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DEPARTMENT OF CHEMICAL ENGINEERING

ASSESSMENT OF WATER POLLUTION ARISING FROM COPPER MINING IN ZAMBIA: A CASE STUDY OF MUNKULUNGWE STREAM IN NDOLA, COPPERBELT PROVINCE

BY

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A thesis submitted in partial fulfilment of the requirements of the award of Master of Philosophy Degree in Sustainable Mineral Resource Development

ABSTRACT

Water pollution is recognized as one of the major environmental problems in the mining industry. This has been compounded with an increase in agriculture activities. Water pollution is a major problem on copper and coal mines throughout the world and Zambia, the focus of this study, is no exception. Worldwide freshwater resources, which provide important ecosystem services to humans, are under threat from rapid population growth, urbanization, industrialization and abandonment of wastelands. There is an urgent need to monitor and assess these resources. In this context, the physical, chemical and ecological water quality of the Munkulungwe Stream located on the Copperbelt of Zambia, was assessed with possible contamination from Bwana Mkubwa TSF, agriculture activities and subsequent impact on the surrounding community.

The chemical and physical parameters were assessed at four sampling locations. Sampling site S1 was located on the Munkulungwe stream upstream of Bwana Mkubwa TSF, S2, S3 and S4 were on the main stream downstream of Bwana Mkubwa TSF. In addition, a macroinvertebrate composition analysis was performed to estimate the quality of water using the biotic index score. Finally, the relationship between physiochemical parameters and biotic index score was analysed to interrogate their inter-relationship with respect to water quality.

The results showed that the average values of dissolved oxygen (DO) of 4.52 mg/l, turbidity (40.96 NTU), Co (0.24 mg/l), Pb (0.25 mg/l), Fe (0.36 mg/l) and Mn (0.22 mg/l) downstream exceeded international standards for drinking water. Upstream, the values of Co, Pb, Fe and Mn were within acceptable standards for drinking water, DO and turbidity were above acceptable standards. The metal concentration and total dissolved solutes were impacted by closeness to the mine tailings deposit with the heavy metal concentration being highest at S2 and S3. Moreover, high turbidity levels revealed that land erosion induced by agriculture activities is a severe problem in the area.

Physical parameters were high in the rainy season due erosion escalated by rains while chemical parameters were high post rainy season. During the rainy season, the chemical contaminants are diluted and thus they are not such a big impact, but they tend to concentrate up during the dry season. The stream at sampling points S2 and S3 was dominated by species tolerant (leech, Isopod and Snail: Pouch) and semi tolerant (Blackfly larvae and Amphipod or Scud) to pollution. The change in season influenced the composition of macroinvertebrates, with the number of species increased post rainy season. The average biotic index score (2.5) showed that the stream condition is not good, it is slightly polluted. The results showed that water quality downstream was substantially affected by Bwana Mkubwa TSF, agriculture activities and is likely to affect human health and food security. It is recommended that groundwater surrounding tailings dams should be monitored in both active and abandoned mines. Curtain boreholes around a tailings dam can be drilled and the water extracted and treated so that it doesn't contaminate other water bodies. To improve the environmental management of mining related impacts in Zambia, mining areas should be completely rehabilitated. There is need for remediation strategies for abandoned mine sites. Constructed wetlands, roughing filtration and phytoremediation are highly promising techniques, as they are reliable, cheap, effective and sustainable.

DECLARATION

I, **LEE MUDENDA** do here by declare that this research is my own original work and that it has not been presented and will not be presented to any other university for a similar or any other degree award. Furthermore, I declare that all secondary sources of information referred in this work have been acknowledged and referenced.

Signature: Signed by candidate

Date: 05/08/2017

DEDICATION

TO MY LATE FATHER FOR HIS ENCOURAGEMENT IN MY PURSUIT OF SUCCESS. THOUGH DEAD, YOUR VALUES AND DETERMINATION ARE ALIVE.

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To the Almighty GOD, am forever indebted to your love and, I am only but clay without you. Your abiding presence is the power that bids me to move on (Jeremiah 29:11-13).

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Table of Contents

List of Figures

List of Tables

List of Abbreviations

AMC	Africa Mining Consultancy
ASPT	Average Score per Taxon
CBE	Citizens for a Better Environment
CSO	Central Statistical Office
BOD	Biochemical Oxygen Demand
ECZ	Environmental Council of Zambia
KCM	Konkola Copper Mines
IRMA	Initiative for Responsible Mining Assurance
IWRM	Integrated Water Resources Management
MEWD	Ministry of Energy and Water Development
MLNREP	Ministry of Lands, Natural Resources and Environmental Protection
MOM	Ministry of Mines
MSD	Mine Safety Department
NWASCO	National Water Supply and Sanitation Council
$SASS_4$	South African Scoring System
SPSS	Statistical Package for Social Science
TN	Total Nitrogen
TSF	Tailings Storage Facility
UN	United Nations
WHO	World Health Organization
ZABS	Zambia Bureau of Standards
ZCCM-IH	Zambia Consolidated Copper Mines – Investment Holdings
ZEMA	Zambia Environmental Management Agency

CHAPTER 1: INTRODUCTION

1.1 Introduction

Water is one of the key elements to sustainable development and plays a very important role in social and economic development, survival of humanity and the health of the ecosystems. It is essential in the reduction of disease and improving the health of humanity at a global scale. Water is vital to production and providing a wide range of benefits and services to humans. It is a very important link between the environments, climate system and society (United Nations, 2012).

Most of the rivers supporting more than 1.7 billion people living near the river basins, are depleted through excess use beyond natural recharge, a trend that is likely to affect more than two thirds of the world population by 2025 (Swilling & Annecke, 2012). Water currently poses a serious challenge in meeting sustainable development goals; however, if well managed, it can play an important role in meeting the social, economic and environmental challenges (United Nations, 2014). Water is naturally an abundant resource, covering over 70% of the earth, yet 97% of this is sea water (Udaybir et al., 2014). Available freshwater on Earth is about 3%, and of this, 87% is as ice and glaciers or underground. Only about 13% (0.4% total water) is found at the surface in streams, rivers and lakes (Halder & Islam, 2015). More than 99% of all the water on Earth is unusable for consumption by humans and other living organisms.

Increased populations coupled with economic growth globally impact on water quality and availability. Water pollution is among the major challenges faced in some parts of the world, particularly in densely populated developing countries where human habitat is usually near mine sites (Ochieng et al, 2010). In the Copperbelt Province of Zambia, water pollution is one of the major environmental challenges posed by mining and other industries (Das & Rose, 2014; Lindahl, 2014). In mining, large quantities of waste is produced and disposed of as waste rock, slimes, sludge and tailings, or discharged as liquid or gaseous emissions. This waste is often composed of different metallic elements which end up in water bodies. Further, depending on leaching reaction, acidification and salinization may occur. The impacts of mining projects on the quality and quantity of water is a contentious issue globally (Bud et al, 2007; Bebbington & Williams, 2008). Equally in Zambia, reports of water pollution induced by mining activities are common (Kambole & Chilumbo, 2001; Mundike, 2004; Auditor General Report, 2014; Das & Rose, 2014) though contentious as well.

Water pollution and river encroachment have been observed to negatively affect aquatic and human life. Livelihoods of humans, animals and aquatic organisms are inter-linked. Understanding this inter-dependence is essential to preserve the natural resource biodiversity from the risks of industrial pollution (Ghouri & Khan, 2011; Halder & Islam, 2015). The pollution of streams and rivers through mining effluents is among the challenges affecting natural communities and ecosystems (Ibemenuga, 2013) in the developing world. In developing countries, most of the streams and rivers are heavily polluted from effluent discharge emanating from mining, agriculture and other industries (Lindahl, 2014). Metals and other dissolved salts such as sulphates, phosphates and nitrates find their way into streams and rivers through different sources such as discharge of treated and untreated liquid waste, leachate from disposal of solid wastes and runoff.

Need has created an urgency to develop monitoring methods that can indicate the ecological status of riverine systems as they respond to natural and biotic activities, such monitoring feed directly into practicable conservation stratagies. With the need to monitor water quality, there has been a proliferation of techniques for rapid bioassessment of water bodies and the evaluation of water quality. These techniques are used for health assessment of general river conditions as influenced by a variety of factors, especially water quality. This awareness has resulted in demand for more information on monitoring the environment, so that we can best preserve our freshwater resources for future generations. Rapid increase in mining activities in Zambia, puts great pressure on evaluation and management of riverine ecosystems. Bio-monitoring is a very useful tool for assessing, prediction and transformation landscape structure, making it a very valid component of policies applicable to rural, industrial and urbanized areas to decrease human mismanagement and lessen pollution levels.

1.2 Problem Statement

Zambia has a long history in mining and is Africa's second largest producer of copper after the Democratic Republic of Congo. It has the largest known copper reserves in Africa amounting to about 6% of the known reserves globally (World-Bank, 2011). Mining plays an important role in Zambia because of its richness in lead, zinc, cobalt and copper deposits (Stockwell et al., 2001). Mining in Zambia is dominant on the Copperbelt and in North Western province. Mining practices have brought many benefits to society, but they have also resulted in widespread degradation of the river ecosystems. The main concerns from the increasing mining activities are those regarding acid mine drainage, air pollution, land degradation and heavy metal contamination in water bodies, with most of these problems not only being environmental problems of their respective countries, but they are also issues that are transboundary and truly an international problem. However, the greatest concern of all is the influence of pollution on our freshwater regime.

The rapid economic progress has been a source of environmental challenges and water pollution by heavy metals is one of the major challenges affecting aquatic organisms and humans (Syakalima et al., 2001; Lindahl, 2014). Most of the mining operations on the Zambian Copperbelt lie within the catchment area of the Kafue River, Zambia's most developed watershed. There is increasing competition on water utilization and pollution of the river (Kambole, 2003). The Upper Kafue supplies most of the domestic water for the major cities in the Copperbelt region, hence concern over water pollution from mining activities is always present (Kasonde, 1990; Mwase, 1994; Nkandu, 1996; Norrgren et al., 2000; Syakalima et al., 2001; Kambole, 2003; Mundike, 2004, Auditor General, 2014; Lindahl, 2014). From an ecotoxicological aspect, heavy metal pollution in Kafue River and its tributaries is severe on the Copperbelt and affects aquatic animal health.

A study on the Mushishima Stream (figure 1) (Das & Rose, 2014), one of the tributaries of the Kafue River showed that it was heavily polluted by KCM's tailings dam number 2 (TD2). The stream is surrounded by mica sludge from KCM's TD2, which has built up along the banks of the stream, thus making fishing and navigation of the stream difficult. Most local people are fishermen and farmers, so depend on the stream for food and water.

Figure 1: a.) A boy fishes on the contaminated sediments at Hippo Pool. b.) children in Hippo Pool village from Das and Rose (2014)

The concentration of Cu, Co and Mn, were all above the limits for effluent and waste water, as well as drinking water in Zambia (ZABS, 2010). The study measured Cu at 29400 μg/l (limit 1000 μg/l), Co at 5, 824 μg/l (limit 1500 μg/l), and Mn at 33, 980 μg/l (limit 1000 μg/l) (Das & Rose, 2014). Sracek et al. (2012) also noted that Mushishima and Uchi streams are the most polluted streams on the Kafue network because of their proximity to mine procssing plants.

For example, in 2006, the discharge of effluents into the Mutimpa Stream (see Figure 2) which runs directly into the Kafue River was above the acceptable limits. It was one of the worst contamination cases experienced in Zambia with concentrations of copper 10 times, cobalt 100 times and manganese 770 times above the acceptable limit (Das & Rose, 2014) exceeding the standards for protecting aquatic life within the Copperbelt mining region (SGAB et al., 2005).

Figure 2: Toxic sludge from Muntimpa tailing dam into Muntimpa stream (2011) from Das and Rose (Copper Colonialism: British miner Vedanta KCM and the copper loot of Zambia, 2014)

The rapid degradation of natural resources due to pollution and exploitation from human activities is of great concern. Rivers are habitat to many aquatic organisms, including plants, animals, insects and micro-organisms that are essential in maintaining a healthy ecosystem, including support of human health and livelihoods. Awareness of the critical role of these water supplies has created a need to monitor the river health, water quality and environment, so that we can preserve our water resources to serve our region and for generations to come (Enderlein et al., 1996). Against this background, the aim of this study is to assess the relationship between water quality and macro-invertebrate species in Munkulungwe Stream.

1.3 Selection of Case Study

The Munkulungwe stream is located about 15 km southeast of Ndola within the Copperbelt of Zambia, about 1 km from the Bwana Mkubwa TSF (Figure 3). The area occurs between latitude Lat. -13.043 and longitude Lon. 28.731 and runs downstream through Mutalula and Munkulungwe Farming Blocks. The stream provides water for domestic use and for agriculture to the surrounding community; the headwaters of the stream are on a lower side in a dambo (shallow wetlands) area upstream of the mine. The Munkulungwe stream is home to many plants, bacteria and animals that depend on it for their survival (Africa Mining Consultancy, 2000). On average, the width of Munkulungwe stream is 1.5 m to 2 m; while the depth 1 m to 2 m in the rainy season and 0.5 m to 0.8 m in the dry season (Mundike, 2004).

The stream flows through Bwana Mkubwa Protected Forest Area. The stream is canalized along much of its length; parts of the stream have been divided into street canals for agricultural purposes. Further downstream, the stream is joined by its major tributary the Kafue River. Figure 3 shows the location of Bwana Mkubwa TSF, Munkulungwe Stream and the sampling points

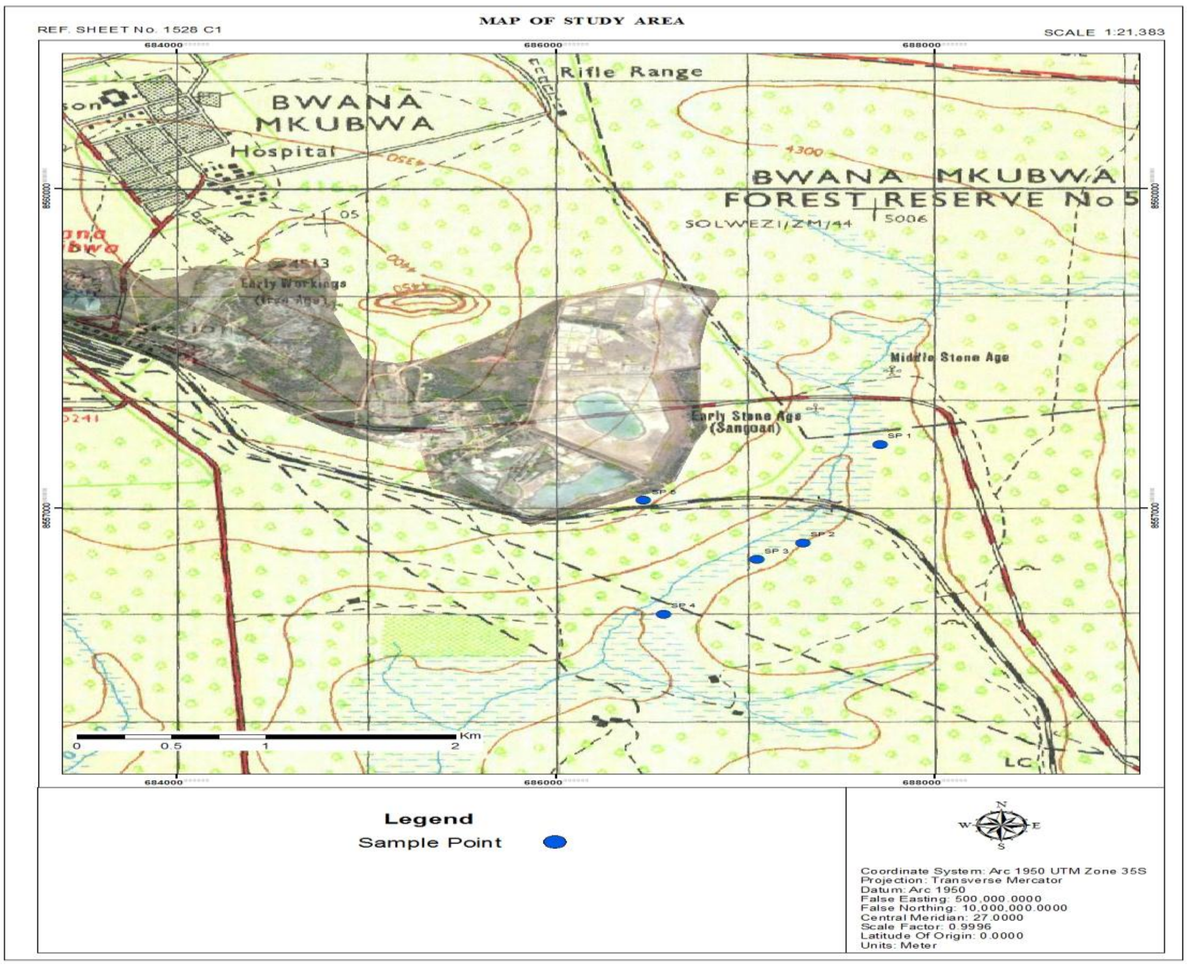


Figure 3: Map of study area

The water quality of the sampling area upstream from the Bwana Mkubwa TSF has remained relatively undisturbed (Mundike, 2004). In the sampling area downstream of TSF, the water quality has, however, been affected by mining activities and agricultural runoff. In addition, the extraction of water for residential and irrigation purposes, have probably, resulted in an increase in the rate of decline in water quality. Previous studies by Mundike (2004) had shown that Munkulungwe stream was a subject of pollution from Bwana Mkubwa TSF due to seepage from TSF that then discharged to the stream.

The Munkulungwe Stream provides surrounding communities with freshwater for domestic and agricultural activities, making it very important to the surrounding community. The stream is 1km away from Bwana Mkubwa TSF and flows through the Mutalula and Munkulungwe Farming Blocks (figure 9). It is a tributary of the Kafue River. The Kafue River is vital to the socio-economic development of Zambia, providing water to more than 40% of people living in the Kafue River Basin (Kambole, 2003).

The proximity of Bwana Mkubwa TSF to Munkulungwe Stream and Mutalula and Munkulungwe farming block provides an opportunity to assess the interactions of aquatic organisms in the stream to environmental stress and likely impact on the surrounding communities.

1.4 Selection of methodology

Several studies done in Southern Africa have shown that the ecosystem is a natural water cleansing system and when damaged, can lead to multiple problems (Neba 2007; Ochieng, et al., 2010). Monitoring methods for ecosystems can be classified as physical, chemical or biological. Studies on effects of industrialization on water bodies in Zambia have been limited to chemical and physical parameters (Kambole, 2003; Ikenaka et al., 2010). Generally, existing studies on water pollution in Zambia have highlighted the profiles of heavy metals in the aquatic systems without indicating the impact of the pollution on the ecosystem.

Biological monitoring (biomonitoring) makes use of the living components of the studied environment, and indicates, as well as assess, ecological degradation, transformation, improvement or other effects, due to a certain cause at a specific or at similar locations, with minimal use of equipment in the field and which non-specialists can do (Rosenberg, 1998). The basic aim of biomonitoring is to indicate the emerging catastrophes at an early stage. after initial standardization and establishment, the biomonitoring techniques must also be cost effective and become part of people's mindset in pinpointing environmental degradation to serve as an effective warning system. In this study, assessment of river health in the Zambian mining region of the Copperbelt is extended to include bio-monitoring, using the Munkulungwe Stream as a test bed.

Macroinvertebrates are used in this study because of their richness in diversity and sensitivity to environmental changes (Paoletti, 1999) as well as their sedentary nature allowing changes to be measured as a function of location in the river. Macroinvertebrates as bio-indicators are very useful in assessing a wide variety of issues ranging from health of water bodies to economic management of the same (Holopainen & Oksanen, 1995). There is a gap in knowledge on the impact of the pollution emanating from effluent discharge on the ecosystem. As such, this study focused on the impact of water pollution on macroinvertebrates to show how historical mine sites, continue to impact aquatic ecosystems.

1.5 Main objective

The aim of the research is to make an ecological assessment on the influence of Bwana Mkubwa TSF on the Munkulungwe Stream, with special reference to macroinvertebrates. The specific objectives and associated research questions of the study are:

- To determine the variation of heavy metals and water quality parameters in Munkulungwe stream near and downstream from the mining operation.
    - What are the levels of heavy metals and water quality parameters in the Munkulungwe stream?
- To determine the variation in population of macroinvertebrates in Munkulungwe stream with proximity to the tailings dam of the mining operation.
    - What type of macroinvertebrates are found in the Munkulungwe stream up and downstream of the pollution event?
    - How do these reflect pollution of the stream?
- To assess the effects of change in season on water quality

- What effects does the change in season have on the quality of water in the Munkulungwe stream?
- What impacts may compromised water quality have on the community?

1.6 Dissertation Structure

This dissertation is divided into six main chapters with each chapter dealing with a specific aspect of the study.

Chapter One gives a brief introduction of the research topic. A description of the research, the research problem and justification of the research is presented. A set of research objectives and the relevant research questions are highlighted in the chapter.

Chapter Two provides a review of literature that is related to water pollution associated with mining activities. Of the different environmental challenges caused by mining activities, the chapter focuses on water pollution. The chapter further reveals how researchers have used the variation of macro invertebrates, heavy metal profile and other related issues, to assess pollution load in water. This sets the background upon which the other chapters in the dissertation have been built.

Chapter Three presents and discusses the research approach and materials that have been employed in the research. The chapter also discusses the analytical tools employed in data analysis.

In **Chapter Four,** the results are presented. The chapter identifies major issues observed in the research and the implication thereof.

In **Chapter Five,** the analysis of the results obtained is presented. It further deals with other issues related to or influencing the results that have been obtained. The chapter ends by considering how the issues are related to pollution load in the stream and likely impact on the surrounding community

Chapter Six provides a summary of the issues that have been raised in the four chapters. From this, conclusions are drawn and recommendations provided on both further research and potential interventions to allow implementation of the findings towards reducing water pollution in this, and other, streams impacted by mining in the Copperbelt of Zambia.

CHAPTER 2: LITERATURE REVIEW

2.1 Mining and Impact on Aquatic Ecosystem

Mining involves the extraction of potentially usable metals from mineral resources which are non-renewable (Kogel, 2013). Mining operations are not infinite, in most cases they are short term activities and mineral resources are finite; the mines will at some point close because of economic changes or exhaustion of mineral deposit i.e. they have a fixed lifespan. Planning for closure is thus essential. The lifetime of a mine is determined by the geotechnical characteristics, technological factors, economic climate, environmental concerns, and size and quality of the mineral resource that is being mined (Shafiee et al., 2009).

These mines provide jobs to thousands of people, providing their main source of income. The mining operations typically disrupt the environment, utilizing natural resources such as water and producing huge quantities of waste that can have deleterious impacts on the aquatic ecosystem and the entire environments near the mining areas (Robertson & Shaw, 1999). Historically, the boundaries within which mining operations have been considered have been geographically and temporally limited, such that many practices in mining have ignored the impact of mining related activities on water bodies, both during and after the life of mine. Fundamental principles of good mining practices have often been neglected: post mine land use, water quality, environmental damage and socio-economic impacts (Limpitlaw, 2004). In developing countries, land reclamation, hazardous mine sites, non-compliant disposal of mine waste, including tailings dams and unplanned mine closures or 'care and maintenance' situations with insufficient closure planning, continue to be a challenge because of insufficient or ineffective implementation of mine legislation. Historically, mining related activities have not been effectively regulated and the organizations charged to enforce environmental protection do not have the capacity to implement such regulations (Michael & Maria, 2003; Lindahl, 2014). Typically mines in developing countries have limited closure plans in place and limited capacity to mitigate environmental liabilities that arise after the mine is closed. In most cases these liabilities are effectively, but not formally, transferred to the local communities. A common practice has been abandonment of the mine site once all the reserves have been extracted, without addressing the environmental challenges (Lindahl, 2014). Attention has not been given to environmental, economic and social challenges that emerge post mining in developing countries. There is need to reconsider the legacy of abandoned mines, the environmental and socio-economic challenges that emanate from them and the impact thereof on aquatic community (Mapani & Kribek, 2012). According to Robertson and Shaw (1999), as soon as a mine begins to operate, plans for its closure must also commence. In this way, provision is made for the mine that may close (either in part or completely) earlier than anticipated due to lack of finances, extinction of resources, high operating costs and many more factors. This allows planning for the environmental challenges to be addressed post mining from the very time that plans for mining commence. Mines must have closure plans that incorporate management of the environment post mining. Such mine closure plans form part of the need to embrace the concept of sustainability in mining (Hopwood et al., 2005).

Sustainable developments imply that activities taking place today should not affect the current and future generations negatively (Blewitt, 2008). Within this concept, is a call to ensure communities, natural capital and the environment are protected from exploitation solely for economic benefit. Sustainable development of mineral resources seeks to address resource productivity, environmental protection, development of a local skills force and potential for long-term livelihoods. Through such approaches, poverty challenges in the community are addressed and continued environmental degradation avoided (Hotra et al., 2003). To address the latter, sustainable mining practices that aim to protect the environment from further degradation must be incorporated effectively (Limpitlaw, 2004) to prevent a site from becoming hazardous or from contributing to pollution post mining (Lindahl, 2014).

2.1.1 Tailings dam facilities

Tailings and overburden materials are one of the major sources of heavy metal pollution. The design of their disposal system affects the movement of these components and hence pollution caused. Although the design of the tailings dam is affected by the site topography, permeability of the underlying rocks influences site selection more (Kossoff et al., 2014). Tailings dam are designed to be stable except in in cases of unforseen failure. For example, failure can occur when the wall structure can nolonger retain the tailings because of being weakened by water under pressure. Post mining, the burden of managing tailings dam in developing countries is passed on to government departments, who in reality have no capacity to manage and maintain them (Haney & Shkaratan, 2003; Lindahl, 2014). Indirectly the liability is passed on to surrounding communities. Water coming from abandoned mine sites like tailings and rock dumps pollutes the streams and land (Ochieng et al., 2010). Unsuspecting communities, continue to use polluted waters from streams and rivers to support their livelihoods through agricultural and domestic usage, as well as fishing (Boularbah et al., 2006; Halder & Islam, 2015). Water seeping from the tailings in an impoundment may cause a rise in the ground water table; this brings saline water closer to the surface and eventually damages vegetation (Ghose & Sen, 1999).

The effects of tailings dam can continue beyond 30 years after mining if no remedial measures are put in place (NRA, 1994; NRA, 1996; Younger, 1997). Community living near tailings dam are at constant risk of influence of tailings dams and other abandoned mine sites. This is compounded by the fact that most communities living near mines in developing countries have no access to piped water and other social amenities. There is need for constant monitoring of abandoned mine sites and water bodies within or near mine sites. Water leaving these sites must be regularly tested to protect the aquatic habitat from pollution effects (Ochieng et al., 2010). Water from the abandoned mine sites can be tested to ensure that it is in conformity with global practices for freshwater standards.

2.1.2 Mine water problems in Zambia

Mining activities on the Copperbelt have continued to severely affect the waterways through extensive siltation. Tailings dams and rock dumps contribute partially through erosion, but the largest impact comes from the ongoing mining activities. A study by Lindahl (2014) showed that 15000 tons/year of silt was discharged from Konkola mine to the Kafue River while Nchanga mine discharged 91000 tons/year.

Figure 3: Solids reporting into Mushishima Stream from Czech Geological Survey (2007)

Figure 4: a.) Effluents reporting into the Mutimpa Stream; b.) Effluents released into the Mushimba Stream from Auditor General Report (2014)

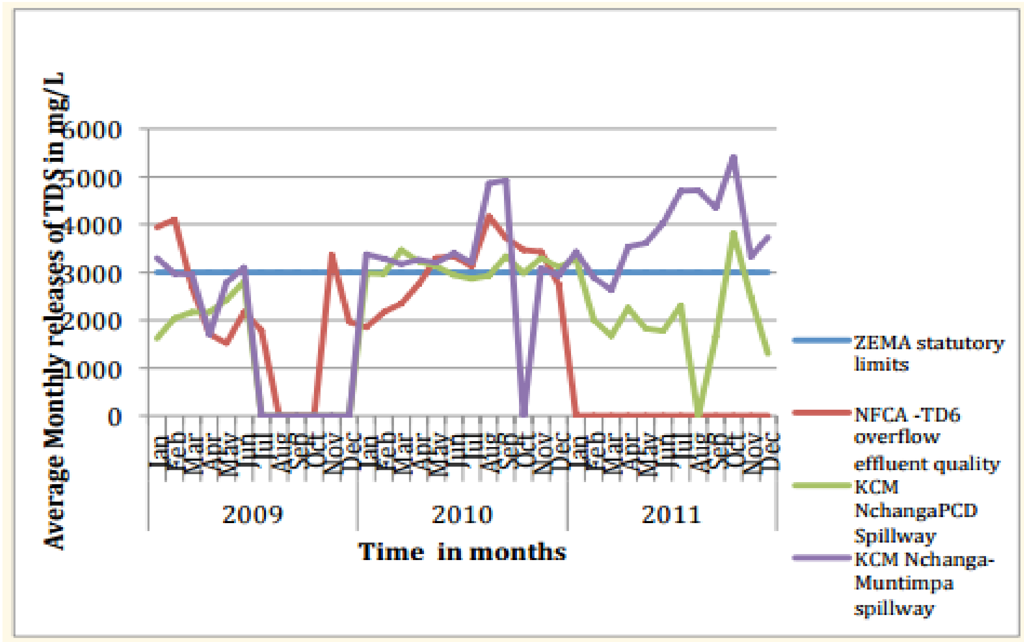


Figure 5: Total Dissolved Solids in Effluents. KCM Nchanga mine discharge waste water from Muntimpa Tailings Dam spillway with a TDS content of 5,411 mg/l which is above the authorized limit of 3,000 mg/l by ZEMA (Auditor General, 2014).

