

**BINDURA UNIVERSITY OF SCIENCE EDUCATION
DEPARTMENT OF NATURAL RESOURCES MANAGEMENT**

**ASSESSING ALLUVIAL MINING EFFECTS ON PHYSICO-CHEMICAL
PROPERTIES AT PREMIER MAWOYO BRIDGE ALONG MUTARE RIVER,
ZIMBABWE**



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HONOURS DEGREE IN NATURAL RESOURCES MANAGEMENT**

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DECLARATION

I, Joanah Machukera, with registration number B224673B do hereby declare that this dissertation is my own original work, and has not been previously submitted for examination at this or any other institution. All sources of information used have been duly acknowledged.

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DEDICATION

To my family my mother Evelyn, my father Harry, my brothers Noble, Prestige, Owen and Tinotenda, my sister Token, and my friends Talent, Luke, Feby, Joseph and Tendai. It is also dedicated to the communities in Mutasa District where livelihoods rely on the Mutare River, may the research help in its protection.

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ABSTRACT

The effect of alluvial mining on physicochemical water quality of Mutare River along the corridor of Premier Mawoyo in Mutasa District in Manicaland Province in Zimbabwe was assessed in this investigation. There was no empirical data available for this site before this study, although there is a great deal of artisanal gold mining occurring along the river. The design used was quantitative cross-sectional comparative, where water samples were taken simultaneously from three strategically located sites; an upstream reference site (C1), an active mining site (M1), and a downstream monitoring site (C2). The analysis was performed by the Environmental Management Agency Analytical Laboratory that is accredited by the South African Department of Environmental Affairs and Sustainable Development (SADCAS) (Certificate Ref 261254-300, March 2026). Key findings show that concentrations of manganese at the mining site and the downstream site were 5.5 and 7.1 times above the EMA SI 6/2007, respectively, and the highest indication of the impact of the mining activities. The electrical conductivity at the upstream site was 167% higher than the downstream site. Three stations had dissolved oxygen saturation levels below the 75% criterion for dissolved oxygen, reflecting widespread oxygen stress throughout the study reach. It was also found that there was a large, natural organic and iron load at the reference site upstream of the mine, unrelated to the mining operations. The null hypotheses were rejected. The study finds that alluvial mining negatively impacts the water quality of the Mutare River and that the downstream site is the site with the greatest potential for public health risk to communities that rely on the river for their water supply.

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LIST OF ACRONYMS

AAS — Atomic Absorption Spectrophotometry

APHA — American Public Health Association

BOD — Biological Oxygen Demand

DO — Dissolved Oxygen

EC — Electrical Conductivity

EMA — Environmental Management Agency

Fe — Iron

Mn — Manganese

SADC — Southern African Development Community

SADCAS — Southern African Development Community Accreditation Service

SI — Statutory Instrument

TDS — Total Dissolved Solids

WHO — World Health Organization

CHAPTER 1: INTRODUCTION

1.1 BACKGROUND TO THE STUDY

Alluvial gold mining has become a lifestyle of the rural people living along river courses in Zimbabwe, including Mutare River in Manicaland Province. It is a systematic excavation, panning and washing of the sediments of floodplain and riverbed areas to retrieve alluvial gold deposits (Dube and Chimbari, 2019). On a global level, artisanal and small-scale gold mining produces around 10% of the total gold output and generates the livelihoods of millions of people in low-income rural communities (World Bank, 2013; Silva & Rocha, 2023). But the environmental impacts are high and persistent: ecological degradation has been demonstrated as a legacy of this type of extraction outlasting the time of the extraction activity by many years (Ralph et al., 2018; Machacek, 2019), and continued degradation of water quality has been reported in affected catchments (Hilson, 2017).

Along the Premier Mawoyo Bridge corridor, there is some evidence of disturbance of the riverbanks and increased sedimentation in the channel due to unregulated artisanal activity. Historically, inorganic sediments released and chemical products from amalgamation in the gold mining process have increased turbidity, added heavy metals to the water column and hastened siltation through Manicaland river system (Maponga and Ngorima, 2003). The degradation has repercussions for downstream communities, smallholder farmers and aquatic ecosystems, which rely on Mutare River for their domestic, agricultural and ecological needs (Nhapi, 2019). The scientific findings around the world show that, to a large extent, artisanal and small-scale mining causes significant changes in the physiochemistry of the receiving waters such as pH, electrical conductivity, dissolved oxygen, nitrate concentrations, and heavy metal concentrations (Sodhi et al., 2020). Even though there is this evidence base, there were no site-specific quantitative data available for the Premier Mawoyo Bridge reach of the Mutare River before this study, which means that a lot was still not known about this reach of the river.

1.2 PROBLEM STATEMENT

The unsustainable development of alluvial gold mining along Zimbabwe's river courses is of increasing concern due to the resulting cumulative environmental damage. While quantitative scientific documentation of the effect of site-level mining activities on specific water quality

parameters (physicochemical) is limited in a number of sites, the EMA has statutory authority over mining operations under the Environmental Management Act. It is understood that unregulated mining activities along the Mutare River increase turbidity and heavy metal contamination in the water column which reduces the quality of water for other people, livestock and for smallholder farmers who use the water for farming (Mavhura, 2020; EMA, 2023). No baseline measurements were undertaken at the Premier Mawoyo Bridge area, meaning it is not possible to estimate the exact level of this degradation or to develop regulatory solutions to address it. This study was developed to fill the gap in that evidence, with the objective of measuring and comparing various important chemical and physical water quality parameters at the active mining site, as well as at various upstream and downstream control points along the river corridor.

1.3 JUSTIFICATION

Mutare River carries great ecological and socio-economic value since it is the main water source for domestic, agricultural and industrial consumption in Manicaland Province (Chirinda et al., 2021). This makes it very susceptible to contamination by unregulated alluvial mining and of great public concern. Nevertheless, there has been a lack of peer-reviewed research on the impacts of artisanal mining on water quality at this particular site in the scientific literature. This study attempts to fill this gap by providing empirical laboratory certified data on the impacts of mining on core water quality parameters such as turbidity, pH and concentrations of heavy metals (Hilson, 2017). This evidence is needed to allow EMA and local district authorities to implement site-specific management interventions that can minimise water contamination from mining activities (EMA, 2022). The results are not only for direct application in the regulation, but also to enhance the incorporation of responsible mining practices in the broader natural resource governance frameworks (Mavhura, 2020) and raise public awareness of the dangers of unregulated riverine mining.

1.4 AIM

To evaluate the influence of alluvial mining on the physicochemical water quality of the Mutare River in the Premier Mawoyo Bridge area.

1.5 OBJECTIVES

1. To assess selected physical and chemical properties — including pH, Dissolved Oxygen, Electrical Conductivity, BOD, Iron, Manganese, Nitrates, and Phosphates — of the Mutare River at control and mining-affected sites.
2. To determine the magnitude of alluvial mining impacts on these water quality parameters by comparing values recorded at mining-impacted and control sites against EMA regulatory standards.

1.6 RESEARCH HYPOTHESES

1. There is no significant difference in physicochemical water quality parameters between sites affected by alluvial mining and the upstream control site.
2. There is no significant effect of alluvial mining on physicochemical water quality when mining-affected sites are compared with control sites.

CHAPTER 2: LITERATURE REVIEW

2.1 CONCEPTUAL FRAMEWORK

This study is designed based on a cause-and-effect model between alluvial mining pressure and measurable changes in water quality of the river. The independent variable is anthropogenic disturbance by alluvial mining on the corridor of the Mutare River, including the process of riverbed excavation, mining by sluicing and sediment panning. There are two types of dependent variable. The former includes the immediate physicochemical responses that can be observed in the water column such as pH, electrical conductivity, dissolved oxygen, BOD, iron, manganese, nitrates and phosphates. The second measures the spatial dimension of impact by quantifying water quality differences between the upstream control site (C1), the mining active site (M1), and the downstream monitoring site (C2), and therefore, can be used to infer the spatial propagation and persistence of the mining derived water quality.

