air conditions during sampling

Results Discussion:

The sample results indicated in the tables above are all below the TLVs for acid mist as recommended by ILO/WHO.

9.4 Potential environmental impacts

Exposure to acid mists can have several potential environmental impacts, both directly and indirectly. Acid mists typically contain strong acids like sulfuric acid (H_2SO_4) or hydrochloric acid (HCl) in aerosol form.

Soil Acidification – Acid mists can settle on soil surfaces, increasing the soil's acidity which can reduce soil fertility, negatively affecting plant growth and altering microbial populations.

Water Contamination - Acid mists that deposit onto rivers, lakes, can lower the pH of water bodies**.** Acidic water harms aquatic life; particularly species sensitive to pH changes (e.g., fish eggs, amphibians).

Vegetation Damage - Acid mist can directly damage plant leaves**,** leading to reduced photosynthesis, leaf burn, and growth inhibition. Sensitive crops and forests may show stunted growth or dieback when exposed to repeated acid mist deposition.

Ecological Disruption - Persistent acid mist deposition can alter species composition in ecosystems, favoring acid-tolerant species over sensitive ones. It may reduce biodiversity in soils, aquatic systems, and forests.

9.5 Photographs of site sampling point (s)

Mr. Shula Peter's House

12°50’52.1″S 28°03′03.8″E

Elizabeth Chapu's House

12°40’47.5″S 28°03′13.8″E

Mr. Epilias Mulenga's House

Mr. Sakala's House

12°40’56.7″S 28°03′13.3″E

10 ASSESSMENT OF IMPACT ON SOCIAL-ECONOMIC

10.1 Introduction

10.1.1 Background

This report focuses on outlining the key social-economic impacts of the incident in the priority affected areas of Kitwe District and Kalulushi District.

From 18th November, 2025 to 29th November, 2025, an independent evaluator was engaged to conduct the assessment for settlement, farming and fishing in the presence of an accompanying officer from ASTA and the Ministry of Agriculture (MoA), District Agriculture Coordinator (DACO).

Based on the field survey, the spill event has adversely affected a substantial number of farmers and fishers across two districts. In Kalulushi District, crop losses have impacted 254 household gardens and fields, while 24 fishing grounds have reported damage to livestock and fish stocks. Similarly, in Kitwe District, 171 family plots and one commercial farm have sustained agricultural damage.

10.1.2 Objectives of the assessment

The main objectives of the study are to conduct a social-economic impact assessment detailing the major impacts of the TD 15 embankment collapse incident and provide mitigation measures. The measures are to improve the social-economic status of the impacted community and avoid reoccurrence of a similar incident in the future. The specific objectives of the assessment are as below:

- To establish the prevailing social-economic situation around the area affected by the acidic discharge as a result of the collapse of the embankment for TD 15.
- Establish the potential direct and indirect social-economic impacts on the surrounding community following the February, 18th environmental incident.
- Provide appropriate and effective mitigation measures that will ensure restoration of the affected social-economic and cultural status of the affected area.
- Ensure compliance with compliance orders as issued by the Mines Safety Department (MSD), Zambia Environmental Management Agency (ZEMA) and the Water Resources Management Authority (WARMA).
- Ascertain the scale, composition and circumstances of individuals occupying land (herein referred to as squatters) within the demarcated mining licensed area. The survey aims to provide a clear demographic and socio-economic profile to inform future planning, potential displacement and mitigation strategies.

10.1.3 Scope of the assessment

The work will involve the undertaking of a social-economic survey to determine the impacts of the pollution incident on the areas around the Sino-Metals Leach Plant in Chambishi area of Kalulushi District. The study will extend to affected areas in Kitwe District and on the banks of the recipient water bodies for the acidic solution, namely; Chambishi stream, Mwambashi stream, the Kafue River up to Itezhi-Tezhi.

However, after findings from government on how far the pollution impacted, it became very clear for the study to confine to the areas in the vicinity of the locality to the SMLZ leach plant and will not include far flung areas. The study will be limited to the areas identified in the reconnaissance study conducted by the Ministry of Agriculture (MOA) as highlighted in the Compensation Report for the Farmers Affected by the Acidic Effluent Discharged from Sino-Metals Zambia Limited due to Dam Failure on the Copperbelt Province.

10.2 Location

The site is located within the operational area of Sino-Metals Leach Zambia Limited in Chambishi, Kalulushi District, on the Copperbelt Province of Zambia.

The site is approximately 20 km East of Kalulushi CBD and is accessible via the T3 Road (Kitwe-Chingola Dual Carriageway) between the cities of Kitwe and Chingola. Chambishi town, which had a population of slightly above 11,000 (2022 Census), lies to the North-east of the project site.

The specific tenement area for the tailings dams falls within Mwambashi Ward. The project site is located in a predominantly mining and industrial area, with the Chambishi Multi-Facility Economic Zone being a major development in the vicinity. The area surrounding the project site is a mix of industrial mining operations, informal settlements, and small-scale agricultural holdings

Water bodies near the site include the Mwambashi River, Chambishi and Lulamba streams, which are used by local communities for agriculture and gardening. The area is devoid of major natural heritage sites but contains critical infrastructure related to the mining industry.

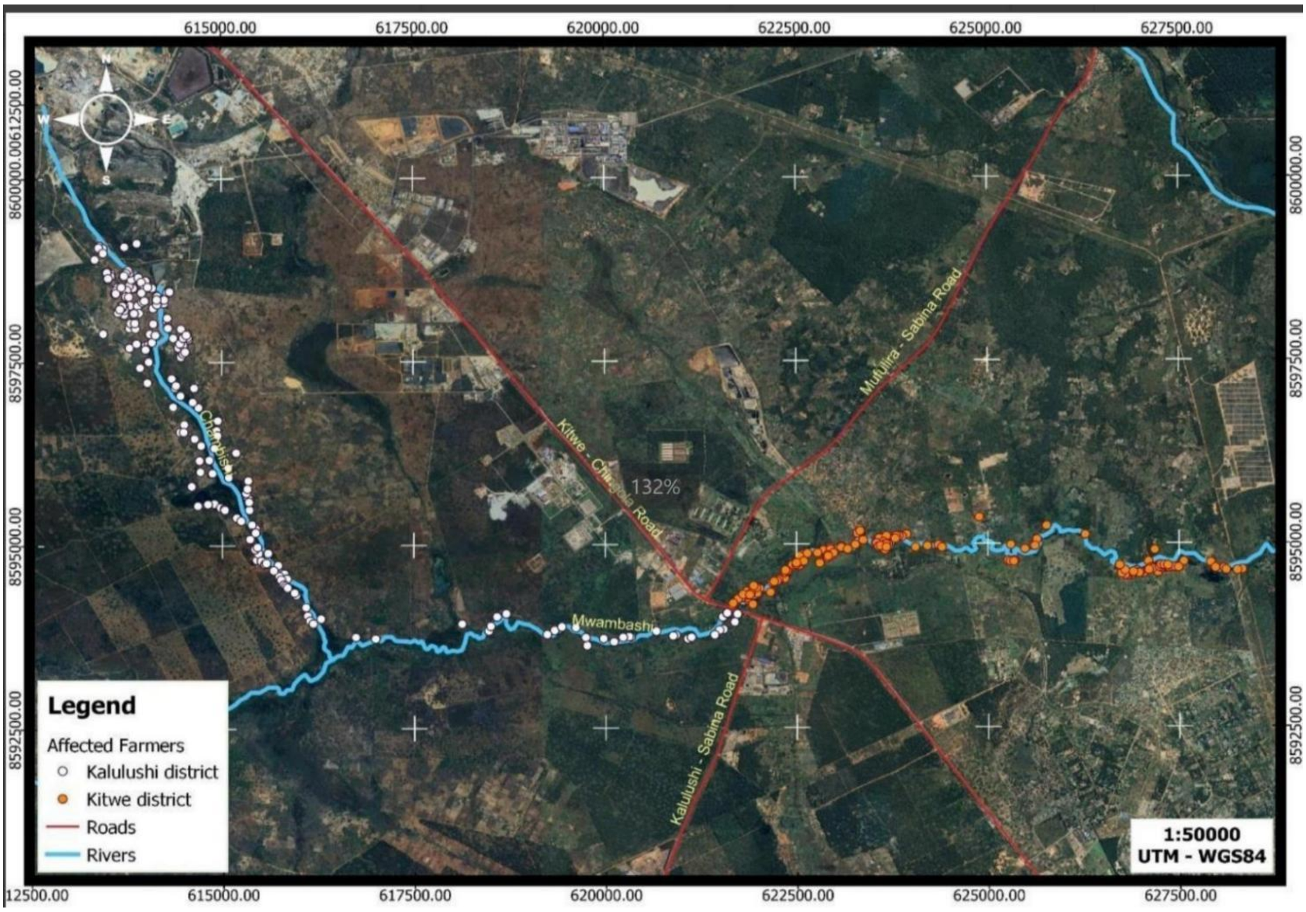


Figure 10-1: Map showing location of the affected farmers

10.3 Legal and Regulatory Framework

The legal and Regulatory Framework has been fully discussed in section 3.0.

10.4 Methodology

10.4.1 Desktop study

A desktop study was conducted to collect secondary data; this involved the review of relevant documentation. This step involved the following:

- Review of the relevant pieces of legislation.
- Review of the compensation report as prepared by the ministry of agriculture together with various authorities.
- Review of the compliance orders as issued by the MSD, ZEMA and WARMA.
- Review of the incident description report.
- Review of company policies and procedures.

10.4.2 Field reconnaissance study

The survey utilized a combination of field visits, headcounts and analysis of recent Google satellite imagery to cross reference physical structures with reported occupancy. Data was collected through enumerator interviews and direct observation within the zone.

Further data was collected from Sino Metals community engagement team which has been providing portable clean drinking water to the Kalusale community since February 2025 when the incident occurred. The information collected was collaborated with the data supplied by the Mine and had a variance of one.

10.5 Social-Economic BASELINE

10.5.1 Demographic profile

The 2022 census of Population and Housing shows that Kalulushi District has a population of 170,701 of which 84,195 are males and 86,502 are female. The district has a population density of 164.5 per km^2. Kalulushi is a highly urbanized district with 82.1% of its population living in the urban area while only 17.9% live in the rural area. In the period 2010 – 2022, the Copperbelt Province is one of the provinces with the lowest annual average population growth rate at 2.9%, while North – Western Province had the highest at 4.8% followed by Central Province at 4.7%. The national average annual population growth rate in the same time frame was 3.5%. Below is table 10-1 showing the population statistics of Kalulushi District.

Kitwe on the other hand has a population of 661,901 individuals of which 321,654 are males and 340,247 are females. It is also the most populated district on the Copperbelt, followed by Ndola with Lufwanyama being the least populated.

Table 10 -1: Population statistics for Kitwe and Kalulushi

Indicator	Kalulushi			Kitwe		
	Total	Male	Female	Total	Male	Female
Population	170,701	84,195	86,502	661,901	321,654	340,247
Area (km^2)	1,038			812.5		
Population Density/km^2	164.5			814.6		
Population %		49.3	50.7		48.6	51.4

10.5.2 Economic activities and livelihood

The main economic activities in Kalulushi District are mining, forestry, and agriculture. Mining is the dominant sector, with companies focused on copper and cobalt extraction. The forestry sector involves timber trading and wood processing, which supplies raw materials to the mining industry and other businesses like ZESCO. Agriculture also plays a key role, alongside small to medium-sized activities such as small-scale mining, retail, and various informal businesses. The district's economy is one of the strongest on the Copperbelt due to huge investment in the mining sector and one of the highest contributors in terms of the Gross Domestic Product (GDP) and employment.

Kalulushi District is home to the Multi Facility Economic Zone (MFEZ) located in Chambishi, allowing a number of industries such as mining to take advantage of the various manufacturing and processing facilities. The district has also seen a rise in a number of mining activities, especially owing to the processing of slag dump from Black Mountain in Kitwe.

Most of the settlers around the SMLZ plant are involved in subsistence farming of crops such as maize, cassava and groundnuts. Some farmers were also involved in irrigated horticultural crops such as Chinese cabbage, eggplant, green pepper as well as some tree crops such as bananas, guavas and mangoes. During the time of the site visit, some sugar cane crops were also observed on the banks of the streams.

The area is also home to some livestock and aquacultural farming activities owing to the availability of fresh water in the vicinity.

Kitwe is called the "hub of the Copperbelt' due to its centrality and major economic activities which include mining, agriculture, trade, commerce, industry, forestry, fisheries and livestock production, energy and transport. From the city's inception, mining has been the central activity which has greatly influenced Kitwe's economic setup and growth. The town is also home to the renowned Chisokone Market, which is a major trading center on the Copperbelt province and the country at large.

10.5.3 Community infrastructure and services

In terms of community infrastructure, the Kalulushi District has a total of twenty-four (24) Health Facilities that offer Primary Health Care services, and one (1) general hospital, namely Kalulushi General Hospital, which is the second level referral hospital, and cases requiring more specialist attention are referred to Kitwe Teaching Hospital (KTH). Fourteen (14) Health Facilities offer HIV-ART Services. Malaria Testing and treatment is done in all the health facilities and mental health cases are referred to Ndola Psychiatric Unit.

There is a total of 77 health facilities in Kitwe District of which 45 are run by the Government of the Republic of Zambia (GRZ) including Kitwe Teaching Hospital and 33 by private health facilities which include 3 hospitals namely; Sino-Zam, Progress Hospital and Wusakile mine hospitals. The district has 15 government health facilities which are delivery centers.

Kalulushi district is home to seventy-eight (78) schools, one (1) Private University and four (4) colleges. Out of the seventy-eight (78), sixty (60) are government owned and eighteen (18) are privately owned. The district has special units for learners in schools namely; St Nicholas Combined School, Masamba Primary and Kalulushi Secondary respectively.

In terms of road infrastructure, the two districts are connected by the Kitwe – Kalulushi road (M7) and the Kalulushi – Sabina Road (M16). The major economic road in the area is the Kitwe – Chingola Dual carriage way (T3) which connects Kitwe to Chingola. It is the same road used to access the SMLZ plant at the Chambishi site.

10.5.4 Administration

There are two administrative systems in the two districts, and these are the central government system and the local authority system. The two towns have mining activity as the main source of income.

Just like in all districts in Zambia, the Central Administration is composed of all government departments and is headed by the District Commissioner. The main role of the District Commissioner is to supervise and coordinate government activities in the district. He also harmonises the activities of the local authority in the district with those of the central government. Heads of departments in line government ministries based in the district, report, on administrative matters to the District Commissioner and technical or professional matters directly to the Provincial Heads.

The mayor represents the people and his main role is to preside over council meetings. The councillor is a channel of communication on social and economic issues between the local authority and the communities he represents.

The Town Clerk heads the administrative wing of the council. Under this administrative wing there are seven departments. The Department of Administration, Department of Legal Services, Department of Development Planning, Department of Engineering Services, Department of Finance, Department of Public Health, and Department of Housing and Social Services. The District Council as a local authority is a semi-autonomous institution operating under the provisions of the Local Government Act No. 22 of 1991. It performs specific functions on behalf of the Government. As the highest decision-making body at the district level, the local authority formulates policies in the form of by-laws and regulations to guide the management and development of the district. The District Council provides a forum for local representation of the public by electing their local representatives, the Councillors.