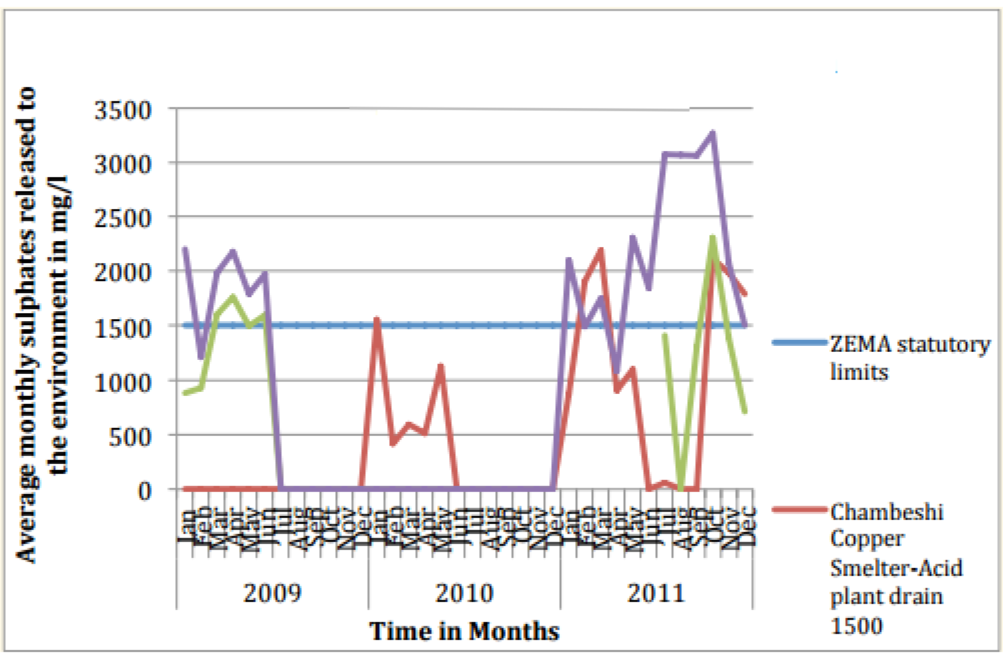


Figure 6: Sulphates (SO_4) in Effluents. Effluents with a Sulphate (SO_4) content above 3,270 mg/l were released into the environment by the KCM Nchanga Division (purple), while Chambeshi Copper Mine (red) discharged effluents containing sulphates (SO_4) above 2,189 mg/l in 2011 (Auditor General, 2014). Other mines not appearing were all below statutory limits.

The Auditor General reports of 2014 show that most of the effluents discharged from the mines were above the acceptable limit of the Zambia Environmental Agency for heavy metals. Further the report showed that Konkola Copper Mine and NFC Mine discharged TDS effluent over the authorized limit into the aquatic environment. Chambeshi Copper Smelter and Konkola Copper Mine discharged sulphate effluents into the aquatic environment above the authorized limit of 1500 mg/l, as shown in Table 1.

Table 1: TDS, Sulphates, TCu, TCo, TMn and TFe actual discharge (Auditor General Report, 2014) against limit (ZABS, 2010)

	NFCA Mining - Chambeshi Stream				Konkola Copper Mine - Mushishima Stream				
mg/l	Min	Median	Max	Average	Min	Median	Max	Average	Limit
TDS	500	2,800	6,000	4,100	600	2,400	9,867	5,411	3,000
Sulphates	170	1,323	3,500	2,189	329	1,800	4,222	3,270	1,500
TCu	0.9	9.4	106	24.6	0	1.1	17	3.1	1
TCo	0.1	2.1	51.5	8	0.9	3.6	10	3.9	0.05
TMn	0.8	5.7	49.5	12.4	4.4	11.5	73.9	20.5	0.02
TFe					2.3	237	465.1	236.5	0.3
	Konkola Copper Nkana South - Uchi Stream				Mopani Copper Mine Nkana - Unchi Stream				
mg/l	Min	Median	Max	Average	Min	Median	Max	Average	Limit
TDS	230	1,400	3,251	1,512	50	1,333	2,000	1,563	3,000
Sulphates	100	650	1,300	959	120	800	1,740	1,215	1,500
TCu	0	1.6	55.5	7	0.5	1.6	13	2.7	1
TCo	0	0.7	311	19.7	0.4	1	4.3	1.6	0.05
TMn	0.3	2.3	9.7	2.8	0.5	2.4	14.7	3.5	0.02
TFe	0	1.5	35.2	4.2	0.3	1.5	6.3	1.7	0.3

According to the Auditor General's 2014 report on environmental degradation caused by mining, it was observed that very little is being done to reduce further degradation of the ecosystem because of mining activities (Auditor General, 2014). The Auditor's General report (2014) further noted that ZEMA has no capacity to ensure that there is environmental compliance by all mining firms in Zambia. As a result, contamination of water by heavy metals is one of the serious environmental problems in Zambia and has significant implications for human health and aquatic organisms (Simukanga et al. 2002; Alvial et al., 2012).

In Zambia, many local communities depend on resources provided by aquatic ecosystems mainly for fishing and supporting small scale farming (Kapungwe, 2013). Studies have shown that there are challenges associated with the usage of polluted water for irrigation of farming (Raschid-Sally & Jayakody, 2008). These include the absence of adequate information in the changes in concentration of heavy metals in water being used for irrigation, crops and soil (Buechler et al., 2002). Although there are challenges in using polluted water for farming, farming remains a major source of livelihood for most communities living near the mines (Marshall et al., 2004; Raschid-Sally & Jayakody, 2008).

Research by Mundike (2004) on the pollution of Munkulungwe Stream showed that more than 300 small scale farmers whose livelihoods depend on the stream were affected. The local community complained that the discharges from leach operations from Bwana Mkubwa Mine operations affected their livestock, crop yields, soil acidity and access to freshwater for domestic use. Several studies on the Zambian Copperbelt have shown that trace metal uptake in agricultural plants like cassava, sweet potatoes and maize, is high in contaminated areas (SGAB et al., 2005; Czech Geological Survey, 2007; Lindahl, 2014). Since cassava, sweet potatoes and maize constitute the diet of locals, the ingestion of it is a pathway for human exposure of potentially toxic metals (SGAB et al., 2005). A comparison of several fish samples found in unaffected waters upstream of mining operations and downstream in affected waters, has shown elevated concentrations of cobalt and copper (SGAB et al., 2005). Norrgren et al. (2000) observed that threespot tilapia (caged fish) revealed bioaccumulation of heavy metals within two weeks of mining exposure.

Although mining is a major contributor to resource rich countries income and economy, it has contributed to the challenges of local communities in developing countries (Czech Geological Survey, 2007). Literature shows that discharge of metals and dissolved salts into rivers, streams and groundwater, through mining activities, is a major challenge affecting the whole environmental eco-system, as the water bodies spread out (Ibemenuga, 2013). The experience of mining and its subsequent effects in Zambia, has raised many challenges to the country, many of which it still faces, especially in water pollution. Various studies have shown that heavy metals and water quality parameters are above acceptable limits in water bodies near mining sites on the Zambian Copperbelt (Mundike, 2004; SGAB et al., 2005; Sracek et al., 2012; Lindahl, 2014; Auditor General Report, 2014). While most research has shown that heavy metal concentration is above acceptable limits in most of the tributaries of Kafue River in the Copperbelt, there is a limited literature on its impact on the aquatic ecosystem and subsequent effects on loss of livelihoods and risks to human health. The lack of frequent monitoring of the stream conditions by the Zambia Environmental Agency also contributes to the deterioration of water quality in the Copperbelt region (Lindahl, 2014). Although many challenges remain in managing mining induced water pollution in Zambia, frequent monitoring and promotion of good water stewardship through environmental compliance, will help in combating mine water pollution.

2.2 Mining effluents and impacts on chemical and physical parameters of aquatic ecosystems/water

Focusing specifically on the potential impact of mining operations on water quality, it is noted that the quality of water in rivers and streams is influenced by different factors. These include the season i.e. rainy or dry season, the possibility of drought, and the impact of mine operations and of human related activities (Atasoy et al., 2006).

Parameters selected to assess water quality or pollution load in water depend on the needs and objectives of the research (Bartran & Balance, 1996). Among others, pH, dissolved oxygen, total dissolved solids, turbidity, heavy metals and macroinvertebrates are essential in determining water quality in streams and rivers (Chapman, 1996; Akoto et al., 2008; Holt, 2011).

2.2.1 Physical parameters

2.2.1.1 pH

The pH is a measurement of hydrogen and hydroxyl ions in a solution, using a logarithmic scale. The measure indicates if the solution under consideration is alkaline (pH > 7) or acidic (pH < 7). Fresh water pH normally ranges between pH 6 and pH 8. The pH affects the availability and solubility of nutrients that are needed by aquatic organisms for utilization (Simon, 2001) as well as the solubility of metals carried in particulate matter and sediments. Further, each organism has a limited pH tolerance range. Though there is no defined pH range in which aquatic life is unharmed, gradual acidification or alkalination can be harmful to aquatic organisms (Robertson, 2004). The acceptable pH range for aquatic life depends on many factors such as acclimatization to pH, water temperature, dissolved oxygen and concentrations of anions and cations (Tripole et al., 2008). Several studies have shown that there is a strong link between the composition of the community of aquatic organisms and water pH (Mulholland et al., 1992; Schindler, 1988; Merrix et al., 2006; McClurg et al., 2007; Earle & Callaghan, 2009). This is also true of the microbial community.

Effluents from mines influence chemical and biological processes taking place in the water (Chapman, 1996). Mine discharge normally has a low pH value which causes a range of minerals to dissolve and thus toxic metals are released into water bodies (Udayabhanu & Prasad, 2010). Where mineral sulfides are present, microbial activity can enhance the acidification process through iron and sulfur-oxidising micro-organisms providing a continual supply of ferric iron and protons as leach agents. Effluents generated from rock and tailings dumps containing mineral sulfides can be a source of acid mine drainage in rivers and streams (Ntengwe & Maseka, 2006). The likelihood of neutralization of this acidity is dependent on the acid neutralizing minerals present within the deposit. The quality of water is affected by the acidity or alkalinity and the dissolved metals and associated anions, making the water inhibitory or toxic for aquatic life (Hare & Campbell, 1992; Herrmann et al., 1993). Studies have shown that these effects continue beyond 30 years after mining (NRA, 1994; NRA, 1996; Younger, 1997). According to Yang et al., (2008), pH in streams and rivers is influenced by effluents from the mines. Depending on the levels of pH in water, it could be rendered unusable for some activities or all form of activities (Washington-State, 1998). Low pH values lead to degradation of soil resource causing significant losses in production as the choice of crops is restricted to acid tolerant species and varieties, thereby affecting profitable market opportunities for affected communities (Lindahl, 2014). In most cases limestone is used to treat acidic soils which is expensive to local communities.

2.2.1.2 Dissolved Oxygen

The quantity of oxygen that is dissolved in a stream or river and is available to sustain aquatic life is called dissolved oxygen. The standard unit for measuring Dissolved Oxygen (DO) is milligrams per liter (mg/l). Dissolved oxygen is vital for the survival of aquatic organisms, including macroinvertebrates and fish, without which they would suffocate and die (Chapman 1996; Mallya, 2007). There is a significant correlation between both diversity and density of benthic macroinvertebrates, and amount of dissolved oxygen in water (Wilhm & McClintock, 1978). Thus, it is an important component in assessing the quality of water in a given stream or river (Dowling & Wiley, 1986). Dissolved oxygen is normally influenced by mine effluents, available nutrients (with excess nutrients leading to eutrophication), temperature, physical aeration and gas liquid mass transfer and biological processes. Aquatic organisms require dissolved oxygen to support aerobic metabolism, thus water with low concentrations of dissolved oxygen can be fatal to aquatic organisms (Ward, 1992). Low dissolved oxygen in streams or rivers can be attributed to increase in temperatures, aerobic metabolism and sediment loads (O'Keeffe & Dickens, 2000). Runoff of foreign material into water bodies from tailings and rock dumps, affects the concentration of dissolved oxygen (Kannel et al., 2007). Dissolved oxygen concentration affects and is affected by, respiration of aquatic organisms and microorganisms. Oxygen maintained near saturation levels result in a positive growth rate of aquatic organisms (Mallya, 2007). Communities, whose livelihood is supported by fishing, are negatively affected where dissolved oxygen concentrations are low, due to the decline of fish populations (Chapman 1996).

2.2.1.3 Total Dissolved Solids

The organic matter and inorganic salts that are present in solution are known as total dissolved solids (TDS). TDS consists of organic matter in small amounts and inorganic substances such as chlorides, sulphates, sodium, calcium, bicarbonates, magnesium and potassium. In general TDS is the sum of ions in water (cations and anions) (Scannell & Jacobs, 2001). Increased concentration of TDS in streams and rivers often results from the discharge of industrial effluents. This is further influenced by the water balance, which in turn is influenced by actions such as limiting the inflow to the river by abstraction by the industry or agriculture, salt water intrusion, increase in precipitation in rainy season or decrease in dry seasons or drought periods or increase in water usage (Weber-Scannell & Duffy, 2007). Total dissolved solids can be inhibitory or toxic if salinity levels are high. Further this effect depends on the composition of ions and the toxicity of individual ions. The biotic community is affected by increase in salinity which can reduce the biodiversity and cause chronic or acute effects in certain life stages of aquatic organisms (Bierhuizen & Prepas, 1985). A study by Derry et al. (2003) showed that increase in salinity had a negative impact on the aquatic biodiversity.

Ion concentrations, when they have reached toxic levels, may inhibit the hatching of salmonid eggs that are exposed during fertilization period (Stekoll et al., 2003) (Erickson et al., 1996.). Further, Stekoll et al. (2003) observed that $Ca2^{+}$ plays a significant role in inhibiting salmonid eggs from hatching when they are exposed during the process of fertilization.

TDS affect the amounts of inorganic and organic substances, and can be a useful parameter in determining quality of water or pollution load in streams or rivers (Rozelle & Wathen, 1993). A change in the density of total dissolved solids is harmful to organisms because total dissolved solids determine the flow of water in and out of cells of organisms. The growth of fish or reefs may be limited by the changes in the amounts of dissolved solids. In most developed countries, fishing is one of the major income ventures for local communities, and thus changes to production of fish could lead to difficulties for local communities. High TDS in water may make the water have unpleasant odor and taste salty, metallic or bitter. Some minerals that make up TDS like nitrates, sulfates, sodium, copper, fluoride, barium and cadmium, could pose health challenges in humans when consumed in high quantities (Mamabolo et al., 2009).

2.2.1.4 Turbidity

Turbidity is the measure of suspended solids in water. Turbidity represents the degree of cloudiness of a stream or river. Turbidity can be caused by mud, silt, plant pieces, wood ash, sawdust, algae or other micro-organisms and precipitated chemicals that find their way into the water body or thrive in the water body. The presence of these suspended solids reduces the amount of light penetrating water for the benefit of aquatic photosynthetic organisms (Lloyd et al., 1987; Anderson, 2003). Turbidity contributes significantly to the decline of aquatic organisms; its impact can be witnessed through pervasive alterations of local food chains (Henley et al., 2010). Suspended particles emanating from effluents absorb heat from the sun, making the water warmer and thus reducing the concentration of oxygen in water; thereby affecting survival of aquatic organisms. Photosynthetic activities of plants and algae also decrease with decreased light penetration, thus reducing oxygen (Anderson, 2003). Suspended particles that settle at the bottom in streams and rivers, may cover and suffocate insect larvae and fish eggs, gill structures also get damaged or clogged (McCoy & Olson, 1986).

Though substances resulting in high turbidity may not be harmful, their effects can be. Too much sediment or algae in rivers and streams can make the water become unsuitable for recreation activities. Turbidity can increase the cost of treating water for drinking and also food processing. Further, it can harm fish and other aquatic organisms thus reducing food supplies, affecting gill function and degrading spawning beds (Henley et al., 2010).

2.2.2 Chemical Parameters

Water pollution ultimately is affected by the type of mining method employed, chemicals used to process the minerals and the type of mineralization. It is evident from different literature that mostly pollution occurs during the leaching process and the point of discharge of effluents (Mestre, 2009; Nude et al., 2011). The pollution of streams and rivers through mining effluents is among the challenges affecting natural communities and ecosystems (Ibemenuga, 2013). In developing countries, most of the streams and rivers are heavily polluted from effluent discharge emanating from mining, agriculture and other industries (Kambole, 2003). Metals and other dissolved salts such as sulphates, phosphate and nitrates find their way into streams and rivers through different sources such as discharge of treated and untreated liquid waste, leachate from disposal of solid wastes and runoff (Akoto et al., 2008). Research has shown that both abandoned and active mine sites can be major contributors to the degradation in quality and quantity of water in streams as well as rivers within the vicinity of mining operations (Earle & Callaghan, 1998). Trace amounts of heavy metals such as Pb, Cu, Co, Mn, Zn and Fe, are important nutrients for animals and plants (Akoto et al., 2008). However, heavy metals are toxic at high concentration (Voegborlo et al., 1999; Vutukuru, 2005).

Toxic metals undergo biogeochemical cycle with substantially different residence times in the various spheres and compartments of the environment. In this cycle, humans consume trace metals predominantly from food and drinking water. Accumulated metals in aquatic organisms are passed up the food chain directly or indirectly through consumption of polluted organisms or water (Speigel, 2002). In the long run, this will exert progressively growing toxic actions depending on the cumulative magnitude of the metal and for how long an individual has been exposed to a particular metal and environment (Sabine & Griswold, 2009).

Polluted water from the mines may be discharged into the surrounding streams in the area thereby contributing the concentration of heavy metals and acidity of the stream water, depending on the quality of the mine water (Gyang & Ashano, 2010; Ochieng et al., 2010; Bernhardt et al., 2012; Merriam et al., 2013).

2.2.2.1 Acceptable Legislative values

Tables 2 shows the global standards by Initiative for Responsible Mining Assurance (IRMA) for different water quality use, while table 3 shows the standards for limiting effluent discharge in Zambia.

Table 2: IRMA Surface Fresh Water Quality Criteria

Metal/ Metaloids	Units	Criteria	Most Senstive Use	Source
Aluminum	µg/L	30	Aquaculture	AUS, WHO
Antimony	µg/L	6	Human Health - Drinking Water	USEPA, Health CA
Arsenic	µg/L	10	Human Health - Drinking Water	USEPA, Health CA, AUS, WHO
Barlum	µg/L	1000	Human Health - Drinking Water	Health CA
Beryllum	µg/L	60	Human Health - Drinking Water	AUS
Cadmium	µg/L	X^5	Aquatic Organisms Fresh Water	USEPA
Calcium	µg/L	Measure		
Chromium (Total)	µg/L	50	Human Health - Drinking Water	Health CA, AUS, EU, WHO
Chromium (VI)	µg/L	20	Aquaculture	WHO
Cobalt	µg/L	50	Agriculture - Irrigation	AUS, CCME, FAO, USEPA, SA
Copper	µg/L	X^5	Aquatic Organisms Fresh Water	USEPA
Iron	µg/L	10	Aquaculture	AUS,WHO
Lead	µg/L	X^5	Aquatic Organisms Fresh Water	USEPA
Magnesium	mg/L	Measure		
Manganese	µg/L	10	Aquaculture	
Mercury	µg/L	0.07	Aquatic Organisms Fresh Water	AUS

Molybdenum	µg/L	10	Aquaculture	EU
Nickel	µg/L	X5	Aquatic Organisms Fresh Water	USEPA
Phosphorous (Total	mg/L	Measure		
Potassium	mg/L	Measure		
Radum 226/228	Bq/L	0.2	Human Health - Drinking Water	USEPA
Selenium	µg/L	5	Aquatic Organisms Fresh Water	USEPA, SA, AUS-NZ
Silver	µg/L	0.25	Aquatic Organisms Fresh Water	CCME
Sodium	µg/L	Measure		
Thallum	µg/L	0.8	Aquatic Organisms Fresh Water	CCME
Uranium 238	µg/L	15	Aquatic Organisms Fresh Water	CCME
Uranium 238	Bq/L	1	Human Health - Drinking Water	WHO
Vanadium	µg/L	100	Aquaculture	AUS
Zinc	µg/L	X5	Aquatic Organisms Fresh Water	USEPA

Table 3: Zambia´s National Effluent Statutory Limits.

Air emission (mg/Nm^3)		**Water effluent discharge (mg/l)**	
Sulphur dioxide	1 000	Suspended solids	100
Arsenic	0,5	Arsenic, total	0,5
Cadmium	0,05	Cadmium, total	0,5
Copper	1	Copper, total	1,5
Lead	0,2	Lead, total	0,5
Mercury	0,05	Mercury, total	0,002
PM10 Smelters	50	Iron, total	2
PM10 Other	50	pH	6-9 units

2.3 Case Studies

Various studies globally have taken note of the negative impact of mining on the quality of water.

Table 4 shows the effects of heavy metals on the environment.

Table 4: Effects of heavy metals

Area	Heavy Metals	Effects	Reference
Gangqu River, China	Cd, Cu, Pb, Zn and Ni	decrease of abundance and species richness in the stream	Qu et al. (2010)
Rgani stream, Republic of Georgia	Fe	decrease in growth of aquatic organisms	Caruso (2012)

Jos South Local Government area of Plateau State, Nigeria	Cu, Pb and Zn	low crop productivity	Adegboye, 2012
India	Cu, Co, Fe, Zn	Afects diversity of aquatic organisms and ecological balance	Baby et al., 2010
Nigeria	Cu	Exposed fish exhibited reduced activity, weakness and were covered in thick mucus	Olaifa et al., 2004
Ogun River, Nigeria	Pb	affect the production of food by algae and growth of aquatic organisms	Farombi et al., 2007

2.3.1 Acid Mine Drainage

In South Africa, Ochieng et al. (2010) observed that Acid Mine Drainage is one of the most difficult mine waste challenges to address. Post mining, water decanting from defunct coal mines to Olifant River catchment was estimated at 62 ml/d (DWAF, 2004; Maree et al., 2004). It is very clear that for decades to come, significant volumes of water need to be managed on continuous basis. Durkin and Herrman (1994) also noted that while groundwater levels are kept well below ground level to permit effective mining operations and easy access to the coal reefs in Gauteng and Mpumalanga coal mines, when mines close and stop pumping, groundwater levels will rise (Scott, 1995). Acid mine drainage is problematic in the highveld coalfield in Mpumalanga as evident in the severe pollution seen in Loskop Dam and Olifants River catchment (Naicker et al., 2003; Garth, 2010).

Figure 7: Mine water pollution in west rand area of Johanesburg (Garth, 2010)

2.4 Bio-indicators of Water Quality

Bio-monitoring has been used successfully in the recent past as an indicator of the integrity of the habitat. Living organisms are used to assess the water conditions (Davies & Day, 1998). The concept of bio-monitoring can be traced back in history to the times of Aristotle, who used fish from freshwater and observed its reaction when placed in sea water (Rosenberg, 1998). In 1816, the experiments on the toxicity of water were published for the first time with several species from freshwaters that could survive polluted water (Rosenberg, 1998). The bio-indicator systems of assessing the quality of surface water were introduced in 1850 by Kolenati and Cohn who noticed that the composition of organisms in polluted waters was different to freshwaters (Bredenhand, 2005). The use of aquatic organisms for assessment of water quality can also be traced back to the early 1900's to work done by German scientist's R Kolkwitz and M Marsson, which was instrumental in developing indicator organisms (Rosenberg, 1998). Bio-indicators today have become very useful in assessing a wide variety of issues ranging from health of water bodies to economic management of the same.

The bio-indicator concept is built on the assemblage of species that are well matched to specified features of a given ecosystem and how they react to impacts and changes in the ecosystem (Paoletti & Bressan, 1996). The use of macroinvertebrates as bio-indicators can reveal interesting diversity in the assessment of natural habitat (Holopainen & Oksanen, 1995). With the passage of time, bio-indicators have become an important concept when it comes to assessing polluted areas, urban and industrial settlements and the aquatic environment (Paoletti, 1999). It is because of this, that freshwater macroinvertebrates offer a compelling advantage in bio-monitoring practices, in that they have numerous vantage grounds (Rosenberg, 1998):

- They are ever present or ubiquitous, thus are affected by changes in aquatic environment
- They are rich in diversity, this provides a wide range of responses from the large number of species
- They have a sedentary lifestyle, this provides a platform to determine the spatial extent of the changes aquatic environment

- They have a long lifespan, this allows changes in age structure and abundance to be assessed; and
- They embrace conditions temporally, thus like most aquatic organisms, they provide evidence of changes in the environment over a period

Out of the estimated 1.4 to 1.8 million species that have been identified (Hammond, 1995), macroinvertebrates are the majority of the organisms. This makes them ideal for assessment of environmental conditions because of their high species diversity, important when it comes to proper functioning of the ecosystem and ubiquitous occurrence (Rosenberg et al., 1986).

Macroinvertebrates contribute towards stability of stream ecology because they are a link between organic resources in water and aquatic organisms (Alvial et al., 2012). The stability of the aquatic ecosystems depends on the richness of the diversity for sustainability in terms of food, breeding habitats and other material benefits (EPA, 2009). Some improve the productivity of the ecosystems as they are an important food source for many other organisms (e.g. mayflies, dragonflies, stoneflies, etc); some are important agents for biological control of harmful insects (e.g. beetle larvae and adults which feed on mosquito larvae); some grow into insects that become an important food source for man while others are useful bio-indicators of the quality of aquatic ecosystems.

Most of the macroinvertebrates are useful bio-indicators or indices of pollution because of their low mobility which makes them incapable of avoiding stressful conditions in water. Some of them have their habitat in sediments and thus are exposed to various changes in the environment such as high concentration of heavy metals and low pH (Holt & Miller, 2011). Macroinvertebrates spend most of their lives in the same water and same area over a long period of time, showing their response to different environmental stressors and adapt accordingly (Cook, 1976; Pratt & Coler, 1976; Hutchinson et al., 1998; M'Erimba & Mathooko, 2006). Normally invertebrates do not swim freely; they find solace at the bottom of surfaces like roots, vegetation that is submerged or trees that have fallen. Because of their propensity for bottom habitats they are referred to as benthic, from Greek (*benthos=depth).*

The composition of aquatic community is normally affected by both physical and chemical composition of the waters in which they live (Holt & Miller, 2011). Many different species like plants, insects, birds, fish, damselfly larvae, dragonfly larvae, mayfly, riffle beetle, water penny and others, find their home in the aquatic ecosystem. The way they are arranged, they form a complete ecosystem from the smallest building block of life, into species, populations and communities (EPA, 2009).

Macroinvertebrates have been used in many countries in monitoring the ecological conditions of water bodies' ecosystems (Hellawell , 1986). They are important components of the aquatic food web as they act as a link between the nutrient resources sand organic matter (Wallace & Webster, 1996). Composition of aquatic organisms' changes in response to environmental stress in a predictable manner; this makes it possible to evaluate the stress (Boyle & Fraleigh Jr, 2003). The changes in response to anthropogenic influences can be grouped into three categories: diversity reduction, individual size reduction of dominant species and retrogression to dominance by opportunistic species (Gray, 1989). In rivers or streams that are characterized by heavy metal pollution or organic matter, the composition of aquatic organisms, especially macroinvertebrates, reduces whether the contamination is direct or indirect (Winner et al., 1975; Whitehurst & Lindsey, 1990; Clements, 1994; Hickey & Clements, 1998).

2.4.1 World perspective

European countries are seen as the leaders in using macroinvertebrate community assessment as a planning tool for managing water uses, for ambient monitoring and for evaluating the effectiveness of pollution control measures (Metcalfe, 1989). In the United Kingdom, the models predominantly make use of multivariate statistics in which a few environmental variables considered to be unaffected by human activities are used, and from which predictions are made for the fauna expected at a given test site (Resh et al., 1995). In France, use is made of the Ephemeroptera, plecoptera, trichoptera and coleoptera (EPTC) species richness and the Indice Biologique Global Normalise (IBGN) (Compin & Cereghino, 2003).

American researchers analyze data several indices presumed to represent ecological features of interest (Resh et al., 1995). This includes the interpretation of potential confounding effects of habitat degradation and water quality (Plfkin et al., 1989) and to a less extent the prediction of biotic communities expected at a given site (Winget & Mangum, 1979). The monitoring programmes that have been developed in the United States include the Environmental Protection Agency (1990), the National Water-Quality Assessment Program (NAWQA) of the Geological Survey (Gurtz, 1994), the Bio-monitoring of Environmental Status and Trends (BEST) Program of the United States Fish and Wildlife Service, and the inter-agency oversight committee called the Intergovernmental Task Force on Monitoring Water Quality (Anonymous, 1992). Other influences on the use of benthos in bio-monitoring include the National Biological Survey of the United States Department of Interior (Anonymous, 1993).

2.4.2 Case studies

Various studies have been reported on the usage of Macroinvertebrates as bio-indicators of the health of a stream or river (Cairns Jr & Der Schalie, 1980; Cairns Jr, 1981; Matthews et al., 1982; Abowei et al., 2012; Ngodhe et al., 2014; Qu et al., 2010; Xu et al., 2014; Resende et al., 2010; Rodrigues & Bueno, 2016). Macroinvertebrates like aquatic insects have been used to assess various environmental changes (table 5) like heavy metal pollution (Winner et al., 1980; Smolders et al., 2003; Poulton et al., 1995), organic pollution (Zamora-Muñoz & Alba-Tercedor, 1996), acidification (Sandin & Johnson, 2000; Sandin et al., 2004; Davy-Bowker et al., 2005) and general stressors (Dolédec et al., 1999; Karr & Chu, 1999).

Table 5: Responses of macroinvertebrates to environmental stressors

Area	**Organisms**	**Indicator**	**Effect of pollutant**	**Reference**
Nigeria	Bivalve Molluscs, Gastropod Molluscs, Polychaetes, Crusteceans	Poor water quality	low diversity of species	Abowei et al. (2012)

Calbor River, Okpoka Creek, Woji Creek, Niger delta	Polychaetes	High concentration of heavy metals, low pH	low diversity of species	Umoezer (1995), Hart & Zabbey (2005), George et al. (2010)
Lagos Lagoons, Nigeria	Tellina nymphalis, Clibanarius africana, and Penaus notialis	High dissolved oxygen	Low density	Nkwoji et al. (2010)
Gangqu River, China	Plecoptera, Ephemeropter a and Trichoptera	Poor water quality	intolerant macroinvertebrates density absent	Qu et al. (2010
Lake Victoria, Kenya	Amphipod, Leech	Low dissolved oxygen, temperature and pH	Low diversity and density of macroinvertebrates	Ngodhe et al. (2014)
Yenga and Mauna Dams	Dragonfly, Mayfly, Amphipod	High temperature, low DO, low TN and high BOD	Low species diversity and composition	Ngodhe et al. (2014)
China	Snail, Isopod, leach	Low pH, high concentration of heavy metals (Cu, Pb, Zn)	species found in water and stream reflects the water pollution levels	Xu et al. (2014)
China	Snail, Isopod, leech	High TDS, turbidity and heavy metal concentration	Characterized by benthic communities that are tolerant to pollution	Zhang et al., (2014)
Rio Doce River, Brazil	Mayfly, Amphipod, Isopod	Poor water quality	decrease in diversity and modification of the composition of aquatic organisms’	Rodrigues & Bueno, 2016
Red Dog Mine in Alaska, USA	Lichens	Good water quality	Species diversity and density improves with distance from pollution source	Hasselbac h et al. (2005

Umatilla River, Oregon, USA	Isopod, snail, Amphipod	Poor water quality	Dominated by tolerant macroinvertebrates	Miller et al. (2007)

Miller et al. (2007) used macroinvertebrates to assess the effect of water withdrawals exceeding 85% ambient levels (Figure 8). The results showed that water withdrawals impacted the aquatic community of the Umatilla River, Oregon, USA. There was a decline in the intolerant invertebrates whilst the tolerant invertebrates thrived and increased (Miller et al., 2007).

