INFLUENCE OF SOCIO-ECONOMIC FACTORS AND WATER HANDLING PRACTICES ON THE MICROBIAL WATER QUALITY IN KITWE DISTRICT, ZAMBIA

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A Thesis Submitted to the Graduate School in Partial Fulfilment of the Requirements for the Master of Science Degree in Environmental Science of Egerton University

EGERTON UNIVERSITY

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DECLARATION AND RECOMMENDATION

Declaration

This thesis is my original work and has not been presented in this university or any other for the award of a degree.

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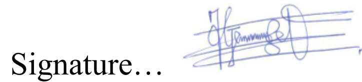
Recommendation

This thesis has been submitted with our approval as University supervisors.

Signature…  Date 11/08/2025

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DEDICATION

With heartfelt gratitude, this work is dedicated to my beloved father, Phillimon Ng'andwe, and my mother, Queen Chama, for their unwavering love and patience throughout my academic journey.

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ABSTRACT

Limited access to safe and good-quality drinking water continues to pose significant public health risks, particularly in low-income communities, where residents face increased exposure to water-related diseases. This study investigated how socio-economic factors and water handling practices influence the drinking water quality in Kitwe District, Zambia. A cross-sectional study involving 215 households was conducted, combining responses from a semi-structured questionnaire with bacteriological testing of water samples. In total, 132 point of use and 48 source samples were collected and analyzed for physicochemical (pH, temperature, residual chlorine) and microbial parameters (total coliforms and *Escherichia coli*) during dry and wet seasons. Multivariable logistic regression was performed to identify key predictors of water quality. The analysis revealed that *E. coli* was present in 61.4% of point of use samples during the dry season and 77.5% during the wet season. At the source, contamination rates were even higher at 87.5% in the dry and 100% in the wet seasons. Several household-level factors were significantly associated with improved microbial water quality. These included household income, educational level, family size, design of storage containers, method of water retrieval, whether containers were covered, water treatment practices and handwashing with soap. Households using narrow-mouthed storage containers (AOR = 0.090; 95% CI: 0.014–0.580), covering their storage vessels (AOR = 0.113; 95% CI: 0.014–0.889), and treating their water (AOR = 0.120; 95% CI: 0.022–0.656) had a significantly lower likelihood of *E. coli* contamination. Seasonal variations were statistically significant, with higher mean counts of total coliforms and *E. coli* during the wet season ($p = 0.001$). These results highlight the urgent need for point of use water treatment strategies, such as chlorination and slow sand filtration, to safeguard public health. Implementing community-focused education on safe water practices, along with initiatives aimed at tackling socio-economic inequalities and enhancing access to clean water, is vital for alleviating the challenges of microbial contamination and waterborne diseases in urban communities.

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LIST OF ABBREVIATIONS AND ACRONYMS

APHA	American Public Health Association
HWT	Household water treatment
IFRC	International Federation of the Red Cross
MFNP	Ministry of Finance and National Planning
POU	Point of Use
UN	United Nations

CHAPTER ONE
INTRODUCTION

1.1 Background information

Clean drinking water is a fundamental need essential for community health. Insufficient availability, inadequate sanitation facilities, and ineffective management can result in waterborne illnesses such as diarrhea, which causes around 1.6 million fatalities in developing and economically disadvantaged regions (Srivastava *et al*., 2022; Troeger *et al*., 2018). Around 88% of deaths caused are associated with consumption of unsafe water, insufficient sanitation and hygiene practices (CDDP, 2023).

Poor water management and environmental conditions compromise water quality in South Asia. In Nepal, inadequate household storage practices renders it unsafe during the wet season (Sarkar *et al.*, 2022; Shrestha *et al*., 2023). In Bangladesh, activities related to handling further worsens the situation (Chowdhury *et al.*, 2024). Microbial contamination in water is a public health issue in Africa, because it can cause the spread of diarrhea and cholera (Merid *et al*., 2023; Siamalube *et al.*, 2024). The pathways of groundwater pollution are; leaks in the distribution systems and inadequate sanitation (Aluma *et al*., 2024; Ducci *et al*., 2023; Zeydalinejad *et al*., 2024).

