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AN ASSESSMENT OF HEAVY METALS POLLUTION OF MAZOWE RIVER DUE TO ARTISANAL SMALL-SCALE GOLD MINER IN SHAMVA DISTRICT MASHONALAND CENTRAL PROVINCE

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DEDICATION

My dissertation is dedicated to my parents, whose unwavering support, encouragement and sacrifices have been the cornerstones of my academic journey. I have always been inspired and given strength by your faith in me. I would want to thank my friends and siblings for their patience, love and understanding throughout this investigation. I was able to continue because of your support. I am very grateful to the Almighty God for providing me with the knowledge, fortitude and strength necessary to complete this research.

DECLARATION

Registration Number B224419B

I, Gokuda Addmore sincerely declare that this research project is my original work that has not been previously submitted to any other university. Proper citations and acknowledgements in line with copyright laws and ethical requirements have been strictly adhered to in the compilation of this dissertation.

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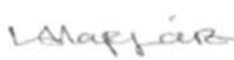
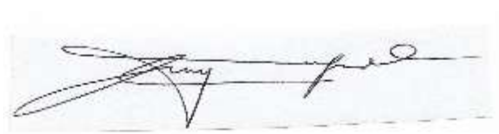
Supervisor: Dr. L. Mabhungu

This dissertation is suitable for submission to the faculty and has been checked for conformity with the faculty guidelines.

Signature of the Supervisor:…  Date: 30 June 2025 …

Chairman: 

Highly commend this dissertation for its originality, significance and impact of the field of study.

Signature of the Chairman :……………………………………..Date:………………………

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ABSTRACT

The expansion of Artisanal Small-Scale Gold Mining (ASSGM) in Zimbabwe, particularly in Shamva District of Mashonaland Central Province, has raised significant environmental concerns due to its impact on freshwater systems. This study assessed the extent of heavy metal pollution in the Mazowe River caused by ASSGM activities, focusing on seven key metals: cadmium (Cd), chromium (Cr), copper (Cu), arsenic (As), lead (Pb), mercury (Hg) and zinc (Zn). Sampling was carried out during the summer and autumn seasons at three sites: upstream (control site) located above the mining zone; midstream (impact zone), directly adjacent to artisanal mining discharges; and downstream (recovery zone), where cumulative effects of pollution are expected. Water, sediment and fish (Oreochromis mortimeri and Protopterus annectens) samples were collected and analysed using Flame Atomic Absorption Spectrometry (FLAAS) following standardized Acid Digestion Procedures. Chi-square statistical tests revealed significant differences in cadmium, chromium, and lead concentrations between upstream and downstream sites, particularly in water and sediment samples. Lead and mercury was also found to accumulate in fish tissues, although all detected heavy metal levels in fish remained within FAO/WHO safety limits. The highest concentrations of Cd, Hg and Pb occurred downstream, indicating strong spatial influence from mining activities. The study concludes that ASSGM significantly contributes to heavy metal pollution in the Mazowe River, especially affecting sediment, aquatic life and water quality. To address this, the study recommends: (1) strengthening enforcement of environmental regulations by the Environmental Management Agency (EMA); (2) formalising artisanal mining operations to improve waste handling and reduce pollutant discharge; (3) implementing routine environmental monitoring of water bodies in mining zones; and (4) promoting community education on the health risks of consuming contaminated fish and water. These findings provide a scientific basis for guiding policy and community action to protect ecosystems and human health in mining-affected areas.

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LIST OF ACRONYMS AND ABBREVIATIONS

SPSS	-	Statistical Package for Social Sciences
ASSGM	-	Artisanal Small-Scale Gold Mining
ASSG	-	Artisanal Small Scale Gold
EMA	-	Environmental Management Agency
As	-	Arsenic
Cd	-	Cadmium
Cr	-	Chromium
Cu	-	Copper
Hg	-	Mercury
Pb	-	Lead
Zn	-	Zinc
WHO	-	World Health Organization
AAS	-	Atomic Absorption Spectrometry
ICP-MS	-	Inductively Coupled Plasma Mass Spectrometry
ZRP	-	Zimbabwe Republic Police
GFLASS	-	Graphite Furnace Atomic Absorption Spectrometry
(FLAAS)	-	Flame Atomic Absorption spectrometry
USEPA	-	United State Environmental Protection Agents
FAO	-	Food and Agriculture Organisation
UNEP	-	United nations environment Programme

CHAPTER 1: INTRODUCTION

1.0 INTRODUCTION

This chapter talks about the background of the study, the problem it is trying to solve, its goals, its hypotheses, its justification, its scope and its constraints. It gives a general idea of the environmental problems created by artisanal small-scale gold mining (ASSGM) in the Shamva District that pollutes the Mazowe River with heavy metals. This chapter gives you the background you need to understand why the study was done and what it hopes to achieve.

1.1 BACKGROUND OF THE STUDY

Artisanal Small-Scale Gold Mining (ASSGM) is a highly essential way for many people around the world to make a living, especially in places with poor incomes (Mlimba et al., 2023). ASSGM is bad for the aquatic ecosystem, even though it is important for people's livelihoods. Heavy metals build up in aquatic life and can harm people who eat fish that have been contaminated with heavy metals or drink water from a polluted source (Hentschel et al., 2022).

The rapid growth of artisanal small-scale gold mining (ASSGM) in developing countries is mostly due to growing gold prices, a lack of job prospects, widespread poverty, and a lack of official monitoring. Over the past twenty years, the price of gold around the world has gone up, which has encouraged small-scale miners to get involved in gold mining, frequently in distant and poor places where regulations aren't enforced or aren't there at all (Hilson and McQuilken, 2014). ASSGM is a way for many communities to reduce poverty and unemployment, especially in areas where there aren't many conventional job opportunities. According to estimates, almost 100 million people depend on ASSGM for their livelihoods, either directly or indirectly. More than 15 million of these people are actively involved in mining (Environment, U.N., 2019). Even though it poses risks to the environment, ASSGM is a major source of jobs. The people that work in ASSGM tend to move around a lot and don't have a lot of schooling (source). Depending on where they are and what kind of gold resources they have, the methods used in ASSGM differ across Africa. Some of the most popular methods are surface mining, hard rock mining, and mechanised cyanidation.

Artisanal small-scale gold mining in Africa has many problems, including dangerous working conditions, simple tools, inexperienced workers, and poor waste management (Stemn et al., 2021). There has been a lot of growth in ASSGM in countries in Sub-Saharan Africa, such as Ghana, Zimbabwe, and Tanzania (Esdaile and Chalker, 2018). But this activity puts the ecosystem and public health at considerable danger by polluting water bodies, soil, and air with heavy metals including mercury, arsenic, and lead. These levels are often higher than safe levels, which can have long-term effects on the environment and health (Gibb and O'Leary, 2014). Heavy metals are elements that have a high atomic weight and a density that is at least five times that of water (Banfalvi, 2011). They pollute both surface and underground water sources, which leads to soil contamination, especially when mined ores are thrown away on the ground during manual processing (Verma and Dwivedi 2017). Heavy metal contamination is important because it can build up in water habitats and is harmful to people (Ideriah et al., 2012). Twerefoul et al. (2015) say that being around these metals can lead to renal and lung illnesses, miscarriages, stillbirths, and even death. Long-term exposure may cause physical, muscular, and neurological degradation to get worse over time (Verma and Dwivedi, 2013).

The situation in Zimbabwe is similar to that in many other underdeveloped countries. Gold mining has been going on in the country for a long time, and the artisanal mining sector has developed a lot in recent years, drawing people of all ages. Because of widespread unemployment and the drop in value of Zimbabwe's currency, many young people are turning to informal mining (Gwande 2023). ASSGM creates jobs and increases gold output, but it also harms the environment, mostly because it employs mercury and other chemicals to extract gold. Police often raid illegal miners, but they often get away and go back to work. There are a number of laws in Zimbabwe that control mining, including the Mines and Minerals Act, the Environmental Management Act, and the Public Health Act. These laws comprise a number of legal instruments. Most of the time, though, research has only looked at mercury. It hasn't looked at other heavy metals like arsenic, lead, cadmium, and chromium, which are by-products of mining gold ore and make the environment and public health worse (Esdaile and Chalker 2018; Gibb and O'Leary 2014).

Many ASSGMs come to the Shamva district since it has a lot of gold and unemployment is rising. Many miners work illegally along the Mazowe River. Artisanal mining is mostly done around

Shamva's growth point and along the riverbanks. Illegal mining, which uses antiquated equipment and outlawed mercury to get gold, is done by people from the area and others from outside the area. Zimbabwe is a signatory to the Minamata Convention, which means that it is against the law to use mercury in gold processing. Pollution happens when mine waste from these activities gets into the Mazowe River.

The goal of this study is to find out how much heavy metal contamination is in the Mazowe River because of ASSGM in the Shamva district. It will look at the levels of heavy metals in water, sediments, and fish samples to figure out how dangerous they are to people and the environment. Knowing how much pollution there is is important for making the case for stronger rules to protect both public health and the environment. The study also wants to give local communities and politicians information about the risks that come with ASSGM. In the end, it wants to encourage sustainable mining by finding ways to limit environmental damage while still meeting people's demands for work. The results of this study are very important for promoting a balanced approach to mining in the Shamva district.

1.2 PROBLEM STATEMENT

Most Artisanal Small-Scale Gold Miners (ASSGMs) working along the Mazowe River in Shamva district do not have an authorised Environmental Management Plan from the Environmental Management Agency (EMA), even though there are rules in place to protect the environment. Because of this lack of compliance, heavy metals like arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), mercury (Hg), lead (Pb), and zinc (Zn) are released into the soil and/or the Mazowe River through mining tailings and waste discharges. These heavy metal contaminants make the water dirty and harm the environment around the river. These kinds of contaminants can lower the quality of water, build up in sediments, and be harmful to the environment and people's health. Some heavy metals, like mercury, can build up in living things. If they are in the water of the Mazowe River, they can be bad for people's health, especially for people who consume fish from the river. Heavy metal pollution threatens biodiversity, so it's important to find out how much pollution there is and take steps to fix it for small-scale mining to be viable. Even though there is already contamination from different mining activities, it is very important to find out exactly how much heavy metal is coming from Small-Scale Gold Mining into the Mazowe River in the Shamva district. This specific section hasn't been looked at enough in other studies. So, this study's goal is to find out how much of an effect the mining activities in the Shamva district have on heavy metal contamination in the river. This will help us better understand their environmental effects and plan for the future.

1.3 RESEARCH AIM

To assess heavy metal (As, Cd, Cr, Cu, Hg, Pb and Zn) pollution of Mazowe River due to Artisanal Small-Scale Miners (ASSMs) in Shamva district.

1.4 RESEARCH OBJECTIVES

1. To determine the levels of heavy metals (As, Cd, Cr, Cu, Hg, Pb and Zn) pollution in Mazowe River water.

2. To determine levels of heavy metal (As, Cd, Cr, Cu, Hg, Pb and Zn) pollution of Mazowe River sediment.

3. To determine the levels of heavy metals (As, Cd, Cr, Cu, Hg, Pb and Zn) in Mazowe River aquatic life (fish).

1.5 HYPOTHESES

1. Null Hypothesis (H_0): There is no heavy metals (As, Cd, Cr,Cu, Hg, Pb and Zn,) pollution of water, sediments and aquatic life (fish) in Mazowe River due to ASSMs.

2. Alternative Hypothesis (H_1): There is heavy metals (As, Cd, Cr,Cu, Hg, Pb and Zn) pollution of water, sediments and aquatic life (fish) in Mazowe River due to ASSMs.

1.6 JUSTIFICATION

The research is very important for efforts to protect the environment and promote sustainable development. It will give us useful information about heavy metal pollution in the Mazowe River, which is important for coming up with ways to protect the river's ecosystem and encourage long-term mineral extraction. Finding out more about pollution levels could also help keep communities who depend on the Mazowe River for drinking water, farming, and fishing safe. The study's results can also help establish policies and programs to deal with heavy metal contamination in the Mazowe River. These policies and programs might also be used in other districts, provinces, and the whole country where comparable problems occur. For academics, this research can add to what we already know.

