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A PROJECT IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE BSc IN AGRICULTURAL ENGINEERING

ANALYSIS OF NON-POINT SOURCES OF WATER POLLUTION. CASE STUDY OF SIYALIMA DAM

By:

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DECLARATION

I **Tafadzwa Stephen Mwenje B190004A,** declare that this research project report is the work of my own. It is submitted for the degree in Bachelors Honors in Agricultural Engineering at Bindura University of Science Education. The report have never been submitted in any degree programme and publication, except where other persons' work or observations where clearly acknowledged by referencing.

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DEDICATION

This work is dedicated to my family, all my mentors, and supporters which include friends, associates, colleagues and junior & senior engineers for their mentorship, support, and encouragement.

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ABSTRACT

Siyalima Dam, a vital water resource supporting irrigation, drinking water, and recreation for surrounding communities, faces threats from non-point sources of pollution. This study aimed to identify and quantify these sources, assess water quality, and determine the impacts of pollution on the environment and human health. A mixed-methods approach combined interviews, questionnaires, observations, water tests, composite soil sampling from tributary streams, and geospatial analysis using Google Earth Engine. Soil samples revealed elevated levels of heavy metals and nutrients, indicating potential pollution sources from agricultural runoff and artisanal mining. Water quality analysis showed elevated levels of nutrients, heavy metals, and bacteria, posing risks to human health and the environment. A land-use model and hydro-shed area mapping were developed to guide sustainable management and mitigation strategies. This research will inform policymakers, environmental managers, and local communities to protect this critical water resource.

Keywords: Effluent, non-point source, pollution, water quality, hydro-shed, Geo-spatial analysis

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LIST OF ACRONYMS AND ABREVIATIONS

Agricultural Research Council of South Africa (ARCSSTE)

Agency for Toxic Substances and Disease Registry (ATSDR)

Ambient Water Quality (AWQ)

Centers for Disease Control and Prevention (CDC)

Digital Elevation Model (DEM)

Deoxyribonucleic acid (DNA)

Environmental Management Agency (EMA)

Environmental Protection Agency (EPA)

Environmental Systems Research Institute (ESRI)

European Earth Observation Programme (COPERNICUS)

European Petroleum Survey Group (EPSG)

Food and Agriculture Organization (FAO)

Geographic Information System (GIS)

Global Positioning System (GPS)

Google Earth Engine (GEE)

Intergovernmental Panel on Climate Change (IPCC)

International Agency for Research on Cancer (IARC)

International Organization for Standardization (ISO)

Natural Resources Conservation Service (NRCS)

Quantum Geographic Information System (QGIS)

Shuttle Radar Topography Mission (SRTM)

United Nations Educational, Scientific and Cultural Organization (UNESCO)

United Nations Environment Programme (UNEP)

United States Environmental Protection Agency (USEPA)

United States Geological Survey (USGS)

Universal Transverse Mercator (UTM)

World Geodetic System 1984 (WGS84)

World Health Organization (WHO)

World Wildlife Fund (WWF)

Zimbabwe National Water Authority (ZINWA)

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Chapter 1

1.1 Introduction

With the ever changing climate and rapid increases in human population across the globe posing a major strain on food resources, there is a new thrust to establish robust sustainable sources in order curb rapid increase in prices of basic commodities and in turn mitigate against hunger and starvation.

On that regard nations have since adopted major interest in the production sector of economics in order to control and maximize the production of these resources. The agricultural sector in particular has seen what can only be regarded as the second agrarian revolution with major capital injection across the board resulting in fully functional agro-industries being established, these mainly focusing on production and value edition and this strategy has since proved effective. With incentives being given to individual farmers for the procurement and utilization of farming resources an example being zero deposit credit lines like command agriculture and presidential input scheme in Zimbabwe and zero duty exemption policies on agricultural technology and inputs.

However the sustainability of this industry is facing an imminent threat as fresh water sources, already finite, are dwindling at an unprecedented rate with major threats coming from ecocidal anthropogenic activities which are going unchecked. Siyalima Dam, a vital water resource supporting irrigation, drinking water, and recreation for surrounding communities, faces threats from non-point sources of pollution. This study aimed to identify and quantify these sources, assess water quality, and determine the impacts of pollution on the environment and human health and to provide tailored solutions on how to mitigate against these effects.

1.2 Background

Zimbabwe's freshwater resources, comprising of a network of rivers, thousands of small dams, lakes, numerous wetlands, surface water and significant amounts of groundwater, are critical for supporting life, economic development and natural ecosystems. To manage these water resources, the country has been divided into seven catchments, Gwayi, Manyame, Mazowe, Mzingwane, Runde, Sanyati and Save. (A.Murwira et.al; 2014) These seven catchments are named after the main river systems most of which drain into international watercourses.

The national surface water generation, i.e. mean annual runoff (MAR) is estimated at 61 mm/year with a coefficient of variation of 122% (ZINWA, 2009.)

This high coefficient of variation indicates the unreliability of runoff from year to year and hence justifies the construction of dams to provide additional water security in times of water scarcity. Although many dams (~14,000) have been constructed on the main rivers for various reasons including supplying water to urban settlements and to irrigate farms, there is still room for additional storage as only 25% of the potential storage has been developed so far (ZINWA, 2009)

Apart from surface water, Zimbabwe boasts of significant groundwater resources. However the potential contribution of this groundwater to economic development under the Zimbabwe National Development Strategy 1 (NDS1) has not yet been fully explored nor fully exploited. While available national water resources are deemed sufficient to satisfy demand ,based on medium to long term population projections, water quality degradation and a 15% projected decrease in precipitation due to climate change (IPCC, 2007), imply that water managers are confronted with the challenges of dealing with a declining resource and addressing conflicts between competing water users.(A.Murwira et.al; 2014)

Traditionally local authorities have attempted to control point source pollution, but recent studies show that diffuse source pollution is now a major source of water quality degradation and Siyalima Dam is not exempted. The Dam lies on Dande river one of Manyame River’s tributary streams which eventually feeds into Zambezi river on the far north side of Zimbabwe. The dam was built in 1990-1991 by Mr J.McGrath and was classified as being small-medium in size with an estimate capacity of 87ML however a damaged spillway and heavy siltation have greatly lessened this capacity. The dam was initially meant to support cattle ranching at the farm by providing cattle drinking and dipping water and irrigating specialized pastured fields summing up to 20 hectares however as of late, Siyalima dam currently supports a 50 hectare state owned center pivot irrigation scheme as the major consumer of water and a school of 50 000 bream under the command agriculture cropping and fisheries projects respectively, both projects were commissioned by the President of Zimbabwe Dr. E.D Mnangagwa in 2018. The dam also supports other minor irrigation activities like gardening and domestic water requirements to the surrounding community like cattle drinking and dipping and domestic use. However the future of the dam is now under threat from pollution and heavy siltation with the dam already showing signs of eutrophication. The sources of contamination are numerous but the main ones include: inadequate sanitation, shared use of water by humans and livestock, industrial effluents and alluvial mining in its tributary streams.

The dam has also developed a wide carpet of water lilies like Salvinia Molesta and blue green algae (cyanobacteria) which threaten the natural oxygen levels of the water however his could just be the tip of an iceberg, as it is also known that blue-green algal bloom in lakes and dams is toxic and can pose adverse, substantial health risks to communities accessing affected water for drinking, irrigation and recreation. (A.Murwira et.al; 2014). Specifically, toxins can destroy cells in the liver and other internal organs, and may act on the nervous system leading to respiratory failure. Other health impacts of algal blooms can include gastric upsets, fever, headaches, skin irritations, and numbness and paralysis of the arms and legs. Human deaths that have been associated with blue green algal blooms, and deaths of livestock and wildlife with an estimated 200-300 deaths annually. (Journal of water and health, 2020)

1.3 Problem Statement

High levels of nutrient pollution and heavy siltation from non-point sources, such as agricultural runoff and artisanal chrome mining, are causing harmful algal bloom in Siyalima Dam, negatively impacting water quality, aquatic life and human recreational activities. This study seeks to identify the sources of this pollution and suggest tailor made strategies that can be implemented to reduce or manage effluent from these non-point sources, mitigate eutrophication and restore the dam's ecosystem health.

1.4 Objectives

General Objective:

An analysis of the non-point sources of water pollution affecting Siyalima Dam in order to develop strategies for sustainable management and mitigation.

Specific Objectives:

1. Identify the non-point sources of water pollution affecting Siyalima Dam.
2. Quantifying the degree of pollution.
3. Assessing the impact the water pollution has on the surrounding environment.
4. Generating context-based mitigation strategies to address water pollution.

1.5 Justification

Zimbabwe's surface and groundwater resources are critical for national economic development, yet there is inadequate information about their quality, extent and condition with respect to pollution threats. The 2013 National Water Policy recognizes that the quality and condition of Zimbabwe's surface and groundwater resources are deteriorating. Pollutants from non-point sources can contaminate water, posing health risks to humans and wildlife, including the potential for waterborne diseases. The cholera outbreak of 2008-2009 and the just recent 2023-2024 outbreak countrywide that claimed over 6,000 lives in total as well as the recent typhoid outbreaks are a clear indications of the need to protect water sources against pollution. (A.Murwira et.al; 2014)

Non-point sources of pollution, such as agricultural runoff, urbanization, and atmospheric deposition, can significantly impact water quality in the dam, affecting its intended uses like, drinking water, irrigation and recreation, by introduction of pollutants like nutrients, sediments, bacteria, and chemicals that could potentially harm aquatic life leading to eutrophication, algal blooms and decreased biodiversity. These sources can be difficult to isolate because of the interconnectedness of the natural and anthropogenic environments however by understanding the sources and transport mechanisms of non-point pollutants targeted strategies to reduce pollution, such as best management practices, watershed management plans, and policy changes can be implemented. And this can help generate a holistic, watershed-based approach to managing water resources, by considering the network of humans and their immediate and distant environments.

By analyzing non-point sources local stakeholder engagement is encouraged, fostering awareness and collaboration to address pollution issues and promote sustainable water management practices and this can help identify opportunities to reduce footprint and adapt to climate change impacts on water quality for a more sustainable local water management policy such as outlined in the

Zimbabwe Water Act of 2000 (Chapter 20.24), and also informs management decisions to mitigate pollution. Reclamation of such degraded water quality can lead to increased treatment costs, reduced recreational and tourism values, and economic losses for industries like agriculture and fishing. This study also helps to contribute to the scientific understanding of non-point source pollution, informing future studies and management decisions for similar water bodies.

1.6.1 Limitations:

- Limited time and resources confine the research to Siyalima farm, Ward 1 Guruve South.
- Lack of cooperation from local farmers and understanding of fertilizer and chemical impacts on the environment.
- Water sampling costs limit the number of tests.
- Illiteracy among community members hinders questionnaire responses.