Numerous pathogens can be found in water, and bacteria is a primary cause for waterborne illnesses (Njuguna, 2016). The most prevalent types are *Shigella spp., Vibrio cholerae*, *Salmonella spp*., and *Escherichia coli*. Among these, *E. coli* is a major indicative of fecal pollution in water. Its presence suggests contamination from human or animal waste. Depending on the environmental conditions, it can persist for 4 to 12 weeks (Khan & Gupta, 2020; Suehr *et al*., 2020; Yang *et al*., 2025). Consuming water with microbes can result in diarrhea, dysentery, cholera, and typhoid (Islam Farhan & Alim Miah, 2024; Jung *et al*., 2023).

Also, socio-economic factors such as, household monthly income, education level, occupation and household family size are possible contributing factors that may be associated with the prevalence of infections (Abanyie *et al*., 2025). For instance, a systematic review by Azanaw *et al*. (2024), found a correlation between education level and the risk of waterborne diseases. The study highlighted that literacy is a key predictor influencing the occurence in Africa. Yang *et al*. (2025) carried out a study in Niger and Zambia and showed notable differences in water accessibility and quality. The results indicated that income were linked to improved water in the two countries.

Contamination of water can occur when it is being transported or during storage in households (Belihu *et al.*, 2023). Researchers have found that jerry cans, clay pots, and plastic buckets are the most common methods utilised in Kenya, Ethiopia, and Zambia (Gizachew *et al.,* 2020; Osiemo *et al*., 2019; Shimamura *et al.,* 2022). Inadequate cleaning of the containers can expose them to pathogens, which then increases the chance of microbial growth. Because of this, it can become unsafe to drink (Agensi *et al*., 2019; Manga *et al*., 2021).

The World Health Organization has been recommending household water treatment, particularly for water collected from unimproved sources such as shallow wells (WHO-UNICEF, 2021). Disinfection rates are still low in Sub-Saharan African countries. With, only 22% of households treating their water, and 18% employing an adequate method (Alemayehu *et al*., 2021). However, unhygienic practices among many may hinder effective water-disinfection ways utilised by houses (Maniragaba *et al*., 2023).

Drinking water can become contaminated at multiple stages, including the source and the point of use (Aydamo *et al*., 2024). While previous research conducted in informal settlements in Zambia have reported elevated levels of microbial contamination in water (Chishimba *et al.,* 2023; Reaver *et al.,* 2021; Siwila & Buumba, 2021) there has been limited investigation into the specific predictors that contribute to contamination during transportation, storage and within the household.

It is against this background that this study was conceptualized to assess the relationship between socio-economic factors, water handling practices, and microbial water quality at the point of use in Kitwe district. It was hypothesized that these factors at the household level significantly contribute to microbial contamination of drinking water.

1.2 Statement of the problem

In Zambia, approximately 6 six million people, particularly those living in settlements or slums, do not have access to clean water and sanitation, out of a population of 13 million (UN-Habitat, 2023). This significant disparity puts these populations at heightened risk for diarrheal diseases, including cholera which is linked to contaminated water. The ideal situation is to have clean piped water in Ipusukilo settlement in Zambia. However, the lack of such water systems has forced many in the settlement to rely on unimproved water sources such as shallow wells. These sources often exhibit poor microbial quality, contributing significantly to the prevalence of waterborne illness, as contaminated groundwater can quickly spread pathogenic microorganisms. This risk is further exacerbated

by socio-economic factors such as montly income, education levels and access to sanitation facilities. In addition, inadequate water handling practices at the household level further compounds the settlement with frequent cases of waterborne diseases. Despite the severity of the mentioned water and sanitation challenges, limited research has been done, concerning how these specific factors affect the microbial quality of drinking water. Therefore, the aim of this study was to bridge this gap by assessing the influence of socio-economic factors and water handling practices on the microbial water quality. The results of this study will go a long way in implementing household and policy interventions in Zambia, and more so in Ipusukilo settlement.

1.3 Objectives

1.3.1 Broad objective

To contribute to the development of strategies for improving water quality and sustainability and enhancing local communities' health and well-being.

1.3.2 Specific objectives

i. To measure the concentration of total coliforms and *Escherichia coli* in water at point of use and the source (shallow wells) during the dry and wet season in the study area.
ii. To determine the relationship between physicochemical parameters and microbial water parameters during the dry and wet season in the study area.
iii. To assess the socio-economic factors that influence microbial water quality in the study area.
iv. To determine the relationship between water handling practices and microbial water quality at point of use in the study area.