10.5.5 Telecommunication

Copperbelt Province in general has good telecommunication infrastructure. Communication companies ZAMTEL, Airtel and MTN provide cellular and Internet services. These facilities are widely accessed in the province.

The government-owned Zambia National Broadcasting Corporation (ZNBC) is the principal public broadcaster. It currently runs two television channels and several radio stations. There are several private TV stations accessible in the country, including the subscription Digital Satellite Television

(DSTV). International broadcasters such as the BBC World Services and RFI provide some radio coverage.

10.5.6Vulnerable groups

According to a World Bank study, vulnerability refers to the conditions determined by physical, social, economic and environmental factors or processes, which increase the susceptibility of a community to the impact of a hazard. During a series of site visits around the communities affected by the SMLZ pollution incident, a number of groups of individuals were identified and classified as vulnerable based on the definition above. The criteria used for declaration of vulnerability or the qualification as a vulnerable group was based on the susceptibility of that group and their possible resilience from the effects of the incident.

The livestock owners and fishermen, subsistence and rural farmers, local residents and household owners are considered to be the most affected group of individuals. The vulnerability status was being exacerbated if the individuals involved are aged, children, pregnant women, disabled, have limited educational background and those with unfavorable economic status. Below is a description of the vulnerability status:

Table 10 - 1: Assessment of vulnerability

Vulnerable group	Vulnerability qualification	Comment
Livestock owners and fishermen	They depended on the water from the two streams and Kafue River. Their source of income was also disrupted.	Majority of them have limited educational background and could not easily understand the impacts of the incident.
Subsistence and rural farmers	They depended on the water bodies for irrigation of their crops. Some had crops so close to the river banks.	Most of the affected in this category were elderly and widowed women.
Local residents and household owners	This category depended on the nearby water bodies for supply of water for domestic purposes.	Mostly were elderly citizens.

10.5.7 Legal status of the Kalusale land

The Kalusale area sits on the overlapping mining licensed area owned by Sino Metals and Non Ferrous Mining Africa Limited. This was established by analyzing little deeds and mining licenses. The two mining companies own legal rights to the land rendering the Kalusale people illegal squatters on the mining licensed area.

Information obtained from the squatters interviewed and some mine personnel revealed that several attempts were made in the past to relocate the people but were successful mainly due to political reasons. These attempts were made in 2008, 2002, 2016 and 2018. It is worth noting that the squatters have been living on this land from the times of Zambia Consolidated Copper Mines when the mining area was simply known as ZCCM Chambishi mine.

10.6 Impacts Assessment

This section highlights the key social-economic impacts associated with the SMLZ environmental pollution incident that resulted in the discharge of low pH solution with a heavy load of heavy metals such as copper, cobalt, etc. The assessment will analyse both direct and indirect social-economic impacts associated with the incident. Below is a list of the identified social-economic impacts of the incident:

10.6.1 Impacts on livelihoods

The discharge of the acidic tailings from the SMLZ tailings storage facility has a direct impact on the livelihood of the nearby communities. The discharge resulted in disruption of soil pH and reduction of the pH in the nearby water bodies which included the Chambishi stream, the Mwambashi stream and the Kafue River as the final recipient of the solution. The local economy depends on subsistence farming, fish farming as well as fishing from the nearby water bodies for their source of income. This is a direct impact on the livelihood of the local community and has a significant impact on the economy at large.

From the assessment by the Copperbelt Provincial Ministry of Agriculture (MOA) office, it was discovered that a total of 449 farmers were affected, of which 278 farmers were in Kalulushi district and 171 farmers in Kitwe district. The affected farmers belong to the Musakashi, Ichimpe, Luongo and Garnerton camps. The total tabulated compensation amount for Kalulushi and Kitwe affected farmers amounted to ZMW 9,780,420.58. Based on the assessment by the Copperbelt Provincial Ministry of Fisheries and Livestock (MF&L), a total of 32 households and farms were found to have been affected to varying degrees, involving a total compensation amount of ZMW 4,349,015.00.

The total damaged area captured under cultivation for the two districts was approximately 132.5 hectares, of which the area under Maize cultivation was nearly 109 hectares, taking up about 85-90% of the total affected area. The other widely grown field crops were cassava and groundnuts with the majority of farmers into irrigated horticultural crop production such as vegetables (Egg Plants, Green Pepper vegetables as well as tree crops (Bananas, Guava, Mango etc.). Also, dominantly affected were sugar cane plantations that are grown along the stream beds. The impact on crops and plants in general appeared to be more physical damage to the crops than chemical content in plant tissues. Physical analysis suggested the scorching of the plants/crops being caused by acidified water that ran off the fields.

The distribution of the affected households near the source of the discharge was observed to be wider in radius from the river channel and decreased towards the Mwambashi river in Kitwe District. Preliminary evaluations carried out along the Kafue river in Kitwe indicated no cultivated crop damage but only damage of natural vegetation along the river beds. Kalulushi District had some farmers with large farm plots slightly under one hectare growing field crops, whereas Kitwe Districts had the majority of farmers with a Lima (50mx 50m) or less.

From the assessment by the Copperbelt Provincial Ministry of fisheries and livestock office, it was discovered that a total of 32 families and farms were affected in one way or the other.

In Kalulushi District, a total of 26 families were affected in one way or the other. The families lost goats, fish, ducks, village chickens and rabbits. The total value of their loss is estimated to be ZMW 618,183.80.[22]

In Kitwe District, a total of 6 families and farms were affected in one way or the other. The families lost goats, sheep, fish, cattle, village chickens, broiler chickens and grazing pasture. The total value of their loss is estimated to be ZMW 3,730,831.20.[15]

From 18th November, 2025 to 29th November, 2025, an independent evaluator was engaged to conduct the assessment for settlement, farming and fishing in the presence of an accompanying officer from ASTA and the Ministry of Agriculture (MoA), District Agriculture Coordinator (DACO).

Based on the field survey, the spill event has adversely affected a substantial number of farmers and fishers across two districts. In Kalulushi District, crop losses have impacted 254 household gardens and fields, while 24 fishing grounds have reported damage to livestock and fish stocks. Similarly, in Kitwe District, 171 family plots and one commercial farm have sustained agricultural damage. The total assessment of compensation is K11,683,014.00 (Eleven Million Six Hundred and Eighty-Three Thousand and Fourteen Kwacha).

10.6.2 Impacts on human health and well being

Public health surveillance data showed minor, short-duration spikes in conditions consistent with potential environmental exposure. However, the interplay of environmental factors, exposure to particulate matter, water and sanitation, and historical exposure in the mining district makes it difficult to ascertain cause and effect. Therefore, it is difficult to link the observed trends to a single event (Tailings spill).

The human health risk assessment suggests that the tailings-dam breach likely contributed to elevated multi-pathway exposure risks, with HM levels in surface water, soils, and food crops driving non-cancer and cancer risks above international benchmarks in Kalusale, Luangwa, and some parts of Kitwe and Mpongwe. Although health risks were also identified in shallow wells, the contamination patterns in these wells could not be directly attributed to the once-off Sino-Metals tailings release. The pronounced spatial variability across environmental media indicates that prevailing risks were influenced by additional factors, including geological inputs and legacy mining contamination.

[15] Sino-Metals Compensation Report by Ministry of Fisheries and Livestock Copperbelt Province Office

Overall, while the incident contributed to measurable health risks, these results must be interpreted alongside wider environmental and geochemical evidence from the ESSIA rather than in isolation.

10.6.3 Impacts on community infrastructure

The environmental incident leading to the discharge of leach solution from TD 15 was acidic and may have corrosive effects on community infrastructure. Items like heritage sites and other related community infrastructure may have been impacted by the discharge.

The main source of water for domestic use for townships is the one provided by the Commercial Utility – Nkana Water Supply and Sanitation Company Limited (NWSC). Immediately after detecting abnormal drops in pH at their Bulangililo and Nkana east water treatment plants on 20th February 2025, both facilities were shut down to prevent the distribution of unsafe water to residents of Kitwe. Alternative water supply using bowsers was activated while chemicaltreatment trials were conducted. Upon restoration of acceptable water quality, both plants were reopened on 23rd and 24th February respectively. Up to date, raw and treated water quality continues to be monitored to ensure compliance with health and safety standards. SMLZ Limited also continuously provided portable drinking water for affected residents.

According to the field assessment conducted from 5th October, 2025 to 30th October, 2025, with the objective of identifying:

a) Affected infrastructure and equipment.

b) Damaged or disrupted cultural sites/ activities.

c) Functional status of critical public assets along the river corridor from the Chambishi and Mwambashi confluences through to the Itezhi-Tezhi Dam intake.

The assessment was carried out using integrated geospatial, participatory, and verification methods to support recovery planning and environmental remediation efforts.

The investigation found that critical infrastructure—including bridges, schools, clinics, solar-powered water pumps, and the majority of water supply points—remains fully operational, and cultural heritage sites as well as socioeconomic activities have not been affected. The findings are as follows:

Table 10 - 2: Affected infrastructure and equipment

LOCATION	INFRASTRUCTURE/EQUIPMENT	STATUS	REMARKS
Chambishi River Area	2 wells, 1 hand pump (borehole), 1 culvert bridge	**Mixed**	- One well not used (located ~20 m from river, likely impacted by contamination) Hand pump and culvert fully functional (100 m from river).
Mwambashi River	3 bridges (Kitwe/Chingola dual carriage, Garnton, Eureka)	**Fully functional**	No structural or operational damage observed.

Kafue River (Musonda–Malembeka)	5 bridges, 2 wells, 1 solar pump	**Mixed**	- Both wells non-functional but operational All bridges and solar pump operational.
Chifumpa–Kamifungo	1 bridge, boats	**Fully functional**	No observed impact.
Machiya Crossing	Pontoon, borehole, boats, school, Chief's palace	**Fully functional**	All assets intact and operational.
Lukanga Swamp	2 wells, 2 boreholes, solar plant, clinic, church, boats	**Not affected**	All infrastructure fully serviceable.
Chief Kaindu Area (Mumbwa/Kasempa)	Wells, boreholes, school, police post, clinic, palace, boats	**Not affected**	No disruption to services.
Itezhi-Tezhi Intake	3 wells, 4 boreholes, irrigation system, school, boats	**Not affected**	Fully operational; no signs of impact from upstream contamination.

Table 10 - 3: Cultural and socioeconomic activities

Location	**Socioeconomic Activities**	**Status**	**Key Observations**
Chifumpa–Kamifungo	brickmaking,	**Not affected**	Livelihood activities continuing normally.
Machiya	brickmaking, charcoal; *Nsengele Kununka* ceremony	**Not affected**	Cultural ceremony site intact; no disruption.
Lukanga Swamp	community meetings at clinic	**Not affected**	Social and economic life unchanged.
Chief Kaindu Area	brickmaking; meetings at school/clinic	**Not affected**	Community institutions fully active.
Itezhi-Tezhi Intake	brickmaking; tree-based meeting venue	**Not affected**	Cultural and livelihood functions preserved.

Cultural Note: No ancestral or sacred sites were reported in the **Chambishi or Mwambashi areas**. However, culturally significant sites were verified downstream:

a) Machiya: Traditional *Nsengele Kununka* ceremony ground;
b) Lukanga: Clinic used as community meeting venue;
c) Chief Kaindu Area: School and clinic as social hubs;
d) Itezhi-Tezhi: Communal tree used for gatherings.
All remain undamaged and accessible.

10.6.4 Social cohesion and community dynamics

In terms of community cohesion, there was no evidence of any damage to community infrastructure such as churches, community halls, clinics, schools, etc that can lead to disturbance in social cohesion.

10.6.5 Gender and vulnerable groups considerations

The most affected groups of individuals for the environmental incident that occurred on 18th February 2025 are the livestock owners and fishermen, subsistence and rural farmers and local residents and households. The vulnerability of these individuals was being exacerbated if the involved individuals fall in any of the following categories, as the aged, women (especially pregnant women), disabled, people with limited educational status and people with unfavourable economic status.

Table 10 - 4: Impact characterisation

Sn	Impact	Nature of impact	Significance	Spatial extent
1	Impacts on livelihood	Direct	Significant	Local
2	Health and wellbeing	Indirect	Significant	National
3	Social cohesion and community dynamics	Direct	Medium	Local
4	Gender and vulnerable groups	Indirect	Medium	Local

10.7 Consultation Process

This section highlights the key consultations that took place between the consultant (acting on behalf of SMLZ) and the incident affected individuals. The minutes for the engagement meetings with the locals are attached in the appendix.

10.8 Mitigation and Enhancement Measures

Some mitigation measures have been identified to correct the negative impacts and enhance the positive impacts. Below are the mitigation measures for the identified impacts:

Impacts on livelihoods – following full assessment of the impacts on the livelihood of the pollution affected individuals, the company is therefore recommended to implement the following mitigation measures:

Compensation of the incident affected individuals. This should include direct loss of livelihood due to the pollution incident. This should be done by a competent independent and non-partisan body so as to avoid compromise of the process. According to the assessment conducted by the Office of the Copperbelt Provincial Ministry of Agriculture (MOA), only the Kalulushi and Kitwe Districts were affected, with a total of 449 individuals impacted. The total compensation amount involved is ZMW 9,780,420.58. Based on the assessment by the Copperbelt Provincial Ministry of Fisheries and Livestock (MF&L), a total of 32 households and farms from Kitwe and Kalulushi were found to have been affected to varying degrees, involving a total compensation amount of ZMW 4,349,015.

Implementation of corporate social responsibility (CSR) activities on the resilient community. This will ensure to empower the individuals or communities that have lost livelihoods due to the pollution incident.

Full-scale cleanup and restoration efforts will be implemented in the impacted zones to restore the environment to its pre-contamination condition. This will involve the engagement of a competent and independent organisation to undertake the works.

Impacts on human health and well-being – According to the above findings on health risk assessment, the following recommendations are made:

1. In Kalusale, Luangwa Town, Braninguilo/Ipsukilo, and residential areas south of Mwambashi stream, it is recommended to gradually reduce reliance on shallow wells for domestic uses such as drinking and bathing.

2. In the Kalusale area under Musakashi AC, Luongo AC in Kitwe, and Machiya AC in Mpongwe, it is recommended to implement specific agronomic measures—such as liming, crop rotation, and switching to low-accumulating crops like common beans and pumpkin leaves—to reduce contamination risks and promote safer food production.

3. Establish long-term HMs level monitoring of water, soils, crops, and human biomonitoring, especially for children.

4. In the long term, the consistently elevated HM levels detected across multiple environmental media in Kalusale suggest that relocating affected residents to safer areas may offer the most sustainable and protective solution.

5. Integrate environmental risk surveillance with routine health data and initiate longitudinal studies to track health outcomes, especially cancer and developmental effects.

Impacts on community infrastructure – Based on the impact assessment conducted, the findings reveal that the pollution incident has not impacted any community infrastructure other than NWSC. Following the incident, SMLZ promptly coordinated with NWSC to implement water treatment measures and ensure supply continuity. SMLZ is currently engaged in discussions with NWSC regarding compensation arrangements. For this reason, no mitigation measures have been proposed for this impact.

