ASSESSMENT OF HEAVY METAL IMPACT ON MUKUVISI RIVER IN HARARE, ZIMBABWE

A DISSERTATION SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE

OF

MASTER OF TECHNOLOGY

IN

ENVIRONMENTAL ENGINEERING

Submitted by

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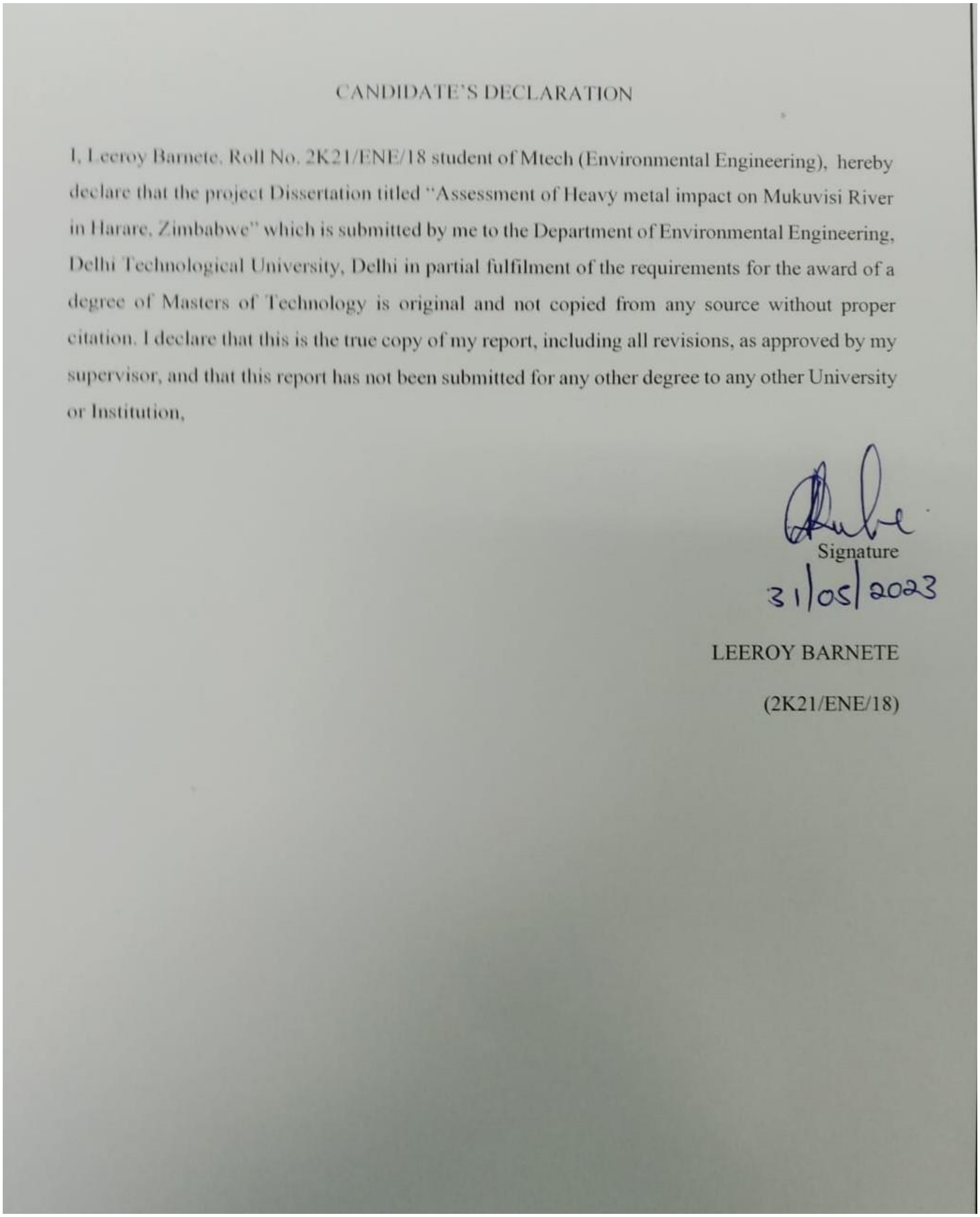

CANDIDATE'S DECLARATION

I, Leeroy Barnete, Roll No. 2K21/ENE/18 student of Mtech (Environmental Engineering), hereby declare that the project Dissertation titled "Assessment of Heavy metal impact on Mukuvisi River in Harare, Zimbabwe" which is submitted by me to the Department of Environmental Engineering, Delhi Technological University, Delhi in partial fulfilment of the requirements for the award of a degree of Masters of Technology is original and not copied from any source without proper citation. I declare that this is the true copy of my report, including all revisions, as approved by my supervisor, and that this report has not been submitted for any other degree to any other University or Institution,

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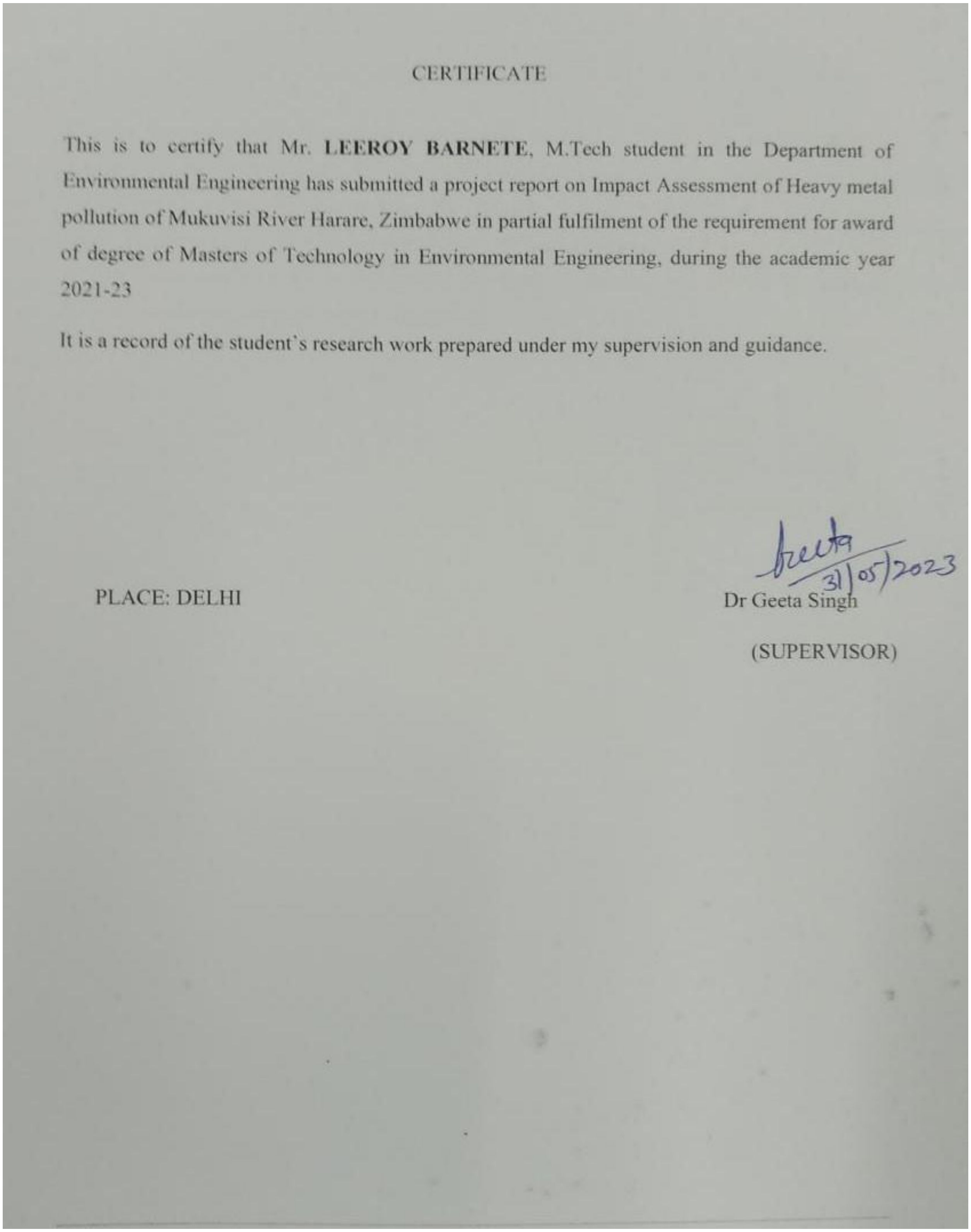

CERTIFICATE

This is to certify that Mr. **LEEROY BARNETE**, M.Tech student in the Department of Environmental Engineering has submitted a project report on Impact Assessment of Heavy metal pollution of Mukuvisi River Harare, Zimbabwe in partial fulfilment of the requirement for award of degree of Masters of Technology in Environmental Engineering, during the academic year 2021-23

It is a record of the student's research work prepared under my supervision and guidance.

Geeta
31/05/2023

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I would like to thank the Almighty for the guidance throughout out the course of this research project I would also like to thank DTU and all the Environmental Engineering department lecturers for the assistance they gave me in doing this research project, I would like to thank Dr Geeta Singh, my project supervisor for her countless assistance, contributions and her wavering support towards this research project; the research; and many discussions; and last but not least, her knowledge of Environmental Impact Assessment.

ABSTRACT

This study examined the impact assessment of heavy metals in the Mukuvisi River, Harare Zimbabwe for the two of its major seasons, the summer and rainy season. Several studies have been done for the impact assessment but this study is the first of its kind in Harare Zimbabwe as it focuses on heavy metal that are discharged by industries along the Msasa industrial area into the river. The objective is to investigate and analyze the quantity of heavy metals that are discharged into the Mukuvisi river and carry out an impact assessment so as to come up with mitigation measures and solutions that will help the Zimbabwe National Water Authority (ZINWA) to make policies and enforcing strict laws to polluting industries so as to maintain the ecological health of the river. We also presented the difference in the heavy metal concentrations between the summer and rainy season while samples were collected according to the Standard Association of Zimbabwe (SAZS 560:1997) procedure using polythene bottles which were previously immersed in 10% nitric acid and scrubbed with deionized distilled water and samples taken to the laboratory for analysis. The water quality parameters analyzed were Arsenic, Mercury, Cadmium, Chromium, and Palladium. The mean level range of Arsenic, Mercury, Cadmium, Chromium, and Palladium was found 0.04, 0.065, 0.045, 0.01, and 0.01 mg/l, respectively, for the summer season, while for the rainy season, the concentrations were 0.04, 0.028, 0.028, 0.009 mg/l, and below 0.01 mg/l respectively for each sampling site. High heavy metal concentrations were recorded in summer, while low heavy metal concentrations were recorded in the rainy season which shows a clear seasonal effect between the two seasons as there were some variations.

Keywords: Heavy metals, Mukuvisi River, impact analysis, water pollution, Harare.

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ABBREVIATIONS

EC- Electrical conductivity

HM- Heavy metal

Ars- Arsenic

TH- Total hardness

WQI- Water Quality Index

Cd- Cadmium

TDS- Total dissolved solids

Hg- Mercury

Cr- Chromium

WHO- World health organization

SAZ- Standard association of Zimbabwe

TA- Total alkalinity

CHAPTER ONE

INTRODUCTION

1.0 Background

The globe is currently threatened by a scarcity of pollutant-free water. The persistent discharge of untreated industrial wastewater into rivers has badly damaged the surface and groundwater. These effluents have harmed the ecosystem, and the majority of organic compounds, with the exception of heavy metals, are digested by microorganisms. Many studies have been undertaken, particularly in industrialized countries (Rahman & Singh, V. P., 2019). Heavy metals, including actinides, lanthanides, metalloids, and metals, have atomic densities more than 4 g cm-3 (Duffus, 2002). Above their legal levels, these are severely dangerous to the environment. Heavy metals such as As, Hg, Pb, and Cd damage the principal antioxidants of cells, primarily enzymes and antioxidants of the thiol group (-SH). However, these metals may increase the generation of reactive oxygen species (ROS) such as hydroxyl radical (OH), hydrogen peroxide (H2O2), and superoxide radical (O2), leading to oxidative stress, a condition in which cells' inherent antioxidant defense is reduced due to increased ROS generation (Duffus, 2002). Because the chemical structure of these poisons is a significant problem in terms of reactivity and toxicity, assessment, control, monitoring, and analysis of metal concentrations are critical. (Azeh Engwa, Udoka Ferdinand, P., Nweke Nwalo, F, & N. Unachukwu, M, 2019). Monitoring of highly hazardous metals and metalloids in various environmental mediums (e.g., soils, sediments) should be done on a regular basis. The discharge of wastewater into the environment, such as industrial effluent and home sewage, contributes to the release of various heavy metals (Masindi & Muedi, K. L., 2018). The usage of chemical fertilisers and the combustion of fossil fuels are two anthropogenic activities that contribute to the flow of heavy metals into the aquatic environment. The biggest sewage treatment plants in the surrounding area, according to (Masindi & Muedi, K. L., 2018), discharge their wastewater into the Mukuvisi River. Nutrient leaching from urban agriculture activities has an impact on the river's nutrient concentration. (Ndebele, 2019) (Nyika, 2022), supports the fact that the water quality upstream of the river has been polluted over the years.

