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MICROBIAL CONTAMINATION, CHEMICAL HAZARDS, AND ANTIMICROBIAL RESISTANCE PATTERNS IN WATER FROM HIGH- AND LOW-DENSITY RESIDENTIAL AREAS OF MUTARE, ZIMBABWE: A STUDY OF WATER QUALITY IN 2025.

BY

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Abstract

This study investigates microbial contamination, chemical hazards, and antimicrobial resistance (AMR) patterns in water samples from high- and low-density residential areas of Mutare, Zimbabwe in 2025. With recent outbreaks of cholera and rising concerns about waterborne diseases, the research aimed to assess the water quality in areas like Sakubva, Chikanga, Murambi, and Greenside Extension. Using culture-based techniques and atomic absorption spectroscopy (AAS), the presence of bacterial species such as *Escherichia coli* and heavy metals (lead, mercury, arsenic) was determined. The findings showed significantly higher levels of microbial and chemical contaminants in high-density suburbs, particularly Sakubva, which also recorded the highest mean concentrations of lead and arsenic. The isolated *E. coli* strains exhibited varying antibiotic resistance patterns, with the highest resistance to Chloramphenicol and Tetracycline, while Ciprofloxacin remained the most effective. These results underscore the urgent need for improved water sanitation hygiene (WASH) infrastructure, monitoring of free residual chlorine (FRC), and targeted interventions by local authorities. The study highlights the disparities in water safety and calls for integrated efforts to mitigate public health risks in urban Zimbabwe.

Declaration

I, Tendai Mukupe, student number 210299 do hereby declare that this proposal is my original work except where sources have been cited and acknowledged. The work has never been submitted, nor will it ever be submitted to another university for the award of a Bachelor of Science degree.

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Acronyms and Abbreviations

CDC- Centers for Disease Control and Prevention

UNICEF- United Nations Children's Fund

WHO- World Health Organization

EPA- Environmental Protection Agency

WASH- Water Sanitation Hygiene

FRC- Free residual chlorine

PCR- Polymerase chain reaction

MJWTW- Morton Jaffray Water Treatment Works

AMR- Antimicrobial Resistance

ARB- Antibiotic Resistant Bacteria

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Chapter 1: Introduction

The primary purpose of this research is to identify the contaminants present in the water of high- and low-density residential areas of Mutare as well as the effects of these on the health of civilians. The comparison of results found in the different residential areas will help in the analysis of the spontaneity of waterborne illnesses in specific areas and aims to provide better understanding.

1.1 Background

Microbial contaminants of potable water include bacteria (*Shigella, Escherichia coli, Vibrio and Salmonella*), viruses (such as Norwalk virus, and rotaviruses) and protozoans (Entamoeba, Giardia and Cryptosporidium). Infectious microorganisms may be present in human or animal waste and cause contamination to drinking water sources by storm water run-off from roadways, farms and livestock operations, discharges from sewage treatment plants or septic system discharges (WHO, 2022). The symptoms which are associated with the use of water containing these contaminants include: nausea, vomiting, diarrhea and stomach cramps. Such symptoms may indicate the following illnesses: cholera, typhoid, hepatitis A and polio, with cholera and typhoid being the most fatal in Africa. In 2008 Zimbabwe experienced the most devastating cholera outbreak in Africa after 15 years due to contaminated water. In this outbreak 4,200 died and at least 100,000 were infected Due to the concern of fundamental issues like access to sanitation and access to clean water not having been addressed meaningfully, the issue resurfaced in September 2018. In total, the country reported more than 10,000 cases and 69 deaths. Throughout 2019 the CDC worked with UNICEF and the environmental health department to improve monitoring of free residual chlorine (FRC) in municipal water and evaluate inline chlorinators installed on hand pumps (Global Waters, 2019). However, even with these measures, concerns of the water quality have continued to be raised. The most recent cholera outbreak in the country having started in February of 2023 and only ending in June of 2024 implies truth to the concern of residents as the outbreak claimed 455 lives throughout its duration (WHO, August 2024). On a global scale, countries have varying regulations regarding acceptable levels of microbial contaminants in drinking water, however, WHO provides guidelines. These may be hard to enforce consistently in some countries as compared to others. The UN also has sustainable development goals which aim to ensure availability and sustainable management of water for all with the emphasis on the need for safe drinking water. The measurements being put in place include regulatory frameworks, water treatment technologies, improved sanitation and hygiene, public health initiatives and international collaboration.

1.2 Problem Statement

Water quality is essential for drinking, recreation, and agriculture, yet Mutare faces challenges related to water safety and periodic cholera outbreaks. While the city has fewer water challenges compared to Harare, recent cholera outbreaks highlight vulnerabilities in water supply and sanitation systems warranting an analysis. (Mapira, 2011)

Mutare's water infrastructure serves a growing population, with aging pipes and inconsistent chlorination posing risks of contamination. Municipal water quality monitoring often reveals inconsistencies in free residual chlorine levels, which may fall below the WHO-recommended 0.5 mg/L.

Additionally, mining activities upstream pose a significant threat to water quality. Runoff from mining operations can introduce heavy metals such as mercury, lead, and arsenic into water sources, increasing health risks for residents. These contaminants can accumulate over time, making water unsafe for consumption and agricultural use.

Chemical hazards, including lead and arsenic from industrial runoff and pipe corrosion, also pose potential risks to drinking water safety. In high-density areas such as Sakubva, residents often have burst sewer systems, which may be vulnerable to contamination due to inadequate sanitation infrastructure. Low-density areas have better access to treated water and better contained sewer systems, highlighting disparities in water safety and accessibility.

While cholera vaccination campaigns and the AMR National Action Plan are steps in the right direction, long-term solutions require continuous investment in water, sanitation, and hygiene (WASH) infrastructure. A comprehensive assessment of microbial contamination, antimicrobial resistance, and chemical hazards in Mutare's water sources is essential to inform policy and protect public health so that Mutare maintains its status as a clean city.