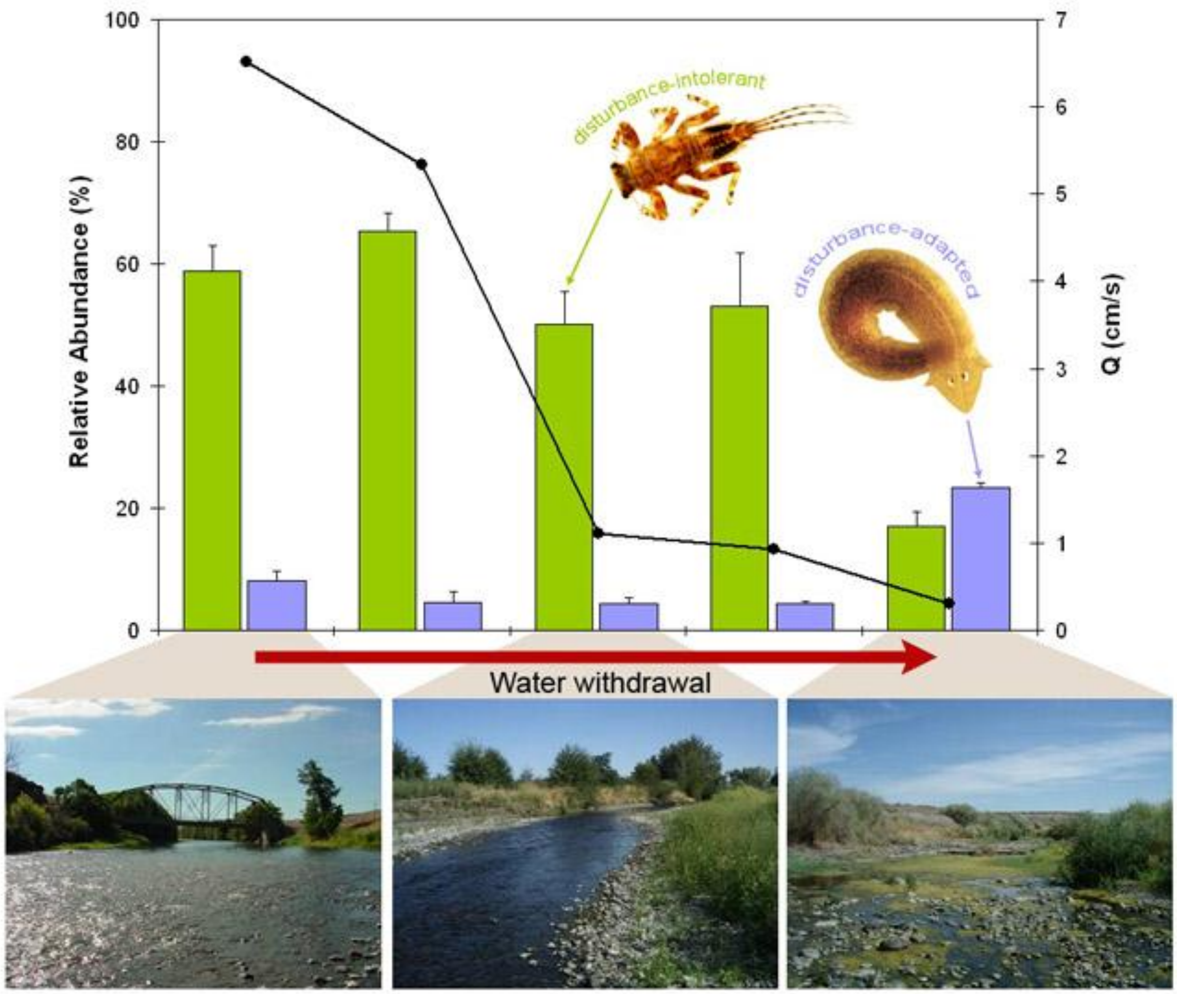


Figure 8: Aquatic Macroinvertebrates document a shift in community composition related to human-induced water withdrawals. The bars represent the intolerant invertebrates (green, Ephemeroptera-Plecoptera-Trichoptera) and tolerant invertebrates (blue, non-insects). The line represents the discharged water at each site.

The diversity of species in water can be affected also by low concentration of heavy metals (Qu et al., 2010). Van Damme et al. (2008), from Bolivia, noted that the biological diversity and stream health is affected by heavy metal concentration even at low level. Accumulation of heavy metals over time changes the community composition of Macroinvertebrates (Freund & Petty, 2007), though the concentration maybe low, long term exposure of heavy metals to invertebrates could change composition (Qu et al., 2010). The accumulated heavy metals can change the function of the ecosystem (Clement et al., 2000). They observed that macroinvertebrate abundance was significantly affected by heavy metal concentration. Highly sensitive invertebrates like mayflies (Ephemetroptera: Heptageniidae) were greatly affected by heavy metals, with a reduction >75% at sampling points that were moderately polluted. The total abundance of heptageniids and mayflies were indicative of the extent of heavy metal pollution. Carlisles & Clements (1999) and Watanable et al. (2008) noted that predators are the most sensitive species to heavy metals.

Nonetheless, the sheer number of macroinvertebrates, leads to major challenges in completely utilising this goal and invertebrates are often avoided for a variety of reasons. As inveretebrates are seen as small and cryptic in their coloration and behaviour, during an environment impact assessment they do not receive attention given to more conspicuous animals such as fish, birds, or mammals, as well as difficulty in keeping invertebrates in captivity for laboratory bioassays or toxicity/tolerance tests (Rosenberg & Resh, 1993). A motion also exixts that the costs of using invertebrates outweigh the benefits (Resh & Gradhaus, 1983). Certainly, the analysis of collections of invertebrates is often labour-intensive and time consuming, but new approaches are developed to deal with this problem (Water-Monitoring, 2007.

The use of wild stock in tests is also hampered by the usual lack of historical information, such as generic variation (within species), health status, previous exposure and age differences (Snell, 1990).

CHAPTER 3: MATERIALS AND METHODS

3.1 Research design

This section illustrates several main themes of this research and highlight important methodological considerations that have shaped how this research was conducted. These methodological considerations and choices are discussed in detail in this chapter.

Quantitative research method, was adopted in this research. The quantitative research method used involved to ascertain whether Munkulungwe stream is polluted. The quantitative method used allows for a mathematical assessment of the pollution state of Munkulungwe stream.

The data-gathering tools, or research instruments, that were used are Physicochemical and bio-indicators Analysis. The aim of physiochemical and bio-indicator analysis was to evaluate the heavy metal concentration and water quality. These methods are discussed in more detail in section 3.4 and 3.5.

3.2 Study area (Bwana Mkubwa TSF)

Five sampling sites were selected for easy access both during and after the rainy season whilst ensuring that valid and quality data was collected. Of the five selected sampling sites, one site (S1) was located on the Munkulungwe stream upstream of the impact of the Bwana Mkubwa Tailings Dam. Three sites (S2, S3 and S4) were on the main river downstream of Bwana Mkubwa Tailings Dam. No tributaries joined the river between sites S1 and S4. Site 5 was located close (200 m) to Bwana Mkubwa Tailings Dam (Figure 10). S5 was chosen for the sole purpose of assessing the quality of the seepage water from the tailings dam. However, access to sampling point S5 was denied by Bwana Mkubwa Mine. S1 was chosen as the control point on the basis that it is located upstream before Bwana Mkubwa Tailings Dam and is unaffected by any discharge from the tailings dam (Davies et al., 2002; Ghose and Sen, 1999). The location of the sampling points is displayed on Figure 10 and their GPS co-ordinates given in Table 6.

Table 6: Sampling sites, locations and stream

Sample Location and Code	**Name of Stream**	**GPS Reading**	**Distance**
S1 (Control Point)	Munkulungwe	Lon. 28.731, Lat. -13.043	S1 – S2 (1008 m)
S2	Munkulungwe	Lon. 28.727, Lat. -13.051	S2 – S3 (252 m)
S3	Munkulungwe	Lon. 28.725, Lat. -13.053	S3 – S4 (699m)
S4	Munkulungwe	Lon. 28.721, Lat. -13.058	S4 – S5 (960 m)
S5	Munkulungwe	Lon. 28.720, Lat. -13.048	S1 – S5 (1354 m)

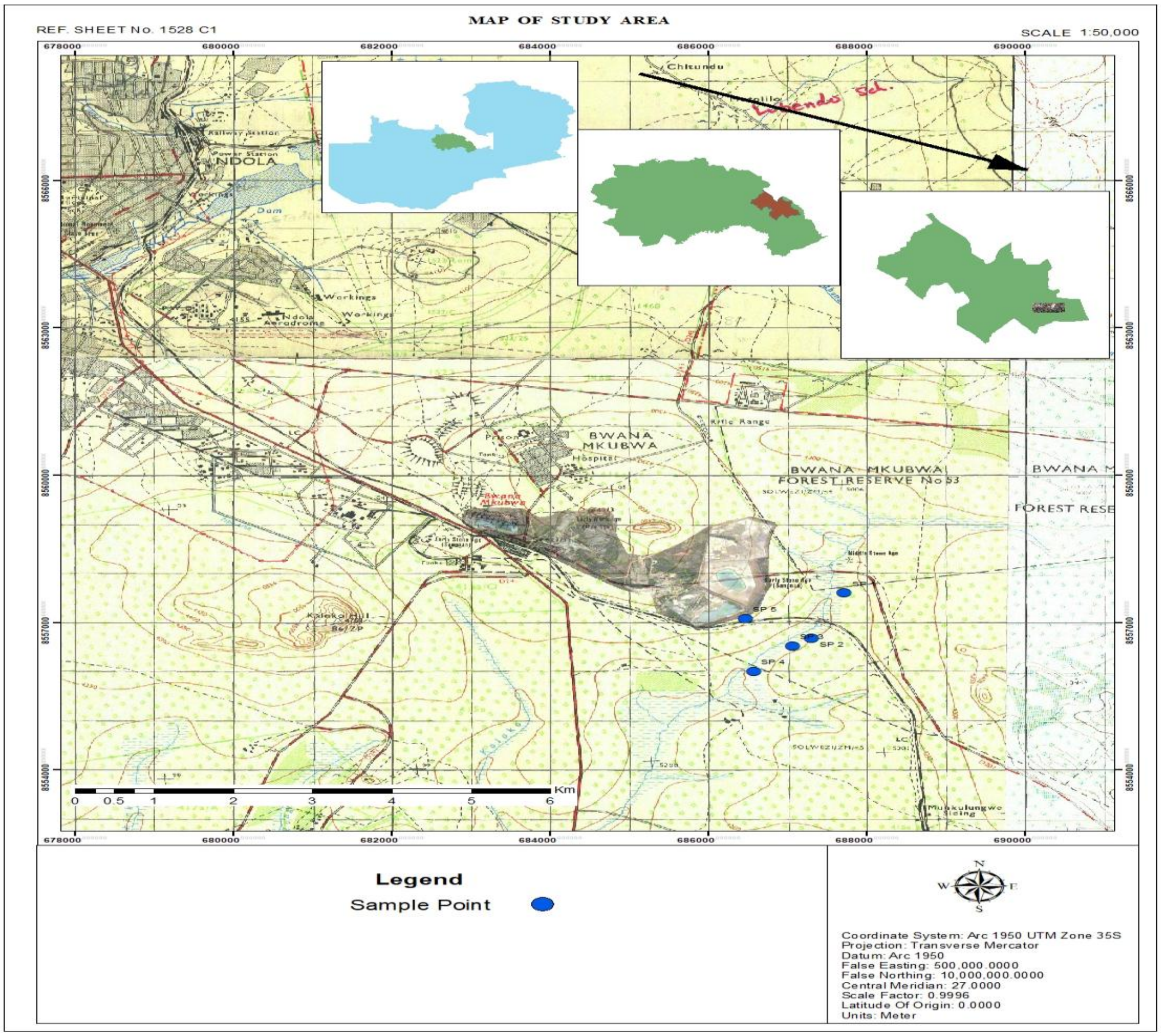


Figure 9: Locale of the study and positioning of sampling points

3.3 Sampling strategy

Samples were obtained using the biotic index kick-sampling method, where rocks and other benthic material were disturbed to flow downstream into a soft, 1mm mesh net, 30 cm in diameter. This was done in all possible microhabitats within any one site for 15 min.

The content of each sample was then washed down to the bottom of the net and carefully tipped into a tray by inverting the net. The net was then flushed out with water to transfer all biota to the tray. Samples were then taken to the laboratory for further analysis.

Sampling was done twice a month across two different seasons and, spanning five months beginning in February 2016 and ending in June 2016, covering dry and wet season. Before sampling, distilled water was used to wash and rinse all the sampling bottles and dried. The sample bottles were washed at least three times with water from the stream on the day of sample collection, before being filled with sample. Thereafter, the date and source of sample was labeled on the bottle. A cooler box was used for storage and transport of the samples. The pH, DO, TDS and turbidity were measured on site. The samples were collected along Munkulungwe stream from different locations specified at sampling times between 09:00hrs and 12:00hrs and transported to the laboratory immediately after sampling. The analysis for each parameter was carried out using respective equipment namely: multimeter probe (dissolved oxygen and total dissolved solids), pH meter (pH) and turbidity meter (turbidity). The heavy metals were analyzed using an Atomic Absorption Spectrophotometer (AAS).

3.4 Sample Analysis

3.4.1 Physicochemical Analysis of Samples

3.4.1.1 pH

The sample water was taken in a small beaker and then the probe of the pH meter was placed inside the water for a few minutes. The pH meter showed the reading, but the final reading recorded was the one when the reading became static.

3.4.1.2 Dissolved Oxygen (DO)

The sample was taken in the bottle and the probe of the multimeter was then placed inside and the reading was then taken.

3.4.1.3 Total Dissolved Solids (TDS)

The probe of the multimeter was placed in the beaker which had the water sample for a few minutes. The static results that was shown on the multimeter was taken as the TDS reading.

3.4.1.4 Turbidity

The water sample was placed in the small tube of the turbidity meter and the meter was switched on. The reading was then taken from the meter.

3.4.1.5 Heavy metals

The samples were digested using concentrated nitric acid. 5 mL of concentrated nitric acid was added to 50 mL of water sample and then heated in a 100-mL beaker until it boiled, and the volume reduced to 20-mL. 5 mL of concentrated nitric acid was again added, and the sample was heated again for about 10 minutes and then allowed to cool. The solution was then transferred into a 50-mL volumetric flask and distilled water was added to make up the mark. A blank was also prepared in a similar manner. The analysis of heavy metals was done using the Atomic Absorption Spectrophotometer. The calibration curve for each metal were then drawn by running suitable concentrations of their standard solutions. Extrapolation was used to obtain the concentration of the heavy metals. The experiment was repeated three times and the average values for each were taken. The blank solution was absorbed before the analysis of the samples.

The results obtained were compared with the limiting values of the different water quality parameters, to assess the quality of water in Munkulungwe stream.

3.4.2 Analysis of bio-indicators

Sampling of macroinvertebrates was carried out using the D-frame net, and the captured macro invertebrates were placed on a white dish pan, then the identification was carried out by the Benthic Macro Invertebrate Key according to Birmingham et al. (2005). Various attributes were considered during identification of macroinvertebrates such as shells, legs etc. Thereafter these invertebrates were grouped according to tolerance levels: Group 1 consisted of macroinvertebrates that are pollution sensitive, Group 2 included macroinvertebrates that are pollution semi sensitive, while Group 3 was comprised of macroinvertebrates that are semi tolerant to pollution and Group 4 included macroinvertebrates that are pollution tolerant (see appendix D). The organisms found were circled in the group to which they belonged, and the total number of circled organisms was counted, and the value recorded in bottom right corner of the Benthic Macroinvertebrate Key (Water-Monitoring, 2007).

3.4.2.1 Calculation of Biotic Index Score

The total number of organisms in each category was multiplied by the relevant group value, given below:

- Group 1 – The value is 4
- Group 2 – The value is 3
- Group 3 – The value is 2
- Group 4 – The value is 1

The products were recorded and totaled to give the total value (b). The numbers of organisms from each group were also totaled to give the total number of organisms (a). The biotic index score was then calculated the quotient of (b) and (a).

Biotic Index Score = b/a

This value was used to verify health of the stream:

Excellent water------------------------3.5+

Good water-----------------------------2.6 – 3.5

Fair water-------------------------------2.1 – 2.5

Poor--------------------------------------1.0 – 2.0

3.5 Statistical Analysis

Two approaches were taken to statistical analysis:

a) Calculation of biotic indices
b) The relationship between variables (biotic index – other variables, relationship between DO – turbidity, metal – DO, metal – metal, and metal-turbidity)

The results that were obtained from each site were analyzed statistically using the Statistical Package for Social Science (SPSS) and Microsoft Excel software, by analyzing the correlation between variables obtained. Correlation provides a good basis to give an indication of the relationship between two variables. Some characteristics can be useful in predicting how others will change. This is very useful in understanding certain changes in behavior patterns that otherwise would not have been understood.

3.6 Limitations of research method

Useful as biomonitoring can be, there remain significant challenges to improving its utility. Largely missing are precise assessments of risk that are necessary to determine the health consequences of exposures. Biomonitoring can improve risk assessments by enabling researchers to couple direct observations of physical symptoms or effects with measurements of chemical uptake. But establishing the correct relationship is no easy task. Biomonitoring data only reflect the amount of a chemical in the body at the time of testing, which may differ from the original exposure. One sample reading could represent exposure from yesterday, last week, or 30 years ago (Juberg et al, 2008).

Moreover, health consequences, if any, may result either from the original exposure or from the presence of the compound in the body over time. Nor is the source of exposure always apparent, further complicating the interpretation of biomonitoring results. The ability to generate new biomonitoring data often exceeds the ability to evaluate whether and how a chemical measured in an individual or population may cause a health risk or to evaluate its sources and pathways for exposure (Kamrin, 2008).

CHAPTER 4: RESULTS

4.1 Munkulungwe Stream

In this section of the document, results are presented. These results represent the water quality in Munkulungwe stream during the period February to June 2016, during which the research was conducted. The range of values of the water parameters, heavy metals, macroinvertebrates and the biotic index score obtained from the data units are presented from the four sampling points along the stream. The variation in values with change in season is also presented in this section.

4.2 Physical parameters

The following parameters were monitored: pH, dissolved oxygen concentration (DO), turbidity and TDS. Table 7 and 8 show the measured values of physical parameters and their range, mean and standard deviation. Each of these parameters varied with season at each sampling point.

Table 7: Variation of physical properties during the period of sampling, February to June 2016, along the Munkulungwe stream

Site/Date	18-Feb	25-Feb	21-Mar	28-Mar	15-Apr	09-May	23-May	13-Jun	20-Jun
	pH Rainy Season					**pH Post Rainy Season**			
S1	7.4	7.6	7.2	7	7.3	7	6.5	6.9	7.2
S2	7.2	7.8	6.4	7.1	6.9	7.2	6.8	7.5	7
S3	7.3	7.8	7.5	6.9	6.8	6.5	6.7	7.2	6.9
S4	7	7.8	7.4	6.5	6.8	7	6.8	7.2	7.5
	DO (mg/l) Rainy Season					**DO (mg/l) Post Rainy Season**			
S1	5.83	4.64	5.05	5.47	5.5	4.12	3.5	5.01	2.52
S2	5.27	4.79	5.03	5.18	5.07	3.16	5.02	2.67	3.9
S3	5.04	5.05	5.47	5.28	5.21	3.21	3.86	4.3	3.05
S4	5.66	5.93	5.27	5.3	5.54	4.01	4.25	3.92	3.65
	TDS (mg/l) Rainy Season					**TDS (mg/l) Post Rainy Season**			
S1	246	305	202	194	227	203	265	187	149
S2	182	345	178	283	302	164	301	158	243
S3	276	342	294	296	230	240	300	273	256
S4	282	340	299	297	275	252	291	259	223
	Turbidity (NTU) Rainy Season					**Turbidity (NTU) Post Rainy Season**			
S1	28	30	45	89	70	30	38	30	55
S2	40	30	67	65	50.5	36	32	40	50
S3	25	11	54	93	45.8	20	22	35	27
S4	22	33	77	39	42.8	30	25	42	33

Table 8: Mean, SDs and Range of values for the physical parameters

Site/Parameter	pH	DO (mg/L)	Turbidity (NTU)	TDS mg/L
S1				
Rainy Season				
Range	7 - 7.6	4.64 - 5.83	28 – 89	194 - 305
Mean + SD	7.3 ± 0.223	5.3 ± 0.46	52.4 ± 26.46	234.8 ± 44.31
Post Rainy Season				
Range	6.5 – 7.2	2.52 - 5.01	30 – 55	149 - 265
Mean + SD	6.9 ± 0.29	3.79 ± 1.05	38.25 ± 11.79	201 ± 48.31
S2				
Rainy Season				
Range	6.4 - 7.8	4.79 - 5.27	30 – 67	178 - 345
Mean + SD	7.08 ± 0.51	5.07 ± 0.18	50.5 ±15.91	258 ± 74.68
Post Rainy Season				
Range	6.8 - 7.5	2.67 - 5.02	32 – 50	158 - 301
Mean + SD	7.13 ± 0.3	3.69 ± 1.02	39.5 ± 7.72	216.5 ± 68.36
S3				
Rainy Season				
Range	6.9 - 7.8	5.04 - 5.47	Nov-93	230 - 342
Mean + SD	7.26 ± 0.42	5.21 ± 0.18	45.76 ± 31.38	287.6 ± 40.38
Post Rainy Season				
Range	6.5 - 7.3	3.05 - 4.3	22 – 55	240 - 300
Mean + SD	6.93 ± 0.39	3.61 ± 0.58	26 ± 6.68	267.25 ± 25.66
S4				
Rainy Season				
Range	6.5 - 7.8	5.27 - 5.93	22 – 77	275 - 340
Mean + SD	7.1 ± 0.51	5.64 ± 0.27	42.76 ± 20.69	298.6 ± 25.25
Post Rainy Season				
Range	6.6 -7.5	3.65 - 4.25	25 – 42	223 - 291
Mean + SD	7.03 ± 0.40	3.96 ± 0.25	32.5 ± 7.14	256.25 ± 27.92

4.2.1 pH

The pH of the stream was largely neutral, lying between pH 6.5 and 7.8 (Table 8). The mean pH values were within acceptable limits for drinking (6.5-8.5), irrigation (6.5-8.4), aquaculture (6.5-9.0), aquatic (6.5-9.0), and recreation (6.5-8.5) as per the water standard given by the IRMA. The difference of pH between sample points and season was minimal. Change in season and sampling point had very little influence on the pH. During the rainy season, the pH was relatively constant between 6.4 to 7.8 and post rainy season 6.5 to 7.5. The natural background of pH (7.0) was slightly lower than the mean values of pH during the rainy season. The lowest pH of 6.4 was recorded in S2 samples during the rainy season. After the rainy season, the lowest pH of 6.5 was recorded at S1 and S3. The highest pH of 7.8 during the rainy season was recorded at S2, S3 and S4, while post rainy season, the highest pH of 7.5 was recorded at S2 and S4 respectively. The low pH (6.4) recorded at S2 in March, could be attributed to runoff from the tailings dam caused by the rain. Figure 12 gives the average days with precipitation per month in 2016. The variation in pHs was most evident at S2 during the rainy season, varying between 6.4 – 7.8 (with a mean of 7.08 ± 0.507). In comparison, the pH varied between 7 – 7.6 (with a mean of 7.3 ± 0.2236) at S1 during the rainy season. After the rainy season, the value of pHs varied between 6.5 – 7.2 (with a mean of 6.9 ± 0.2944) at S1 and 6.8 – 7.5 (with a mean of 7.125 ± 0.2986) at S2 (Table 8).

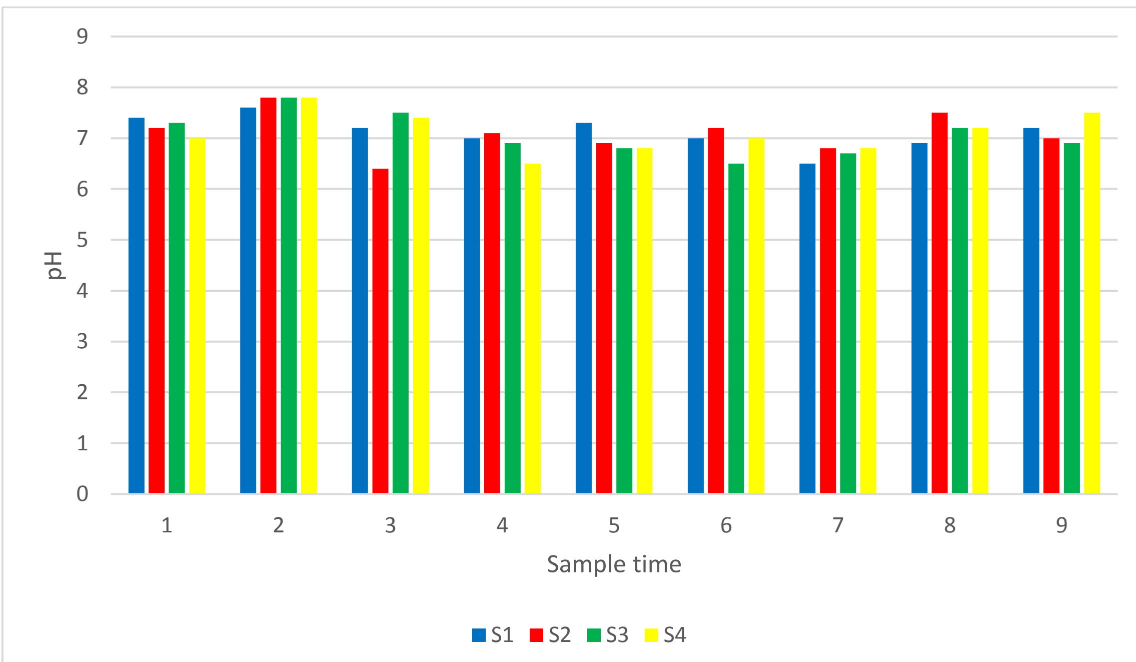


Figure 10: Variation of pH values between sampling points S1 – S4, February 2016 to June 2016, along the Munkulungwe stream; sample t1 (18-Feb), sample t2 (25-Feb), sample t3 (21-Mar), sample t4 (28-Mar), sample t5 (15-Apr), sample t6 (9-May), sample t7 (23-May), sample t8 (13-Jun) and sample t9 (23-Jun)

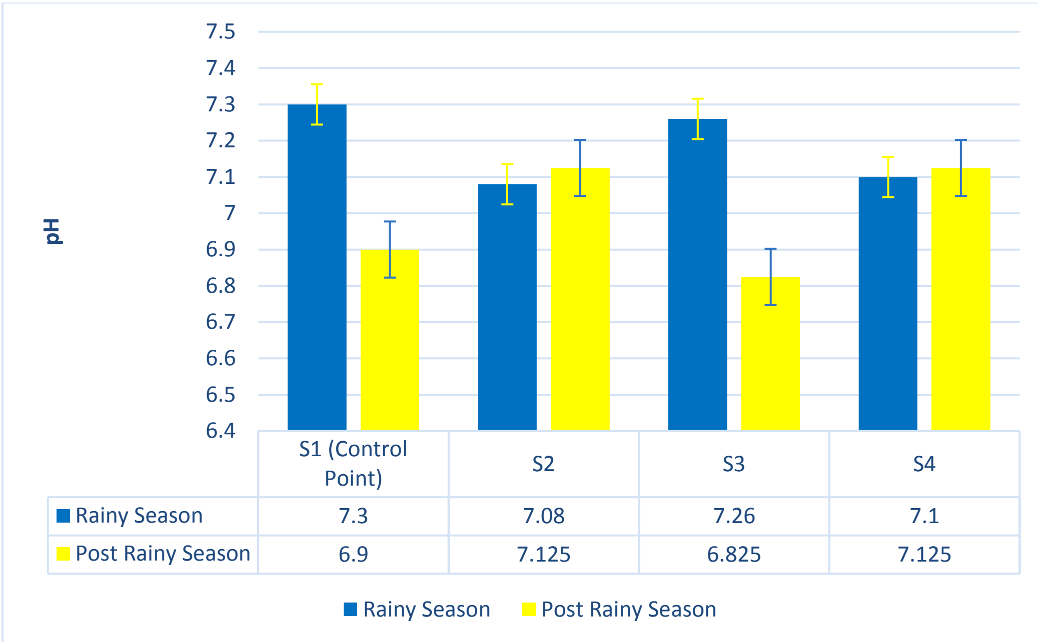


Figure 11: Average differences in pH values between sampling points S1 - S4, with change in season

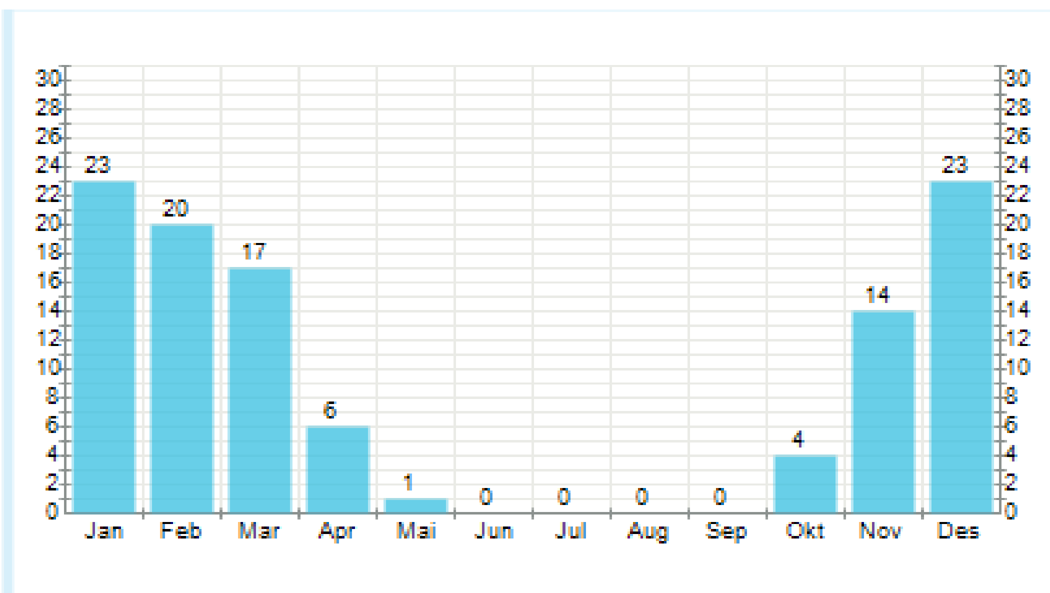


Figure 12: Average days with precipitation per month, 2016, from Zambia Meteorological Department, Ndola

4.2.2 Dissolved Oxygen

The variation of DO between seasons and sampling points was significant (Table 7). Higher DO concentration was recorded in the rainy season ranging from 4.64 to 5.93 mg/L while the lowest DO concentration was observed post rainy season ranging from 2.52 to 5.02 mg/L. The stream was characterized with low DO at all sampling points and this could be attributed to rainfall and increased turbidity due to agricultural activities.