1.1 Problem statement.

According to a report published by the Environment Management Agency (EMA) on October 26, 2016, daily news reported that "over 200 industries in Harare have been found disposing toxic wastes in rivers that supply drinking water to the city." Many industrial sites lack pre-treatment plants, which process toxic goods, poisons, non-biodegradable compounds, and organic debris before they are discharged into the river. Heavy metals, sulphates, ammonium salts, phosphates, and other organic compounds were the most common pollutants. As a result of this, when phosphorus and nitrogen meet in freshwater ecosystems, algae take over the water, sunlight has a harder time reaching the surface, and plant development eventually ceases. Also, too many nutrients cause the oxygen level to plummet. As a result, there will be insufficient oxygen supply in bodies of water with a dense population of animals and plants. According to Global Cancer Observatory data for the year 2020, 16,083 new cases of cancer and 10,676 deaths were reported in Zimbabwe, with heavy metal exposure being the leading cause of the majority of the cancers.

1.2 Justification

This research is critical because it will identify, anticipate, and analyze the effects of heavy metal contamination on people who use untreated Mukuvisi river water for irrigation, washing, and drinking, as well as provide mitigating techniques to protect natural resources and the ecosystem.

1.3 Aim

To Identifying and forecasting the environmental effects of heavy metal pollution and effluent dumped into the Mukuvisi River waters by industries in Msasa, Harare.

1.4 Objectives

1. To identify the untreated heavy metals that are discharged into Mukuvisi River.
2. To predict the potential effects of the heavy metals on the environment and human beings.
3. To provide possible impacts of heavy metals.
4. To identify appropriate alternatives and mitigation measures.

CHAPTER TWO

LITERATURE REVIEW

2.0 Introduction

This chapter presents the perspectives of several scholars on the study that has been conducted in assessing, identifying, and analyzing the effects of heavy metal pollution in the upper Mukuvisi River by industry. The goal of a literature review is to guide the researcher through the investigation by giving previously available information. This provides an appraisal of what has been done in comparison to what can and should be done. Various researchers' published texts, books, bulletins, abstracts, journals, periodicals, magazines, manuals, handbooks, encyclopedias, and internet websites will be consulted.

2.1 History of Mukuvisi River.

Mukuvisi River (42km length; 230 km2) originates from Cleveland Dam, which is around 2km from the river, it has been a part of the landscape for centuries, with indigenous communities living along its banks. The river provided water for drinking, irrigation, and sustenance for the local population. However, as Harare expanded and urbanization intensified, the Mukuvisi River and its surrounding areas underwent significant changes. Industrial and residential developments began encroaching on the riverbanks, leading to increased human activities and pollution. The river travels through the Msasa industrial region, Mukuvisi forests, and urban residential suburbs of Sunnigndale, Waterfalls, Mbare, Highfields, and Glenview before reaching Harare Municipality farms. In recent years, there has been a growing recognition of the importance of conserving the Mukuvisi River ecosystem and its associated woodlands. Efforts have been made to promote ecotourism and environmental education within the Mukuvisi Woodlands, highlighting its biodiversity and ecological value. The Mukuvisi River, like many urban rivers, faces environmental challenges, including pollution from industrial and domestic sources. Effluents containing heavy metals, organic pollutants, and other contaminants have been a concern, affecting the water quality and ecosystem health of the river.

2.2 Sources of heavy metal pollutants

Heavy metals can originate from both natural and anthropogenic sources. Heavy metals can be naturally present in the Earth's crust and are released into the environment through natural processes. Weathering of metal-bearing rocks, erosion, and volcanic activities can contribute to the release of heavy metals into soil, water, and air. Natural sources are generally more localized and less significant compared to anthropogenic sources. Anthropogenic activities, primarily industrial and urbanization processes, contribute significantly to the release of heavy metals into the environment. These activities include industrial processes various industries, such as mining, smelting, manufacturing, and energy production, release heavy metals into the environment through emissions, wastewater discharges, and improper waste management practices.

1) Macro elements- They are known as the structural elements and they constitute most of the cells and tissues.

2) Trace elements are the necessary elements. If one of the elements is missing or deficient, it can lead to irregularities in normal life processes such as inability to reproduce and delayed development. Iron, iodine, copper, and manganese are examples.

3) Toxic elements- Any material that is detrimental to human health if inhaled, swallowed, or absorbed through the skin is considered a toxic element. Aluminium, cadmium, lead, mercury, barium, and arsenic are examples of hazardous elements, whereas zirconium, silver, gold, uranium, tungsten, indium, and germanium are examples of potentially dangerous elements.

Zimbabwe Phosphate Industries (ZimPhos) was founded 70 years ago on the banks of the Mukuvisi River on the eastern outskirts of Harare with the mission of producing phosphate fertiliser. However, there is severe groundwater contamination surrounding the fertiliser factory due to ancient unlined waste dumps that continue to release pollutants into the earth (Ravengai et al, 2004). The three oldest dump sites are unlined, contaminating both surface and groundwater sources (Phiri, 2000). The areas surrounding the fertiliser plant (ZimPhos) showed a high prevalence of contaminated water in streams, wells, and rivers, according to (Phiri, 2000). Superphosphates and sulfuric acid are the principal pollutants, and the majority of wastes are gypsum (80 Gg/y), alum sludge, and pyrites cinder (50 Gg/y). Heavy metals detected in fluoride-rich scrubbing alcohol include As, Hg, Cd, Pa, and chromium from the Msasa industrial site. The river flows through an industrial sector, a woodland, and some residential districts of Hatfield, Sunnigndale, Mbare, Waterfalls, Highfields, and Glenview after passing past the fertiliser plant. At several spots along the river, many poor people rely on it because the city no longer supplies piped clean water to some of its citizens as a result of rising urbanization, therefore many people are now using untreated river water for a variety of reasons such as cleaning, irrigation, and even drinking.

Figure 1: Picture showing residents using Mukuvisi untreated river water for washing

2.3 Environmental relevance of hazardous heavy metals.

The most frequent environmental poisons are heavy metals, which might be anthropogenic or natural. These are the most prevalent and pervasive contaminants in the environment. Heavy metal contamination has increased dramatically in recent decades as a result of increased urbanisation and industry. Heavy metals are harmful to the ecosystem and human health because they do not disintegrate over time and remain in the environment, indicating that they are non-biodegradable in nature (Jan et al., 2015). They have a lengthy half-life and generate organometallic compounds, which accumulate in cells and organs. They accumulate in the food chain and, if consumed on a regular basis, can create major health problems because they are non-biodegradable, which means that nature cannot break them down.

2.3.1 Arsenic in the Environment

According to Chung, J.Y., Yu, S.D. and Hong, Y.S (2014), Arsenic is a natural element that is found in the environment in different forms. It can also be released into the environment through different processes either by human activities, geogenic activities and natural activities. Weathering of minerals, volcanic activities and erosion of arsenic-containing rocks are some major natural sources of arsenic. Human activities that are associated with the release of arsenic includes the use of arsenic-containing pesticides and herbicides, mining and smelting and there are some industrial processes that contribute to the release of arsenic into the atmosphere and they include the burning of fossil fuels. It can exist in two different forms which are organic and inorganic forms. However, the most toxic among the two is inorganic arsenic compounds than organic forms. Groundwater can be easily contaminated by inorganic arsenic compounds through agricultural practices, pollution from industrial activities and natural processes (Morais, S., Costa, F.G. and Pereira, M.D.L., et al 2012). People can also be exposed to arsenic through different sources which includes the soil through dermal contact with contaminated soil, water through ingestion of contaminated water. Arsenic can cause many health effects because it is carcinogenic in nature. It can lead to skin cancer, neurological effects, skin lesions, cardiovascular disease, an increased risk of several types of cancer, such as lung and bladder. To address arsenic contamination, various measures can be taken, including water treatment to remove arsenic, regulation and monitoring of industrial discharges, and implementing best practices in agriculture to minimize arsenic uptake by crops. Regular testing of water sources and adherence to safety standards for arsenic levels in food and drinking water are crucial to protect human health. It's important to note that environmental regulations, standards, and mitigation efforts can vary across different countries and regions, so it's advisable to consult local authorities or environmental agencies for specific information on arsenic levels and mitigation measures in a particular area. Long-term consumption of inorganic "Blackfoot disease" in China (Taiwan Province) has been connected to a number of negative health effects, including a significant blood vessel disease that leads to gangrene. It has also been related to an increase in young people's death due to multiple heart attacks, malignancies, and lung sickness, as well as a high newborn mortality rate, poor pregnancy outcomes, and negative effects on child health.

2.3.2 Cadmium in the Environment

According to Farhan, A.S. and Jasim, S.T. (2020) Cadmium is a naturally occurring heavy metal present in the Earth's crust that has been classified as a toxic substance due to its detrimental impact on both the environment and human health. While cadmium can be released into the environment through natural processes, human activities, such as mining, manufacturing, and improper waste disposal, are the primary sources of cadmium pollution. Once released, cadmium has the potential to persist in the environment for extended periods, accumulating in soils, sediments, and aquatic systems. People can be exposed to cadmium through inhalation, ingestion, or dermal contact with contaminated air, food, water, soil, or dust. Prolonged exposure to cadmium can have harmful effects on various organs, including the kidneys, lungs, liver, and skeletal system fish (Okocha, R.C., and Adedeji et al 2011). It is also associated with an increased risk of cancer. Cadmium contamination poses significant risks to ecosystems as it can disrupt plant growth, accumulate in organisms throughout the food chain, and contaminate water sources (Morais, S., Costa, F.G., and Pereira, M.D.L., et al 2012).

2.3.3 Mercury in the Environment

As stated by Driscoll, C.T., Mason, R.P., Chan, H.M., Jacob, D.J., and Pirrone (2013), Mercury is a highly toxic heavy metal naturally occuring in the Earth's crust and poses significant risks to the environment and human well-being. While both natural processes and human activities contribute to the release of mercury, human actions are the primary cause of mercury pollution. Industrial processes like coal burning, gold mining, and waste incineration release mercury into the air, water, and soil. Improper disposal of mercury-containing products such as thermometers and fluorescent light bulbs also contributes to environmental contamination. Once in the environment, mercury undergoes transformations, with methylmercury being the most harmful form. Methylmercury is produced by microorganisms in aquatic environments and accumulates in fish and other organisms, leading to biomagnification up the food chain. Human exposure to mercury occurs through inhalation of mercury vapor, consumption of contaminated fish and seafood, and, to a lesser extent, dental amalgams. Mercury toxicity can have severe neurological effects, particularly on developing fetuses and young children. It can impair cognitive function, memory, attention, and language skills. Other health effects include cardiovascular problems, immune system dysfunction, and kidney damage. Elemental mercury vapor can also cause respiratory and neurological symptoms according to (Caserta, D., Graziano, A., Monte, G.L., Bordi, G., and Moscarini et al. 2013) Mercury contamination has adverse consequences for ecosystems as well. It can harm fish, impair their reproduction, growth, and development, and impact bird populations that rely on mercury-contaminated fish as a food source. To address mercury pollution, international agreements like the Minamata Convention on Mercury aim to reduce mercury emissions and regulate its use. Strict regulations on industrial emissions, proper waste management, and the promotion of alternative technologies are vital in mitigating mercury pollution (Engwa, G.A., Ferdinand, P.U., Nwalo, F.N., et al. 2019).