1.3 Research Objectives

1.3.1 Broad Objectives

This research aims to:

To assess the microbial contamination, chemical hazards, and antimicrobial resistance patterns in water from high- and low-density residential areas of Mutare City in 2025

1.3.2 Specific objectives

The study specifically seeks to:

1. Determine the microbial safety in the water supplied to the high- and low-density suburbs of Mutare City in 2025.
2. Assess the antimicrobial resistance patterns in the organisms isolated
3. Evaluate the presence and concentrations of heavy metals (lead, mercury, arsenic), in water samples from high- and low-density residential areas of Mutare using atomic absorption spectroscopy (AAS)

1.4 Research Questions

The questions which this research seeks to answer are:

1. Which bacteria are found in water supplied to the high- and low-density suburbs of Mutare in 2025?

2. To what extent does Mutare city water meet microbial water quality standards and guidelines for safe human consumption, considering the presence of potentially harmful microorganisms or indicators of contamination?

3. How do factors such as water source type, treatment methods, and distribution network characteristics influence the microbial composition and abundance in Mutare city water?

1.5 Justification of the Study

A study investigating microorganisms in Mutare city water is justified for several reasons. Public health concern being the main focus. The presence of microorganisms in water can pose significant risks to public health as they can cause waterborne diseases. Understanding the microbial composition and potential sources of contamination is crucial for safeguarding public health and implementing appropriate interventions to minimize the risk of illness. Water quality assurance is also a key element as this investigation will evaluate the effectiveness of water treatment processes, hence enabling authorities to take corrective actions to maintain and improve water quality standards. Furthermore, Mutare city water can provide insights into the state of water infrastructure and distribution networks. By identifying sources of contamination, and understanding how microorganisms enter the water supply system, authorities can implement targeted infrastructure improvements, maintenance and management to enhance the reliability and safety of water.

1.6 Delimitations of the study

1. To ensure that the study remains focused, feasible, and achievable within the given time and resource constraints, the following delimitations were applied:
2. Geographic Scope

   The study was geographically limited to Mutare City, specifically targeting water sources and distribution systems within the city limits. This delimitation ensures a localized focus and avoids the complexities associated with sampling and analyzing water from external or rural sources.
3. Microbial Focus

   The study will be limited to the analysis of bacterial contaminants, excluding other microorganisms such as viruses, protozoa, or fungi. This restriction enables a more targeted investigation into bacterial water quality indicators and simplifies laboratory processes.
4. Sampling Locations

   Water samples will be collected from pre-selected sites representing both high-density residential areas (e.g., Sakubva and Chikanga) and low-density residential areas (e.g., Greenside Extension and Murambi). These areas were chosen to facilitate a comparative analysis while ensuring manageable field logistics and representativeness.

5. Analytical Methods

   The identification of bacterial species will rely exclusively on culture-based microbiological techniques. This delimitation excludes molecular or rapid diagnostic methods and reflects the study's alignment with available laboratory resources and technical capacity.

1.7 Limitations of the Study

While every effort has been made to ensure the rigor and relevance of this research, the study is subject to the following limitations:

1. Restricted Geographic Scope

   As the study is confined to Mutare City, the findings may not be generalizable to other urban centers or rural areas in Zimbabwe. Environmental, infrastructural, and socio-economic variations elsewhere may influence water quality differently.

2. Exclusion of Non-Bacterial Contaminants

   The exclusive focus on bacterial contaminants excludes potential viral, protozoal, or fungal pathogens that may also pose health risks. As such, the microbiological profile presented does not represent the full spectrum of waterborne hazards.

3. Limited Sampling Points

   The number and location of sampling sites were restricted to selected high- and low-density suburbs due to logistical and time constraints. This may limit the representativeness of the water quality status across the entire city.

4. Use of Culture-Based Techniques Only

The reliance on culture-based microbiological methods may result in the under-detection of fastidious or non-culturable bacterial species. In addition, chemical hazards such as heavy metals were only assessed using selected parameters, which may not capture the full range of possible contaminants

5. Temporal Constraints

The study is cross-sectional, capturing water quality at a specific point in time. Seasonal variations, which may influence both microbial and chemical contamination levels, were not considered in this design.

1.8 Summary

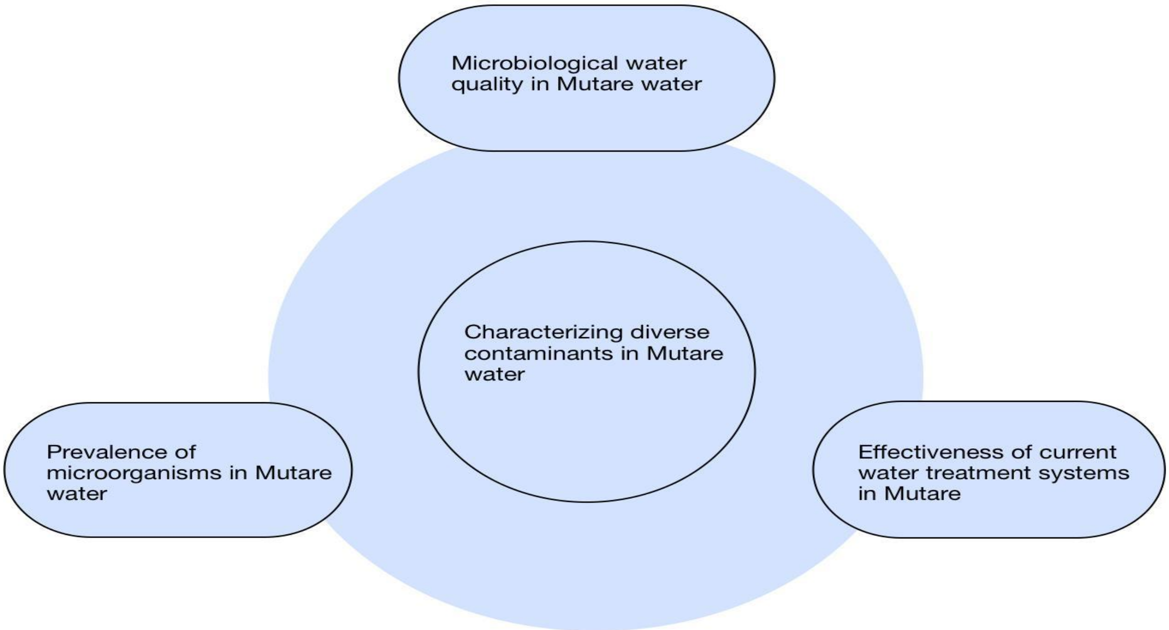
This chapter highlighted the problem at hand. Mutare is at risk of facing water challenges and the portable water may be of very low quality in terms of microbial load and chemical contaminants. The goal of this study is to determine the water quality of high- and low-density areas in the city.