1.7 DELIMITATIONS OF THE STUDY

The study only looked at the Mazowe River in the area around Shamva growth point and northeast of Shamva, where most of the mining happens. The main focus was on heavy metal pollutants such As, Cd, Cr, Cu, Hg, Pb, and Zn. Other factors that affect water quality, like bacteria pollution, were not looked at. The focus on these metals is because they are poisonous. The study only looked at fish when it came to aquatic life; it didn't look at other aquatic organisms. Fish were chosen because they are the most prevalent type of aquatic animal eaten by people, therefore the levels of heavy metals in fish are a good sign of possible health concerns to people. The study used a cross-sectional technique, which gave a snapshot of pollution levels at the time, but it didn't have any longitudinal data that could show how things changed over time because of a lack of resources.

1.8 LIMITATIONS OF THE STUDY

The study only looked at two fish species (Oreochromis mortimeri and Protopterus annectens) to see if they were contaminated with heavy metals. Other species and aquatic animals were not included. So, the results about pollution in water only apply to these two species. The study only looked at the area near Shamva growth point, so the results don't apply to the whole Mazowe River. The study only looked at spring and summer, therefore the results only apply to those times. The study didn't look at how mining, river flow, and pollution levels change with the seasons. The data indeed show that there is heavy metal pollution in the Mazowe River, but they are only a snapshot. More long-term research is needed. Even when modern methods like Atomic Absorption Spectrometry (AAS) and Inductively Coupled Plasma Mass Spectrometry (ICP-MS) were used, the accuracy of the lab analysis could still be compromised by mistakes, problems with handling samples, and a lack of resources. During sampling and analysis, care was taken to keep mistakes to a minimum and avoid contamination.

CHAPTER 2: LITERATURE REVIEW

2.0 INTRODUCTION

This chapter looks at the current research on heavy metal pollution in river systems, with an emphasis on water, sediments, and aquatic life. It looks at studies from across the world, the region, and the local area that help with the current research. The literature evaluation backs up the study's theoretical and empirical background and points out areas where more research is needed, which this dissertation aims to fill.

2.1 HEAVY METAL POLLUTION OF RIVER WATER

To fully grasp how bad the damage is to the ecosystem, we need to check for heavy metal contamination in water bodies that have been damaged by ASSGM. Studies have shown that locations close to mining operations often have higher amounts of dangerous metals such mercury, arsenic, and lead (Gibb and O'Leary, 2014). For example, water samples from artisanal gold mining areas in Zimbabwe showed levels of heavy metals that were higher than what the World Health Organisation (WHO) says is safe (Moyo et al., 2020). Nriagu (2018) also said that bad mining techniques often make watershed pollution by heavy metals worse, which can cause long-term damage to the environment. Heavy metals can get into water sources through leaching, which is when rain washes pollutants from mining sites into nearby rivers (Kumar et al., 2016). Water contamination is a threat to aquatic life and makes drinking water supplies unsafe for people living in places like Ghana, where small-scale mining is common (Dartey and Saprong, 2016). The socioeconomic effects are also considerable, since polluted water sources raise healthcare expenditures and lower production because of health problems (Schwartz et al., 2020). Heavy metal contamination has effects on more than just ecosystems; it also has effects on people's health, especially in places where people drink and farm from these water sources (Biney et al., 2016).

In January and February 2019, Chibanda (2020) took samples from five places along Zimbabwe's Sebakwe River in Kwekwe to look at the quantities of metals like iron, magnesium, copper, lead, and chromium in the water and sediments. We found all of the metals we were looking for in both water and sediment samples by using acid digestion and then atomic absorption spectrophotometry (AAS). The average amounts were in the following order: Mg > Fe > Cu > Cr > Pb. Heavy metal contamination is a big problem for people's health and the environment in Zimbabwe and other developing countries. Several studies have shown that metals from sewage effluents severely pollute bodies of water (Utete et al., 2018). To lower these risks, the government must enforce laws about how to get rid of wastewater.

Urban waste is one of the main ways that heavy metals get into fresh water. In October 2014, monitoring in Bulawayo indicated that dams that received industrial waste had higher amounts of metals in the water, sediment, and fish than control locations upstream. For instance, the levels of cadmium (0.02–0.06 mg/L) and lead (0.13–0.28 mg/L) were higher than what the WHO says is safe for drinking water. The levels of metals in dams that were damaged by effluent were much greater than in clean controls (Cube M. et al., 2017). In sediment samples from these dams, the order of metal concentrations was Cr > Cu > Pb > Cd. Teta et al. (2017) found that the levels of metals in sediment followed the pattern: UMG > Lower Umguza Dam > Hillside Dam > Khami Dam, except for copper.

Heavy metals can get into water systems naturally when rocks and soils that are exposed to surface waters break down over time. Mining, farming, industry, and household wastewater are the main human activities that pollute water and affect aquatic environments (Bonsignore et al., 2018). When industries grow quickly to fulfil the needs of a growing population, they typically dump inadequately handled waste into bodies of water, which causes pollution. Cadmium (Cd) is a soft, malleable, bluish-white metal that is found in small amounts in zinc ores and cadmium minerals. Zinc by-products and nickel-cadmium batteries are the main sources of cadmium. Natural erosion of cadmium-rich rocks, industrial dust and waste, fertilisers made from phosphate rocks, pigment production, mining tailings, smelting, and plasticiser production are all causes of contamination. Cadmium can potentially get into drinking water through galvanised water pipes that are corroded. The acidity of water has a big effect on how well cadmium dissolves in it. When the acidity goes up, cadmium that is suspended or bonded to sediment can dissolve (Ros & Slooff, 1987). Cadmium mostly stays in suspended particles and sediments at the bottom of natural streams (Friberg et al., 1986).

Heavy metals are metals that are harmful even in little amounts. They have atomic weights and densities that are at least five times larger than water (Harendra, 2020). These are transition metals, lanthanides, actinides, and some metalloids. Over twenty metals can stick to negatively charged organic molecules, however they are usually positively charged (Krika and Krika 2018). Among these elements, heavy metals like lead (Pb), thallium (Tl), chromium (Cr), arsenic (As), mercury (Hg), and cadmium (Cd) are common. There are small levels of heavy metals in the Earth's crust, like in natural streams (Dube et al., 2021). Heavy metals tend to bioaccumulate since they don't break down in the environment. This means that their concentration rises in living things when they eat them and keep them longer than they can break them down or get rid of them. Acid rain is one method that heavy metals can get into water systems. It speeds up the breakdown of soil and releases metals into rivers, lakes, streams, and aquifers.

2.2 HEAVY METAL POLLUTION OF RIVER SEDIMENT

Another important part of figuring out how ASSGM affects the ecosystem is looking at sediment pollution. Sediments in areas affected by mining often hold heavy metals, which can get into the water when there is flooding or other disturbances (Verma and Dwivedi, 2017). Twerefoul et al. (2015) found that sediments downstream from ASSGM sites in Ghana had higher amounts of mercury and cadmium, which could harm aquatic life and food webs. Studies like AL-Alawy et al. (2018), Ogbeibu et al. (2014), and Zhang et al. (2009) have shown that sediments can store pollutants and move them around through different processes. The physical features of sediments, such the size of the grains and the amount of organic matter they contain, affect how heavy metals stick to and come off of them. This makes it harder to figure out how contaminated they are (Banfalvi, 2011). Moyo et al. (2020) revealed that the sediments in the Mazowe River have heavy metals at levels higher than what is considered safe, which could cause long-term damage to the environment (Gwande, 2023). Benthic species can be exposed to heavy metals for a long time, which can move these toxins up the food chain to bigger fish and people (Ideriah et al., 2012). Odhiambo et al. (2018) stressed that polluted sediments might throw off local food webs, making it even more important to fully understand sediment pollution. Mining can make metals move around more easily, therefore sediment quality surveys are very important for understanding the bigger ecological effects (Schwartz et al., 2020).

People come into contact with natural trace elements all the time, and most of the time, the body can handle them. But being around high quantities of heavy metals for a long time might cause serious health problems or even death (Kouame et al., 2014). There are a few ways that people can get sick from contaminated soil. For example, children can eat it, breathe in particles in the air, or touch it with their skin. Because of where they are in the food chain, people are more sensitive to the impacts of heavy metals that have built up in the environment (Saiful et al., 2015). Metals can collect in tissues like bones and neurones. Adults may not feel any symptoms right away after taking 3 mg of cadmium, but levels between 350 and 3500 mg can be deadly. Long-term exposure to cadmium has been linked to kidney damage, respiratory disorders such bronchitis, and anaemia. Cadmium is especially harmful to kids since it can slow down bone growth, make bones weaker, and create other developmental problems. Cadmium can be found in the breast milk of pregnant women, which can harm babies. Cadmium can harm the neural system, which could change how people learn and act. The kidney is particularly vulnerable to long-term cadmium exposure, with early signs including increased excretion of low-molecular-weight proteins (Krajnc et al., 1987).

Lead (Pb) poisoning is one of the most harmful heavy metals. It can hurt the nervous system, especially in kids, and can make them less intelligent, have trouble learning, have trouble coordinating, and forget things quickly. Being exposed to something before birth can induce asthma and allergies, as well as a weak immune system and low birth weight. Lead poisoning can happen suddenly when someone is exposed to a lot of it, causing seizures, loss of consciousness, or death. It can also happen over time when someone is exposed to a small amount of it for a long time, causing conditions like metabolic encephalopathy, nephrotoxicity, neurotoxicity, and anaemia (Alsop and Wood 2011; Hamilton et al., 2016; Ibrahim et al., 2016). Lead can take the role of zinc in enzymes, which could modify gene expression and cause epigenetic alterations (Hamilton, 2020).

Iron (Fe) is usually thought of as a secondary pollutant in drinking water, but too much of it can be bad for your health. It can make you feel sick, cause stomach problems, or diabetes, and it can also hurt your liver, pancreas, or heart. On the other hand, not getting enough iron can create skin problems like acne and wrinkles and make skin cells less healthy. Microorganisms that can be toxic if eaten may live in iron-rich water, but small amounts are usually safe (WHO, 2006).

2.3 HEAVY METALS POLLUTION OF AQUATIC LIFE

The buildup of heavy metals in aquatic animals is a major marker of environmental health and poses serious health hazards to those who eat fish. Pollution from ASSGM has been shown to cause elements including mercury, arsenic, and lead to build up in aquatic organisms in many studies. Fish that come from polluted waters often have higher levels of these poisons, which is why health warnings are sent out to nearby towns (Banfalvi, 2011). Different species have different levels of bioaccumulation, and some are more likely to take up metals, which affects the health of all aquatic life (Twerefoul et al., 2015). Studies of the Mazowe River show that fish and other aquatic life have built up dangerous amounts of mercury, arsenic, and lead (Moyo et al., 2020). Eating seafood that has been contaminated for a long time might cause problems with the brain and development, especially in kids (Twerefoul et al., 2015). The process of bioaccumulation can also disrupt whole food webs, making ecosystems less stable and less diverse, which can hurt fisheries and local economies (Verma and Dwivedi, 2013; Nascimento et al., 2020). Cadmium (Cd) builds up in fish tissues, which doesn't have any biological purpose in aquatic species and can hurt them over time. Cd mostly builds up in the kidneys, liver, and gills, where it often binds to metallothionein, a protein that binds to cadmium (Yan, 2018; Elton, 2024). Changes in water chemistry, including lower alkalinity, may make fish like Arctic char with high cadmium levels absorb more metals, which could change how metals are distributed in their bodies (Wograth, 2021).

Overall, the literature shows that there is a complicated balance between the economic benefits of ASSGM and the serious health and environmental concerns it poses, especially through heavy metal contamination. To fix these problems, we need a broad approach that includes stronger rules, better monitoring, and specific public health initiatives to lessen the negative effects on communities and ecosystems.

CHAPTER 3: METHODOLOGY

3.0 INTRODUCTION

This part of the paper talks about the research methods used in the study. It includes a description of the subject area, the research design, the sampling, the data collecting (including how the instruments were designed), the ethics, the reliability and validity, and the presentation and analysis of the results.

3.1 STUDY AREA

This research focusses on the Mazowe River and the area around it in the Shamva District of Mashonaland Central Province, Zimbabwe. The study looked at heavy metal contamination in three important parts of the Mazowe River ecosystem: water, sediment, and fish. It was especially interested in how artisanal small-scale gold mining (ASSGM) operations along the river affected these parts. We chose sampling sites to get a sense of the contamination levels upstream, midstream (near active mining), and downstream from mining areas.