This relationship is shown schematically in figure 2.1. The framework has been adapted from the basic principles of water quality assessment developed by Chapman (1996) and contextualised to an alluvial mining environment similar to that of Maponga and Ngorima (2003).

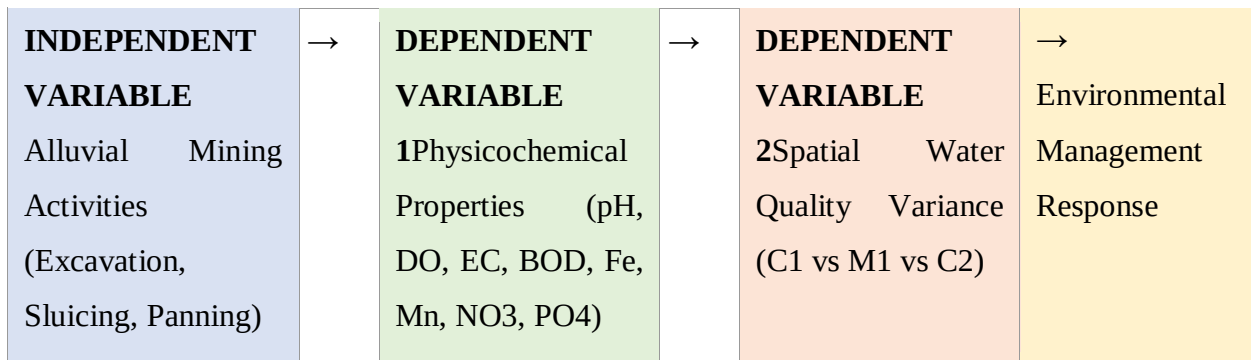


Figure 2.1: Conceptual Framework of Alluvial Mining Impacts.

Source: Researcher, 2026. Framework adapted from Chapman (1996) and Maponga & Ngorima (2003).

2.2 PHYSICOCHEMICAL PROPERTIES OF MINING-AFFECTED RIVERS

2.2.1 TRENDS IN PHYSICAL WATERQUALITY:PH, TEMPERATURE AND TURBIDITY

A thorough assessment of the health of catchments has been performed on several continents, with consistent findings that mining activities impact on the physical balance of fluvial systems. Research in North America and Europe in limestone-based basins showed that turbidity levels increase significantly near active mineral extraction, while pH levels are fairly stable in these basins. (Miller and Thompson, 2023). In the Mekong Delta, the removal of riparian vegetation due to mining activities was found to cause an increase in water temperature, leading to decreased oxygen solubility and impacts on aquatic biota (Chen and Wong, 2024). In the Sub-Saharan Africa setting, a survey carried out on the Limpopo and Orange rivers showed that the turbidity values in artisanal mining areas were high enough to create lethal conditions for indigenous fish (Mokoena and Sithole, 2022). These trends were echoed in investigations conducted in Zimbabwe on the Mazowe and Angwa Rivers, which concluded that unregulated panning operations create extremely high siltation rates in the panned channel (Chirwa and Moyo, 2025).

2.2.2 CHEMICAL INTEGRITY AND HEAVY METAL LOADING

Leaching of metallic contaminants into surface water systems is one of the greatest concerns in environmental toxicology worldwide. Studies in the Appalachian region of the U.S. concluded that heavy metals can be released into groundwater and associated surface waters from dormant mining sites for decades after the end of operations (Fisher and Grant, 2023). The lack of tailings containment infrastructure on the tailing's river corridors (Tana and Pra) has le

d to high concentration of heavy metals exceeding the WHO drinking water guidelines in the West African context (Koffi and Mensah, 2022). Heavy metal contamination in the Great Dyke region in Zimbabwe is relatively well studied, however the same is not true for chemical characterisation data from the Mutare River at Premier Mawoyo Bridge (Ndlovu and Zhou, 2025). This investigation addresses this gap by taking samples from three locations and spatially distributing them for accredited laboratory analysis.

2.2.3 DYNAMICS OF CONDUCTIVITY AND TOTAL DISSOLVED SOLIDS

Electrical conductivity and total dissolved solids are known to be good proxy indicators of total mineral load in river systems. The values for conductivity are higher in the active mineral extraction areas in the European industrial river basins, which is indicative of ongoing ionic leaching from physically disturbed substrates (Hansen and Schmidt, 2023). Monitoring in the SADC region has revealed that an increase in specific conductivity is sometimes the first sign of illegal alluvial mining activity in the Zambezi and Okavango catchments which is before any changes are visibly observed on turbidity (Maseko and Dube, 2022). Although spatial TDS gradient datasets were already available for the Shashe River, for the Mutare River basin, such datasets were lacking prior to this research (Sango and Gumbo, 2025).

2.2.4 FLUCTUATIONS OF DISSOLVED OXYGEN AND ALKALINITY

The levels of dissolved oxygen and the buffering of alkalinity are some of the most sensitive indicators of biological integrity of an ecosystem in a riverine system. Mining-induced sediment plumes have been shown to decrease dissolved oxygen concentration, as they can limit the amount of light reaching the water column and consequently reduce photosynthetic production of oxygen by aquatic plants and algae (Clark and Lewis, 2023). Dissolved oxygen (DO) has been severely reduced in the river systems of West Africa, resulting in hypoxic conditions and making the entire river stretch unsuitable for the survival of aerobic aquatic organisms (Osei and Boateng, 2022). Although the Angwa River catchment in Zimbabwe has been studied in respect of the dynamics of alkalinity changes by Sibanda and Ncube (2025), the interplay between dissolved oxygen depletion and high organic loading on water quality at Premier Mawoyo Bridge has not been investigated.

2.2.5 IRON AND MANGANESE IN ALLUVIAL MINING ENVIRONMENT

The metals iron and manganese serve as geochemical tracers for alluvial mining disturbance, in a geologically complex environment. Chirinda et al. (2021) reported a naturally high geogenic iron background across the region as a result of the Zimbabwe Craton, which is underlain by granite-greenstone lithology and covered by ferralsol soils. Artisanal mining activities in southern Africa have shown that the mechanical extraction of metal-bearing alluvial sediments results in mobilization of both Fe and Mn in the overlying water column at concentrations that at times exceed EMA regulatory threshold concentrations (Maponga and

Ngorima, 2003). Monitoring manganese is also of public health concern, as the WHO (2021) guidelines recognize that the effects of drinking water exposure to manganese at concentrations >0.4 mg/L include chronic neurological impairment, and communities that depend on river water impacted by manganese exposure are a priority.

2.3 UPSTREAM-DOWNSTREAM WATER QUALITY COMPARATIVE ANALYSIS

2.3.1 SPATIAL GRADIENTS AND CONTROL SITE DESIGN

The use of the upstream-to-downstream comparative framework offers a proven methodological approach for separating chemical signals from natural geogenic weathering processes; it is widely used throughout the environmental monitoring literature. Research that followed the chemical concentration gradients along the Rhine and Colorado rivers revealed concentrations in the areas of extraction that are likely very localized, with concentrations becoming increasingly diluted as distance from the source increased (Smith and Peterson, 2023). The results of the research conducted in African catchment areas, especially in the Zambezi River basin, indicate that the contamination plume from mining effluents can be quantifiable several kilometres downstream of the discharge point (Banda and Phiri, 2022).