Gender and vulnerable groups - Compensation of the affected individuals can assist in alleviating the impacts on gender and vulnerable groups such as the aged. Immediately after the incident, SML carried out humanitarian assistance in the affected communities by distributing drinking water, cooking oil, maize meal, and cash to vulnerable groups, ensuring the daily needs of affected residents were met.

10.9 Monitoring and Evaluation

Implementation of the aforementioned mitigation measures will require strict monitoring to ensure 100% compliance. The measures will be monitored through the following methods;

- Community liaison activities – strict objectives and key performance indicators (KPI) will be set to ensure that progress of the implementation of the mitigation measures is monitored. This will be done through the engagement of a competent community liaison officer. The community will be engaged on a regular basis for data collection on the effectiveness of the proposed mitigation measures.
- Grievance redress system – a grievance redress mechanism will be developed specifically for this project. The mechanism will include grievance procedural issues and formation of a grievance redress committee.
- Engagement register – an engagement register will be maintained to track all engagements conducted.

10.10 Appendix

Appendix 10-1: Photos of the affected communities

Appendix 10-2: Minutes for focus group discussion

Appendix 10-3: Report & Assessment of Compensation For Sino-Metals Tailings Impacted Persons In the of Kalulushi and Kitwe Districts

11. FISHERIES IMPACT ASSESSMENT ON THE KAFUE RIVER ECOSYSTEM

11.1 Introduction

This report details the post-incidence status of fisheries in the Kafue River and provides recommendations for future remediation programs. Fish and fisheries are important economic strands for communities along the Kafue River, with most rural communities directly dependent on fishing, fish processing and fish trading. Fisheries along the Kafue River supports over 13,000 active fishers and over 23 fish species are exploited commercially (Fisheries Frame Survey, 2024; WWF, 2022). Therefore, the study aimed at providing preliminary fisheries information, especially on the status of fishes (growth, reproduction and health) and benchmark direction for future bioremediation, conservation and management of the Kafue River ecosystem.

Conversely, following the collapse of the tailing dams at Sino Leach Metals in Chambeshi District which resulted in the release of mining waste into the Mwambashi stream, a tributary of the Kafue River, there is a need to estimate the extent of the damage. Heavy metal pollutants, particularly, endanger the lives of aquatic life (flora and fauna) and, more significantly, people who eat aquatic products, which are an essential source of protein (Hasimuna *et al*., 2023; Hashima *et al* 2020). After being absorbed by organisms, heavy metals can bind to different biomolecules, altering their normal structure and function. Heavy metals refer to the relatively high atomic and density metallic elements compared with water.

In small quantities, some heavy metals may be nutritionally essential for health, also referred to as trace elements or micronutrients. These include iron, boron, manganese, zinc, copper and molybdenum, which are micronutrients essential for plant and animal growth (Chilesha et al., 2020). To further understand this component, the study determined heavy metal contamination from iron-Fe, copper-Cu, Cobalt-Co, Zinc-Zn, Manganese-Mn, chromium-Cr. Nickel-Ni, cadmium-Cd and magnesium-Mg, their accumulation and transportation along the Kafue River from near the source of Sino-metal spillage to before the Kafue gorge in Kafue town. The study will further investigate the impacts of the pollution event on fisher livelihoods

Study objectives

The study was conducted with the aim of providing fisheries baseline information especially on the status of fishes (recolonization, growth, reproduction and health) and benchmark direction for future bioremediation, conservation and management of the Kafue River ecosystem. The specific objective included;

1. Establish recolonization levels (presence/absence) of fish in the Kafue River
2. Determine growth and condition of fish in the Kafue River
3. Establish fish food safety status for fish communities exposed to the polluted environment
4. Provide plausible recommendations for possible bioremediation options

11.2 Methodology

11.2.1 Fisheries Assessment Methodology

11.2.1.1 Study design and area

A multistage sampling design was adopted in this study, with the study executed in two stages; firstly, focusing on establishing the general status in the fishery and secondly, to profile the condition of the fish in the fishery.

To understand the present status of the fishery and environmental quality, sampling localities were spread across the fishery taking into account differences in the physical parameters that have been summarised in **Appendix 11-1**.

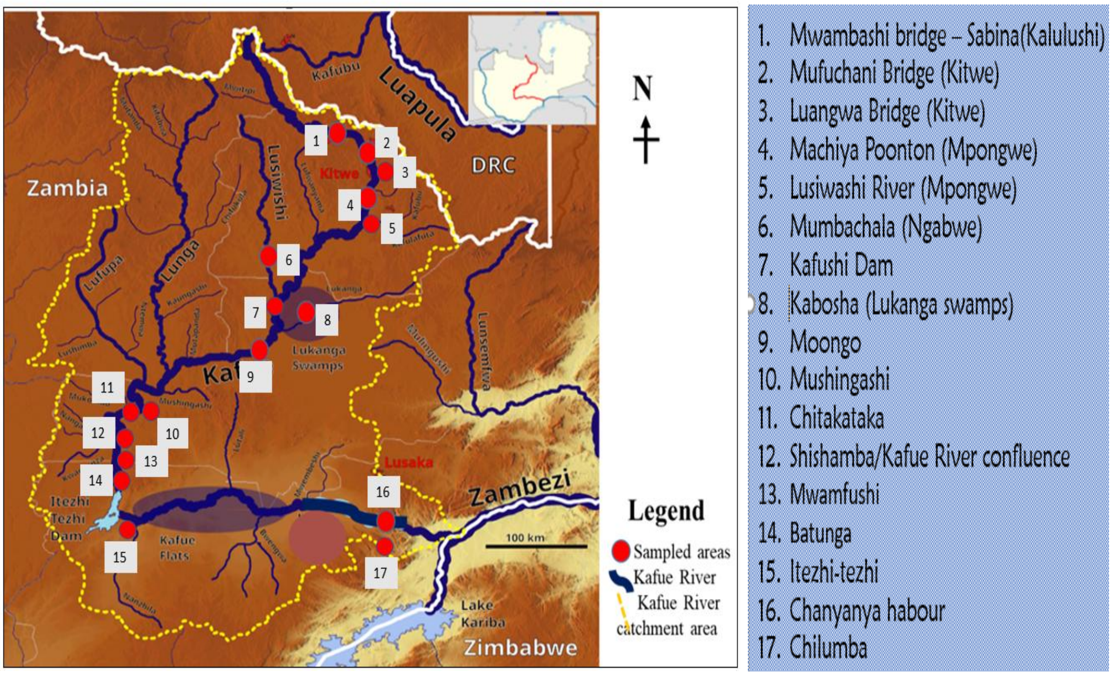


Figure 11-1: Map showing sampling localities across the Kafue River system

The second and similar assessment was done in the months of Nov/Dec, 2025 in two localities/clusters of Kafue River, at Ngabwe/Mukubwe area near the confluence of the river in Ngabwe District and the Lukanga Swamps and Machiya area in Mpongwe, stretching to near Ibenga in Masaiti District. A third sampling cluster (upstream) was planned as the control – area not affected by the pollution, however, no major fish biodiversity was observed there, except for a few *Pseudocrenilabrus philander,* so it was left out in the comprehensive sampling (**Figure 11-1**). This sampling exercise concentrated on establishing the condition of the fish using a reasonable representative sample size from Machiya and Ngabwe whose locality gave a much higher catch rate compared to other sites.

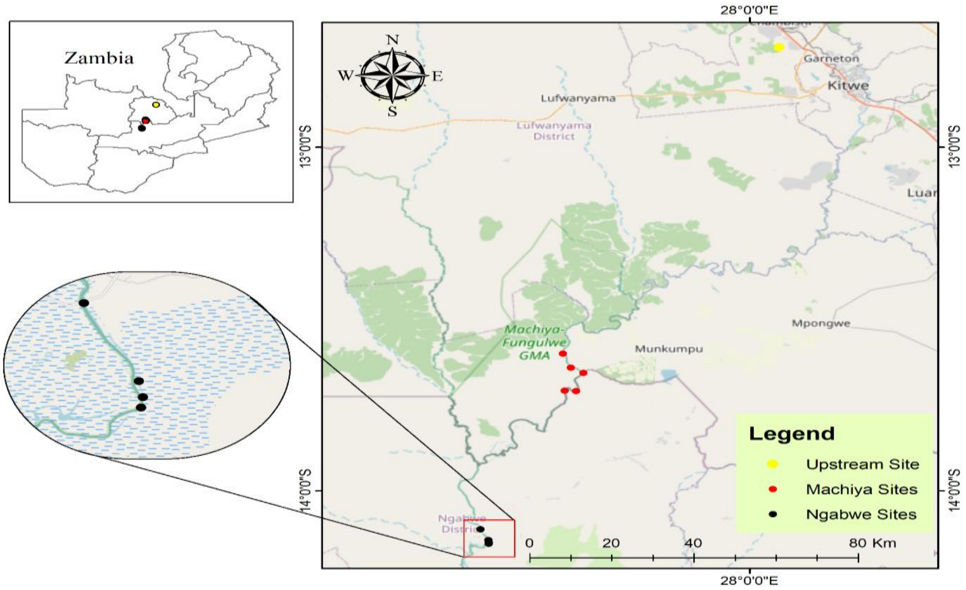


Figure 11-2: Map depicting the two sampling localities at Ngabwe and Machiya, with associated study sites.

The two sampling localities (Ngabwe/Mukubwe and Machiya) were chosen on the basis of being part of the Kafue Fishery, a commercial fishery area of Zambia, thus fully encompassing Mwambashi and Chambishi as part of the river's key tributaries in the headstream. It was hypothesized that Ngabwe locality will offer insight on the ichthyofauna associated with the swamp/oxbow lake and main river channel, while Machiya area was designated for species of the main river channel. The sampling sites had a minimum 100.0km river coverage and actual sites spatially distributed within the main river channel and associated lagoons/oxbow lakes.

For this study, a rapid fisheries assessment method (RFAM) was used to provide insight on the fisheries status after the acid pollution of the Mwambashi, Chambishi and Kafue River systems. Key methods used included profiling recolonisation (species inventory), length-weight (L-W) relationship and reproductive potential of fish in the system. Rapid fisheries assessment methods are suitable for unique situations (like the present case) and have been used to provide valuable information for management and conservation decisions (Hlungwani et al., 2024; World Bank 2022; White et al., 2014).

Data was collected using a mixed approach method; fishery independent and fishery dependent. In the fishery independent approach, a fleet of multi-meshed experimental gillnets (25,38,50,63 &76mm) was used, with different panels staggered on the fleet to overcome selectivity limitation of the gear. Further, gillnets were complemented by 25mm meshed traps (different from the traditional traps – *Imyono*) and handlines with hook sizes ranging from 1/0, to 4/0 (**Figure 11-2**). fishery dependent approach involved assessing and buying of fish species not encountered by the research team.

a. Fleet of experimental gillnets

b. Meshed fish trap

Figure 11-3: Some of the fishing gears used in sampling fish from the Kafue River.

11.2.1.2 Sampling protocol

Indigenous ecological knowledge

Prior to fish sampling, key informant interviews (KII) were conducted in the fishing camps around Mukubwe and Machiya area to incorporate indigenous ecological knowledge (IEK) in the study were gathered through interviews with local fishers, delving into the fishery's status. Of interest was, prominent fish species caught using the described fishing gears (gillnets, traps and hooks), seasonal variations, species of economic significance, identification of rare fish species, and species mostly affected by the acid pollution.

Collection and analysis of ichthyofauna

Sampling gears (gillnets, traps and hooks) were strategically positioned along the riverbanks and midwater regions, both during daylight and nighttime, to encompass a wide range of diurnal and nocturnal fish species. Soak time for gillnets was maintained at 3 hours and 12 hours for diurnal and nocturnal fish species, respectively. On the other hand, a 12hrs soak time was maintained for traps and each site was sampled for three consecutive days.

All captured fish were identified up to species level, and in cases where specific identification was not feasible, categorized at the genera/family level using Utsugi & Mazingaliwa (2002), Skelton (2001), and Hughes (2019) as field guides for this purpose. Biometric measurements, including total length (TL_ mm), wet weight (g), sex, and maturation status, were recorded for each individual fish.

For sexing of the fish, specimens were individually dissected by making an incision from the anal vent and running it laterally to the pelvic fins, then sex was determined by checking the state of the gonads. Development of the gonads was quantified by stages on the basis of physical characteristics described by Bagenal (1978) and Jennings *et al*. (2001; Table 11-1). Individual fish exhibiting gonadal maturation of III-V were considered as mature and below that as immature.

Table 11-1: Classification of gonadal development based on physical characteristics

Stage	Description	Characteristics
I	Immature	Thin transparent ovaries without blood vessels.
II	Quiescent	Small developing eggs, ovary not full, blood vessels apparent.
III	Active	Ovary full with visible but not hydrated eggs.
IV	Ripe	Hydrated eggs present but not released via oviduct.

V	Ripe running	Eggs released via oviduct with pressure on the ovary.
VI	Spent	Flat deflated ovaries, eggs in resorption, slime in ovary.

Adapted from Jennings *et al*., (2001) and Bagenal (1978).

Fish's health status was conducted by physical inspection of body deformities (e.g fin/tail rot, body lesions etc), inspection of abnormalities in the gill's region and profile of the visceral (swelling of the stomach, defective gonads etc). Local fishers were also interviewed on the prevalence of fish disease/fish mortality within their area.

Water quality analysis

From each site, water quality measurements, focusing on physicochemical parameters, were collected using calibrated multi-parameter probes: pH, dissolved oxygen (DO), temperature, conductivity, turbidity, and redox potential. pH level was the parameter of focus, taken as the proxy for stable environmental status and physiological process of fish. A time series dataset from the National Aquaculture Research and Development Center (NARDC) and Copperbelt University (CBU) was incorporated in the study to establish a trend in the physicochemical parameters in the Kafue River ecosystem.

11.2.1.3 Heavy metal bioaccumulation analysis

Fish was also collected across the river channel for analysis of heavy metal contamination in the fish (**Figure 4**) Seven fish species from six families; ***Mormyridae***, ***Schilbeidae***, ***Mochokidae***, ***Characidae***, ***Claridae*** and ***Cichlidae,*** were preserved whole on dry ice and shipped to the Central Veterinary Research Institute (CVRI) Laboratory in Lusaka for heavy metal analysis. Field samples were collected, prepared and preserved with close adherence to standard procedures postulated by American Public Health Association guidelines (APHA, 2012). At the laboratory, accumulation/concentration of metal were measured using Atomic Absorption Spectroscopy (AAS) method on fish samples using standard operating procedures in line with Codex standards.

11.2.1.4 Data analysis

To understand the status of fisheries after the acid pollution in the Kafue River, seven species from six families were subjected to detailed analysis. The six families acted as indicator/flagship species in the population. Biometric data collected was subjected to analysis using PASGEAR II (Version 2.10), a fish stock assessment tool, providing insights into the population dynamics of the fish. Due to multiple sampling gears (effort) used to collect fish (gillnet, traps and hooks) and varied soak times, analysis did not take into account standardization of fishing pressure (CpUE) and catchability coefficients. Thus, PASGEAR was mainly used for normality tests of the data (LW, gonadal data), whereas, related calculations and graphs were generated in Microsoft Excel Spreadsheet.