Chapter 2: Literature Review

2.1 Introduction

This literature review aims to explore and synthesize existing knowledge on the investigation of contaminants in Mutare city water. It will provide a comprehensive overview of relevant studies, research findings, and methodologies employed in contamination in the water supply system. The review will focus on studies conducted within Mutare city limits, considering both peer-reviewed scientific literature and gray literature sources, such as government reports and technical documents. The review will address several key research questions, as illustrated by the conceptual framework below. By critically examining the existing body of knowledge, this review will identify gaps, inconsistencies, and areas requiring further investigation.

2.2 Conceptual Framework



2.3 Relevance of the Framework

The objective of the study is to characterize the diverse bacterial, viral, and other microbial species in the water supplied to Mutare City' s suburbs for 2025. The framework shows that the outcome of the study will be affected by these variables: the prevalence of microorganisms in Mutare city water, the microbiological water quality in Mutare city water and the effectiveness of current water treatment methods in eradicating or managing microbial populations in water supplied in Mutare. The literature review will explore existing literature on each variable.

2.3.1 The Prevalence of Contamination in Mutare Water Sources

Water contamination in Mutare has been a growing concern. Research concluded unsatisfactory bacteriological test results increasing from 2019 to 2023 (Mukuzunga et al, 2022). The presence of coliform bacteria (>1 coliform/100ml of water) indicates fecal contamination primarily in high density areas with inadequate sanitation and infrastructure. The sources of this microbial contamination were several. Inadequate waste management being a main one as poorly segregated waste and open defecation contribute to water contamination, particularly in high density suburbs. Additionally, sewage overflows and leakages also play a major role as malfunctioning sewer systems lead to direct contamination of community water points. Lastly the use of unprotected water sources contributed to microbial contamination due to limited clean water access, residents in high density areas rely on rivers, wells, and boreholes, many of which tested positive for bacterial contamination. The report goes on to state that even following the cholera outbreak of 2022 in Mutare, there were still limited water sources in some areas. This made the community continue using unsafe water sources such as water from rivers and unprotected wells with limited aqua tabs to purify the water hence exposing the, to water related illnesses such as cholera, typhoid, and dysentery. Additionally, there is an emergence of resistant *Salmonella* and *Vibrio*, particularly in areas with Sanitation and frequent outbreaks of waterborne diseases. The Sakubva and Dora rivers are heavily polluted due to urbanization, industrial discharge, and inadequate sewage treatment. The Gimboki Sewage Treatment Plant in Mutare is overburdened, processing 90 million liters of sewage per day while the capacity is only 41 liters. Due to infrastructure problems such as sewer bursts and power cuts, raw sewage discharges into the Sakubva river hence exacerbating contamination downstream. The bacteriological analysis of these rivers indicates high coliform counts, confirming fecal contamination especially near human settlements, increasing the risk of waterborne diseases (Basvi et al, 2018).

2.3.2 Chemical and Metallic Hazards in Mutare Water Sources

Industrial and agricultural activities contribute to chemical pollution in Mutare's water sources. Key contaminants include lead, arsenic, mercury from industrial waste as well as nitrates and phosphates from agricultural runoff, leading to eutrophication and oxygen depletion in water bodies. Unregulated urban farming and livestock rearing near riverbanks contribute fertilizers, pesticides and animal waste to water pollution. The elevated levels of nitrates and phosphates have been recorded in the Sakubva and Dora Rivers, leading to algal blooms that degrade water quality and threaten aquatic life. Frequent exposure to sublethal levels of chlorine, antibiotics, and industrial chemicals promotes the development of antibiotic-resistant bacteria (ARB) in Mutare's water sources (Basvi et al, 2018). Studies have identified multi drug resistant (MDR) E. coli in community boreholes. In low density areas industrial pollutants may indirectly contribute to the development of AMR by exerting selective pressure on microbial communities (Mukuzunga et al, 2022).

2.3.3 The Effectiveness of Current Water Treatment Methods

Access to clean and safe water is essential for public health and sustainable urban development. In Mutare, water treatment faces challenges which include aging infrastructure, inadequate sewage treatment and water losses due to leaks. The absence of water pollution control policies in Mutare contributes to the unchecked disposal of hazardous chemicals. High density areas experience seasonal water shortages forcing residents to use contaminated alternative sources while low density areas benefit from more reliable municipal water. Currently, aqua-tabs (chlorine-based disinfectants) are used but in limited supply leading to inconsistent water disinfection in high density areas. Additionally, the lack of pH and turbidity monitoring results in poor chemical balance in drinking water. The city of Mutare was losing millions of dollars' worth of treated water due to leakages in outdated pipelines (Chirisa, 2010). This reduces the overall effectiveness of treatment efforts as a large portion of treated water never reaches consumers. Efforts to replace these pipelines have been largely ineffective as maintenance costs remain high and funding is limited. Additionally, the three sewage treatment plants of Mutare also have shortcomings of frequent blockages, equipment failures and incomplete infrastructure projects, leading to poor sewage treatment. When untreated or partially treated sewage water is discharged into nearby rivers it contaminates drinking water sources, increasing the risk of waterborne diseases such as cholera and typhoid. The lack of consistent maintenance and expansion of these facilities reduces the overall effectiveness of wastewater treatment in the city. Water treatment methods used in Zimbabwe may be dated and therefore not supply the highest quality of water as compared to the advanced multi-stage water treatment processes used in developed countries such as reverse osmosis and ultrafiltration, ozonation, ultraviolet disinfection and desalination just to name a few (Mojiri, 2022).

2.4 Summary

All of these publications show how difficult it is for Harare to manage its water resources, deliver dependable water services, and guarantee clean drinking water. They highlight the necessity of all-encompassing approaches to deal with these problems and advance sustainable water management in Mutare, Zimbabwe, including legislative changes, infrastructural upgrades, and public health initiatives.

Chapter 3: Methodology

3.1 Introduction

This chapter will detail the methods and techniques used to collect data for the investigation of microorganisms in Harare city water, comparing between high and low densities. By examining the microbial populations in different water sources commonly used by the population, a comprehensive assessment of the microbial contamination levels was obtained. The findings of this investigation provided valuable insights into the microbial quality of water in Harare and highlighted potential disparities between high-density and low-density areas.

3.2 Study Design

The investigation was conducted as a cross-sectional study, comparing water samples from different locations in Mutare city. The study focused on comparing high-density areas (such as urban centers or densely populated neighborhoods) with low-density areas (such as suburban or rural areas) to assess the differences in microorganism densities.