1.4 Research questions

i) What are the concentrations of total coliforms and *Escherichia coli* of water at point of use and the source (shallow well) and how do these vary across seasons in the study area?
ii) What is the relationship between physicochemical parameters (such as pH, temperature, and residual free chlorine) and microbial water quality indicators (such as *E. coli* and total coliforms) during the dry and wet seasons in the study area?

iii) What are the predominant socio-economic factors that significantly influence microbial water quality in the study area?

iv) Is there a significant relationship between water handling practices and microbial water quality at the point of use in the study area?

1.5 Justification

The study is justified by the urgent need to address public health concerns in relation to water related diseases, such as diarrhea, caused by microbial contamination. The study's findings provided an overview of microbial water quality and identified various factors influencing it at the point of use, as well as the pathways of contamination originating from the source. The information from this study will provide a foundation for sustainable development. When individuals adopt effective water management practices and understand the consequences of consuming contaminated water, they are less prone to illness and associated medical expenses, which helps them stay economically active. Additionally, with children particularly at risk from water-related diseases, access to clean water can lead to better health, improved school attendance and longer-term positive outcomes for their lives. The published findings of this study will inform targeted interventions to provide solutions and educational campaigns and contribute to improved public health outcomes and economic development by reducing healthcare costs and enhancing productivity.

This research aligns with the Sustainable Development Goals, SDG 3 (good health and well-being), and 6 (clean water and sanitation). Additionally, the study supports the objectives outlined in the Africa Agenda 2063, aiming for universal access to clean water by the year 2063.

1.6 Scope, limitations and assumptions

This study was carried out in Ipusukilo settlement of Kitwe District, with a focus on assessing the microbial quality of drinking water at both the source and the point of use. The analysis specifically targeted the presence of total coliforms and *E. coli*. Physical parameters, including pH and temperature, which can impact microbial water quality were measured on-site. The study was carried out during the dry and wet months from October to December 2024. Water samples were collected during the two seasons to capture the seasonal variability of microbial water quality. Household surveys were conducted to assess the water handling practices. Laboratory data obtained on microbial quality was used to establish the relationship with water handling practices in the study area.

This study was limited in scope, it did not encompass all potential pathogens that may pose significant health threats but focused on total coliforms and *E.coli*. This limitation highlights the need for a broader range of microorganisms. Additionally, the study did not did not include Biological Oxygen Demand, Total Dissolved Solids, turbidity and electrical conductivity due to resource constraints. The study was on the assumption that the selected households truly provided a representation of the water handling practices and gave honest answers.

1.7 Definition of terms

The definitions of terms are outlined below to ensure a clear understanding and relation to the subject being discussed in this study**.**

Contamination: The presence of pathogenic microorganisms in water that can cause health risks to humans.

Disinfection: The process of reducing pathogenic microorganisms in drinking water so as to make it safe for consumption.

Drinking water standards: Regulatory limits set by authorities (e.g. WHO, ZABS) for various contaminants, including microbial pathogens, to ensure water safety.

Fecal contamination: The introduction of fecal matter in water, which leads to serious health risks when consumed.

Indicator organisms: Microorganisms, like coliforms, that are used to signal the potential contamination of water by harmful pathogens.

Microbial quality: The safety of water for domestic use, determined by the presence or absence of microorganisms such as total coliforms and *E. coli* in drinking water.

Point of use (POU): Water that is used in households, which may involve practices and conditions that may affect water quality after collection from the source.

Prevalence: This is the measure used to determine the number of individuals affected by a waterborne disease.

Shallow wells: These are water sources that are dug to a relatively shallow depth, typically less than 20 meters, and are often more vulnerable to contamination.

Socio-economic factors: Variables related to an individual's economic and social conditions, such as their income and education level which can influence water quality.

Source water: The original water source, such as a shallow well from which water is collected.

Water handling practices: The behaviors and methods used by households to collect, store and treat water, which can influence its microbial quality.

Waterborne diseases: Illnesses resulting from the intake of water contaminated with harmful microorganisms.

CHAPTER TWO
LITERATURE REVIEW

2.1 Global water status

The demand for water globally is expected to increase by 55%, while presently, 25% of large cities are undergoing water stress (Schlamovitz & Becker, 2021). Approximately 2.2 billion people lack access to safe drinking water worldwide (UNESCO, 2024). Although there have been advancements in increasing access to safe drinking water, with 2.6 billion people obtaining improved sources since 1990, there is still a significant amount of work to do. Presently, it is estimated that 1.7 billion individuals take water that is contaminated and 2.4 billion lack proper sanitation facilities worldwide (WHO, 2023).