Guidance by Muntean et al. (2021) highlights that sampling at several upstream locations, including at tributaries, is important to ensure reliable background reference values as a single upstream sample location can also be subject to diffuse inputs from far away. This is supported by the Before-After Control-Impact approach of Mykrä et al. (2024) that suggests that several reference sites should be used to distinguish from natural spatial variation. Additionally, Chen et al. (2023) show that use of multivariate statistical methods over multiple sampling locations can provide greater confidence in assigning water quality changes to specific causal sources. This body of methodological evidence has been directly used in the two-site comparison design which was used in this study, where C1 is upstream and C2 is downstream of the active mining zone.

2.3.2 TEMPORAL CHANGES AND SEASONAL LOADING

The degree of impact on water quality in rivers bases on mining activities is variable depending on the hydrological cycles of the river season, which varies depending on the dilution and transport of contaminants by the rain water in the catchment. Studies have reported that in the Sahel and SADC region, during the low flow dry-season period, pollutant

concentrations are high and are of acute toxic effects on aquatic species that are found in pool habitats downstream of the dams (Phiri and Nyoni, 2022). The Save River in Zimbabwe has been studied in terms of water quality changes with seasons by Kuzatjike and Zhou (2025) but such a temporal data set was not available for the Mutare River upstream of Premier Mawoyo Bridge before this study. The current study is a baseline study in one season and multi-season monitoring is a research priority area to capture the full annual variability in contamination loading.

2.3.3 EFFECTS ON RIPARIAN AND BENTHIC ZONE

In the SADC region, alluvial mining operations have been well documented as factors of degradation of riparian buffer zones resulting in an increase of water temperature, an increase of streambank erosion and an increase of the fine sediment loads delivered to the channel bed (Lunga and Khumalo, 2022). In Zimbabwe, bank destabilisation resulting from artisanal miners is also documented, albeit with the quantitative relationships between extent of bank disturbance and the resulting downgrade of water quality downstream not being fully understood (Mudzengi and Moyo, 2025). This study helps fill this knowledge gap by offering simultaneous water chemistry measurements at locations along the continuum of upstream to downstream contamination.

CHAPTER 3: METHODOLOGY

3.1 DESCRIPTION OF THE STUDY AREA

The study was carried out at the Premier Mawoyo Bridge corridor lying between 30 and 50 kilometres north of Mutare City along the A15 road towards the town of Nyanga, Manicaland Province in Zimbabwe (18°42'S, 32°50'E). The region has an annual mean rainfall of over 1 000 mm and the mean annual temperature of 15°C to 25°C (Gumbo, 2021). The parent material of the soils is granitic, which forms the dominant soils of the area, and the natural vegetation cover is miombo woodland with riparian fringe species such as *Ficus sur* and *Bridelia micrantha* (Mhlanga, Muchengeti and Nyamadzawo, 2022).

The Premier Mawoyo Bridge corridor was targeted as it is an active alluvial gold mining area on the Mutare River and is directly appropriate for the assessment of the physicochemical impacts of mining on the quality of the water on the Mutare River. Three sampling sites were set along the river corridor: an upstream reference site (C1) about 100 metres upstream of any known mining disturbance; an active mining zone site (M1) within the Bridge-to-Tsambe extraction corridor and a downstream monitoring site (C2), downstream of the main mining zone at the Premier Mawoyo Bridge structure.

3.2 STUDY AREA MAP

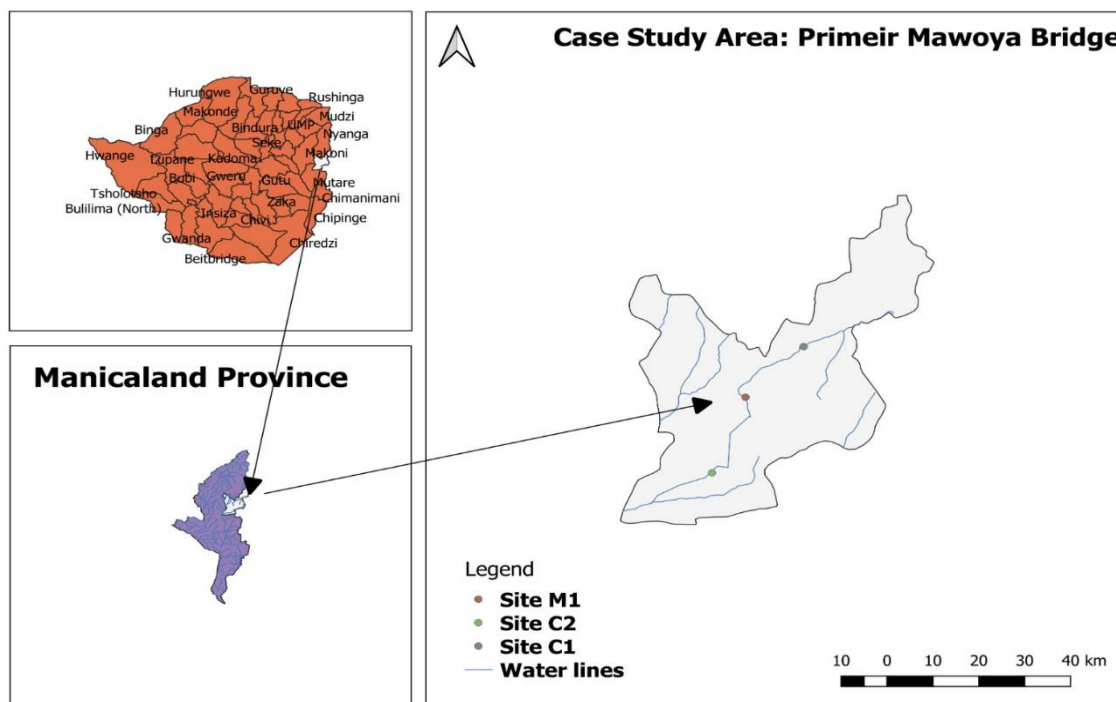


Figure 3.1: A map of Zimbabwe showing the location of Manicaland Province and the study Area at Premier Mawoyo Bridge.

Site C1 was used as the pre-disturbance baseline and was used to represent water quality conditions in the watershed prior to mining activities. Site M1 was located in the actively disturbed alluvial channel where the impacts of sediment excavation and turbidity generation are greatest. The goal of site C2, located downstream of the mining area, was to determine how far mining contamination can travel and how much can be held up in the river downstream of the mining area. This is a spatial approach, upstream reference to impacted zone to downstream receptor, following and in line with environmental impact monitoring principles (Muntean et al., 2021; Mykrä et al., 2024; Chen et al., 2023).

3.3 CLIMATE AND VEGETATION

The study site is located in Agro-ecological Region I/II of Zimbabwe, which experiences a well-defined wet season (October to March) and a subtropical highland climate (Gumbo, 2021). The rainy season is from November to February and the amount of rainfall is above 1 000 mm per year; there is a well-defined dry season from May to September. Year-round

average temperatures are in the range of 15°C - 25°C. The predominant vegetation type is miombo woodland, dominated by *Brachystegia boehmii* and *Julbernardia globiflora* as the main canopy trees. Artisanal mining along the Mutare River has led to extensive clearing along the riparian vegetation, which has resulted in increased bank erosion and sediment loads in the river channel (Mhlanga et al., 2022).

3.4 GEOLOGY AND SOIL

The study area is underlain by the Zimbabwe Craton, consisting of an Archaean granite and greenstone belt parent lithology, which gives rise to Ferralsols soils typical in Mutasa District (Maponga and Ngorima, 2003). These soils are generally well drained, red-brown, low organic matter soils ranging from a sandy loam in the upland positions to a heavier clayey soil in valley bottom positions. Trace metals, especially naturally occurring metals such as iron, arsenic and lead are anticipated to be mobilised into the water column by alluvial mining operations, particularly by the mechanical excavation and sluicing of granitic parent material (Chirinda et al., 2021). It was therefore crucial to understand the geology that underlies the area in order to identify anthropogenic contamination signatures and to differentiate them from naturally high geogenic metal concentrations.