1.6.2 Delimitations

- Water samples were taken on 5 separate sites which are on different points on the dam and along tributary streams.
- The researcher carried out interviews to overcome language barriers and illiteracy

1.7 Summary

The proposed evaluation will enable small holder farmers to assess and improve their agricultural practices reducing the effluent of saline water into natural water bodies and preserve the precious resource in face of the imminent threat of climate change. It will also provide a detailed account of effects the agro-fertilizers and chemicals and effluent from mining activities upstream from the dam, contributing to a sustainable local policy on water and environmental management.

1.8 Conclusion

In conclusion, Siyalima Dam, a vital water resource for surrounding communities, faces significant threats from non-point sources of pollution. The dam’s water quality is deteriorating due to agricultural runoff, artisanal mining, and other human activities, posing risks to human health and the environment. This study aims to investigate and analyze the non-point sources of water pollution affecting Siyalima Dam and develop strategies for sustainable management and mitigation. By understanding the complex relationships between land use, water quality, and pollution sources, this research seeks to inform policymakers, environmental managers, and local communities about the necessary measures to protect this critical water resource. The findings of this study will contribute to the development of effective strategies for managing non-point sources of pollution and ensuring the long-term sustainability of Siyalima Dam.

Chapter 2: Literature review

2.0 Introduction

This chapter provides a comprehensive review of existing literature on non-point pollution, water quality, and human health effects. The aim is to gain a deeper understanding of the research topic, identify knowledge gaps, and inform the methodology and analysis of the case study. The literature review covers definitions of key terms, previous research on non-point pollution, water quality monitoring, and human health impacts.

2.1 Definition of Terms

Pollution:

This is the introduction of contaminants, in any form chemical or energy, into the natural environment that cause adverse change. (USEPA; 2020)

Pollutants:

Pollutants are foreign or naturally occurring substances that have the potential to cause short term or long term harm to the environment. These can be classified as point source or non-point source. (USEPA; 2020)

Non-point source:

Non-point source pollution refers to the diffuse pollution of water bodies resulting from the release of pollutants from multiple, widespread and often unidentifiable sources such as agricultural runoff, urban Stormwater and atmospheric deposition, which can accumulate and affect water quality over a large area. (USEPA; 2020)

Salinity:

Salinity is the total amount of dissolved inorganic solids in water expressed in concentration of dissolved salts, mainly sodium chloride, but also including other ions such as calcium, magnesium and potassium. Salinity is used to classify water bodies into freshwater, brackish or marine environments. (UNESCO; 2019)

Water Quality:

Water quality refers to the chemical, physical and biological characteristics of water; it is a measure of the condition of water relative to the requirements of living organisms and human need. (Murwira et al., 2014)

Ambient Water Quality (AWQ):

This is a monitoring exercise which seeks to make a measurement of the pristine conditions of water bodies (Murwira et al., 2014). The term ambient refers to the immediate, undisturbed surroundings of the environment.

Water sampling

This is the process of collecting and testing samples of water from a particular, Lake Dam or river in order to determine physical, chemical and biological properties of the water and to assess the overall quality. (United States Environmental Protection Agency; 2020).

Watershed

A watershed is an area of land that drains all the streams and rainfall to a common waterbody such as a river, lake, or ocean. (USEPA; 2020)

Runoff

Runoff is the water that flows over the land and into nearby waterways. It can carry pollutants such as sediment, nutrients, and bacteria into water bodies. (USEPA; 2020)

Sedimentation

Sedimentation is the process of settling or deposition of suspended solids in water. (WHO; 2018)

Eutrophication

Eutrophication is the process by which a body of water becomes enriched with excess nutrients, leading to an overgrowth of algae and depletion of oxygen in the water. (USEPA; 2020)

Spatial Data Analysis:

Spatial data analysis is the process of examining and interpreting data that is associated with geographic or spatial locations. It involves the use of geographic information systems (GIS) and other spatial analysis techniques to identify patterns, relationships, and trends in data that are tied to specific locations or areas. (ESRI, 2020)

Hydro shed

A hydro shed is a geographic area of land that drains water into a specific body of water, such as a river, lake, or ocean. It is a watershed that is defined by the hydrologic cycle, and it can be used to identify areas that contribute to water pollution or flooding. (USGS, 2020)

In Zimbabwe, a statutory instrument empowers the Environment Management Agency (EMA) a role in water quality management (Murwira et al., 2014). The Environmental Management Agency is mandated to maintain an extensive surface water quality monitoring network along major and minor water bodies across the country, which includes streams (rivers), dams and lakes but unfortunately it is yet to come up with quality standard guidelines for environmental, aquatic life, navigation and tourism water use (Murwira et al., 2014).

2.2 Literature Review

This chapter provides an overview of previous research on the analysis of non-point pollution and effects of water pollution on human and environmental health. It introduces the framework for the case study that comprises the main focus of the research. An appreciation of previous work in this area served three further purposes. First, through providing direction in the construction of data collection tools, it guarded against the risk of overload at the primary data collection stages of the project. Second, working the findings from extant literature into a formal review helped maintain throughout the study a sense of the topic’s perspective. Finally, this activity raised the opportunities for articulating a critical analysis of the actual “meaning” of the data collected when the data analysis stages of the research were reached.

2.3 General factors affecting surface water quality in Zimbabwe

Deterioration of water quality in rivers usually comes from excessive nutrient inputs, eutrophication, acidification, heavy metal contamination, organic pollution and obnoxious fishing

(Mustapha, 2008). The effects of these “imports” into the river do not only affect the socioeconomic functions of the river, but also bring loss of structural biodiversity of the river (Mustapha, 2008)

Zimbabwe’s surface water sources can be classified into (1) surface streams and rivers and (2) surface water bodies comprising numerous impoundments/dams. These artificial impoundments consisting of small and medium dams with an ‘annual yield’ as well as large dams with a carry-over storage capacity have been established as part of the country’s overall water development strategy (Ministry of Water Resources and Development 1984).

The availability of water and its physical, chemical, and biological composition affects the ability of aquatic environments to sustain healthy ecosystems. When water quality and quantity are eroded, organisms suffer and ecosystem services may be lost. The quality of water required to maintain a healthy ecosystem is largely a function of natural background conditions. (Makaka et al; 2019)

Concentrations of nitrate, phosphate, and probably sulfate reflect the impact of human activities in the watershed, such as leached fertilizers from farmland and washing of cow dung (Mustapha, 2008; Wepener et al., 2009; Nhiwatiwa et al., 2007). Bathing and washing also contribute to non-point source nutrient pollution (Mustapha, 2008; Wepener et al., 2009; Nhiwatiwa et al., 2007). Seasonal variations in nutrient loads due to diffuse pollution are common and have drawn attention to water quality problems in Africa (Marshal, 1997; Nhapi and Tirivarombo, 2004).

The ecological impacts of these pollutants range from simple nuisance substances to several effects involving macroinvertebrates, other aquatic fauna and human health (Tafangenyasha and Dube, 2005; Bere et al., 2017). (Carignan et al 2000) and (Armengol et al.;1999) reported that non-point source nutrient input from water shed are leading causes of eutrophication and water quality problems in rivers. The eutrophication could affect the water quality of the water by giving rise to unpleasant taste and odor, colors the water, and affects the dissolution of other gases, mostly dissolved oxygen as a result of algal bloom (Gombiro et al.;2014)

One of the effects of global warming is a fundamental change in phytoplankton communities. At temperature above 28oC, cyanobacteria, also known as blue green algae dominate the aquatic phytoplankton. These produce micro-cysteines which are known to be carcinogenic.

However for these to proliferate they need water rich with phosphorus, a common fertilizer residue, which is the case with Siyalima Dam and other eutrophic waters in Zimbabwe like Lake Chivero (Ndebele and Magadza; 2006).

2.3.1 Sewage discharges

The most contaminated rivers in the country tend to be those draining catchments with major urban settlements (see Figure 2 showing the location and distribution of urban centers in relation to major catchments). All major catchments in Zimbabwe have urban centers with sewage output ranging from tens of mega liters to hundreds of mega-liters per day, most of which finds its way into surface water.

Sewer discharges contain coliform bacteria, Coliform bacteria are a group of bacteria predominantly found in the intestines of warm-blooded animals, including humans. While not all coliform bacteria are harmful, their presence in water can indicate potential fecal contamination and the possible presence of pathogens such as Escherichia coli (E.Coli) which is a type of coliform bacteria commonly used as an indicator of water quality and fecal contamination.

Due to frequent sewer outbursts as well as direct discharge of raw or partially treated sewage into public waterways draining urban areas, urban water quality is generally poor. For example, due to sewage discharges, nitrogen (N) levels averaging 13.5 mg/ℓ and phosphorus (P) levels averaging 2.6 mg/ℓ have been measured in the Marimba River which drains into Lake Chivero (Nhapi and Tirivarombo,2004). This concentration level of P far exceeds the statutory limits for sewage discharge into public waterways, which is 0.1 mg/ℓ for phosphorus. The presence of cyanotoxins in Harare's treated drinking water reported in literature can also be attributed to the discharge of raw or partially treated sewage (Mhlanga et al. 2006; Ndebele and Magadza 2006).

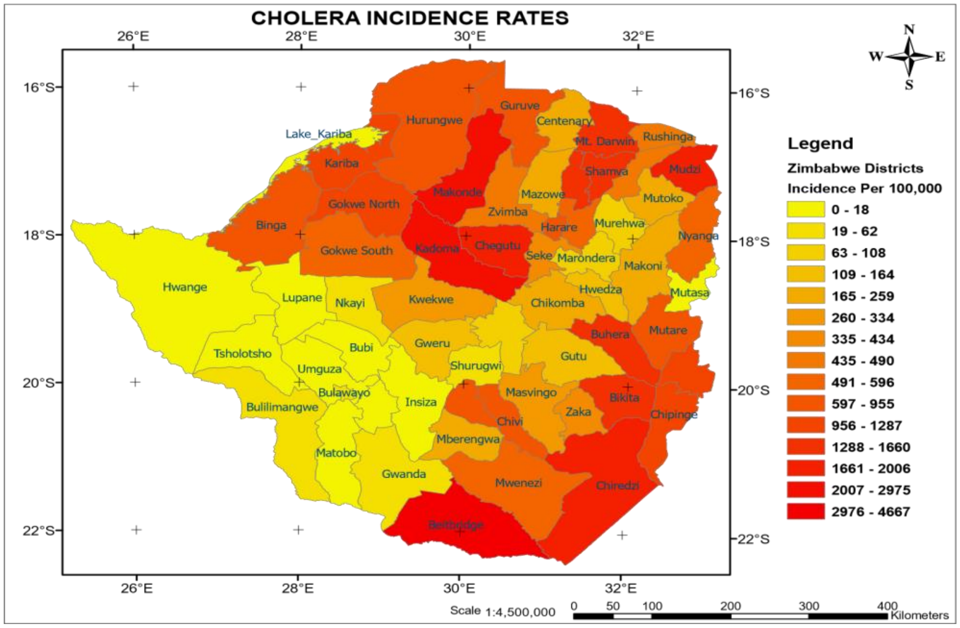


Figure 1:Cholera Incidence Rates for the 2008/9 cholera epidemic in Zimbabwe

(Source:Farai. Kuri PGD Dissertation ARCSSTE-E, Obafemi Awolowo University, Nigeria 2009.