Sustainable Development Goal 6 focuses on providing everyone with equal access to safe drinking water by 2030 (UN, 2015). In the year 2020, a significant portion of the global population (26%) did not have reliable access to clean and safe drinking water and nearly half lacked proper sanitation services (46%). Without a substantial acceleration in progress, billions of people are projected to face these challenges well into 2030 (WHO, 2021). In addition to ensuring the availability and quality of water, household water handling practices are essential for reaching this goal.

Access to water and sanitation facilities differs in developing countries and developed countries, especially in parts of Asia and Africa (Mohammadi *et al*., 2020; Hlongwa *et al.*, 2024). Insufficient water and sanitation infrastructure has a major impact on human health. Unsafe water and poor hygiene practices are major factors driving the transmission of waterborne diseases and large-scale outbreaks (Mapingure *et al.,* 2024). For instance, 1.5 million deaths are as a result of acute infectious diarrhea (UNICEF & WHO, 2019). According to Shrestha *et al.* (2022) this necessitates improving sanitation and water practices to in order to achieve better health outcomes.

2.2 Groundwater

Groundwater is usually the main water source for drinking and domestic use among many households in urban slum areas of developing countries. These areas are characterized by poor waste management which often deteriotrates groundwater quality, hence posing serious health risks to humans (Sahoo & Goswami, 2024). Groundwater such as shallow wells are commonly utilized as a water source, and some lack proper protection, making them vulnerable to pathogen contamination. Surface contamination can arise from flooding

during the wet season, unsanitary handling of the rope and bucket, or poor sanitation practices (Bazaanah & Mothapo, 2024).

For example, in India, both the quantity and quality of groundwater are rapidly declining due to human activities such as excessive extraction and improper disposal of industrial, domestic, and agricultural waste into groundwater systems (Chaudhari *et al.*, 2024). In Nigeria's urban regions, nearly 60% of the people depend on groundwater sources like shallow wells as their main supply of water. This reliance is largely driven by the inadequate provision of alternative water sources and the adoption of cheaper borehole drilling technologies (Olaniyan *et al*., 2016). However, depending on local wells poses significant health risks mostly during the rainy season, when fecal contaminants can infiltrate the water supply (Figure 2.1). Furthermore, polluted wastewater from latrines and other sources can infiltrate the soil and contaminate underlying aquifers.

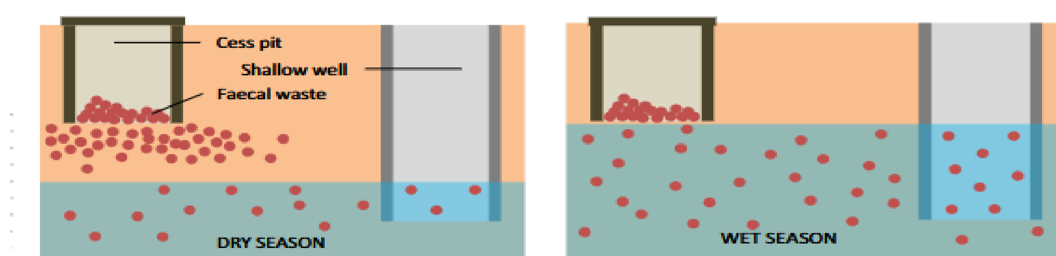

Figure 2.1: Fecal contamination in groundwater during dry and wet seasons
Source: Chuah and Ziegler (2018)

Household reliance on wells as the primary water source varies significantly by region, with 30% to over 66% of households in Sub-Saharan Africa depending on them, compared to only about 3% in Latin America (Grönwall *et al.,* 2010). This indicates that an estimated 66 million people in Africa, 201 million people in Southeast Asia and 2 million in Latin America and the Caribbean rely on groundwater for domestic use.

Some countries, such as Namibia and Gabon, have low percentages of households that depend on wells for drinking water, while others such as Liberia and Nigeria have high percentages (Grönwall *et al.,* 2010). Factors such as income, population growth and groundwater resources may account for the variations in the percentage of urban households that rely on wells in different countries.