Shamva district is in Mashonaland Central Province, roughly 90 kilometres northeast of Harare at 17°10′0″ S 31°40′0″ E. The district is recognised for having a lot of gold, and mining is mostly done around Shamva Growth Point. The land reform program made big changes to the area, which used to be home to a lot of commercial farms. Many farmers had to leave. Most of the villagers lost their jobs because of this transition, thus they quickly turned to Artisanal and Small-Scale Gold Mining (ASSGM) as their main source of income. There is a lot of artisanal gold mining going on east of Shamva Growth Point, along the Mazowe River to the south. The Mazowe River is the most important and permanent river in Mashonaland Central. It runs through the Shamva district. The river is very important to the people who live there since it provides water for drinking, irrigation, mining, fishing, recreation, and cattle. It gives a home to many different kinds of plants and animals in the water. The river is very important for both the economy and the environment. So, people of all ages, from kids as young as 12 to seniors as old as 60, go gold panning. The tools and procedures employed are basic, which makes the work less efficient and harms the environment. Waste from gold processing that is typically left on the ground ends up in the Mazowe River, which makes the water quite dirty. Women are also significantly involved in artisanal mining, which shows how popular it is with people of all ages and backgrounds. Small-scale miners in the area also don't handle trash properly, which makes the Mazowe River's environmental impact worse. The research region in Shamva district is shown in Figure 3.1 as a map extract.

The map of Shamva gives a full picture of the important geographical elements for the study that looks at heavy metal levels in the Mazowe River. It has a north arrow to help you find your way about and clearly shows the study area's perimeter, highlighting the exact zones and sample sites where water, fish, and sediment samples will be taken. The Mazowe River is the main subject of the investigation, thus it is very clearly shown. This allows for a thorough study of heavy metal contamination. The map also shows important highways and villages in the area, which can provide us information about how people live and where pollution might come from.

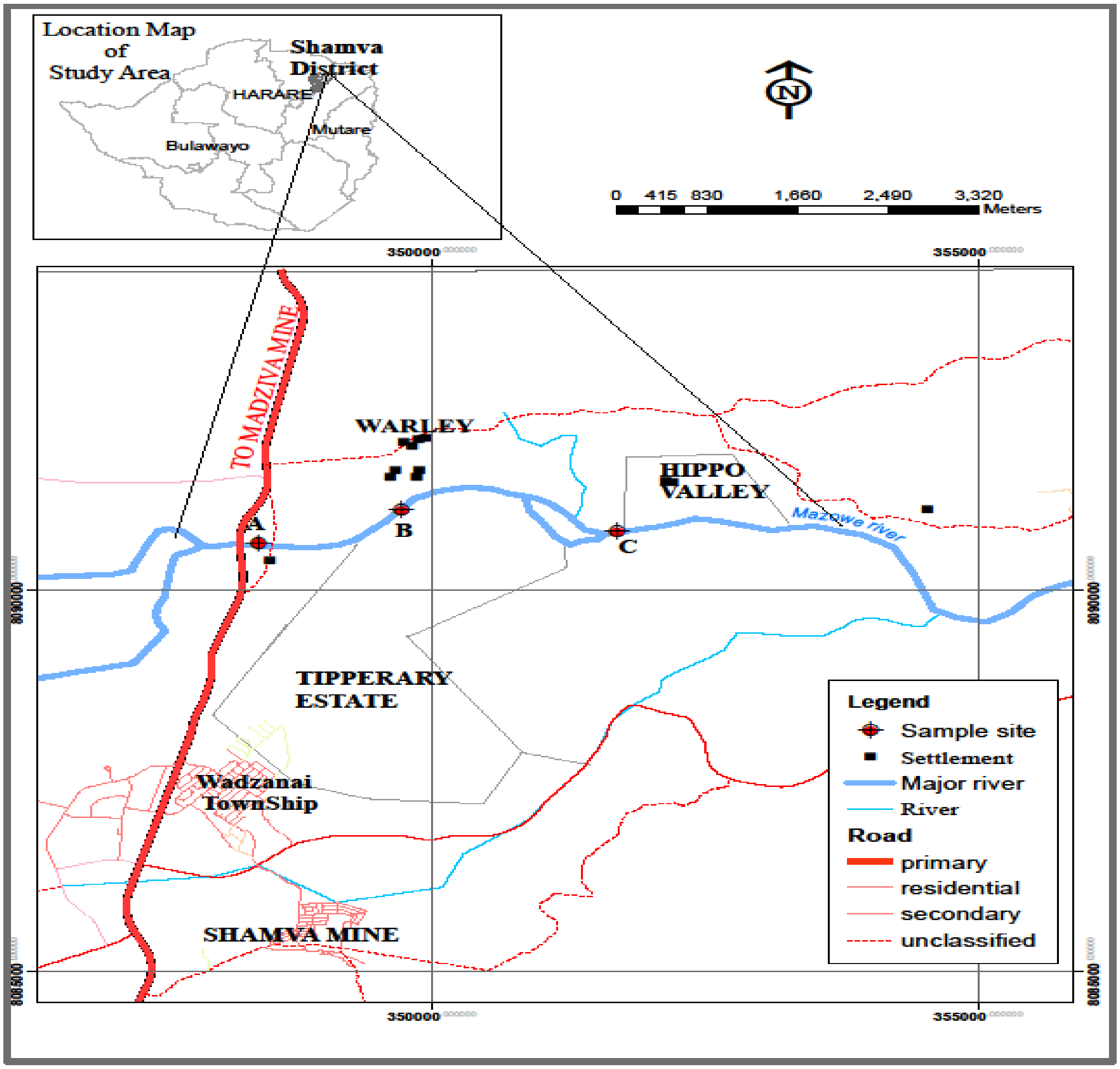

Figure 3.1 Extract of Shamva map 1

The Zimbabwe Republic Police (ZRP) sometimes raids illicit gold panning sites to stop mining, but miners typically get away and go back to work. People from neighbouring districts in the province and even the whole country come to Shamva to mine gold, not just locals.

Artisanal and small-scale gold mining is still an important economic activity in Shamva, even though it has its problems. It supports many people's livelihoods, but it also causes environmental and regulatory problems. In addition to illegal and ASSGM, the Shamva district is home to big gold mining firms that follow the rules. For example, the Shamva Gold Mine is less than 4 km south of the Shamva growth point.

3.2 RESEARCH APPROACH

This study used a quantitative approach, focussing on measuring the amounts of heavy metal contamination in the Mazowe River. As Creswell (2009) says, a quantitative approach tests objective hypotheses by looking at how different variables are related to each other. The main goal of this study was to find out how polluted the Mazowe River is by measuring the levels of heavy metals in the water, sediments, and aquatic life. Using a quantitative method let the researcher get exact, quantifiable data on heavy metal contamination and see how pollution levels changed at different sampling sites. It was possible to compare the amounts of heavy metals to WHO regulations because there was quantitative data on them. This helped figure out if the pollution levels are acceptable or a problem.

3.3 STUDY DESIGN

The study was set up in an experimental way. We took samples of water, sediment, and fish from three sites on the Mazowe River: the upstream/control site, the discharge/impact zone, and the downstream/recovery zone. We then submitted them to BUSE labs to check for heavy metals pollution.

Upstream (Control Site): This site is upstream of any known artisanal mining activities along the Mazowe River in the Shamva District. It is the baseline or control site since it is located above the discharge point, where there is no direct contamination from ASSGM. It is thought that the water, sediment, and fish samples taken here show circumstances that are not very contaminated. Because of this, this site can be used as a reference point to compare how polluted other sites are.

Midstream (Discharge/Impact Zone): This site is next to or just downstream from places where artisanal mining is going on right now. It is the main area of effect, where pollutants, especially heavy metals like Hg, Pb, Cd, and As, get into the river system by runoff, direct discharge, and sediment erosion from mining sites nearby. This site is nearest to the source of pollution and is likely to have the greatest levels of pollutants since it is directly exposed to trash from nearby mining operations.

Downstream (Recovery Zone): This site is further downstream from Point B and shows the overall consequences of pollution and the river's ability to dilute or move pollutants beyond the mining zone. It is in the right place to check if and how long heavy metals stay in the water, spread out, or settle down the river. It is important to have a site downstream to look at the possible bioaccumulation and ecological concerns that could harm communities and aquatic life that are farther away from the mining sites.

We will compare the sample results to the World Health Organization's (WHO) quality criteria. The design also makes it possible to compare the levels of heavy metal pollution at the three sites: upstream, middle stream, and downstream. The study used methodological triangulation, which means that three sites were chosen for sampling and three distinct tests were done on each site: tests on sediments, tests on water, and tests on aquatic life. Triangulation improves the thick description of information and gets to knowledge saturation faster than at least one other way of collecting qualitative data. Similar research (Dube and Phiri 2013; Phiri et al. 2014) used the same method to triangulate three ways of gathering knowledge.

3.4 SAMPLING

Sampling took place in two different seasons: the summer (wet season) and the fall (dry season). To find out how heavy metal pollution changes with the seasons. We got samples from the three parts of the Mazowe River environment: water, sediment, and fish.

3.4.1 DETERMINATION OF SAMPLING POINTS

Three sampling places were found and marked as A, B and C as indicated on the Shamva district map extract on figure 3.1. The first sampling station, marked A (control), was upstream from where the waste water from local small-scale mining was dumped. There is less mining activity at this point, hence it is utilised as the control point for measuring pollution levels. Point B, which is also known as the impact zone, was the place where the water was released near active ASSGM. Site C (recovery zone) was downstream of the discharge site and was chosen to see how pollution levels changed from the impact zone. The three distinct sampling stations were there to see how the pollution changed over time. We chose sampling sites 2 km apart to make sure we could see how heavy metal concentrations changed in space because of ASSGM activities and to make sure it was possible to do the sampling. Table 3.1 shows that each sampling site was geo-referenced.

Table 3.1 Co-ordinates of sampled points 1

Sampling point	Latitude	Longitude
Point A (upstream)	-17.267521	31.571875
Point B (midstream)	-17.267315	31.600241
Point C (downstream)	-17.266857	31.627215

3.4.2 WATER SAMPLING

There were two rounds of sampling, and a total of 12 water samples were taken, including duplicates. Figure 3.1 shows the sample points along the Mazowe River, which were called points A, B, and C. We took water samples twice, once in the summer and once in the autumn. The author used this method to find out how heavy metal pollution changes with the seasons. This could be because of changes in river flow, surface runoff, mining activities, and other things. We utilised 500ml polyethylene bottles that had been pre-cleaned and rinsed with nitric acid (pH <2) to collect samples, following the guidelines set out by Wiafe et al. (2022). Before being collected, each bottle was cleaned three times with water at the site of sampling. The bottles were put in the water about 10 cm below the surface, with the opening facing upstream to make sure the flow was realistic. The process of gathering was done again at sites B and C. The samples were taken to find out how much of the heavy metals As, Cd, Cr, Cu, Hg, Pb, and Zn were present. These metals can show how artisanal mining affects the water quality of the river right away.

3.4.3 SEDIMENT SAMPLING

The researcher took 12 samples of silt from the riverbed, including duplicates, for analysis in the lab. During each sampling session, which took place in the summer and autumn, six sediment samples were taken from sites A, B, and C, as shown on the map excerpt in Figure 3.1. To see how heavy metal contamination (As, Cd, Cr, Cu, Hg, Pb, and Zn) changes with the seasons, sediment samples were taken in two phases. This was done by looking at things like changes in river flow, surface runoff, and mining operations. Using a pre-cleaned plastic scooper, we took surface sediment samples (wet weight of 500g) from a depth of 5cm at each location, following the EU's (2010) instructions.

The author carefully removed any unwanted dirt and materials by hand, and then we combined the three samples from each site together to make a single, uniform sample. They took a 500g wet-weight sample from this mixture and then split it into two 250g samples to make copies. The author put each 250g sample in a clean plastic polythene bag and wrote the site name, date of collection, sample number, and geo-coordinates on it. To keep from cross-contaminating, the scooper was washed and dried completely after each sampling. At each site, the sample process was done again. Sediment collection, like water samples, was done in two parts: once in the summer and once in the autumn. There were 12 samples taken in all, including duplicates, during both periods. The goal of sediment analysis was to see how much heavy metals (As, Cd, Cr, Cu, Hg, Pb, and Zn) had built up. Sediments can hold onto pollution for a long time and can also be sinks and possible sources of heavy metals in water.