2.3.4 Copper in the Environment

According to Arshad, N.A (2013), Copper is a naturally occurring element that is widely distributed in the environment. It can be found in rocks, soil, water, and air. Copper is an essential trace element required by living organisms, including humans, for various biological processes. However, excessive amounts of copper can have detrimental effects on the environment. Copper enters the environment through natural processes such as weathering of rocks and volcanic activity. Additionally, human activities contribute to copper release, including mining, smelting, industrial processes, and the use of copper-containing products like pesticides, wood preservatives, and plumbing materials. Copper can undergo various transformations in the environment. It can bind to organic matter and minerals in soil, and it can also dissolve in water. In aquatic environments, copper can adsorb to sediments or be taken up by aquatic organisms. Elevated copper concentrations in water bodies can be toxic to aquatic organisms. Copper affects the gills and other respiratory structures of fish, impairing their ability to breathe and reducing their overall fitness (Akpor, O.B., and Muchie, et al 2010). It can also impact invertebrates and plants, disrupting their growth and reproduction. Copper can also accumulate in soil due to its adsorption to organic matter and clay minerals. High copper levels in soil can affect plant growth and microbial activity. Copper toxicity can lead to reduced crop yields and damage to soil ecosystems. While copper is an essential nutrient for humans, excessive exposure can have adverse health effects. Occupational exposure can occur in industries such as mining and metalworking. Copper contamination in drinking water can also be a concern if plumbing materials or water sources contain elevated levels of copper (Engwa, G.A., Ferdinand, P.U., Nwalo, F.N. and Unachukwu, et al 2019).

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2.3.5 Chromium in the Environment

According to Das, N. and Mathew (2011), Chromium is a naturally occurring element found in the Earth's crust and exists in different forms. It can be present as trivalent chromium (Cr(III)) or hexavalent chromium (Cr(VI)). Chromium compounds are widely used in industries, but they can also be released into the environment through natural processes and human activities. Natural sources of chromium include the erosion of rocks and minerals containing chromium, as well as volcanic activity. Human activities, such as metal plating, leather tanning, stainless steel production, and the use of chromium-based pigments and dyes, contribute to chromium pollution. Chromium in the environment can have different levels of toxicity. Trivalent chromium (Cr(III)) is less harmful and has essential roles in biological processes. On the other hand, hexavalent chromium (Cr(VI)) is highly toxic and poses risks to human health. It is a known carcinogen and can cause various health issues, including respiratory problems and skin irritation (Teklay, A. et al. 2016). Industries that use or release chromium compounds can contaminate soil, water, and air. Inadequate disposal of industrial waste containing chromium can lead to the leaching of hexavalent chromium into groundwater. Chromium can undergo changes in the environment, influenced by factors like pH, temperature, organic matter, and the presence of other chemicals. In aquatic environments, chromium can accumulate in sediments and bioaccumulate in organisms, leading to higher concentrations up the food chain. To mitigate chromium pollution, measures such as wastewater treatment, proper waste management, and remediation of contaminated sites are implemented. Regulatory agencies in many countries have set limits on acceptable chromium levels in drinking water, soil, and air to protect both humans and the environment. Regular monitoring and testing are essential for identifying and addressing potential sources of chromium contamination.

2.3.6 Lead in the Environment

According to Arshad, N.A (2013), Lead is a dangerous element that occurs organically in the Earth's crust. There have been major public health hazards, environmental degradation, and impacts on people as a result of its widespread consumption in many different parts of the globe. Mining, smelting, manufacture, recycling, and use in a wide range of products are all major polluters. Lead is a toxin that accumulates in numerous biological systems and is especially hazardous to children. Lead can enter the brain, kidneys, and liver through the bones. It is stored in the teeth and bones, where it accumulates over time. Lead levels in the blood are commonly used to assess human exposure. During pregnancy, lead in bone is released into the circulation, exposing the unborn child. According to Dapul, H., and Laraque, D., et al. (2014), children who survive acute lead poisoning may have intellectual disabilities and behavioural issues. Long-term neurological or behavioral repercussions are thought to be caused by lead (Engwa, G.A., Ferdinand, P.U., Nwalo, F.N., et al. 2019). Adults may be exposed to leadership due to their occupations and surroundings. The principal causes are inhaling lead particles from burning lead-containing things, such as when recycling, ingesting lead-contaminated dust, drinking water from lead pipes, eating food from lead-glazed or lead-soldered containers, and consuming leaded aviation fuel. Young children are more prone to lead's harmful effects, which can have major long-term health ramifications, notably on nervous system and brain development. Lead increases the likelihood of two ailments in adults: kidney disease and high blood pressure. Pregnancy lead exposure can result in stillbirths, early births, low birth weights, and miscarriages. Lead exposure also damages the reproductive system, produces immunotoxicity, hypertension, anaemia, and renal impairment in the reproductive organs.

2.3.7 Nickel in the environment

According to Adriano, D.C (2001), Nickel is a naturally occurring element found in the environment and is commonly used in industry. Nickel is naturally present in the Earth's crust and can be released into the environment through processes like weathering and erosion of rocks and minerals containing nickel. Volcanic activity and forest fires can also contribute to nickel emissions. Human actions play a significant role in nickel pollution. Industrial processes such as mining, smelting, and refining of nickel ores release substantial amounts of nickel into the air, soil, and water. Nickel is also used in the production of stainless steel, batteries, and various alloys, which can result in the release of nickel-containing waste. Nickel can be emitted into the air as fine particles or attached to dust. Industries, power plants, and fossil fuel combustion are major sources of airborne nickel contamination. Once released, nickel particles can travel long distances and settle on land and water surfaces. Industrial sites, mining areas, and landfills where nickel-containing waste is disposed of can lead to the accumulation of nickel in the soil. Over time, repeated deposition and runoff of nickel-containing particles can result in elevated soil concentrations. Agricultural practices and the use of nickel-based fertilizers can also contribute to soil contamination. Industrial discharges, runoff from polluted sites, and improper disposal of nickel-containing waste can introduce nickel into surface water and groundwater. Nickel can bind to sediments and can be taken up by aquatic organisms, potentially affecting the food chain. Nickel is classified as a potential carcinogen and can cause respiratory problems, skin allergies, and other adverse health effects. High concentrations of nickel can be toxic to aquatic life (Kasprzak, K.S., Salnikow, K., et al 2007).

2.3.8 Zinc in the Environment

According to Arshad, N.A (2013), Zinc is an essential trace element, naturally occurs in the Earth's crust and plays a critical role in biological processes. While zinc enters the environment through natural processes like weathering, human activities also contribute to zinc pollution. Industrial processes such as mining and manufacturing release zinc into the air, water, and soil. Zinc-containing products, like galvanized coatings and fertilizers, also introduce zinc into the environment. Once released, zinc undergoes transformations. It can settle onto land or water surfaces after binding to airborne particles. In soil, zinc can either remain in place or leach into groundwater. In aquatic environments, zinc can be adsorbed by sediments or taken up by plants and animals. Zinc is essential for the health and growth of plants, animals, and microorganisms. It serves as a crucial nutrient, supporting enzyme function and development. Dietary intake is the primary route of human exposure to zinc, with various foods containing this element. Occupational exposure may occur in industries associated with zinc production and usage. While zinc is generally considered to have low toxicity, excessive intake or exposure to high levels can lead to health problems (Hambidge, M., et al 2000). Zinc pollution has minimal environmental impact at moderate concentrations. However, elevated zinc levels can be toxic to aquatic organisms, particularly sensitive species. Excessive zinc concentrations in soil can affect plant growth and microbial activity. Runoff from zinc-containing fertilizers or industrial activities can also lead to localized water contamination. Regulatory measures are implemented to control industrial emissions and wastewater discharges, while best practices in agriculture aim to minimize zinc runoff. Responsible mining practices and recycling of zinc-containing products are also encouraged. Regular monitoring and assessment of zinc levels are important for identifying and addressing potential risks to ecosystems and human health.

CHAPTER THREE

METHODOLOGY

3.0 Introduction

This chapter's objective is to define the research strategy that will be employed to complete this project. It will detail all of the processes that will take place during the impact assessment phase, such as data collection, analysis, and mitigation plans. Conceptual research will be used to establish new linkages.

3.1 Approach to research

The method that will be employed in this study is a quantitative experimental method. In this example, some factors will be changed to see how they affect the other variables, which is characteristic of the experimental technique, which offers considerably better control over the research setting.

3.2 Data collection methods

This study used primary and secondary sources as its two data sources.

3.2.1 Primary sources of data

These include

- Field work (sampling)
- Interviews
- Questionnaires
- Observations

3.2.2 Secondary sources of data

These include

- Journals

- Internet
- Research papers

3.3 Site selection and sampling points.

The Mukuvisi River (42 km long; 230 km2) is one of Zimbabwe's largest rivers, supplying Lake Chivero, Harare's primary water source, as well as the Mukuvisi woodlands, Sunningdale, Waterfalls, Mbare, Highfields, and Glenview urban residential areas, and Harare Municipality farms (Ndebele, 2019). The first sampling site, as shown in the figure below, is directly after the ZimPhos fertilizer plant, which served as a reference point (Site 1), and about 5 km downstream from the plant are Msasa industrial districts (Site 2), Mukuvisi forests (Site 3), and Hillside residential area (Site 4).

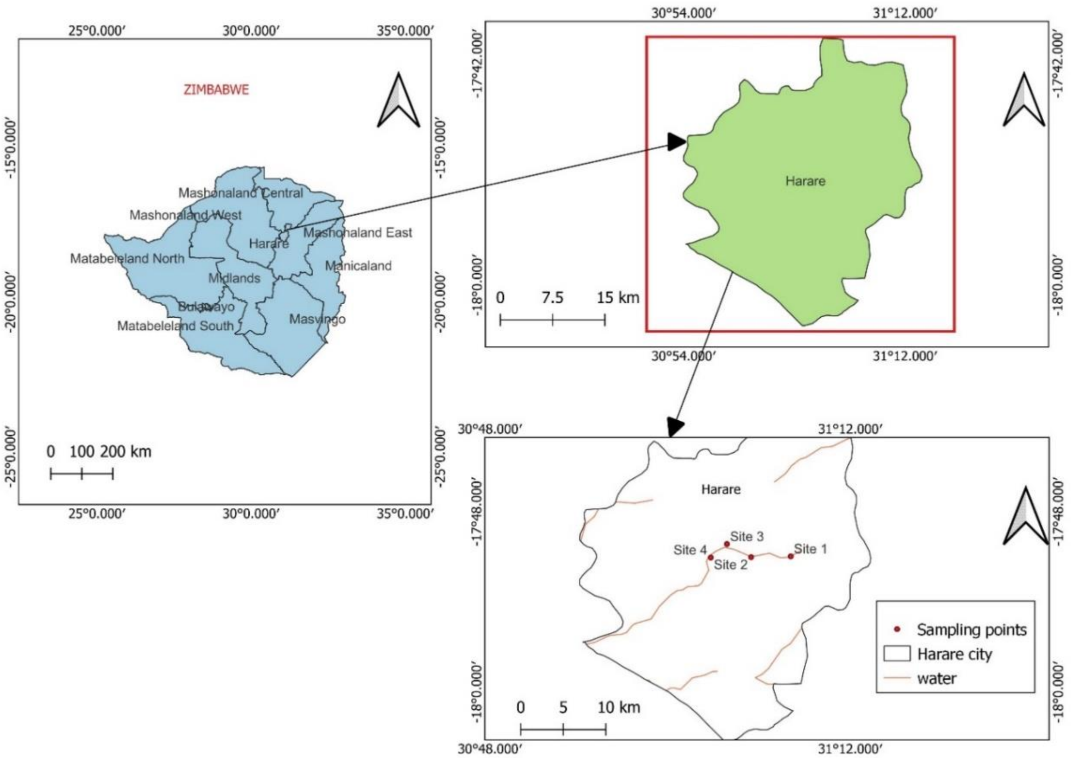

Figure 2: The sampling sites (Harare, Zimbabwe)

Collection of samples

During the summer and rainy seasons, the samples were gathered using polythene bottles that had previously been soaked in 10% nitric acid and washed with deionized distilled water, according to the Standard Association of Zimbabwe. One sample was taken at each sampling point within a 5 km radius. The samples were collected and delivered to ZimLabs for testing. The water quality was determined for the following parameters pH, TDS (Total Dissolved Solids), Nitrates (NO- 3), Phosphates (PO- 4), Sulphate(SO4 2), Conductivity, Th (Total Hardness), TA (Total Alkalinity), Chlorides, Potassium, Sodium, As, Hg, Cd, Cr and Pa . The results from the laboratory were compared with standard limits set by various regulatory bodies including the Standard Association of Zimbabwe (SAZS 560:1997) and the World Health Organization (WHO 2011).