In Zambia's informal settlements, most households either have their own shallow well or rely on a neighbor's. However, in some of these areas, shallow wells often run dry during the hot season, leaving many households without a reliable water source. It has been

recorded that 13.7% of people living in urban slums rely on water from wells, suggesting exposure among these people to contaminated drinking water (Liddle *et al.*, 2015). These shallow wells are hand dug and hand drawn, some are constructed by Non-Governmental Organizations or active Church Organizations such as Water Aid. According to Liddle *et al.* (2015), although some wells have protective linings and covers, many remain open and unlined, lacking proper structural support. The presence of coliform bacteria in groundwater has been linked to nearby pit latrines and open defecation. Additionally, while septic tank and sewer system leaks can lead to groundwater pollution, the more significant problem in informal settlements is the widespread absence of adequate sanitation infrastructure.

2.3 Water and sanitation in Zambia

According to USAID more than 6 million people in Zambia do not have access to safe drinking water, and around 11 million do not have adequate sanitation (USAID (2022). Even in areas with water and sanitation infrastructure, there is often insufficient investment in its upkeep. According to WHO/UNICEF (2024), 32% of Zambian households have less access to essential water, the situation being significantly worse among the lowest income groups, where 60% are without such access. Additionally, 64% lack basic sanitation facilities and 82% have no access to basic hygiene services. While the 8th National Development Plan (MFNP, 2022) outlines Zambia's commitment to enhancing water and sanitation services, progress could be undermined by inadequate monitoring of water resources and sanitation systems.

Insufficient access to water and sanitation continues to significantly contribute to the prevalence of water-related illnesses and diseases in Zambia. Ensuring reliable water and sanitation services is a key development challenge, especially in rapidly growing peri-urban communities (Pesa, 2019). Cholera outbreaks occur annually in Zambia, especially during the rainy season (Reaver *et al*., 2021). In response, local authorities, NGOs, international aid organizations, and faith-based groups occasionally distribute free chlorine bottles during these periods. For years, chlorine use has been promoted as a key measure to prevent waterborne disease outbreaks. The World Health Organization recommends household-level water treatment methods, including chlorination, as effective in reducing diarrhea diseases (WHO/UNICEF, 2021). Research by Rosa *et al.* (2016) identified chlorination as the most widely practiced method of water treatment, surpassing boiling. However, several barrier such as treatment costs, limited public awareness, negative perceptions and unhygienic household practices continue to weaken the effectiveness of these interventions (Maniragaba

et al., 2023). Changing behavior and effectively communicating the health benefits of hygiene remain persistent challenges. The health authorities recommend constructing shallow wells uphill from pit latrines and ensuring a minimum separation of atleast 30 meters to minimize contaminating the groundwater (Choma, 2006). Despite this guidance, many communities still rely on shallow wells and live in environments lacking proper sanitation, drainage and waste management systems. Consequently, diarrheal diseases remain widespread and cholera outbreaks recur frequently. Yet, the consistent use of chlorine and other water treatment options remains limited across the country (Chakanyuka *et al.,* 2025; Kanyunge, 2020). This situation calls for urgent intervention to achieve sustainable development in these areas.

2.4 Water quality testing

Monitoring water quality is a fundamental part of water supply initiatives that aim to ensure access to microbiologically safe drinking water for large populations. Water quality assessment involves assessing the physical, chemical and biological parameters (Dohare *et al*. (2014).

2.4.1 Bacteriological water quality

The primary microbial risk in drinking water arises from contamination with human and animal fecal matter, although other exposure pathways may also contribute significantly. Ensuring microbial safety involves multiple barriers from the water source to the point of use to prevent or reduce contamination (WHO, 2008). According to Gwimbi *et al.* (2019), water may contain microorganisms which can make it unsuitable for human consumption. Among these microorganisms, the most concerning ones are total coliforms and *Escherichia coli*, which is an indicative of fecal contamination that can cause diarrheal diseases. A large proportion of recognizable health issues related to water stem from microbial contamination, which encompasses bacteriological, viral, protozoan, and other biological pollutants. Consequently, bacteriological analyses primarily entail the assessment of fecal coliforms and total coliforms (Shields *et al*., 2015).