The focus of the analysis was on the growth status of the fish using the Length-weight (L-W) relationship ($W=aTL^b$ - with growth factor *b* as the indicator for general growth pattern of the fish, a as the intercept of the regression on the y-axis), condition factor (K =((W/L^3) *x100*)) - indicative of general fish fitness in relation to the environment). Shannon-Weiner Diversity Index (H) for selected fish species calculated as:

$$H = -\sum_{j=1}^{S} p_i \ln p_i$$

Where *p* is the proportion of species *i*, ln is the natural log of the proportion of species *i.*

Sex ratio and size at first maturity (L_{50}) were considered for reproductive aspects. Size in terms of length at which 50% of the fish attain maturity (L_{50}) was estimated by fitting a logistic curve to the relationship between proportion of mature fish (P) and total length (Jennings *et al*., 2001):

$$P = \frac{1}{(1+e^{-r\,(L-L_{50})})}$$

To obtain L_{50}, the function was transformed into a linear equation as follows:

$$Log_e\left(\frac{1-P}{P}\right) = rL_{50} - r$$

Thereafter, the linear fit of $\log_e$ ((1-P)/P) against total length (TL) was done by maximizing the likelihood of binomial distribution using Excel add-in tool solver, taking into account that r = -b and L_{50} = a/r.

Bioaccumulation of heavy metals focused on establishing toxicity levels in the fish for both the human and ecosystem health.

11.2.2 Livestock Assessment Methodology

11.2.2.1 Sampling protocol

Indigenous Livestock knowledge

Prior to Environmental Sampling, key informant interviews (KII) were conducted in the affected area to incorporate indigenous livestock knowledge in the study. The interviews with local farmers, Government officials delving into the Livestock status prior to and after the incident. Additionally, data associated with the incident from other sources, including government ministries and agencies, was collected and analysed accordingly.

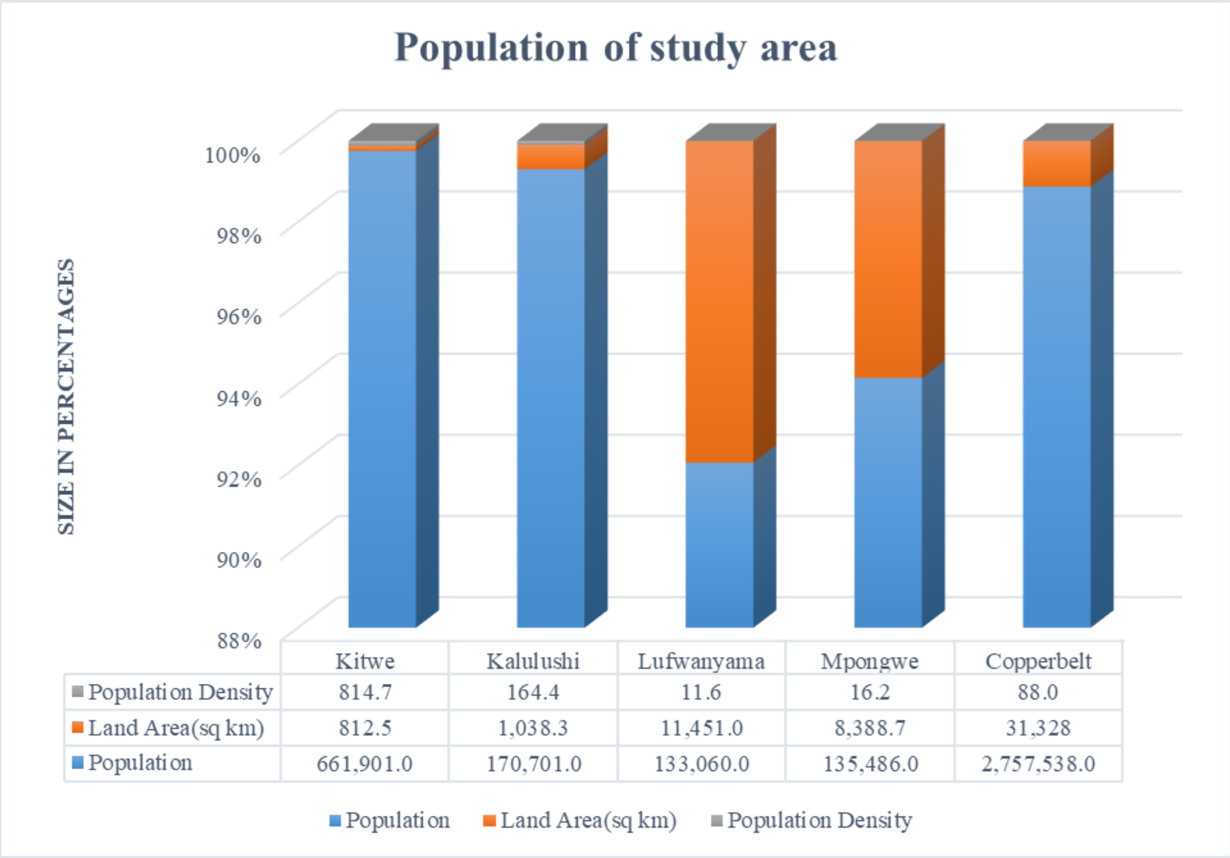


Figure 11-5: Map depicting population of the study area. Source 2022 Census Report.

11.2.2.2 Heavy metal bioaccumulation analysis

294 livestock blood sample data sets (live animals) were collected across the river channel for analysis of heavy metal contamination and submitted for Laboratory testing at Central Veterinary Research Institute (CVRI) Laboratory in Lusaka for heavy metal analysis. Field samples were collected, prepared and preserved with close adherence to standard procedures postulated by the American Public Health Association (APHA) guidelines (APHA, 2012). At the laboratory, accumulation/concentration of metal were measured using Atomic Absorption Spectroscopy (AAS) method using standard operating procedures in line with FAO Codex standards.

11.3 Key Findings

11.3.1 Fisheries

11.3.1.1 Water Quality

Water quality monitoring was done from different sites within the Kafue river system in order to appreciate spatial changes in selected physicochemical parameters (**Appendix 11-2**). Analysis of key physicochemical parameters showed a mix between the effects associated with mining and other allochthonous nutrients sources from the catchment (e.g higher influx of sewage treatment). Of interest to this study was the pH levels in the water that have direct bearing on the homeostatic process, bioavailability of heavy metals and influence general physiological performance of the fish. Time series data from February when the spillage incidence occurred to late October when the last set of water quality samples were collected, show a significant improvement in the pH levels from acidity (3.3) to normal and/or above normal (9.7) (Figure 5).

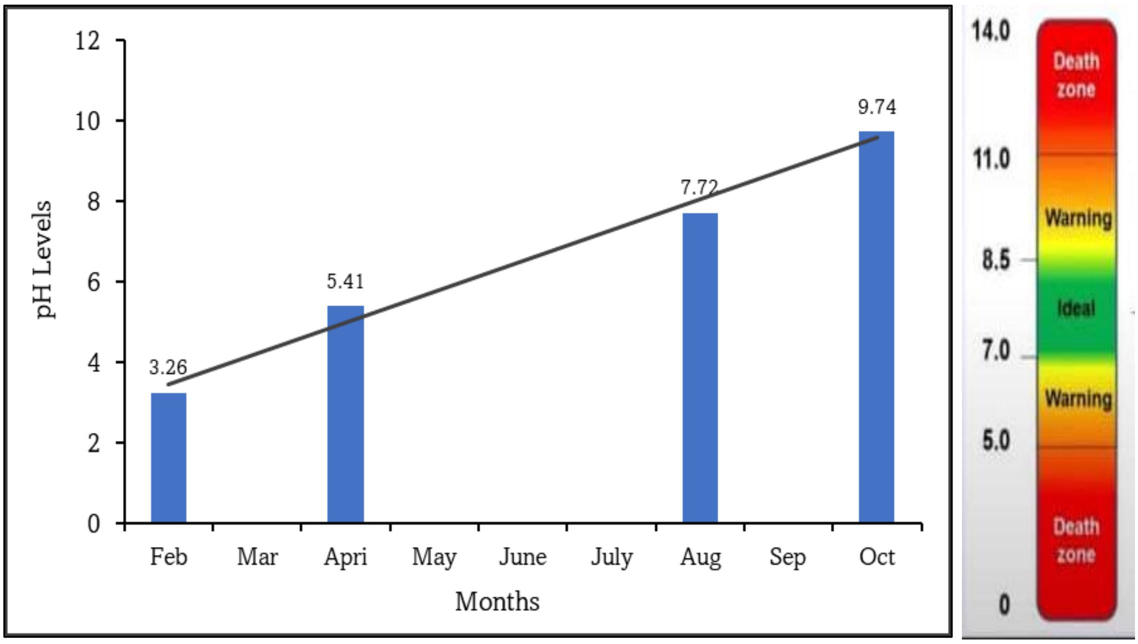


Figure 33. Average pH recordings monitored between February and October.

Over the period, recordings for selected physicochemical parameters showed abnormal/below threshold readings especially for dissolved oxygen (**Appendix 11-2).** With such a case, changes in the reading could in most sites be associated with high nutrient loading with a direct influence on photosynthesis and related bloom of algae (cyanobacteria). Flactuations in physicochemical parameters, except for acute pH levels (>4.5), are regarded as normal because they reflect the spatiotemporal interaction between the biotic and abiotic components in the system.

11.3.1.2 Situation Analysis

Data collected for indigenous ecological knowledge (IEK) through key informant interviews (KII), reviewed rich ecological information on the status and fisheries practices of the Kafue ecosystem. A total of fifteen (15) KII were conducted in fishing camps and villages between Ngabwe and Machiya. Though the fishery was declared closed after the pollution incident, fishing communities have continued fishing, processing and selling of fish. Table 11-2. Summaries the situation analysis of fisheries along the Kafue River.

Table 11-2: Summary of the fishery's situational analysis along the Kafue River ecosystem

Parameter	Description
Fishing practices	The fishery is presently characterised by illegal, unreported and unregulated (IUU) practices, with prominent use of under-meshed nylon monofilament gillnets below the recommended statutory mesh sizes of 73mm & 37mm for all and smaller species (*Brycinus lateralis*), respectively (Fisheries Regulations, 2012); construction of weirs in the swamps and non-adherence to fisheries regulations (closure period, mesh restriction etc).
Fish production	The fishery is still rich in fish species as seen from the family and species documented, however, the size of the fish caught and quantities are gradually reducing (recruitment overfishing). Use of unconventional fishing gears and high influx of fishers from urban areas are cited as reasons for the reduction in fish production.
Fish mortality/health from acid pollution	Massive loss of fish was experienced for almost all species in the first week of the pollution incidence. However, species from the Mochokidae, *Cichlidae* and *Schilbeidae* families were observed to be more vulnerable to acid toxicity compared to others. No actual fish disease outbreak within the past five years has been recorded in the fishery.
Incidence of human deaths	No incidence of human death(s) related to consumption of acid poisoned fish has been reported/observed in the fishery and beyond.

Monofilament gillnets in the fishery

A fisher's landing during the survey

11.3.1.2 Fish Composition & biodiversity

The Kafue River has about 77 documented fish, of which 23 species are of economic importance (WWF, 2022). In this assessment twenty-two (22) finfish species from nine (09) families and one crayfish species (*Cherax quadricarinatus*) were recorded. A total of 910 fish specimens were profiled during the study and a summary of their biometric parameters have been summarized in **Appendix 11-3**.

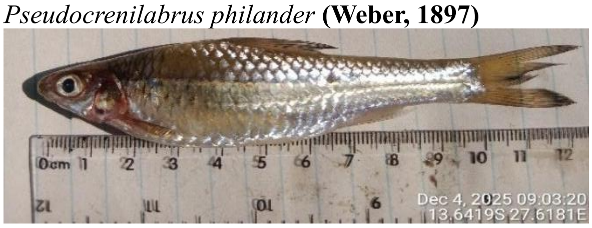
Based on ubiquitous distribution, abundance (taken as high fisher catch rate) and resilience to environmental perturbation, seven species from six (6) families were chosen as indicator/flagship species. Table 11. 3. Shows the seven indicator/flagship species for the fishery and their descriptive statistics of the biometric parameters have been summarised in **Appendix 11-2**.

Table 11-3: Indicator or flagship species considered in the analysis for the Kafue River ecosystem.

Family	Spp. name	Habitat type	Foraging type	Distribution
Cichlidae	*Pseudocrenilabrus philander*	Littoral	Top feeders	Ubiquitous
	Tilapia sparmanii.	Littoral	Top feeders	Ubiquitous
Characidae	*Rhabdalestes maunensis.*	Intermediate	Intermediate feeders	Ubiquitous
Claridae	*Clarias ngamensis*	Benthic	Bottom feeder	Ubiquitous
Mochokidae	*Synodontis woosnami*	Intermediate	Intermediate feeder	Ubiquitous
Mormyridae	*Marcusenius macrolepidotus*	Benthic	Bottom feeder	Ubiquitous
Schilbeidae	*Schilbe intermedius*	Benthic	Bottom feeder	Ubiquitous

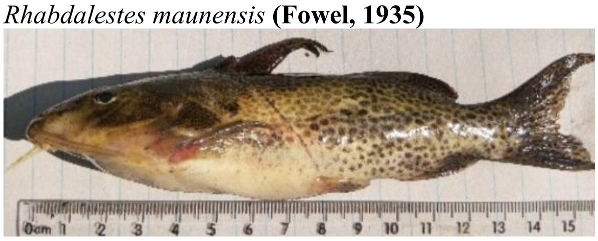
Pseudocrenilabrus philander **(Weber, 1897)**

Tilapia sparmanii (Smith, 1840)

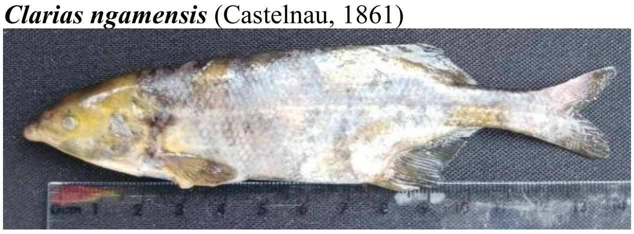


Rhabdalestes maunensis **(Fowel, 1935)**

Clarias ngamensis (Castelnau, 1861)