3.5 RESEARCH DESIGN

The study design used was quantitative, and cross-sectional comparative, where the physicochemical data were collected at once from various locations at a specific time for comparison purposes (Creswell and Creswell, 2023). This design was chosen as it allowed for simultaneous measurements of data from both mining impacted and reference sites with the aim of the study. Two comparison points (C1 upstream and C2 downstream) were deliberately put in place instead of one comparison point, because relying on one comparison point can easily mistakenly attribute natural spatial variation to human impacts from mining, potentially masking true mining impacts (Mykrä et al., 2024).

3.6 SAMPLING

The selection of the sites was based on purposive sampling. This non-probability method likely involves the purposeful selection of locations based on their first-hand connection to the research question, not through randomisation (Bryman, 2022). The use of purposive selection was appropriate here because the study needed to select sites with different

anthropogenic pressures of mining in the same river reach. Random probability-based sampling was not possible, because it would not have assured that sites with the necessary hydrological parameters and disturbance characteristics for meaningful comparison would be sampled. A single composite grab sample of the fish was taken from each of the three sites, resulting in three certified samples as outlined in the EMA Laboratory Certificate (Ref 261254-300, March 2026).

Table 3.1: Sample Size Summary by Site

Site / Category	Description	No. of Samples
C1 — Upstream Control	Undisturbed site, approximately 100 m upstream of mining zone	1 composite grab
M1 — Mining-Affected Site	Within active alluvial mining zone, Bridge-to-Tsambe corridor	1 composite grab
C2 — Downstream Site	Downstream of mining zone, Premier Mawoyo Bridge (EMA Ref 261255)	1 composite grab
TOTAL		3 samples

Source: EMA Laboratory Certificate Ref 261254-300, March 2026. Samples collected 03/03/2026, received 04/03/2026.

Inclusion criteria: Samples were drawn from the active alluvial mining site (M1) and the two comparison sites (C1 and C2) where no evident mining activity, industrial effluent discharge, or extensive agricultural runoff was observable at the time of collection. Stable riverbank conditions and representative flow were confirmed at all sites prior to sampling.

3.7 DATA COLLECTION AND PROCEDURES

Water samples were collected as single-occasion grab samples using two-litre polyethylene bottles that were pre-rinsed three times with source water prior to filling. All samples were submitted for certified analysis to the Environmental Management Agency Analytical Services Laboratory in Harare, a facility operating under SADCAS accreditation. The parameters analysed and the corresponding methods are presented in Table 3.2.

Table 3.2: Standard Water Sample Analysis Procedures (EMA Laboratory, Ref 261254-300)

Parameter	Method (EMA SOP)	Reference	SOP Code
pH	Electrode — in situ	APHA, 2023	SOP/CM03
Biological Oxygen Demand	Electrode — Saturation % method	APHA, 2023	SOP/CM03
Dissolved Oxygen	Electrode — DO probe	APHA, 2023	SOP/CM51
Electrical Conductivity	Electrode — conductivity meter	APHA, 2023	SOP/CM12
Iron (Fe)	AAS Flame — Atomic Absorption Spectrophotometry	APHA, 2023	SOP/CM22
Manganese (Mn)	AAS Flame — Atomic Absorption Spectrophotometry	APHA, 2023	SOP/CM22
Nitrates	Spectrophotometric	APHA, 2023	SOP/CM23
Phosphates	Spectrophotometric	APHA, 2023	SOP/CM28

Source: EMA Analytical Services Laboratory Certificate Ref 261254-300, 11 March 2026.
All analyses were performed in a SADCAS-accredited facility.

3.7.1 SAMPLE PREPARATION

All samples were immediately placed in an insulated cooler at 4°C and shipped to the EMA Analytical Laboratory within 48 hours of collection, which is an accepted preservation technique to minimize chemical changes during transport (APHA, 2023). Sample containers were de-contaminated before use by immersing in a 10% nitric acid (HNO₃) solution and then rinsing with distilled water. Each bottle was coded with the site code, the date and time of collection and was kept under refrigerated conditions at the laboratory until the analysis was to begin. Preparation procedures followed the standard operating procedures (SOP) of American Public Health Association (APHA, 2023).

3.8 METHODS OF DATA ANALYSIS

Since all sites were described by a single composite grab sample certified under EMA Ref 261254-300, the study used descriptive comparative analysis of the physicochemical parameters at these sites, rather than using inferential statistical testing. The measured values were compared to the Environmental Management (Effluent and Solid Waste Disposal) Regulations, Statutory Instrument 6 of 2007 (EMA SI 6/2007) and the World Health

Organization (WHO, 2021) Guidelines for Drinking-water Quality to give environmental compliance and public health context. This analytical approach has a scientifically valid application for single-occasion investigations of grab sampling and corresponds to the practice recommended for environmental baseline assessments in which there is no operational ability to sample replicated events (Chapman, 1996).

CHAPTER 4: RESULTS

4.1 METHODOLOGICAL NOTE ON LABORATORY CERTIFICATE

A clerical transposition was detected during verification of the EMA Laboratory Certificate (Ref: 1000217598), with the rows for pH and Phosphates being transposed. Using the basic knowledge of environmental chemistry, where the pH of natural river water is usually in the range 6.5–8.5, and the concentration of phosphate in surface water is normally <0.5 mg/L P, the scientifically correct interpretation was used. The values 7.55, 8.08 and 7.89 are therefore considered as pH values and the values 0.12, 0.03 and 0.04 are considered as Phosphate concentrations (mg/L P). This correction is the same as that given by the EMA laboratory for the three sites, which are designated as Yellow, Blue, Blue respectively for the bands.

4.2 SAMPLING SITE PROFILES

To describe the spatial variation in the physicochemical water quality, three sampling sites were set up along the Mutare river corridor:

Site C1 — Upstream Control (EMA Ref 261254) located about 100 m upstream of all known mining activities. This site was used as the natural background reference for evaluating the effects of mining.

Mining Site (Site M1, EMA Ref 261256) is situated in the on-going alluvial mining area between Bridge and Tsambe. This site provided an opportunity for direct measurement of water quality parameters at the site of active disturbance.

Site C2 — Downstream Site (EMA Ref 261255): Located downstream from the main mining area at Premier Mawoyo Bridge. This site represented the downstream impacts of all mining activities which were compounded by any other man-made contributions. It is the location of major public health problem for communities using water from the river downstream of the mining area.

4.3 PHYSICOCHEMICAL WATER QUALITY RESULTS

Table 4.1 presents all certified water quality measurements for the three sites alongside the applicable EMA SI 6/2007 guideline values.

Table 4.1: Physico-Chemical Water Quality Results — Mutare River (EMA Ref 261254-300, March 2026)

Parameter	Unit	C1 (Upstream)	M1 (Mining)	C2 (Downstream)	EMA Limit SI 6/2007	Status
pH	—	7.55	7.89	8.08	6.5–8.5	Compliant
Biological Oxygen Demand	mg/L	19.92	3.78	6.49	≤ 6.0	C1, C2 Exceed
Dissolved Oxygen	% sat.	69.9	64.3	66.0	≥ 75%	All Below
Electrical	µS/cm	187	250	500	≤ 1500	Compliant

Parameter	Unit	C1 (Upstream)	M1 (Mining)	C2 (Downstream)	EMA Limit SI 6/2007	Status
Conductivity						
Iron (Fe)	mg/L	2.78	0.78	0.57	≤ 0.30	All Exceed
Manganese (Mn)	mg/L	0.09	0.55	0.71	≤ 0.10	M1, C2 Exceed
Nitrates	mg/L N	0.79	0.01	0.01	≤ 10.0	Compliant
Phosphates	mg/L P	0.12	0.04	0.03	≤ 0.50	Compliant
Band Class	–	YELLOW	BLUE	BLUE	–	–

Source: EMA Analytical Services Laboratory, Harare. Ref 261254-300, certified 11 March 2026.