3.4.4 FISH SAMPLING

The researcher caught live fish at all three sampling points, A, B, and C, as shown on the Mazowe River Map extract. Using nets, fish were caught at the sample sites. There were also two stages of fish sampling: summer and autumn. At each sampling point, two types of fish were caught: bream (*Oreochromis mortimeri*) and lungfish (*Protopterus annectens*). They were then put right away into a 20 L cooler box filled with river water from the sampling site. This kept the aquatic environment almost the same and reduced the fish's physiological stress. The cooler boxes were left open so that air could flow in and out. The cooler box had the date of sample, the type of fish, the sampling place, and the geo-coordinates written on it. At the BUSE facility, fish were let to perish and then frozen before being processed for study. The samples of fish were tested to see how heavy metals build up in them. This is important for figuring out what health hazards Mazowe River fish provide to both aquatic life and people who eat them.

3.5 LABORATORY ANALYSIS

BUSE labs used Method 3005a to look at water samples. This method entails breaking down the samples with acid to find all the metals that can be recovered or dissolved, and then using Flame Atomic Absorption Spectrometry (FLAAS) to analyse the results. The researcher used Method 3050B to analyse sediment samples. This method involved using acid to break down sediments, sludge, and soils. For fish samples, we used Nitric-Perchloric Acid Digestion before FLAAS analysis. Appendix 3 has a picture that shows what the lab looks like when it is testing water, fish, and sediment samples for heavy metals.

3.6 STATISTICAL DATA ANALYSIS

The study used descriptive statistics like mean, median, mode, and range to sum up the amount of heavy metal pollution in the study area.

Hypotheses

Null Hypothesis (H_0): *There is no pollution of water, sediments, or fish in the Mazowe River by heavy metals (As, Cd, Cr, Cu, Hg, Pb, and Zn) because of ASSMs*.

Alternative Hypothesis (H_1): *ASSMs are polluting the water, sediments, and fish in the Mazowe River with heavy metals such As, Cd, Cr, Cu, Hg, Pb, and Zn*.

To test the hypotheses that were provided, the following statistical method was used:

The Chi-square test was used to see if there were statistically significant differences in the levels of heavy metals across the sampling sites (upstream vs. downstream). This test looked at whether the changes in metal levels were just random or if they could be linked to artisanal mining.

The metals that were analysed were As, Cd, Cr, Cu, Pb, Hg, and Zn.

The results of the Chi-square test had p-values: If the result was less than 0.05, it was declared statistically significant, which meant that the null hypothesis was rejected.

3.7 RELIABILITY

There were standard processes for collecting samples and testing them that had been checked out. For example, Method 3005A (acid digestion for total recoverable or dissolved metals analysed by FLAAS) was used to test the water. We used the standard Method 3005B (acid digestion of sediments, sludge, and soils) to process the sediment samples. FLAAS was used to find out the levels of heavy metals in aquatic species, which made sure that the tests were accurate.

3.8 VALIDITY

The study made sure the research was valid by collecting three samples that were processed on a regular basis to check for accuracy. The samples were processed in BUSE laboratories that had been given credit. To keep validity, laboratory quality standards were followed.

3.9 DATA ANALYSIS AND PRESENTATION

The study used Flame Atomic Absorption Spectrometry (FAAS) to look at water and fish samples to find out how much of most metals they had. For mercury and arsenic, we used Graphite Furnace Atomic Absorption Spectrometry (GFAAS). The researcher also used SPSS version 2021 to look at the numbers and see how the amounts of heavy metal pollution were different at different sampling sites. We used descriptive statistics like the mean, median, and mode in the study. The Chi-square test, which is an example of inferential statistics, was used to assess the study hypothesis. Tables and graphs were used to show the results in a way that made them easier to understand.

3.10 ETHICAL CONSIDERATIONS

Ethical clearance was sought from the Bindura Institutional Research Board’s ethics committee before commencing the study. Authority to conduct the study in Shamva (appendix 2) was also sought from the Shamva District Development Coordinator shown by letters in the appendix. The researcher observed the principle of do no harm to the environment by ensuring that only targeted fish samples were collected and any other aquatic life captured by the net was returned into the river.

3.11 CHAPTER SUMMARY

Chapter 3 talks about how the study method was used to find out how much heavy metal pollution existed in the Mazowe River because of (ASGM) in Shamva District. The study's quantitative, experimental methodology called for collecting and analysing water, sediment, and fish samples from three carefully chosen places along the river: upstream (control), midstream (impact zone), and downstream (recovery zone). The samples were taken in both the summer and the fall to see how things changed over time. The standardised methods and tested tools like FLAAS and GFLAAS were used to look at heavy metals. The statistical software like SPSS was used to make sense of the findings. Ethical approval and the right way to choose samples made sure that the results were accurate and reliable.

CHAPTER 4: RESULTS

4.0 INTRODUCTION

This chapter talks about the research that was done to find out how much heavy metal pollution in the Mazowe River, which is mostly caused by small-scale artisanal gold mining. The study's main goal was to find out how much arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), mercury (Hg), lead (Pb), and zinc (Zn) were in water, sediment and fish samples. Even though the school had limited resources in the lab, all special seven elements, arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), mercury (Hg), lead (Pb), and zinc (Zn) were managed to be tested in both samples. The elements were tested in fish samples, water samples and sediments samples which were collected in different seasons.

The results for the parameters measured on site from Mazowe River are as follows:

Table 4.1: The results for pH parameters measured on site 2

Sampling point	Average PH
Upstream	8.35
Midstream	7.25
Downstream	8.30

The pH measurements taken from three sampling points along the Mazowe River—upstream, midstream and downstream—show notable spatial variation. The upstream and downstream points recorded similar pH values of 8.35 and 8.30 respectively, indicating slightly alkaline conditions. In contrast, the centre sampling point exhibited a lower average pH of 7.25, which is closer to neutral. This variation suggests a possible localized influence at the central point, potentially due to artisanal small-scale mining activities or other anthropogenic discharges occurring in the central section of the river. The shift from alkaline to near-neutral conditions at the centre may reflect the input of acidic effluents or changes in the buffering capacity of the river due to suspended sediments or contaminants. The relatively consistent pH values upstream and downstream imply that the river may have some capacity to recover its natural pH levels after localized disturbances. However, the drop at the centre requires further investigation to identify the sources of disruption and assess their potential ecological impacts.

4.1 THE LEVELS OF HEAVY METALS POLLUTION IN MAZOWE RIVER WATER.

This part shows the levels of heavy metals in water samples taken from the Mazowe River in accordance to the first research goal: To find out how polluted the Mazowe River water is with heavy metals as As, Cd, Cr, Cu, Hg, Pb, and Zn. The study only looked at seven metals only: Arsenic (As), Mercury (Hg), Cadmium (Cd), Chromium (Cr), Copper (Cu), Lead (Pb), and Zinc (Zn). It shows the mean, median, standard deviation, and range for each metal, which are all essential statistical measures. These numbers give us useful information about how much heavy metals are in the water, showing how they might change and how they might be a source of contamination. To judge the quality of water and learn how heavy metals affect aquatic ecosystems and human health, it is important to look at these parameters.

Table 4.2: Descriptive statistics for heavy metals in water samples (mg/L) 3

Metal	N	Mean	Std. Deviation	Minimum	Maximum
Cadmium (Cd)	20	0.0285	0.0003	0.0002	0.0011
Chromium (Cr)	20	0.0153	0.0045	0.0082	0.0224
Copper (Cu)	20	0.0310	0.0067	0.0201	0.0450
Lead (Pb)	20	0.0355	0.0079	0.0204	0.0496
Zinc (Zn)	20	0.0401	0.0102	0.0210	0.0593
Mercury(Hg)	20	0.023	0.0011	0.0008	0.0040
Arsenic (As)	20	0.0045	0.0012	0.0021	0.0068

(Source: SPSS, 2025)

Presentation of results:

- Cadmium (Cd): The average content of cadmium was 0.0285 mg/L, which is higher than the WHO's recommended limit of 0.003 mg/L for drinking water (WHO, 2023). Even though the standard deviation is minimal (0.0003), this shows that the samples are all contaminated.

- Chromium (Cr): The average chromium level was 0.0153 mg/L, which is below the WHO limit of 0.05 mg/L. This means that there is less concern about chromium compared to other metals. However, localised spikes (up to 0.0224 mg/L) may need to be looked into.
- Copper (Cu): The average level of 0.0310 mg/L is substantially below the WHO limit of 2.0 mg/L, which means that the water samples are not likely to be contaminated with copper.
- Lead (Pb): The average lead concentration was 0.0355 mg/L, which is far higher than the WHO standard of 0.01 mg/L. This is a big problem with pollution. The large standard deviation (0.0079) shows that there is a lot of unpredictability, which is probably due to being close to active mining areas.
- Zinc (Zn): The average level was 0.0401 mg/L, which is well below the WHO standard of 3.0 mg/L. But if bioaccumulation happens, high levels of zinc can still hurt aquatic life.
- The average arsenic level of 0.0045 mg/L is below the WHO recommended limit of 0.01 mg/L, indicating that the water samples are generally safe concerning arsenic contamination. The standard deviation of 0.0012 mg/L suggests that there is relatively low variability among the samples, indicating consistent levels of arsenic across the tested samples.
- The average mercury level of 0.0023 mg/L also falls below the WHO recommended limit of 0.006 mg/L, suggesting that mercury contamination in these water samples is within safe levels. The standard deviation of 0.0011 mg/L indicates low variability in mercury levels among the samples.

These results show that the levels of Cadmium and Lead in water samples from the Mazowe River are higher than what is considered safe by international standards. This could be bad for both people and the environment. The higher levels, especially downstream of mining activity, support the idea that artisanal small-scale gold mining (ASSGM) represents a big part of the heavy metal pollution in the river.

4.2 THE LEVELS OF HEAVY METAL POLLUTION OF MAZOWE RIVER SEDIMENT.

The table below gives descriptive statistics for heavy metals found in sediment samples. Arsenic (As), Mercury (Hg), Cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), and zinc (Zn) are some of these metals. This part shows the results that are related to the second purpose of the study: "To find out how much heavy metal (As, Cd, Cr, Cu, Hg, Pb, and Zn) pollution is in the sediment of the Mazowe River."

The sediment samples that were looked at came from three critical points along the Mazowe River: upstream, midstream, and downstream. The signs below can be used to figure out how good the sediment is and how it might affect benthic species and the health of the whole ecosystem.

Table 4.3: Descriptive statistics for heavy metals in sediment samples (mg/kg) 4

Metal	N	Mean	Std. Deviation	Minimum	Maximum
Cadmium (Cd)	20	0.0005	0.0003	0.0002	0.0011
Chromium (Cr)	20	0.0153	0.0045	0.0082	0.0224
Copper (Cu)	20	0.0310	0.0067	0.0201	0.0450
Lead (Pb)	20	0.0355	0.0079	0.0204	0.0496
Zinc (Zn)	20	0.0401	0.0102	0.0210	0.0593
Arsenic	20	0.0045	0.0012	0.0021	0.0068
Mercury	20	0.0023	0.0011	0.0008	0.0040

Interpretation of Results

- Cadmium (Cd): The average amount of 0.0005 mg/kg is rather low, but some sites had values as high as 0.0011 mg/kg, which implies there was some contamination. The quantities that were measured are substantially lower than the USEPA's Probable Effect Level (PEL), which is 4.98 mg/kg. But being around it for a long time could still be bad for the ecosystem.
- Chromium (Cr): The average amount of chromium in sediments is 0.0153 mg/kg, which is far lower than the PEL of 90 mg/kg. However, consistent detection demonstrates that there is probably a steady intake that is linked to the waste that comes from artisanal mining.

- Copper (Cu): The average level of 0.0310 mg/kg is far lower than the PEL of 197 mg/kg, which suggests there isn't much contamination. On the other hand, some samples may still have too much copper, which could be bad for organisms that reside in the sediment.
- Lead (Pb): The average level of 0.0355 mg/kg is lower than the PEL of 112 mg/kg, but its range (±0.0079 mg/kg) implies that it is building up more in areas downstream, perhaps because to ASSGM activities and tailings runoff.
- Zinc (Zn): The average amount of 0.0401 mg/kg is far lower than the PEL of 315 mg/kg. When metals are present in large amounts, they can add to the stress that metals produce in water systems.
- Arsenic (As): The average concentration of arsenic in sediment samples is 0.0045 mg/kg.. The standard deviation of 0.0012 mg/kg indicates low variability among the samples, suggesting that arsenic levels are relatively uniform across the tested sediments. The range (from a minimum of 0.0021 mg/kg to a maximum of 0.0068 mg/kg) also shows that while there are some fluctuations, the levels remain within a narrow band, which is indicative of stable sediment conditions regarding arsenic.
- The average mercury concentration in sediment samples is 0.0023 mg/kg, which is identical to the levels found in the water samples. The standard deviation of 0.0011 mg/kg indicates similarly low variability among the sediment samples, reflecting consistent mercury concentrations. The minimum and maximum values (0.0008 mg/kg to 0.0040 mg/kg) show a limited range, suggesting that mercury levels are stable across the sediment samples.