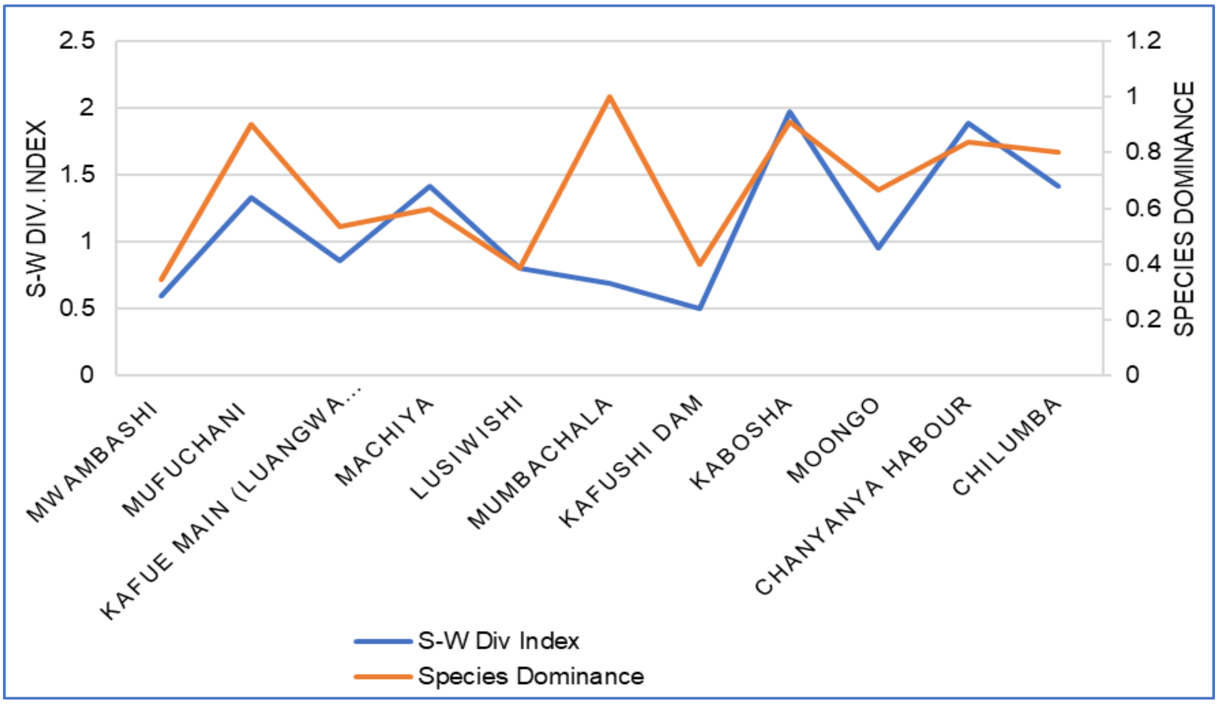
Synodontis woosnami **(Boulenger, 1911)**



Marcusenius macrolepidotus (Peters, 1852)

Schilbe intermedius **(Ruppell, 1832)**

A gradual increase in fish abundance (diversity and dominance) was recorded from the headstream localities/cluster in the Copperbelt (Mwambashi) to the midwaters (Machiya_Mufuchani) and downstream, to sampling localities in Lusaka province (Kabosha). The southern mouthbrooder (*P. philander*) was the only species recorded in the headstream; however, species diversity increased after the Kafue bridge coming downward to Machiya area.



Mwambashi and Kafue Dam had the lowest species diversity indices. At Mwambashi River, *Enteromius* spp and *Clarias* species were common. Amphibians (Xenopus *laevis*) and various larval forms of aquatic arthropods.

11.3.1.3 Fisheries baseline condition

The growth pattern (b) and general condition (*K*) of the fish in the Kafue ecosystem (including Mwambashi and Chambishi River systems), revealed uneven status among families and species. The two indices were used to appreciate the general fish welfare in the Kafue Fishery.

i. **Cichlidae:** *T. sparmanii* and *P. philander* represented the *Cichlidae* family showed a generally stable growth and condition status within the habitat, with both males and females exhibiting isometric growth (b=3) and body condition ($K \leq 1.0$) (Table 11-4). Other species in the family include *Oreochromis placidus*, *Captodon rendali* and are expected to show similar resilience to existing lower water pH levels in the catchment. All species profiled were fully mature and in breeding phase – this could be a contributing factor for stable growth and body condition.
ii. **Characidae:** *R. maunensis* represented the *Characidae* family exhibited significantly poor growth status, with males exhibiting positive allometric growth, while females were of negative allometric growth. However, condition status was stable for the species ($K \leq 1.0$, Table 11-4). Both poor water quality and deviation of somatic energy to reproduction could account for the poor growth status, especially for females of the species in this family. This would be a key indicator species for future remedial actions
iii. **Claridae:** *C. ngamensis* represented the *Claridae* family that showed stable growth and condition status for both males and females (b=3; $K \leq 1.0$ - Table 11-4). Major species in this family include *C. gariepinus* and *C. theodorae* which mostly shore resilience to environmental perturbation especially in their breeding season.

iv. **Mochokidae:** *S. woosnami* represented species from the *Mochokidae* family, with a focus on the *Synodontis* genus. Like the *Characidae*, the *Synodontis* species showed poorer growth and environmental response for both males and females. However, males were in better body shape compared to females (Table 11-4). Mortality of these species due to acidity toxicity was also reported to be high.

v. **Mormyridae:** *M. macrolepidotus* represented the *Mormyridae* family and exhibited more stable growth and condition status (b=3; $K \leq 1.0$ - Table 11-4). Species in the family, including Petrocephalus *catastoma, Pollimyrus castelnaui,* commonly known as 'Imintesa' contribute significantly to the overall fish production in the fishery.

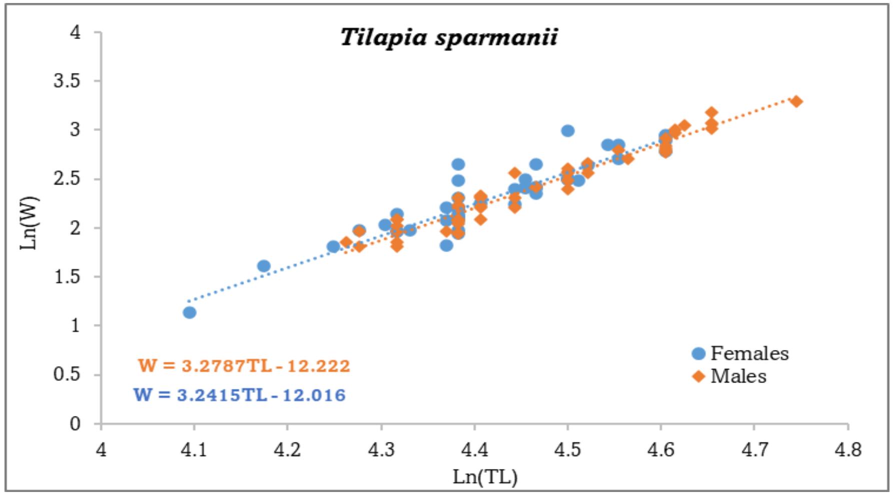
vi. **Schilbeidae:** *S. Intermedius* represented the *Schilbeidae* family, which was the only species sampled in this family. *S. Intermedius* showed poor growth for both males and females, but had a rather stable condition (Table 11-4). This species is also reported to have suffered high mortality during the pollution incidence.

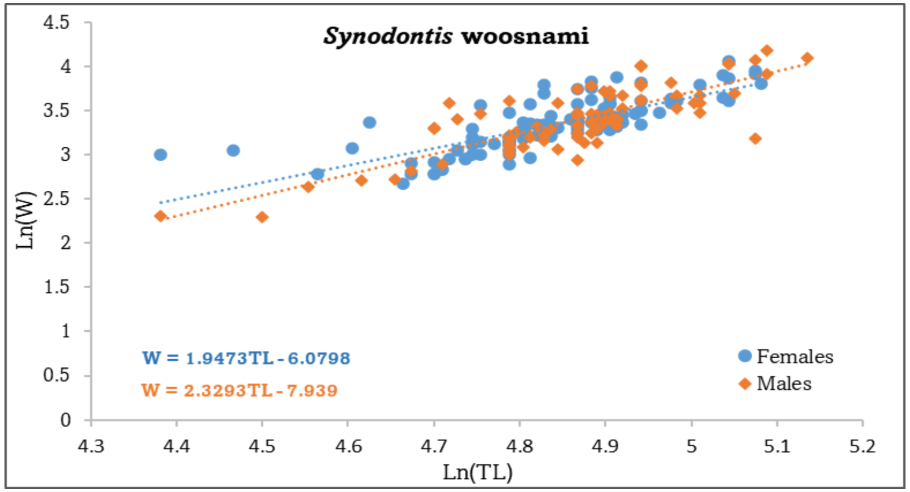
Table 11-4: Growth coefficient (b) and Condition (K) factor of indicator/flagship species in the Kafue Ecosystem.

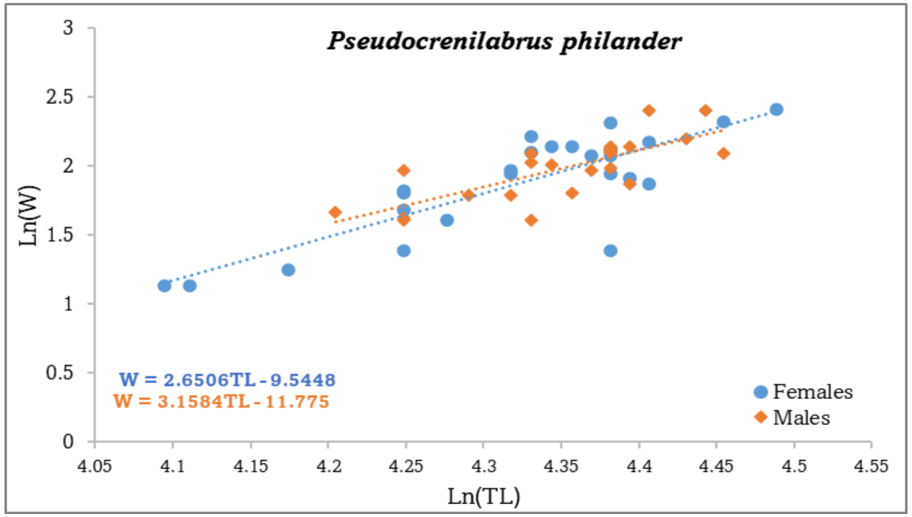
	Males						Females					
Species	***L-W Equation***	R^2	***b***	***K* (mean± SD)**	**n**	**growth type**	***L-W Equation***	R^2	***b***	**K (mean ±SD)**	***n***	**growth type**
T. sparmanii	$W=2.2E\text{-}6L^{3.27}$	**0.94**	**3.27**	**1.0 ±013**	55	(=)	$W=6.0E\text{-}6L^{3,24}$	**0.85**	**3.24**	**1±0.16**	50	(=)
S. intermedius	$W=1.5E\text{-}7L^{3.81}$	**0.73**	**3.81**	**1.0±0.346**	37	(+)	$W=1.7E\text{-}3L^{1.91}$	**0.30**	**1.91**	**1.1±0.34**	38	(-)
P. philander	$W=7.2E\text{-}05L^{2.65}$	**0.58**	**2.65**	**1.0±0.144**	25	(-)	$W=7.7E\text{-}6L^{3.12}$	**0.68**	**3.12**	**1.0±0.190**	25	(=)
R. maunensis	$W=1.7E\text{-}6L^{3.34}$	**0.41**	**3.34**	**1.0±0.208**	41	(=)	$W=1.1E\text{-}6L^{3.45}$	**0.67**	**3.45**	**1.0±0.165**	90	(+)
M. macrolepidotus	$W=1.9E\text{-}5L^{2.90}$	**0.51**	**2.90**	**1.0±0.200**	40	(=)	$W=1.0E\text{-}5L^{3.03}$	**0.61**	**3.03**	**1.0±0.123**	24	(=)
C. ngamensis	$W=5.0E\text{-}6L^{3.08}$	**0.91**	**3.08**	**1.0±0.179**	10	(=)	$W=4.6E\text{-}5L^{2.71}$	**0.75**	**2.71**	**1.0±0.325**	13	(-)
S. woosnami	$W=2.6E\text{-}4L^{2.39}$	**0.62**	**2.39**	**1.1±1.245**	79	(-)	$W=2.3E\text{-}3L^{1.95}$	**0.40**	**1.95**	**0.03±0.01**	104	(-)

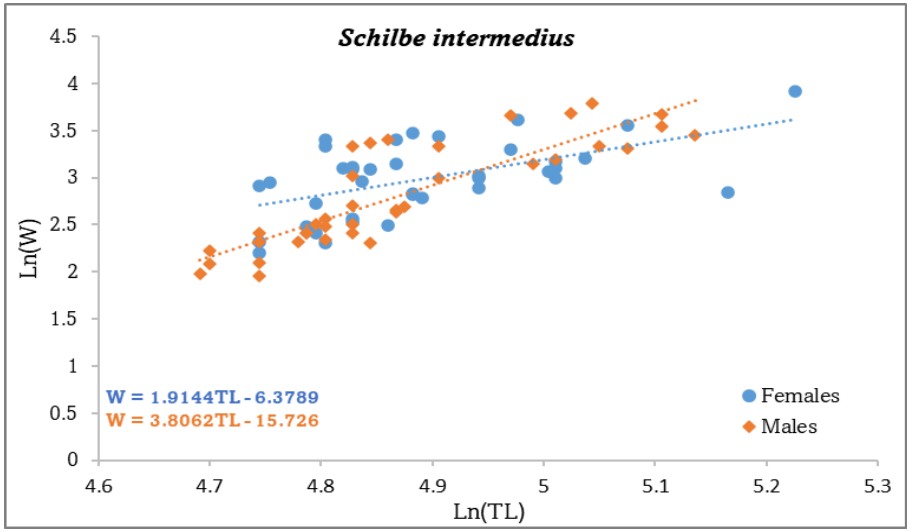
Interpretation of the growth factor *b* from the L-W Relation ($W=aL^3$)

Negative allometric (-)	**Isometric**	**Positive Allometric (+)**
$b \leq 2.4$	$b \geq 2.5$ **but** ≤ 3.4	$b \geq 3.5$
Fish length increases faster than its weight (suboptimal)	Fish body weight increases as the cube of its length (optimal)	Fish body weight increases faster than its length (beyond)


Tilapia sparmanii
Ln(W)
Ln(TL)
W = 3.2787TL - 12.222
W = 3.2415TL - 12.016
Females
Males


Synodontis woosnami
Ln(W)
Ln(TL)
W = 1.9473TL - 6.0798
W = 2.3293TL - 7.939
Females
Males


Pseudocrenilabrus philander
Ln(W)
Ln(TL)
W = 2.6506TL - 9.5448
W = 3.1584TL - 11.775
Females
Males


Schilbe intermedius
Ln(W)
Ln(TL)
W = 1.9144TL - 6.3789
W = 3.8062TL - 15.726
Females
Males