2.4.1.1 Total coliforms

Coliform bacteria are gram-negative, rod-shaped, that do not form spores and can ferment lactose, producing acid and gas when incubated at temperatures between 35 and

37°C (Tambi *et al*., 2023). These organisms are widely used as indicators of water quality, especially in the context of drinking water safety (Li & Liu, 2019). Their effectiveness as indicators stems from their easy detection, affordability, and the reliability of enumeration methods. The presence of coliforms is frequently associated with the presence of other waterborne pathogens, including viruses, protozoa, and different kinds of harmful bacteria. Detecting coliform bacteria in treated water may signal ineffective disinfection, post-treatment microbial regrowth, or possible fecal contamination within the water distribution network (Shen & Zhang, 2022).

2.4.1.2 Fecal coliforms

Fecal coliforms are a category of bacteria that includes species such as *Escherichia coli, Enterobacter agglomerans,Klebsiella pneumonia, Enterobacter aerogenes, Enterobacter cloacae, and Citrobacter freundii*. These bacteria thrive at a temperature of 44.5 °C (Tambi *et al*., 2023). According to Robbins (2012) these bacteria can be found in human and animal waste. The infections caused by fecal coliform bacteria can have serious, potentially fatal consequences. Typically, symptoms such as diarrhea, abdominal cramps, headaches, and fever manifest within two to four days after infection. According to Smith and Fratamico (2017), antibiotics are effective in treating such infections, though there are growing concerns about the emergence of antibiotic resistant strains of these bacteria. Fecal coliforms can persist outside their typical environments for several weeks, for instance, *E. coli* can survive in drinking water for a duration ranging from four to twelve weeks, posing a risk for widespread illness among humans. The water quality standards stipulate that fecal coliforms must not be present in a 100 ml sample of drinking water, meaning that each sample must demonstrate an absence of these bacteria to comply with safety standards (Zambia Bureau of Standards, 2010).

2.4.1.3 Escherichia coli

Escherichia coli, part of the Enterobacteriaceae family, is identified as a gram-negative, rod-shaped bacterium known for its ability to ferment lactose and its lack of spore formation. This bacterium is frequently present in the digestive systems of both humans and animals, and most of its strains are harmless (Erkmen, 2022). However, several pathogenic strains have emerged that possess various virulence genes, resulting in a spectrum of illnesses, including meningitis, pneumonia, urinary tract infections, and gastrointestinal disorders (Smith & Fratamico, 2017). *E. coli* should be entirely absent from water.

2.4.2 Physicochemical parameters of water quality

2.4.2.1 pH

The pH scale is used to determine how acidic or basic a liquid solution is, with values ranging from 0 to 14. It is worth noting that, water has a neutral pH of 7, which indicates that it is neither acidic nor basic. According to the Zambia Bureau of Standards (2010), a pH between 6.5 and 8.0 is recommended, as values outside this range are not advisable for consumption. A pH of 6 indicates that the water is acidic, while a pH of 7 indicates neutrality. According to WHO (2011), a pH of 6.5-8.5 is recommended for drinking water.

2.4.2.2 Temperature

Temperature is among the various physical aspects influencing water quality. This is the case because, the growth of bacteria in groundwater is impacted by temperature, where by, higher temperatures can lead to faster micro-organism growth, increased chemical reactions and reduced gas solubility. This may compromise the palatability of drinking water by affecting its taste and odor quality (WHO, 2008). Season and time of day can lead to fluctuations in groundwater. Although there are no strict limits to temperature, the WHO recommends 20-35 Degrees Celsius (WHO, 2008). Evidence from literature (Marois-Fise *et al*., 2013) suggests that pH and temperature influence microbial water quality.

2.4.2.3 Residual chlorine

This is the amount of chlorine left in water after it has been disinfected. It can kill additional pathogens that are added to the water (Gonzalez *et al*., 2020). Measuring chlorine shows how well households are using treatment methods. The levels standards should be between 0.02-0.5 mg/L to ensure microbiological safety (WHO, 2008). The presence of adequate residual free chlorine helps prevent bacteria recontamination, especially in places where the water may be handled in an unsanitary way (Gillespie *et al.,* 2014; Mao *et al.,* 2018). But too much of it may cause taste and odor problems among people consuming it.