Table 1: Locations of different sampling stations

Sampling site	Name of the Sites	Latitude	Longitude
Fertilizer plant	S1	17º 50′ 57.1236″ S	31º 8′ 8.4192″ E
Msasa industrial area	S2	17º 51′ 58.5456″ S	31º 8′ 1.68″ E
Mukuvisi woodlands	S3	17º 51′ 2.698″ S	31º 5′ 23.2008″ E
Hillside residential area	S4	17º 50′ 17.9556″ S	31º 4′ 19.1892″ E

3.4 Parameters analyzed

3.4.1 Heavy metals

Ars (Arsenic), Hg (Mercury), Cd (Cadmium), Cr (Chromium), Pa (Palladium).

3.5 Methods for Parameter Analysis

Standard techniques (SAZS 560:1997) were used to determine the various parameters.

CHAPTER FOUR

RESULTS and DISCUSSIONS

4.1 Results

The impact assessment was conducted to analyze the environmental pollution status of the Mukuvisi River during two major seasons of Zimbabwe, the summer and rainy seasons. The five heavy metals were analyzed; As, Hg, Cd, Cr, and Pd

Table 2: Heavy metal concentrations at several sampling points (S1-S4) for the summer season

Name of the parameters	S1	S2	S3	S4	Mean
	Conc,	Conc,	Conc,	Conc,	Conc
Arsenic	0.05	0.05	0.04	0.02	0.04
Mercury	0.08	0.06	0.06	0.04	0.065
Cadmium	0.06	0.05	0.04	0.03	0.045
Chromium	0.01	0.01	0.01	0.01	0.01
Palladium	0.01	0.01	0.01	0.01	0.01

* Units of concentrations are in mg/l

Table 3: Heavy metal concentrations at several sampling points (S1-S4) for the rainy season

Name of the parameters	S1	S2	S3	S4	Mean
	Conc	Conc,	Conc,	Conc,	Conc,
Arsenic	0.03	0.02	0.02	<0.01	0.04
Mercury	0.04	0.03	0.02	0.02	0.0275
Cadmium	0.04	0.03	0.02	0.02	0.0275
Chromium	<0.01	<0.01	<0.01	<0.01	<0.01
Palladium	<0.01	<0.01	<0.01	<0.01	<0.01

- Units of concentrations are in mg/l

Table 4: Recommended limits according to SAZ and WHO

Parameter	Recommended limits according to (SAZS 560:1997)	Recommended limits according to WHO (2011)
Arsenic	0.005	0.01
Mercury	0.001	0.008
Cadmium	0.010	0.003
Chromium	Not specified	0.05
Palladium	Not specified	0.01

- Units of concentrations are in mg/l

4.1.1 Mercury

Figures 3 (a), (b), and (c) showed the mercury concentration of different sampling stations compared with the WHO standard for the summer season, rainy season, and both seasons, respectively. From figure 2, it was observed that the mercury concentration for both summer and rainy seasons was above the allowable limits recommended by WHO. Mercury concentrations from four sampling sites during the summer period, mercury concentrations were 0.08 mg/l, 0.06 mg/l, 0.06 mg/l, and 0.04 mg/l, respectively, whereas during the rainy season, concentrations were 0.04mg/l, 0.03mg/l, 0.02mg/l, and 0.02 mg/l, respectively.. This might be due to the mining company which manufactures chemicals for mineral extraction (Mining and industrial suppliers, Zimbabwe) located in Msasa industrial area. This industry uses many heavy metals such as mercury to manufacture mineral absorbers. Wastewater containing these chemicals is discharged into the Mukuvisi River after production. Figure 3(c) showed that during the rainy season, the concentration of mercury decreased at each location as compared to the summer season. It might be due to higher dilution due to flow increment in this season. At S1, the concentration was high due to the industries near the river bank. Furthermore, moving from the site 5km downstream of each sampling location, the concentration of mercury was decreased from S1 to S4. This might be due to the bioaccumulation of the mercury by aquatic plants and the phytoremediation process that has happened between sampling sites 2 and 3. Studies show that there is a wetland called Mukuvisi woodlands where some of the heavy metals are assimilated by plants _(Nyika, 2022) (Awa &

Hadibarata, T., 2020), and some of the mercury might be absorbed by the soil, and during the rainy season, the rate of dilution is very high. However, the mean mercury exposure for four sampling sites was higher than the WHO recommended range.

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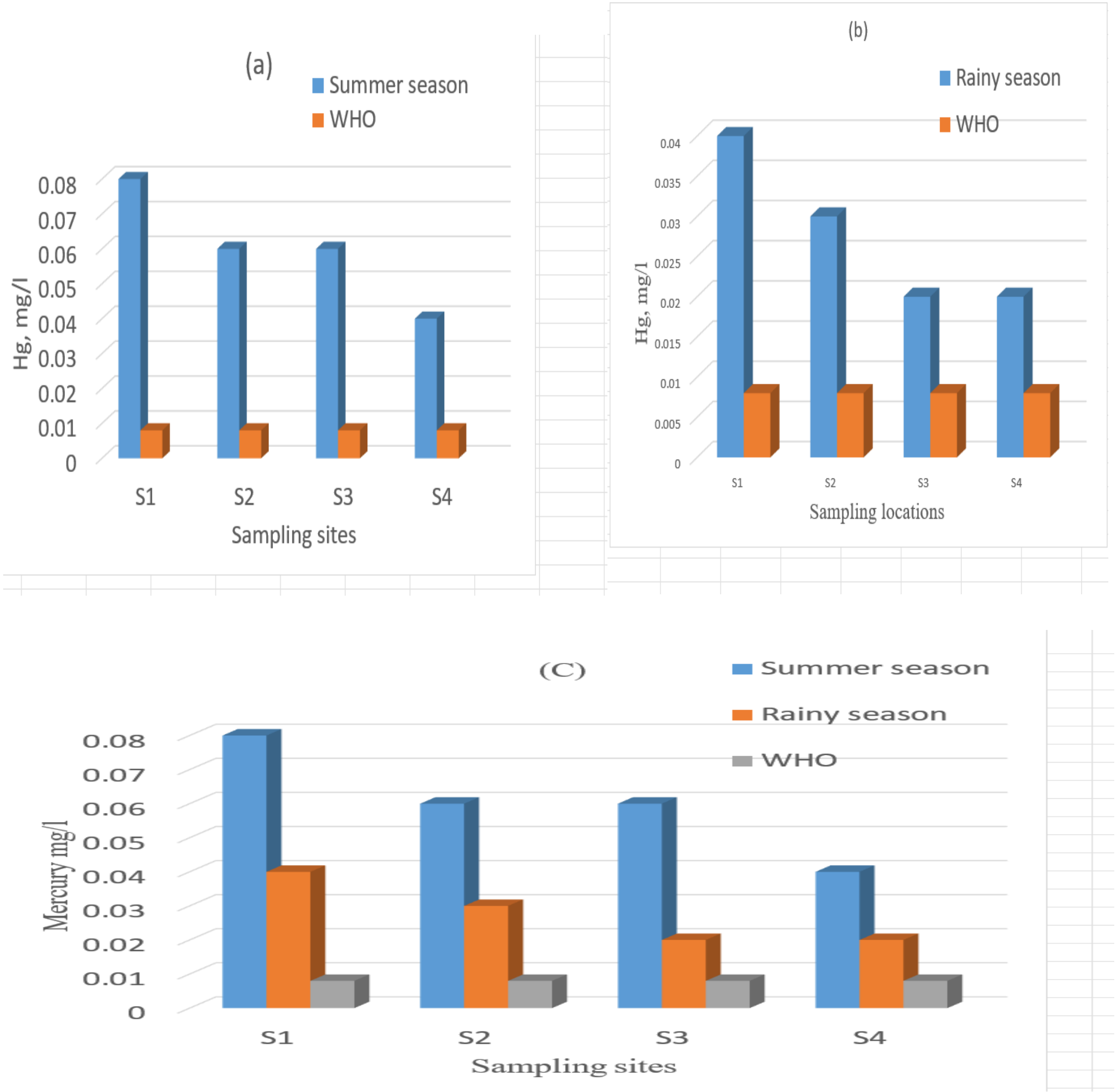


Figure 3: (a-c) Mercury concentrations at different sampling sites for the summer season, rainy season, and both seasons.

4.1.2 Cadmium

Figures 4 (a) and (b) showed that the cadmium concentration for both the summer and rainy seasons was above the allowable limits recommended by WHO Cadmium concentrations for S1-S4 sites were 0.06, 0.05, 0.04, and 0.03 mg/l, respectively, during the summer season, while Cd concentrations for the four sample sites were 0.04, 0.03, 0.02, and 0.02 mg/l, respectively, during the rainy season. These levels exceeded the WHO-recommended limit of 0.003 mg/l. This could be due to wastewater discharge from the Msasa industrial area, as well as the presence of Exide Express, a battery manufacturing company that produces Nickel-Cadmium batteries with nickel oxide hydroxide and metallic cadmium as electrodes. Because Ni-Cd battery waste contains a high percentage of Cd, it should be treated and recycled differently than waste from other types of batteries. (Huang, K., Li, J, & Xu, Z., 2010). Moreover, companies along the Msasa industrial area use Cadmium to electroplate steel, copper, and iron, and the waste is not properly treated as some of the machines were acquired during the colonial period by the Rhodesian government and are not able to perform their functions for the longer handling period. This results in many side reactions and a lot of by-products which are disposed of as effluent directly into the Mukuvisi River. Figure 4(c) showed that during the rainy season, the concentration of Cadmium decreased in each sampling location as compared to the summer season. At sampling site 1, the concentration was high because it is closer to the industry, but moving from this site downstream to other sampling locations the concentration of Cadmium decreased due to bioaccumulation. Cadmium can accumulate in aquatic biota especially fish due to its persistence and ubiquitous nature. Generally, fish can gather toxic substances from the polluted water through ingestion of suspended substances from water, adsorption through tissue or skin, ingestion of food material, and lipophilic tissues like gills. Cadmium is poisonous to aquatic organisms as well as human beings. Hence, Cadmium uptake for a long time, causes sever disease to human beings including fatality.

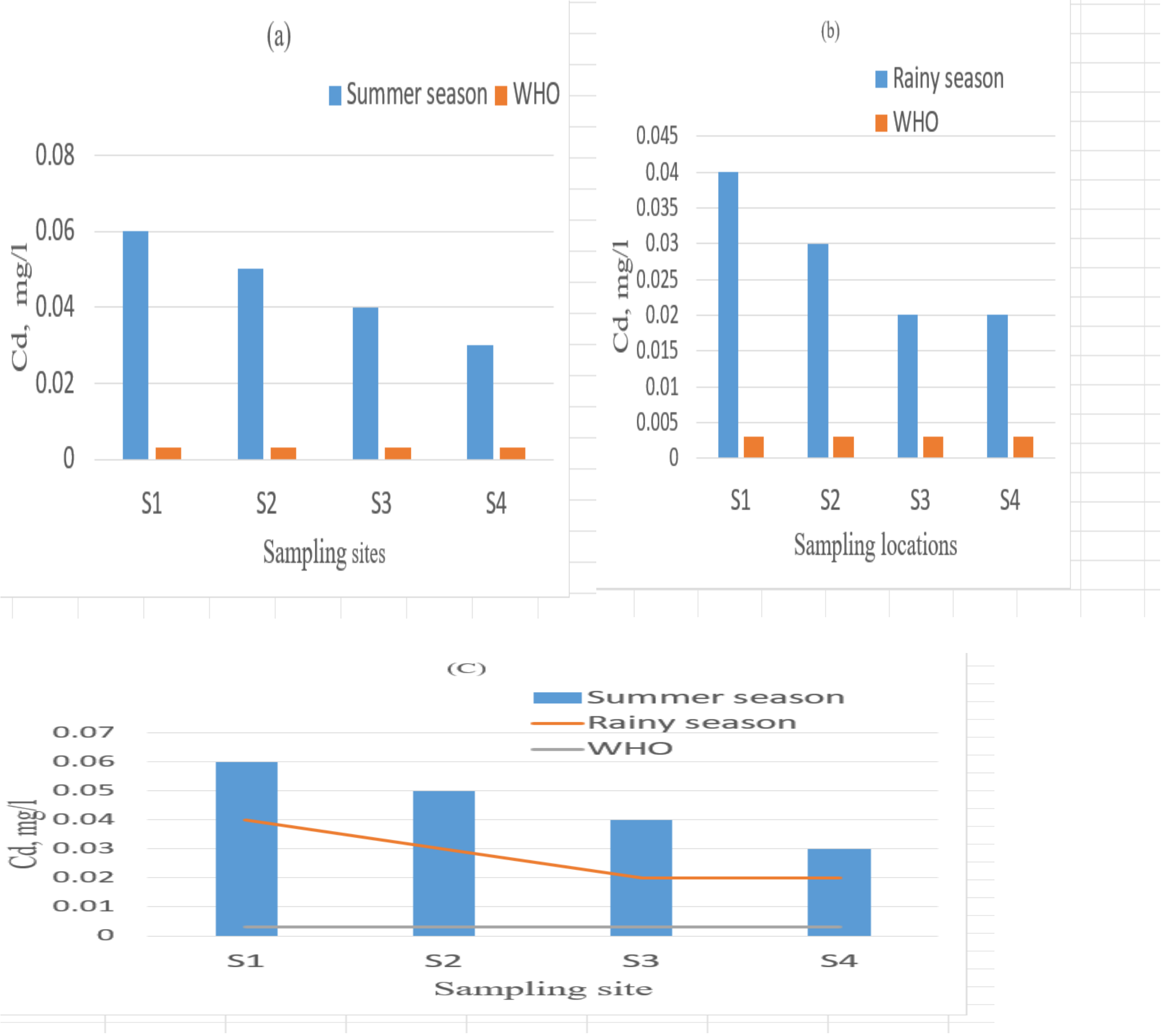


Figure 4: (a-c) Cadmium concentrations of different stations for Summer, rainy, and both seasons