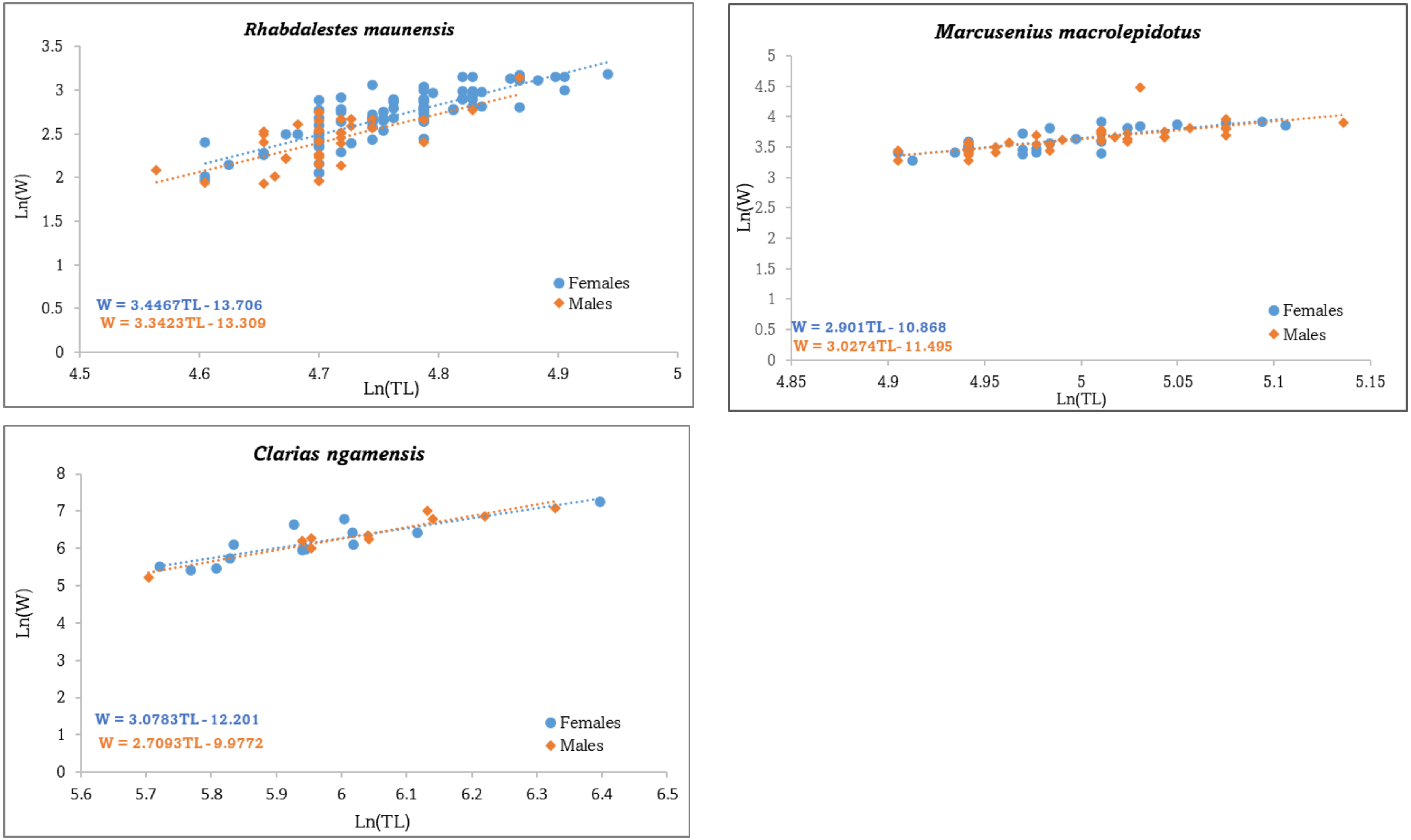


Figure 11-6: Scatter plots for the L-W Relationship of seven indicator/flagship species with corresponding L-W equations in the Kafue River

11.3.1.4 Fish recovery potential

The reproductive potential of ichthyofauna in the fishery was used as a proxy for profiling recovery levels after the acid pollution. Gonadal analysis revealed 98% of fish sampled during the survey to be mature – many of the gravid female had fully developed or ripe running ovaries (Table 11-5). The size at first maturity (L_{50} - taken as total body length at which 50% of individuals in a population exhibit puberty and spawning potential) for species across all families studied, showed a reduced size at first maturity. However, *C. ngamensis* showed a more stable maturation status (L_{50} ≥300mm males and females) than the reported L_{50} =250mm. Sex ratios within families were rather stable, except for *C. Maunensis* that had more females than males in the studied population (Table 11-5).

Size at first maturity (L_{50}) is an important indicator of the reproductive status of fish population. However, there are limitations to the use of this index because factors such as habitat/food quality, biotic interactions (competition/predation) and fishing pressure may cause fish species to exhibit varying thresholds. Lack of adult breeding cohorts in the fishery is another contributing factor. The present reported L_{50} for studied families is generally less than expected and this may be attributed mainly to high fishing pressure, poor habitat quality (Moombe *et al*., 2025) and absence of adult parental lines within extant populations.

Table 11-5: Size at first maturity for indicator/flagship species in the Kafue River during the survey – 98% of the fish sampled were mature, with all the species exhibiting reduced size at first maturity (L_{50}).

Males					Females			
Species name	**L_{50} (mean: SD_mm)**	**95% CI of L_{50}**	**n**	***Sex Ratio***	**L_{50} (mean: SD_mm)**	**95% CI of L_{50}**	**n**	***Sex Ratio***
T. Sparmnii	75±1.46	71.1, 78.9	54	0.52	65±1.30	61.4, 68.6	50	0.48
P. Philander	69±0.77	66.0, 72.0	25	0.52	65±0.95	61.1, 68.9	23	0.48
C. Gariaepinus	350±9.54	291.0, 409.0	10	0.43	347±3.93	325.6, 36.84	13	0.57
C. Maunensis	100±1.10	96.6, 103.4	41	0.31	105±1.42	102.1, 107.9	90	0.69
S. Woosnami	90±3.04	83.3, 96.7	79	0.42	85±2.70	79.8, 90.2	102	0.58
M. Macrolepidotus	137±0.95	133.7, 14.03	31	0.67	137±0.95	132.2, 141.8	15	0.33
S. Intermedius	110±2.06	103.3, 116.7	36	0.48	120±2.06	113.5, 126.5	38	0.52

Display of a mature and breeding female Mormyrid from Kafue River

Display of a mature and breeding female catfish from Kafue River

11.3.1.5 Bioaccumulation of heavy metals and fish health

Whole fish analyses for bioaccumulation of selected heavy metals included Chromium (Cr), Cadmium (Cd), Zinc (Zn), Copper (Cu) Lead (Pb), Cobalt (Co). Results for studied metals indicated concentrations to be below international recommended thresholds, except for copper that had concentrations below detectable levels (Tables 11-6, 7 & 8). *C. ngamensis* had elevated concentration levels of cobalt (Co), suggesting the need for further investigation. Summary of the rest of the fish species analysed are presented in Appendix 11-5. No diseased fish was recorded in the survey.

Table 11-6. Preliminary heavy metal analysis in fish carcases after the spill incidence (MFL, February, 2025)

Aquatic Species	Heavy Metal					
	Cr (mg/Kg)	**Cd** (mg/Kg)	**Zn** (mg/Kg)	**Cu** (mg/Kg)	**Pb** (mg/Kg)	**Co** (mg/Kg)
Bubble Fish	0.00	0.00	8.242	2.461	0.400	0.391
Tilapia spp	0.00	0.054	3.994	13.40	0.011	0.190
Crabs	0.00	0.119	5.098	2.272	0.343	0.414

Table 11-7. Follow-up progressive heavy metal analysis in selected fish (MFL, October, 2025)

Aquatic species	Heavy Metal					
	Cr (mg/Kg)	**Cd** (mg/Kg)	**Zn** (mg/Kg)	**Cu** (mg/Kg)	**Pb** (mg/Kg)	**Co** (mg/Kg)
Bubble Fish (mambashi stream)	0.080	0.024	0.829	-	0.00	0.096
Tilapia sparmanii (Mufuchani bridge)	0.143	0.06	2.335	-	0.00	0.202
Entromius eutaenia (lwangwa bridge)	0.249	0.110	1.562	-	0.00	0.196

Table 11-8. Selected heavy metals profiled for indicator/flagship fish species from the study area (results reported as averages)

Fish Species	Heavy metal						Notes
	Cr (mg/Kg)	**Cd** (mg/Kg)	**Zn** (mg/Kg)	**Cu** (mg/Kg)	**Pb** (mg/Kg)	**Co** (mg/Kg)	
P. philander	0.187	0.011	4.056	0.00	0.346	0.082	Safe for consumption
S. Woosnami	0.095	0.027	1.488	0.00	0.155	0.027	Safe for consumption

R. maunensis	0.052	0.045	3.873	0.00	0.413	0.024	Not Safe for consumption
C. ngamensis	0.079	0.021	2.337	0.00	0.451	0.174	Not Safe for consumption
T. sparmanii	0.154	0.016	2.908	0.00	0.139	0.055	Safe for consumption
S. intermedius	0.052	0.033	1.210	0.00	0.493	0.021	Not Safe for consumption
M. macrolepidotus	0.055	0.017	1.336	0.00	0.517	0.027	Not Safe for consumption

Interpretation of heavy metal toxicity according EU/FAO upper limits

Authority	Heavy metal					
EU/FAO/US-FDA	**Cr** (mg/Kg)	**Cd** (mg/Kg)	**Zn** (mg/Kg)	**Cu** (mg/Kg)	**Pb** (mg/Kg)	**Co** (mg/Kg)
upper limits	0.5	0.1	40-150	2.5	0.3 -0.5	0.04 -0.26
CXS 193 (Code)	-	-	-	-	0.3	-

CONCLUSIONS

As expected, fish species from the Kafue Fishery are responding differently depending on their physiology, habitat preference and foraging types. Low dosages of toxic substances are more impactful compared to a once-off incidence. Considering the latter, as was the case in February 2025, massive loss of fish stocks was experienced, however, fish are able to quickly recover after the event should the toxin be halted. From the study, the following conclusions have been drawn;

i. **Water quality** – Average pH values across the study area were within the acceptable ranges (6.0 – 7.2). Since these results were obtained at the onset of the rain season, it's likely that the pH levels will reduce owing to the large influx of allochthonous material from areas where acid may have sedimented.

ii. **Potential fish for recovery** – while the impact of acid pollution has been fully recognised, the nature as a once-off incidence gives the ichthyofauna biodiversity impetus to rebound. Results of this assessment show the potential of fish species in full reproductive maturity and some spawning. The growth patterns and physical condition of the fish is expected to improve considering that the survey was conducted at the onset of the rain season when fish is thriving on both autochthonous and allochthonous nutrient sources.

iii. **Prolonged reproductive recovery** – though not estimated, reviewed reports and results of this assessment provide evidence of significant fish loss from the acid pollution. Our results demonstrate the current spawning stock biomass (SSB) to be weak and fragile – as most fish have a reduced size at maturity (L_{50}) with nuptials probably from the same cohort/year class. Females are maturing earlier than males across all families studied, an indication of fishery dependent pressures (pollution, overfishing, unbalanced population structure). This shows that adult fish were significantly affected by the pollution event, resulting in new recruits maturing early this year. Lack of adult breeding pairs in a population has serious demographic implications that may influence growth rates, survival rates/offspring quality and genetic diversity/stability. Assuming effective pollution containment, habitat recovery, and temporary fishery closures with effective enforcement to protect early spawners, the system could regain functional reproductive stability within 3 breeding seasons. However, full recovery of age - class structure, genetic diversity, and pre-incident yield potential may take longer up to 5 years if recruitment success is consistent and anthropogenic pressures such as over fishing are properly mitigated. Therefore, this assessment concludes that the Kafue fishery faces significant reproductive instability for at least three years, with the window for intervention being most critical in the first 12-18 months post incident.

iv. **Heavy metal Analysis and human health** - This study suggests low human health risk (HHR) for post incidence consumption of fish from the Kafue fish as selected heavy metal analysed all were below recommended international safe limits (possibly, hazardous quotient values are also expected to be below 1). The sample analysis of aquatic animal mortalities following the incident indicated toxic levels of Heavy metals for aquatic animals e.g. Lead at 8mg/Kg in Bubble fish. The levels were also above the recommended Codex standard limit thus not safe for Human consumption.

The October MFL survey of live fish from the affected areas indicated levels below the Codex Maximum Level and thresholds, thus the fish was safe for human consumption and of no risk to human health. The Analysis of samples collected during this assessment indicated 4 samples above the Maximum Codex Limit. The 4 samples were collected in Mpongwe/Ngabwe portions of the Kafue River. These findings in fish indicate chronic toxicity levels rather than acute. This assessment concludes that there is a very low risk associated with consumption of fish from the affected area. However, there is need for continued aquatic health and food safety surveillance in the affected areas and the domestic market.

PROPOSED REMEDIAL ACTIONS

a. **pH stabilization** – Due to the higher presence of macrophytes in the Lukanga Swamps, these plants could act as sinks for heavy metals and perpetuate lethal concentrations. There is a need for continued sediment remediation to help long-term pH stabilization. Adaptive application of sodium hydroxide/calcium carbonate in key tributaries, coupled with consistent water quality monitoring, to enhance stabilization of water pH for improved biodiversity productivity. pH is an important physicochemical parameter in fisheries as it governs general fish/macroinvertebrate physiology and primary production.

b. **Enhanced in-situ conservation measures** – instigate the mapping, creation and legalization of freshwater protected areas (FPAs)/breeding areas in key/critical biodiversity areas (KBAs) along the Kafue River and its tributaries. These should be long-term restorative and conservation programs tailored at rebuilding stable fisheries stocks, improved community engagement/dialogue, ownership and participation and full participation of mining and other corporate entities in these initiatives.

c. **Fish Restocking**: In-situ restocking programs using flagship species is recommended. In this situation, initiatives such as multitrophic restorative aquaculture can be implemented – where desired fish species are produced under captivity within the river channel to allow free recolonization of the system by the fish.

d. **Stock assessment** – an updated species inventory, extinction status of fish species (IUCN Red List) and annual production is required. Information generated in these studies will help share the management trajectory in the fishery.

e. **Strengthened Co-management institutions and law enforcement**: currently the fishery is grappling with recruitment overfishing that has resulted mainly from low /poor adherence to fisheries regulations. Establishment and/or strengthening community-led conservation programs and promoting stewardship among resource users is recommended. A strengthened fisheries monitoring, control and surveillance (MCS) systems are required to be put in place to ensure responsible fish harvests and consumption.

f. **Ecotoxicological Monitoring**: A comprehensive and long-term ecotoxicological monitoring program is proposed here. While the Kafue River system provides a lifeline for mining industries, sustenance of biodiversity in the ecosystem and human safety need to be prioritised, to ensure equitable ecosystem services. Such initiatives may include consistent water quality monitoring, food fish safety, as well as fauna and flora welfare (timely bioaccumulation analyses).

11.3.2 Impacts on Livestock

11.3.2.1 Situational Analysis for Livestock

Data collected for indigenous ecological knowledge (IEK) through key informant interviews (KII), reviewed rich ecological information on the status and fisheries practices of the Kafue ecosystem. A total of fifteen (15) KII were conducted in fishing camps and villages between Ngabwe and Machiya. Though the fishery was declared closed after the pollution incident, fishing communities have continued fishing, processing and selling of fish. Table 11-7. Summaries the situation analysis of fisheries along the Kafue River.