2.5 Prevalence of water-related diseases

Diarrhea is caused by taking water contaminated with microorganisms (Aluma *et al*., 2024; Zeydalinejad *et al*., 2024). Enteropathogenic *E. coli* strains are one of the primary contributors to water disease incidents in developing countries (Ko & Sakai, 2022;

Mebrahtom *et al.*, 2022). Lack of adequate sanitation and poor waste management often leads to fecal pollution, which increases the risk of waterborne illness (Mapingure *et al.,* 2024). When pathogens in drinking water are not eliminated by disinfection processes, they canuse serious health problems (Silva *et al.,* 2020). For instance, in Nepal (Sedhain & Odland, 2014), poor sanitation is one of the major causes of infections, accompanied with factors such as low income and limited education. A prevalence of 50.7% was recorded, with literacy level being identified as a factor affecting the occurrence. In Congo, 60% of individuals suffering from water diseases resulted from not having adequate water supply (Kapembo *et al*., 2019), while in Zambia the most severly affected were the low income populations (WHO, 2024).

Efforts to mitigate these challenges are aligned with the sixth Sustainable Development Goal (Treacy, 2019). Achieving this goal requires routine monitoring of water quality to detect bacterial contaminants, particularly *Escherichia coli*, in domestic water sources. Unfortunately, lack of intervention strategies in developing regions worsen the occurrence of water diseases (Alum *et al*., 2024).

2.6 Contamination at point of use

In examining the issue of point of use contamination in drinking water, it becomes apparent that recontamination at the household level can significantly counteract reductions in contamination observed from source water to household storage. This means that even if people try to treat water, their everyday practices may unintentionally lead to the introduction of contaminants. Studies have pointed out a trend, whereby household water samples often exhibit higher levels of contamination when compared to the original source water (Asefa *et al*., 2021; Mahmud *et al*., 2019; Wright *et al*., 2004). Moreover, the higher contamination levels recorded at the source, contrary to the expected trends, may reflect the inherently poor quality of the water source in the community studied.

For instance, Onabolu *et al*. (2011) revealed significant increases in coliform counts in household water from wells, while water household water from springs displayed a decrease in contamination. This suggests that in areas with water sources harboring high initial contamination, the effectiveness of storage and treatment methods can vary widely. Musa *et al*. (1999) further illustrated this variability by showing that rural and nomadic communities in Sudan, relying on contaminated sources, had less coliforms in stored water than the source, while peri-urban areas demonstrated increased contamination in home storage. However, a systematic review by Wright *et al.* (2004) selectively emphasized the

findings on household recontamination, overlooking cases where bacterial counts decreased in household stored containers. The findings indicate a multifaceted interaction between the quality of source water and the potential for recontamination at the household level. Contrary to other studies Levy *et al*. (2008) observed that source waters were found to contain substantially more indicator organisms than water samples obtained from household storage, possibly due to natural die off or settling. Fecal contamination can occur at various stages, from collection at the source to the point of use at household level. Water is transported, possibly stored in a bucket at home and after treatment, placed in a drinking vessel before consumption. Therefore, it is essential to investigate all potential contamination pathways to ensure water safety at the household level (Figure 2.2).

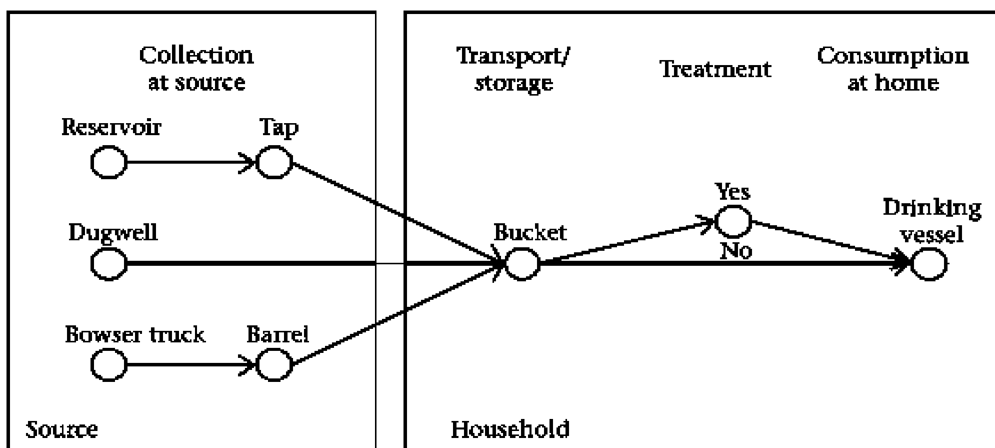

Figure 2.2: Possible pathways for drinking water contamination
Source: Rufener *et al*. (2010)

As explained in literature, interventions aimed solely at household level treatment may not suffice if the sources of contamination are not concurrently addressed. This integrated approach is vital, as the transmission of waterborne diseases involves numerous interdependent pathways (Eisenberg *et al*., 2007). Hence, in areas with poor source water quality, it becomes clear that point of use water treatment and safe storage practices must be complemented by broader initiatives aimed at improving sanitation and overall water quality at the source. This multifaceted strategy is essential to reducing the risk of contamination and to enhance the effectiveness of drinking water interventions.