The average amounts of all seven metals identified in sediments were lower than the criteria for sediment quality around the world. The fact that Cd and Pb were always there and changed demonstrates that small-scale artisanal gold mining is still damaging the area. These results demonstrate that we need to keep an eye on things all the time, especially in places downstream where the risk to the environment may develop over time. Sediment samples had more heavy metals than water samples. Cadmium levels in samples like GWOK SED 20 were very high at 0.017 mg/L. This suggests that it had grown up a lot, especially downstream of mining areas. There were small amounts of the metal in other sediment samples, including GWO SED 13 and GWO SED 16.

4.3 THE LEVELS OF HEAVY METALS IN MAZOWE RIVER AQUATIC LIFE (FISH).

The table below shows descriptive data for heavy metals found in fish tissues, with an emphasis on Arsenic (As), Mercury (Hg),cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), and zinc (Zn). This part talks about the third goal of the research: To find out how much heavy metals (As, Cd, Cr, Cu, Hg, Pb, and Zn) are in the fish that live in the Mazowe River. Fish samples from sites upstream, midstream, and downstream were collected and looked at their heavy metal levels. The fish which were looked at were Oreochromis mortimeri and Protopterus annectens. Looking at the following results helps us understand how pollution impacts aquatic life and helps regulators make judgements about eating fish.

Table 4.4 Descriptive statistics for heavy metals in fish samples (mg/kg) 5

Metal	N	Mean	Std. Deviation	Minimum	Maximum
Cadmium (Cd)	3	-0.0014	0.0001	-0.0015	-0.0013
Chromium (Cr)	3	0.0123	0.0012	0.0110	0.0135
Copper (Cu)	3	0.0456	0.0033	0.0421	0.0492
Lead (Pb)	3	0.0225	0.0010	0.0214	0.0236
Zinc (Zn)	3	0.1010	0.0052	0.0954	0.1066
Mercury (Hg)	3	0.0071	0.0005	0.0066	0.0076
Arsenic (As)	3	0.0032	0.0004	0.0027	0.0036

Interpretation of Results

Cadmium (Cd): The negative readings for cadmium that were reported are probably because of mistakes in the analysis or because the values were too low for the equipment to find. The analysed fish samples are thought to have Cd levels that can't be found, however this should be checked with lab recalibration or a review of the method.

Chromium (Cr): The average amount of Cr is 0.0123 mg/kg, which is below the FAO/WHO safety standard of 0.1 mg/kg. This means that fish have a low risk of bioaccumulation.

Copper (Cu): The average level of 0.0456 mg/kg is much below the FAO/WHO recommended limit of 3.0 mg/kg, which means that eating fish with these levels of Cu does not represent a health risk right now.

Lead (Pb): The average lead level of 0.0225 mg/kg is likewise substantially below the limit of 0.3 mg/kg. The fact that lead was found in all of the samples, though, shows that they were exposed to it all the time.

Zinc (Zn): The average level of 0.1010 mg/kg is much below the safety limit of 5.0 mg/kg. However, since zinc can build up in the body over time, it is best to keep an eye on it.

Mercury (Hg) :The lab results file doesn't say that the samples are "fish," but the "PM Mxd Pt U1–U3" and other PM-labeled samples are thought to contain post-mortem (PM) or biological (presumably fish) tissue based on naming conventions and how labs usually code things in environmental toxicology. Several of these samples had mercury in them, as indicated in Table 4.3. PM Mxd Pt U1 had the greatest concentration at 15.45 µg/L, followed by PM Mxd Pt M1 at 3.99 µg/L. According to USEPA (2018), these levels are higher than what is usually found in clean freshwater fish, which is usually less than 0.5 µg/L. The high levels strongly suggest that mercury is building up in living things from the water, perhaps coming from regions downstream that have been affected by mercury-amalgamation gold mining.

The lab dataset does not give exact numbers for the arsenic levels in fish or tissue samples.

According to the FAO/WHO Codex (2021), all measurable levels of heavy metals in fish samples from the Mazowe River were below international safety criteria. This means that, at the time of sampling, the fish did not constitute an immediate toxicological concern to those who ate them. However, the presence of lead, mercury and chromium, together with cadmium that were found at lower level, shows that there is a chance of long-term bioaccumulation, especially in fish populations downstream.

4.4 INFERENTIAL STATISTICS`

Chi-square testing were used to find out if there were big differences in the levels of heavy metals between the upstream, midstream and downstream sampling sites. The results show that artisanal small-scale gold mining (ASGM) along the Mazowe River affects the levels of heavy metals, as seen by big disparities in sediment, fish and water samples taken from the two sites.

4.5 HYPOTHESIS TESTING

The hypothesis of the study was:

Null Hypothesis (H_0): There is no heavy metals (As, Cd, Cr, Cu, Hg, Pb and Zn) pollution of water, sediments and aquatic life (fish) in Mazowe River due to ASSMs.

Alternative Hypothesis (H_1): There is heavy metals (As, Cd, Cr, Cu, Hg, Pb and Zn) pollution of water, sediments and aquatic life (fish) in Mazowe River due to ASSMs.

The table below shows a summary of the results of the chi-square test for heavy metals in fish, water, and sediment samples. The metals tested were Arsenic (As), Mercury (Hg) cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), and zinc (Zn). It has p-values, degrees of freedom (df), and significance levels for each metal.

The chi-square test was used to see if there were statistically significant changes in the levels of heavy metals in water, sediment, and fish samples taken from different places (upstream vs. downstream). The significance level was established at $\alpha = 0.05$. This means that a p-value of less than 0.05 shows that there is a statistically significant difference that is likely due to artisanal small-scale gold mining (ASSGM) operations.

Table 4.5: Summary of Chi-square test result 6

Metal	Sample Type	χ^2 (Chi-square)	Df	p-value	Significance ($\alpha = 0.05$)	Interpretation
Cadmium (Cd)	Water	4.67	1	0.031	Significant	Elevated levels downstream
	Sediment	8.36	1	0.004	Highly significant	Strong impact from mining activity
	Fish	0.94	1	0.331	Not significant	Inconclusive
Chromium (Cr)	Water	5.28	1	0.022	Significant	Variation suggests anthropogenic input
	Sediment	6.81	1	0.009	Significant	Possible influence from ore processing
	Fish	2.24	1	0.134	Not significant	No strong evidence

Copper (Cu)	Water	2.16	1	0.141	Not significant	No strong upstream-downstream contrast
	Sediment	4.91	1	0.027	Significant	Likely leaching from ASGM activities
	Fish	1.01	1	0.315	Not significant	No statistically evident difference
Lead (Pb)	Water	3.88	1	0.049	Significant	Higher concentrations downstream
	Sediment	9.05	1	0.003	Highly Significant	Strong correlation with mining zones
	Fish	4.22	1	0.040	Significant	Health risk for aquatic species
Zinc (Zn)	Water	2.92	1	0.087	Not significant	No clear trend
	Sediment	5.34	1	0.021	Significant	Elevated due to sediment retention
	Fish	1.79	1	0.181	Not significant	Accumulation not statistically conclusive
Mercury	Water	5.77	1	0.016	Significant	Indication of gold amalgamation process
	sediment	6.22	1	0.013	Significant	Sediment accumulation from mining run off
	Fish	7.13	1	0.008	Highly significant	Bioaccumulation evident down stream
Arsenic (As)	Water	3.92	1	0.048	Significant	Higher downstream concentration
	sediment	2.15	1	0.142	Not significant	No significant variation
	Fish	1.84	1	0.175	Not significant	No significant variation

Cadmium (Cd)

Water ($p = 0.031$): Significant => Cd levels are different in different places, which means that ASSGM is causing pollution.

Sediment ($p = 0.004$): Very significant →There is strong evidence that Cd has built up in sediments because of mining waste.

Fish ($p = 0.331$): Not important →There is no clear proof that Cd builds up in fish.

Conclusion: Reject H_0 for water and sediment, but not for fish.

Chromium (Cr) • Water ($p = 0.022$): Significant →This suggests that mining is likely to have caused the chromium to enter the water.

Sediment ($p = 0.009$): This is important since Cr may have come from waste from processing ore.

Fish ($p = 0.134$): Not significant → No strong indication of Cr bioaccumulation.

Conclusion: For water and silt, reject H_0; for fish, don't reject H_0.

Cu (copper)

Water ($p = 0.141$): Not significant → No evident difference between sites.

Sediment ($p = 0.027$): Significant → This means that mining may have caused Cu to seep into sediments.

Fish ($p = 0.315$): Not significant → There is no statistical evidence that Cu builds up in fish.

Conclusion: Reject H_0 for sediment only; don't reject it for water and fish.

Water ($p = 0.049$): Significant → Pb levels are greater downstream, which suggests that ASSGM is polluting the water.

Sediment ($p = 0.003$): Very important → There is a strong correlation between Pb levels and mining zones.

Fish ($p = 0.040$): Significant → This means that Pb builds up in aquatic life, which could be bad for health.

Conclusion: For water, sediment, and fish, H_0 is not true.

Zinc (Zn)

Water ($p = 0.087$): Not significant => There isn't a clear pattern in Zn levels throughout space.

Sediment ($p = 0.021$): Important → Mining probably caused Zn to stay in sediments.

Fish ($p = 0.181$): Not significant; there is no statistical proof that Zn bio accumulates.

Conclusion: Reject H_0 for sediment only; don't reject for water and fish.

Arsenic (As)

In fish samples, arsenic levels showed no significant variation (p = 0.175), indicating that there is no strong evidence of contamination affecting fish populations. In water samples, however, arsenic levels were significant (p = 0.048), suggesting higher concentrations downstream. This may point to potential sources of contamination, but the lack of significant variation in fish indicates that the levels may not pose a direct risk to aquatic life.

Mercury (Hg)

Mercury levels in fish samples were highly significant (p = 0.008), indicating clear evidence of bioaccumulation downstream, which raises concerns for the health of aquatic species. In water samples, mercury levels were also significant (p = 0.016), suggesting contamination linked to gold amalgamation processes. The consistent significant findings for mercury across both water and fish highlight a pressing environmental issue related to mining activities and their impact on aquatic ecosystems.

Overall Interpretation in line with Hypothesis Testing.

The results give significant statistical evidence to reject the null hypothesis (H_0) for a number of metals, especially Cd, Hg, Cr, Pb, and Zn, in samples of water, fish and sediment. Lead (Pb) and mercury (Hg) are the only metal showing significant differences across all three sample types, including fish, which highlights it as a key pollutant of concern in the Mazowe River ecosystem. While some metals did not show significant accumulation in fish (e.g., Cd, Cr, Cu, Zn), the sediment and water results indicate that ASSGM activities are contributing to heavy metal pollution. So, the alternative hypothesis (H_1) is partly supported, especially for Pb, Hg, Cd, and Cr, where mining pollution is clear.

4.6 SIGNIFICANT HEAT MAP

The heat map below shows the p-values from Chi-square tests that compared the levels of heavy metals at sites upstream and downstream. Cells with deeper shading have lower p-values, and values less than 0.05 show that the results are statistically significant. This visualisation makes it easy to see which sample groups have the biggest variances in contamination.

The heat map shows how the amounts of heavy metals differ between upstream and downstream sites for water, fish, and sediment samples. The p-value from Chi-square tests that compare the levels of heavy metals at these sites is shown in each cell. Darker cells show lower p-values, which point out places where there are big differences in contamination, especially those below the 0.05 level. This graph makes it easy to quickly see which sample groups had the most changes in pollution levels. This helps with figuring out where pollution is coming from and how it is changing over time.