Table 11-7: Summary of the Livestock situational analysis in the affected area

Parameter	Description
Livestock production practices	The livestock farming in the affected area is stable with traditional farmers.
Livestock population raised by households	74628 (Livestock census 2017/18)
Livestock mortality/health from acid pollution	Responses Percent of Cases N Percent Livestock Mortalities Village chicken 11 37.9% 42.3% Ducks 7 24.1% 26.9% Sheep 3 10.3% 11.5% Broilers 1 3.4% 3.8% Cattle 1 3.4% 3.8% Pigs 1 3.4% 3.8% Goats 4 13.8% 15.4% Rabbits 1 3.4% 3.8% Total 29 100.0% 111.5% Source: SPSS Survey output (MFL report 2025)
Incidence of human deaths	No incidence of human death(s) related to consumption of acid poisoned Livestock has been reported/observed in the affected area.

11.3.2.2 Livestock mortalities

The survey results indicated that there was a number of livestock mortalities in the two (2) districts following the pollution event. The variable "N" is taken as the number of times the respondents indicated the response "yes" to having observed the livestock mortality on their farm. Thus, "N" is the number of cases rather than the number of livestock.[6] To this effect, the results indicated that there was a total of 29 cases of livestock mortalities in the two districts following the pollution event. The table below gives a summary of the livestock mortalities from the four districts.

Table 11-8: Livestock mortalities

		Responses		Percent of Cases
		N	**Percent**	
	Village chicken	11	37.9%	42.3%

Livestock Mortalities	Ducks	7	24.1%	26.9%
	Sheep	3	10.3%	11.5%
	Broilers	1	3.4%	3.8%
	Cattle	1	3.4%	3.8%
	Pigs	1	3.4%	3.8%
	Goats	4	13.8%	15.4%
	Rabbits	1	3.4%	3.8%
	Total	**29**	**100.0%**	**111.5%**

Source: SPSS Survey output

The pollution event appears to have impacted a range of livestock species, with the highest vulnerability observed in village chickens and ducks—likely due to their higher exposure to contaminated water or environments near the tailings site. While the total number of cases (29) may seem moderate, the diversity of livestock affected suggests widespread environmental and economic risk to households dependent on mixed farming systems. Livestock losses compound the socio-economic burden already caused by declines in fisheries and aquaculture, further threatening household food security and income stability.

11.3.2.3 Livestock Pasture

The assessment of how effluent from tailings dam affected livestock pasture across four districts: Kitwe, Kalulushi The pastures assessed include a range of forage crops and grasses that support livestock feeding. Losses were reported as the number of households indicating whether their pasture was affected or not by the pollution.

v. Kitwe District:

- A total of 22 households reported owning livestock pasture.
- Out of these, 5 households (22.7%) reported pasture losses due to pollution.
- Most affected pasture types: Star Grass (3 households) and Maize, Sorghum, Rhodes Grass (2 each).
- Kitwe had the highest relative impact, with nearly a quarter of pasture-owning households affected.

vi. Kalulushi District:

- About 113 households owned pasture, but no reported losses due to pollution.
- This may indicate that the pollution impact was geographically limited

or that Kalulushi pastures were located away from the affected water bodies.

The loss of pasture reduces available feed for livestock, which can lead to poor animal health, productivity, especially for smallholder farmers relying on natural grazing systems. In Kitwe, where pasture losses were reported, households are at risk of secondary livelihood impacts, compounding earlier losses from fish kills and livestock deaths. Pasture degradation also affects long-term land productivity and may require restoration efforts.

11.3.2.4 Losses of Livestock pasture

The survey results indicated that there was a number of households who suffered losses to livestock pasture across the four (4) districts due to the effluent from the tailings dam[4]. The table below provides details on the losses of livestock pasture.

Table 11-9: Livestock pasture losses

			Affected by Pollution		
District			**No**	**Yes**	**Total**
Kitwe	**Livestock Pasture**	Maize	9	2	11
		Sorghum	5	2	7
		Millet	1	0	1
		Rhodes Grass	8	2	10
		Star Grass	4	3	7
		Total	**17**	**5**	**22**
Kalulushi	**Livestock Pasture**	Maize	55		55
		Sorghum	39		39
		Velvet beans	27		27
		Rhodes Grass	21		21
		Star Grass	15		15
		Total	**113**		**113**

Source: SPSS Survey output

11.3.2.5 Bioaccumulation of heavy metals and Livestock Health

Livestock Blood Sample analyses for bioaccumulation of selected heavy metals included Chromium (Cr), Cadmium (Cd), Zinc (Zn), Copper (Cu), Lead (Pb), Cobalt (Co). Results for studied metals indicated concentrations to be below international recommended thresholds.

11.3.2.6. Recommendations on Livestock

a) Heavy metal monitoring of the food chain for livestock should be enhanced to ensure early detection of any elevation, and onset of animal health implications

b) Livestock compartments for comprehensive animal health management in the areas within the vicinity of the Chambishi-Mwambashi-Kafue system for effective surveillance of livestock potentially exposed to elevated heavy metal contamination.

11.3.2.7 Appendices

Appendix 11-6. Description of sampling sites

Appendix 11-7. Descriptive statistics for length and weight of flagship/indicator species considered in the survey.

Appendix 11-8. Summary of fish species covered in the study.

12 RECOMMENDATIONS AND WAY FORWARD

12.1 Surface Water

This section outlines key proposed measures to address water pollution and improve long-term water resource management in the study area. The recommendations are structured into two focus areas: pollution mitigation strategies, monitoring and management.

12.1.1 Pollution mitigation strategies

The following recommendations are made to prevent pollution of surface water sources:

1. The wetland known as New Dam has demonstrated to be effective at removing pollutants from water, both suspended particulates and dissolved metals. It is therefore recommended that the use of wetlands to clean up water be utilised before the effluent is discharged to the environment.
2. There is uncontrolled reclamation of TD 6 in the area. This activity is destroying the function of TD 6 as a Pollution Control Dam as well as generating fine particulates which will be washed into the rivers where it will cause water pollution. This activity needs to be stopped and the facility rehabilitated.
3. There are multiple sources of pollution to Mwambashi and Kafue Rivers. There is a need to take an inventory of pollution sources and their impact on surface water quality.

12.1.2 Monitoring and management

1. It is recommended that follow up monitoring be conducted during the rainy season at strategic points to assess the impact of the rainy season on water quality and especially secondary pollution.
2. The Zambia Bureau of Standards should establish a standard for water quality monitoring to be used by different stakeholders.
3. The government through ZEMA should limit the number of mineral processing facilities in the Mwambashi catchment to prevent further deterioration of the River.

12.2 Groundwater

Based on the findings of this study, the following recommendations are made:

1. Shallow wells should NOT be used as sources of potable water.
2. Given that Kalusale is located within the mining license area, it is recommended to relocate the community to a non-mining area promptly.

3. There is a need to monitor groundwater pollution from the Pollution Control Dam, TD 6. Leachate from TD 6 is expected to be transported through groundwater and will daylight in Chambishi Stream and eventually affect Mwambashi River. Currently, there are no groundwater monitoring boreholes at TD 6. Groundwater monitoring can be conducted by NFCA which is licensed to operate TD 6 as a Pollution Control Dam and/or the company that is reclaiming tailings from the facility for reprocessing to recover copper.

12.3 Soil

The lime application will be done through broadcasting with a tractor and incorporated into the soil using a sub-soiler or disking for potentially concentrated areas. This will allow the effect of the lime throughout the root zone. For areas which were slightly affected, it is proposed that the affected farmers in the community will be given lime according to their affected hectares at the proposed rate and they will apply at any time when they want to grow the crops. This is because most of the areas along the Mwambashi River and Kafue River may not be suitable for use of heavy machinery. Another method to be used in Phase one is the use of plants to extract pollutants from the soil. The general term used for this method is called Phytoremediation. It is proposed that long term tree species including Miombo and Acacia tree species depending on seeds availability can be planted in strategic areas such as around the tailings dam.

Phase Two mainly involves with the crops planting. For short term measures, some short term crops including Vetiver grass, Sunflower, tobacco and Amaranth will be grown by farmers which are known to phyto-extract a number of heavy metals from the soil. After maturity, these crops will be harvested and the residues destroyed so that the contaminants cannot be recycled into the ecosystem. These plants are targeted to be planted in at least 40% of the area.

In the event that interventions proposed in phase one and two do not yield the desired results, such as recording remnants of heavy metals, phase three will be necessary in the restoration program. In phase two, the major intervention proposed is the use of organic acids to immobilise heavy metals that may still be found in the soils above the permissible limits. This intervention is proposed to be implemented as a backup when the soils show some residue metals after the first and second phases in course of the coming rain season. The available chemicals will be explored at the time but it will be a backup. Depending on the outcome of measures in phase one and two, it will even be appropriate to repeat interventions of phase 1 but in a more moderate way.

12.4 Ecology

12.4.1 Recommendations (Vegetation-Specific)

a) Avoid premature restocking or planting in high-metal zones (e.g., CHM-02); prioritize sediment stabilization (e.g., capping, phytostabilization with *Typha* or *Phragmites*) before revegetation.

b) Monitor NDVI trends quarterly to track recovery and detect setbacks during rainy seasons.

c) Integrate community sentinel network with NDVI hotspots to report vegetation dieback or soil discoloration in real time.

d) Use Class 4-5 NDVI thresholds (0.33) as restoration targets for riparian buffer rehabilitation projects.

Immediate action (Q4 2025-2026) is critical to:

a) Stabilize contaminated sediments,

b) Restore riparian buffers,

c) Institutionalize biomonitoring, and

d) Embed transparency in governance.

Long-term resilience depends on integrating scientific rigor, regulatory oversight, and community stewardship.

12.4.2 Community Sentinel Network

Train 15 community ecological monitors (farmers, youth) to document and report:

a) Water discoloration or odors,

b) Livestock illness after watering,

c) Vegetation dieback or fish kills,
via a U-report SMS system managed by ZEMA.

12.5 Agronomy

A key outcome of this assessment is the need for targeted, practical interventions to restore safe and productive agriculture in the affected areas, as outlined below:

- Apply soil amendments like lime and organic matter to stabilize soil pH and enhance fertility.
- Implement crop zoning to prioritise low-uptake crops (e.g., maize, beans, pumpkins) in higher-risk areas.

- Enhance routine monitoring of soils, irrigation water, and food crops to identify emerging contamination risks.
- Offer farmer support and extension services with advice on safe cropping methods and good agricultural practices.
- Implement land-use planning to designate specific zones where agricultural activities should be prohibited due to high contamination or persistent risk.

12.6 Air

Continued monitoring and verification: Implement periodic follow-up ambient air monitoring for gases and acid mist in Kalusale Ward, particularly during periods of high humidity, low wind, or when plant operations change. Integrate air quality monitoring into the broader Environmental Incident Impact Assessment and long-term environmental management plan for the site.

Strengthening source control: Ensure that processes with potential to generate acid mists within the plant are adequately enclosed or isolated and fitted with appropriate extraction and scrubbing systems. Maintain and periodically audit compliance with Environmental Management (Licensing) Regulations SI 112 of 2013 and relevant occupational health requirements under the Occupational Health and Safety Act (No. 36 of 2010).

Community health and communication: Maintain an open grievance and communication mechanism with affected communities to receive, document and respond to any future odour or air-quality complaints. Where necessary, collaborate with health authorities to carry out targeted medical surveillance or health education for residents in the most affected areas.

Integration with remediation and ESIIA outcomes: Use the air-quality findings to complement surface water, groundwater and ecological assessments within the ESIIA, ensuring a holistic understanding of post-incident risks. Incorporate air quality considerations into any remediation, restoration and plant upgrade measures recommended by the ESIIA.

12.7 Social-Economy

The following mitigation measures are proposed:

- Compensation of the incident affected individuals. This should include direct loss of livelihood due to the pollution incident. This should be done by a competent independent and non-partisan body so as to avoid compromise of the process.
- Implementation of corporate social responsibility (CSR) activities on the resilient community. This will ensure to empower the individuals or communities that have lost livelihoods due to the pollution incident.

- Full-scale cleanup and restoration efforts will be implemented in the impacted zones to restore the environment to its pre-contamination condition. This will involve the engagement of a competent and independent organisation to undertake the works.
- The residents who have permanently settled in the pollution control zone of the Mine need to be resettled urgently. Addressing this issue requires a nuanced, transparent and lawful approach that prioritizes verification, dialogue and the development of a clear equitable path forward for all affected parties.

Some Monitoring and Evaluation strategies have also been proposed which included serious and strategically organized community liaison activities, development and implementation of a Grievance Redress Mechanism and logging of any form of community interactions in the engagement register, as well as strict implementation of the highlighted mitigation measures. Ensuring all the affected individuals are compensated accordingly.

12.8 Fisheries and Livestock

a. **pH stabilization** – Due to the higher presence of macrophytes in the Lukanga Swamps, these plants could act as sinks for heavy metals and perpetuate lethal concentrations. There is a need for continued sediment remediation to help long-term pH stabilization. Adaptive application of sodium hydroxide/calcium carbonate in key tributaries, coupled with consistent water quality monitoring, to enhance stabilization of water pH for improved biodiversity productivity. pH is an important physicochemical parameter in fisheries as it governs general fish/macroinvertebrate physiology and primary production.

b. **Enhanced in-situ conservation measures** – instigate the mapping, creation and legalization of freshwater protected areas (FPAs)/breeding areas in key/critical biodiversity areas (KBAs) along the Kafue River and its tributaries. These should be long-term restorative and conservation programs tailored at rebuilding stable fisheries stocks, improved community engagement/dialogue, ownership and participation and full participation of mining and other corporate entities in these initiatives.

c. **Fish Restocking**: In-situ restocking programs using flagship species is recommended. In this situation, initiatives such as multitrophic restorative aquaculture can be implemented – where desired fish species are produced under captivity within the river channel to allow free recolonization of the system by the fish.

d. **Stock assessment** – an updated species inventory, extinction status of fish species (IUCN Red List) and annual production is required. Information generated in these studies will help share the management trajectory in the fishery.

e. **Strengthened co-management institutions and law enforcement**: currently the fishery is grappling with recruitment overfishing that has resulted mainly from low /poor adherence to fisheries regulations. Establishment and/or strengthening community-led conservation programs and promoting stewardship among resource users is recommended. A strengthened fisheries monitoring, control and surveillance (MCS) systems are required to be put in place to ensure responsible fish harvests and consumption.

f. **Ecotoxicological Monitoring**: A comprehensive and long-term ecotoxicological monitoring program is proposed here. While the Kafue River system provides a lifeline for mining industries, sustenance of biodiversity in the ecosystem and human safety need to be prioritised, to ensure equitable ecosystem services. Such initiatives may include consistent water quality monitoring, food fish safety, as well as fauna and flora welfare (timely bioaccumulation analyses).

g. A comprehensive Heavy Metal Residue Monitoring program in feed, livestock and foods of animal origin from the affected area be introduced for animal health, feed and food safety.

h. Long-term response would include establishing and/or strengthening of community-led conservation initiatives, promoting stewardship among resource users and establishing an eco-toxicological monitoring network that provides for synergistic and responsible livestock, Mining and environmental resource usage along the Kafue River system.