3.3 Sampling Locations

Representative sampling sites in both high-density and low-density areas of Mutare City were selected. High-density areas included Sakubva and Chikanga, while low-density areas included Greenside Extension and Murambi. The selected sites covered a range of water sources—such as taps, boreholes, wells, rivers, and lakes—in order to capture the diversity of water sources used by the population.

3.4 Sample Collection

Standard protocols for water sample collection to ensure accuracy and consistency were followed. Thereafter multiple samples were collected from each selected location to account for temporal and spatial variability. Water was collected in pre labeled sterile containers to avoid contamination and then they were immediately sealed and taken to the laboratory.

3.5 Microorganism Analysis

Laboratory analysis on the collected water samples to determine the presence and density of microorganisms were performed. To do so, total coliform count, fecal coliform count, and identification of specific microbial pathogens were conducted with the use of lauryl sulfate media, and biochemical tests.

3.6 Data Analysis

To assess the microbial safety of water in high- and low-density suburbs of Mutare City, descriptive statistics were used to summarize contamination levels, including frequency distributions, means, and standard deviations. Comparative analysis, using Chi-square tests, determined if there were significant differences in microbial presence between the two residential areas. The microbial load was quantified by analyzing colony-forming unit (CFU) counts, categorizing samples according to standard water quality guidelines. (WHO, 2022)

For the assessment of antimicrobial resistance (AMR) patterns, descriptive statistics was applied to summarize the resistance profiles of bacterial isolates, including the percentage of resistance for various antibiotics. Comparative analysis using Chi-square tests determined significant differences in resistance rates between different locations.

To evaluate the presence and concentrations of heavy metals (lead, mercury, and arsenic), descriptive statistics was used to report mean, median, and standard deviation values of metal concentrations, comparing them against WHO drinking water quality standards. t-tests were used to determine significant differences in heavy metal concentrations between high- and low-density areas.

3.7 Ethical Considerations

Ethical approval was sought from Mutare city council as well as Africa University Research Ethics Council prior to conducting the study.

3.8 Summary

By following this methodology, the investigation provided valuable insights into the prevalence of microorganisms in Mutare city water, comparing high-density and low-density areas. The findings can contribute to evidence-based decision-making and the development of strategies to improve water quality and protect public health in Mutare, Zimbabwe.

Chapter 4: Data Analysis and Presentation

This chapter is for the results presentation, discussion and of the comparative Analysis of Microbial Contamination, Chemical Hazards, and Antimicrobial Resistance Patterns in Water from High- and Low-Density Residential Areas of Mutare, Zimbabwe: A Study of Water Quality in 2025. In this chapter, the exploration of the report on the bacterial species in the water supplied to the high- and low-density suburbs of Mutare City for the period. It also evaluated the presence and concentrations of heavy metals (lead, mercury, arsenic), in water samples from high- and low-density residential areas of Mutare in 2025. Additionally, the assessment of the antimicrobial resistance patterns in the organisms isolated was also displayed. Lastly, the chapter summary was provided.

4.1 Demographics of samples tested

This section provided the data for the samples that were tested for the microbial contamination, chemical hazards, and antimicrobial resistance patterns. The data showed that Sakubva had the most collected samples (10; 33.3%) whilst Murambi had the least samples collected (5; 16.7%). The table below showed that for the densely populated areas of Chikanga and Sakubva a total of 29 samples constituting 63.3% were collected for testing. However, for the lowly populated areas of Murambi and Greenside extension a total of 11 samples were collected constituting a percentage of 36.7%.

Table 4.1 Demographics of the samples collected for testing

Sample collection sites	Sample numbers collected	Percentage (%)
Chikanga	9	30.0
Sakubva	10	33.3
Greenside extension	6	20.0
Murambi	5	16.7
Totals	**30**	**100**

Source: Primary data, (2025).

4.2 The bacterial species in the water supplied to the high- and low-density suburbs of Mutare City for the period in 2025

This section provided the results of the bacterial contamination that were found in the water supplied to high- and low-density suburbs of Mutare city in 2025. The table below showed the prevalence of bacteria and the suburbs.

Table 4.2 The bacterial contamination (*E.coli*) in the water supplied to the high- and low-density suburbs of Mutare City for the period in 2025

Sample collection sites	Bacterial contamination
	E. coli
Chikanga	33.3% (3)
Sakubva	40% (4)

Densely populated Total	73.3% (7)
Greenside extension	30% (2)
Murambi	20% (1)
Lowly populated total	50% (3)

Source: Primary data, (2025)

The data in table 4.2 showed that the densely populated areas of Sakubva and Chikanga had the highest prevalence of bacterial contamination, than lowly populated areas. It was noted that *E. coli* was most found in Sakubva (40%) which is a densely populated area and combining with the Chikanga results it adds up to 73.3% for the bacteria. However, this is more than the values obtained in low populated areas of Murambi and Greenside Extension which had small differences which added up to 50% for the presence of E. coli though Greenside Extension had slightly higher value (30%).

The results were tested for the significance difference between densely populated bacteria species and lowly populated bacteria species. The hypothesis was tested using Chi-squared test at 0.01 and v=15.9 degrees of freedom).

H_0: There is a significant difference between densely populated bacteria species and lowly populated bacteria species.

H_1: There is no significant difference between densely populated bacteria species and lowly populated bacteria species.

The results showed that 1.753< 15.771, therefore there was no basis to reject H_0, hence the results showed a significant difference between bacteria species in low and densely populated areas of Mutare.

Table 4.3 Result of the bacterial contamination in the water supplied to the high- and low-density suburbs of Mutare City for the period in 2025 in comparison with WHO Recommended Standard values.

Biological parameter	Sakubva	Chikanga	Murambi	Greenside Extension	**WHO**	**Remarks**
Total coliforms	**3**	**4**	**2**	**1**	**0**	**All exceeded**

Source: Primary data, (2025)

The table showed that all of the suburb water exceeded the recommended WHO values for the total coliforms that should be found in drinking water. This however, showed that all the water seemed to be contaminated.

4.3 The results of the assessment of the antimicrobial resistance patterns in the organisms isolated

This section showed the results of the antimicrobial resistance patterns of the isolated bacteria.