Cholera Incidence Data were obtained from WHOARCSSTE-E - African Regional Centre for Space Science and Technology Education in English)

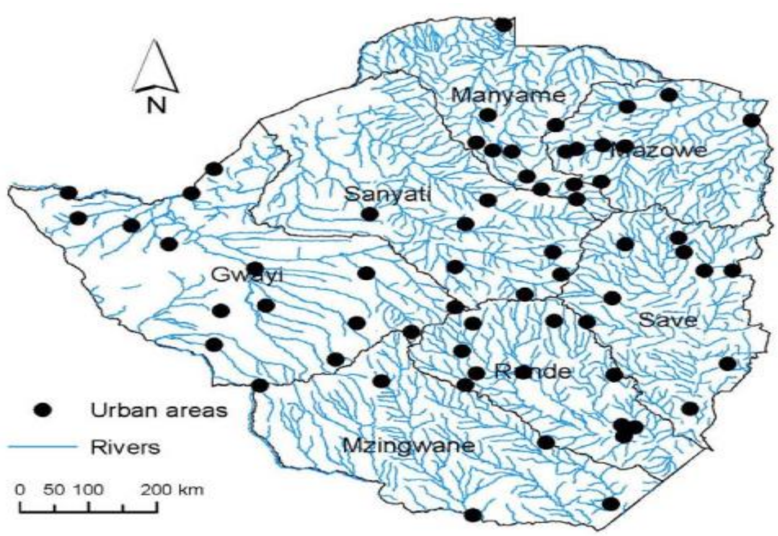


Figure 2:The distribution of urban areas in the seven catchments of Zimbabwe.

Sourced from Rapid Assessment – Identification and Characterization of Hotspots of Water Pollution and Source Degradation. (A.Murwira et.al; 2014)

2.3.2 Mining

Zimbabwe is a mineral rich country with over 40 minerals that can be developed economically there is a major knowledge gap on the statistics of chrome mining in the country which is the predominant mining activity in the Siyalima area. The gold sector however has approximately 200 registered ‘formal’ medium-small scale gold mines and thousands of small-scale unregistered gold operations, most of which use mercury (Hg) for the processing of primary gold quartz veins and supergene gold mineralization. The techniques that are used are inefficient, hence, gold mines, especially artisanal gold mines, are major point and non-point sources of Hg and other heavy metals such as arsenic (As) and lead (Pb).

Zimbabwe is currently facing a chrome rush as the global prices for the metal have gone up in recent years. Chrome mining activities range from very low technology panning (on the major internal rivers) to sophisticated extraction technology practiced at an increasing number of larger and smaller mining and re-treatment operations. The economic crisis in Zimbabwe saw the closure of most of the big mines that use sophisticated extraction technology and the sprouting of more small-scale and artisanal mining activities at a unprecedented rate. Small scale mining has been practiced since time immemorial by the early Shona and their contemporaries, although shallow by contemporary standards, the old workings developed into considerable undertakings, with open casts (wide deep trenches) and shafts (Summers, 1969; Swan, 1994). Small-scale mining is commonly associated with informal, unregulated, under-capitalized and under-equipped mining operations, where technical and management skills are lacking. For example, the Global Mercury Project (GMP) identified Kadoma-Chakari region as having the highest population of artisanal and small-scale miners in Zimbabwe (~ 20,000) and documented the widespread use of mercury during gold processing, but its impact on water quality was not quantified. The mechanisms through which mercury may impact aquatic ecosystems and human health were however described.

Chrome mining activities, which have become prevalent in Zimbabwe, can lead to heavy metal contamination, specifically chromium, arsenic, cadmium, and mercury (Ravengai et al., 2005; van Straaten, 2000). For example, chrome mining has been linked to increased chromium levels in nearby water sources (Ravengai et al., 2005). Similarly, mercury pollution from small-scale gold mining has been reported in Zimbabwe (van Straaten, 2000).

Chromium ions pose a significant threat to human health due to their toxic and corrosive properties (ATSDR, 2020). The generation of reactive oxygen species (ROS) by chromium ions leads to oxidative stress, causing damage to cellular components (Kawanishi et al., 2016). This disrupts cellular function, resulting in harm to tissues and organs (Shrivastava et al., 2018). Moreover, chromium ions can bind to DNA, causing mutations and disrupting cellular reproduction, potentially leading to genetic damage and cancer (IARC, 2012).

Chromium ions also cause cellular toxicity, disrupting cellular metabolism and leading to cell death or damage (Graziano et al., 2018). This results in tissue and organ damage, as well as bioaccumulation, where chromium ions build up in organs and tissues, causing chronic damage and disease (EPA, 2020). Additionally, chromium ions can displace essential nutrients like iron and calcium, leading to deficiencies and related health problems (WHO, 2018). They can also trigger inflammation, leading to tissue damage and potentially chronic diseases (Kamp et al., 2019), and weaken the immune system, making it harder for the body to fight off infections and diseases (Liu et al., 2019).

The specific health effects of chromium ions depend on factors such as the amount and duration of exposure, individual susceptibility, and the specific form of chromium (e.g., hexavalent or trivalent) (ATSDR, 2020).

2.2.3 Industrial effluent

Industrial effluent discharges from various industries, such as the chrome mining industry, can also contribute to water pollution (Nyamangara et al., 2008). For instance, heavy metal pollution from chrome mining activities has been reported in the Mukuvisi River (Nyamangara et al., 2008).

The treatment and disposal of industrial effluent is also a major factor contributing to the deterioration of surface water quality in the country. While most industries are connected to sewerage reticulation, several industries discharge directly into public waters. For example, due to the discharge of industrial effluent, Heavy metal pollution has been linked to industrial effluent discharge and, in urban centers such as Harare; it has been linked to the deterioration in potable water quality (Zaranyika et al. 1997) Thousands of backyard industries have mushroomed in urban centers, but their contribution to water source pollution is largely unaccounted for. Backyard industries in places such as Mbare have been identified as polluters of the Mukuvisi River, disposing of pollutants such as oils. They also have great potential as diffuse polluters when there is runoff.

2.3.4 Agriculture

Agricultural activities, especially those involving the use of fertilizers and pesticides, can lead to diffuse pollution (Moyo and Mafara, 1997). For example, the use of fertilizers in commercial farming has been linked to increased nutrient levels in nearby water sources (Begg, 1970). Additionally, agricultural effluent from cattle ranching can lead to water pollution through nutrient pollution, bacteria, and pathogens from cattle waste (Makaka et al., 2019).

The eutrophication of water bodies due to excessive nutrient inputs can lead to unpleasant tastes, odors, coloration of water, and decreased dissolved oxygen levels, affecting aquatic life (Gombiro et al., 2014). Cyanobacteria, which are known to produce microcystins, can proliferate in water bodies rich in phosphorus, leading to carcinogenic effects (Ndebele and Magadza, 2006).

Figure 3: Evidence of stream bank Cultivation

(Source: Image taken at Siyalima dam on 11/05/24. At GPS coordinate S°38’37’’, E30°49’21’’)

2.3.5 Aquatic invasive weeds

The presence of aquatic invasive weeds is a manifestation of eutrophication Aquatic invasive weeds, such as water hyacinth, can also thrive in eutrophic water bodies, further exacerbating water quality issues (Gombiro et al., 2014). For example, the invasive weed Salvinia molesta (Kariba weed), which has infested Lake Kariba, declined after nutrient levels dropped. Due to nutrient pollution, Khami dam, Lake Chivero and Lake Mutirikwi have both been infested by water hyacinth (Eichhornia crassipes).

Figure 4: Evidence aquatic invasive weeds

(Source: Image taken at Siyalima dam on 11/05/24. At GPS coordinate S°38’33’’)

2.6 Knowledge gaps on surface water quality

Despite the various studies on surface water quality in Zimbabwe, there are still significant knowledge gaps, particularly regarding the characterization of water bodies and the impact of human activities on water quality (Makaka et al., 2019). Most studies have focused on perennial rivers and large reservoirs, with limited attention given to wetlands, springs, small rivers, and small reservoirs, which are mainly located in the headwaters of most perennial rivers and large reservoirs (Makaka et al., 2019).

2.7 Effects of water pollution on human, environmental and aquatic life

The combined effluent from agricultural, chrome mining, and human settlement activities poses a significant risk to human health. Exposure to heavy metals such as chromium, arsenic, cadmium, and mercury can increase the risk of cancer, reproductive problems, and neurological damage (ATSDR, 2020; EPA, 2020). For example, chromium, a common pollutant from chrome mining, can cause respiratory problems, skin irritation, and damage to the liver and kidneys (ATSDR, 2020). Furthermore, consuming water contaminated with bacteria, viruses, and parasites can lead to gastrointestinal problems, diarrhea, and cholera (WHO, 2018). The effluent can also contaminate soil and air, leading to further human health risks.

The effluent also has devastating effects on aquatic health. Excess nutrients from agricultural runoff can lead to harmful algal blooms and decreased oxygen levels in water bodies, causing harm to aquatic life (Anderson et al., 2002). Heavy metals can bio-accumulate in aquatic organisms, leading to bio-magnification up the food chain (Rainbow, 2002). This can have long-term effects on aquatic ecosystems, leading to decreased biodiversity and extinction of sensitive species (Barnes et al., 2019).

The environmental health impacts are also significant. Soil pollution due to heavy metal contamination can lead to decreased agricultural productivity and ecosystem resilience (Khan et al., 2019). Air pollution from particulate matter and gas emissions can lead to decreased air quality and climate change (EPA, 2020). Habitat destruction and fragmentation can also lead to decreased ecosystem resilience and biodiversity (IPCC, 2019).

Figure 5:image of heavily silted spillway and juvinile fishermen at Syalima dam

(Source: Image taken at Siyalima dam on 11/05/24. At GPS coordinate S°38’35’’, E30°49’24’’)

2.8 Summary

This chapter discusses the effects of water pollution on human, aquatic, and environmental health. The combined effluent from agricultural, chrome mining, and human settlement activities poses significant risks to human health, including that of cancers, reproductive problems, and neurological damage. The effluent also has devastating effects on aquatic health, leading to harmful algal blooms, decreased oxygen levels, and bio-magnification of heavy metals up the food chain. Additionally, the effluent contaminates soil and air, leading to further human health risks and decreased ecosystem resilience. The chapter highlights the importance of addressing water pollution to protect human, aquatic, and environmental health.

Water pollution from agricultural, chrome mining, and human settlement activities poses significant risks to human, aquatic, and environmental health. The effluent increases the risk of cancer, reproductive problems, and neurological damage, and contaminates soil and air. Aquatic health is also affected, leading to harmful algal blooms and bio-magnification of heavy metals.