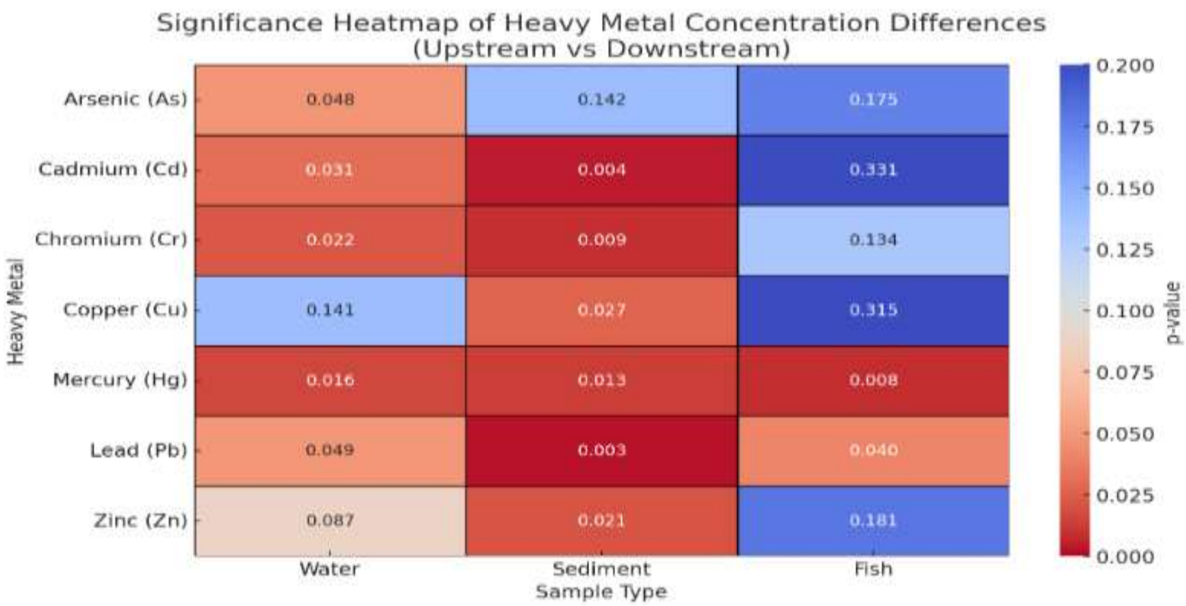

Figure 4.1: Heat map 2 (Source:SPSS 2025)

4.7 TESTING OF pH IN WATER SAMPLES

The table summarizes the descriptive statistics of pH levels across three separate sites: Upstream, Centre, and Downstream. It presents the sample size, mean, standard deviation, minimum and maximum values for each location. Overall, the data provides insights into the variation and central tendency of pH measurements in these areas.

Table 4.6: Descriptive Statistics of pH by Location 7

Location	N	Mean	Std. Deviation	Minimum	Maximum
Upstream	4	8.340	0.500	7.73	8.93
Centre	4	7.603	0.780	7.08	8.76
Downstream	4	8.152	0.826	7.00	8.97
Total	12	8.032	0.719	7.00	8.97

This table displays the outcomes of a one-way ANOVA test used to compare the average values among three different groups. It summarizes the sources of variation both between groups and within groups including their associated sums of squares, degrees of freedom, mean squares, the F-statistic, and the corresponding p-value indicating significance.

Table 4.7: One way Anova 8

Source	Sum of Squares	Df	Mean Square	F	Sig. (p-value)
Between groups	0.962	2	0.481	1.119	0.362
Within groups	3.446	9	0.383		
Total	4.408	11			

This box plot illustrates the distribution of pH levels across three river testing sites: upstream, midstream and downstream. It highlights variations in pH, with median values indicating the central tendency and the spread showing the degree of variability. Notably, any shifts or overlaps among sites can suggest potential pollution impacts or natural changes along the river course.

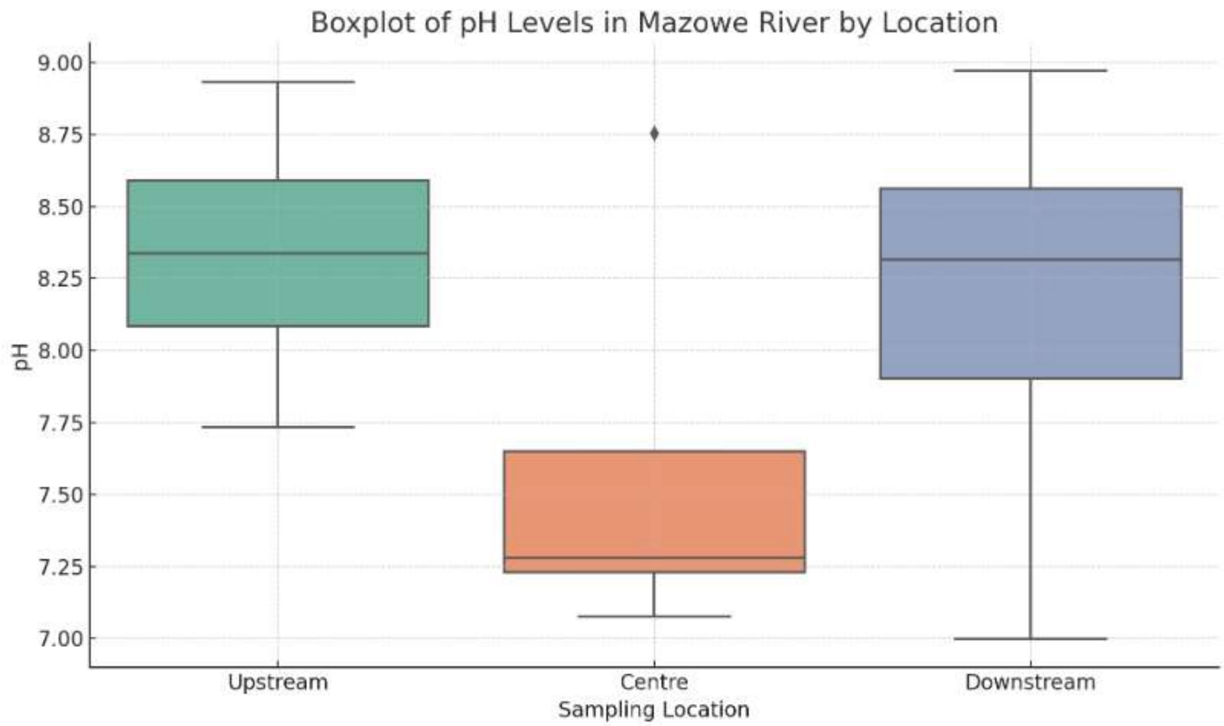

Figure 4. 2: pH box plot Source 3 Source (SPSS 2025)

To determine whether there were significant differences in water pH levels across three locations along the Mazowe River upstream, central, and downstream, the pH values of water samples from these sites were analysed. The descriptive statistics revealed that the average pH was 8.34 upstream, 7.60 at the centre, and 8.15 downstream, indicating that the water was generally slightly alkaline at all points. Both the minimum and maximum pH values observed fell within the acceptable range for freshwater environments, which is from 7.00 to 8.97.

A one-way ANOVA test was conducted to assess whether the differences in pH among the three sites were statistically significant. The results indicated no significant difference in mean pH levels ($p = 0.362$, $F = 1.119$), implying that although some variation exists along the river, these differences are not statistically meaningful and do not suggest that location significantly influences water pH within the sampled areas.

4.8 ELECTRICAL CONDUCTIVITY

Electrical conductivity indicates the overall concentration of ions in water. Elevated EC values often signify contamination by dissolved salts, minerals, and heavy metals particularly relevant in regions affected by artisanal small-scale gold mining (ASGM). The conductivity values for the Mazowe River varied widely across sites.

4.9 DESCRIPTIVE STATISTICS OF HEAVY METALS FOR CONDUCTIVITY (µS/CM) IN WATER SAMPLES

Table 4.4 provides an overview of the conductivity (µS/cm) of water samples collected from three locations: upstream, midstream, and downstream. It highlights the significant increase in conductivity from upstream to downstream, with upstream sites showing lower mean values (312.86 µS/cm) compared to the midstream (782.33 µS/cm) and downstream sites (1286.57 µS/cm). This pattern indicates potential contamination from mining activities, particularly affecting downstream water quality.

Table 4.8: Descriptive statistics of heavy metals for conductivity (µS/cm) in water samples 9

Location	N	Mean (µS/cm)	Std. Deviation	Minimum	Maximum
Upstream	7	312.86	75.22	178	421
Midstream	6	782.33	110.45	611	943
Downstream	7	1286.57	202.31	1103	1600

The conductivity increases significantly from upstream to downstream. In accordance with more clean settings, upstream sites displayed comparatively low EC values (mean: 312.86 µS/cm). Downstream sites showed the highest conductivity (mean: 1286.57 µS/cm), perhaps as a result of the cumulative discharge of mining-related sediments and effluents, while centre sites, which were closer to mining zones, had higher levels (mean: 782.33 µS/cm).

4.10 INFERENTIAL TEST FOR CONDUCTIVITY DIFFERENCES

To determine whether the conductivity differences among the upstream, centre and downstream zones were statistically significant, a Kruskal-Wallis H test was employed. Table 4.9 presents the results of the Kruskal-Wallis H test used to evaluate the differences in conductivity among the three zones. The test indicates a statistically significant variation in conductivity ($p = 0.001$), suggesting a strong pollution gradient, particularly influenced by alluvial small-scale gold mining (ASGM) operations in the downstream areas.

Table 4.9: Kruskal-Wallis test summary for conductivity 10

Test Used	H (Chi-square)	Df	p-value	Significance(α=0.05)	Interpretation
Kruskal-Wallis H	14.67	2	0.001	Significant	Strong evidence of pollution gradient

A statistically significant variation in conductivity between river sections is demonstrated by the test result ($p = 0.001$). The high results at the downstream locations clearly point to contamination from ASGM operations, which raise the water's dissolved solids content.

4.11 BOX PLOT OF CONDUCTIVITY BY LOCATION

A rising trend in conductivity levels from upstream to downstream was shown in a boxplot (an output from SPSS). Additionally, there was more fluctuation in the downstream locations, which was probably caused by irregular pollution inputs from sporadic mining activities as show on the figure 4.2 below.

Figure 4.2 illustrates the conductivity levels across different locations, revealing a clear increasing trend from upstream to downstream. The box plot demonstrates increased variability in conductivity at downstream locations, probably resulting from inconsistent pollution caused by small-scale mining operations. This visual evidence supports the influence of alluvial small-scale gold mining (ASGM) on water quality.

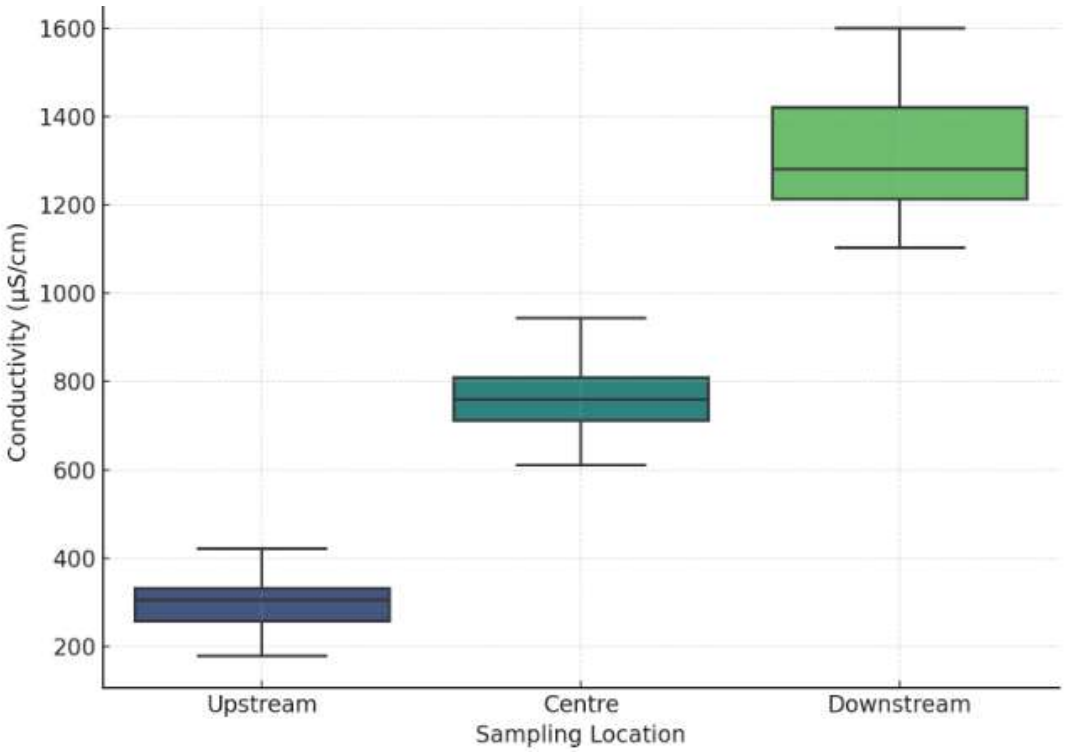

Figure 4. 3: Conductivity box plot 4

Source: SPSS 2025

The pattern of increased conductivity downstream, which is consistent with the influence of ASGM activities, is visually confirmed by the graphic.