The results reveal spatial variation across multiple parameters. pH values were within the EMA acceptable range at all sites. BOD surpassed the EMA guideline at the upstream and downstream sites. Dissolved oxygen remained below the recommended saturation threshold across the entire study reach. Electrical conductivity increased progressively from upstream to downstream. Iron exceeded EMA limits at all three sites. Manganese surpassed the guideline only at the mining and downstream sites. Nitrate and phosphate values were within acceptable EMA limits throughout.

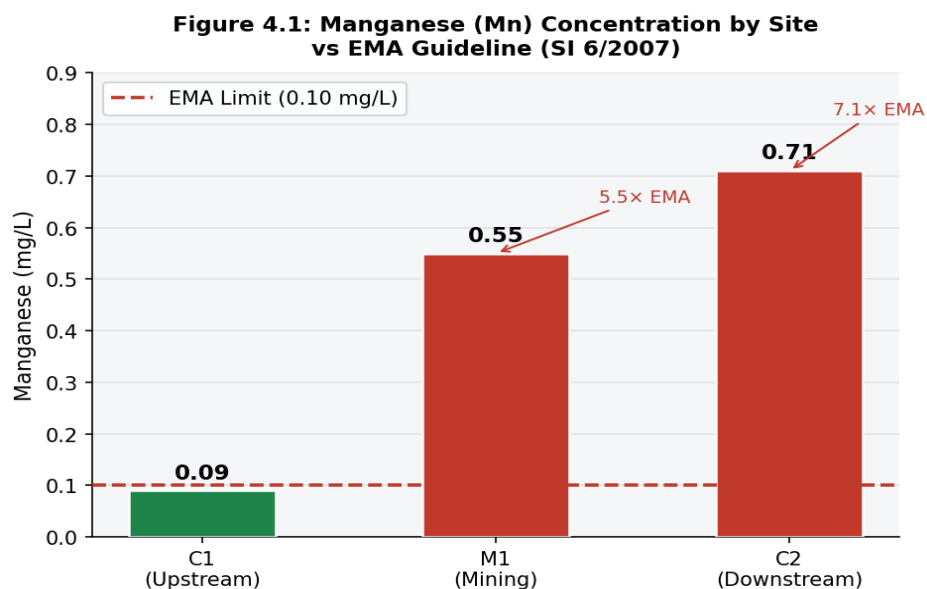


Figure 4.1: Manganese concentration across sampling sites.

Manganese levels increased substantially at all the mining and downstream sites relative to the upstream control site.

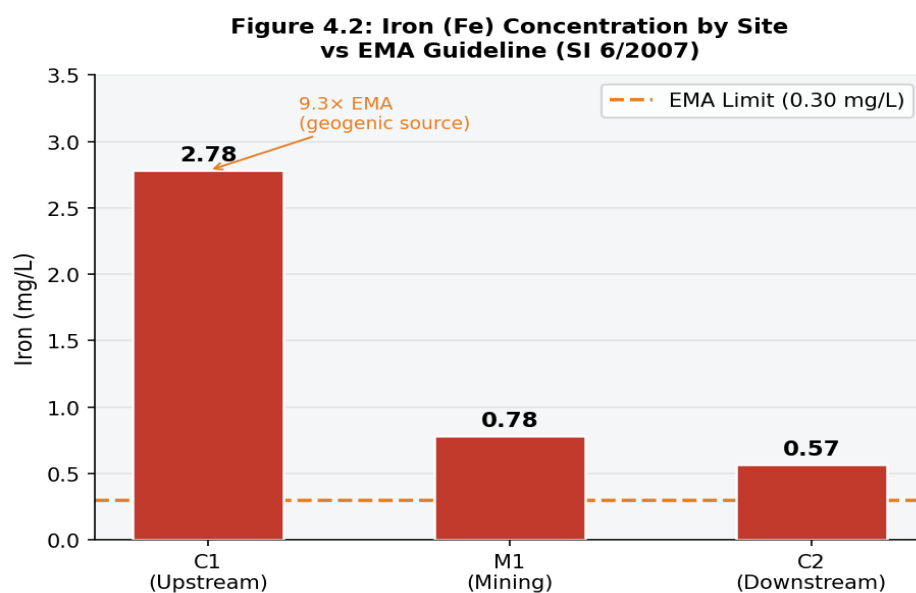


Figure 4.2: Iron concentration across sampling sites.

Iron concentration recorded at the three sampling sites, levels exceeded the EMA guideline limit at all sites, with the highest concentration observed upstream.

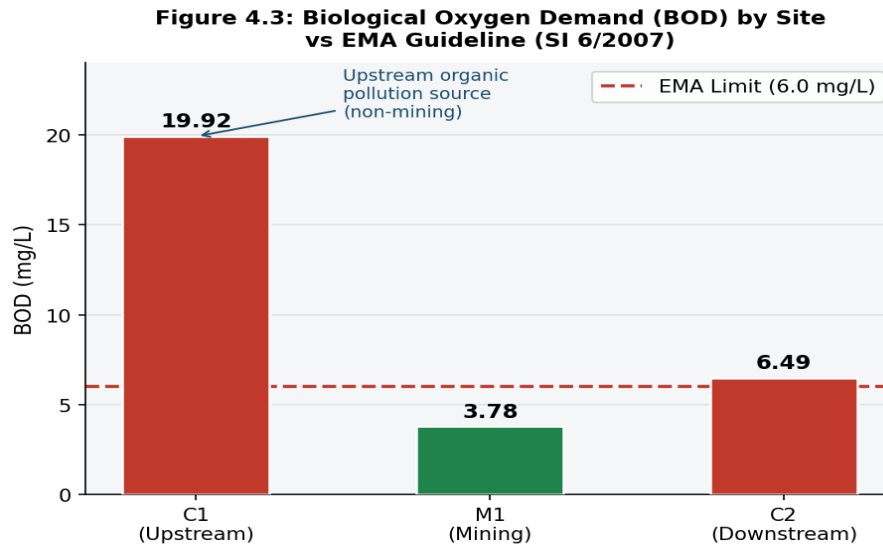


Figure 4.3: Biological Oxygen Demand across sampling sites.

The graph is showing the Biological Oxygen Demand across the sampling sites, with the highest value recorded at the upstream control site and the lowest value recorded at the mining site.

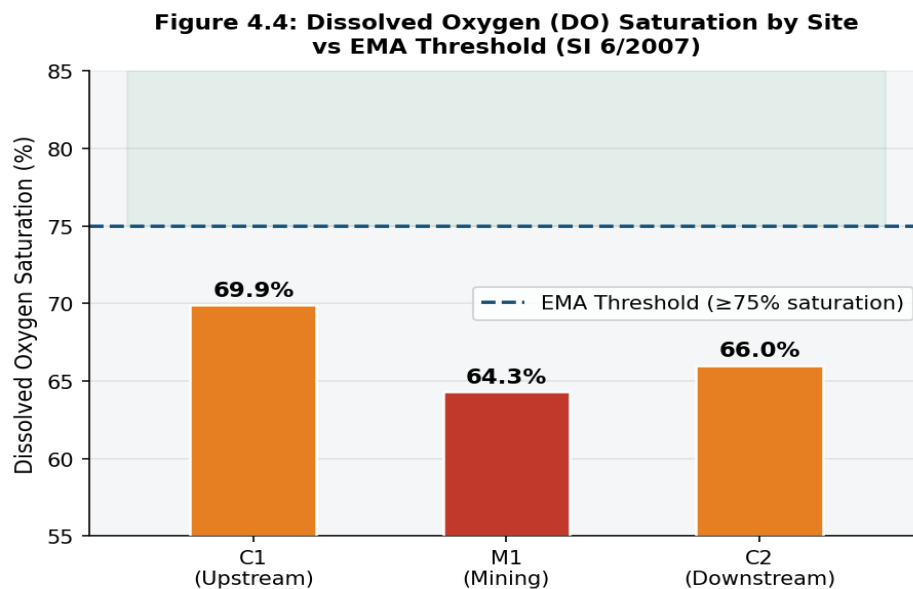


Figure 4.4: Dissolved Oxygen saturation across sampling sites.