The chapter emphasizes the need to address water pollution to protect human, aquatic, and environmental health, and promote ecosystem resilience. Effective management strategies and policies are required to mitigate the effects of water pollution and ensure sustainable water resources for future generations.

2.9 Conclusion

Surface water quality in Zimbabwe is facing numerous challenges, including excessive nutrient inputs, eutrophication, acidification, heavy metal contamination, organic pollution, and harmful fishing practices. Human activities such as chrome mining, agriculture, and industrial effluent discharges have significant impacts on water quality.

Chapter 3: Methodology

3.1 Introduction

This chapter outlines the research design, data collection methods, and data analysis techniques used in this study. The aim is to provide a clear understanding of the research approach and methods used to investigate the impacts of water pollution on human, aquatic, and environmental health in the Siyalima Dam catchment area. A well-defined methodology is essential in ensuring the validity and reliability of research findings (Creswell, 2014).

3.2 Research Design

The research design is primarily explanatory in nature, although some descriptive elements are present (Creswell, 2014). Explanatory research seeks to identify the causes and effects of a phenomenon, while descriptive research provides a detailed description of the phenomenon. This study uses a mixed-methods approach, combining both qualitative and quantitative data collection and analysis methods.

3.3 Primary data Collection Tools

The researcher used various data collection tools, including:

- Interviews (semi-structured)
- Focus group observations
- Questionnaires (structured)

To identify the likely sources of water pollution.

- Direct observations
- Spatial data from QGIS and Google Earth Engine
- Water chemical tests
- Soil tests

To quantify the degree of pollution being generated from these sources.

3.4 Questionnaires

A total of 70 questionnaires were issued to obtain quantitative data and create a usage model for the communities interacting with the dam. The population was divided into clusters based on a framework (Refer to annex 2). With the questionnaires structured to allow multiple selection in each criteria, widening the field of information obtained. The results were tabulated, and this technique proved effective in obtaining and handling ready information over a large population and geographical area.

3.5 Interviews

Semi-structured interviews were used to obtain in-depth information from respondents. The researcher asked questions, and respondents answered, providing an opportunity to discover how they felt about the study area. Interviews were appropriate for exploring sensitive topics and obtaining detailed insights from individual participants. (Refer to annex 1 for sample questionnaire).

3.6 Observations

Field observations were made to determine human activities that might affect water quality. Particular attention was paid to activities such as bathing, washing, car wash, oil spills, and garages, roads, and quarrying, mining, and agricultural activities.

3.7 Water Tests

Water tests were conducted to analyze various parameters of water quality, including pH level, turbidity, and contaminant presence. 4 water tests were conducted, including one composite test, to provide a comprehensive understanding of water quality in the study area. Water samples were collected using a composite sampling approach, with a minimum separation distance of 1 kilometer between sampling locations to ensure spatial independence. Samples were taken from 2 locations along each of the 3 streams, resulting in 6 samples. These 6 samples were then composited into 3 final samples, one representing each stream. Additionally, 7 samples were collected along the dam and composited into a single sample, representing the dam. Water material was specifically targeted for collection using sterile containers and stored in sealed bags to prevent contamination and preserve water properties. Samples were well-labeled for quality control and sample tracking, and then refrigerated at a temperature of 4°C to slow down biological and chemical reactions, thereby maintaining water integrity and minimizing sample degradation. The samples were then sent for laboratory testing on 14 May 2024, and the test results were produced on 15 May 2024. Refer to the test results for details on the testing methods used. All sampling and handling procedures were carried out in accordance with ISO 5667-1:2019, ensuring a representative and reliable dataset for subsequent analysis of water properties.

3.8 Soil Tests

Soil tests were conducted to analyze the pH level, nutrient content, and contaminant analysis of the soil in the study area. Soil samples were collected using a composite sampling approach, with a minimum separation distance of 500 meters between sampling locations to ensure spatial independence. Samples were taken at a minimum distance of 30 meters from the river to avoid potential contamination and unique soil conditions influenced by the riparian zone. Topsoil material, defined as the uppermost 10-20 cm of soil, was specifically targeted for collection using a trowel and stored in sealed bags to prevent contamination and preserve soil properties. The sampling depth of 10-20 cm was chosen to represent the topsoil layer, which is most relevant for soil properties and potential contamination. Samples were well-labeled for quality control and sample tracking, and then refrigerated at a temperature of 4°C to slow down biological and chemical reactions, thereby maintaining soil integrity and minimizing sample degradation. Soil samples were collected from 9 different locations, with 3 locations along each of 3 separate rivers. Samples from each river were then composited into a single sample, resulting in 3 final composite samples, each representing a different river. All sampling and handling procedures were carried out in accordance with ISO 18400-101:2017, ensuring a representative and reliable dataset for subsequent analysis of topsoil properties. (Refer to figure 6 for sampling map)

3.9 Sampling Techniques

The researcher used cluster sampling, dividing the population into 16 subgroups according to occupation, age, sex, and proximity from the dam (Fink, 1995). This technique helped control for sampling error and ensured a representative sample. To determine the degree of risk that pollution posed to the population, a cluster sampling framework was developed to categorize respondents based on their proximity to the mine and dam, history of waterborne illnesses, source of drinking water, and domestic use of the dam. A questionnaire was drafted incorporating these criteria to collect data from the respondents. The if-then-else parameters were applied to the responses to classify the degree of risk as High, Medium, or Low. This approach enabled the identification of patterns and trends in the data, which informed the conclusions and recommendations of this study. (Refer to annex 2 for cluster sampling framework)

3.10 Spatial Data Analysis

The spatial data analysis was done using Google Earth Engine involved defining a new Region of Interest (ROI) using Universal Transverse Mercator (UTM) coordinates and projecting it to World Geodetic System 1984 (WGS84) (Latitude/Longitude) projection. A land cover dataset (Copernicus Global Land Cover Layers) was loaded, and a random forest classifier was trained using sampled data within the ROI. The classified land cover image was displayed with a custom color palette. Additionally, SRTM DEM data was used to generate contour lines with elevation labels, and Sentinel-2A imagery was visualized. The Hydro-SHEDS dataset (rivers and streams) was also filtered within the ROI. Finally, the data was generated into a GeoTIFF file, and the image was produced using QGIS (see Annex C for the complete GEE java-script code used for this analysis).

3.11 Summary

This chapter outlined the research design, data collection methods, and data analysis techniques used in this study. A mixed-methods approach was used, combining both qualitative and quantitative data collection and analysis methods. The researcher used various data collection tools, including questionnaires, interviews, observations, water tests, soil tests, and spatial data analysis. Cluster sampling was used to divide the population into subgroups and ensure a representative sample.

3.12 Conclusion

In conclusion, this chapter has outlined the research design, data collection methods, and data analysis techniques used in this study. A mixed-methods approach was employed, combining both qualitative and quantitative data collection and analysis methods to provide a comprehensive understanding of the impacts of water pollution on human, aquatic, and environmental health in the Siyalima Dam catchment area. The use of various data collection tools, including questionnaires, interviews, observations, water tests, soil tests, and spatial data analysis, ensured a robust and reliable data collection process. Additionally, cluster sampling was used to divide the population into subgroups and ensure a representative sample. This chapter has provided a solid foundation for the research methodology used in this study, and the findings presented in the subsequent chapters are based on the rigorous data collection and analysis methods outlined here.

Chapter 4 Analysis of Results

4.1 Introduction

This chapter presents a comprehensive analysis of the results obtained from the study on the Siyalima dam catchment area. The study involved sampling seven distinct sites to evaluate various environmental and human factors impacting water quality and overall ecosystem health. These sites ranged from upstream to downstream zones, each exhibiting unique characteristics and anthropogenic activities. This analysis aims to highlight critical areas of concern and provide insights into potential solutions for sustainable management of the catchment area.

4.2 Site Descriptions and Activities

The study encompassed seven sites along the Siyalima dam catchment, each with unique environmental and human interaction dynamics. Table 1 outlines the characteristics of these sites, including altitude, riparian vegetation, and human or animal activities.

A total of seven sites were sampled on the Siyalima dam catchment. Starting upstream from site 1 down to site 2 Nyambari tributary stream close at a site that was previously used for cattle ranching near a local shopping area closer to the confluence with dam (refer to image 1). There was a drop in altitude of 840 m from 1 352 to 512 m.a.s.l. Site 3 in upstream zone, sites 5, 6, 7 in midstream zone, and sites 6 and 7 in downstream river reach had their riparian areas mostly covered by acacia vegetation. Sites 1 and 2 in upstream zone had mainly savanna grasslands and Miombo type of vegetation, respectively (Table 1).

Table 1 summarizes the human and domestic animal activities noted at various sites along the river. All zones were characterized by human activities such as bathing, washing and fishing except for sites 1 and 3 in upstream zone, 7 in midstream zone, and 9 in downstream reach, which were shunned by the locals because of accessibility from homesteads and high traffic or being far away from homesteads. Site 1 was near a busy dust road for humans and scotch carts, and occasionally motor vehicles. Veld fires used in clearing of virgin land and hunting were also a common site during the study period. Human and cart pathways crisscrossed the riparian area. The riparian areas for most sites were used as grazing pasture lands associated with low intensity subsistence crop farming and gardening.

Zone	Site	Altitude (m)	Riparian vegetation	Human or animal activity in river	Riparian human or animal activity
Hariyatsva	(Site 1)	952	Savanna grassland, with acacia trees	• Dust road, • Washing and bathing	• Mining • settlement, • semi-intensive tobacco farming
	(Site 2)	941	Miombo woodland, Acacia trees	• Extensive washing and bathing, • Goat and cattle grazing area, • High rate of deforestation. • fishing point	• Very low intensity subsistence farming, • Cattle and goat grazing area, • Widespread veld fires, • Motor vehicle, • Scotch cart and sledge pathways, • Semi- intensive tobacco farming
Nyambari	(Site 3)	956	Clear of vegetation	• Bathing and washing; • Cattle grazing and drinking point	• Settlement (rural) and subsistence farming, • Cattle and goat grazing area, gardening
	(Site 4)	947	Acacia trees	• Extensive washing and bathing zone,	• Settlement and subsistence crop farming; • Cattle and goat grazing area,

				• Cattle and goat grazing and drinking point.	
Varden	(Site 5)	948	Acacia trees	• Cattle grazing and drinking zone, • drinking water collection point	• Settlement and subsistence crop farming, • Cattle grazing area
	(Site 6)	942	Acacia trees	• Washing and bathing restricted zone, • cattle grazing and drinking point	• Settlement (rural and semi-urban), • Gardening
Dam Composite Collection	(Site 7)	937	Acacia trees	• heavy cattle grazing and drinking point with numerous animal droppings, • Washing and bathing zone, • Water collection point	• Brick moulding, • Maize and tobacco farming, • Gardening • Settlement (rural and semi-urban), • Motor vehicle, Scotch cart and sledge pathways, • Semi- intensive tobacco farming

Table 1: Environmental and vegetation characteristics of the sampling locations.