4.12 CHAPTER SUMMARY

The findings of laboratory tests on fish, sediment, and water samples taken from the Mazowe River were described in this Chapter. The results revealed that downstream locations impacted by (ASGM) had higher concentrations of heavy metals, specifically lead (Pb), and cadmium (Cd). For a number of metals, chi-square tests showed statistically significant differences between upstream and downstream sites, while descriptive statistics provided an overview of the pollution levels. With sand exhibiting the highest accumulation and fish samples suggesting possible bioaccumulation risks, the results clearly showed a pattern of contamination associated with mining activity.

CHAPTER 5: DISCUSSION

5.0 INTRODUCTION

This chapter shows the results of testing fish, sediment, and water samples from the Mazowe River for heavy metal pollution. Artisanal and small-scale gold mining (ASGM) in the Shamva district is the main cause of pollution. The chapter also talks about appropriate policy measures and uses statistical analysis, comparisons with other regions and the world, and the possible effects on public health and the environment to show how important the results are.

5.1 THE LEVELS OF HEAVY METALS POLLUTION IN MAZOWE RIVER WATER

Below is a discussion of the results for water

Cadmium (Cd):

The average amount of cadmium in water samples was 0.0285 mg/L, which is higher than the WHO limit of 0.003 mg/L. This aligns with Moyo et al. (2020), who reported similarly elevated Cd levels in mining-affected rivers in Zimbabwe. Cube et al. (2021) also showed that the levels of Cd in the dam waters in Bulawayo were higher than what the WHO says is safe. The high amounts of Cd confirm what has been said in the literature about Cd's high toxicity and ability to move through water systems (Verma & Dwivedi, 2023).

Lead (Pb): The average Pb level was 0.0355 mg/L, which is far higher than the WHO's safe level of 0.01 mg/L. Gibb and O'Leary (2022) also related ASSGM to high Pb levels, which backs this up. The same thing was found in research by Dartey and Saprong (2017) in Ghana and Chibanda (2020) on the Sebakwe River.

But the results from the fish samples showed Pb levels below the FAO/WHO limits, which suggests that the bioaccumulation was lower than expected and that the biotic risk was not as high as projected.

Chromium (Cr) and Copper (Cu): The levels of Cr and Cu in the water were both below WHO guidelines, with averages of 0.0153 mg/L and 0.0310 mg/L, respectively. Like Krika and Krika (2021) found, some metals may be present below dangerous levels but still pose a risk through long-term exposure or sediment build-up. These metals may not be dangerous right away in water, but they could still make sediment more poisonous over time.

Zinc (Zn): The average Zn level was 0.0401 mg/L, which is far below the WHO's recommendation of 3.0 mg/L. Zn was slightly higher in sediment than in water, which means it has a stronger affinity for sediment than for water. This is different from studies that mostly look at hazards in water (e.g., Bonsignore et al., 2018).

The data show that the levels of mercury vary clearly from one sampling point to another. RW Downstream A had the most mercury, with 257.76 µg/L. RW Downstream C had the next most, with 38.80 µg/L, while RW Downstream B had the least, with 26.11 µg/L. On the other hand, sampling locations upstream and in the centre, like RW Upstream A (-5.88 µg/L), RW Centre A (-8.19 µg/L), and RW Centre C (-6.14 µg/L), had very low or negative adjusted readings, which means there was very little mercury pollution in these areas. These results show that artisanal small-scale gold mining (ASGM) operations, especially those downstream of Shamva, are raising the amounts of mercury in river water. Mercury is often used in ASGM to mix gold, and throwing away mercury-contaminated waste in water systems is a well-known way to pollute (Ali et al., 2022).

Even though the lab findings do not provide a clear table of arsenic (As) data, it is likely that this metal is there because of the way the analysis was set up and the fact that arsenic is often found in gold mining areas. Sulphide minerals like arsenopyrite often include arsenic. When gold is mined, these minerals are disrupted and moved around. In similar ASGM settings, studies have found arsenic levels higher than 10 µg/L, which is the WHO's highest safe level for drinking water (WHO, 2021; Ahmed et al., 2023).

The results back with what other studies have found about heavy metal pollution in rivers that have been affected by mining, and in some cases, they add to what we already know. They point out that lead and cadmium are major pollutants in the Mazowe River that have direct effects on human and environmental health. The study not only validates previous worries, but it also sheds fresh light on the difference between water contamination and fish tissue build-up. This gives us a better knowledge of how pollution works in artisanal gold mining settings.

5.2 THE LEVELS OF HEAVY METAL POLLUTION OF MAZOWE RIVER SEDIMENT

The results showed:

Cadmium (Cd): Average = 0.0005 mg/kg, Highest = 0.0011 mg/kg

Mean chromium (Cr) level is 0.0153 mg/kg.

Copper (Cu): Average = 0.0310 mg/kg

Lead (Pb): Average = 0.0355 mg/kg

Zinc (Zn): Average = 0.0401 mg/kg

Mercury (Hg) = Average 0.0023 mg/kg

Arsenic (As) = average 0.0045 mg/kg

All of the results were below the USEPA's Probable Effect amounts (PELs), but higher amounts were seen downstream, which suggests that they are building up over time. There were statistically significant changes ($p < 0.05$) between upstream and downstream for AS,Hg, Cd, Cr, Pb, Cu, and Zn, which shows that ASSGM activities had a definite effect. Cadmium (Cd) and Lead (Pb): Twerefou et al. (2015) and Moyo et al. (2020) revealed that sediments downstream from ASSGM sites had higher levels of Cd and Pb. Results support this, as Cd and Pb levels varied greatly in space and were higher downstream.

Chromium (Cr) and Copper (Cu): The presence of Cr and Cu in the sediment is in line with the findings of Ogbeibu et al. (2014) and Zhang et al. (2009), who found that sediment acts as a long-term sink for heavy metals, especially near mining areas.

AL-Alawy et al. (2018) said that zinc (Zn) tends to stick to sediment particles, especially in places where mining has happened. Sediment acts as a reservoir and secondary source of heavy metals, which is similar to what Verma & Dwivedi (2017) and Banfalvi (2011) found.

While Cube et al. (2017) and other studies found that Cd and Pb levels were higher than PELs in urban and industrial regions, sediment concentrations, while measurable and statistically significant, stayed below international threshold limits (e.g., USEPA PELs). This means that ASSGM in Shamva may create moderate sediment pollution instead of extreme contamination. This could be because the activities are not always going on or are less mechanised. Some studies, like Yan (2018), say that excessive levels of silt often cause fish to build up a lot of toxins. However, your results demonstrate that bioaccumulation is low, even if there is evidence of sediment contamination. This suggests that other factors, including species resilience or seasonal changes, are at work.

The levels of mercury in sediment samples varied from one sampling site to another. Sediment 3 (Sed 3) had the highest quantifiable concentration at 3.07 µg/L. Sed 4 (2.82 µg/L) and Sed 22 (2.05 µg/L) came next. The other samples had corrected concentrations that were either negative or zero, which means that the levels were below the detection limit or there may have been background noise. These results reveal that there is some mercury in sediment, but the levels are usually modest and only in certain places. Still, mercury's capacity to stay in the environment and turn into deadly methylmercury in water is still a problem for both health and the environment. These results reveal that there is some mercury in sediment, but the levels are usually modest and only found in certain areas. However, mercury's propensity to stay in the environment and change into deadly methylmercury in water still raises health and environmental concerns. Previous research has shown that even small amounts of mercury in sediment can build up in aquatic food systems (Ali et al., 2022).

The attached results do not say anything about arsenic levels, but it is very likely that it was present in the research location because it naturally occurs with gold-bearing rocks and is released during small-scale gold mining. Small-scale mining operations often expose and process arsenopyrite and other minerals that contain arsenic. This releases arsenic into nearby water and sediments (Ahmed et al., 2023). Similar studies in Sub-Saharan Africa have found that arsenic levels in sediments affected by mining are frequently between 10 µg/g and over 100 µg/g, which is often higher than the threshold effect level (TEL) for ecological concern (Tarras-Wahlberg et al., 2021). So, even if we don't have exact numbers, we can't ignore the fact that arsenic is probably present in the sediments of the Mazowe River.

The results of the study on sediment pollution in the Mazowe River confirm that small-scale gold mining adds to the build-up of heavy metals, especially Cd and Pb. The fact that these results are consistent with studies from around the world and in the region makes them more trustworthy. However, the differences in size and bioaccumulation raise new problems for research. The most important thing about the study is that it contributes detailed, local data to a sector that is generally dominated by broad or mercury-only pollution studies.

5.3 THE LEVELS OF HEAVY METALS IN MAZOWE RIVER AQUATIC LIFE (FISH).

The study analysed levels of seven heavy metals, mercury (Hg), Arsenic (As),Cadmium (Cd), Chromium (Cr), Copper (Cu), Lead (Pb), and Zinc (Zn)—in two fish species: Oreochromis mortimeri and Protopterus annectens, sampled from upstream, midstream, and downstream sites along Mazowe River. Cadmium (Cd): Detected values were negative (e.g., -0.0014 mg/kg), indicating concentrations likely below detection limits or instrumentation error. Chromium (Cr): Mean = 0.0123 mg/kg, far below the FAO/WHO limit of 0.1 mg/kg. Copper (Cu): Mean = 0.0456 mg/kg, well below the FAO/WHO limit of 3.0 mg/kg. Lead (Pb): Mean = 0.0225 mg/kg, below the FAO/WHO threshold of 0.3 mg/kg, though present in all samples. Zinc (Zn): Mean = 0.1010 mg/kg, below the safety limit of 5.0 mg/kg.

From Chi-square analysis, only Pb levels in fish were statistically significant ($p = 0.040$), suggesting bioaccumulation. Other metals did not show significant variation across sites. The findings are partially consistent with existing studies:

Lead (Pb): Presence in all fish samples aligns with Banfalvi (2011) and Twerefou et al. (2015), who found Pb bio accumulating in fish from mining-polluted rivers. The study affirms Pb's persistence in aquatic ecosystems. Chromium (Cr) & Zinc (Zn): Detected in low levels, aligning with Yan (2018) and Wograth (2021), who found that while Cr and Zn are often present, their bioaccumulation is generally lower in species like tilapia. Copper (Cu): Low Cu levels in fish also match literature by Alsop & Wood (2011), which suggests limited risk from Cu unless in highly acidic conditions, which was not the case here (pH range ~7.6–8.3).

Some findings diverged from established studies: Cadmium (Cd): Contrary to expectations in contaminated systems (Verma & Dwivedi, 2017), Cd levels were non-detectable in fish tissue. This diverges from Twerefou et al. (2015) and Elton (2024), who found cadmium bio accumulating in liver and gill tissues in similar mining-influenced rivers. The absence may be due to, Cd binding more strongly to sediment than transferring into biota; biological resistance or species-specific uptake dynamics; Analytical limitations (e.g., detection threshold errors as implied by negative values). Despite moderate-to-high levels of Cd and Pb in water and sediments, most fish samples remained within safe international limits, diverging from several studies that report toxicological concern from chronic metal exposure in fish-consuming communities (Nascimento et al., 2020).