Run-off containing organic matter from the rain and agricultural fields increase suspended solids in water. Suspended solids prevent aquatic plants from accessing light. The process of photosynthesis is reduced without light, leading to a reduction in the amount of dissolved oxygen in the water. Increased nitrates and phosphates may lead to eutrophication and O_2 is depleted by aerobic microorganisms. Dissolved oxygen is very important for macroinvertebrates and other aquatic organisms (Kannel et al., 2007; Moss, 2008). The variation of dissolved oxygen for the sampling points is depicted during and after the rainy season in Figure 13. The DO ranged from 4.64 – 5.83 mg/L (mean value of 5.298 ± 0.4604 mg/L) at S1 and 5.27 – 5.93 mg/L (with a mean value of 5.54 ± 0.2725 mg/L) at S4 during the rainy season. After the rainy season, the DO decreased substantially, varying between 2.52 and 5.01 mg/L (mean value of 3.7875 ± 1.04795.93 mg/L) at S1 and between 3.65 and 4.25 mg/L (mean value of 3.9575 ± 0.2478 mg/L) at S4. A drop in DO post rainy season (timepoint samples t6 to t9) was noted in the months May and June (Figure 13). During this period, it was noted that there was an increase in agricultural activities compared to other months, which could contribute to the drop in DO. The concentration of DO in the stream was below the standard limit of ZABS (6 mg/L) and WHO (8-15 mg/L) for aquatic freshwater i.e. out of specification.

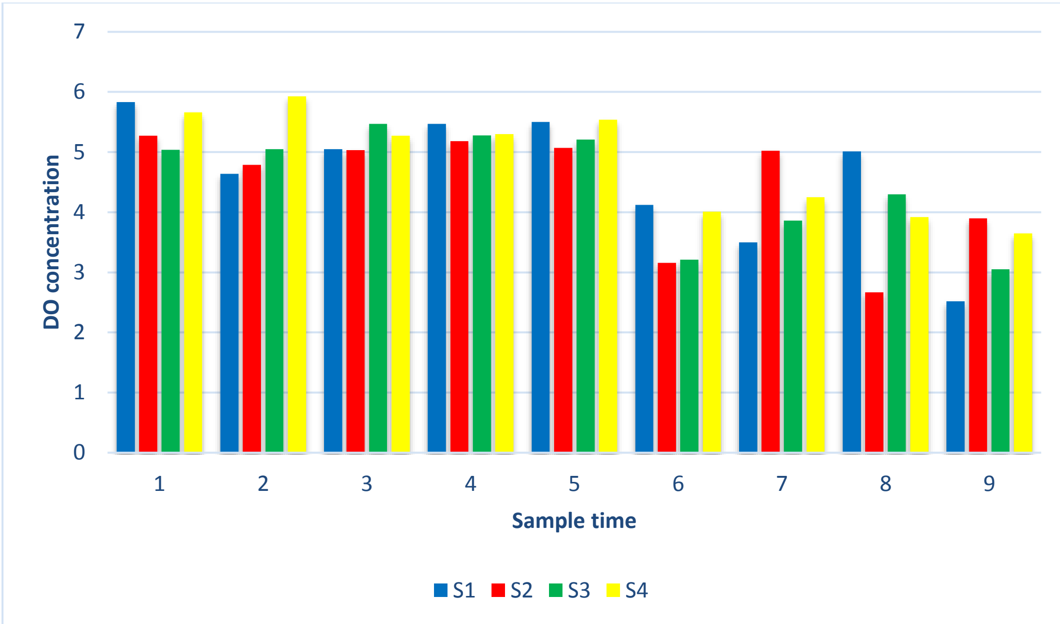
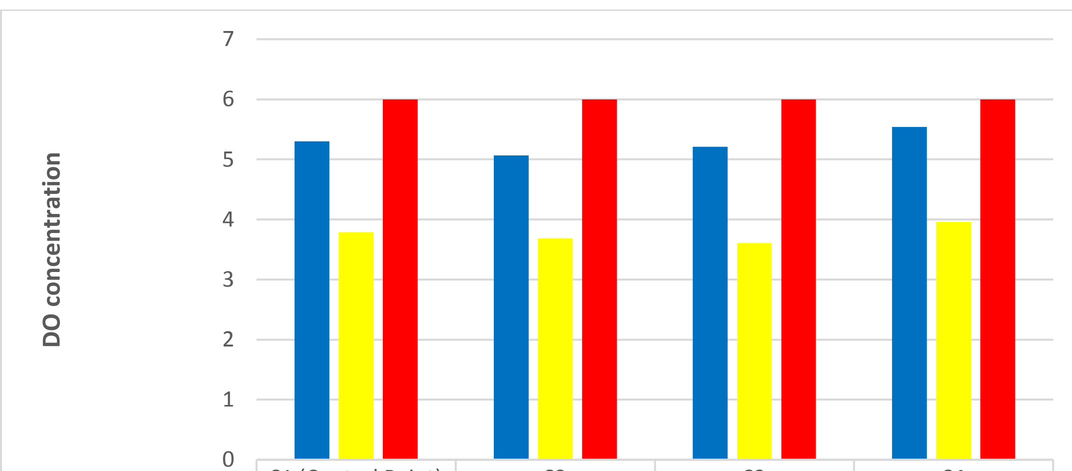


Figure 13: Variation of DO values between sampling points S1 – S4, February 2016 to June 2016, along the Munkulungwe stream; sample t1 (18-Feb), sample t2 (25-Feb), sample t3 (21-Mar), sample t4 (28-Mar), sample t5 (15-Apr), sample t6 (9-May), sample t7 (23-May), samplet 8 (13-Jun) and sample t9 (23-Jun)



	S1 (Control Point)	S2	S3	S4
Rainy Season	5.298	5.068	5.21	5.54
Post Rainy Season	3.7875	3.6875	3.605	3.9575
ZABS limit	6	6	6	6

Rainy Season Post Rainy Season ZABS limit

Figure 14: Differences in DO values between sampling points S1 - S4 along Munkulungwe Stream, with change in season

4.2.3 Total Dissolved Solids

Variation of TDS in the stream ranged from 178 to 345 mg/L in the rainy season, while after the rainy season the value ranged from 149 to 301 mg/L. No significant difference was noted with change in sampling point. The mean TDS values ranged from a minimum of 234.8 ± 44.31 mg/L at S1, to a maximum of 298.6 ± 25.25 mg/L at S4, during the rainy season (Table 8). After the rainy season, the mean TDS with a minimum 201 ± 48.31 mg/L was recorded at S1, while the maximum TDS of 267.25 ± 25.66 mg/L, was recorded at S3. TDS values were higher during the rainy season at all sampling points (Figure 16). No significant differences were noted in all the sampling points. All the values obtained for TDS were within the recommended limits for drinking water of ZABS (100-800 mg/L) and IRMA (500 mg/L). The lowest TDS value was recorded in June at S1 with a value of 149 (Table 7).

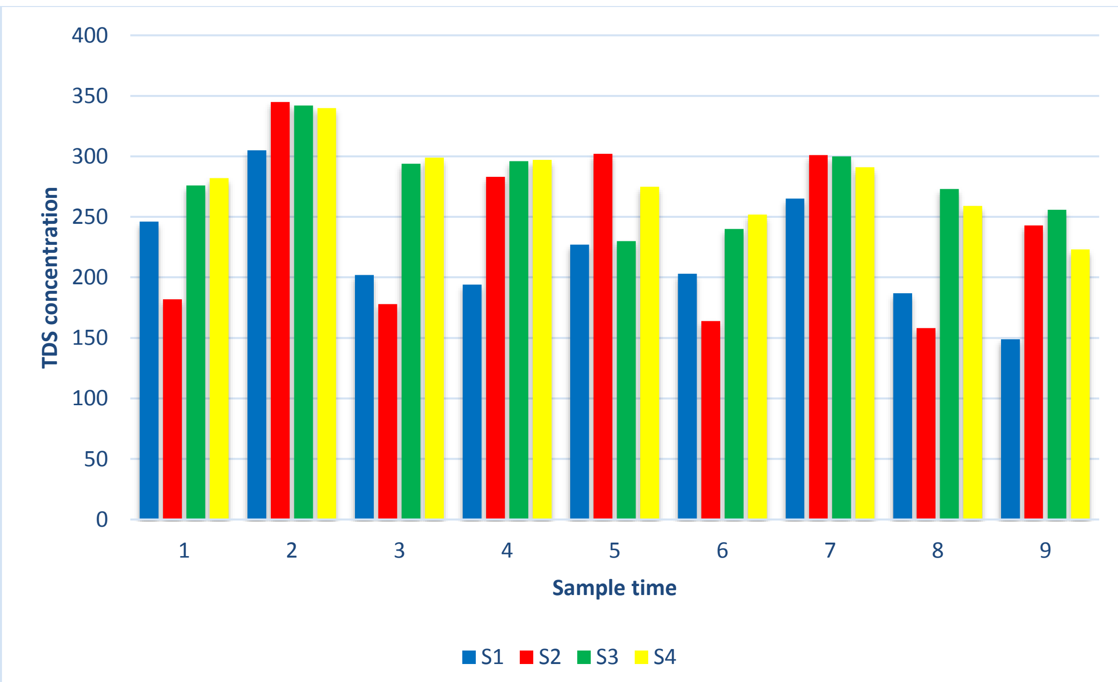


Figure 15: Variation of TDS values between sampling points S1 – S4, February 2016 to June 2016, along the Munkulungwe stream; sample t1 (18-Feb), sample t2 (25-Feb), sample t3 (21-Mar), sample t4 (28-Mar), sample t5 (15-Apr), sample t6 (9-May), sample t7 (23-May), sample t8 (13-Jun) and sample t9 (23-Jun)

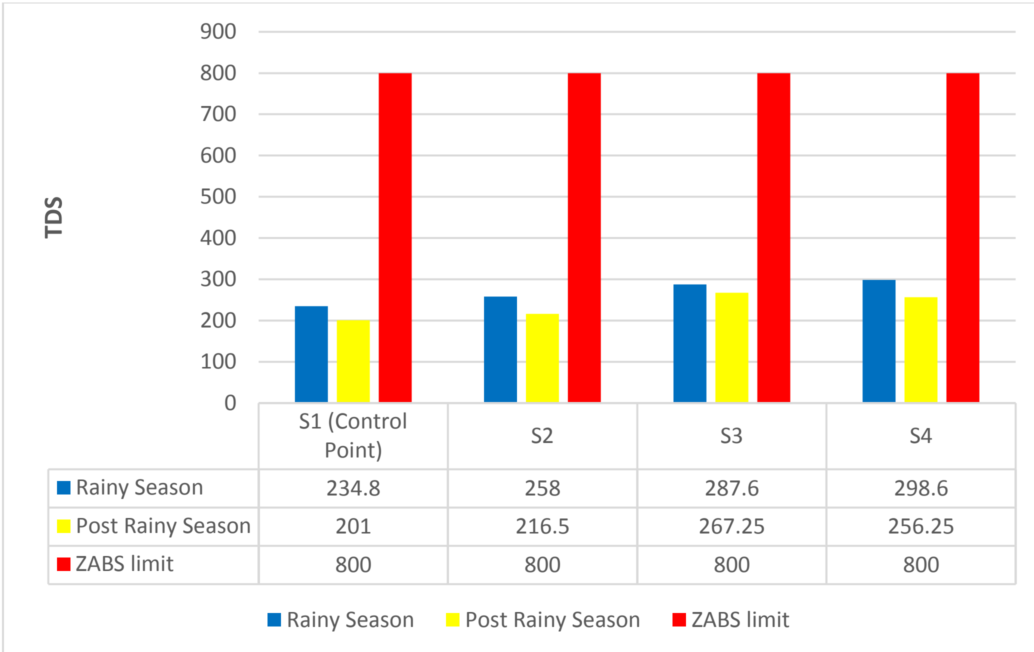


Figure 16: Difference in TDS values between sampling points S1-S4 along Munkulungwe Stream, with change in season

4.2.4 Turbidity

The variation of turbidity in the stream can be seen in Table 7, ranging from 11 to 93 NTU during rainy season and 22 to 55 NTU post rainy seasons. Turbidity values at all sampling points was above the acceptable limits of 5 NTU by ZABS and WHO for drinking water. The average value of turbidity in the stream varied from a minimum of 42.76 ± 20.69 NTU at S4, to a maximum of 52.4 ± 26.4631 NTU at S1; this was during the rainy season. After the rainy season, the average value of turbidity ranged from a minimum of 26 ± 6.68 NTU at S3, to a maximum of 39.5 ± 7.72 NTU at S2. Sampling points S2 and S3 recorded the highest values of turbidity. The values of turbidity at these sampling points could be influenced runoff from the rains and increased agriculture activities (Mallya, 2007). Most agricultural activities increased towards the end of the rainy season (end of March, timepoint samples t3 and t4)). Figure 18 shows the variation of turbidity during and after the rainy season. Turbidity values were on average lower post rainy season than during the rainy season. Weather changes affect turbidity, particularly heavy rainfall. The increase in the flow of water during the rainy season affects turbidity through the impact of erosion due to rainfall (Goransson et al., 2013).

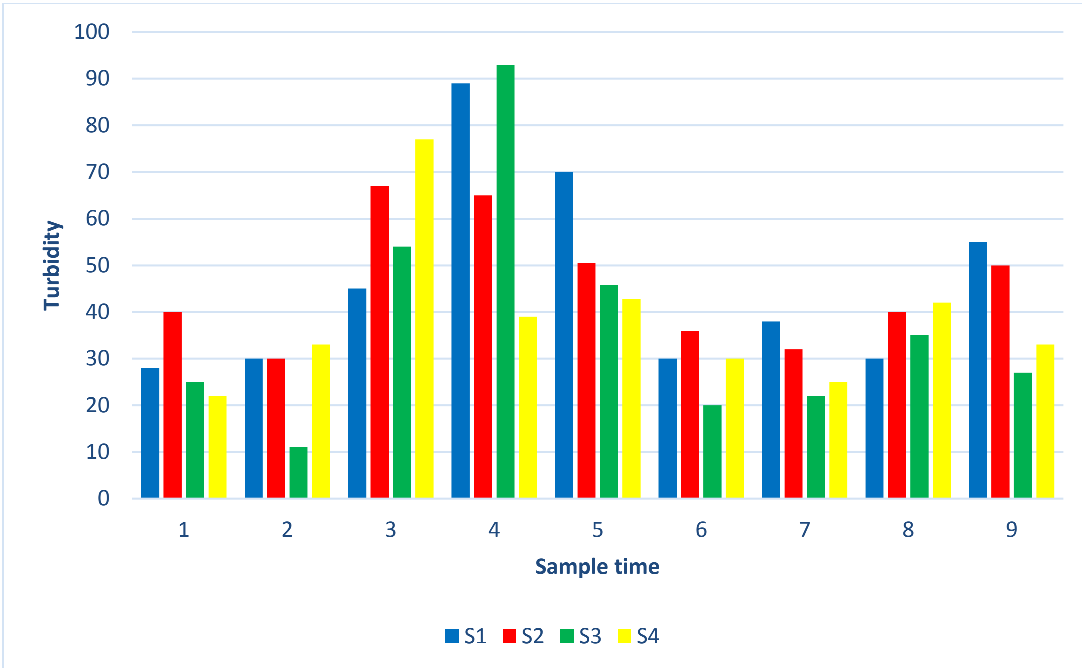
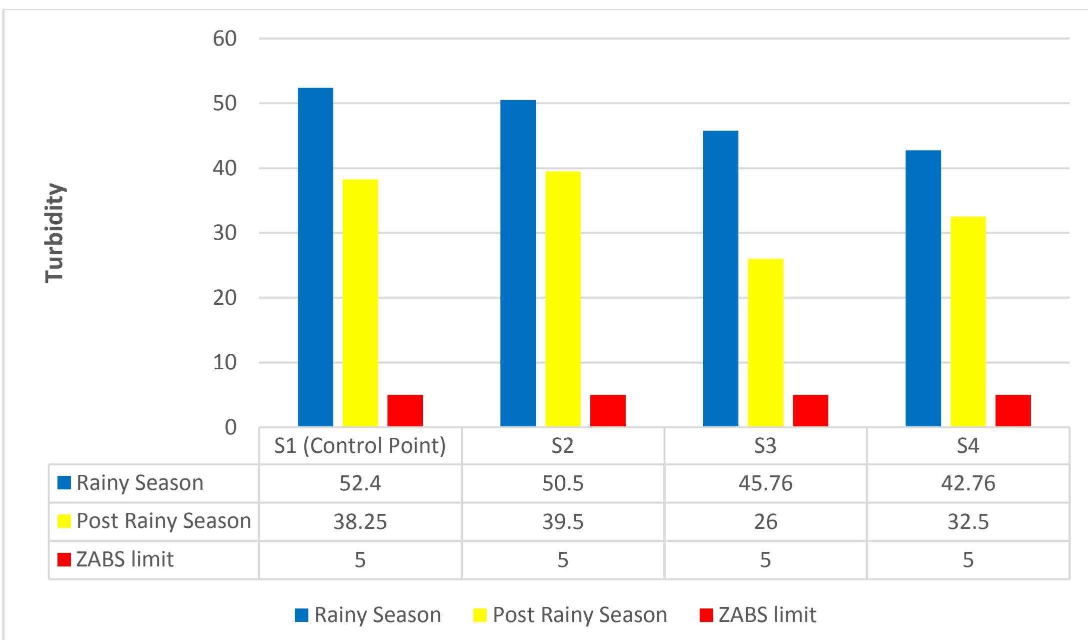


Figure 17: Variation of Turbidity values between sampling points S1 – S4, February 2016 to June 2016, along the Munkulungwe stream; sample t1 (18-Feb), sample t2 (25-Feb), sample t3 (21-Mar), sample t4 (28-Mar), sample t5 (15-Apr), sample t6 (9-May), sample t7 (23-May), sample t8 (13-Jun) and sample 9 (23-Jun)



	S1 (Control Point)	S2	S3	S4
Rainy Season	52.4	50.5	45.76	42.76
Post Rainy Season	38.25	39.5	26	32.5
ZABS limit	5	5	5	5

Figure 18: Differences in Turbidity values between sampling points S1 - S4 along Munkulungwe Stream, with change in season

4.3 Chemical Parameters

Table 10 shows the variation of heavy metal pollution in the Munkulungwe Stream at Sites 1 to 4 over a period of five months. The mean, SD and range of values are presented in Table 11. Comparatively between seasons, heavy metal concentration is higher post rainy season.

Table 9: Variation of heavy metals (mg/L) during the period of sampling, February 2016 to June 2016, along Munkulungwe stream

Site/Date	18-Feb	25-Feb	21-Mar	28-Mar	09-May	23-May	13-Jun	20-Jun
	Cu Rainy Season					Cu Post Rainy Season		
S1	0.1	0.1	0.05	0.3	0.2	0.25	0.1	0.3
S2	0.1	0.1	0.1	0.2	0.7	0.5	0.6	0.4
S3	0.3	0.1	0.5	0.1	0.4	0.6	0.45	0.32
S4	0.4	0.1	0.1	0.2	0.3	0.4	0.3	0.25
	Co Rainy Season					Co Post Rainy Season		
S1	0.1	0.1	0.05	0.4	0.1	0.1	0.05	0.08
S2	0.1	0.05	0.1	0.2	0.3	0.65	0.4	0.8
S3	0.1	0.1	0.1	0.2	0.35	0.5	0.5	0.4
S4	0.1	0.1	0.05	0.2	0.2	0.5	0.35	0.4
	Pb Rainy Season					Pb Post Rainy Season		
S1	0.01	0.2	0.02	0.2	0.2	0.3	0.1	0.25
S2	0.01	0.2	0.01	0.1	0.4	0.8	0.5	0.6
S3	0.03	0.2	0.01	0.25	0.6	0.4	0.7	0.64
S4	0.05	0.4	0.01	0.1	0.5	0.3	0.3	0.4
	Fe Rainy Season					Fe Post Rainy Season		
S1	0.1	0.2	0.03	0.05	0.04	0.2	0.1	0.1
S2	0.2	0.1	0.3	0.3	0.8	0.9	1	1.2
S3	0.1	0.1	0.2	0.2	0.5	0.6	0.82	0.7
S4	0.1	0.8	0.1	0.4	0.3	0.3	0.25	0.5
	Mn Rainy Season					Mn Post Rainy Season		
S1	0.05	0.25	0.02	0.3	0.2	0.01	0.1	0.3
S2	0.1	0.2	0.1	0.2	0.2	0.17	0.5	0.4
S3	0.2	0.4	0.1	0.3	0.3	0.3	0.4	0.35
S4	0.1	0.1	0.1	0.1	0.4	0.2	0.3	0.35

Table 10: Means, SDs and Range of values for heavy metal analysis (mg/L)

Site/Parameter	Cu	Co	Pb	Fe	Mn
S1					
Rainy Season					
Range	0.05 -0.36	0.05 - 0.4	0.02 - 0.2	0.03 - 0.2	0.04 - 0.3
Mean + SD	0.14 ± 0.11	0.16 ± 0.16	0.11 ± 0.11	0.09 ± 0.07	0.16 ± 0.14
Post Rainy Season					
Range	0.1 – 0.3	0.01 - 0.1	0.1 - 0.3	0.04 - 0.2	001 - 0.3
Mean + SD	0.21 ± 0.08	0.08 ± 0.02	0.21 ± 0.09	0.11 ± 0.07	0.15 ± 0.13
S2					
Rainy Season					
Range	0.1 - 0.2	0.01 - 0.2	0.01 - 0.2	0.1 - 0.3	0.1 - 0.2
Mean + SD	0.13 ± 0.05	0.09 ± 0.08	0.08 ± 0.09	0.23 ± 0.1	0.15 ± 0,06
Post Rainy Season					
Range	0.4 - 0.7	0.2 - 0.8	0.3 - 0.8	0.8 - 1.2	0.17 - 0.5
Mean + SD	0.55 ± 0.13	0.54 ± 0.23	0.4 ± 0.17	0.98 ± 0.17	0.32 ± 0.16
S3					
Rainy Season					
Range	0.1 - 0.5	0.01 - 0.2	0.01 - 0.25	0.1 - 0.2	0.1 - 0.4
Mean + SD	0.25 ± 0.19	0.1 ± 0.08	0.12 ± 30.12	0.15 ± 0.06	0.25 ± 0.13
Post Rainy Season					
Range	0.32 - 0.6	0.35 - 0.5	0.5 - 0.7	0.6 - 0.82	0.2 - 0.4
Mean + SD	0.44 ± 0.12	0.44 ± 0.01	0.59 ± 0.13	0.66 ± 0.14	0.34 ± 0.05
S4					
Rainy Season					
Range	0.1 - 0.2	0.05 - 0.2	0.01 - 0.4	0.1 - 0.8	0.1
Mean + SD	0.15 ± 0.06	0.11 ± 0.06	0.14 ± 0.18	0.35 ± 0.33	0.1 ± 0
Post Rainy Season					
Range	0.25 - 0.4	0.2 - 0.5	0.3 - 0.5	0.25 - 0.5	0.2 - 0.4
Mean + SD	0.25 ± 0.06	0.36 ± 0.13	0.38 ± 0.10	0.34 ± 0.11	0.31 ± 0.09

During the study, the mean concentration of the heavy metals analyzed during the rainy season from each sampling point equaled (in descending order) 0.35 ± 0.33 mg/L for Iron at S4, 0.25 ± 0.19 mg/L for Copper at S3, 0.25 ± 0.13 mg/L for Manganese at S3, 0.16 ± 0.16 mg/L for Cobalt at S1 and 0.14 ± 0.18 mg/L for Lead at S4. After the rainy season, the mean concentration of heavy metals analyzed in descending order, 0.98 ± 0.17 mg/L for Iron at S2, 0.59 ± 0.13 mg/L for Lead at S3, 0.55 ± 0.13 mg/L for Copper at S2, 0.54 ± 0.23 mg/L for Cobalt at S2 and 0.34 ± 0.05 mg/L for Manganese at S3. The average or mean concentration and range of values of the heavy metals recorded from the samples were shown in Table 11 with time course data for each metal as a function of location shown in Figures 19 to 23. At sampling point S1 (upstream), the concentration of metals was lower than at sampling points downstream, supporting the fact that the TSF probably contributes to heavy metal contamination of the stream. The results show that the concentration of metals was higher after the rainy season than during the rainy season. This may be attributed partly to evaporation and low flows and partly to the ongoing seepage from the tailings dam in the absence of dilution through flow of the river. The Cu concentration for drinking water was within acceptable limits of ZABS (1 mg/L) and IRMA (1 mg/L) at all sampling points across both seasons (Figure 19). However, most of the Cu concentration were above acceptable limit for irrigation water (0.2 mg/L) standard by IRMA post rainy season downstream. The results showed elevated levels of Co, Pb, Fe and Mn, though the concentration was not very high. The mean Co concentration was above the acceptable limit by ZABS (0.05 mg/L) for drinking water at sampling points downstream, ranging from 0.09 ± 0.08 mg/L to 0.54 ± 0.23 mg/L. The concentration of Pb, was above the acceptable limit for drinking water by ZABS of 0.05 mg/L (Figure 21). The results show that the mean level of Pb ranged from 0.08 ± 0.09 mg/L for S2 to 0.14 ± 0.18 mg/L for S4, during the rainy season and 0.21 ± 0.0.09 mg/L for S1 to 0.59 ± 0.13 mg/L for S3, after the rainy season.

The concentration of Fe on was above recommended limits (Figure 22 and 24) of 0.3mg/l set by ZABS and IRMA for drinking, aquatic organisms, recreation and aquaculture water at sampling points downstream (S2, S3 and S4). In the rainy season, the average concentration of Fe was ranging from 0.09 ± 0.07 mg/L to 0.35 ± 0.33 mg/L, while post rainy season the range was 0.11 ± 0.07 mg/L to 0.98 ± 0.17 mg/L. The highest concentration of Fe was recorded at sampling points S2 downstream, in the month of June (Table 10). Mean concentration of Mn was above acceptable standards by IRMA for drinking water (0.05 mg/L), and recreation water (0.1 mg/L) at most sampling points (Table 11).

For the other metals in the rainy season, the mean concentration varied from 0.13 ± 0.05 mg/L to 0.25 ± 0.19 mg/L for Cu, 0.09 ± 0.08 mg/L to 0.16 ± 0.16 mg/L for Co, 0.08 ± 0.09 mg/L to 0.12 ± o.12 mg/L for Pb and 0.1 ± 0 mg/L to 0.25 ± 0.13 mg/L for Mn. Post rainy season, the average concentration of Cu varied from 0.21 ± 0.08 mg/L to 0.55 ± 0.13 mg/L, for Co 0.08 ± 0.02 mg/L to 0.54 ± 0.23 mg/L, for Pb 0.21 ± 0.09 mg/L to 0.59 ± 0.13 mg/L and 0.15 ± 0.13 mg/L to 0.34 ± 0.05 mg/L for Mn. S2 recorded the highest average concentration of 0.54 ± 0.23 mg/L for Co, while S3 recorded the highest average concentration of 0.55 ± 0.13 mg/L for Cu, 0.59 ± 0.13 mg/L for Pb and 0.34 ± 0.05 mg/L for Mn (Figure 24).