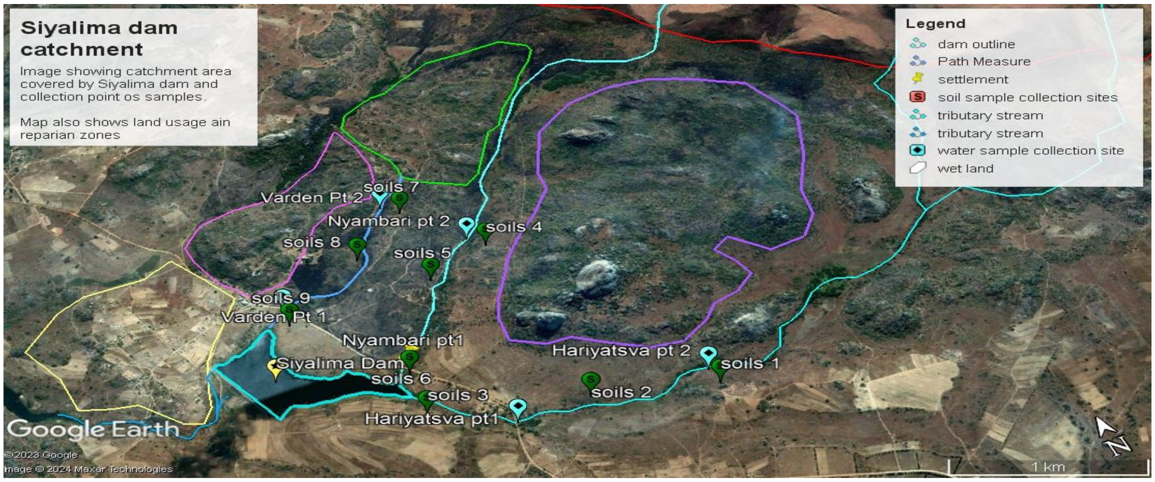
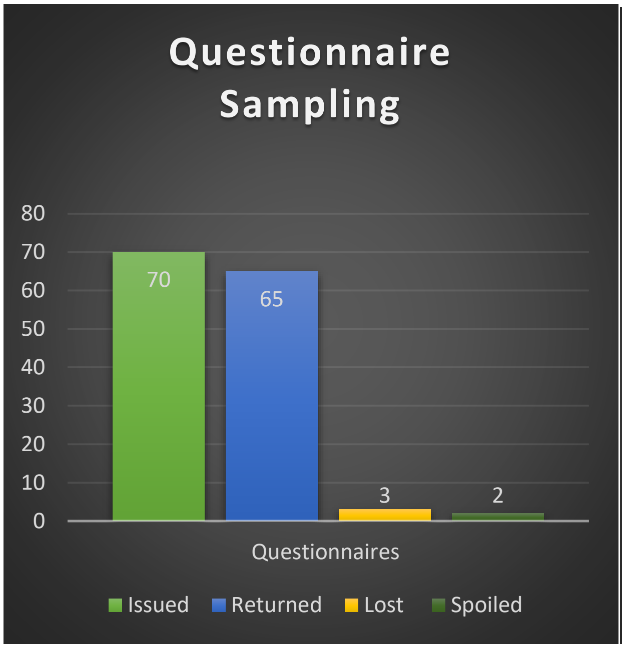


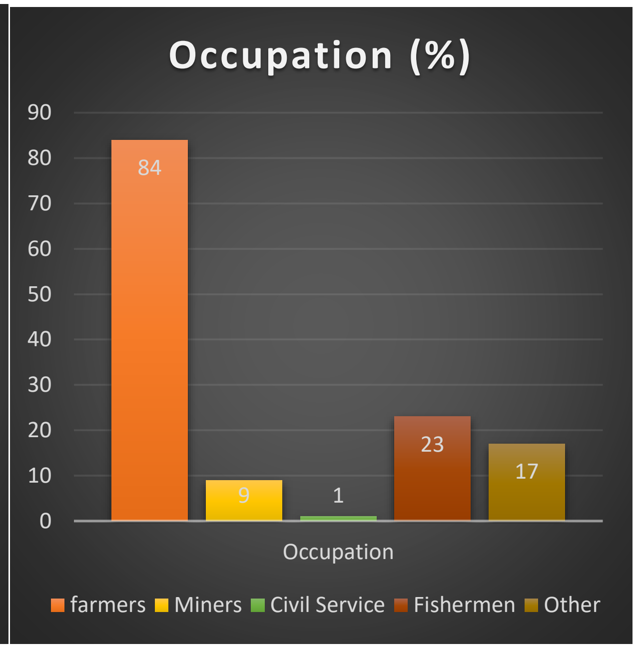
Figure 6:Sampling map

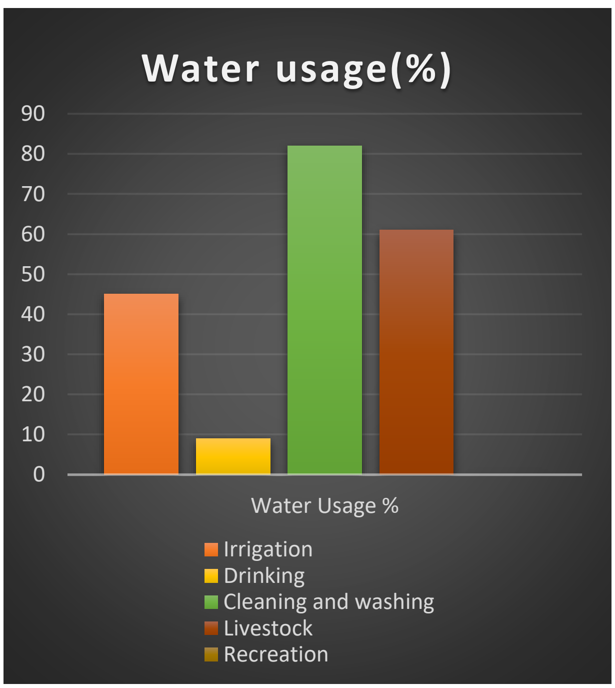
Questionnaires	Issued 70	Returned 65	Spoiled 2	Lost 3	Response 93%
Age results	Below 20 **24%**	20-30years **19%**	30-40 **41%**	50-60 **11%**	>50 **5%**
Livelihood	Farmers **84%**	Miners **9%**	Government employees **1%**	Fishermen **23%**	Other **17%**
Major water usage results	Domestic use **82%**	Irrigation **45%**	Drinking **9%**	Livestock **61%**	Recreation **0%**
Suffered Waterborne Illnesses	**54%=35**	Recurring 32%=**12**	Once off 67%=**24**	Treated 40%=**15**	Untreated 59%=**21**

Table 2: Water usage analysis

Table 1 above outlines results from the questionnaires an outline of results from the survey carried out for residents of Siyalima and surrounding communities. Date 27/04/24-01/05/24. The interviewer allowed multiple selection for the questionnaire.







Bottom left Figure 7: Water usage analysis

Top right Figure 8: Population occupation

Top Left Figure 9: Questionnaire recovery

4.3 Siyalima Dam water usage model

The model outlined in this study outlines the interaction of sampled population with the dam. The population was categorized as having primary or secondary interaction or no interaction at all. The cluster sampling framework developed earlier in the study helped categorize the population into said criterion.(refer to annexure A).

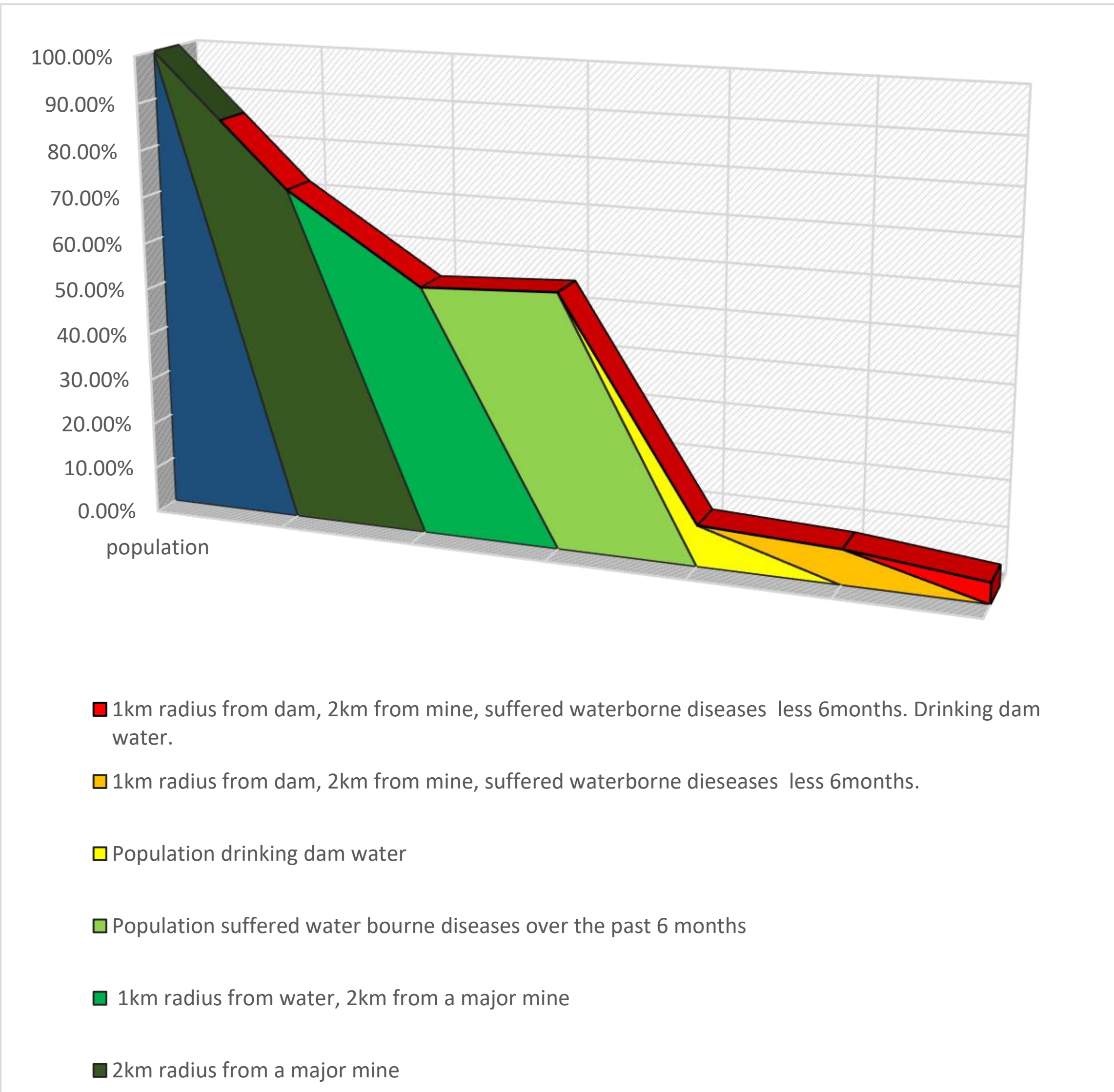


Figure 10: Population risk graph

Figure 9 Representation of population according to interaction with the dam from results of interviews and questionnaires showing over lap and distributed risk across the whole board.