4.1.3 Arsenic

During the summer season, arsenic concentrations were 0.05 mg/l, 0.05 mg/l, 0.04 mg/l, and 0.02 mg/l, respectively, while during the rainy season, they were 0.03mg/l, 0.02mg/l, 0.02mg/l, and 0.01 mg/l (site 4). The reason could be the locals' farming practices and the spraying of pesticides from farmlands near the industrial area.

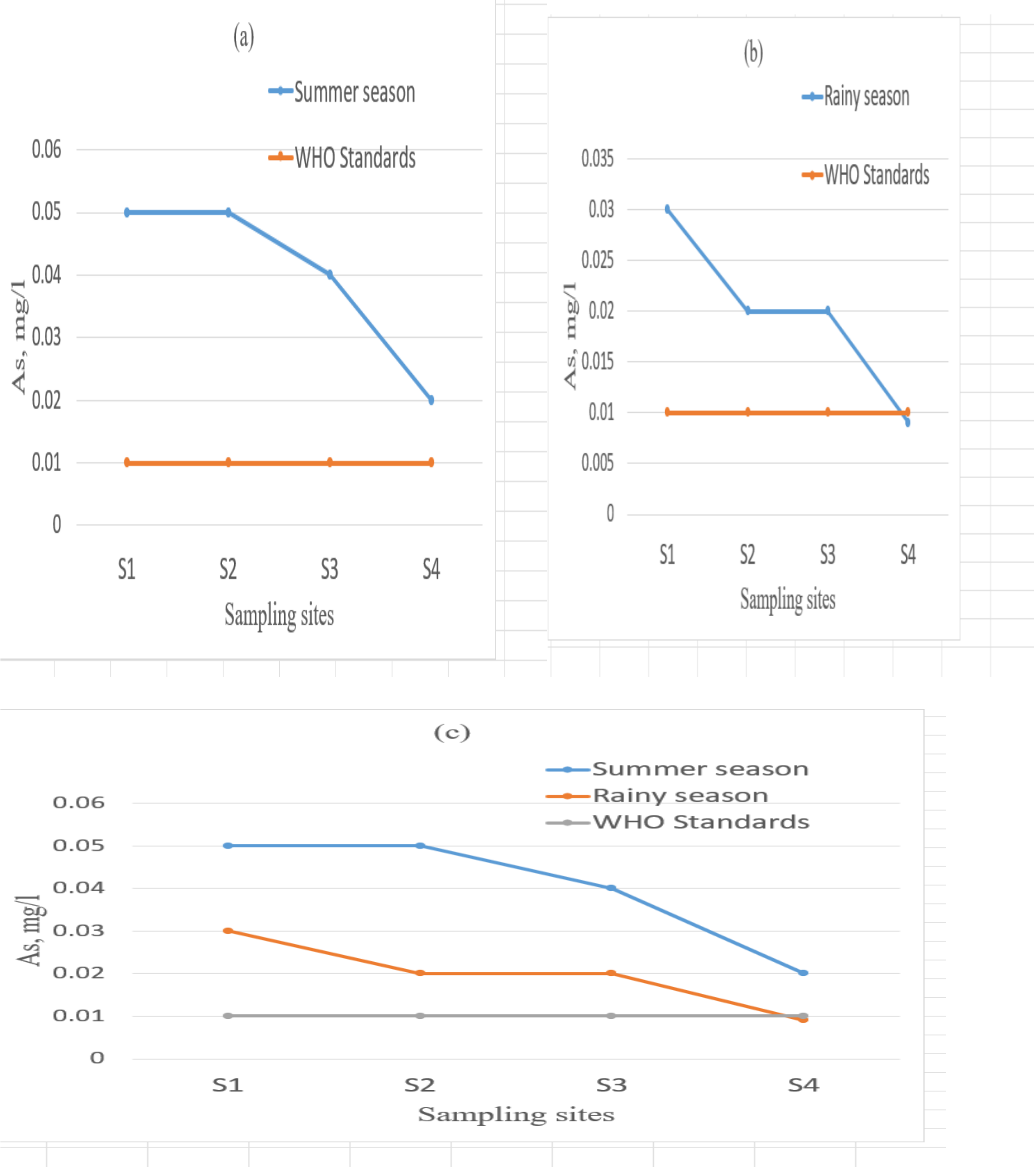
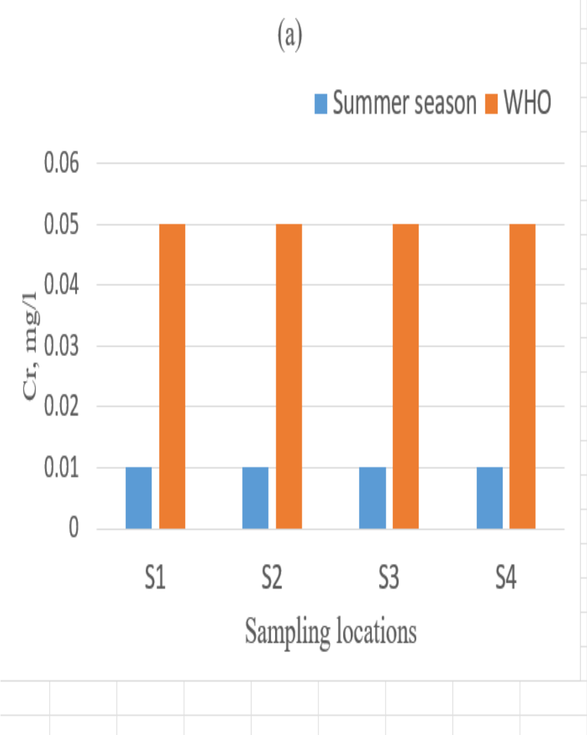
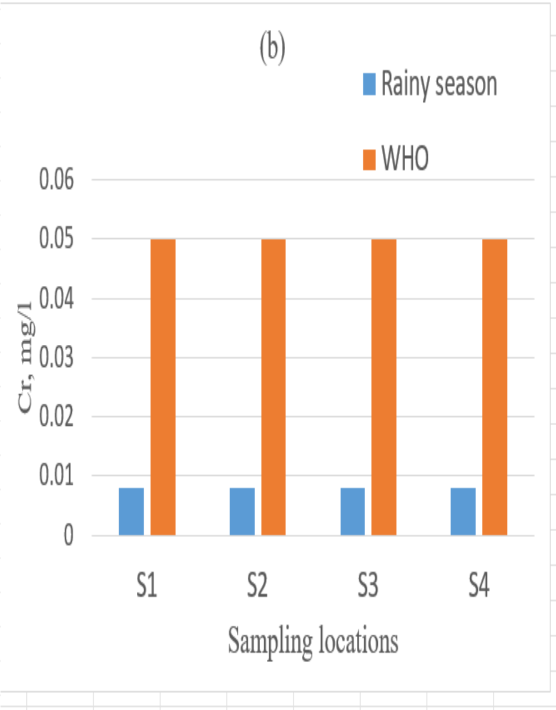


Figure 5: Graphical representation of heavy metal Arsenic exceeding WHO Standards.

4.1.4 Chromium

Figures 6 (a) and (b) showed that the chromium concentration for both the summer and rainy seasons was lower than the permissible limits recommended by WHO. Chromium concentrations for the four sites were 0,01mg/l during the summer season which is lower than 0.05 mg/l, the permissible limit prescribed by WHO. For the rainy season, the concentrations obtained from the sample of all the sites were less than 0.01 mg/l, which was below the WHO standard. Although the concentrations were within the standards, small amounts were recorded and this might be because wastewater discharged from the Msasa industrial area into the river. A rubber manufacturing company, known as Universal Rubber and Hose Msasa, specializes in leather tanning and there are a lot of smelting and metal welding operations that take place car garages in nearby. Therefore, 10% of the chromium compounds used for leather tanning are discharged without being treated into surface waters. In contrast, Figure 3c demonstrated that concentrations were lower during the rainy season than during the summer season.





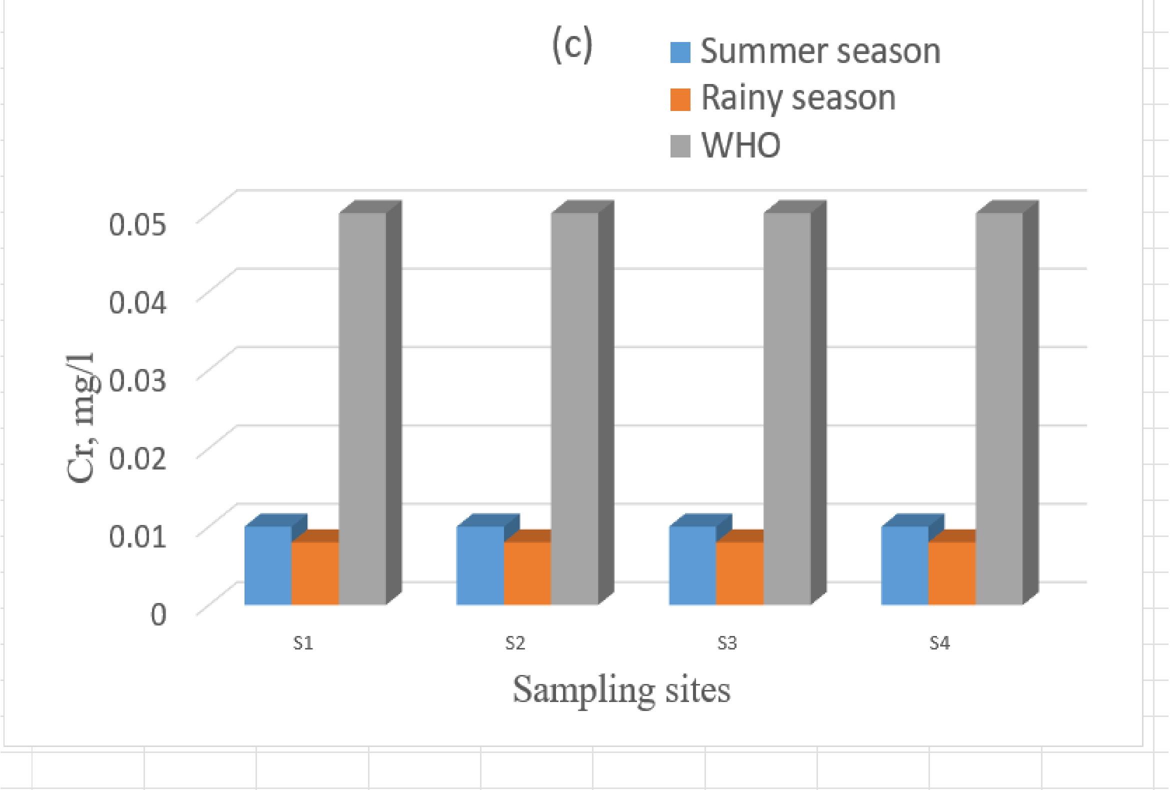


Figure 6: (a-c) Chromium concentrations at different locations for summer, rainy, and both seasons.