Table 4.4 the antimicrobial resistance patterns in the organisms isolated (n=10 times each antibiotic was used)

Antibiotic used	***Antimicrobial resistances of E. coli (R)***
Ciprofloxacin	2
Gentamicin	3
Ceftazidime	4
Chloramphenicol	7
Ampicillin	5
Tetracycline	6

Source: Primary data, (2025).

The mean resistance is 5. Ciprofloxacin has been found to have the least resistance than any other antibiotic (20%) and Chloramphenicol having the most resistance by *E. coli* (70%). However, the antibiotics; Tetracycline, and Chloramphenicol have resistances above the mean. This showed that they are not recommended for the treatment of the infections caused by *E. coli.* However, Ciprofloxacin, Ceftazidime, Gentamicin and Ampicillin have resistances lower than the mean resistance hence can be recommended as treatment for *E. coli* infections. Regardless of this, Ampicillin resistance is at the mean and therefore can be tried but not based upon since it can be effective or ineffective for *E. coli* infection treatments. *E. coli* is known for its high levels of antimicrobial resistance, particularly to older antibiotics like Ampicillin and Tetracycline. Fluoroquinolones like Ciprofloxacin are also commonly used to treat *E. coli* infections, but resistance to this antibiotic has been rising in recent years. Azithromycin and Gentamicin are usually reserved for specific cases due to their lower levels of resistance in *E. coli*. Ceftazidime is a newer antibiotic with slightly lower resistance rates compared to the older antibiotics, while Chloramphenicol is rarely used nowadays due to high levels of resistance. Below shows the pattern for each antibiotic used.

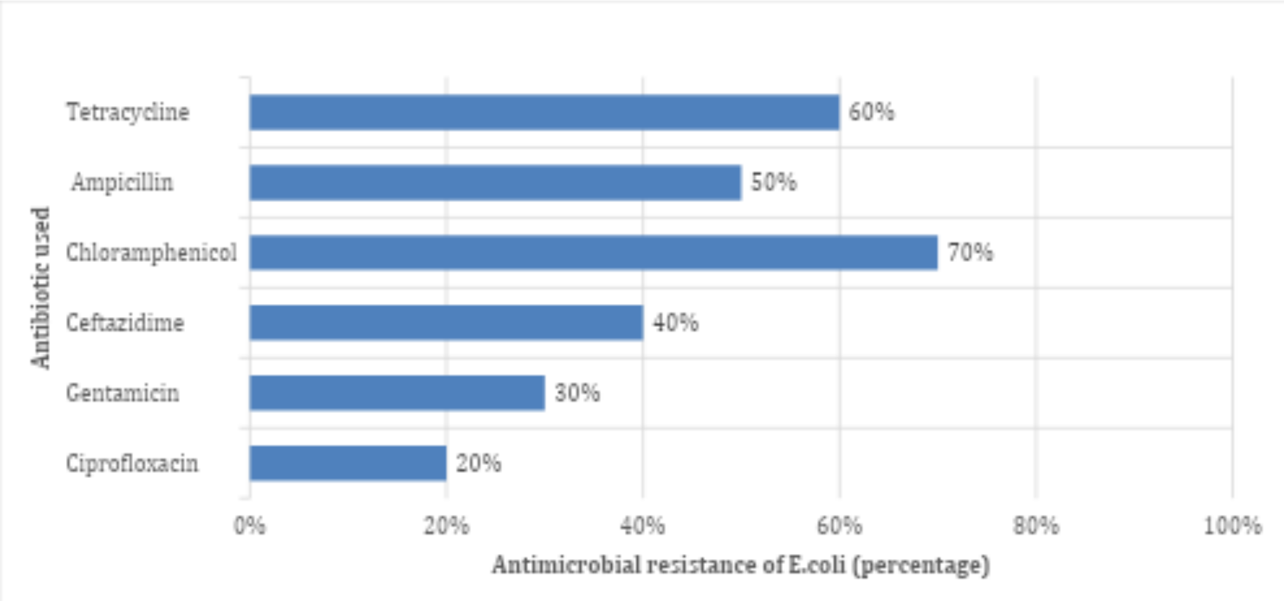


Figure 4.3 Antimicrobial resistance patterns of *E. coli*

4.4 The presence and concentrations of heavy metals (lead, mercury, arsenic), in water samples from high- and low-density residential areas of Mutare in 2025

The results shown in this section is for the presence and concentrations of heavy metals (lead, mercury, arsenic), in water samples from high- and low-density residential areas of Mutare in 2025. The results are compared for the high-density suburbs (Sakubva and Chikanga) and low-density suburbs (Murambi and Greenside Extension). The results are classified in mean values.

Table 4.5 Mean variations showing the presence and concentrations of heavy metals (lead, mercury, arsenic), in water samples from high- and low-density residential areas of Mutare in 2025

Suburb	Lead (mg/L)	Mercury (mg/L)	Arsenic (mg/L)
Sakubva	0.1667	0.0222	0.0419
Chikanga	0.0950	0.0105	0.0203
Murambi	0.0023	0.0005	0.0012
Greenside Extension	0.0014	0.0003	0.0009

Source: Primary data, (2025).

The data above showed that the high-density suburbs had the most presence of heavy metals with Sakubva having the highest values for the metals. However, low density suburbs had the least presence of heavy metals with Greendale Extension having the least. The presence of lead was most found in both of the suburbs though high-density suburbs (Sakubva and Chikanga) having most of it. Mercury was the least heavy metal that was present in the water samples found from the suburbs with higher mean values in high-density suburbs (Sakubva and Chikanga) compared to low-density suburbs (Murambi and Greenside Extension). Generally high-density suburbs are affected by heavy metals compared to low density suburbs. However, Sakubva is an industrial area with lots of activity hence it has the highest mean values for the three metals compared to any other residential suburb.

Table 4.6 Result of the presence and concentrations of heavy metals (lead, mercury, arsenic), in water samples from high- and low-density residential areas of Mutare in 2025 in comparison with WHO Recommended Standard values.

Heavy metals (mg/L)	Sakubva	Chikanga	Greenside Extension	Murambi	WHO
Mercury	0.0222	0.0105	0.0003	0.0005	0.006
Lead	0.1667	0.0950	0.0014	0.0023	0.01
Arsenic	0.0419	0.0203	0.0009	0.0012	0.01

4.5 Chapter summary

This chapter was for the results presentation, discussion and of the comparative Analysis of Microbial Contamination, Chemical Hazards, and Antimicrobial Resistance Patterns in Water from High- and Low-Density Residential Areas of Mutare, Zimbabwe: A Study of Water Quality in 2025. The data obtained showed that both bacteria and chemical hazards were more prevalent in the high-density suburbs of Mutare for the period of testing.