Total sample	65							
Risk	**Cluster**						**Population**	
High	1	2	3	9	10		18	27.69%
Medium	4	5	6	11	13	15	25	38.46%
Low	7	8	12	14	16		22	33.85%

Table 3 Population risk assessment

Risk	Population		Criterion
High	18	27.69%	Primary consumption
Medium	25	38.46%	Secondary consumption
Low	22	33.85%	No consumption

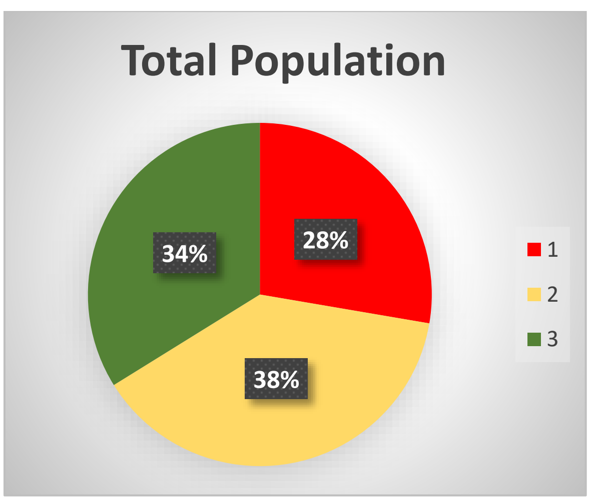
Table 4 Population risk Criterion

High	Population	
Cluster	18	27.69%
1	3	4.62%
2	4	6.15%
3	4	6.15%
9	3	4.62%
10	2	3.08%

Medium	Population	
Cluster	25	38.46%
4	4	6.15%
5	3	4.62%
6	3	4.62%
11	5	7.69%
13	4	6.15%
15	4	6.15%

Low	Population	
Cluster	22	33.85%
7	4	6.15%
8	3	4.62%
12	3	4.62%
14	3	4.62%
16	4	6.15%

Table 5 Population risk distribution as high medium and low



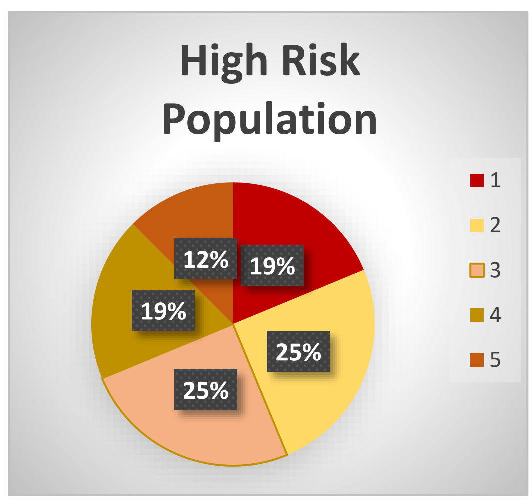


Figure 11 Population graph left

Figure 12: High Risk Population Assessment right

From this model 4.62% of the total sampled population (19% of high risk population)(under cluster 1, high risk category) experienced stomach problems, these were people drinking dam water, living within a 1km radius from dam, 2km from mine, suffered waterborne diseases and reported suffering recurring stomach illnesses in a period dating back less than 6months. This is the population that is most at risk of health complications associated with the compromised water quality in the dam.

4.4 Test results

Although most physio-chemical parameters were within acceptable water quality standards and tolerable ranges for aquatic life, there were significant variations in some parameters between tributary streams and across sites. These could be attributed mainly to variations in local riparian land uses and anthropogenic activities given the uneven geological template of Siyalima. (Tafangenyasha and Dube, 2005).

Significant spatial variations in sulphates and phosphates and temporal variations in all water quality parameters were observed, indicating the important role played by anthropogenic activities like agriculture and vehicular traffic as well as natural phenomena like water replenishments through runoffs in the riparian areas, rock formations on the upstream areas as well as vegetative cover. Temporal variations may be largely attributed to natural differences in the environments from which the tributary streams originate. (Wepener et al., 2009).

Water Test Result Analysis						
Parameter	**WHO Standards**	**Method Used**	**Sample 1**	**Sample 2**	**Sample 3**	**Sample 4**
pH	6.5-8.5	pH meter	**7.2**	**7.5**	**7.1**	**7.4**
Dissolved Oxygen (mg/L)	>5	Winkler Method	**6.8**	**5.5**	**7.0**	**4.5**
Nitrates (mg/L)	<50	Colorimetric Method	**10.0**	**20.0**	**15.0**	**35.0**
Phosphates (mg/L)	<0.5	Colorimetric Method	**0.4**	**1.2**	**0.6**	**2.5**
Total Dissolved Solids (mg/L)	<1000	Gravimetric Analysis	**700.0**	**800.0**	**750.0**	**950.0**
Chromium (mg/L)	<0.05	Atomic Absorption Spectroscopy	**0.0**	**0.1**	**0.0**	**0.1**
Turbidity (NTU)	<5	Nephelometric Method	**4.0**	**6.0**	**5.0**	**9.0**
Coliform (CFU/100mL)	0	Membrane Filtration	**20.0**	**50.0**	**30.0**	**100.0**

Table 6: Water test results

Soil Test Result Analysis					
Parameter	WHO Standards	Method Used	Sample 1	Sample 2	Sample 3
pH	6.5-8.5	pH meter	6.8	7	6.5
Nitrogen (mg/kg)	20-40	Kjeldahl Method	35	30	32
Phosphorus	10-20	Olsen Method	18	22	17
Potassium (mg/kg)	100-200	Flame Photometry	150	140	210
Organic Matter (%)	3-6	Loss on Ignition	4.5	4	4.3
Chromium (mg/kg)	<100	Atomic Absorption	90	110	95
Moisture Content	5-20	Gravimetric Analysis	15	18	16

KEY		
	Exceeding raage (warrants immediate attention)	>20% deviatio
	approaching limits of acceptable range (needs attention)	10%-20% Deviatio
	Within acceptable range	0-10% deviation

Table 7: Soil test results

4.4.1 Test results analysis

1. Chromium Levels: Sites 2 and the dam water show chromium levels exceeding WHO standards in both water and soil, indicating potential contamination from upstream chromium mining.

2. High phosphate levels and low dissolved oxygen in the dam water indicate signs of eutrophication, possibly due to runoff from agricultural and domestic activities.

3. Coliform presence in all water samples suggests significant microbial contamination, particularly in Sites 2 and the dam water, posing health risks.

4. Soil parameters are generally within acceptable ranges, except for chromium levels in Site 2 and the dam water, which need attention.

The results indicate significant environmental stressors affecting both water and soil quality across the tested sites. Chromium contamination, microbial presence, and signs of eutrophication in the dam highlight potential pollution sources, such as upstream mining and domestic activities. Agricultural runoff also contributes to nutrient loading in water bodies. Total coliform count indicates that the dam water is unsafe for human consumption.

4.4.2 Limitation of tests

The scope of tests conducted was limited due to budget constraints. The levels of these results fluctuate over time, and more extensive testing over a larger period is necessary to obtain a comprehensive understanding of the environmental conditions.

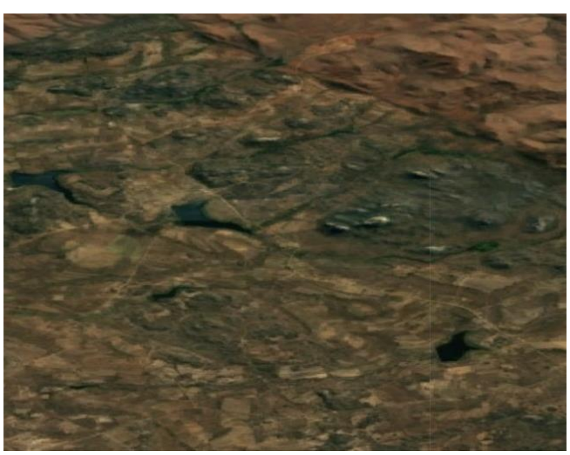
The tests done were composite to indicate average quality of parameters being tested over the test area.

Samples were preserved under chilled conditions immediately upon collection to maintain their integrity and prevent any alterations in quality before analysis. The samples were tested under strict lab conditions to prevent contamination and the methods used are as stated in the results.

Poverty has led to desperate activities, and in particular alluvial mining. The use of toxic substances to effluent from extract minerals such as chrome is slowly poisoning water with toxins that do not degrade easily. These are Chromium ions and copper, and further prolonged exposure to such toxins can result in serious health problems (Hutton, 1987). In addition, the excavation of riverbanks and transfer of soil into streams through chrome panning is changing the flow and nature of streams, leading to both physical and ecological damage to river systems.

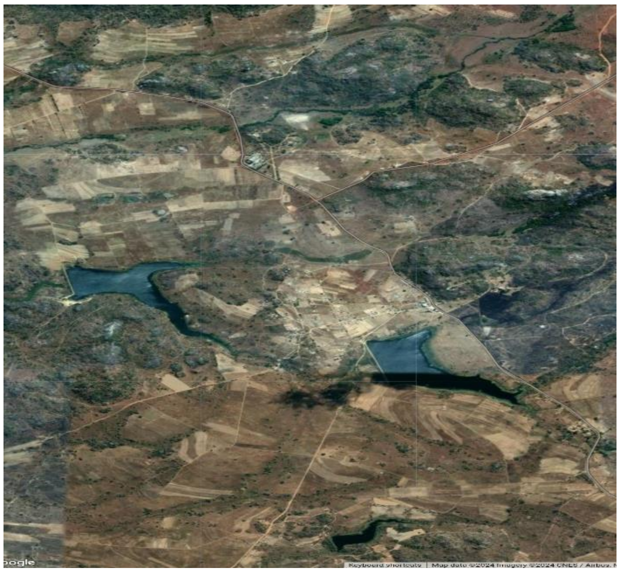
4.5 Land usage model, Spatial Data analysis

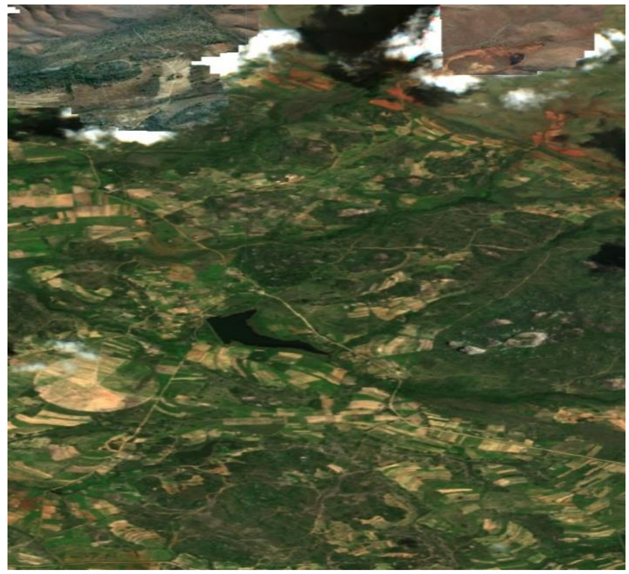
The Google Earth Engine script (Annex C) conducted a spatial analysis to identify non sources of pollution affecting siyalima dam using a trained random forest classifier (Breiman, 2001), the script categorized land cover into different classes, pin pointing areas with potential pollution sources. By examining land use patterns, the script identified areas with intensive agricultural activities, urbanization, and human settlement that may have contributed to pollution thus generating a land usage model (Novotny, 2003). The script also utilized The Hydro-SHEDS dataset to trace rivers and streams flowing into The Siyalima Dam, locating areas where pollution may have entered the waterbody (Lehner et al., 2011). The results were visualized, providing a spatial representation of land use, topography, and water bodies, informing watershed management strategies to mitigate pollution and protect The Siyalima Dam's water quality (USEPA, 2019).