4.1.5 Palladium

Table 2 showed that Palladium concentrations for four sampling sites during the summer dry season were within the allowable limits (0.01 mg/l) prescribed by the WHO. For the rainy season, the concentrations obtained were below 0.01 mg/l.

4.2 Discussion

Mercury is a dangerous element that can enter the body via the air or via the skin. Chronic exposure has the potential to alter the genetic and enzyme systems. It can also affect the nervous system and weaken the immune system. Mercury poisoning also harms growing embryos. In water bodies, mercury can produce organic mercury compounds such as methyl mercury, which are significantly more poisonous than the elemental form of mercury. Mercury concentrations ranged from 0.08 mg/l to 0.06 mg/l, 0.06 mg/l, and 0.04 mg/l for sampling locations 1, 2, 3, and 4, respectively, and during the rainy season, concentrations were 0.04mg/l, 0.03mg/l, 0.02mg/l, and 0.02mg/l, all of which were higher than the WHO recommended permissible limit (0.008mg/l). The reason might be because at Msasa industrial area there is a mining company that manufactures chemicals for mineral extraction called (Mining and industrial suppliers Zimbabwe). It uses many heavy metals such as Mercury to manufacture mineral absorbers, so some of these chemicals are discharged into Mukuvisi River as effluent after chemicals are manufactured. It can be noted from the results that during the rainy season the concentration of mercury decreased from each sampling location as compared in the summer dry season. At sampling site 1 the concentration is high because it is close to the industry, but as we move from the site 5km downstream the concentration of Mercury is decreasing from site 1 to 4 due to bio accumulation of the mercury by aquatic plants.

Cadmium is a hazardous metal that is harmful to aquatic life and human health. Extreme Cd consumption can result in lung and prostate cancer and during the summer season, the concentrations of were 0.06, 0.05, 0.04, and 0.03 mg/l, respectively, while during the rainy season, the concentrations of Cd were 0.04, 0.03, 0.02, and 0.02 mg/l, which is higher than the WHO recommended permissible limit (0.003 mg/l). The reason could be that there is a mining firm named Exide Express in Msasa industrial area that manufactures Batteries composed of nickel-cadmium are rechargeable batteries that use nickel oxide hydroxide and metallic cadmium as electrodes. Because of their high Cd content, waste Ni-Cd batteries are designated as hazardous waste and should be recycled before other types of batteries. The results show that the concentration of Cadmium levels decreased at each test site during the wet season compared to the summer dry season. At sampling site 1 the concentration is high because it is close to the industry, but as we move from the site 5km downstream to each sampling location the concentration of Cadmium decreased from site 1 to 4 due to, phytovolatilization process because between sampling site 2 and 3 there is a wetland called Mukuvisi woodlands where some of the heavy metals are absorbed by the plants like Eichhornia (water hyacinth) and Phragmites (Reed) (Ali, Hazrat; Khan, Ezzat; Sajad, Muhammad Anwar et al 2013). The removal of chemicals from soil or water and their release into the air, which occurs regularly as a result of phyto-transformation to more volatile and/or less polluting molecules, is referred to as phytovolatilization. The pollutants are taken up by the plant during this process and evaporate into the atmosphere via transpiration. Volatilization takes place in the plant's stem and leaves, but indirect phytovolatilization takes place when pollutants are discharged from the root zone. (Limmer, Matt; Burken, Joel et al 2016). Cadmium (Cd) is frequently removed from soil and water via phytovolatilization (Pilon-Smits, Elizabeth et al. 2005

Drinking arsenic-rich water over an extended length of time causes As poisoning, also known as Arsenicism can develop over a period of 5 to 20 years of exposure. Numerous studies have demonstrated that drinking As-rich water over an extended period of time has major health consequences. It causes noncancerous cutaneous consequences such as hyper- and hypopigmentation and keratosis, as well as an increased risk of diabetes, hypertension, and cardiovascular disease and for sampling locations 1, 2, 3, and 4 the concentrations of Arsenic varied. During the summer season, arsenic concentrations were 0.05 mg/l, 0.05 mg/l, 0.04 mg/l, and 0.02 mg/l, respectively, while during the rainy season, they were 0.03mg/l, 0.02mg/l, 0.02mg/l, and 0.01 mg/l (site 4). The reason might be the farming practiced adopted by the local people and the application of pesticides from farmlands near the industrial area.

In nature, chromium appears in two forms: Cr+3 and Cr+6. It might have natural or anthropogenic origins and has great environmental mobility. Human activities such as nonferrous smelters, refineries, tanneries, urban storm water discharges, pulp and paper mill effluents, and thermal power station discharges account for more than 70% of total Cr in the environment. The toxicity of Cr in humans varies depending on the compound's form, oxidation state, and route of exposure.. Based on the results, the present study shows Chromium concentrations for the four sites were

0,01mg/l during the summer season which is lower than 0.05 mg/l, the permissible limit prescribed by WHO. For the rainy season, the concentrations obtained from the sample of all the sites were less than 0.01 mg/l, which was below the WHO standard. Although the concentrations were within the standards, small amounts were recorded and this might be because wastewater discharged from the Msasa industrial area into the river. A rubber manufacturing company, known as Universal Rubber and Hose Msasa, specializes in leather tanning and there are a lot of smelting and metal welding operations that take place car garages in nearby. Therefore, 10% of the chromium compounds used for leather tanning are discharged without being treated into surface waters. During the wet season, concentrations were lower than during the summer season.. Wastes from the leather tanning industry is not properly treated as some of the machines where acquired during the colonial period by the Rhodesian government and they are too old to perform their functions which results in many side reactions and a lot of by-products which are disposed as effluent directly into the river

4.2.1 Phytoremediation processes

Phytostabilization

Phytostabilization is a technique used in environmental remediation to manage and stabilize contaminated soil or sediments. It uses plants to immobilize, reduce the mobility, and mitigate some potential risks associated with hazardous substances, particularly heavy metals and metalloids. (Lone, Mohammad Iqbal; He, Zhen-li; Stoffella, Peter J.; Yang, Xiao-e et al 2008). In phytostabilization, certain plant species are selected for their ability to tolerate and accumulate high concentrations of contaminants without being significantly affected by their presence. These plants are often referred to as "hyperaccumulators" or "metallophytes." They can uptake contaminants from the soil through their roots and store them in their tissues, primarily in the roots and shoots.The uptake of contaminants by the plants helps to reduce their bioavailability in the soil, limiting their movement and preventing their entry into the food chain. By immobilizing the contaminants, phytostabilization reduces the risk of human exposure and the potential for the pollutants to leach into groundwater or be transported by erosion (Hazrat Ali, Ezzat Khan, Sajad, Muhammad Anwar et al. 2013).

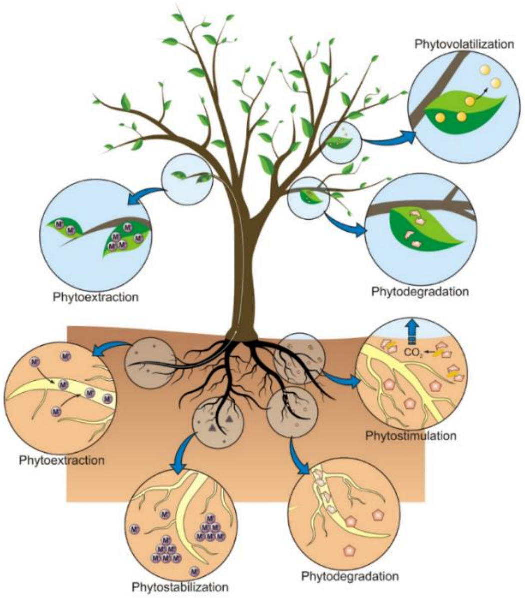


Figure 7: Phytoremediation processes

Phytodegradation

Is a process in which plants, with the help of associated microorganisms, can directly degrade or break down organic pollutants present in soil, water, or air unlike phytovolatilization and phyto-stimulation, which involve the transformation or removal of contaminants, phytodegradation focuses on the actual degradation and mineralization of pollutants by plants and their associated microbial communities. During phytodegradation, plants produce enzymes and release various chemical compounds into the rhizosphere. These enzymes and compounds can directly or indirectly facilitate the breakdown of organic pollutants. The roots of the plants play a crucial role in this process, as they provide physical contact and transport pathways for pollutants to interact with the plant and associated microorganisms (Pilon-Smits, Elizabeth et al 2005). The microorganisms associated with the plant roots, including bacteria, fungi, and other soil microbes, are responsible for the actual degradation of the organic pollutants. These microorganisms possess enzymes can reduce macro molecules into simpler forms that can be used by the microbial community or incorporated into the plant's own metabolic processes (Kvesitadze, G.; et al. 2006).

Phyto-stimulation

It is an important process done by plants because it allows the release of different compounds such as sugars and organic acids into the rhizosphere. These substances serve as a food source and energy supply for soil microorganisms. The increased availability of nutrients stimulates the growth and activity of beneficial bacteria and fungi in the rhizosphere. All biodegradable organic pollutants present in the soil are broken down by the enhanced microbial activity. The microorganisms present in the rhizosphere can metabolize and transform these contaminants into less harmful substances through their enzymatic activities (Dzantor, E. Kudjo, et al. 2007).

Phytovolatilization

During phytovolatilization, the contaminants are assimilated by the plant and transported to various parts including the stem and leaves. Through a combination of metabolic processes and transpiration, the contaminants are converted into a volatile form and released into the air.

Phytovolatilization has been studied and applied as a remediation technique for removing specific contaminants such as selenium (Se) and mercury (Hg) from contaminated soil and water. Certain plants, known as hyperaccumulators, have the ability to accumulate high levels of these contaminants, and their use in phytovolatilization can help reduce the overall concentration of these pollutants in the environment. (Pilon-Smits, Elizabeth et al. 2005).

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.0 Conclusions

The seasonal variation in heavy metals in the Mukuvisi River was assessed during the summer and wet seasons. The mean level range of Arsenic, Mercury, Cadmium, Chromium, and Palladium was found to be (0.04, 0.065, 0.045, 0.01, and 0.01) mg/l for the summer season, whereas for the rainy season, the concentrations were (0.04, 0.028, 0.009, and below 0.01) mg/l for each sampling site. Summer had high heavy metal densities, while the rainy season had low heavy metal concentrations. The concentrations varied from high to low from each sampling site for both seasons. The highest values were recorded at the first sampling site (ZimPhos) fertilizer plant for both the summer and the rainy seasons because most of the industries are situated nearby the river and discharge effluents with contaminants into the river. These industries include ZimPhos, Exide Express, Universal Rubber Msasa, and Mining industrial suppliers in Zimbabwe. Small industries use heavy metals as part of their manufacturing processes and dispose of their effluents without proper treatment. Meanwhile, the minimum values were recorded at the last sampling (Hillside residential area) site because between sampling site 2 (Msasa industrial area) and sampling site 3 (Mukuvisi woodlands) there is a wetland called Mukuvisi woodlands where some of the heavy metals are assimilated by the plants (Awa and Hadibarata, T. 2020) through Phyto-transformation. Mercury (Hg), and Cadmium (Cd) are often removed from water through phytovolatilization (Nyika, 2022). This specifies that the river has an assimilation capacity as heavy metal presence in water reduces after it has passed through sampling site 2 (Msasa industrial area) and sampling site 3 (Mukuvisi woodlands). Nevertheless, site 4 is still under threat due to the dumping of solid wastes by the residents. With the surface runoff in the rainy season, garbage's mixes with water, and toxins from plastics and other materials mix with river water. The findings of this study will assist the Zimbabwe National Water Authority (ZINWA) in enforcing severe environmental laws on all enterprises. Implementing proper guidelines will help in preventing water pollution from polluting sources thus safeguarding in attaining one of the African Unions Agenda for 2063 *"A sustainable, prosperous, equitable and climate-resilient Africa"* as well as carry out the United

Nations Sustainable Development Goal 6 (clean water and sanitation) for 2030 by "*incorporating climate change measures into national policies, strategies, and planning.*"

5.1 Recommendations

1. There is a need to use remote sensing and GIS techniques in water quality monitoring to reduce monitoring expenses. This will also provide information on the spatial changes of the important water parameters, removing the need for statistical assumptions based on sampling. Knowing different polluting sectors can also help water treatment organizations understand spatial variations in water quality metrics. Water quality parameter computing software decrease processing errors.
2. Computer programming remote sensing techniques can be used to compute parameters and compare them to those obtained manually.
3. Heavy metals, insecticides, pesticides, disinfectants, and other chemicals should ideally be managed at the source because producers are the most familiar with their compositions and, as a result, should be able to devise efficient control or prevention methods for their discharges into water. The polluter must pay for the pollution, according to current Harare Municipality legislation (polluter-payer principle).
4. Implement heavy metal removal technologies for each polluting sector, such as oxidation, coagulation-precipitation, absorption, ion exchange, and membrane techniques, which are efficient and low-cost means of removing heavy metals from industrial effluent before it enters the river.
5. Education and community involvement are critical to the success of interventions. The risks of using Mukuvisi river water for irrigation, washing, and other domestic purposes must be communicated to community members.