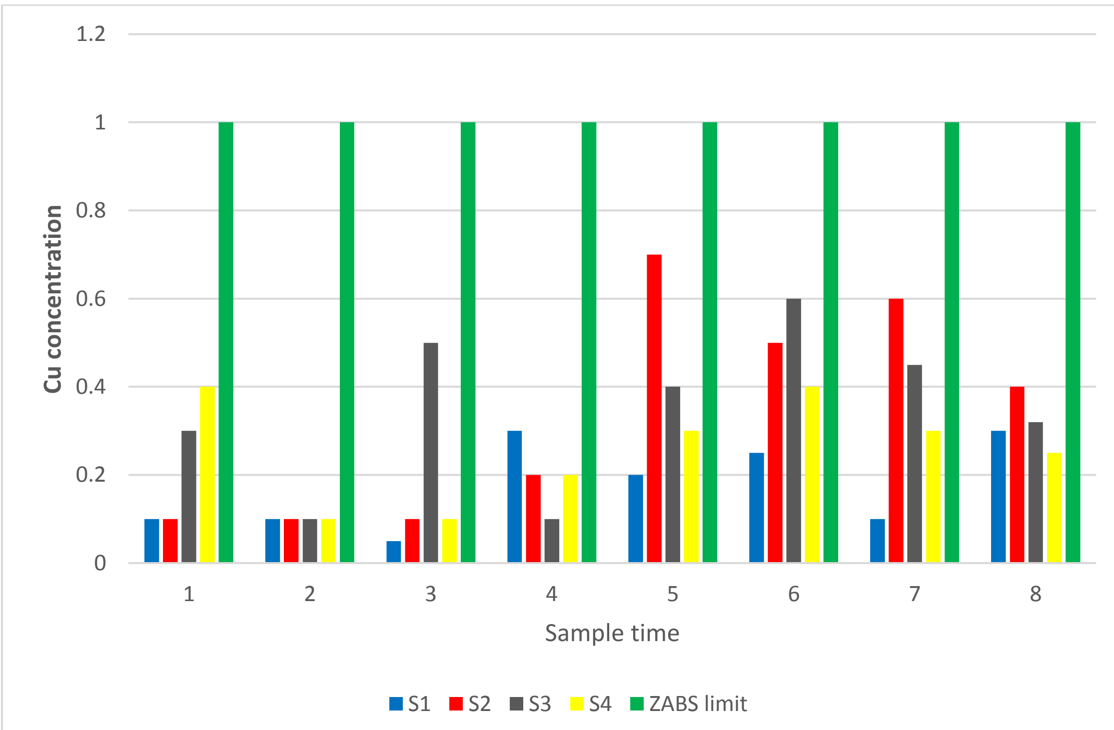


Figure 19: Variation of Cu concentration along Munkulungwe Stream, from February 2016 to June 2016; sample t1 (18-Feb), sample t2 (25-Feb), sample t3 (21-Mar), sample t4 (28-Mar), sample t5 (15-Apr), sample t6 (9-May), sample t7 (23-May), sample t8 (13-Jun) and sample t9 (23-Jun)

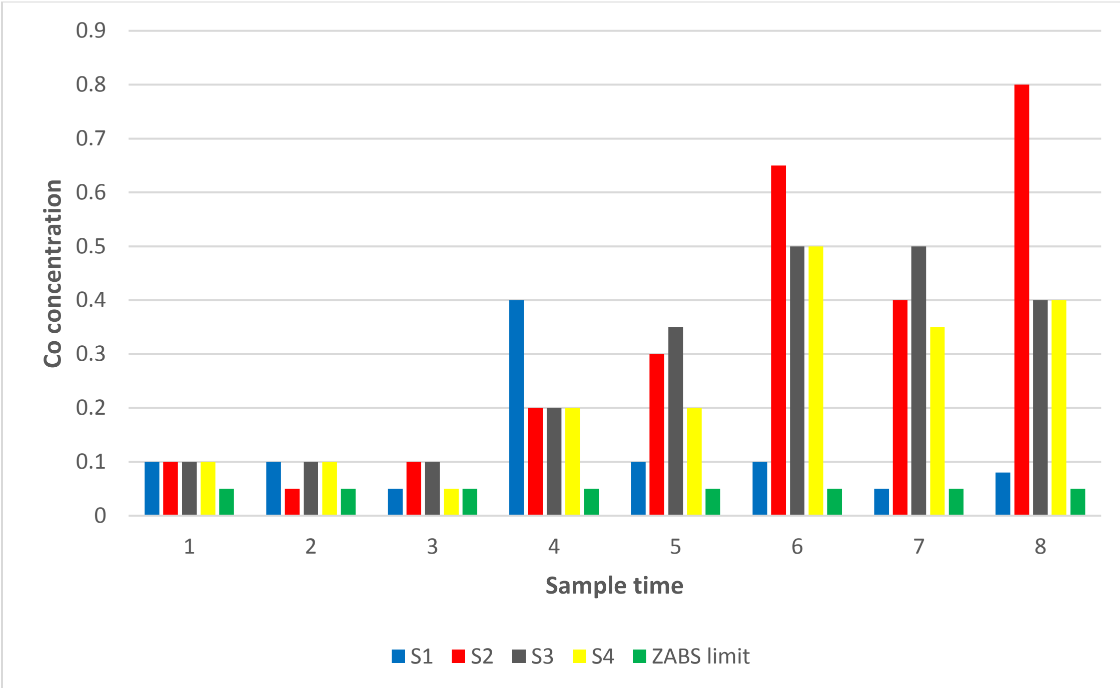


Figure 20: Variation of Co concentration along Munkulungwe Stream, from February 2016 to June 2016; sample t1 (18-Feb), sample t2 (25-Feb), sample t3 (21-Mar), sample t4 (28-Mar), sample t5 (15-Apr), sample t6 (9-May), sample t7 (23-May), sample t8 (13-Jun) and sample t9 (23-Jun)

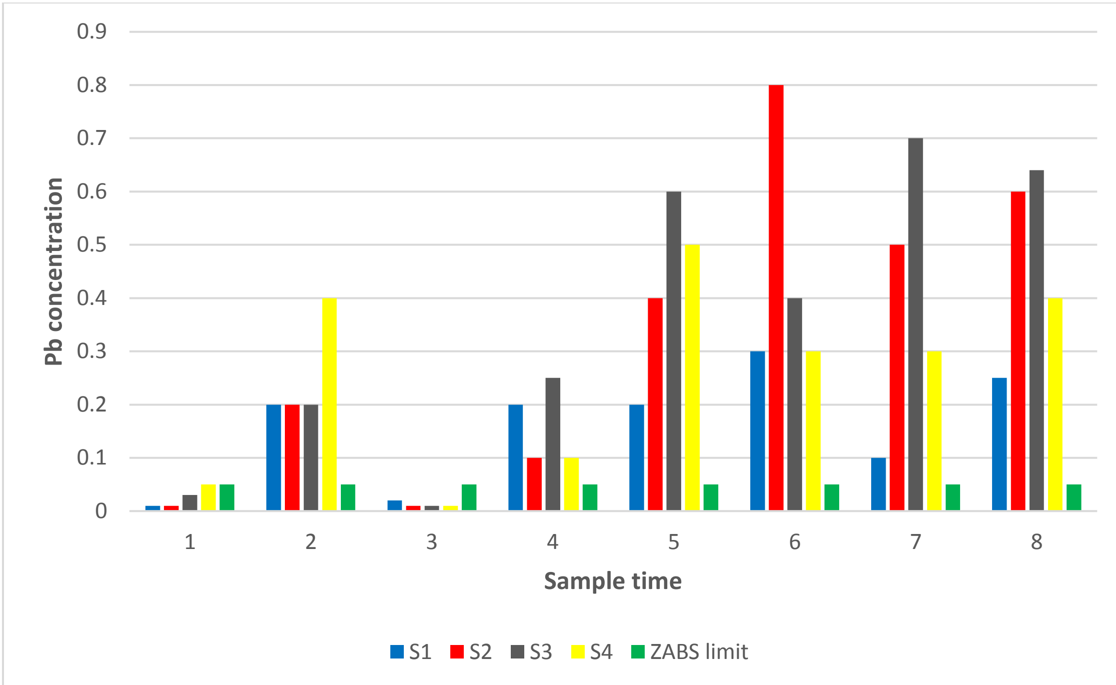


Figure 21: Variation of Pb concentration along Munkulungwe Stream, from February 2016 to June 2016; sample t1 (18-Feb), sample t2 (25-Feb), sample t3 (21-Mar), sample t4 (28-Mar), sample t5 (15-Apr), sample t6 (9-May), sample t7 (23-May), sample t8 (13-Jun) and sample t9 (23-Jun)

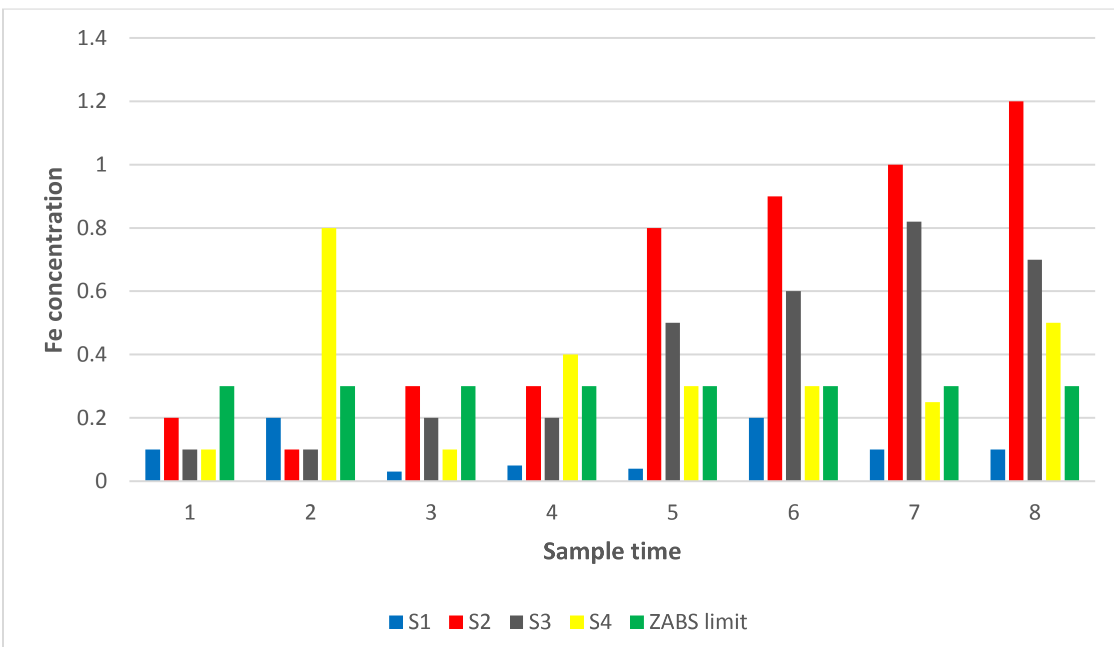


Figure 22: Variation of Fe concentration along Munkulungwe Stream, February 2016 to June 2016; sample t1 (18-Feb), sample t2 (25-Feb), sample t3 (21-Mar), sample t4 (28-Mar), sample t5 (15-Apr), sample t6 (9-May), sample t7 (23-May), sample t8 (13-Jun) and sample t9 (23-Jun)

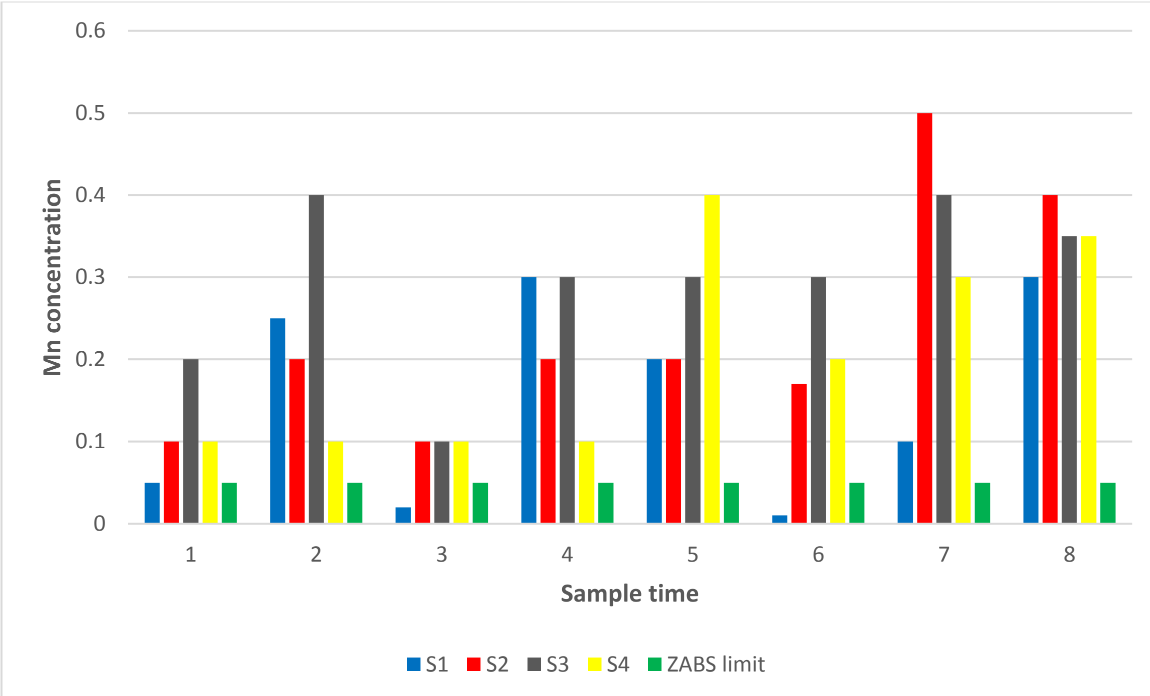


Figure 23: Variation of Mn concentration along Munkulungwe Stream, from February 2016 to June 2016; sample t1 (18-Feb), sample t2 (25-Feb), sample t3 (21-Mar), sample t4 (28-Mar), sample t5 (15-Apr), sample t6 (9-May), sample t7 (23-May), sample t8 (13-Jun) and sample t9 (23-Jun)

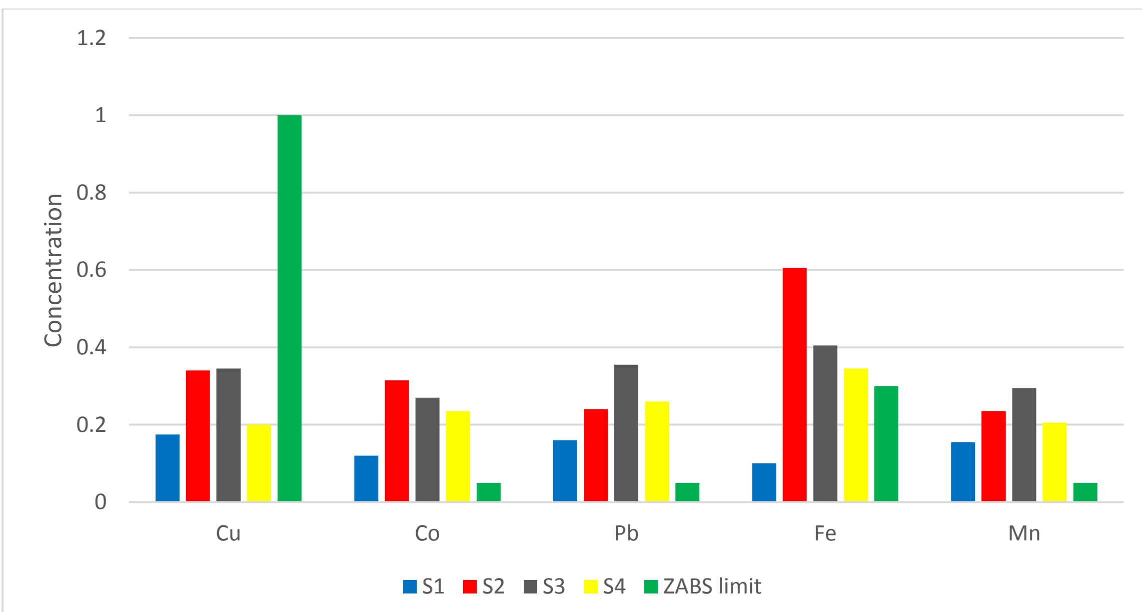


Figure 24: Average concentration of metals at each sampling point, along Munkulungwe Stream, from February 2016 to June 2016

4.4 Comparison of Munkulungwe Stream with other Streams

The average results (from each sampling points) on the Munkulungwe Stream were compared with results from other streams on the Copperbelt (Auditor General Report, 2014) and against the ZABS and IRMA standards. Table 12 shows the concentration of heavy metals (Cu, Co, Mn and Fe) and TDS from five streams on the Zambian Copperbelt. The results compared streams near active mines (Chambeshi, Mushishima, Uchi and Unchi Streams) and an abandoned mine (Munkulungwe Stream). Concentration of heavy metals in the streams near active mines was above acceptable limits presented by ZABS and IRMA for drinking water, with the highest concentration of Cu recorded in the Chambeshi Stream, Co in the Uchi Stream, and Mn and Fe in the Mushishima Stream. The analysis showed that concentration in the Munkulungwe Stream is low compared to the other streams. However, with an exception of Cu, the heavy metal concentration was above acceptable local (ZABS) and global (IRMA) limits (Table 12). The results showed that the water quality in the stream was still affected by the inactive mine site six years after closure. TDS were above acceptable global standards (IRMA, 2016) in all the measured streams near active mines.

Table 11: TDS, TCu, TCo, TMn and TFe concentration of Copperbelt streams

mg/l	Chambeshi Stream (2011)	Mushishima Stream (2011)	Uchi Stream (2011)	Unchi Stream (2011)	Munkulungwe Stream (2016)	ZABS Limit	IRMA Limit
TDS	4,100	5,411	1,512	1,563	252.4	3,000	500
TCu	24.6	3.1	7	2.7	0.23	1	1
TCo	8	3.9	19.7	1.6	0.24	0.05	0.05-
TMn	12.4	20.5	2.8	3.5	0.22	0.02	0.01
TFe		236.5	4.2	1.7	0.36	0.3	0.3

Studies-taken in Zambia have shown that concentration of heavy metals and other physical parameters are significantly above acceptable limits. These studies have not shown the effect of heavy metal concentration on aquatic habitat; however, global studies indicate the impact on aquatic systems. A study by Ngodhe et al. (2014) showed that high concentration of heavy metals recorded in the streams had severe impact on the aquatic ecosystem (Ngodhe et al., 2014). Other studies have also shown that low concentration of heavy metals over time changes the composition of aquatic community (Clement et al., 2000; Freund & Petty, 2007; Van Damme et al., 2008; Qu et al., 2010). To protect current human and ecosystem health, and future end users of water, the health of water bodies must be monitored to ensure conformity with acceptable global practices (IRMA, 2016). Bio-monitoring is very useful in evaluating the overall impact of pollution in water bodies.

4.5 Presence of Macroinvertebrates

The biotic index score was used in assessing quality of water based on the composition of macroinvertebrates in each stream. During the period of data collection (February 2016 to June 2016), a total of 652 macroinvertebrate individuals were sampled and identified in Munkulungwe stream. These were grouped according to their sensitivity to pollution (Water-Monitoring, 2007) to give the overall picture of the distribution of diversity in the stream during the period of study: Sensitive (1.5%; Stonefly larva), Semi sensitive (30.7%; Damesfly larva, Dragonfly larva, Mayfly larva, Water penny and Riffle beetle), Semi tolerant (31.8%; Amphipod or Scud and Black larva) and Tolerant (36%; Isopod, leech and snail) species as shown in Figure 25. The richness of diversity is a useful indicator of health of the stream (Orwa et al., 2013; Ngodhe et al., 2014; Xu et al., 2014). The stream was characterized with low diversity, few sensitive species and many semi-tolerant and tolerant species, an indication that the health of the stream was compromised.

Table 13 shows the influence of season on the numbers of individual species ranked in the order of sensitivity to pollution, with amphipod or scud (semi-tolerant) as the dominant species. Their abundance was highest post rainy season, with numbers increasing from March to June. Isopod or aquatic sowbug (tolerant), were the second dominant species, with their numbers similarly increasing post rainy season. Blackfly Larvae (semi-tolerant) and Snail: Pouch (tolerant) also recorded an increase in abundance post rainy season. The invertebrates leech, water penny, dragonfly larvae, riffle Beetle, mayfly larvae and damselfly also increased in density with change in season (Figure 26).

It was noted that the invertebrate community in the samples taken was influenced by the distance downstream from Munkulungwe tailings dam. Macroinvertebrates tolerant to pollution were much higher in abundance downstream compared with upstream (Figure 27). Species that are sensitive to pollution were only found upstream, giving an indication that the water quality downstream was not conducive to their survival.

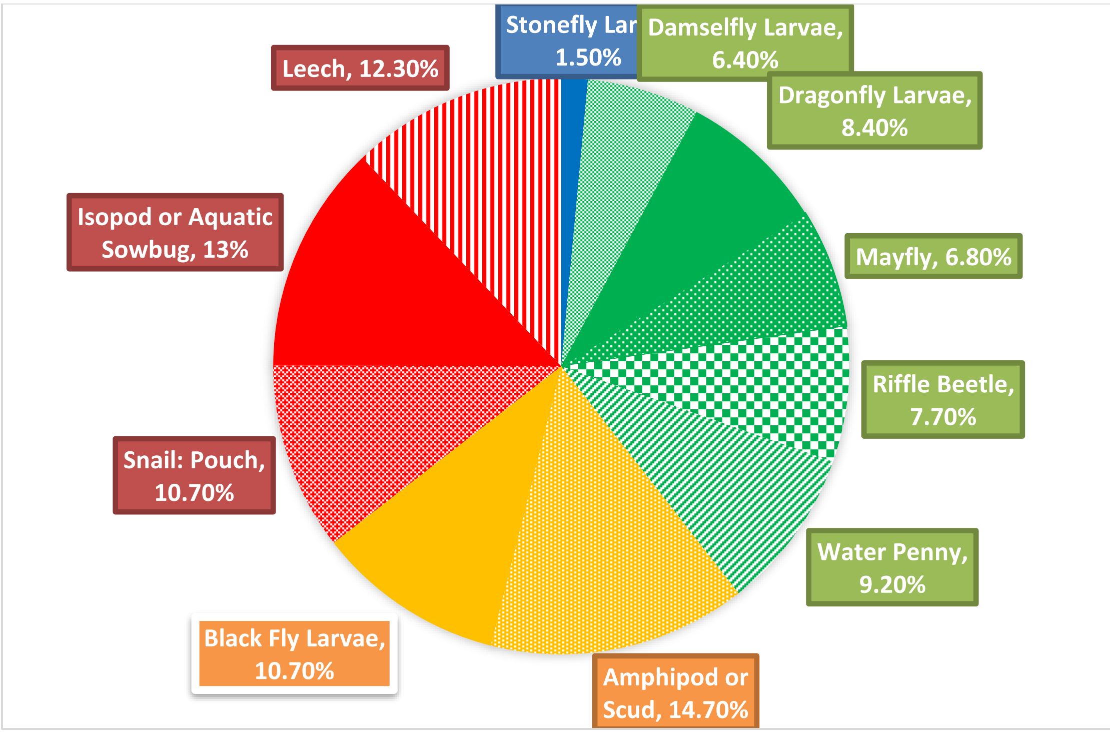


Figure 25: Distribution of Macroinvertebrates found in Munkulungwe Stream during sampling period

Table 12: Density and diversity of macro invertebrates found in Munkulungwe Stream during sampling period

MACRO INVERTEBRATES FOUND	**GROUP NUMBER**	**RAINY SEASON**	**POST RAINY SEASON**	**TOLERANCE TO POLLUTION**
Stonefly Larva	**1**	**4**	**6**	**Sensitive**
Damselfly Larvae	2	15	27	Semi-sensitive
Dragonfly Larvae	2	23	32	Semi-sensitive
Mayfly	2	24	20	semi-sensitive
Riffle Beetle	2	10	30	Semi-sensitive
Water Penny	2	27	33	Semi-sensitive
Amphipod or Scud	3	40	56	Semi-Tolerant
Black Fly Larvae	3	18	52	Semi-Tolerant
Snail: Pouch	3	30	40	Tolerant
Isopod or Aquatic Sowbug	4	35	50	Tolerant

Leech	4	32	48	Tolerant
	Total	258	394	

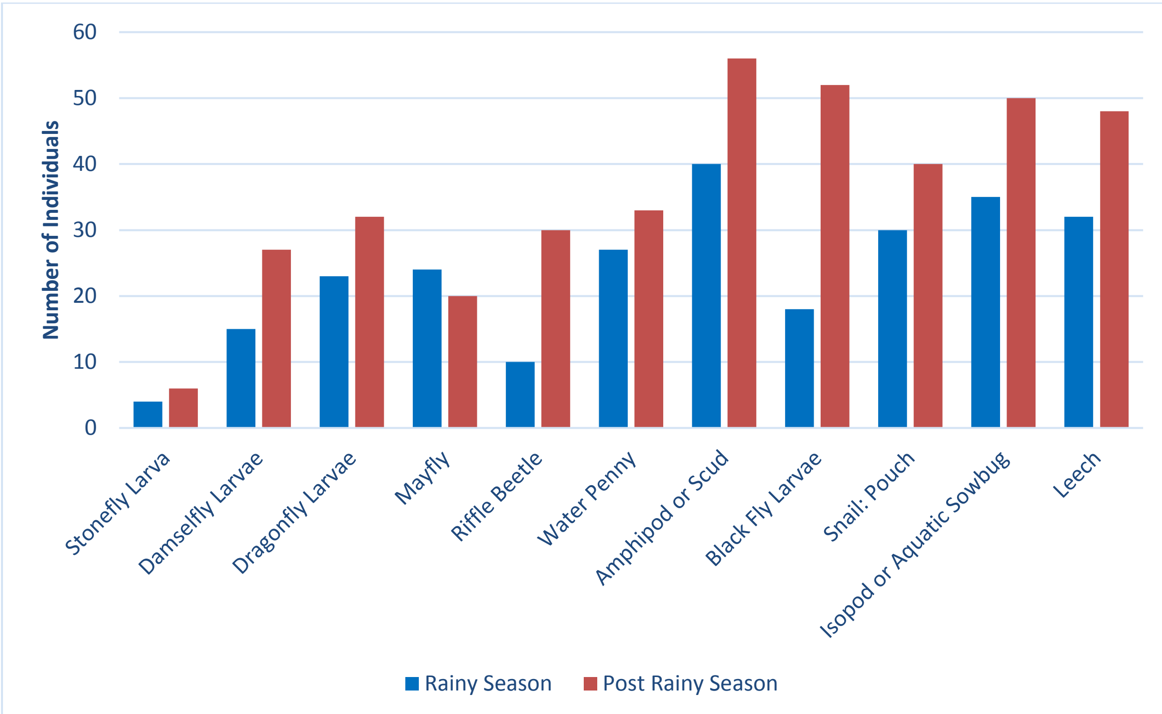


Figure 26: Distribution of macroinvertebrates in the Munkulungwe Stream with change of season during the sampling period February to June 2016

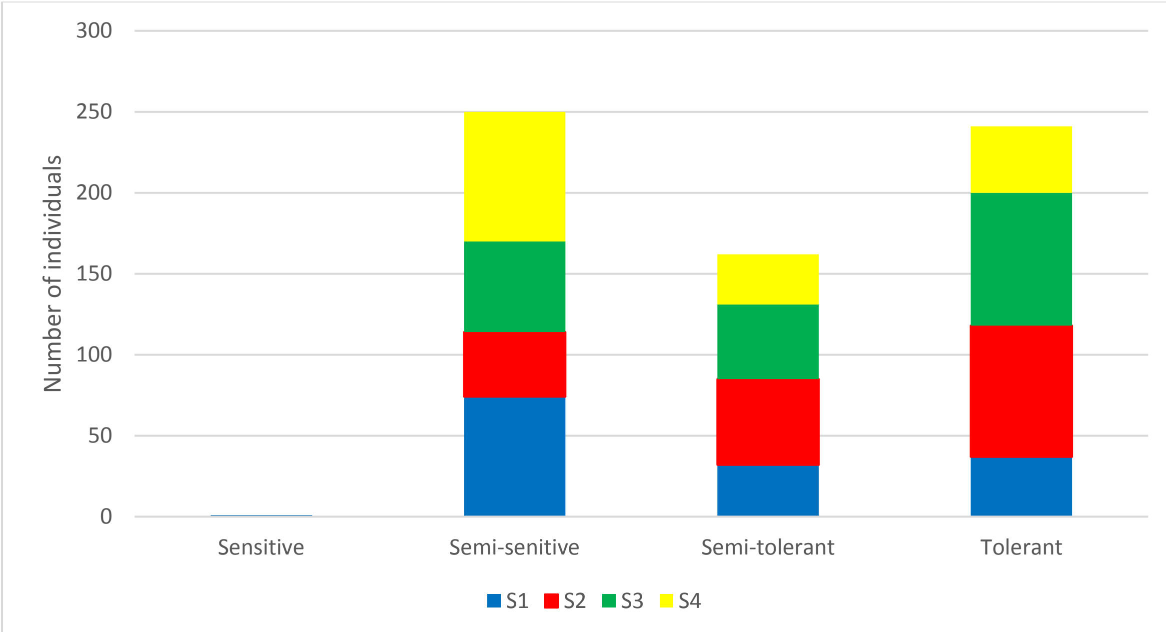


Figure 27: Differences in numbers of macroinvertebrates tolerant to pollution found, February to June 2016, between sites upstream and downstream of the Bwana Mkubwa tailings dam on the Munkulungwe Stream

The population of tolerant species increases downstream at all sampling points in comparison to sensitive species. Density of tolerant macroinvertebrates changed with change in season, the months of May recorded the highest population at sites 2 and 3 respectively. It was noted that sites 2 and 3 are the closest sampling sites to the tailings dam (Figure 9) and recorded the highest concentration of heavy metals during the sampling period (Figure 27). The results show that polluted water is dominated by species that are tolerant to pollution (Kari & Rauno, 1993; Griffith et al., 2005; Orwa et al. 2013). Runoffs from the Munkulungwe tailings dam influenced the composition of the aquatic community (White et al. 2008). The downstream sampling area is richer in Snails, Isopod or Scud and Leech, than upstream (Figure 28).

Figure 28: Semi tolerant and tolerant macroinvertebrates found in Munkulungwe stream (Hauler & Resh, 1996)

Some 36% (234) of 652 macroinvertebrates sampled were composed of species tolerant to pollution, of which 15.4% were found in sampling areas upstream, while 84.6% were found in sampling areas downstream. Isopods were the most common tolerant macroinvertebrates found, contributing about 85 of the 234-tolerant species recorded. A further 79 of the 234 tolerant macroinvertebrates were Leech while 70 were Snails.

Semi tolerant species numbers (Figure 29) are highest at sites S2 and S3 near the tailings dam. Further downstream from the tailings dam, the area is dominated by semi-sensitive over semi tolerant macroinvertebrates. This change demonstrated that pollution of the stream is worst closest to the tailings dam. Qu et al. (2010) and Zhang et al. (2014) also observed that tolerant species are dominant in polluted areas. Some 25.4% (166) of species (652) recorded during sampling period comprised of amphipod or scud and blackfly larvae i.e. semi tolerant organisms. Amphipod showed the total highest individual number (96) of macroinvertebrates recorded, while Blackfly larvae had a total of 70. In the months of April and May, semi tolerant macroinvertebrates were higher at S1 upstream than S4 downstream. Throughout the sampling period, sampling areas with a concentration of heavy metals were dominated by semi tolerant and tolerant species.