Left Figure 13: Satellite imagery of Siyalima catchment land usage modelled from Copernicus 2A satellite.

Right Figure 14: terrain model of Siyalima catchment developed using GEE





Left Figure 15: Siyalima Catchment before script

Right Figure 16: Siyalima Catchment after script showing land usage model

4.6 Summary

The analysis revealed significant variations in water quality parameters across different sites. Key findings include elevated chromium levels at sites 2 and the dam, indicating contamination from upstream mining activities. Phosphate levels and low dissolved oxygen in the dam water suggest eutrophication, likely due to agricultural runoff. The presence of coliform bacteria in all samples points to microbial contamination, with sites 2 and the dam posing the highest health risks. Soil quality remained mostly within acceptable ranges, except for chromium levels at site 2 and the dam. The results highlight the need for targeted interventions to mitigate the impact of these contaminants.

4.7 Conclusion

The results of this study indicate that the Siyalima dam catchment area is experiencing significant environmental challenges due to both natural and anthropogenic factors. The contamination from chrome mining, agricultural runoff, and microbial pollution are critical issues that need addressing to ensure the sustainability of the water resources and the health of the local communities. Key findings include elevated chromium levels at sites 2 and the dam, indicating contamination from upstream mining activities. Phosphate levels and low dissolved oxygen in the dam water suggest eutrophication likely due to agricultural runoff. The presence of coliform bacteria in all samples points to microbial contamination with sites 2 and the dam posing the highest health risks. Soil quality remained mostly within acceptable ranges except for chromium levels at site 2 and the dam. The results highlight the need for targeted interventions to mitigate the impact of these contaminants. Future studies should focus on long-term monitoring and the implementation of remediation strategies to address these pollution sources effectively.

Chapter 5: Recommendations and Conclusions

5.1 Introduction:

This chapter presents the recommendations and conclusions drawn from the study's findings. The water quality in Siyalima Dam is compromised, posing risks to human health and the environment. Based on the results, immediate measures are necessary to reduce pollution, improve water treatment, and promote public health education. This chapter outlines the comprehensive approach required to protect this critical water resource.

A multi-faceted approach involving long-term and short-term measures is necessary to address the water pollution issues in the rural community. This approach will allow for immediate action to be taken to mitigate the effects of pollution, while also working towards sustainable solutions for the future.

5.1.1 Short-Term Measures

Emergency Water Treatment

Emergency water treatment measures can be implemented to provide clean drinking water to the community. This can be achieved through the distribution of water purification tablets or bleach, allowing residents to treat up to 20 liters of water per day.

Pollution Hotspot Monitoring

Pollution hotspot monitoring can be conducted to track changes and adjust interventions accordingly. This can be done through progressive monitoring and assessment of identified pollution hotspots.

Sanitation and Hygiene Promotion

Sanitation and hygiene promotion can be conducted through public awareness campaigns to promote good sanitation and hygiene practices, such as proper handwashing and waste disposal.

Community Education and Awareness

Community education and awareness can be conducted through public awareness campaigns, local meetings, posters, and word of mouth. For example, holding community meetings to educate residents about the risks of pollution and promote safe water practices.

Short-Term Water Quality Monitoring

Short-term water quality monitoring can be conducted using simple, low-cost water testing kits to monitor water quality.

Emergency Funding and Resources

Emergency funding and resources can be mobilized through local organizations and government agencies.

For example, partnering with local NGOs and government agencies to secure funding and resources.

Interim Waste Management.

Interim waste management can be established through temporary waste collection points and community-led waste management. For example, designating a community-led waste collection point and encouraging residents to participate.

Collaborative Task Force

A collaborative task force can be established with local stakeholders and authorities. For example, forming a task force comprising local community leaders, government officials, and environmental experts.

Rapid Assessment and Response

Rapid assessment and response can be conducted using local knowledge and resources to identify pollution sources and respond quickly. For example, using local knowledge to rapidly assess pollution levels and respond with targeted interventions.

Construction and Rehabilitation of Sedimentation Ponds

Construction and rehabilitation of sedimentation ponds along tributary streams can be implemented to reduce siltation and sediment load entering the dam. For example, building or rehabilitating sedimentation ponds along tributary streams.

Water Rationing

Water rationing can be implemented for small holder schemes drawing water from the dam for irrigation. These schemes should be registered with the Siyalima Irrigation scheme office for proper usage management, ensuring that water is used efficiently and sustainably.

Alternate Safe Sources of Drinking Water

Alternate safe sources of drinking water can be provided where feasible, such as boreholes or rainwater harvesting systems, to reduce reliance on contaminated dam water. The reported stomach problems among the sampled population emphasize the importance of public health education and improved water treatment (CDC, 2020)

5.1.2 Long-Term Measures

Enforceable Water Quality Standards

Establish and enforce strict water quality standards for the dam and its tributaries, including limits on pollutants like chromium, phosphates, and coliform bacteria.

Pollution Control Measures

Require industries and agricultural activities in the catchment area to implement pollution control measures, such as wastewater treatment and best management practices for nutrient loading.

Mining Regulations

Strengthen regulations on mining activities in the catchment area, including requirements for environmental impact assessments, pollution control, and rehabilitation of mined land.

Agricultural Runoff Management

Implement regulations and incentives for farmers to adopt best management practices for reducing nutrient runoff, such as buffer strips, cover crops, and conservation tillage.

Monitoring and Enforcement

Regularly monitor water quality and enforce regulations through inspections, penalties, and public disclosure of pollution sources.

Public Education and Awareness

Educate local communities, industries, and farmers about the importance of protecting the dam's water quality and the consequences of pollution.

Watershed Management Plan

Develop and implement a comprehensive watershed management plan, involving stakeholders from various sectors, to coordinate conservation efforts and address pollution sources.

Environmental Impact Assessments

Require environmental impact assessments for all new projects and activities in the catchment area, to identify and mitigate potential pollution risks.

Collaborative Governance

Foster collaborative governance among government agencies, local communities, industries, and other stakeholders to share responsibilities, resources, and expertise in protecting the Siyalima Dam.

Controlled Irrigation

Implement controlled irrigation systems for agricultural activities in the catchment area, ensuring that water is used efficiently and sustainably. This can include measures such as drip irrigation, sprinkler systems, and crop rotation.

By implementing these measures, the Siyalima community can take a comprehensive approach to addressing water pollution and enhancing the overall health and well-being of its residents. Effective water management practices will significantly reduce the risk of waterborne diseases, leading to a healthier and more productive population. Furthermore, the adoption of sustainable agricultural practices will not only promote environmental stewardship and conserve natural resources but also support the local economy. By diversifying their water sources and providing alternate safe sources of drinking water where feasible, the community can reduce its reliance on contaminated dam water and significantly improve public health. This comprehensive approach, which combines effective water management practices, pollution control measures, and collaborative governance, will help ensure a sustainable and healthy environment for the community. By working together towards this shared vision, the Siyalima community can effectively address the complex issue of water pollution and build a cleaner, healthier, and more prosperous future through sustainability.

Furthermore, the study's findings suggest that the dam's water levels are low, and the nearby scheme's yields are decreasing, indicating a need for efficient water management strategies (FAO, 2017). Additionally, the study's results highlight the need for regular monitoring and enforcement of regulations to prevent pollution from industrial and agricultural activities (UNEP, 2019).

Prolonged consumption of heavy metals, particularly chromium, can lead to severe health issues, including kidney damage, liver disease, and cancer (ATSDR, 2020). Chromium, a common pollutant from artisanal mining, can accumulate in the body over time, causing long-term health problems (WHO, 2018). Therefore, it is essential to address the issue of heavy metal pollution in the dam's water to prevent long-term health risks for the surrounding communities.

5.2 Recommendations for further research

While this study has provided valuable insights into the impacts of water pollution on human, aquatic, and environmental health in the Siyalima Dam catchment area, there are several limitations that should be acknowledged and addressed in future research (Fink, 1995; Creswell, 2014). Firstly, the sample size of 70 participants may be too small to be representative of the entire population, which could limit the generalizability of the findings (Krejcie & Morgan, 1970).

Additionally, the cluster sampling method used may not have fully accounted for other sources of bias or variability (Lohr, 2010). Furthermore, the reliance on self-reported data from questionnaires and interviews may be subject to biases and inaccuracies (Podsakoff et al., 2003). The spatial data analysis may have been limited by the availability and quality of the data, as well as the methods used to analyze it (Longley et al., 2015). The water and soil tests may have been limited by the specific parameters tested and the methods used, which may not have fully captured the complexity of water pollution (WHO, 2017). Future studies should aim to address these limitations by increasing the sample size, using more robust sampling methods, and incorporating additional data collection methods such as observational studies or experimental designs (Shadish et al., 2002).

Additionally, future studies could benefit from more advanced statistical methods to fully capture the complexity of the data (Gelman & Hill, 2006). Furthermore, future studies could explore other indicators of water pollution and its impacts on human, aquatic, and environmental health (UNEP, 2016). It would also be beneficial to conduct longitudinal studies to capture changes over time and to control for extraneous variables that could affect the results (Menard, 2002). Finally, future studies could aim to generalize the findings to other populations and contexts, and to explore the implications of the findings for policy and practice (WHO, 2018).