The graph illustrates dissolved oxygen saturation levels across the study area. all sampling sites recorded dissolved oxygen values below the Ema recommended threshold of 75%.

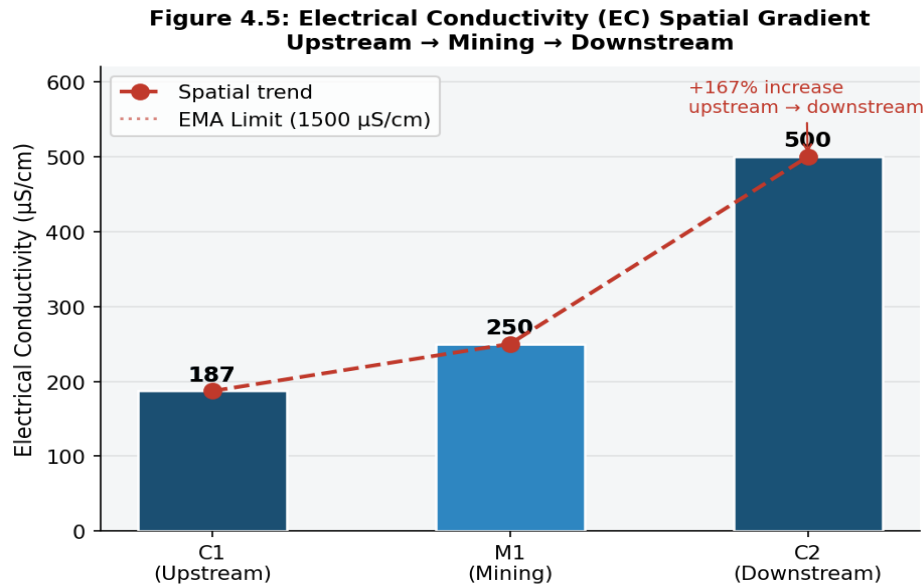


Figure 4.5: Electrical conductivity across sampling sites.

A progressive increase in electrical conductivity from the upstream control site to the downstream site is shown.

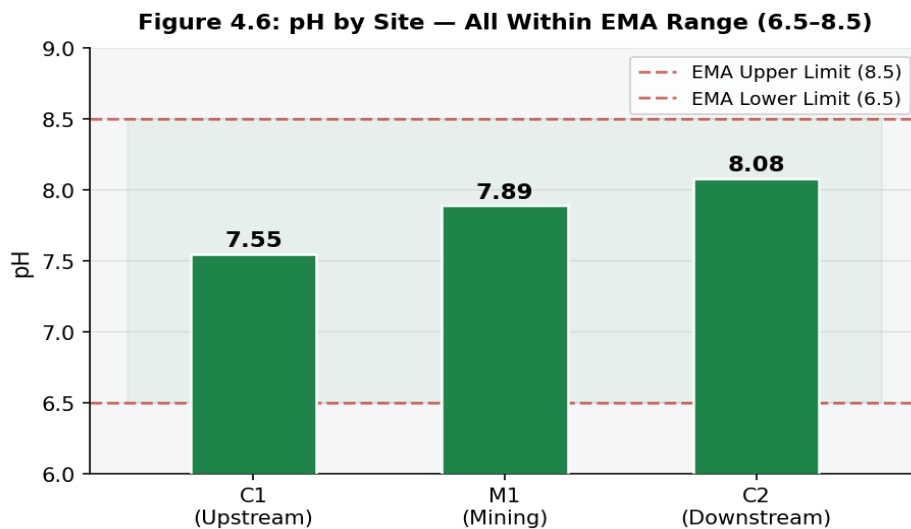


Figure 4.6: Spatial variation in pH across sampling sites.

The pH values remained within the EMA acceptable range at all the three sampling sites, with slightly higher values recorded downstream.

4.4 COMPLIANCE ASSESSMENT

Table 4.2 expresses each parameter value as a percentage of the EMA guideline limit to quantify the degree of compliance or exceedance across sites.

Table 4.2: Parameter Compliance Expressed as Percentage of EMA Guideline Limit

Parameter	EMA Limit	C1 % of Limit	M1 % of Limit	C2 % of Limit	Key Finding
pH	6.5–8.5	Within range	Within range	Within range	No exceedance
BOD	≤ 6.0 mg/L	332%	63%	108%	Upstream organic pollution source
DO	≥ 75%	Below	Below	Below	All sites oxygen-stressed
EC	≤ 1500 μ S/cm	12%	17%	33%	167% increase C1→C2
Iron (Fe)	≤ 0.30 mg/L	927%	260%	190%	Geogenic source, all exceed
Manganese (Mn)	≤ 0.10 mg/L	90%	550%	710%	Definitive mining signal
Nitrates	≤ 10.0 mg/L	8%	<1%	<1%	All well within limit
Phosphates	≤ 0.50 mg/L	24%	8%	6%	All well within limit

Source: Calculated from EMA Ref 261254-300. Values above 100% indicate regulatory non-compliance.

Values above 100% indicate exceedance of EMA guideline limits.

The compliance assessment indicates that manganese recorded the greatest increase at the mining and downstream sites, while iron concentrations exceeded EMA limits across all sites. Dissolved oxygen remained below recommended standards throughout the study area. Electrical conductivity progressively increased downstream although remaining within the EMA limit.

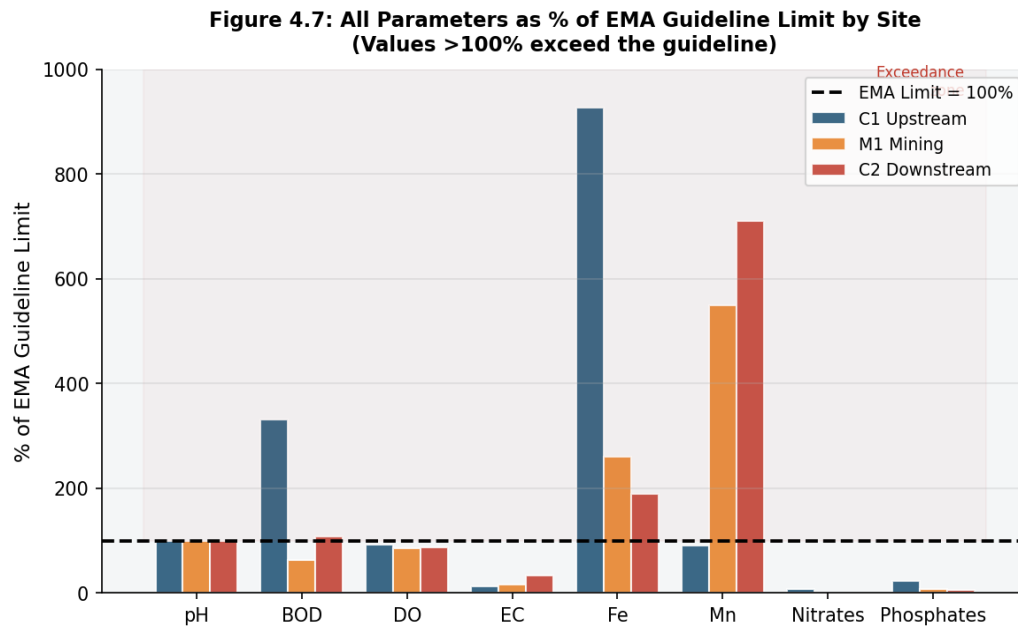


Figure 4.7: Parameters expressed as percentage of EMA guideline limits.