APPENDIX

APPENDIX I: TEST CERTIFICATES

A: ZIMLABS QUOTATION

zimlabs

GNK LABORATORIES - T/A ZIMLABS
123 Borgward Road
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Harare
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Cell +263-773750668,787176915
accounts@zimlabs.co.zw
info@zimlabs.co.zw
www.zimlabs.co.zw

Date	1
Page	Q4539
Quotation No	10045362
V.A.T Number	200046629
B.P. Number	

Account BA6186
Barnete Leeroy

Deliver to
BARNETE LEEROY

Your Reference CHEM & MICRO ANALYSIS

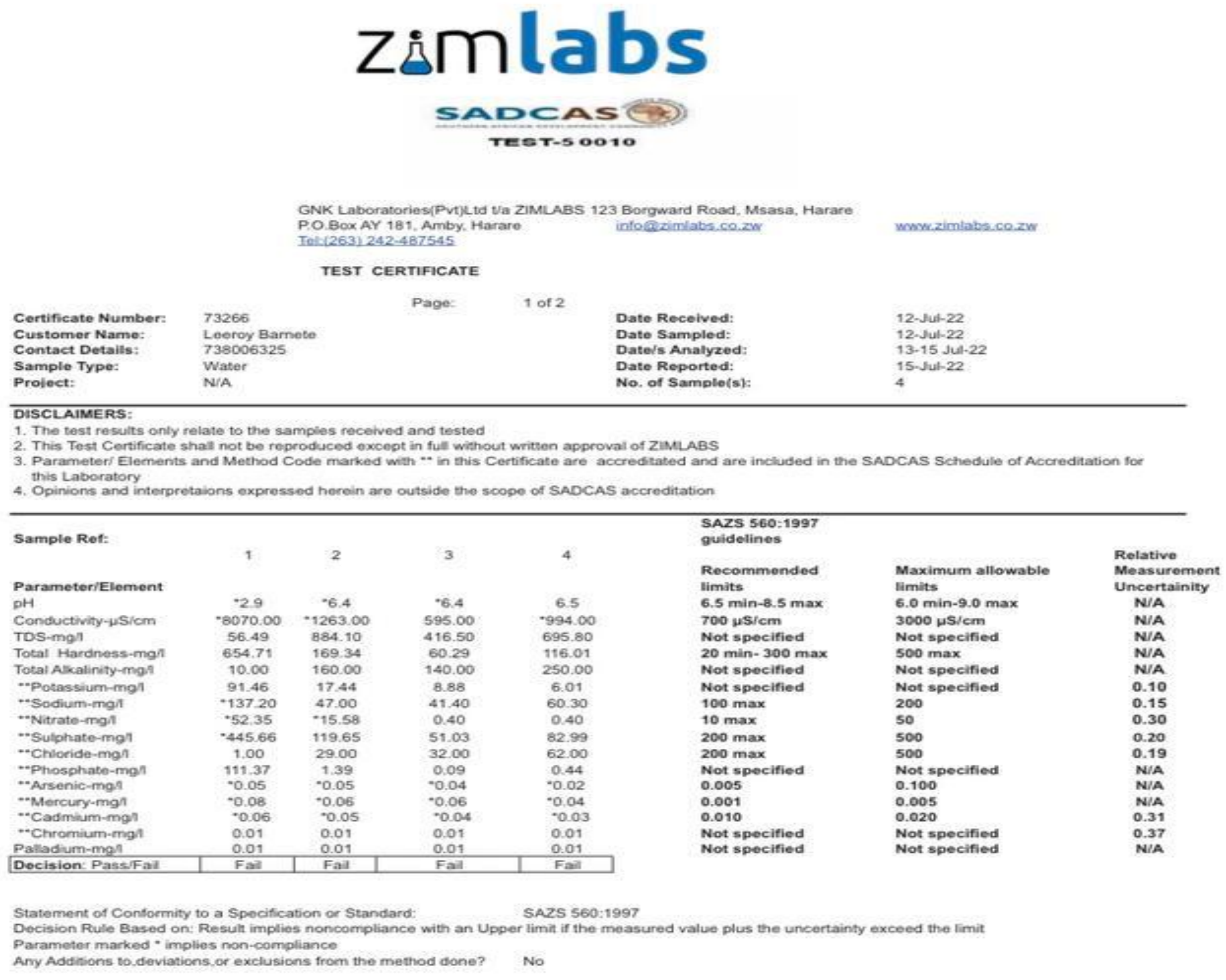
Code	Description	Quantity	Unit	Unit Price	Disc%	Tax	Nett Price
1000110	1 x Waste water analysis (Chem)@ $73					US9.24	US73.00
1000120	1 x Waste water analysis (micro) @ $30					US3.80	US30.00

GNK LABORATORY (PVT) LTD
123 [illegible]
[illegible]
[illegible]
Cell 0772[illegible] 0712 865 146

Banking Details
GNK LABORATORIES T/A ZIMLAB
STANBIC BANK
MSASA BRANCH
ACCOUNT NUMBER: 9140000463913
SWIFT CODE: SBICZWHX
Received in good order
Signed______________ Date______________

Sub Total		US89.96
Discount @	0.00%	US0.00
Amount Excl Tax		US89.96
Tax Total @ 14.5 %		US13.04
Invoice Total		US103.00

B. PHYSIOCHEMICAL PARAMETERS FOR SUMMER SEASON



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SADCAS

TEST-5 0010

GNK Laboratories(Pvt)Ltd t/a ZIMLABS 123 Borgward Road, Msasa, Harare
P.O.Box AY 181, Amby, Harare info@zimlabs.co.zw www.zimlabs.co.zw
Tel:(263) 242-487545

TEST CERTIFICATE

Page: 1 of 2

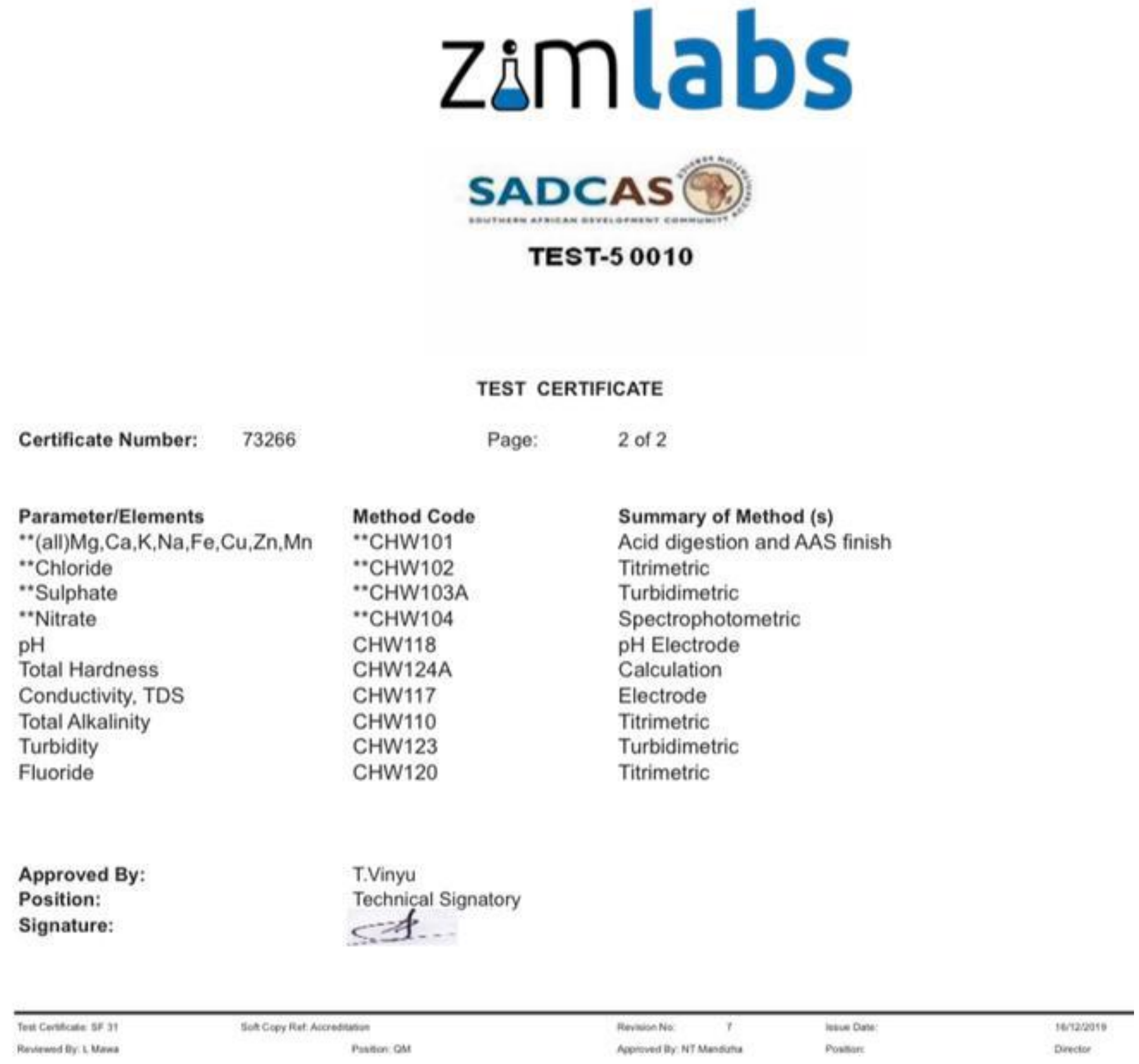
Certificate Number:	73266	**Date Received:**	12-Jul-22
Customer Name:	Leeroy Barnete	**Date Sampled:**	12-Jul-22
Contact Details:	738006325	**Date/s Analyzed:**	13-15 Jul-22
Sample Type:	Water	**Date Reported:**	15-Jul-22
Project:	N/A	**No. of Sample(s):**	4

DISCLAIMERS:

1. The test results only relate to the samples received and tested
2. This Test Certificate shall not be reproduced except in full without written approval of ZIMLABS
3. Parameter/ Elements and Method Code marked with ** in this Certificate are accreditated and are included in the SADCAS Schedule of Accreditation for this Laboratory
4. Opinions and interpretaions expressed herein are outside the scope of SADCAS accreditation

Sample Ref:					**SAZS 560:1997 guidelines**		
Parameter/Element	1	2	3	4	**Recommended limits**	**Maximum allowable limits**	**Relative Measurement Uncertainity**
pH	*2.9	*6.4	*6.4	6.5	**6.5 min-8.5 max**	**6.0 min-9.0 max**	**N/A**
Conductivity-µS/cm	*8070.00	*1263.00	595.00	*994.00	**700 µS/cm**	**3000 µS/cm**	**N/A**
TDS-mg/l	56.49	884.10	416.50	695.80	**Not specified**	**Not specified**	**N/A**
Total Hardness-mg/l	654.71	169.34	60.29	116.01	**20 min- 300 max**	**500 max**	**N/A**
Total Alkalinity-mg/l	10.00	160.00	140.00	250.00	**Not specified**	**Not specified**	**N/A**
**Potassium-mg/l	91.46	17.44	8.88	6.01	**Not specified**	**Not specified**	**0.10**
**Sodium-mg/l	*137.20	47.00	41.40	60.30	**100 max**	**200**	**0.15**
**Nitrate-mg/l	*52.35	*15.58	0.40	0.40	**10 max**	**50**	**0.30**
**Sulphate-mg/l	*445.66	119.65	51.03	82.99	**200 max**	**500**	**0.20**
**Chloride-mg/l	1.00	29.00	32.00	62.00	**200 max**	**500**	**0.19**
**Phosphate-mg/l	111.37	1.39	0.09	0.44	**Not specified**	**Not specified**	**N/A**
**Arsenic-mg/l	*0.05	*0.05	*0.04	*0.02	**0.005**	**0.100**	**N/A**
**Mercury-mg/l	*0.08	*0.06	*0.06	*0.04	**0.001**	**0.005**	**N/A**
**Cadmium-mg/l	*0.06	*0.05	*0.04	*0.03	**0.010**	**0.020**	**0.31**
**Chromium-mg/l	0.01	0.01	0.01	0.01	**Not specified**	**Not specified**	**0.37**
Palladium-mg/l	0.01	0.01	0.01	0.01	**Not specified**	**Not specified**	**N/A**
Decision: Pass/Fail	Fail	Fail	Fail	Fail			