5.3 Conclusion:

In conclusion, the water quality in Siyalima Dam is compromised, posing risks to human health and the environment. Immediate measures are necessary to reduce pollution, improve water treatment, and promote public health education. A comprehensive approach incorporating pollution reduction, water treatment, monitoring, and public education is necessary to protect this critical water resource. The findings of this study highlight the need for sustainable water management and conservation strategies to address the low water levels and decreased yields in the nearby scheme. By implementing these recommendations, the water quality in Siyalima Dam can be improved, protecting the health and well-being of the surrounding communities.

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List of annexures.

Annexure A Questionnaire.

Tafadzwa Mwenje Questionnaire on Siyalima Dam Water Usage

How old are you? (years)	***(Tick where appropriate)***	*Below 20*	*20-30*	*30-40*	*40-50*	*Older than 50*				
How long have you been living in Siyalima?		*Less than 1 year*	*Less than 5 years*	*Less than 10 years*	*Longer than 10 years*					
What is your profession?		*Farmer*	*Miner*	*Civil service*	*Fisherman*	*Other*				
Do you have any interaction with Siyalima dam? How?		*Yes*	*No*	***How?***	Irrigation	*Drinking*	*Domestic use (cleaning & washing)*	*Livestock (drinking & dipping)*		
Where do you get your drinking water?		*Well*	*Borehole*	*River*	*Dam*	*Other*				
Have you or any member of your close family (living in Siyalima) suffered from any water related illnesses e.g. cholera dysentery, typhoid...e.t.c		*Yes*	*No*	***If yes how long has it been?***	*>1 mnths*	*>6 mnths*	*>1 yr*	*>2 (yrs)*	*>5 (yrs)*	*>10 (Yrs)*

<table>
<tr><td>Is it a recurring illness or was it once off?</td><td></td><td><table><tr><td>Recurring</td><td>Once off</td></tr><tr><td></td><td></td></tr></table></td></tr>
<tr><td>Did you get any medical assistance?</td><td></td><td><table><tr><td>Yes</td><td>No</td><td rowspan="2">Where?</td><td>Local clinic</td><td>Hospital</td><td>Traditional herbs</td><td>Other</td></tr><tr><td></td><td></td><td></td><td></td><td></td><td></td></tr></table></td></tr>
<tr><td>Do you irrigate? Which irrigation method do you use?</td><td></td><td><table><tr><td>Yes</td><td>No</td><td rowspan="2">Which irrigation method do you use?</td><td>Sprinkler</td><td>Drip</td><td>Centre Pivot</td><td>Flood</td><td>Other</td></tr><tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr></table></td></tr>
<tr><td>How big is your pump? How long are your cycles?</td><td></td><td><table><tr><td>Pump size (HP)</td><td>Cycle (days)</td></tr><tr><td></td><td></td></tr></table></td></tr>
<tr><td>Do you have any soil conservation measures in place? i.e. Contours storm drains etc.</td><td></td><td><table><tr><td>Yes</td><td>No</td><td rowspan="2">What condition are they in?</td><td>Excellent</td><td>good</td><td>ok</td><td>Need rehabilitation</td></tr><tr><td></td><td></td><td></td><td></td><td></td><td></td></tr></table></td></tr>
</table>

- How many hectares do you irrigate? [ ] *Hectares*
- Where do you draw your irrigation water from? [ ]
- How much fertiliser can you say you use per

  Hectare per season? [ ] *Litres*

Hoeing	*Chemical*	*Other*

- Which weeding method do you use?

- How much chemical do you apply for weeding per season per hectare? [ ] *Hectares*

- How much chemical do you apply for pest control per Season per hectare? [ ] Litres
- How many crops do you grow a year? [ ]
- Are there any mining activities in your area? (2km radius)

Yes	*No*

- What is being mined [ ]
- How far away do you live from Siyalima dam? [ ] Km

General comment on the state of Siyalima dam?

Very well maintained	Maintained	In condition	Ok	Needs attention	Neglected

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Annexure B: Cluster Sampling Framework.

Cluster Sampling Framework:

Population: Residents living in the Siyalima Dam catchment area

Clusters: Grouped by proximity to a mine and dam, history of recurring waterborne illnesses, source of drinking water, and domestic use of the dam

Criteria for forming clusters:

1. Proximity to a mine (within 1 km or more than 1 km)

2. Proximity to the Siyalima Dam (within 1 km or more than 1 km)

3. History of recurring waterborne illnesses in the past 6 months (yes or no)

4. Source of drinking water (drinking water from the Siyalima Dam or not)

5. Domestic use of the dam (using the dam for cleaning, washing, or bathing, or not)

Number of clusters: 16

Clusters:

Cluster 1: Residents living within 1 km of a mine and within 1 km of the Siyalima Dam, with a history of recurring waterborne illnesses, and drinking water from the dam

Cluster 2: Residents living within 1 km of a mine, but more than 1 km from the Siyalima Dam, with a history of recurring waterborne illnesses, and drinking water from the dam

Cluster 3: Residents living more than 1 km from a mine, but within 1 km of the Siyalima Dam, with a history of recurring waterborne illnesses, and drinking water from the dam

Cluster 4: Residents living more than 1 km from both a mine and the Siyalima Dam, with no history of recurring waterborne illnesses, and not drinking water from the dam

Cluster 5: Residents living within 1 km of a mine and within 1 km of the Siyalima Dam, with no history of recurring waterborne illnesses, and drinking water from the dam

Cluster 6: Residents living within 1 km of a mine, but more than 1 km from the Siyalima Dam, with no history of recurring waterborne illnesses, and not drinking water from the dam

Cluster 7: Residents living more than 1 km from a mine, but within 1 km of the Siyalima Dam, with no history of recurring waterborne illnesses, and not drinking water from the dam

Cluster 8: Residents living more than 1 km from both a mine and the Siyalima Dam, with a history of recurring waterborne illnesses, and not drinking water from the dam

Cluster 9: Residents living within 1 km of a mine and within 1 km of the Siyalima Dam, with a history of recurring waterborne illnesses, and using the dam for domestic purposes

Cluster 10: Residents living within 1 km of a mine, but more than 1 km from the Siyalima Dam, with a history of recurring waterborne illnesses, and using the dam for domestic purposes

Cluster 11: Residents living more than 1 km from a mine, but within 1 km of the Siyalima Dam, with a history of recurring waterborne illnesses, and using the dam for domestic purposes

Cluster 12: Residents living more than 1 km from both a mine and the Siyalima Dam, with a history of recurring waterborne illnesses, and using the dam for domestic purposes

Cluster 13: Residents living within 1 km of a mine and within 1 km of the Siyalima Dam, with no history of recurring waterborne illnesses, and using the dam for domestic purposes

Cluster 14: Residents living within 1 km of a mine, but more than 1 km from the Siyalima Dam, with no history of recurring waterborne illnesses, and using the dam for domestic purposes

Cluster 15: Residents living more than 1 km from a mine, but within 1 km of the Siyalima Dam, with no history of recurring waterborne illnesses, and using the dam for domestic purposes

Cluster 16: Residents living more than 1 km from both a mine and the Siyalima Dam, with no history of recurring waterborne illnesses, not drinking water from the dam, and not using the dam for domestic purposes

Sample size: 4-5 residents from each cluster (total sample size = 70)

Annexure C Google Earth Engine Land Use Hydro-SHED modelling script

```
// Define UTM Zone 36K projection
Var utm36K = ee.Projection('EPSG:32736');
// Define the new region of interest (ROI) using the provided UTM coordinates
Var newROI = ee.Geometry.Polygon([[
  26507600, 816039600
], [
  26996400, 815586400
], [
  27635600, 815937800
], [
  26859200, 816465300
]], utm36K, false);
// Reproject the new ROI to WGS84 Lat Lon
Var newROIWGS84 = newROI.transform(ee.Projection('EPSG:4326'), 1);
// Print the new ROI in WGS84 projection
Print('New ROI in WGS84 projection:', newROIWGS84);
// Load a land cover dataset (e.g. Copernicus Global Land Cover Layers)
Var landCover = ee.ImageCollection('COPERNICUS/Landcover/100m/Proba-V/Global/first');
// Select all bands available for land cover classification
```

```
Var bands = landCover.bandNames().remove('discrete_classification');

// Sample the land cover dataset within the ROI

Var training =
landCover.select(bands).addBands(landCover.select('discrete_classification')).sampleRegion({

  Region: newROIWGS84,

  Scale: 10,

  numPixels: 1000,

  seed: 0

});

// Print the training data

Print('Training Data:', training);

// Train a classifier (e.g. RandomForest) using the training data

Var numberOfTrees = 100;

Var classifier = ee.Classifier.smileRandomForest(numberOfTrees).train({

  Features: training,

  classProperty: 'discrete_classification',

  inputProperties: bands

});

// Print the trained classifier

Print('Trained Classifier:', classifier);

// Classify the image using the trained classifier

Var classified = landCover.select(bands).classify(classifier);
```

```
// Define color palette for land cover classes

Var palette = ['1B5E20', '1565C0', '1A237E', 'B71C1C'];

// Display the classified image with custom palette

Map.centerObject(newROIWGS84, 10);

Map.addLayer(classified.clip(newROIWGS84), {min: 0, max: 3, palette: palette}, 'Land Cover
Classification');

// Load SRTM DEM data

Var dem = ee.Image('USGS/SRTMGL1_003');

// Generate contour lines

Var contourInterval = 10;

Var contours = ee.Algorithms.TerrainDem(dem).select('elevation').reduceToVectors({

  Geometry: newROIWGS84,

  Scale: 10,

  geometryType: 'polygon',

  eightConnected: false,

  labelProperty: 'elevation',

  maxPixels: 1e8

}).filter(ee.Filter.notNull('elevation')).map(function(f) {

  Return f.set('elevation', ee.Number(f.get('elevation')).round());

});

// Add contour lines to the map

Map.addLayer(contours, {palette: 'yellow'}, 'Contours');
```

```
// Define a function to create elevation labels

Function addElevationLabels(feature) {

  Var elevation = ee.Number(feature.get('elevation'));

  Var text = elevation.format('Elevation: %.2f meters');

  Return feature.set('text', text);

}

// Map the function over the contours to add elevation labels

Var labeledContours = contours.map(addElevationLabels);

// Display elevation labels for each contour

Map.addLayer(labeledContours, {color: 'cyan', strokeWidth: 1}, 'Elevation Labels');

// Load Sentinel-2A imagery

Var sentinel2 = ee.ImageCollection('COPERNICUS/S2').filterBounds(newROI).filterDate('2021-01-01',
'2021-12-31').sort('CLOUDY_PIXEL_PERCENTAGE').first();

// Visualize Sentinel-2 imagery

Map.centerObject(newROIWGS84, 10);

Map.addLayer(sentinel2, {bands: ['B4', 'B3', 'B2'], min: 0, max: 3000}, 'Sentinel-2 Imagery');

// Load the HydroSHEDS dataset (rivers and streams)

Var hydrosheds = ee.FeatureCollection('WWF/HydroSHEDS/v1/Basins/hybas_7');

// Filter rivers and streams within the ROI
```