The graph presents all measured parameters expressed as percentage of EMA guideline limits. Values exceeding 100% indicate non-compliance with EMA standard.

4.5 EMA BAND CLASSIFICATION

Table 4.3 summarises the EMA Band classifications assigned to each site based on laboratory assessment.

Table 4.3: EMA Band Classification Results and Interpretation

Site	Band Class	EMA Interpretation	Parameters Driving Classification
C1 — Upstream	YELLOW	Moderate impairment	BOD 19.92 mg/L (332% of limit); Fe 2.78 mg/L (927% of limit); DO below 75%
M1 — Mining Site	BLUE	Slight impairment	Mn 0.55 mg/L (550% of limit); Fe 0.78 mg/L; DO 64.3% (below threshold)
C2 — Downstream	BLUE	Slight impairment	Mn 0.71 mg/L (710% of limit); EC 500 µS/cm; BOD 6.49 mg/L (108% of limit)

Source: EMA Band Classification System, SI 6 of 2007. Band Class assigned by EMA Analytical Laboratory, Ref 261254-300.

4.6 INTEGRATED FINDINGS

Finding 1 — Manganese is the definitive mining impact indicator: Manganese concentration at C1 (0.09mg/L) was within the EMA limit. Values rose to 0.55 mg/L at M1 (550% of the limit) and reached 0.71 mg/L at C2 (710% of the limit). The spatial gradient clearly demonstrates that manganese enrichment in the Mutare River at the Premier Mawoyo Bridge site is mainly due to alluvial mining.

Finding 2 – Pre-existing upstream organic and iron burden: BOD at C1 (332% of the limit) and iron at C1 (927% of the limit) suggest that there is significant non-mining pollution entering the river upstream of the study area, possibly from agricultural runoff, animal husbandry, and informal domestic effluent. In addition to any response specific to mining, catchment-wide management is required.

Finding 3 — Generalised dissolved oxygen stress: All three sites were below the 75% EMA threshold for dissolved oxygen saturation, which suggests that oxygen deficient conditions throughout the study reach are due to a combination of upstream organic loading, mining induced turbidity and reduced riparian shading.

CHAPTER 5: DISCUSSION

5.1 PH

pH values at all three sites — C1 (7.55), M1 (7.89), and C2 (8.08) — fell within the EMA acceptable range of 6.5 to 8.5. There was no AMD found at any location. The same can be said for the buffering effect of the surrounding geological formation as the lithology of Zimbabwe Craton is made up of calcite and dolomite veins which release bicarbonate ions during mining, which temporarily neutralise any acidity produced (Chirinda et al. 2021; Maponga & Ngorima 2003). Downstream alkalisation in carbonate-rich mining terrains is similar to that found by Miller and Thompson (2023). However, the lack of pH exceedance should not be viewed as an indication that there was no or little mining impact, as the manganese, iron, and dissolved oxygen data show that there was a significant impact to water quality that occurred via other mechanisms.

5.2 BIOLOGICAL OXYGEN DEMAND (BOD)

The BOD results appear to be the most complicated part of this investigation. The upstream control site was the highest of all sites at 19.92 mg/L, which is over three times the EMA limit and much higher than the M1 (3.78 mg/L, below the limit) and C2 (6.49 mg/L, just above the limit). The upstream BOD elevation suggests that there are existing BOD inputs upstream of the study area, likely from agricultural discharges, animal husbandry and from unrecorded domestic discharges. The BOD concentrations from agricultural sources are found to be 3 to 5 times greater than those of high livestock density mining areas on a regular basis in similar African catchment settings, as was shown by Chen et al. (2023). It is interesting that BOD was lowest at the actively mined site (3.78 mg/L); perhaps higher

velocities in the channel cross section caused by the excavation or the loss of inputs of organic leaf litter due to the removal of riparian vegetation along the mining corridor.

5.3 DISSOLVED OXYGEN (DO)

Dissolved oxygen saturation fell below the 75% EMA minimum at all three sites: C1 (69.9%), M1 (64.3%), and C2 (66.0%). The sub-threshold DO record at the upstream reference site C1 suggests that oxygen depletion in the Mutare River is not only due to the mining itself and that it actually existed prior to the mining zone, which is partly due to the high organic oxygen demand indicated by the BOD record at site C1. In the active mining area, additional oxygen consumption is seen as a consequence of reduced photosynthetic production, which would result from increased suspended sediment levels, reducing light transmittance through the water column (Clark and Lewis, 2023). Similar additive impacts of turbidity and microbial oxygen uptake have been reported in the rivers of West Africa impacted by artisanal mining (Boateng and Osei, 2022). The slightly higher DO saturation at C2 (66.0%) indicates that partial re-aeration from the atmosphere is taking place downstream of the active disturbance zone, but the saturation is still well below the regulatory value.

5.4 ELECTRICAL CONDUCTIVITY (EC)

EC in all three locations were below the EMA limit of 1 500 $\mu\text{S}/\text{cm}$, but the 167% rise from C1 (187 $\mu\text{S}/\text{cm}$) to C2 (500 $\mu\text{S}/\text{cm}$) is ecologically important and reflects an increase in ionic accumulation. The intermediate value measured at M1 (250 $\mu\text{S}/\text{cm}$) and the peak measured at C2 are not at variance with the downstream transport and concentration of the dissolved ionic species released from mechanically disturbed alluvial substrates. According to Maseko and Dube (2022), EC is a good early proxy indicator of the alluvial mining activity in rivers of the SADC, which preceded turbidity changes that were visually detected. Hansen and Schmidt (2023) also observed conductivity accumulation downstream in river basins in Europe that are continually supplied with dissolved ions from active extraction areas.

5.5 IRON (FE)

Iron was found to be in excess of the EMA recommended guideline of 0.30mg/l at all three sampling locations, C1 (2.78mg/l), M1 (0.78mg/l) and C2 (0.57mg/l). The highest concentration at the upstream reference site suggests that the natural geogenic mobilisation from iron-bearing ferralsol soils and granitic parent material is the main source (Chirinda et

al., 2021; Nhiwatiwa et al., 2017). The naturally occurring iron is released into the water column independently of mining activity by land-use and agricultural disturbances upstream of the study area. The downstream decrease in iron concentration is in accord with progressive sedimentation and dilution on the river as it moves farther from the main iron source. However, iron is still above the guideline value (0.78 mg/L) from the mining activity of M1, indicating that the mining activity also helps load the iron even if it is not the major source. Exposure to high concentrations of iron in water for a long time, may lead to aesthetic and health problems (WHO, 2021).

5.6 MANGANESE (MN): PRIMARY MINING IMPACT INDICATOR

In this study, manganese shows the most clear and unambiguous spatial signal of alluvial mining impact. The concentrations at the mining site (M1 = 0.55 mg/L) and the downstream site (C2 = 0.71 mg/L) were 5.5 and 7.1 times the guideline value of 0.10 mg/L, respectively, while that at the upstream site (C1 = 0.09 mg/L) was marginally below this guideline value. This spatial pattern (compliant upstream, and substantially exceedent at and below the mining zone) is a good piece of evidence that alluvial mining at Premier Mawoyo Bridge is the main source of manganese enrichment in the Mutare River at this location. The process of releasing manganese from the manganese bearing mineral phases in alluvial sediments is by physical disruption of the sediment and exposure to oxygenated flowing water (Maponga and Ngorima, 2003). The downstream dissolution and cumulative transport is supported by the higher Mn concentration at C2 than at M1. The guideline value of manganese in drinking water set by the WHO (2021) is 0.4 mg/L, which is exceeded by 78% at C2 (0.71 mg/L) raising direct public health concerns for the communities taking water from the river downstream of the bridge.