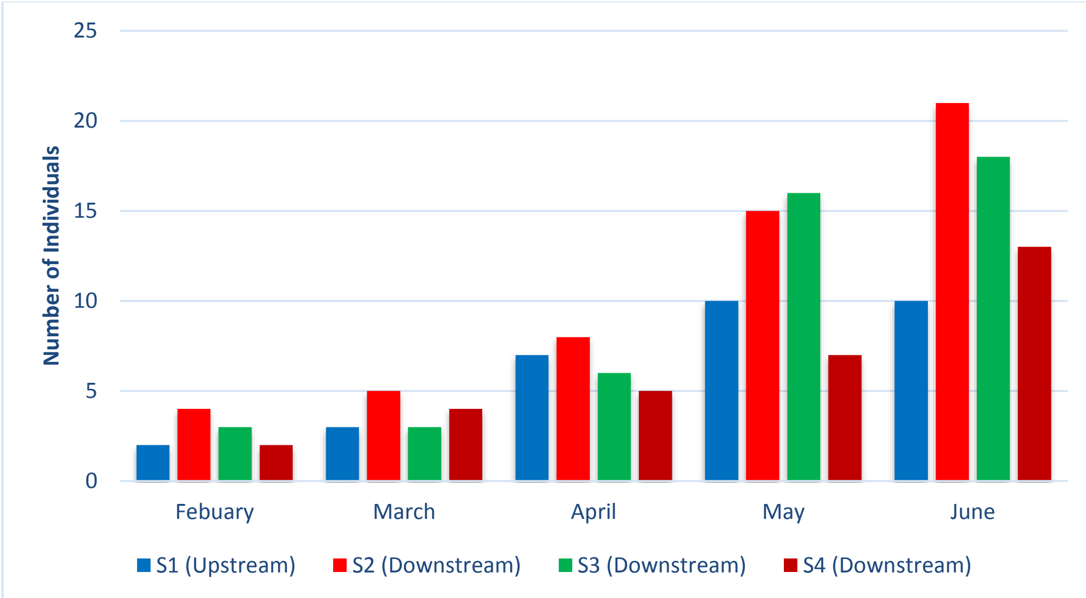


Figure 29: Differences in numbers of macroinvertebrates semi tolerant to pollution found, February 2016 to June 2016, between sites upstream and downstream of the Bwana Mkubwa tailings dam on the Munkulungwe Stream

The upstream sampling area (S1) had the highest abundance of species semi sensitive to pollution, with an exception of S4 (Figure 29) downstream which recorded the highest number of semi sensitive organisms in the month of June. In the region of the tailings dam, the river health is lowest and with increasing distance from the pollution point, the stream condition improves (Hasselbach et al., 2005). The downstream sampling areas S2 and S3 near the tailings dam recorded a low number of species semi sensitive to pollution compared to S1 and S4. The trend was consistent throughout the sampling period. The upstream sampling area showed a steady increase in abundance of semi sensitive species towards the end of the rainy season. Figure 30 shows the semi sensitive and sensitive macroinvertebrates found in the Munkulungwe Stream.

Figure 30: Semi sensitive and sensitive macroinvertebrates found in Munkulungwe Stream (Hauler & Resh, 1996)

The diversity of the semi sensitive species was higher compared to other species (Figure 25). Some 251 semi sensitive macroinvertebrates were recorded, representing 38.5% of the total number (652); 60 of the 251-semi sensitive were water penny, 55 dragonfly larvae, 50 riffle beetles, 44 mayfly larvae and 42 damselfly larvae. Of these, throughout the sampling period, the dragonfly larvae were the most common at all sampling areas. The species composition of semi sensitive species increased downstream (S4) with distance away from the pollution point, suggesting that the stream was remediating. Mayfly and damselfly larvae are common in waters less polluted and thus their abundance in presence downstream (S4) is indicative of improved stream conditions compared to sampling points S2 and S3 (Carlisle & Clements, 1999; Watanable et al., 2008).

Sensitive macroinvertebrates were only recorded upstream of the tailings site and their abundance was very low, this is possibly due to stream contamination from agriculture. The pattern was consistent throughout, an indication that the waters in the stream are polluted.

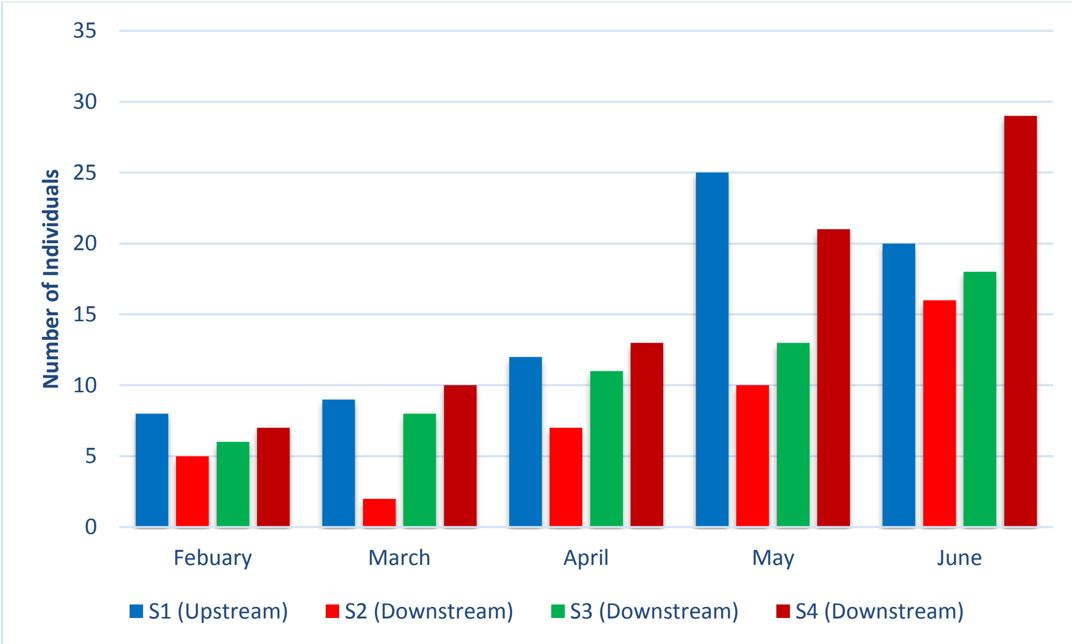


Figure 31: Differences in numbers of macroinvertebrates semi senstive to pollution found, February 2016 to June 2016, between sites upstream and downstream of the Bwana Mkubwa tailings dam on the Munkulungwe Stream

The month of June recorded the highest number of macroinvertebrates (Figure 31); an indication that changes in season had an impact in the composition of species in the stream. With the reduction in volume and flow of water due to change in season, stream conditions also improved.

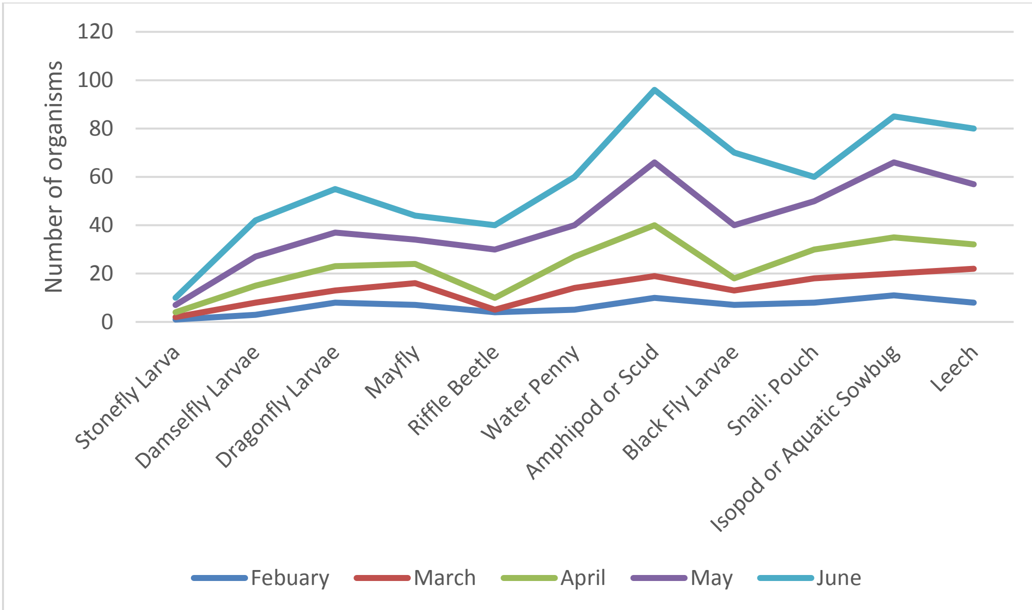


Figure 32: Variation of macroinvertebrates along Munkulungwe Stream during the period of sampling, from February 2016 t0 June 2016

4.6 Biotic Index Score

The biotic index score was calculated using the identification key and placing the species according to the category on the key with an assigned numerical value to that organism. A worksheet was then used to indicate the water quality (excellent, good, fair or poor) at each sampling point (Water-Monitoring, 2007). The average biotic index score was 2.5 (Table 13). On average, the sampling area upstream (S1) had a better index score (overall mean 2.7) than the sampling areas downstream, with the S1 score ranging from 2.1 to 3. The lowest index score on average was recorded at the downstream sampling area S2, overall mean 2.35, ranging from 2 to 2.6. At sampling point S3, the overall mean was 2.42, ranging from 2 to 2.6. The sampling area S4 at furthest point downstream, recorded an overall mean of 2.6, ranging from 1.8 to 3. The biotic index score and stream rating recorded at each sampling point and each period, is given in Table 13. This is summarized per sample point and season in Table 14.

Table 13: Biotic Index Score values and stream rating for each sampling point, along Munkulungwe stream. Note: Excellent = 3.6+; Good = 2.6-3.5; Fair = 2.1-2.5; Poor = 1.0-2.0. From Water-Monitoring, 2007

	Sampling Site							
	S1		S2		S3		S4	
Date	**Index Score**	**Rating**	**Index Score**	**Rating**	**Index Score**	**Rating**	**Index Score**	**Rating**
18/02/16	3	Good	2.2	Fair	2.4	Fair	2.7	Good
25 /02/16	2.9	Good	2.2	Fair	2	Poor	2.5	Fair
21/03/16	3	Good	2	Poor	2.2	Fair	1.8	Poor
28/03/16	2.5	Fair	2.6	Good	2.5	Fair	2.1	Fair
15/04/16	3	Good	2.5	Fair	2.6	Good	2.7	Good
09/05/16	3	Good	2.3	Fair	2.4	fair	3	Good
23/05/16	2.1	Fair	2.4	Fair	2.7	Good	2.1	Fair
13/06/16	2.3	Fair	2.4	Fair	2.4	Fair	2.1	Fair
20/06/16	3	Good	2.5	Fair	2.5	Fair	3	Good

Table 14: Average biotic index score and stream rating (Health) for each site during the sampling period. Note: Excellent = 3.6+; Good = 2.6-3.5; Fair = 2.1-2.5; Poor = 1.0-2.0. From Water-Monitoring, 2007

Biotic Index Score and Stream Rating (Health)							
Site	**Rainy Season**	**Rating**	**Post Rainy Season**	**Rating**	**Overall Mean**	**SD**	**Overall Rating**
S1	2.9	Good	2.6	Good	2.75	0.122474	Good
S2	2.3	Fair	2.35	Fair	2.35	0.040825	Fair
S3	2.34	Fair	2.5	Fair	2.42	0.06532	Fair
S4	2.38	Fair	2.6	Good	2.49	0.089815	Fair

Table 14 showed that the index score was high upstream (S1). The average stream rating upstream was good throughout the sampling period. The lowest score upstream at S1 was in the month of May at 2.1 (Table 13). The highest biotic index score recorded during the sampling period was 3 (with a stream rating of good), scored six times at S1 and four at S4. The lowest index score was 1.8 (stream rating of poor) downstream at S4 (Table 13), in the month of March. The highest biotic index score was recorded at sampling points S1 upstream and S4 downstream.

4.7 Statistical Analysis of Results

The possible relationship between biotic index score and DO, biotic index score and turbidity, biotic index score and heavy metals, DO and turbidity, DO and heavy metals, turbidity and heavy metals and heavy metals and other heavy metals are presented and discussed in this section. The data set analyzed was between February and June 2016. The statistical relationship between variables was measured using Microsoft Excel (2013) to predict relationship between biotic index score (health of stream) and other variables. The tables show a two-tailed correlation of the data samples collected, with significance at 0.05.

4.7.1 Correlations at S1 (Control Point)

Table 16 and 17 showed the correlation at control point (S1) during and after the rainy season. During the rainy season, significant correlation was noticed between Biotic index score-Pb (0.968), DO-turbidity (-0.664), DO-Cu (0.643) and Cu-Co (0.894). No significant correlation was noticed between heavy metals with turbidity. After the rainy season, significant correlation was noticed between Biotic index score-Pb (-0.759), Biotic index score-Fe (0.925), DO-turbidity (-0.917), DO-Cu (-0.981), DO-Pb (-0.799), Turbidity-Cu (0.824), Cu-Co (0.640), Cu-Pb (0.886), Co-Pb (0.805) and Fe-Mn (-0.686) respectively.

Table 15: Correlation of Biotic Index Score, DO, Turbidity and heavy metals of the water samples at Control Point (Rainy Season)

	Biotic Index Score	*DO*	*Turbidity*	*Cu*	*Co*	*Pb*	*Fe*
Biotic Index Score	1						
DO	0.426	1					
Turbidity	-0.244	-0.664	1				
Cu	0.238	0.643	0.142	1			
Co	0.545	0.465	0.304	0.894	1		
Pb	0.968	0.195	-0.029	0.147	0.529	1	
Fe	-0.472	0.585	-0.31	0.522	0.085	-0.654	1

Table 16: Correlation of Biotic Index Score, DO, Turbidity and heavy metals of the water samples at Control Point (Post Rainy Season)

	Biotic Index Score	*DO*	*Turbidity*	*Cu*	*Co*	*Pb*	*Fe*	*Mn*
Biotic Index Score	1							
DO	-0.449	1						
Turbidity	0.384	-0.917	1					
Cu	0.427	-0.981	0.824	1				
Co	0.271	-0.482	0.093	0.64	1			
Pb	0.065	-0.799	0.542	0.886	0.805	1		
Fe	-0.759	-0.234	0.2	0.265	0.149	0.559	1	
Mn	0.925	-0.494	0.575	0.401	-0.037	-0.051	-0.686	1

4.7.2 Correlations at S2

At S2, Biotic index score and heavy metals (Cu, Pb and Mn) showed a significant correlation with r value of -0.889, 0.813 and 0.989. DO-Turbidity (0.681), Cu-Co (-0.841), Cu-Pb (-0.918), Cu-Mn (-0.944), C0-Pb (0.816), Co-Mn (0.615) and Pb-Mn (0.847), also exhibited a significant correlation. There was no significant correlation shown between turbidity-heavy metal and DO-heavy metal during the rainy season. It was noticed that after the rainy season, DO-Cu (0.672), DO-Co (0.905), DO-Mn (-0.622), turbidity-Fe (0.897), turbidity-Mn (0.672), Cu-Co (0.988), Cu-Pb (-0.680), Cu-Fe (-0.832), Co-Pb (0.715), Co-Fe (0.758) and Fe-Mn (0.673) had significant correlation. There was no significant correlation between the biotic index score and heavy metals, DO and turbidity. Equally no significant correlation was noticed between turbidity and heavy metals. Table 18 and 19 detail the correlation as discussed above at S2 during and after the rainy season.

Table 17: Correlation of Biotic index score, DO, Turbidity and heavy metals of the water samples at S2 (Rainy Season)

	Biotic Index Score	*DO*	*Turbidity*	*Cu*	*Co*	*Pb*	*Fe*	*Mn*
Biotic Index Score	1							
DO	0.484	1						
Turbidity	-0.056	-0.681	1					
Cu	-0.889	-0.034	-0.247	1				
Co	0.504	-0.486	0.45	-0.841	1			
Pb	0.813	0.073	-0.07	-0.918	0.816	1		
Fe	-0.442	-0.281	-0.51	0.302	0.037	0.072	1	
Mn	0.989	0.351	0.069	-0.944	0.615	0.847	-0.447	1

Table 18: Correlation of Biotic index score, DO, Turbidity and heavy metals of the water samples at S2 (Post Rainy Season)

	Biotic Index Score	*DO*	*Turbidity*	*Cu*	*Co*	*Pb*	*Fe*	*Mn*
Biotic Index Score	1							
DO	-0.239	1						
Turbidity	-0.293	-0.271	1					
Cu	0.135	-0.577	-0.568	1				
Co	-0.247	0.672	0.505	.988-0	1			
Pb	0.153	0.905	-0.215	-0.68	0.715	1		
Fe	-0.051	0.028	0.897	-0.832	0.758	0.2	1	
Mn	0.477	-0.622	0.672	-0.219	0.072	-0.298	0.673	1

4.7.3 Correlation at S3

Table 20 shows that there was significant correlation during the rainy season between Biotic index score and DO (-0.990), Cu (-0.768), Pb (0.865) and Fe (0.745). DO exhibited significant correlation with heavy metals Cu (0.825), Pb (-0.786) and Fe (-0.645), while turbidity-Cu (0.657), Cu-Co (0.688) and Pb-Fe (0.964), also had significant correlation. Post rainy season showed that there was significant correlation between biotic index score and DO (0.836), Cu (0.820) and Co (0.629); DO-turbidity (0.605), DO-Cu (0.634) and DO-Co (0.878); turbidity-Pb (0.668), turbidity-Fe (0.976) and turbidity-Mn (0.990); Cu-Co (0.702) and Cu-Pb (-0.776); Co-Fe (0.608); Pb-Mn (0.763) and Fe-Mn (0.953).

Table 19: Correlation of Biotic index score, DO, Turbidity and heavy metals of the water samples at S3 (Rainy Season)

	Biotic Index Score	*DO*	*Turbidity*	*Cu*	*Co*	*Pb*	*Fe*	*Mn*
Biotic Index Score	1							
DO	-0.99	1						
Turbidity	-0.246	0.252	1					
Cu	-0.768	0.825	0.657	1				
Co	-0.428	0.552	0.065	0.688	1			
Pb	0.865	-0.786	-0.146	-0.424	0.075	1		
Fe	0.745	-0.645	-0.287	-0.348	0.28	0.964	1	
Mn	0.045	-0.02	0.007	-0.418	-0.078	0.366	0.286	1

Table 20: Correlation of Biotic index score, DO, Turbidity and heavy metals of the water samples at S3 (Post Rainy Season)

	Biotic Index Score	*DO*	*Turbidity*	*Cu*	*Co*	*Pb*	*Fe*	*Mn*
Biotic Index Score	1							
DO	0.836	1						
Turbidity	0.106	0.605	1					
Cu	0.82	0.634	-0.182	1				
Co	0.629	0.878	0.532	0.702	1			
Pb	-0.326	-0.016	0.668	-0.776	-0.265	1		
Fe	0.034	0.574	0.976	-0.131	0.608	0.548	1	
Mn	0	0.501	0.99	-0.318	0.406	0.763	0.953	1

4.7.4 Correlation at S4

At S4 during the rainy season, there was significant correlation between Biotic index score and DO (0.714), Cu (-0.932), Co (-0.951), Pb (-0.658) and Mn (-0.732); DO-Cu (-0.762), DO-Co (-0.782) and DO-Fe (0.745); Cu-Co (0.998), Cu-Pb (0.643) and Cu-Mn (0.765); Co-Pb (0.626) and Co-Mn (0.744), and Pb-Mn (0.982). No significant correlation was noticed between turbidity and heavy metals during and after the rainy season. Post rainy season, significant correlation was noticed between biotic index score and heavy metals Cu (-0.688), Pb (0.905), Fe (0.651) and Mn (0.845); DO and heavy metals Cu (0.954), Fe (-0.723) and Mn (-0.620); Cu-Mn (-0.814); Cu-Pb (-0.801) and Cu-Mn (-0,878), and Pb-Mn (0.866).

Table 21: Correlation of Biotic index score, DO, Turbidity and heavy metals of the water samples at S4 (Rainy Season)

	Biotic Index Score	*DO*	*Turbidity*	*Cu*	*Co*	*Pb*	*Fe*	*Mn*
Biotic Index Score	1							
DO	0.714	1						
Turbidity	0.401	0.012	1					
Cu	-0.932	-0.762	-0.042	1				
Co	-0.951	-0.782	-0.098	0.998	1			
Pb	-0.658	-0.007	-0.222	0.643	0.626	1		
Fe	0.366	0.745	0.392	-0.228	-0.281	0.441	1	
Mn	-0.732	-0.167	-0.118	0.765	0.744	0.982	0.365	1

Table 22: Correlation of Biotic index score, DO, Turbidity and heavy metals of the water samples at S4 (Post Rainy Season)

	Biotic Index Score	*DO*	*Turbidity*	*Cu*	*Co*	*Pb*	*Fe*	*Mn*
Biotic Index Score	1							
DO	-0.594	1						
Turbidity	-0.162	-0.534	1					
Cu	-0.688	0.954	-0.575	1				
Co	-0.577	0.222	-0.271	0.503	1			
Pb	0.905	-0.284	-0.219	-0.484	-0.801	1		
Fe	0.651	-0.723	-0.158	-0.567	0.195	0.275	1	
Mn	0.845	-0.62	0.287	-0.814	-0.878	0.866	0.286	1

The statistical analysis showed that there was significant correlation between the biotic index score-DO, biotic index score-heavy metals (Cu, Pb and Mn) in the stream. Further, significant correlation was noticed between DO-turbidity, DO-Cu, Cu-Co, Cu-Pb, Co-Pb and Pb-Mn. No significant correlation was observed between the biotic index score and turbidity. The results showed that overall, there was a significant relationship between the health of the stream (index score) and physical and chemical parameters measured. This significance in correlation showed that the composition of aquatic organisms in the stream was affected greatly by heavy metal and DO concentration. Correlation between metals showed that the source of heavy metal pollution in Munkulungwe stream was the same.

4.8 Summary

The measured physical parameters showed that pH and TDS are within the acceptable range in the stream, while DO is below the acceptable limit and turbidity above the limit in comparison to global practices IRMA and ZABS. Chemical parameters measured, showed that Cu concentration is within acceptable range. Other metals (Co, Pb, Fe and Mn) were above the acceptable range by ZABS and IRMA although the concentrations were not high. The low concentration of metals, DO and high turbidity in the stream influenced the aquatic habitat as evident in the low density and diversity of organisms in the stream. The biotic index calculated showed that the stream is polluted, with sampling sites (S2 and S3) close to the tailings dam more affected. There was a significant relationship between the stream condition (biotic index score) and the concentration of physical and chemical parameters measured. However, it was observed that stream pollution is not only coming from the tailings dam but also from agricultural activities along the banks of the stream. The change in season influenced in the condition of the stream. Both impacts on metal concentrations, influenced by the tailings dam and dissolved oxygen and turbidity, postulated to be influenced by the agricultural activity, was observed.

CHAPTER 5: DISCUSSION

5.1 Water Quality

Streams and rivers are the major source of freshwaters and provide industries and surrounding communities with potable water. With the growth of industrialization and unplanned settlements along water bodies, humanity has learnt the art of manipulating fresh water bodies to satisfy their needs. This has led to changes in the abiotic and biotic factors which, in turn, affect the aquatic ecosystem (Azevêdo et al., 2015). The impacts resulting from industrialization results in many changes, including high turbidity, temperature, acidity and reduction in biodiversity.

While Zambia has made significant strides to address the challenge of mine water management through shift in policy framework and the mining industry has, increasingly, demonstrated compliance to the same, vulnerabilities still exist in the system. Mine water is characterized by low pH, high turbidity and high concentration of heavy metals (Auditor General, 2014). Typically, it is assessed by physicochemical methods only. The disadvantage of using physical and chemical methods is that equipment is expensive and can be limited to sites that are serviced by laboratories (Dickens and Graham, 2002). In the past, traditional methods of assessing pollution load or water quality using chemical assays or physical parameters such as temperature, pH, dissolved oxygen, light, nutrients and many others have been used, but not biotic indicators.

Biological assessment of water quality may be more useful than using physical and chemical methods only (Basset et al., 2004). Water resources can be characterized through biological assessment by monitoring the trends in the aquatic community caused by anthropogenic perturbation (Resh et al., 1995). In the recent past, biological assessments have shown that they give a comprehensive and cost-effective monitoring approach (Madikizela, 2001). However, the use of biological indicators such as macro invertebrates offers many advantages. While chemical or physical measurements show the water conditions during sampling period, biological indicators integrate the present and past environmental conditions and may impact the future. Secondly, no matter how small the concentration of pollutants, the tolerance range of biological indicators detects it. Biological indicators can indicate the indirect effects of pollutants while chemical or physical measurements cannot. Biological indicators provide the best platform for predicting the ecosystem's response to pollution loads or presence of stressors (Holt & Miller, 2011).

Macroinvertebrates, diatoms, fish, riparian and aquatic plants have been used as bioindicators of water quality (Wright et al., 1984; Barbour et al., 1995; Bredenhand, 2005). This method is well-documented (Qu et al., 2010; Resende , et al., 2010; Abowei et al., 2012; Ngodhe et al., 2014; Xu, et al., 2014; Rodrigues & Bueno, 2016). Benthic macroinvertebrates have been the most used among aquatic organisms (Rosenberg, 1998; Bredenhand, 2005) as they allow spatial analysis. The methods employed for bio-assessment are cheaper and more cost effective in comparison to traditional physiochemical methods and require less effort in analysis compared to traditional methods (Resh & Jackson, 1993).

The study of aquatic macroinvertebrates has increased in the past decades. Research has indicated the importance of aquatic organisms on the ecosystem and their use in reconstructing data on polluted environments, but most dominantly their use in assessing the water quality (Williams & Feldmate, 1992). Macroinvertebrates show a distinctive symptom or characteristic preference of certain habitats and specific water quality. This distinctive dominance and abundance in certain aquatic environments is indicative of the state of the ecosystem in which they are found (Mackie, 2001). Whether the aquatic environment has deteriorated or ameliorated, the type of macroinvertebrates found is indicative of the state of aquatic environment. Because of their visibility to the naked eye, easiness in identification, cycle life based on season and sedentary habits, macroinvertebrates, are valuable organisms for bio-assessments (Dickens & Graham, 2002).

5.2 Factors affecting biodiversity

The distribution of macroinvertebrates in Munkulungwe streams was affected by many factors. Some of the factors that affect aquatic community include chemical and physical parameters of the water, seasonal and weather changes. The response of species to environmental stressors differs; some species are more tolerant while others are sensitive to their environmental conditions.

5.2.1 Physical Parameters

Many parameters were observed to vary from season to season and from location to location. Among the parameters observed were pH, DO, turbidity and TDS.

5.2.1.1 pH

Unpolluted streams normally have a pH range of 6.5 to 8.5 (Ward, 1992). Water with pH below 6.0 is normally considered to be acidic and is usually characterized with low diversity and reproduction of aquatic organisms (Alabaster & Lloyd, 1980). In the research, the mean pH values were within acceptable limits, both upstream and downstream catchment areas. The variance of pH between sample points and season was minimal. Change in season and sampling point had very little influence on the pH. During the rainy season, the pH was relatively constant between 6.4 to 7.8 and post rainy season 6.5 to 7.5 (Table 7 and 8). Mihu-Pintilie & Stoleriu (2014) observed that the season has an influence on water pH due to change in properties of water being transported. Runoff of foreign material into water bodies from tailings and rock dumps affects the pH.

Generally, the first half of the sampling campaign showed no exceptional trends in pH from all the sampling points except for site S2. All the values were within the acceptable range of ZABS and IRMA i.e. 6.0 – 8.5 (ZABS) and 6.5 -8.5 (IRMA) for drinking and aquatic habitat. Similarly, no significant difference was observed in the second half of the sampling campaign. Most of the sampling sites maintained a pH value above the minimum standard presented by IRMA (6.5). Hence, the differences in the biotic index are unlikely to be due to pH, and no correlation between pH and biotic index was found. Similarly, Ngoghe et al. (2014), on studying the Lake Victoria Basin in Kenya, reported that in the pH range between 6.5 and 8.5 no impact on the aquatic biodiversity was observed. Robertson – Bryan (2004) also observed that a pH between 6.5 and 8.5 is conducive to supporting aquatic life and correlates with good water quality.

5.2.1.2 Dissolved Oxygen

Aquatic organisms depend on oxygen to survive, thus low levels of DO in water, are fatal to aquatic organisms (Nebeker et al., 1996). The study showed that the DO was high in the rainy season ranging from 4.64 to 5.93 mg/l, while post rainy season the DO ranged from 2.52 to 5.02 mg/l. Generally, the DO for all the sites during the rainy season was below the acceptable limit of 6mg/l (ZABS, 2010) and 9 mg/l (WHO, 2006). This could be attributed to rainfall and agriculture runoff from farm fields. Decomposition of organic matter and nutrients such as nitrates and phosphates could be responsible for low DO. This is a well-documented process, known as eutrophication, in which the excess nutrients present allow dissolved oxygen to become the limiting nutrient for groups of aquatic organisms, leading to its depletion and the formation of anoxic or anaerobic systems. Similar observation was reported by Kannel et al. (2007) on River Bagmati in China.

There was a decrease of DO post rainy season which could be attributed to discharge of pollutants into the stream from the tailings, increase in agricultural activities along the banks of the stream and natural decay of vegetation. Significant correlation was observed between DO and turbidity at all sampling points. Various studies have shown that runoff organic matter following the rains and runoff from agricultural fields contribute to the reduction of DO through biodegradation resulting from increased respiration from organisms (Kannel et al., 2007; Moss, 2008; Mesner & Geiger, 2010). Figure 33 shows agriculture activities 10 m away from S2. Other researchers have also attributed reduced DO to the reduction of density of aquatic organisms. Dowling & Wiley (1986) investigated the effect of dissolved oxygen on aquatic organisms (fish) and concluded DO concentration between 1 and 5 mg/l contributed to the reduction in the growth rate of catfish. No spawning occurred at a DO concentration of 1.0 mg/l while the number of eggs produced per female was reduced at a DO concentration of 2 mg/l.

Figure 33: Garden at Mwase Farm near S2

The low density and diversity of macroinvertebrates in Munkulungwe Stream could be attributed to the low DO in the stream. Significant correlation was observed between DO and biotic index y at sampling points S3 and S4 (Table 19-22). Similarly, research by Mallya (2007) and Ngoghe et al. (2014) has shown that oxygen saturation level has a positive effect on growth of aquatic organisms. Dowling and Wiley (1986) observed that, in the Wisconsin River, United States of America, the proportion of aquatic organisms was larger in waters with high levels of dissolved oxygen.