Statement of Conformity to a Specification or Standard: SAZS 560:1997
Decision Rule Based on: Result implies noncompliance with an Upper limit if the measured value plus the uncertainty exceed the limit
Parameter marked * implies non-compliance
Any Additions to,deviations,or exclusions from the method done? No



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TEST-5 0010

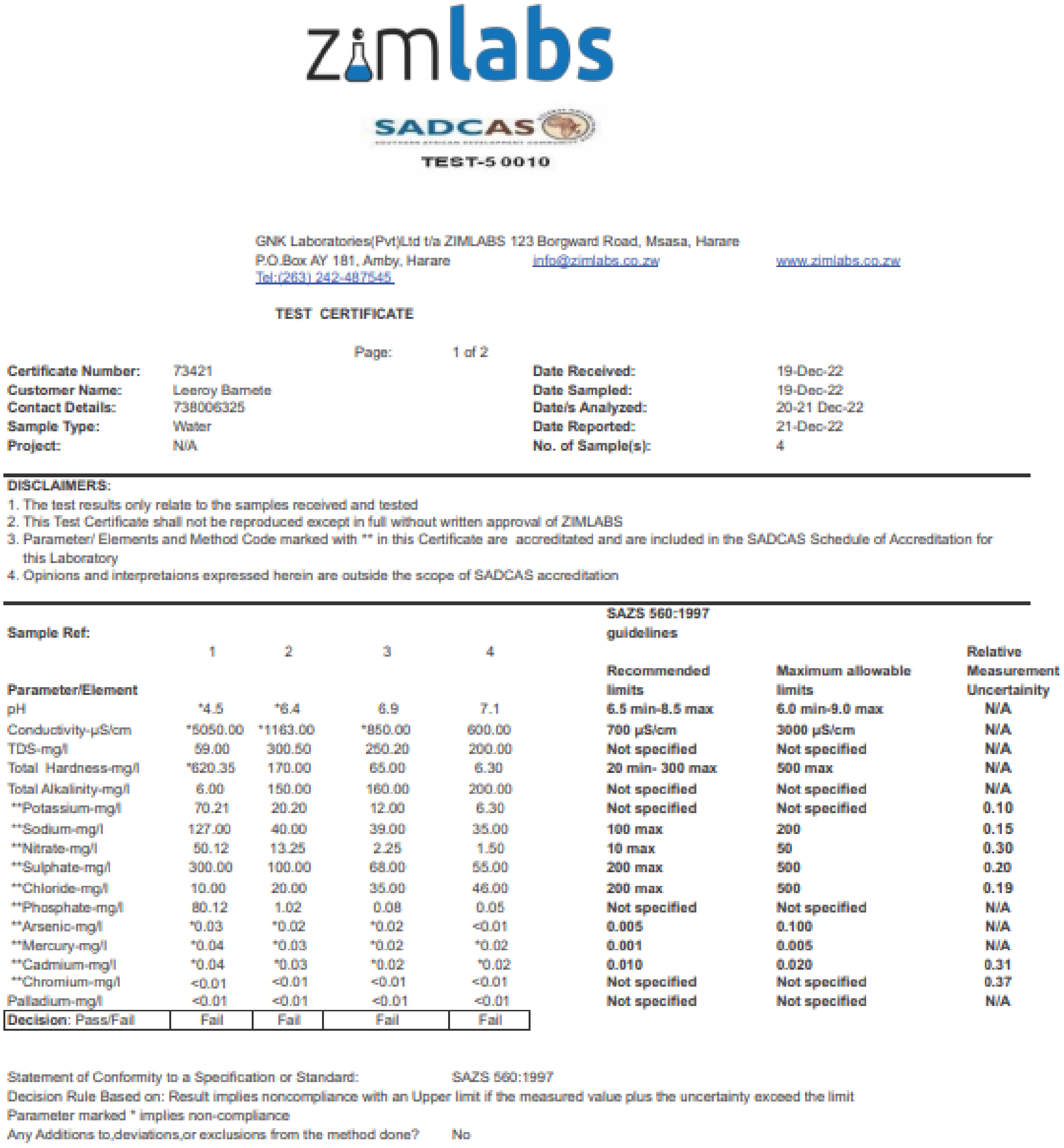
TEST CERTIFICATE

Certificate Number: 73266 Page: 2 of 2

Parameter/Elements	Method Code	Summary of Method (s)
**(all)Mg,Ca,K,Na,Fe,Cu,Zn,Mn	**CHW101	Acid digestion and AAS finish
**Chloride	**CHW102	Titrimetric
**Sulphate	**CHW103A	Turbidimetric
**Nitrate	**CHW104	Spectrophotometric
pH	CHW118	pH Electrode
Total Hardness	CHW124A	Calculation
Conductivity, TDS	CHW117	Electrode
Total Alkalinity	CHW110	Titrimetric
Turbidity	CHW123	Turbidimetric
Fluoride	CHW120	Titrimetric

Approved By: T.Vinyu
Position: Technical Signatory
Signature:

C. PHYSIOCHEMICAL PARAMETERS FOR THE RAINY SEASON.



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P.O.Box AY 181, Amby, Harare info@zimlabs.co.zw www.zimlabs.co.zw
Tel:(263) 242-487545

TEST CERTIFICATE

Page: 1 of 2

Certificate Number: 73421
Customer Name: Leeroy Bamete
Contact Details: 738006325
Sample Type: Water
Project: N/A
Date Received: 19-Dec-22
Date Sampled: 19-Dec-22
Date/s Analyzed: 20-21 Dec-22
Date Reported: 21-Dec-22
No. of Sample(s): 4

DISCLAIMERS:

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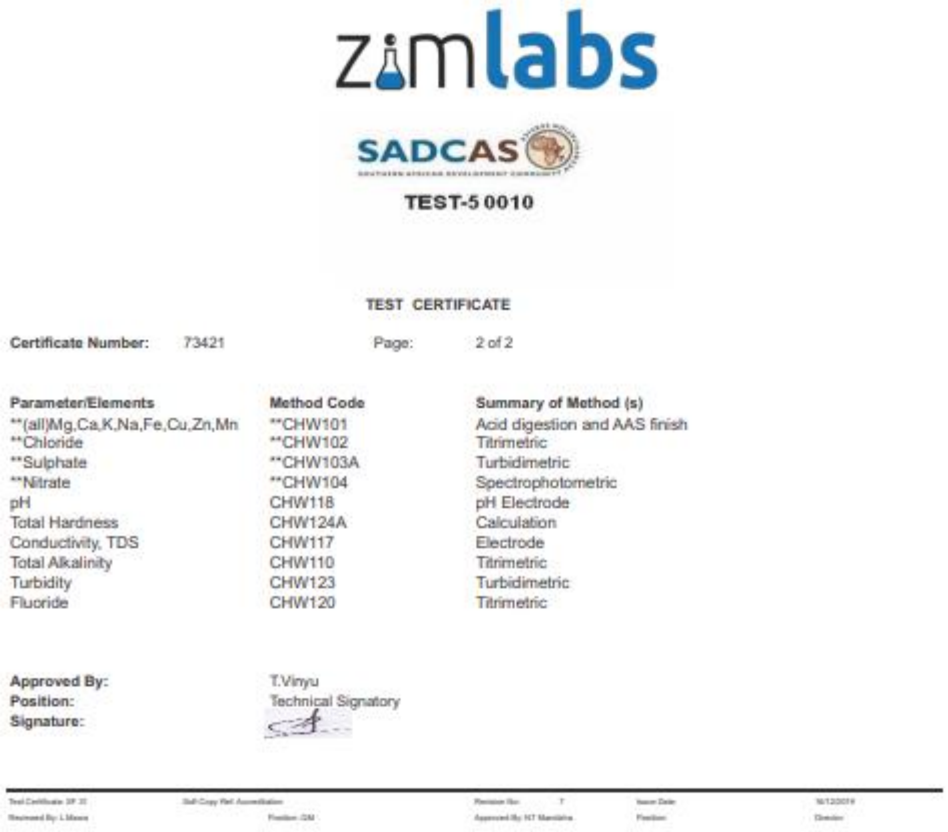
2. This Test Certificate shall not be reproduced except in full without written approval of ZIMLABS
3. Parameter/ Elements and Method Code marked with ** in this Certificate are accreditated and are included in the SADCAS Schedule of Accreditation for this Laboratory
4. Opinions and interpretaions expressed herein are outside the scope of SADCAS accreditation

Sample Ref:					**SAZS 560:1997 guidelines**		
Parameter/Element	1	2	3	4	**Recommended limits**	**Maximum allowable limits**	**Relative Measurement Uncertainity**
pH	*4.5	*6.4	6.9	7.1	**6.5 min-8.5 max**	**6.0 min-9.0 max**	**N/A**
Conductivity-µS/cm	*5050.00	*1163.00	*850.00	600.00	**700 µS/cm**	**3000 µS/cm**	**N/A**
TDS-mg/l	59.00	300.50	250.20	200.00	**Not specified**	**Not specified**	**N/A**
Total Hardness-mg/l	*620.35	170.00	65.00	6.30	**20 min- 300 max**	**500 max**	**N/A**
Total Alkalinity-mg/l	6.00	150.00	160.00	200.00	**Not specified**	**Not specified**	**N/A**
**Potassium-mg/l	70.21	20.20	12.00	6.30	**Not specified**	**Not specified**	**0.10**
**Sodium-mg/l	127.00	40.00	39.00	35.00	**100 max**	**200**	**0.15**
**Nitrate-mg/l	50.12	13.25	2.25	1.50	**10 max**	**50**	**0.30**
**Sulphate-mg/l	300.00	100.00	68.00	55.00	**200 max**	**500**	**0.20**
**Chloride-mg/l	10.00	20.00	35.00	46.00	**200 max**	**500**	**0.19**
**Phosphate-mg/l	80.12	1.02	0.08	0.05	**Not specified**	**Not specified**	**N/A**
**Arsenic-mg/l	*0.03	*0.02	*0.02	<0.01	**0.005**	**0.100**	**N/A**
**Mercury-mg/l	*0.04	*0.03	*0.02	*0.02	**0.001**	**0.005**	**N/A**
**Cadmium-mg/l	*0.04	*0.03	*0.02	*0.02	**0.010**	**0.020**	**0.31**
**Chromium-mg/l	<0.01	<0.01	<0.01	<0.01	**Not specified**	**Not specified**	**0.37**
Palladium-mg/l	<0.01	<0.01	<0.01	<0.01	**Not specified**	**Not specified**	**N/A**
Decision: Pass/Fail	Fail	Fail	Fail	Fail			

Statement of Conformity to a Specification or Standard: SAZS 560:1997
Decision Rule Based on: Result implies noncompliance with an Upper limit if the measured value plus the uncertainty exceed the limit
Parameter marked * implies non-compliance
Any Additions to,deviations,or exclusions from the method done? No



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TEST CERTIFICATE

Certificate Number: 73421 Page: 2 of 2

Parameter/Elements	**Method Code**	**Summary of Method (s)**
**(all)Mg,Ca,K,Na,Fe,Cu,Zn,Mn	**CHW101	Acid digestion and AAS finish
**Chloride	**CHW102	Titrimetric
**Sulphate	**CHW103A	Turbidimetric
**Nitrate	**CHW104	Spectrophotometric
pH	CHW118	pH Electrode
Total Hardness	CHW124A	Calculation
Conductivity, TDS	CHW117	Electrode
Total Alkalinity	CHW110	Titrimetric
Turbidity	CHW123	Turbidimetric
Fluoride	CHW120	Titrimetric

Approved By: T.Vinyu
Position: Technical Signatory
Signature:

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