13 CONCLUSION

This chapter synthesises the key findings of the Environmental and Social Incident Impact Assessment across all media and disciplines, drawing together evidence on water, groundwater, soil, ecology, agronomy, air quality and socio-economic impacts. The conclusions below reflect measured data and field observations and do not alter the underlying analytical results.

13.1 Surface Water

The historical water quality data monitored by the stakeholders show that the three surface water sources, namely, Chambishi Stream, Mwambashi River and Kafue River, were significantly impacted by the tailings slurry discharged from TD 15 at Sino-Metals. The impact was indicated by low pH, elevated metals and sulphates in the water.

The current analytical results show that the water quality has returned to its pre-incident levels. This may be attributed to the following:

- Dosing of the water with lime and sodium hydroxide at strategic sites in the days immediately following the incident most likely assisted to raise the pH of the water.
- Dilution due to inflow of streams from tributaries and runoff from precipitation

13.2 Ground Water

The groundwater contamination assessment investigated the potential contamination of groundwater. Using EC and the concentration of sulphates in groundwater as pollution indicators, analytical results show that the groundwater in the shallow wells in Kalusale was not affected by the tailings discharge. The shallow wells exhibit low EC below 100 µS/cm which is indicative of uncontaminated groundwater and sulphates below the Method Detection Limit.

This conclusion is also supported by the flow direction of groundwater. The analysis of groundwater flow direction shows that the shallow wells are upstream while the Chambishi Stream is downstream. Therefore, the local flow direction of groundwater is from the direction of the shallow wells to the Chambishi Stream. Consequently, the pollutants in Chambishi Stream cannot be transported upstream to the shallow wells.

The low pH observed in the shallow wells throughout the study area maybe attributed to the decomposition of organic matter in the subsoil which releases carbon dioxide. When the later dissolves in water it forms a weak carbonic acid, and hence the low pH throughout the study area.

Where metals have been detected in groundwater, these are attributed to leaching from the sub-soil rather than from the pollution incident.

13.3 Soil

A comprehensive assessment of heavy metal contamination in soils within the TD 15 tailings dam area and the Chambishi Stream, Mwambashi River, and Kafue River catchments leads to the following systematic conclusions:

- Major Pollution Characteristics and Spatial Differentiation

Soils across the study area have developed a widespread contamination pattern centered on copper (Cu) and cobalt (Co), with the Chambishi Stream catchment being the most significant affected. Contaminants exhibit an 'N'-shaped fluctuating trajectory along the spatial sequence 'TD 15 → Chambishi Stream → Mwambashi River → Kafue River,' indicating that pollutant transport is not a simple linear process but is jointly influenced by complex geochemical processes along the pathway and inputs from additional pollution sources. The contamination peaks observed downstream in the Kafue River cannot be adequately explained by continuous transport from upstream sources alone.

TD 15 is a clear point source for copper, cadmium, and lead in both subsurface and topsoil, resulting from residual materials from the tailings dam. These elements have also accumulated in soils of the Chambishi Stream catchment.

Chambishi Stream catchment shows elevated levels of cadmium, cobalt, nickel, lead, and manganese—elements that were within acceptable limits at the tailings dam. This suggests long-term accumulation likely due to historical exposure to tailings from other mining activities, facilitated by wind and water erosion in the absence of remediation measures at the tailings dam.

Mwambashi River catchment exhibits elevated copper levels, though lower than those in Chambishi and near TD 15. These copper concentrations are comparable to levels in surface and subsurface soils of control samples. Other elements exceeding thresholds include cobalt and nickel, but only in a few localized areas.

The Kafue River stretch shows higher concentrations of cadmium, cobalt, copper, lead, and manganese, some of which are inconsistent with levels in the tailings dam area and the Mwambashi Watershed. This indicates the presence of other contamination sources.

- Pollution Load and Risk Level Assessment

The Pollution Load Index (PLI) for surface soils in most areas is below 1.0, indicating that, from the perspective of integrated multi-heavy-metal effects, widespread systemic contamination has not yet developed, and the overall environmental risk remains within a relatively controllable range. However, the Chambishi Stream catchment and localized sites exhibit severe exceedances of single or multiple heavy metals (e.g., copper concentrations up to 4.5 times the WHO/FAO limit), constituting clear ecological and health risk hotspots that require prioritized management.

- Soil Contamination Extent Assessment

Measured parameters from all sampling points within the incident-affected area were evaluated against international regulatory standards (FAO/WHO) and established regional baseline concentrations. The single-factor contamination index method was used to quantify the exceedance status of each element. The geographical delineation of the affected boundary was achieved using an uncontaminated-node linkage approach, which integrated data from uncontaminated peripheral sampling points with the hydrological network (including mining-affected tributaries) and field observations. The final determination indicates that the affected area is primarily distributed along the Chambishi Stream and its confluence with the Mwambashi River, covering a total area of 5.35 km² (535 hectares).

- Radiological Risk Assessment

No neutron radiation anomalies were detected at TD 15 or surrounding monitoring points, ruling out any significant neutron-induced radioactive contamination risk from mining activities within the assessed area.

13.4 Ecology

The TD 15 tailings dam failure caused significant but geographically confined ecological damage. While emergency interventions have reduced acute risks, legacy contamination in sediments originating from SMLZ tailings, continues to impair benthic and riparian ecosystems.

Vegetation health, as quantified by NDVI, reflects a classic impact–recovery trajectory:

- **January**: Healthy baseline.
- **March**: Severe degradation due to acid-metal slurry.
- **October**: Partial, uneven recovery driven by natural resilience and emergency liming.

13.5 Agronomy

This agronomic assessment shows a nutrient concentration gradient in farmers' fields and crops along the Chambishi-Mwambashi-Kafue corridor, with the most substantial impacts observed in Musakashi (Kalusale, Mukulumpe, Sabina), Luongo in Kitwe, and Machiya in Mpongwe. These areas recorded elevated levels of copper, cobalt, lead, sulphates, and other contaminants that exceed agronomic safety thresholds. In contrast, Milyashi in Luanshya and Chisangwe Peshelungu in Ngabwe exhibited moderate and variable contamination. At the same time, Banamwaze in Itezhi-Tezhi remained largely free from contamination and serves as an important reference site.

The findings also reveal that specific locations, most notably Luongo, show unexpectedly high metal levels even where direct spill influence should be lower. This also applies to Kalusale. This indicates the potential for background contamination from long-term mining activities, industrial emissions, or natural geochemical processes in the Copperbelt, underscoring the importance of broader regional monitoring beyond the immediate spill area.

Crop analysis reveals that leafy vegetables, impwa (African eggplant), onions, and fast-growing biomass species accumulate significantly higher levels of metals compared to maize grain, beans, or pumpkins. This suggests that agriculture can persist in many areas, but crop selection, land-use planning, and safe production practices are crucial to safeguarding food security and public health.

The results show that although contamination is present, many affected areas remain suitable for agriculture if targeted soil remediation, enhanced water and crop monitoring, and continuous technical support for farmers are implemented. These measures will help restore soil function, lower exposure risks, and promote the long-term sustainability of farming communities along the affected corridor.

13.6 Air

The acid mist and ambient gas monitoring survey conducted in Kalusale Ward following the 18th February 2025 TSF failure at Sino-Metals indicates that ambient air quality at the time of sampling complied with ZEMA statutory limits and relevant international exposure guidelines. Measured concentrations of gases were at background levels, and acid mist was not detectable at any sampling point. On the basis of this survey, there is no evidence of significant ongoing air-quality impacts or health risks due to acid mist or the monitored gases in the affected community. Continued periodic monitoring, robust source control at the plant, and effective community engagement are recommended to confirm and sustain these conditions going forward.

13.7 Social-Economy

During the impact assessment study, major social-economic impacts were identified and evaluated as below:

Impacts on livelihood – According to the assessment conducted by the Office of the Copperbelt Provincial Ministry of Agriculture (MOA), only the Kalulushi and Kitwe districts were affected, with a total of 449 individuals impacted. The total compensation amount involved is ZMW 9,780,420.58. Based on the assessment by the Copperbelt Provincial Ministry of Fisheries and Livestock (MF&L), a total of 32 households and farms from Kitwe and Kalulushi were found to have been affected to varying degrees, involving a total compensation amount of ZMW 4,349,015.

Impacts on human health – Public health surveillance data showed minor, short-duration spikes in conditions consistent with potential environmental exposure. However, the interplay of environmental factors, exposure to particulate matter, water and sanitation, and historical exposure in the mining district makes it difficult to ascertain cause and effect. Therefore, it is difficult to link the observed trends to a single event (Tailings spill).

The human health risk assessment suggests that the tailings-dam breach likely contributed to elevated multi-pathway exposure risks, with HM levels in surface water, soils, and food crops driving non-cancer and cancer risks above international benchmarks in Kalusale, Luangwa, and some parts of Kitwe and Mpongwe. Although health risks were also identified in shallow wells, the contamination patterns in these wells could not be directly attributed to the once-off Sino-Metals tailings release. The pronounced spatial variability across environmental media indicates that prevailing risks were influenced by additional factors, including geological inputs and legacy mining contamination. Overall, while the incident contributed to measurable health risks, these results must be interpreted alongside wider environmental and geochemical evidence from the ESSIA rather than in isolation.

Impacts on community infrastructure – Apart from the disruption in water supply at the Nkana Water and Sewerage Company Limited treatment center from the 20th to 24th of February, no other community infrastructure has been known to be affected.

Impacts on social cohesion – No damage to any community infrastructure that can lead disruption to any form of community gathering. No clinics, hospitals, schools, etc. were known to be affected.

Impacts on gender and vulnerable groups – Livestock owners and farmers, fishermen and rural farmers, local residents and households were categorized as the most affected group and their situation became exacerbated if the individuals are women, the aged, of limited educational background or considered to be of unfavorable economic status.

Impacts on resettlement – The squatting situation within the Sino Metals pollution control zone in Kalusale is multi-faceted and dynamic. The population of 338 is not homogeneous but comprises resident squatters. A variety of agricultural tenants and individuals entangled in informal and illegal land markets. The dam failure and compensation process have further complicated the scenario.

13.8 Fisheries and Livestock

Fisheries

As expected, fish species from the Kafue Fishery are responding differently depending on their physiology, habitat preference and foraging types. Low dosages of toxic substances are more impactful compared to a once-off incidence. Considering the latter, as was the case in February 2025, massive loss of fish stocks was experienced. However, fish are able to quickly recover after the event should the toxin be halted. From the study, the following conclusions have been drawn:

a. **Water quality –** Average pH values across the study area were within the acceptable ranges (6.0 – 7.2). Since these results were obtained at the onset of the rain season, it's likely that the pH levels will reduce owing to the large influx of allochthonous material from areas where acid may have sedimented.

b. **Potential fish for recovery** – while the impact of acid pollution has been fully recognised, the nature as a once-off incidence gives the ichthyofauna biodiversity impetus to rebound. Results of this assessment show the potential of fish species in full reproductive maturity and some spawning. The growth patterns and physical condition of the fish is expected to improve considering that the survey was conducted at the onset of the rain season when fish is thriving on both autochthonous and allochthonous nutrient sources.

c. **Prolonged reproductive recovery** – Prolonged reproductive disruption is evident following the acid pollution event from the Sino Metals TD15 spill. Current data show spawning stock biomass (SSB) is critically low and dominated by a single recent cohort, with individuals maturing at significantly smaller sizes (reduced L_{50}). Notably, females are maturing earlier than males across multiple families, a stress response commonly linked to the loss of older age classes due to acute pollution and compounded fishery pressure. The near-absence of mature adult breeders indicates a demographic bottleneck that compromises gamete quality, larval viability, and genetic diversity. While such impacts are severe, tropical freshwater fish in the Kafue River typically exhibit high fecundity and rapid life cycles, with many key species completing maturity within 12–18 months.

d. This assessment concludes that the Kafue fishery will face a negative reproductive instability period lasting around 12-24 months or more, with the 12–18 months following the incident being the most critical window for intervention. If timely and effective remedial measures are taken, this period of negative reproductive instability could be significantly shortened.

e. **Heavy metal toxicity and human health** - This study suggests low human health risk (HHR) for post incidence consumption of fish from the Kafue fish as selected heavy metal analysed all fall below recommended international safe limits (possibly, hazardous quotient values are also expected to be below 1).

Livestock

The pollution event also led to reported livestock mortalities across species. A total of 29 cases were recorded, affecting village chickens (11 cases), ducks (7), goats (4), and other species like sheep and cattle. The impact across different species—especially poultry—suggests environmental contamination affecting both water and forage resources. These losses compound the economic strain already facing affected households.

Pasture

Out of 307 households owning pasture, 21 (6.8%) reported pollution-related losses. Kitwe had the highest relative impact (22.7%), Affected forage types included Rhodes Grass, Maize, and Star Grass. The degradation of pasture further threatens livestock productivity and household resilience, especially among smallholders reliant on natural grazing systems.

Other parameters analyzed were:

- Feed Safety – while the impact of acid pollution has been fully recognized, the extent of the impact on animal feed and food safety is not fully appreciated. It requires constant surveillance for feed and food safety assurance.

- Livestock Productivity – though not estimated, reviewed reports and results of this assessment provide evidence of minimal livestock losses and impact from the acid pollution. Our results demonstrate the low to moderate risk of contamination due to continued presence of contaminants in the affected environment. This shows that livestock production potential is very high in the affected areas.

- The October MFL survey of blood samples of livestock from the affected areas indicated levels below the Codex Maximum Level and thresholds, confirming the findings of the short term low risk associated with this incident. However, heavy metals accumulate overtime, hence the need for continuous monitoring of the feed, livestock and foods of animal origin for safety.

Taken together, the surface water, groundwater, soil, ecological, agronomic, air quality and socio-economic assessments indicate that the TD 15 tailings dam breach at Sino-Metals Leach Zambia Limited has been found to be a relatively significant negative impact on surface water, soils, ecosystems and livelihoods in the Chambishi and Mwambashi catchments.

While the acute phase of the incident has passed and air quality and broad-scale ecological conditions in the Kafue River remain within acceptable bounds, the ESIIA demonstrates that:

- Acidic, sulphate-rich tailings from TD 15 relatively significant impact on water quality in Chambishi Stream and Mwambashi River and disrupted municipal water supply;
- A core area of approximately 5.35 km^2 (535 hectares) exhibits elevated heavy metals in soil and sediments, with associated ecological impairment and agronomic risks;
- Groundwater used by communities is already vulnerable due to existing sanitation and historical mining activities, and shallow wells are not safe as potable sources;
- The incident occurred within a context of adequate law on paper but weak implementation, highlighting systemic gaps in TSF management, enforcement, and emergency preparedness.

If the recommended remediation, monitoring, and governance measures are implemented in full and in a timely manner, there is a realistic prospect of restoring environmental quality, reducing long-term health and livelihood risks, and strengthening the resilience of both ecosystems and communities in the affected corridor.

This ESIIA therefore provides a technical and institutional roadmap for ZEMA, Sino-Metals and other stakeholders to move from emergency response to structured, accountable, and sustainable recovery and to ensure that similar incidents are less likely to occur in future.

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