5.2.1.3 Total Dissolved Solids

Total Dissolved Solids (TDS) occur naturally in water or are a result of mining activities or other industrial effluents. TDS are composed of organic and inorganic molecules. They may be of benefit by providing nutrients or may include toxic substances such as metals (Scannell & Jacobs, 2001). The study showed that there was no significant difference in TDS all the sampling points. The Total Dissolved Solids in the stream fell in the acceptable range 20 – 500 mg/l for ZABS and IRMA standards. These values do not pose any harm to aquatic organisms or human life. Rozelle & Wathen (1993) also noted that there are no harmful effects to humans or aquatic organisms attributed to low TDS.

5.2.1.4 Turbidity

Turbidity above 5 NTU in streams and rivers, is unsuitable for aquatic life (Anderson, 2003). The presence of these suspended solids makes the water appear muddy or cloudy thereby reducing the amount of light penetrating water for the benefit of aquatic organisms. During the study, turbidity ranged from 11 NTU to 93 NTU during rainy season and 22 NTU to 55 NTU post rainy season.

In all the sampling points, there was significant difference in variation of turbidity during and after the rainy season. The recorded mean turbidity values at each sampling point were all above the recommended safe limit of 5 NTU for ZABS and WHO. The high turbidity in the stream could be one of the contributing factors for the low density and variation of aquatic organisms. Similar studies by Cutts & Batty (2005) have shown that turbidity (6.57 – 11.5 NTU) is a contributing factor to the reduction of fish in streams and rivers. Increase in particle concentration leads to increased light absorption and scattering and affects the ability of larvae to feed. Bash & Berman (2001) also noted that turbid conditions can cause physiological stress and thereby reduce growth, and thus adversely affect the composition of aquatic organisms. Turbidity influenced the dissolved concentration in the stream. Light is prevented from reaching aquatic plants by suspended solids. Without light, photosynthesis cannot take place thus the amount of dissolved oxygen is reduced in water (Mesner & Geiger, 2010).

The presence of agricultural activities near the stream that have left the soils bare makes these susceptible to erosion which contributes to high levels of turbidity in the stream. Nearly every sampling point upstream and downstream except S4 has agriculture activities taking place at the banks of the stream which could influence turbidity values to be above the acceptable limit. The values of turbidity were not influenced with proximity to the mine site. Further, there was no significant correlation between heavy metals and turbidity, whilst significant correlations were observed between turbidity and DO at all sampling points (Tables 17-22).

5.2.2 Chemical Parameters

The profiles of Cu, Co, Pb, Fe and Mn in Munkulungwe stream were observed to vary between sampling point and with change in season. The study showed that comparatively, heavy metal concentration is higher post the rainy season. The Cu concentration remained within acceptable limits at all sampling points while the concentration of heavy metals Co, Pb and Mn were above the acceptable standard by ZABS and IRMA. Table 23 showed that Fe concentration was above the ZABS limit but in most cases within the allowable global practices (IRMA). Although the concentration of metals was not significantly high, it was sufficient to affect aquatic community in the stream. The findings agree with a study by Qu et al. (2010) on Ganqu River in China, where low concentration of heavy metals was sufficient to change the composition of macro invertebrates. Statistical analysis showed significant correlation between heavy metals and the biotic index score (Tables 15 – 22). Biotic index score-Cu, biotic index-Pb and biotic index score-Mn showed significant correlation, suggesting the biotic index score is impacted by the legacy from associated mining activities. Beasley & Kneale (2002), observed in their study on the impact of Cu on macroinvertebrates that there was population decline of many macroinvertebrates *(Daphnia, Gammarus seudolimnaeus, Physa integra, Campeloma decisum, Campeloma decisum)* with increasing Cu concentration (0.5 – 2 mg/l). Research on Gangqu River by Qu et al. (2010) showed that Pb, Cu and Zn concentrations above 0.02 mg/L had deleterious effects on the composition of the macroinvertebrates community. This resulted in the reduction of diversity and changes in community compositions in the Shangrila region watercourses. Heavy metals mainly affected the sensitive macroinvertebrates stoneflies, mayflies and caddisflies while tolerant macroinvertebrates amphipod and leech were observed in Gangqu River. Brinkman & Johnston (2008) field survey of metal contaminated streams suggests that stoneflies *(Plecoptera)* and mayflies *(Ephemeroptera)* are highy sensitive to metals Cu, Pb, Zn and Mn. The observations correlate with this study. Stoneflies and mayflies were dominant in sampling areas (S1 and S4) with low concentration of Cu, Pb, Zn and Mn, but not in S2 and S3 with increased metals concentration. Clements (1994) found that the concentration of Pb and Zn correlated with reduced damseflies and mayflies in the Upper Arkansas River Basin. Similarly Clements et al. (2000) observed that Heptageniid mayflies had been recognized as especially senstive to metals. Although the concentration of heavy metals in the stream was low, research by Qu showed that long term exposure of aquatic organisms to heavy metals affect the composition and density of aquatic organisms (Qu et al., 2010).

Table 23: Comparison of concentration of heavy metals with ZABS and IRMA standards

mg/l	Rainy Season (mean value)				Post Rainy Season (mean Value)				Peak	ZABS Limit	IRMA Limit Drinking Water
Cu	0.14	0.1	0.3	0.2	0.21	0.55	0.4	0.3	0.7	1	1
Co	0.16	0.1	0.1	0.1	0.08	0.54	0.4	0.4	0.8	0.05	0.05
Pb	0.11	0.1	0.1	0.1	0.21	0.4	0.6	0.4	0.8	0.05	0.01
Fe	0.09	0.2	0.2	0.4	0.11	0.98	0.7	0.3	1.2	0.02	0.3
Mn	0.16	0.2	0.3	0.1	0.15	0.32	0.3	0.3	0.5	0.3	0.05

The results factor analysis presented in Section 4.7 indicates a common source of pollution for the five metals (Figure 17 – 22), as evident in the significant correlation observed with Cu-Co, Cu-Pb, Co-Pb, Pb-Fe and Pb-Mn. The concentration of metals increased with change in season and, was highest post rainy season (Table 23) on a time basis and at sampling points S2 and S3 near the tailings dam on a location basis. The results from this research clearly show that Bwana Mkubwa TSF, shown in Figure 34, affects the quality of water in Munkulungwe Stream about 1 km away. Ghose & Sen (1999) also showed that tailings dams built near water bodies may be a source of pollution even when dam is nolonger active, particularly where these dams are inadequately lined as is often found for older tailings dams. The volumes of water flowing from tailings dam need to be managed on a continous basis to minimize the impact on the aquatic ecosystem and the surrounding communities. The results agree with the general pattern of streams on the Zambian Copperbelt near mining sites in which it was observed that the quality of water is influenced by effluent discharge (Mundike, 2004; SGAB et al., 2005; Sracek et al., 2012; Lindahl, 2014; Auditor General Report, 2014).

Figure 34: Bwana Mkubwa TSF (09/05/2016)

From the observations made during the inspections of the Bwana Mkubwa TSF, the dam is statically stable, but does not have toe drains. The water from the tailings dam during the rainy season appears to percolate underground and/ or drain into the stream. Ground water monitoring around the dump and rain out wash may be necessary to ensure dissolved minerals, pH and particulate contents are within acceptable statutory limits as defined by ZABS and IRMA, allowing appropriate water management. Initially it would be necessary to establish the chemical and particulate content of the rain out wash to determine monitoring elements or parameters. The parameters could then be used to monitor the dam's effect (pollution) on the surrounding area, surface and ground water and determine approaches to minimize these.

The effects of several environmental factors such as pH, DO, TDS, turbidity and heavy metals (Cu, Co, Pb, Fe and Mn) were revealed through the composition and distribution of patterns of macroinvertebrates in Munkulungwe Stream. Though the effects were compounded with different factors, the influence of heavy metals was clearly identified on macroinvertebrate communities in the stream, with a decrease in density and diversity in species composition at S2 and S3 corresponding to high metals.

5.3 Macroinvertebrates presence

In this study of the Munkulungwe Stream, sampling upstream of the tailings dam formed the control sample. This sample point (S1) was dominated by damselfly and dragonfly larvae, which are semi sensitive invertebrates to pollution. This trend was consistent throughout the sampling period. Only one sensitive macroinvertebrate was found upstream, there are no significant changes in the pattern of abundance with change in seasons. The low species composition and diversity upstream of the tailings dam suggested exposure to pollution within the sampling area i.e. before the stream is affected by the tailings dam. Although human population density is low in the area, agriculture, as well as mineral exploitation, affects the stream quality.

Amphipod and isopod dominated Munkulungwe stream in the areas adjacent to and downstream of the tailings dam i.e. they formed a higher proportion of the range of macroinvertebrates species found in the stream. They are species that are adaptive to changes in the aquatic environment because of their tolerance levels to pollution (Williams & Feltmate, 1992). Overall, downstream of the mine, abundance of species sensitive to pollution was very low. Downstream sampling areas were characterized with invertebrates that are semi tolerant and tolerant to pollution throughout the sampling period, an indication that the quality of water downstream was poor compared to upstream. This was supported by the high heavy metal concentration downstream, with sampling areas S2 and S3 near the tailings dam recording the highest concentration of metals. The abundance of species that are semi sensitive to pollution was low in the rainy season but increased after the rainy season. The change could be attributed to the reduction in the flow rate of the stream post rainy season. There was distinct distribution in pattern over the sampling points, with sampling point upstream (S1) and further downstream (S4), recording the highest abundance of Damselfly larva and Dragonfly larva. Semi tolerant and tolerant species dominated sampling areas S2 and S3 downstream (Figure 27). The density of macroinvertebrate species increases post rainy season, with the month of June recording the highest number (188), while the lowest number (72) of macroinvertebrates was recorded in the rainy season in the month of February (Figure 32). As with semi tolerant species, Amphipod and Blackfly larva dominated the stream.

The species composition in the stream was low, suggesting that the water quality was not good for aquatic habitat. Significant correlation of biotic index score-Cu, biotic index score-Pb, biotic index score-Mn and biotic index score-DO showed that macroinvertebrate composition is affected by physiochemical changes in the stream. This was also noted for composition of benthic macro invertebrates in the Niger Delta area by Abowei et al. (2012). It is widely perceived that diversity correlates well with the environmental well-being, playing an important role in environmental assessment (Magurran, 2004). Dauvin et al. (2007) observed that tolerant species dominate polluted environments, as is the case in these data collected from the Munkulungwe Stream. Blanchet et al. (2008) and Lavesque et al. (2009) similarly observed that polluted waters are dominated by aquatic organisms that are resistant to pollution. The most tolerant species like amphipod or scud exploit the new habitat and increase in biomass. Similarly, Williams & Feltmate (1992) observed that with change in environmental conditions, invertebrates less tolerant to stream pollution (ephemeroptera, trichopetera and plecoptera) are replaced by the tolerant ones (diptera) in Melksham, UK,

It is clear from the data collected that the dominance of tolerant and intolerant populations showed that the stream was polluted. This was more pronounced in water samples taken from sample points within close proximity to and downstream from the tailings dam. Although the pollution is not heavy in metal concentration in comparison to data collected near active mines on the Zambian Copperbelt (Section 4.4), it still had a negative effect on macroinvertebrates in the stream.

During the study period, the overall biotic index score showed a fair rating or slight pollution of Munkulungwe stream, with index scores varying across sampling points and with changes in season. The average biotic index score of 2.5 (Table 13), indicated that the stream is polluted (Water-Monitoring, 2007). The biotic index score worked well and was consistent with findings of others (Williams & Feltmate 1992; Blanchet et al. 2008; Lavesque et al. 2009; Abowei et al. 2012; Wright & Michelle 2016).

5.4 Comparison of biotic index score with historical data

In 2004, a research was conducted to assess the pollution of Munkulungwe Stream by Bwana Mkubwa, following reports from residents of Munkulungwe and Matalula farming blocks (Mundike, 2004). At this time, Bwana Mkubwa Mine was active. The research assessed pollution in the stream using physiochemical parameters (pH, DO, TDS, turbidity, Co, Cu, Pb, Mn, Zn, Ni and As) and bio-indicators. Historical data collected by Mundike (2004) showed that the stream was heavily polluted, with all the physiochemical parameters measured above the ZABS and IRMA standards (Table 24). The level of chemical and physical pollution has decreased between 2004 and 2016, during which closure also occurred.

Table 24: Comparison of physiochemical parameters measured in Munkulungwe Stream in 2004 and 2016 against ZABS and IRMA limits

	2004 Mine Operational	**2016 Mine Closed**	**ZABS Limit**	**IRMA Limit**
pH	3.5-6	6.4-7.8	6-8.5	6.5-8.4
DO (mg/l)	4-20	5.93	100	-
TDS (mg/l)	1500	345	800	500
Turbidity (NTU)	100	93	5	5
As (mg/l)	38.8	-	0.03	0.01
Cu (mg/l)	51.3	0.7	1	1
Co (mg/l)	27	0.8	0.05	0.05
Pb (mg/l)	23.4	0.8	0.05	0.01
Fe (mg/l)	8	1.2	0.02	0.3
Mn (mg/l)	17	0.5	0.3	0.05
Ni (mg/l)	17	-	0.04	0.02

The Rapid Biological Assessment of Water Quality method called South African Scoring System (SASS4) was used for bio-monitoring. The research was carried out during the rainy season and post rainy season (March 2004 to July 2004). Six sampling sites were selected, including sampling sites S2, S3 and S4 used in this research; however, the research by Mundike had no control points upstream for comparison. The previous variation of biotic index score (Mundike, 2004) between sampling areas downstream S2, S3 and S4, was compared with results obtained in 2016 in Table 25. The results showed that the stream in the rainy season of 2004 was heavily polluted as evident by the low biotic index score (Table 25). Sampling sites S2 and S3 near the tailings dam were the most polluted, with a biotic score averaging 1.67. The pollution reduced further downstream of the tailings dam downstream (S4) where the biotic index was 2.5. This indicated a heavily polluted stream (Water-Monitoring, 2007). The stream was dominated with macroinvertebrates tolerant to pollution (leech, Isopod, amphipod, and snail). The significant correlation between macroinvertebrates and heavy metals, suggested that effluents from Bwana Mkubwa tailings dam were the major source of the pollution in the stream. Local communities whose livelihoods depended on the stream were affected and reports on loss of livestock, contamination of crops and lack of access to safe drinking water were noted (Mundike, 2004).

The 2016 research five years after the mine operations were shut down at Bwana Mkubwa Mine, showed that Munkulungwe Stream was still polluted. However, the pollution load is lower compared to the previous research (Mundike, 2004). The stream rating on average was fair throughout the study (Table 25), indicating that it is not as heavily polluted as before (Water-Monitoring, 2007). Reduction in mining activities contribute to this. Although the stream was not as severely polluted as before, the research showed similar pattern as noticed by Mundike (2004). Sampling sites (S2 and S3) near the tailings dam were more affected (Figure 35), an indication that the tailings dam post mining still had a significant impact on the water quality of Munkulungwe Stream. The biotic index score still showed pollution in the stream and this manifested as a low density and diversity in macroinvertebrates, with tolerant and semi tolerant species dominating the composition.

Post rainy season showed similar trends. S2 and S3 were severely polluted in 2004, with water quality improving further downstream (S4) (Table 25). In both cases, the stream was remediating downstream with distance away from pollution point; the pattern was consistent in 2016 (Figure

35). Similarly, Hasselbach et al. (2005), on Red Dog Mine in Alaska, USA, observed that concentration of metals reduces with distance from pollution point.

Table 25: Comparison of biotic index score for Munkulungwe Stream in 2004 and 2016. Note: Excellent = 3.6+; Good = 2.6-3.5; Fair = 2.1-2.5; Poor = 1.0-2.0. From Water-Monitoring, 2007

Biotic Index Score and Stream Rating (Health)				
	2004		2016	
Site	**Rainy Season**	**Rating**	**Rainy Season**	**Rating**
S2	1.6	Poor	2.3	Fair
S3	1.75	Poor	2.34	Fair
S4	2.5	Fair	2.38	Fair
	2004		**2016**	
Site	**Post Rainy Season**	**Rating**	**Post Rainy Season**	**Rating**
S2	1.8	Poor	2.3	Fair
S3	2	Poor	2.34	Fair
S4	2.62	Fair	2.38	Fair

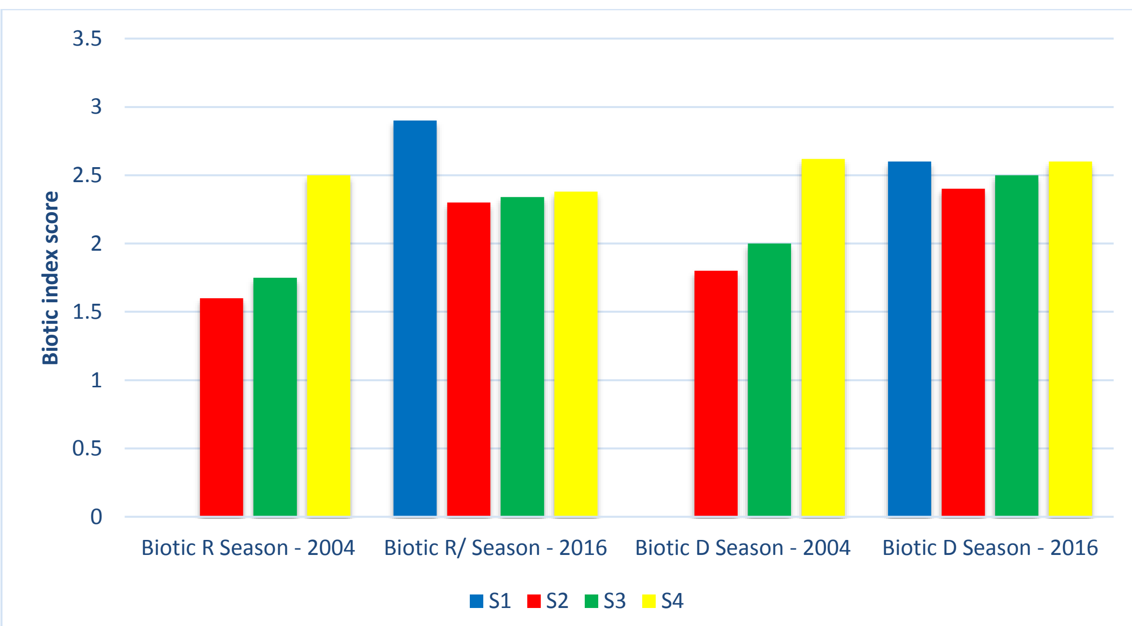


Figure 35: Comparison of the biotic index score Munkulungwe Stream during the periods 2004 and 2016

5.5 Impact of water pollution in Munkulungwe Stream on the community

Water pollution is recognized as one of the more serious environmental challenges in the mining industry (Ochieng et al., 2010). Mine drainage worldwide is a major problem and the Zambian

Copperbelt, the focus of this study, is no exception. Because of resource depletion and pollution, supply of fresh waters continues to dwindle. Water demand, on the other hand, continues to rise due to growth in industrialization, mechanization, urbanization and population (Falkenmark, 1994). Johnson & Hallberg (2005) report that in 1989 more than 19,300 km of rivers and streams had been heavily polluted worldwide by mine effluents, although it is difficult to assess and quantify environmental pollution.

Contamination of water caused by mine effluents is a serious environmental challenge, particularly in highly populated developing countries where human habitat is usually closer to mine sites (Lee, 2003) and in water scarce countries. Water decanting from base metal and coal mines containing heavy metals and sulfuric acid at high concentration could lead to contamination of streams and agricultural lands when the affected stream is used for the purposes of irrigation. This entry of contaminants from the mine into streams and agricultural land can also be facilitated by heavy rainfall events that lead to over-bank flooding (Ochieng et al., 2010). High concentrations of heavy metals in streams and soils increase the chance of uptake of heavy metals by humans and plants, posing a health risk to humans consuming the contaminated water and agricultural products (Boularbah et al., 2006; Lindahl, 2014).

This research showed that the Munkulungwe Stream was polluted, with most of the heavy metals analysed being above the acceptable ZABS and IRMA limits (Table 26). The stream is integral to the surrounding community (Mutalula and Munkulungwe Farming Blocks), supporting more than 300 small scale farmers (Mundike, 2004). Water from the stream is used for agriculture, domestic activities and fishing. Continued pollution of the stream is likely to affect agricultural yield in terms of losses to agricultural production and livestock as the stream is vital in supporting agriculture activities in the area. The stream poses a health challenge to the community, as they continue to consume heavy metals through the consumption of agricultural products, water and fish from the stream (Kadom et al., 2010; Nakayama et al., 2010). It is well known that heavy metals accumulate in the food chain, aggravating their impact. A comparison of the physical and chemical parameters measured in the stream with global practices showed that DO, turbidity, Co, Pb, Fe and Mn concentrations did not meet acceptable standards for drinking, aquatic, agriculture and aquaculture use (Table 26). This was the general trend observed with most streams on the Copperbelt in Zambia.

Table 26: Comparison of water quality in Munkulungwe Stream with local (ZABS) and global standards (IRMA)

	Munkulungwe Stream	ZABS Drinking Water	Human Health and Drinking Water IRMA	Aquatic Organisms - Fresh Water IRMA	Agriculture - Irrigation Water IRMA	Aquaculture Water IRMA
pH	6.4-7.8	6-8.5	6.5-8.5	6.5-9.0	6.5-8.4	6.5-9.0
DO mg/l	5.93	6	8-15	-	-	-
TDS mg/l	345	800	500	-	1	1
Turbidity NTU	93	5	10	25	-	25
Cu mg/l	0.7	1	1	0.0013	0.2	0.2
Co mg/l	0.8	0.05	0.05	0.001	0.05	-
Pb mg/l	0.8	0.05	0.01	0.004	0.01	-
Fe mg/l	1.2	0.02	0.3	0.3	5	0.001
Mn mg/l	0.5	0.3	0.05	1.7	0.2	0.001

Several streams assessed showed that heavy metal concentration of Cu, Co, Pb, Fe and Mn in water and soils on the Zambian Copperbelt is above the acceptable limits (Sawula, 1985; Kasonde, 1995; Sinkala, 1998; Petterson & Ingri, 2001; Von Der Heyden & New , 2004; Lindahl, 2014). Irrigating crops with contaminated water stunts their growth and reduces the yields. A study by the Czech Geological Survey in 2007 revealed that metals build up in leaves and roots of cassava and sweet potatoes grown with metal-contaminated water; maize is less affected. The study recommended that there should be a reduction in the production and consumption of cassava and sweet potatoes in areas dominated by mining activities in Zambia. Other studies have shown that mine water pollution in Zambia has led to loss of access to freshwater, arable land, livelihoods and increase in health-related problems (Das & Rose, 2014).

The livelihoods of local communities on the Zambian Copperbelt, depends on fishing and farming, thus pollution of streams has severe consequences on the community. This study and other literature presented on pollution in the streams on the Copperbelt Province showed that heavy metal concentration is above the recommended global standards for aquaculture (Table 26). Growth of fish in the Kafue River has been affected thereby affecting the local people whose livelihood is dependent on fish farming (Norrgren et al., 2000; SGAB et al., 2005). Further, it has been established that most communities do not have access to potable water in developing countries; hence they are heavily dependent on the available natural water bodies. Pollution of these natural water bodies complicates their ability to gain access to safe water. As a result, they must travel long distances to fetch unpolluted water (Mundike, 2004), often on foot which compromises productive time for earning of livelihoods. The effects of pollution on the community could be summarized as (Dashwood, 2007; Gilbert, 2010; Bayram & Onsoy, 2014; Kitetu, 2014; Padmalal & Maya, 2014):

- Loss of freshwater supply due to contamination of the natural water through heavy metals
- Loss of food due to contamination of plants, fish and other organisms by mine effluents
- Degradation of ecosystem through damage to wildlife and water systems in drier regions
- Loss of livelihood like fishing due to reduction in growth rate of aquatic organisms and agriculture due to sub-optimal yields and quality of produce

Though data related to impacts of mining activities on humans are not rigorous, there is need to determine the extent of mine pollution impacts. Based on the extent of pollution and location of the mine, there is a need to identify remedial actions and areas, because it is evident from this study that the challenge of water pollution is widespread on the Zambian Copperbelt, where mining is taking place. In order to protect the community, environment and ecosystems, there is need to control the pathway of mine effluents into surrounding water bodies, control the disposal of acid-generating waste in terms of location and method and prevent seepage from contaminant sites flowing into affected areas (Akcil & Koldas, 2006). Regular assessment of pollution and comprehensive analyses are needed to clarify the impact of these chemicals on human and aquatic organisms, for protection and management of the environment in African countries (Ochieng et al., 2010). There is need to remediate the seepage coming from the tailings dam prior to it entering the stream, to reduce the impact on the surrounding communities.

5.6 Treatment of Mine Water

5.6.1 The need for mine water treatment

To ensure that the quality of water leaving the mine site does not have a negative impact on people that use water downstream, there is a need for mining companies to further develop ways of water management and waste disposal that minimize water contamination and prevent the discharge of polluted water into the environment. Further, there is the need to develop remediation strategies for abandoned mines. The treatment of mine water can be classified into two categories: passive or active treatment (Ochieng et al., 2010). Active treatment of water uses conventional processes for mine water treatment. Typically, these involve pumping of water from the mine, adding chemical reagents, optimization of reaction and separation and recovery of clean water and a waste product. An example is the water treatment plant at Emalahleni, Mpumalanga, South Africa in which mine drainage is processed to potable water via neutralization, precipitation and reverse osmosis with concomitant production of gypsum products for construction (Gunther, 2009). Passive treatment of water uses naturally available chemical processes and energy sources like gravity (Taylor et al., 2005). Examples here include the use of wetlands, both natural and constructed. Success has been recorded in the treatment of mine water using active methods although it requires a long-term commitment to the treatment process. The advantage of using an active treatment system is that it requires a small footprint in comparison to passive treatment systems like wetlands. Examples of active treatment methods are the use of lime for neutralization, carbonate neutralization, active biological sulphate reduction and ion exchange. This method uses chemicals, energy input and mechanical parts, and often requires skilled labor. The latter is rarely available in the mines located in the rural parts of Zambia post closure. Thus, there is need to adapt to technology to make use of local materials, skills and other resources that may be necessary in enhancing effective ways of treating mine water.

Passive treatment of mine water uses systems that do not require frequent human interventions, nor significant expenditure on energy and other operating costs (IIED, 2002). Passive methods allow nature to purify itself over a period or makes use of artificial systems based on this principle i.e. biomimicry. This can be done by linking ponds or using artificial wetlands where organic matter, bacteria and algae join forces in purifying water by filtering, adsorbing, absorbing and precipitating heavy metal ions and reducing acidity (Jarvis & Younger, 2001). According to Barton & Karathanasis (1999), effective passive systems when constructed can treat mine water for more than 15 years with minimal supervision and maintenance. An alternative is for these systems to be run as semi-passive systems. The most common methods of passive treatment in Southern Africa are wetlands and roughing filtration.

5.6.2 Wetlands

Wetlands use available natural energy like the topographical gradient of an area, energy from microbial metabolism and the sun's energy through photosynthesis to contact streams to facilitate adsorption, metabolize nutrients, provide buffering capacity and oxidize or reduce metals to facilitate precipitation thus reducing the acidity and heavy metal content of water (IIED, 2002). Such systems typically require large land areas to be effective.

Wetlands may use imported substrate which is about 400 to 700 mm deep, like mushroom compost, to overlay a limestone layer of 100 to 200 mm where acid neutralization is required. The limestone base is effective in raising the pH and produces alkalinity that helps in sulphate reduction (Vymazal , 2010). Alternatives include the use of gravel and woodchips as the matrix for microbial attachment and adsorption and the use of desulfurized tailings as an acid neutralizing matrix (Kazadi et al. 2015; Kotsiopoulos and Harrison 2017). By microbial colonization of the wetland, alkalinity can be produced. Development of anaerobic conditions can be used to foster biological sulfate reduction can be fostered to reduce acidity and allow precipitation of metal sulfides. Planted wetlands or algal systems may also be used for metal removal via uptake by the biomass.

5.6.3 Roughing filtration

One of the major pre-treatment processes for mine water is the use of roughing filters to separate out fine solids over a period without the use of chemicals. In comparison to conventional methods, roughing filters are very simple and efficient. They do not require skilled labor or daily operation, are low maintenance yet operate efficiently. Research on a pilot plant at Delmas coal in Mpumalanga, South Africa, by Nkwonta & Ochieng (2009), showed that the use of charcoal filters was effective in removing suspended solids, heavy metals such as magnesium and increasing the pH of mine water. The pilot plant was monitored for period of 60 days, from commissioning until the end of the project and showed that roughing filters are efficient for pre-treatment of mine water.

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

From the review of the literature, it is evident that pollution of rivers and streams at operating mines on the Copperbelt region of Zambia is intense. Pollution results in conditions at 10-100-fold that of the limits, presenting a threat to the water resources, aquatic habitat, food security and human health. However, limited work has been done on the impact of abandoned mines on water resources, hence this case study is a rare such example for Zambia. While pollution in rivers adjacent to the abandoned Bwana Mkubwa mine site is lower, it is still present. The effects of physical and chemical factors were revealed through both distributional and compositional patterns of macroinvertebrates in the Munkulungwe Stream. Although the effects were compounded with different factors such as change in season and agricultural activities, the influence of heavy metals on macroinvertebrate communities was clearly identified, with a decrease in species richness in prevalence of sensitive species and species composition. Even though contamination by heavy metals was lower in the sampling area than near active mines, the concentration of most metals exceeded the guidelines and the consequences upon macroinvertebrate diversity were significant, indicating that the chronic effects of long term exposure of aquatic communities to heavy metals could be serious in Munkulungwe Stream. The biotic index rating of the stream at S2 (2.35) and S3 (2.42) downstream near the tailings dam showed that the Munkulungwe stream was moderately polluted compared to index score at S1 (2.75) upstream.

Physiochemical variables showed a moderate degree of variability in the Munkulungwe Stream and these values were much higher downstream than upstream of the Bwana Mkubwa TSF. The influence of physiochemical variables in the stream was visible, especially in the case of DO, turbidity, Pb and Mn. Physical variables DO and turbidity had a greater impact on the Munkulungwe Stream than pH and TDS. The chemical variables Co, Pb, Fe and Mn all exceeded the values for recommended water quality range in the Zambian Bureau of Standards (ZABS, 2010) and IRMA. Most of the heavy metals measured had median values higher than the guideline concentrations (Table 23). The concentration of metals was highest at sampling points S2 and S3 downstream near the tailings dam. The research has shown that the values of DO (4.52 mg/l), turbidity (40.96 NTU), Co (0.24 mg/l), Pb (0.25 mg/l), Fe (0.36 mg/l) and Mn (0.22 mg/l) did not meet international standards for drinking water and aquatic organisms in freshwater (IRMA). Concentration of heavy metals (Cu, Co, Pb and Mn) was also above the limits for irrigation water.