Chapter 5: Discussion

This chapter covers the discussion of the major findings of the study, recommendations and overall conclusions.

5.1 The bacterial contamination in the water supplied to the high- and low-density suburbs of Mutare City for the period in 2025

Densely populated suburbs such as Sakubva and Chikanga in Mutare have a higher prevalence of microbial contaminants in their water sources compared to low density suburbs like Murambi and Greenside Extension. One of the main factors is the higher population density in these areas. With more people living in close proximity, there is an increased potential for contamination of water sources through activities such as improper waste disposal, inadequate sewage systems, and lack of proper sanitation facilities (Gebeyehu et al., 2020).

The high population density in these suburbs put a strain on the existing water infrastructure, leading to issues such as leaky pipes and water contamination during transportation and storage processes (Nixon et al., 2017). This can create opportunities for pathogens like *Escherichia coli*, *Pseudomonas aeruginosa*, and *Vibrio cholerae* to enter the water supply and pose a health risk to residents. Densely populated suburbs may also face challenges in terms of access to clean water sources and proper water treatment facilities. Inadequate water treatment processes can fail to effectively remove or kill pathogenic microorganisms, leading to higher levels of contamination in the water supplied to residents (UNICEF, 2015). Low density suburbs like Murambi and Greenside Extension have fewer residents and less pressure on the water infrastructure, reducing the likelihood of contamination in the water supply. Additionally, residents in these areas may have better access to clean water sources and more reliable water treatment facilities, minimizing the risk of microbial contamination.

5.2 The presence and concentrations of heavy metals (lead, mercury, arsenic), in water samples from high- and low-density residential areas of Mutare in 2025

The high concentrations of heavy metals in high-density suburbs like Sakubva and Chikanga in Mutare can be attributed to several factors related to urbanization, industrialization, and human activities. The presence of high levels of heavy metals in these areas is the discharge of industrial effluents and wastes into water bodies and soils. In densely populated suburbs, there may be a higher concentration of industries and manufacturing activities, leading to increased pollution and contamination of the environment with heavy metals such as lead, cadmium, mercury, and arsenic (Orisakwe et al., 2016).

Urbanization and the rapid expansion of residential areas in high-density suburbs can also contribute to the accumulation of heavy metals in the environment. The use of pesticides, fertilizers, and other chemicals in agriculture and landscaping practices can result in the release of heavy metals into the soil and water sources. In addition, the disposal of electronic waste, batteries, and other products containing heavy metals can further exacerbate the contamination of the environment in densely populated suburbs (Machado et al., 2019).

The inadequate waste management and lack of proper sanitation facilities in high-density suburbs can also contribute to the accumulation of heavy metals in the environment. Improper disposal of waste, including electronic waste, batteries, and household products containing heavy metals, can lead to leaching of these contaminants into the soil and water sources, posing a risk to human health and the ecosystem (Achieng et al., 2020).

The higher prevalence of lead compared to arsenic and mercury in water sources in high-density suburbs of Mutare, such as Sakubva and Chikanga, as opposed to low-density suburbs like Murambi and Greenside Extension, can be attributed to various factors related to industrial activities, urbanization, and human behaviors. The primary reasons for the higher levels of lead in water sources in high-density suburbs is the presence of lead pipes and plumbing fixtures in older buildings. Lead pipes were commonly used in the past for water distribution, and in areas with older infrastructure like high-density suburbs, these pipes may still be in use, contributing to the leaching of lead into the water supply (Rabin et al., 2017). The use of lead-based paints, which can deteriorate over time and contaminate the surrounding environment, may also contribute to the higher levels of lead in water sources in urban areas (Laidlaw and Filippelli, 2008).

Arsenic and mercury contamination in water sources may be more related to industrial activities, agricultural practices, and natural sources rather than direct infrastructure issues. Arsenic contamination is often associated with mining activities, agricultural runoff, and industrial pollution, while mercury contamination can be linked to mining, coal combustion, and waste incineration (Ravenscroft et al., 2009; Wilson and Xue, 2016). In low-density suburbs, where there may be fewer industrial activities and agricultural operations, the levels of arsenic and mercury in water sources may be lower compared to high-density suburbs with more industrial and human activities. The population density and land use in high-density suburbs can also play a role in the distribution of heavy metals in water sources. Higher population densities may result in increased runoff of contaminants from urban areas, such as lead from vehicle emissions and building materials, contributing to the higher levels of lead in water sources in densely populated suburbs (Li et al., 2018).

5.3 Antimicrobial resistance patterns in the organisms isolated.

The resistance levels of different antibiotics among bacterial species such as *Escherichia coli*, can be attributed to various mechanisms of resistance developed by these bacteria. The lower resistance of Azithromycin compared to Ampicillin is the difference in the mechanisms of action of these antibiotics. Azithromycin inhibits bacterial protein synthesis by binding to the 50S subunit of the bacterial ribosome, while Ampicillin interferes with bacterial cell wall synthesis by inhibiting peptidoglycan synthesis (Nakatsu et al., 2017). The differing targets of these antibiotics make it less likely for bacteria to develop cross-resistance mechanisms simultaneously.

In contrast, Ampicillin resistance in bacteria like *E. coli,* is often associated with the presence of beta-lactamase enzymes that can inactivate the antibiotic by hydrolyzing its beta-lactam ring (Bush and Fisher, 2011). The production of beta-lactamase enzymes is a common resistance mechanism employed by many bacterial species to evade the effects of beta-lactam antibiotics, such as Ampicillin. The overuse and misuse of antibiotics like Ampicillin in clinical settings, agriculture, and livestock production can contribute to the selective pressure that drives the development and spread of resistance mechanisms in bacterial populations (Thomson et al., 2010). Thus, accelerating the emergence of resistance to antibiotics like Ampicillin, making them less effective against bacterial infections over time.