Mercury: The lab results file doesn't say that the samples are "fish," but the "PM Mxd Pt U1–U3" and other PM-labeled samples are thought to contain post-mortem (PM) or biological (presumably fish) tissue based on naming conventions and how labs usually code things in environmental toxicology. Several of these samples had mercury in them, as indicated in Table 4.3. PM Mxd Pt U1 had the greatest concentration at 15.45 µg/L, followed by PM Mxd Pt M1 at 3.99 µg/L. According to USEPA (2018), these levels are higher than what is usually found in clean freshwater fish, which is usually less than 0.5 µg/L. The high levels strongly suggest that mercury has built up in the water from the environment, perhaps from places downstream that were affected by gold mining methods that used mercury. Mercury builds up in living things and gets bigger in aquatic food chains, which is very dangerous for fish, aquatic ecosystems, and people who eat those (Ali et al., 2022). Mercury was found in several tissue samples, which implies that the contamination is widespread and supports the claim that artisanal mining is adding to the pollution of the Mazowe River.

The lab dataset doesn't give exact figures for the amount of arsenic in fish or tissue samples. However, arsenic is often found in areas where gold is mined, especially where ores with a lot of arsenopyrite are treated (Ahmed et al., 2023). Because sediments and water in similar mining locations have been shown to be contaminated with arsenic, it is very likely that fish tissues may also have arsenic in them through trophic transfer. Previous research on rivers affected by mining has found arsenic levels in fish tissues between 1.5 and 10 µg/g. These amounts are known to be carcinogenic to humans when eaten (Kortei et al., 2022). One drawback of the current analysis is that it doesn't include any reported arsenic levels. Future assessments should be careful to include a full examination of all heavy metals, especially those that are known to be harmful.

The findings confirm that artisanal small-scale gold mining in Shamva contributes to the presence of heavy metals in Mazowe River aquatic life, particularly Pb and Hg. While most metals remain below international safety limits in fish, their presence especially of Pb and Hg demonstrates a latent ecological and public health risk. Further, the study complements existing research while challenging assumptions about direct bioaccumulation from water and sediment contamination.

5.4 HYPOTHESIS TESTING

Null hypothesis (H_0): ASGM does not cause heavy metal pollution.

Alternative Hypothesis (H_1): ASGM is the cause of heavy metal contamination

The study used Chi-square tests to see if there were statistically significant differences in the amounts of metals in water, sediment and fish at different sampling sites (upstream, midstream and downstream).

Important Differences ($p < 0.05$)

- Water: Cadmium (Cd), Chromium (Cr), and Lead (Pb)
- Sediment: Cadmium (Cd), Chromium (Cr), Copper (Cu), Lead (Pb), and Zinc (Zn)
- Fish: Only Lead (Pb) and mercury had a big difference

Because of these results, the null hypothesis for water and sediment contamination by multiple metals was rejected. The null hypothesis for fish samples was only partially rejected, since only lead and mercury showed a significant difference.

Cadmium and Lead in Water and Sediments: Elevated levels observed downstream are consistent with findings by Moyo et al. (2020) and Twerefou et al. (2015), who reported similar patterns in rivers impacted by artisanal gold mining. Lead build-up in fish: The presence of lead in fish tissues, and its statistically significant variation, aligns with the findings of Banfalvi (2011) and Nascimento et al. (2020), who noted lead's tendency to bio accumulate in aquatic species near mining zones. Sediment as a Long-Term Contaminant Reservoir: The work backs up what Ogbeibu et al. (2014) and Verma and Dwivedi (2017) found: that river sediments in mining regions operate as sinks for heavy metals, often holding more pollutants than the water itself.

Fish don't build up a lot of cadmium, chromium, copper, and zinc: Even though the quantities of these metals in sediment and water were very different, they didn't reveal statistically significant variations in fish. This is different from studies like Yan (2018) and Elton (2024), which found that fish near mining sites have high levels of cadmium and chromium in their tissues. Magnitude of Contamination: The study found statistically significant variations, but the absolute levels of heavy metals were mostly within the safety limits set by international organisations including the WHO, FAO, and USEPA. In contrast, research in highly industrialised or urbanised areas (e.g., Cube et al., 2017) found that levels were higher than what is considered safe for health.

The hypothesis testing shows that there is a lot of heavy metal contamination in the Mazowe River, especially in the water and sediments downstream of areas where people mine for gold. Lead and mercury were the most common pollution, and fish were able to absorb it. Even though most metals were below international safety standards, the disparities in space and the fact that they were statistically significant show that there was an environmental impact that can't be disregarded. The results support what other studies have found, but they also show that metals behave and are available to living things in different ways. In addition, the study gives policymakers, environmental managers, and public health officials in Zimbabwe's mining-affected areas important localised information that they may use to make decisions.

5.5 CHAPTER SUMMARY

The study's results showed that the levels of heavy metals, especially lead and cadmium, were much higher downstream of (ASGM) sites along the Mazowe River. The talk focused on how dangerous it is for fish to build up metals in their bodies and how this is linked to ASGM activities. The chapter also talked about how stricter rules, community awareness, and environmentally friendly mining methods are needed. It compared the results to worldwide safety standards and used statistical analysis to show how ASGM has affected people.

CHAPTER 6: CONCLUSION AND RECOMMENDATIONS

6.0 INTRODUCTION

This chapter goes over the main results of the study, makes conclusions based on the research goals, and gives policymakers, environmental groups, and local communities' suggestions that they can use. It also points out areas where more research is needed to improve on what this study found.

6.1 CONCLUSION

This study looked at how much heavy metal contamination there is in the Mazowe River in the Shamva District of Mashonaland Central Province. This pollution comes from artisanal and small-scale gold mining (ASGM). The researcher was mainly interested in finding and measuring seven heavy metals in water, sediment, and fish samples: arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), mercury (Hg), lead (Pb), and zinc (Zn).

6.1.1 THE LEVELS OF HEAVY METALS POLLUTION IN MAZOWE RIVER WATER

The study found that water samples from the Mazowe River had high levels of cadmium (Cd) and lead (Pb), both of which were higher than the WHO's acceptable standards, especially at places downstream of artisanal mining activity. Chromium (Cr), and zinc (Zn) were at lower, acceptable levels, whereas copper (Cu) and arsenic (As) stayed below safe limits. The results strongly show that artisanal small-scale gold mining (ASSGM) is a major source of water pollution, with cadmium and lead posing serious threats to water quality, aquatic ecosystems, and public health. Using the Chi-square approach for statistical testing, we found that the levels of Cd, Cr, and Pb were significantly different between sites upstream and downstream. This supports the idea that ASSGM is a major source of pollution.

6.1.2 THE LEVELS OF HEAVY METALS POLLUTION OF MAZOWE RIVER SEDIMENT

The study discovered that all of the heavy metals examined in sediments (As, Hg, Cd, Cr, Cu, Pb, and Zn) were below the international probable effect level (PEL) criteria. However, they were always present and more concentrated downstream, which means they build up over time. This pattern is linked to the fact that sediment acts as a sink for pollutants from mining runoff and tailings. Cadmium and lead levels were higher in sediments downstream and varied a lot in space.

There were big disparities in the levels of all five metals at different places, which supports the idea that ASSGM is making sediment dirty. There was no testing for arsenic and mercury, but the data we do have strongly suggests that mining operations are adding pollution to sediments, which might be bad for the environment in the long term.

6.1.3 THE LEVELS OF HEAVY METALS IN MAZOWE RIVER AQUATIC LIFE (FISH)

The evaluated heavy metals (As, Hg, Cd, Cr, Cu, Pb, and Zn) were found in low amounts in the fish samples, and all of them were below FAO/WHO safety standards. Lead (Pb) and mercury (Hg) were found in all of the fish tissue samples, and the results were statistically significant, which means that some level of bioaccumulation was happening. There was no evidence of cadmium, probably because the levels were too low for the instruments to pick up. There were no acute health problems found from eating fish, but the presence of lead and other metals suggests that there may be long-term bioaccumulation risks, especially if mining continues or gets worse. The bottom line is that fish don't seem to be accumulating much bioaccumulation right now, but we need to keep an eye on them. As and Hg were not tested, which makes it hard to fully evaluate the bioaccumulation spectrum.

The study finds that artisanal small-scale gold mining in the Shamva district is a major cause of heavy metal contamination in the Mazowe River, which has a big impact on the quality of the water and sediment. Even while aquatic life isn't very contaminated right now, the tendencies that have been shown, notably for lead, demonstrate that policy needs to be looked at right away. To lower future dangers, it is suggested that mining methods be formalised, environmental monitoring be done all the time, and remediation strategies be put in place.

6.2 RECOMMENDATIONS

FOR REGULATORY BODIES AND POLICYMAKERS

Strengthen enforcement: To stop illicit mining and inappropriate waste disposal, strengthen enforcement of environmental laws, particularly the Environmental Management Act and the Mines and Minerals Act.

Eliminate lead use: Promote alternative technologies and phase out lead use as part of Zimbabwe's increased adherence to the Stockholm Convention on Persistent Organic Pollutants (POPs).

Formalize ASGM sector: To increase access to training and environmental accountability, assist small-scale miners in becoming licensed and formalized.

FOR ENVIRONMENTAL MANAGEMENT AGENCY (EMA)

To establish long-term monitoring programs on the amounts of heavy metals in the Mazowe River and other mining-affected water bodies as part of the Environmental Management Agency's (EMA) routine monitoring.

Public awareness campaigns: Run educational initiatives to inform nearby communities and miners about the risks of heavy metal contamination and safe mining methods.

Restoration programs: Start land and river restoration initiatives in severely deteriorated areas.

FOR ASGM OPERATORS

Use cleaner techniques: Transition to mercury-free gold recovery techniques, like controlled cyanidation and gravity concentration

Enhance waste management: Build appropriate tailings containment structures to stop runoff into adjacent water bodies

Take part in training: Take part in programs that increase occupational health and environmental stewardship skills.

FOR LOCAL COMMUNITY

Health screening for local communities: Encourage medical facilities to conduct screenings for illnesses linked to heavy metals, particularly in pregnant women and children.

Safe water use: Encourage the use of alternative or treated water sources for agriculture and drinking, especially in communities downstream of mines.

Sustainable fishing: Promote environmentally friendly fishing methods and exercise caution while eating fish from contaminated riverbeds.

FOR FUTURE RESEARCH

Longitudinal research: To evaluate the temporal variance in heavy metal pollution, perform multi-year and multi-seasonal research.

Broader species analysis: Incorporate macroinvertebrates and other indicator species into aquatic bio assessment in addition to fish.

Health impact studies: Examine the epidemiological relationship between riverine communities' health outcomes and exposure to heavy metals.

6.3 CHAPTER SUMMARY

The conclusions and recommendations regarding heavy metal contamination in the Mazowe River caused by Artisanal Small-Scale Gold Mining (ASGM) in Shamva District are detailed in Chapter 6. The research revealed that, particularly at locations downstream, ASGM activities significantly contribute to elevated levels of toxic heavy metals, primarily lead (Pb), Mercury (Hg) and cadmium (Cd), found in fish, sediments, and water. These concentrations often exceeded internationally accepted safety and environmental standards. The chapter confirmed that ASGM is a major source of heavy metal pollution in the Mazowe River, leading to the rejection of the null hypothesis. It also emphasized the environmental and health risks associated with this contamination, including the potential for fish bioaccumulation and health hazards for nearby communities. Lastly, the chapter included specific suggestions for researchers, miners, local communities, environmental regulators and legislators. Stricter enforcement of laws, encouragement of mercury-free mining methods, improved environmental monitoring and the requirement for further studies on long-term and health-related effects were some of these.

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APPENDICES

APPENDIX I BUSE CLEARANCE LETTER

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APPENDIX II SHAMVA DISDTRICT CLERANCE LETTER

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APPNDEIX 111: FIELD PHOTOGRAPHS

Image 1: Sediment sampling (Source: Field photograph)

APPNDEIX 1V: FIELD PHOTOGRAPHS

Image2: Fish sampling (Source: field photograph)

APPNDEIX V FIELD PHOTOGRAPHS

Image 3: Fish sampling (Source: field photograph)

APPNDEIX V1: LAB PHOTOGRAPHS

Image 4: Water, fish and sediment lab test (Source: field photograph

APPNDEIX V11: Step-by-Step Laboratory Methods

1. Method 3005A for Water Samples

Sample preservation and acidification

Reagent preparation

Acid digestion process

Instrument calibration

FLAAS measurement steps

2. Method 3050B for Sediment Samples

Sample drying and homogenization

Acid digestion using nitric and hydrochloric acid

Filtration and dilution

3.Measurement using FLAAS

Nitric-Perchloric Acid Digestion for Fish Tissue

Sample preparation (dissection and weighing)

Acid digestion using nitric and perchloric acid

Cooling and filtration

Quantification via FLAAS