5.7 NITRATES AND PHOSPHATES

All sites had low levels of nitrate and phosphate, which were within EMA limits. The relatively high values at C1 are in line with upstream farming activity instead of contamination from mining activities. These results further indicate that nutrient enrichment and eutrophication risk are not a major environmental concern for the Premier Mawoyo Bridge site at present.

5.8 INTEGRATED SPATIAL RISK ASSESSMENT

Upstream (C1) — Organic and Iron Burden: The upstream reference site has an elevated BOD (19.92 mg/L — 3.3 times the EMA limit), high concentration of iron (2.78 mg/L — 9.3 times the limit), sub-threshold dissolved oxygen (69.9%), and marginal nutrient inputs. This pollution load is not caused by mining but is from catchment sourced pollution and needs to be managed by land-use regulation upstream and by improving domestic sanitation.

Mining Zone (M1) — Active Ionic and Metal Loading: The mining site has very strong chemical indicators of active disturbance, including high EC (250 μ S/cm), high manganese (5.5 times the EMA limit, 0.55 mg/L), high iron (above the limit, 0.78 mg/L), and low dissolved oxygen saturation (compared to all sites, 64.3%). It is clear that the mining area is the main source of manganese contamination in the study reach.

Downstream (C2) — Accumulation and Persistence: The downstream site provides evidence that impacts from the mining activities are not necessarily limited to the area of the mine: EC is at a maximum (500 μ S/cm), manganese is at its highest concentration (0.71 mg/L, 7.1 times the EMA limit), and BOD just exceeds the limit. This downstream accumulation is consistent with the results of Banda and Phiri (2022) in the Zambezi basin where mining-related contaminants were observed to accumulate several kilometres downstream of the source. The Premier Mawoyo Bridge downstream site is the site of greatest public health concern in the study area.

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSION

The alluvial mining activity at Premier Mawoyo Bridge has a measurable and significant effect on the physicochemical quality of the Mutare River which is best seen by the gradient of manganese concentration from within the limit values upstream to 7.1 times the EMA threshold at the downstream site. The downstream site at Premier Mawoyo Bridge is the site of highest public health risk. Both the null hypotheses are rejected – water quality parameters at the mining affected site are significantly different from those at the upstream control and there are clear propagation and amplification of those effects in the downstream direction. At the same time, there is an existing upstream pollution load – indicated by the high BOD and Fe at C1 – which needs to be addressed, for which catchment-wide management solutions are needed beyond the mining area.

6.2 RECOMMENDATIONS

Table 6.1: Prioritised Recommendations for Mutare River Water Quality Management

Stakeholder	Recommendation	Priority	Timeframe
EMA	Establish quarterly monitoring at C1, M1 and C2 for Mn, Fe, EC, BOD, DO and pH; publish results for community access	HIGH	6 months
EMA	Issue formal enforcement notice to Tsambe Bridge operators requiring compliance with SI 6/2007 Mn and Fe limits	HIGH	3 months
EMA	Commission a source apportionment study for upstream BOD and Iron to identify and regulate non-mining upstream pollution sources	MEDIUM	12 months
Mining Cooperatives	Install lined settling ponds to retain process wastewater before any discharge to the river	HIGH	12 months

Mining Cooperatives	Restore riparian vegetation along the mining corridor using native species (<i>Ficus sur</i> , <i>Bridelia micrantha</i>) to reduce bank erosion and support DO recovery	MEDIUM	24 months
Local Authority	Issue an immediate community water quality advisory informing downstream residents of Mn and Fe exceedances and advising on household treatment	HIGH	Immediate
Local Authority	Evaluate feasibility of alternative or supplementary water supply for downstream communities	MEDIUM	12 months
Research Institutions	Conduct seasonal longitudinal monitoring (wet and dry seasons) to characterise annual contamination cycles	MEDIUM	24 months
Research Institutions	Investigate Mn and Fe bioaccumulation in fish and macroinvertebrates to assess community exposure through food chain consumption	LOWER	36 months

Priority: HIGH = immediate action required; MEDIUM = planned within 1–2 years; LOWER = important but not time-critical. All recommendations are grounded in EMA-certified data (Ref 261254-300).

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APPENDIX A: EMA SAMBLE RESULTS

Ref : 261254-300

Partial Ambient														
Customer Ref 'CP'			U/S of Mature R	D/S of Mature @ Premier	Along Mature @ Bridge to Tsambe	Nyakaunga R	D/D/TZ 02	Environmental Management (Effluent & Solid Waste Disposal) Regulations SI 6 of 2007						
Type of Sample 'CP'			Grab / Systematic	Grab / Systematic	River / Systematic	River / Systematic	Grab / Systematic	Grab / Systematic						
Sampling type/plan 'CP'														
Lab ref number			261254	261255	261256	261257	261258							
Date sample taken 'CP'			03/03/2026	03/03/2026	03/03/2026	03/03/2026	03/03/2026							
Date sample received			04/03/2026	04/03/2026	04/03/2026	04/03/2026	04/03/2026							
								Blue	Green	Yellow	Red			
								Sensitive	Normal					
Parameters	Units	Method	Status	Measurement Uncertainty(+)										
Biological oxygen Demand	mg/l	Electrode SOP CM03		TBA	19.92	6.49	3.78	2.52	17.80	<15	<30	<50	<100	<120
Dissolved oxygen	Saturation %	Electrode SOP CM51		TBA	69.9	66.0	64.3	69.1	58.2	>75	>60	>50	>30	>15
E. Conductivity	uS/cm	Electrode SOP CM12		TBA	187	500	250	143	555	<200	<1000	<2000	<3000	<3500
Iron	mg/l Fe	AAS Flame SOP CM22	SA	0.1252	2.78	0.57	0.78	0.90	0.34	<0.1	<0.1	<0.3	<0.4	<0.5
Manganese	mg/l Mn	AAS Flame SOP CM22	SA	0.0051	0.09	0.01	<0.01	0.02	<0.01	<0.1	<1.0	<2.0	<5.0	<8.0
Nitrates	mg/l N	Spectrophotometric SOP CM21	SA	0.0286	0.79	0.07	<0.01	0.02	<0.01	<0.1	<0.1	<0.3	<0.4	<0.5
pH		Electrode SOP CM27		TBA	7.55	8.68	7.89	7.90	7.86	6.0-7.5	6.0-9.0	5-6-9-10	4-5-10-12	0-4-12-14
Phosphates	mg/l P	Spectrophotometric SOP CM28	SA	0.0131	0.12	0.03	0.04	0.02	0.07	<0.5	<0.5	<1.5	<3	<5
Band Class				Yellow	Blue	Blue	Blue	Blue	Green					

NOTE: Conditions of sample(s) upon receipt at the laboratory. All samples were in good condition. This test report shall not be reproduced except in full, without written approval of the laboratory.

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The Results relate only to items tested

The Results apply to the sample as received

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Decision rule on uncertainty of measurement (UoM): The lowest value obtained after incorporation of UoM was considered for band classification.

Compiled by: Name: G. Chilenge Signature: [Signature] Date: 10/03/2026
 Authorised by: Technical signatory; Name: G. Mwanaka Signature: [Signature] Date: 11/03/2026

Authorised by: Technical signatory; Name: S. MURUGAN Signature: [Signature]