The difference in resistance levels of Azithromycin among bacterial species like *Enterococcus faecalis* and *Pseudomonas aeruginosa* can be attributed to various factors, including the inherent characteristics of the bacteria, their mechanisms of resistance, and the mode of action of the antibiotic. *Enterococcus faecalis*, a Gram-positive bacterium commonly found in the gastrointestinal tract, urinary tract, and wounds, is known for its ability to develop resistance to multiple antibiotics through various mechanisms, such as the acquisition of resistance genes and the formation of biofilms (Kayaoglu and Ørstavik, 2004). Enterococcus species are also known for their intrinsic resistance to certain antibiotics due to the presence of efflux pumps and modification of drug targets (Palmer et al., 2010). These resistance mechanisms can contribute to the higher resistance of *Enterococcus faecalis* to antibiotics like Azithromycin. *Pseudomonas aeruginosa*, a Gram-negative bacterium commonly found in soil, water, and hospital environments, is known for its intrinsic and acquired resistance to various antibiotics, including Azithromycin (Breidenstein et al., 2011). *Pseudomonas aeruginosa* possesses multiple mechanisms of resistance, such as the production of beta-lactamases, efflux pumps, and antibiotic-modifying enzymes, which enable it to evade the effects of antibiotics (Oliver et al., 2015). Despite this, *Pseudomonas aeruginosa* may exhibit lower resistance to Azithromycin compared to other antibiotics due to its unique membrane structure, drug efflux systems, and other adaptive mechanisms that can affect the uptake and efflux of antibiotics (Molina and Miller, 2016)

The similar resistance patterns exhibited by *E. coli* and *Pseudomonas aeruginosa* for antibiotics such as Ciprofloxacin, Ceftazidime, Ampicillin, and Azithromycin can be attributed to a combination of common mechanisms of resistance shared by these bacterial species and the specific modes of action of the antibiotics.

Resistance to Ciprofloxacin and ceftazidime in both *E. coli* and *Pseudomonas aeruginosa* can be linked to the development of mutations in the genes encoding the antibiotic targets, such as DNA gyrase and topoisomerase IV for Ciprofloxacin, and penicillin-binding proteins for Ceftazidime (Lodise et al., 2005; Strateva and Yordanov, 2009). Mutations that alter the structure or function of these target proteins can lead to reduced binding affinity of the antibiotics, rendering them ineffective against the bacteria.

Both *E. coli* and *Pseudomonas aeruginosa* are known to possess efflux pump systems that actively pump out antibiotics from the bacterial cell, reducing the intracellular concentration of the drugs and conferring resistance (Livermore, 2002; Poole, 2005). The presence of these efflux pumps can contribute to the resistance of both bacterial species to Ciprofloxacin and Ceftazidime, as well as other antibiotics with similar mechanisms of action. The resistance patterns observed for Ciprofloxacin and Ceftazidime across *E. coli*, *Enterococcus faecalis, Pseudomonas aeruginosa*, and *Vibrio cholerae* may also be influenced by the prevalence of specific resistance mechanisms in these bacterial species. For example, the presence of beta-lactamase enzymes that can hydrolyze ceftazidime and other beta-lactam antibiotics may lead to similar resistance patterns in *E. coli, Enterococcus faecalis, Pseudomonas aeruginosa,* and *Vibrio cholerae* (Bush and Fisher, 2011). Similarly, mutations in DNA gyrase or topoisomerase IV may confer resistance to Ciprofloxacin in multiple bacterial species (Li et al., 2017).

Ciprofloxacin is a fluoroquinolone antibiotic that acts by inhibiting bacterial DNA replication. *Pseudomonas aeruginosa* has shown high levels of resistance to Ciprofloxacin due to the presence of efflux pumps, mutations in target enzymes (DNA gyrase and topoisomerase IV), and the production of biofilms that limit antibiotic penetration (Ozkan et al., 2017). On the other hand, *Vibrio cholerae*, the causative agent of cholera, has shown relatively low resistance to

Ciprofloxacin. This could be attributed to the fact that *Vibrio cholerae* lacks the efflux pumps and mutations that confer resistance to Ciprofloxacin seen in *Pseudomonas aeruginosa*. Ceftazidime, a third-generation cephalosporin, inhibits bacterial cell wall synthesis by binding to penicillin-binding proteins. *Pseudomonas aeruginosa* has been reported to have high resistance rates to ceftazidime due to the production of extended-spectrum beta-lactamases (ESBLs) and AmpC beta-lactamases, which can degrade the antibiotic (Dorfman et al., 2017). *Vibrio cholerae*, on the other hand, has shown lower resistance to ceftazidime compared to *Pseudomonas aeruginosa*. This could be due to the differences in the mechanisms of resistance present in these two bacteria.

5.4 Conclusions

The results concluded that the bacteria, E. coli is mainly found in high-density suburbs of Mutare as compared to the low-density suburbs.

Lead was found to be the most present heavy metal in water sources in both low- and high-density suburbs, however, more of it is found in the high density compared to the low density of Mutare suburbs. Arsenic is the second most prevalent heavy metal in water sources of Mutare though most of it is found in high density suburbs. The least prevalent is mercury.

The results furthermore concluded that Ciprofloxacin is most effective over *E. coli* than other drugs.

5.5 Recommendations

a) The Mutare city council should improve the sources of water and the way it is transported to the consumers such as though repair of damaged pipes

b) EMA, ZRP, and the Mutare local authorities should collaborate to monitor human activities such as proper monitoring of industrial refuge disposals and environmental remediation (in case of spillages) which lessen the contamination of water sources.

c) The purification process should be enhanced by Mutare local authorities to prevent heavy metals finding their way into the water sources.

5.6 Areas of further studies

There should be an assessment on the health implication of lead in the water sources in Mutare high density suburbs.

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Appendices

Appendix 1: Data Collection Tool

Site	Microbes Identified	Chemicals Identified	Antimicrobial Resistance
Sakubva			
Chikanga			
Greenside			
Murambi			

Appendix 2: Timeline

The following tasks are to be executed within the allocated time frame from January to April 2025. They are represented by the Gantt chart following.