Considering the physiochemical variables discussed, dominant macroinvertebrates gave a good indication of the prevailing water quality conditions in the Munkulungwe Stream. Canonical correspondence analysis confirmed this point by clearly distinguishing four groups of invertebrate species in the Munkulungwe Stream, each of these groups showing clear preferences towards physical and chemical conditions that were consistent with the ecological preferences of these species. The stream at sampling points S2 and S3 were dominated by species tolerant (leech, Isopod and Snail: Pouch) and semi tolerant (Blackfly larvae and Amphipod or Scud) to pollution. Change in season influenced the composition of macroinvertebrates, with the number of species increasing post rainy season.

Correlation analysis showed that stronger correlations existed between biotic index score and DO, Cu, Pb, Mn, suggesting that the macroinvertebrate community (and biotic index derived from the community composition) that were in the stream were influenced by the prevailing water quality. This has highlighted the value of macroinvertebrates as a bio-monitoring tool in that it suggests that macroinvertebrates community are representative of the prevailing conditions at a site over a longer period. Correlations of physiochemical variables DO-turbidity, DO-Cu, Cu-Co, Cu-Pb, Co-Pb and Pb-Mn yielded stronger correlations at the 95% confidence level (Tables 17, 18, 19, 20, 21 and 22). There was no significant correlation between turbidity and heavy metals, suggesting that the exploitation of minerals was not the only main disturbance to water quality in Munkulungwe Stream. Human activities such as agriculture could be contributing to turbidity and DO values in the stream. Turbidity and DO values were not better at the control point (S1) and these correlate with all sampling points. From the results of the correlation analysis, it can be concluded that macroinvertebrates are suitable indicators of contamination with heavy metals, as the results showed that correlation between the macroinvertebrate (biotic index) and heavy metals were strongest of all correlations between physiochemical variables and biotic index. Therefore, the macroinvertebrate community structure was influenced to a high degree by the concentration of heavy metals in the stream.

Similar observations were made by Mundike (2004). Although the research by Mundike (2004) showed a heavily polluted stream (Table 25) in comparison to this study, both research studies showed that pollution was high in sampling areas near the tailings dam (S2 and S3) with water quality improving further downstream (S4). In both cases, the stream was remediating downstream with distance away from pollution point. The studies show that the stream was characterized by a low density and diversity in macroinvertebrates, with tolerant and semi tolerant species dominating the composition. The conclusion from both studies was that heavy metal concentration had an impact on the deterioration of water quality in the stream. The pollution threat posed by mine wastes and seepage to the environment is likely to persist over an extended period.

Whilst mine waste presents a threat to freshwater resources, human health and food security in Zambia, it has opened opportunities to use appropriate technologies to achieve usable water fit for defined purpose from these contaminated sites. These treatment technologies may include passive or active treatment. Here, where there is limited availability of personnel, passive or semi-passive treatment options are preferred.

6.2 Recommendations

In this study, the value of biotic studies to assess water quality, such as the analysis of macroinvertebrates, has been demonstrated. Looking beyond this study, it is recommended that the efficacy with which macroinvertebrates can accurately represent the quality of water be tested on a larger scale in Zambia, such as Lusaka, Kafue, Kitwe, Chingola, Chambeshi, Luanshya, Mufulira, Kalulushi, Chililabombwe and other cities. This distribution of cities would allow for the testing in different climatic and geographical regions, where the quality of the aquatic environments may differ because of the different influences of physiochemical variable concentrations. These areas would also subject the use of macroinvertebrate as a measure quality of water to different anthropogenic impacts on the aquatic environments. The areas have impacts inherent to them and the response of the macroinvertebrates to the cumulative effects of these areas and their impacts may provide a more holistic picture in terms of the suitability of macroinvertebrates. Other environmental factors that affect water quality and aquatic habitat such as geography, hydro-morphology, temperature, conductivity, shade, water depth, insecticides and farming inputs need to be included. Further research on the effect of water quality on crops, silt and soil quality in the area needs to be conducted. Ground water must also be assessed for possible contamination.

It is suggested that groundwater surrounding tailings dams should be monitored in both active and abandoned mines. Curtain boreholes around a tailings dam can be drilled and the water extracted and treated so that it doesn't contaminate other water bodies. To improve the environmental management of mining related impacts in Zambia, mining areas should be completely rehabilitated. There is need for remediation strategies for abandoned mine sites. One of the recent technologies that uses plants and associated soil microbes to reduce the concentration of contaminants on mine waste lands is phytoremediation (Ali et al., 2013). Although the technology is limited to root-zone plants, it is a cost-effective restoration technology for waste lands. It is nondestructive to the soil compared to engineering procedures. The techniques of phytoremediation include phytodegradation, phytoextraction, phytostabilization, phytofiltration and phytovolatilazation (Arora et al., 2008). It is proposed that the role of phytoremediation in the restoration of the Munkulungwe Stream and associated areas be investigated, with potential to extend to further mining regions.

There is also need to improve on implementation of existing environmental legislation. The Zambia Environmental Agency (ZEMA) suffers from inadequate resourcing to fulfill its mandate and has insufficient staff to adequately pursue compliance monitoring and auditing. Ineffective control and monitoring of the mines' environmental performance leaves the existing legal framework to a large extent unimplemented. Surveillance of the industry is much needed for better implementation of the legislation.

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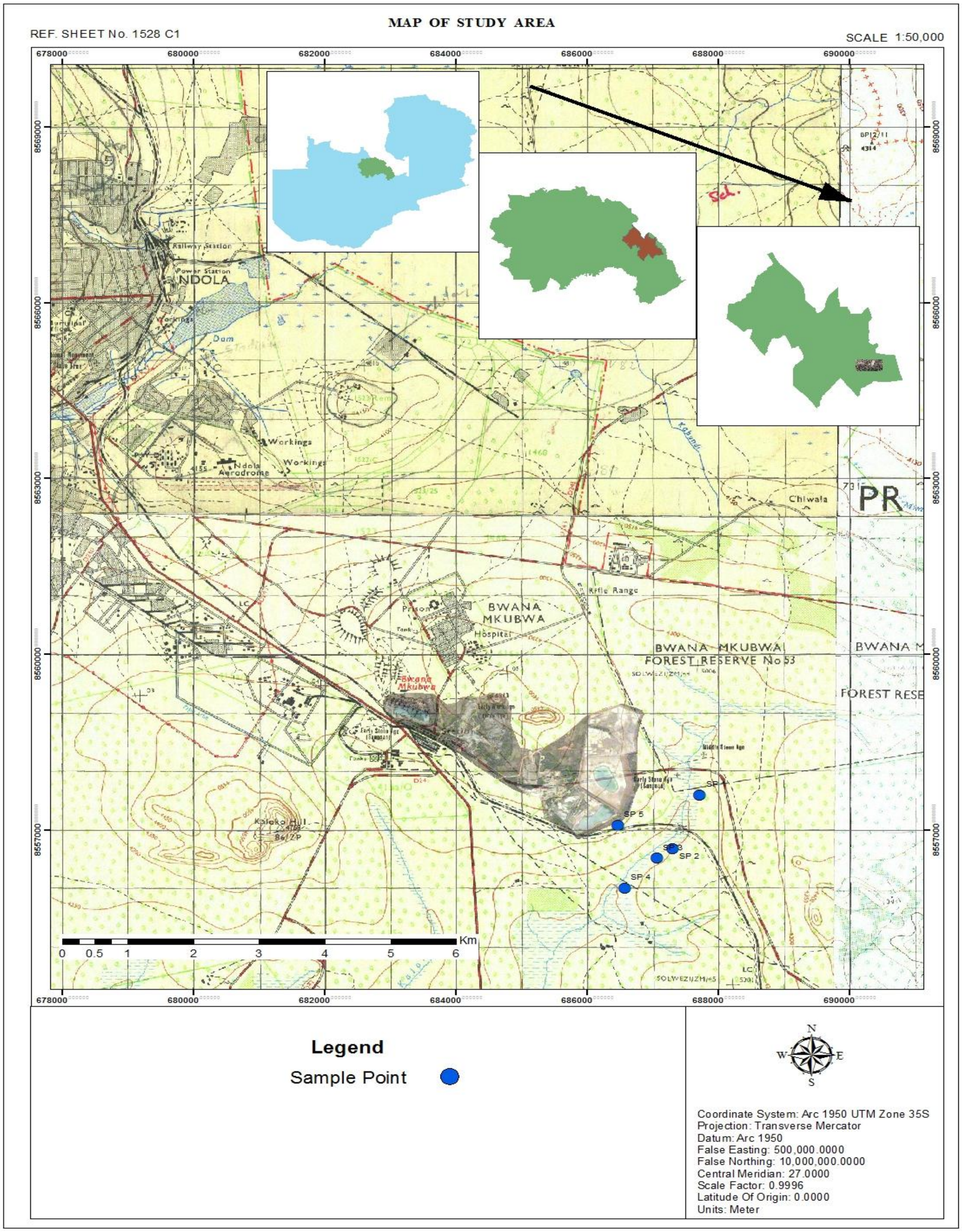
APPENDIX A: Study Area



APPENDIX B: Results for Assessed Parameters

THE COPPERBELT UNIVERSITY

School of Mines and Mineral Sciences

Analytical service unit

P.O Box 21692 – Kitwe – Zambia   Cell: 0968-646575 / 0977-681549

CLIENT	LEE MUDENDA	**DATE SUBMITTED**
ADDRESS	RIVERSIDE	
SAMPLE DESCRIPTION	WATER(Borehole)	**30.06.16**
SERVICES REQUESTED	S1 Water Quality analysis – After Rainy Season	

Parameter	Unit	Result	Zabs Limits
pH		6.9	6.0 - 8.5
Turbidity	NTU	38.25	5
Conductivity	µS/cm	-	1500
DO	mg/l	3.788	100
TDS	mg/l	201	800
Total hardness	mg/l	-	500
Cl^-	Mg/g	-	250
So^4	mg/l	-	250
No_3	mg/l	-	45
Ca	mg	-	200
Mg	mg	-	30
Fe	mg	0.11	0.3
Cu	mg	0.21	1
CO	mg	0.08	0.05
Mn	mg	0.15	0.02
Pb	mg	0.21	0.05
Na	mg	-	200
K	mg	-	12
Fecal Coli form	# / 100	-	0
Total Coli form	# / 100	-	0

Comment:

Most of the parameters tested are within the acceptable limits; the source of concern however, is the presence of high Turbidity. Pb and Mn were also above the acceptable limit

Authorizing Officer's Approval:	**Sign:**	**Date:**
	Name**: DR L.Mukosha**	
Designation	Head of Department - Analytical services	

THE COPPERBELT UNIVERSITY

School of Mines and Mineral Sciences

Analytical service unit

P.O Box 21692 – Kitwe – Zambia   Cell: 0968-646575 / 0977-681549

CLIENT	LEE MUDENDA	**DATE SUBMITTED**
ADDRESS	RIVERSIDE	
SAMPLE DESCRIPTION	WATER(Munkulungwe Stream)	**30.04.16**
SERVICES REQUESTED	S1 Water Quality analysis – Rainy Season	

Parameter	Unit	Result	Zabs Limits
pH		7.3	6.0 - 8.5
Turbidity	NTU	52.4	5
Conductivity	µS/cm	-	1500
DO	mg/l	5.3	6
TDS	mg/l	234.8	800
Total hardness	mg/l	-	500
Cl^-	Mg/g	-	250
So^4	mg/l	-	250
No_3	mg/l	-	45
Ca	mg	-	200
Mg	mg	-	30
Fe	mg	0.09	0.3
Cu	mg	0.14	1
CO	mg	0.16	0.05
Mn	mg	0.16	0.02
Pb	mg	0.11	0.05
Na	mg	-	200
K	mg	-	12
Fecal Coli form	# / 100	-	0
Total Coli form	# / 100	-	0

Comment:

Most of the parameters tested are within the acceptable limits; the source of concern however, is the presence of high Turbidity. CO, Mn and Pb were above the acceptable limit

Authorizing Officer's Approval:	**Sign:**	**Date:**
	Name: **DR L.Mukosha**	
Designation	Head of Department - Analytical services	

THE COPPERBELT UNIVERSITY

School of Mines and Mineral Sciences

Analytical service unit

P.O Box 21692 – Kitwe – Zambia   Cell: 0968-646575 / 0977-681549

CLIENT	LEE MUDENDA	**DATE SUBMITTED**
ADDRESS	RIVERSIDE	
SAMPLE DESCRIPTION	WATER(Borehole)	**30.06.16**
SERVICES REQUESTED	S2 Water Quality analysis – After Rainy Season	

Parameter	Unit	Result	Zabs Limits
pH		7.125	6.0 - 8.5
Turbidity	NTU	39.5	5
Conductivity	µS/cm	-	1500
DO	mg/l	3.688	100
TDS	mg/l	267.25	800
Total hardness	mg/l	-	500
Cl^-	Mg/g	-	250
So^4	mg/l	-	250
No_3	mg/l	-	45
Ca	mg	-	200
Mg	mg	-	30
Fe	mg	0.98	0.3
Cu	mg	0.55	1
CO	mg	0.54	0.05
Mn	mg	0.44	0.02
Pb	mg	0.32	0.05
Na	mg	-	200
K	mg	-	12
Fecal Coli form	# / 100	-	0
Total Coli form	# / 100	-	0

Comment:

Most of the parameters tested are within the acceptable limits; the source of concern however, is the presence of high Turbidity. Fe, CO, Mn and Pb, were also above the acceptable limit.

Authorizing Officer's Approval:	**Sign:**	**Date:**
	Name: **DR L.Mukosha**	
Designation	Head of Department - Analytical services	

THE COPPERBELT UNIVERSITY

School of Mines and Mineral Sciences

Analytical service unit

P.O Box 21692 – Kitwe – Zambia   Cell: 0968-646575 / 0977-681549

CLIENT	LEE MUDENDA	**DATE SUBMITTED**
ADDRESS	RIVERSIDE	
SAMPLE DESCRIPTION	WATER(Borehole)	**30.04.16**
SERVICES REQUESTED	S2 Water Quality analysis – Rainy Season	

Parameter	Unit	Result	Zabs Limits
pH		7.08	6.0 - 8.5
Turbidity	NTU	50.5	5
Conductivity	µS/cm	-	1500
DO	mg/l	5.068	100
TDS	mg/l	258	800
Total hardness	mg/l	-	500
Cl^-	Mg/g	-	250
So^4	mg/l	-	250
No_3	mg/l	-	45
Ca	mg	-	200
Mg	mg	-	30
Fe	mg	0.09	0.3
Cu	mg	0.13	1
CO	mg	0.09	0.05
Mn	mg	0.15	0.02
Pb	mg	0.08	0.05
Na	mg	-	200
K	mg	-	12
Fecal Coli form	# / 100	-	0
Total Coli form	# / 100	-	0

Comment:

Most of the parameters tested are within the acceptable limits; the source of concern however, is the presence of high Turbidity. Mn was above the acceptable limit

Authorizing Officer's Approval:	**Sign:**	**Date:**
	Name: **DR L.Mukosha**	
Designation	Head of Department - Analytical services	

THE COPPERBELT UNIVERSITY

School of Mines and Mineral Sciences
Analytical service unit
P.O Box 21692 – Kitwe – Zambia   Cell: 0968-646575 / 0977-681549

CLIENT	LEE MUDENDA	**DATE SUBMITTED**
ADDRESS	RIVERSIDE	
SAMPLE DESCRIPTION	WATER(Borehole)	**30.06.16**
SERVICES REQUESTED	S3 Water Quality analysis – After Rainy Season	

Parameter	Unit	Result	Zabs Limits
pH		6.925	6.0 - 8.5
Turbidity	NTU	26	5
Conductivity	µS/cm	-	1500
DO	mg/l	3.605	100
TDS	mg/l	267.25	800
Total hardness	mg/l	-	500
Cl^-	Mg/g	-	250
So^4	mg/l	-	250
No_3	mg/l	-	45
Ca	mg	-	200
Mg	mg	-	30
Fe	mg	0.66	0.3
Cu	mg	0.44	1
CO	mg	0.44	0.05
Mn	mg	0.34	0.02
Pb	mg	0.59	0.05
Na	mg	-	200
K	mg	-	12
Fecal Coli form	# / 100	-	0
Total Coli form	# / 100	-	0

Comment:

Most of the parameters tested are within the acceptable limits; the source of concern however, is the presence of high Turbidity. Fe, CO, Mn and Pb, were also above the acceptable limit.

Authorizing Officer's Approval:	**Sign:**	**Date:**
	Name: **DR L.Mukosha**	
Designation	Head of Department - Analytical services	

THE COPPERBELT UNIVERSITY

School of Mines and Mineral Sciences

Analytical service unit

P.O Box 21692 – Kitwe – Zambia   Cell: 0968-646575 / 0977-681549

CLIENT	LEE MUDENDA	**DATE SUBMITTED**
ADDRESS	RIVERSIDE	
SAMPLE DESCRIPTION	WATER(Borehole)	**30.04.16**
SERVICES REQUESTED	S3 Water Quality analysis – Rainy Season	

Parameter	Unit	Result	Zabs Limits
pH		7.26	6.0 - 8.5
Turbidity	NTU	45.76	5
Conductivity	µS/cm	-	1500
DO	mg/l	5.21	100
TDS	mg/l	287.6	800
Total hardness	mg/l	-	500
Cl^-	Mg/g	-	250
So^4	mg/l	-	250
No_3	mg/l	-	45
Ca	mg	-	200
Mg	mg	-	30
Fe	mg	0.12	0.3
Cu	mg	0.25	1
CO	mg	0.10	0.05
Mn	mg	0.25	0.02
Pb	mg	0.12	0.05
Na	mg	-	200
K	mg	-	12
Fecal Coli form	# / 100	-	0
Total Coli form	# / 100	-	0

Comment:

Most of the parameters tested are within the acceptable limits; the source of concern however, is the presence of high Turbidity

Authorizing Officer's Approval:	**Sign:**	**Date:**
	Name: **DR L.Mukosha**	
Designation	Head of Department - Analytical services	

THE COPPERBELT UNIVERSITY
School of Mines and Mineral Sciences
Analytical service unit
P.O Box 21692 – Kitwe – Zambia   Cell: 0968-646575 / 0977-681549

CLIENT	LEE MUDENDA	**DATE SUBMITTED**
ADDRESS	RIVERSIDE	
SAMPLE DESCRIPTION	WATER(Borehole)	**30.06.16**
SERVICES REQUESTED	S3 Water Quality analysis – After Rainy Season	

Parameter	Unit	Result	Zabs Limits
pH		7.025	6.0 - 8.5
Turbidity	NTU	32.5	5
Conductivity	µS/cm	-	1500
DO	mg/l	3.958	100
TDS	mg/l	256.25	800
Total hardness	mg/l	-	500
Cl^-	Mg/g	-	250
So^4	mg/l	-	250
No_3	mg/l	-	45
Ca	mg	-	200
Mg	mg	-	30
Fe	mg	0.34	0.3
Cu	mg	0.25	1
CO	mg	0.36	0.05
Mn	mg	0.31	0.02
Pb	mg	0.38	0.05
Na	mg	-	200
K	mg	-	12
Fecal Coli form	# / 100	-	0
Total Coli form	# / 100	-	0

Comment:
Most of the parameters tested are within the acceptable limits; the source of concern however, is the presence of high Turbidity. Fe, CO, Mn and Pb, were also above the acceptable limit.

Authorizing Officer's Approval:	**Sign:**	**Date:**
	Name: **DR L.Mukosha**	
Designation	Head of Department - Analytical services	

THE COPPERBELT UNIVERSITY
School of Mines and Mineral Sciences
Analytical service unit
P.O Box 21692 – Kitwe – Zambia   Cell: 0968-646575 / 0977-681549

CLIENT	LEE MUDENDA	DATE SUBMITTED
ADDRESS	RIVERSIDE	30.04.16
SAMPLE DESCRIPTION	WATER(Borehole)	
SERVICES REQUESTED	S4 Water Quality analysis – Rainy Season	

Parameter	Unit	Result	Zabs Limits
pH		7.1	6.0 - 8.5
Turbidity	NTU	50.5	5
Conductivity	µS/cm	-	1500
DO	mg/l	5.54	100
TDS	mg/l	298.6	800
Total hardness	mg/l	-	500
Cl^-	Mg/g	-	250
So4	mg/l	-	250
No3	mg/l	-	45
Ca	mg	-	200
Mg	mg	-	30
Fe	mg	0.35	0.3
Cu	mg	0.15	1
CO	mg	0.11	0.05
Mn	mg	0.1	0.02
Pb	mg	0.14	0.05
Na	mg	-	200
K	mg	-	12
Fecal Coli form	# / 100	-	0
Total Coli form	# / 100	-	0

Comment:
Most of the parameters tested are within the acceptable limits; the source of concern however, is the presence of high Turbidity

Authorizing Officer's Approval:	Sign:	Date:
	Name: **DR L.Mukosha**	
Designation	Head of Department - Analytical services	

APPENDIX C: - Statutory Dumps Inspections Research Assistant Check List

DUMP NAME: ………………………………………………………………………………………….

DATE OF INSPECTION: …………………………………………………………………………….

BY WHOM: …………………………………………………………………………….

S/N	PARAMETER DESCRIPTION	COMMENTS	ANY OTHER ISSUES
1	AREA COVERED		
2	TYPE OF MATERIAL		
3	LAST TIME DUMPED		
4	STABILITY OF SLOPES		
5	ANY GULLYING OBSERVED		
6	DRAINAGE AROUND THE DUMP?		
7	SURFACE COVER (TREES SHRUBS OR GRASS OR BARE?)		
8	ANY GROUND WATER MONITERING FACILITIES		
9	SIGNS OF FUGITIVE DUST GENERATION?		
10	IS THERE ANY STREAM OR RIVER NEAR BY		
11	DO THEY HAVE SETTLING PONDS IN CASE OF ROCK DUMPS?		
12	FOR TAILINNGS DUMPS IS IT A CLOSED SYSTEM OR OPEN		
12a	CLOSED TAILINGS DUMPS		

	(LEACH PLANT AND HEAP LEACH PAD)		
i	IF CLOSED SYSTEM WHERE IS THE EFFLUENT RECYCLED TO?		
ii	IF CLOSED, WHAT ARE THE pH LEVELS IN THE RAFFINET		
12b	OPEN TAILINGS DUMP (MUSI DUMP)		
i	IF OPEN WHAT IS THE CLARITY OF THE DISCHARGED WATER		
13	ANY REHABILITATION WORKS BEING DONE		
14	IS THERE ANY SIGN OF PLANT RECOLONISING THE DUMP (FOR CLOSED DUMPS)		
15	IN YOUR VIEW IS THE DUMPS STABLE		
16	IN YOUR VIEW IS THE DUMP ENVIRONMENTANRY OK		
17	ANY OTHER INFORMATION		

APPENDIX D: Recording Form for the Citizen Monitoring Biotic Index

Name: ______________________________ Date: ______________

Stream Name: ______________________________ Time: ______________

Location: ______________________________ Site: ______________

(County, Township, Range, Section, Road, Intersection, Other)

At this point, you should have collected a wide variety of aquatic macroinvertebrates from your three sites. You will now categorize your sample, using the *Key to Macroinvertebrate Life in the River* to help you identify the macroinvertebrates found. **The number of animals found is not important; rather, the variety of types of macroinvertebrates and their tolerance to pollution tells us the biotic index score**. Before you begin, check off the habitats from which you collected your sample (see right).

- ☐ Riffles
- ☐ Undercut banks
- ☐ Snag areas, tree roots, submerged logs
- ☐ Leaf packs

1. You should have removed large debris (e.g. leaves, rocks, sticks) from your sample and placed this material in a separate basin (after removing macroinvertebrates from it).
2. Check the basin with the debris to see if any aquatic macroinvertebrates crawled out. Add these animals to your prepared sample.
3. Fill the ice cube tray half-full with water.
4. Using plastic spoons or tweezers, (be careful not to kill the critters – ideally, you want to put them back in their habitat after you're finished) sort out the macroinvertebrates and place ones that look alike together in their own ice cube tray compartments. Sorting and placing similar looking macroinvertebrates together will help insure that you find all varieties of species in the sample.
5. Refer to the *Key to Macroinvertebrate Life in the River* and the *Citizen Monitoring Biotic Index* to identify the aquatic macroinvertebrates:

   A. On the back of this page, circle the animals on the index that match those found in your sample.

   B. Count the number of types of animals that are circled in each group and write that number in the box provided. Do not count individual animals in your sample. Only count the number of types of animals circled in each group.

   C. Enter each boxed number in work area below.

   D. Multiply the entered number from each group by the group value.

   E. Do this for all groups.

   F. Total the number of animals circled.

   G. Total the calculated values for all groups.

   H. Divide the total values by the total number of types of animals that were found: **TOTAL VALUES (b.) / TOTAL ANIMALS (a).**

   I. Record this number.

   SHOW ALL MATH (Use space below to do your math computations)

No. of animals circled from group 1 ________ x 4 = ________

No. of animals circled from group 2 ________ x 3 = ________

No. of animals circled from group 3 ________ x 2 = ________

No. of animals circled from group 4 ________ x 1 = ________

________ TOTAL ANIMALS (a): ________ TOTAL VALUE (b):

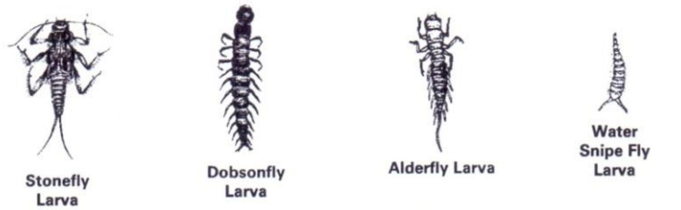
Index score: ☐

How Healthy is the stream?	
Excellent	3.6+
Good	2.6 - 3.5
Fair	2.1 - 2.5
Poor	1.0 - 2.0

Divide totaled value (b)_____by total no. of animals (a) _____for index score:

Report your results online at **www.uwex.edu/erc/wavdb** *or submit your data to your local coordinator.*
Call your local monitoring coordinator if you have questions about sampling or determining the Biotic Index Score.

Group 1: These are sensitive to pollutants. Circle each animal found.



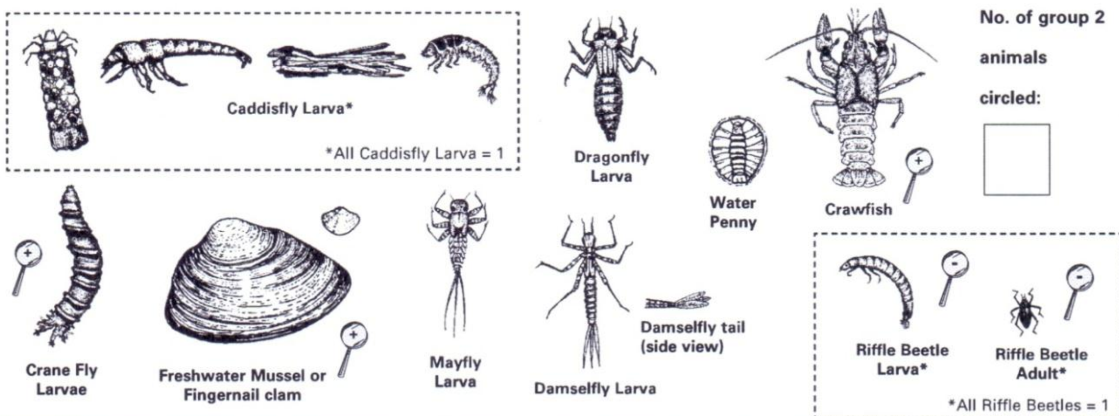
No. of group 1 animals circled: ☐

Relative Size Key:

(+) = larger than picture

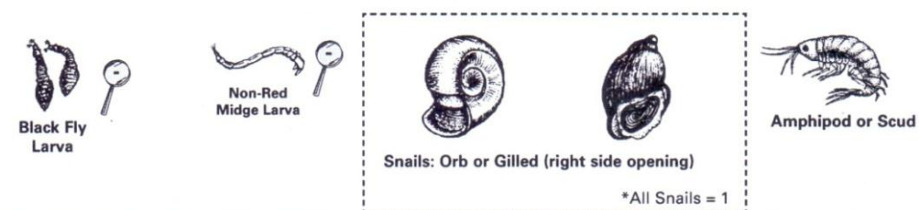
(-) = smaller than picture

Group 2: These are semi-sensitive to pollutants. Circle each animal found.



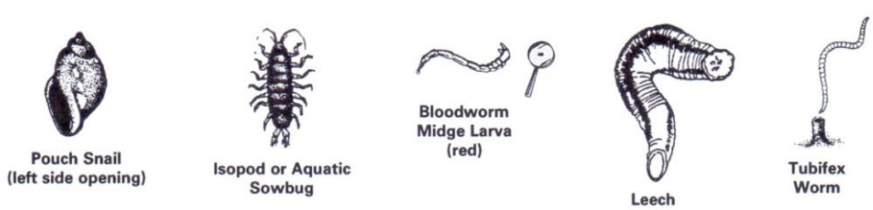
No. of group 2 animals circled: ☐

Group 3: These are semi-tolerant of pollutants. Circle each animal found.



No. of group 3 animals circled: ☐

Group 4: These are tolerant of pollutants. Circle each animal found.



No. of group 4 animals circled: ☐

For more information, call (608) 265-3887 or (608) 264-8948.
Download and print data sheets from
watermonitoring.uwex.edu/wav/monitoring/sheets.html

Water Action Volunteers

APPENDIX E: Aanalyst 200; Atomic Absorption Spectrometer

The Instrument consists of a high efficiency burner system which has a high nebulizer and an atomic absorption spectrometer. Thermal energy that is necessary to dissociate the chemical compounds is provided by the burner, it provides free analyte atoms so that atomic absorption occurs. The spectrometer is the one that measures the amount of light absorbed at a specific wavelength using a hollow cathode lamp as the primary light source, a monochrometer and a detector. A deutrum arc lamp corrects for background absorbance caused by non-atomic species in the atom cloud.