Task	January	February	March	April
Finalize study design and methodology				
Train on sampling and analysis procedures				
Test sampling techniques and data collection methods				
Make necessary adjustments to study design				
Obtain ethical approval from Mutare city council				
Obtain ethical approval from Africa University ethics committee				
Collect water sampling from designated water sources across Mutare				
Ensure all samples are correctly labeled and transported to the laboratory for analysis				
Perform microbial and heavy metal analysis on collected water samples				
Document records of laboratory results				
Analyse data using statistical software to assess water quality and health outcomes				
Prepare preliminary findings and interpretations				
Compile and finalize report including recommendations based on the findings				

Appendix 3: Procedure

<u>Materials</u>

Sterile 1litre bottles

Acid washed containers (for heavy metal analysis)

Permanent marker

Cooler box

Ice packs

Sterile Membrane filter

Known positive and Negative controls (for QC)

Petri dishes

Sterile pads

Lauryl Sulphate media

Sterile pipets

Ethanol

Metlylated spirit

Forceps

Filter membrane

Filter chamber

Antimicrobial disk

Atomic Absorption Spectrophotometer

Nitric acid

Sterile swab

Gloves

Lighter

Lab coat

<u>Sample collection procedure</u>

- Label one-liter sterile containers with collection site and date
- Collect samples directly from the water source, avoid contact with the hands or other surfaces.
- Fill the container to the neck and cap it tightly
- Store samples in a cooler with ice packs and transport them to the laboratory within 24 hours of collection.

Laboratory procedure (microbial analysis)

- Label petri dishes with collection site and date, each water sample should have its own petri dish
- Sterilize all the equipment using methanol and flame.
- Using a pad dispenser place one pad on each petri dish.
- Using a pipet, soak the pad with lauryl sulphate media.
- Filter 100ml of sample water through the membrane filter and place on Lauryl sulphate media.
- Incubate the plates at 37 degrees Celsius for 24 hours.
- After incubation, count the number of colonies that exhibit characteristic E. coli morphology (yellow colonies on lauryl sulphate)
- If *E. coli* is present further incubate at 44 degrees celicius to confirm if it's a true positive
- Calculate the concentration of E. coli in CFU/100ml of water.
- After calculating concentration, perform antimicrobial susceptibility testing on the *E. coli* by:
    - Prepare a bacterial suspension by inoculating organism picked from MacConkey agar using a sterile inoculation loop into saline, mix well to

disintegrate any clumps. The suspension should meet the McFarland standard.

- Open a sterile swab, dip it into the tube with bacterial suspension, move the swab in the suspension as if you are mixing.
- After collecting bacteria, loan/ inoculate the bacteria into the Mueller-Hinton agar plate.
- Place antimicrobial disks into the plate, incubate for 24 hours.
- After incubation read the results to see which drugs are resistant and which drugs are sensitive.

Record all observations including colony counts and any abnormalities.

Quality Control Measures

Include known positive and negative controls to ensure reliability of the tests.

Perform duplicate analyses for each sample to verify results

Ensure that all media and equipment are sterile to prevent contamination.

Laboratory Procedure (heavy metal analysis)

- Prepare a series of standard solutions for each heavy metal to create a calibration curve.
- Dilute water samples as necessary to fall within calibration range.
- Aspirate the sample into the atomic absorption spectrophotometer instrument.
- Measure absorbance at the specific wavelengths for each metal

· Compare absorbance readings to the calibration curve to determine concentrations in mg/l

Appendix 4: Budget

Item	**Cost**
Transportation	$50
Sample Collection Tools	$50
Lab Equipment	$100
Total	**$200**

Appendix 5: Approval letters

ADDRESS ALL CORRESPONDENCE TO THE TOWN CLERK

OUR REF: MN/mm

CITY OF MUTARE

CIVIC CENTRE NO.1 QUEENS WAY
P.O BOX 910, MUTARE, ZIMBABWE
GENERAL LINE : +263202064412
DIRECT LINE :+262202060271
EXT: 309/331

TOWN CLERKS DEPARMENT

Our Ref: MN/mm

04 March 2025

TENDAI MUKUPE
Africa University
P. Bag 1320
MUTARE

Dear Sir/Madam

RE: PERMISSION TO CARRYOUT A RESEARCH: COLLECTION AND TESTING OF WATE FROM HIGH AND LOW DENSITY SURBUBS OF MUTARE CITY.

Your letter dated 28 February 2025 on the above matter refers.

I wish to advise that you have been granted permission to carry out a research titled, "collection and testi of water from high and low density surbubs of Mutare City". **Case of City of Mutare,**

Could you please therefore liaise with Engineering and Technical Services Director on the above matter.

Yours faithfully

K.B CHAFESUKA
TOWN CLERK

CITY OF MUTA
HUMAN RESOURCES S
12 2025
P. O. B 0, MUTAR
TEL: 02020 64412

“Investing in Africa’s future”

AFRICA UNIVERSITY RESEARCH ETHICS COMMITTEE (AUREC)

P.O. Box 1320 Mutare, Zimbabwe, Off Nyanga Road, Old Mutare-Tel (+263-20) 60075/60026/61611 Fax: (+263 20) 61785 Website: www.africau.edu

Ref: AU 3896/25

26 March, 2025

TENDAI KAREN MUKUPE
C/O Africa University
Box 1320
MUTARE

RE: ***COMPARATIVE ANALYSIS OF MICROBIAL CONTAMINATION, CHEMICAL HAZARDS, AND ANTIMICROBIAL RESISTANCE PATTERNS IN WATER FROM HIGH- AND LOW-DENSITY RESIDENTIAL AREAS OF MUTARE, ZIMBABWE: A STUDY OF WATER QUALITY IN 2025***

Thank you for the above-titled proposal you submitted to the Africa University Research Ethics Committee for review. Please be advised that AUREC has reviewed and approved your application to conduct the above research.

The approval is based on the following.

a) Research proposal

- **APPROVAL NUMBER** AUREC 3896/25
  This number should be used on all correspondence, consent forms, and appropriate documents

- **AUREC MEETING DATE** NA
- **APPROVAL DATE** March 26, 2025
- **EXPIRATION DATE** March 26, 2026
- **TYPE OF MEETING**: Expedited
  After the expiration date, this research may only continue upon renewal. A progress report on a standard AUREC form should be submitted a month before the expiration date for renewal purposes.
- **SERIOUS ADVERSE EVENTS** All serious problems concerning subject safety must be reported to AUREC within 3 working days on the standard AUREC form.
- **MODIFICATIONS** Prior AUREC approval is required before implementing any changes in the proposal (including changes in the consent documents)
- **TERMINATION OF STUDY** Upon termination of the study a report has to be submitted to AUREC.

AFRICA UNIVERSITY
RESEARCH ETHICS COMMITTEE (AUREC)
APPROVED
P.O. BOX 1320, MUTARE, ZIMBABWE

Yours Faithfully

Chinzou

MARY CHINZOU
FOR CHAIRPERSON
AFRICA UNIVERSITY RESEARCH ETHICS COMMITTEE