2.7 Socio-economic factors influencing water quality

Various socio-economic factors has been associated with water quality among households (Ondieki *et al*., 2022). According to Kioko and Obiri (2012), higher levels of

education are usually associated with better knowledge of water safety and hygiene practices, which impact water. Onjala *et al*. (2014), reported that high levels of thermo-tolerant coliforms were linked to a lack of awareness about the health hazards. This is due to insufficient understanding, negative attitudes within homes. Age also has an effect on water. Older women are good at comprehending the risks of contamination since they use healthcare services more (Figueroa & Kincaid, 2010). Then, gender of the househead and family size also affect water at the point of use (Usman *et al*., 2016) as nuclear ones tend to maintain it better, likely because there are fewer cross-contamination cases. Higher income exhibit lower *E. coli* presence, because they may possess good sanitation infrastructure, such as access to flush toilets rather than pit latrines (Ondieki *et al.,* 2017).

2.8 Water handling practices

Water handling practices include all activities that are carried out by households from the point of collection to consumption (Gizachew *et al*., 2020). Studies have shown the correlation between handwashing behaviors, and microbial contamination (Hasan *et al*., 2022; Mugumya *et al*., 2020; Makokove *et al*., 2022). How water is stored can impact the quality hence, leading to higher incidences of diseases among consumers because such water is susceptible to bacteria (Agensi *et al*., 2019; Manga *et al*., 2021). According to and Luvhimbi *et al*. (2022) and Moropeng *et al*. (2021) the deterioration can occur at any stage, even with access to reliable source. This is mostly due to unhygienic ways being carried out through the chain. Due to their accessibility, jerry cans and clay pots are the most utilized in developing nations (Murphy *et al*., 2016; Osiemo *et al*., 2019).

In Ghana, a study by Addo *et al*. (2014) investigated the relationship with how people handled water and the spread of diseases. Their findings showed the impact of sanitation on microbial water. In Sub-Saharan Africa, where open defecation is still common, fecal contamination of groundwater is sremains a big public health concern (WHO, 2003). In Kenya Kurui *et al*. (2019) investigated how people handled water in their homes. Research indicated that although certain households treated their drinking water, a significant number still consumed water that failed to meet safety standards due to improper management. In Ethiopia Sharma *et al*. (2013) highlighted the importance of safe water handling behaviors to maintain water quality at the point of use.

Studies have used a number of different criteria to assess these kinds of practices. These include; washing hands before collecting water, cleaning collection containers,

covering containers while they are being transported, the types of storage vessels used, the methods used to take water out, the safe storage of drinking cups, using separate cups for drinking, treating water at home, the types of washing materials used, the frequency and length of time spent cleaning storage containers, and the overall cleanliness of stored water (Gizachew *et al*., 2020; IFRC, 2012).

2.9 Informal settlements and microbial contamination

As more people move to cities in Africa the population inncreases. This has led to challenges in terms of resources and capacity. Many developing countries lack planned settlements in their urban areas, which make the issue of slums with poor living conditions and inadequate sanitation services worse (Tidwell *et al*., 2019). Many of the informal settlements, lack access to toilets, so some families have to use pit latrines or open fields, which pollutes the ground water when human waste seeps into the soil (Bishoge, 2021). Studies conducted in Uganda and Rwanda, have raised the concern regarding poor living conditions in slums. Residents often rely on contaminated water sources and do not access to waste disposal systems (Kulabako *et al*., 2010; Uwizeye *et al*., 2014). Also, research in Ethiopia has shown that increase in settlements is associated to inadequate sanitation facilities, which leads to diarrhea (Mulu & Smith, 2020). Proximity of pit latrine to groundwater in Zambia have been linked to the high rates of water-related diseases (Sasaki *et al*., 2008). Lack of drainage systems makes the situation even worse by causing flooding and pollution.

2.10 History of informal settlements in Zambia

These came up in 1891 when the British South African Company obtained mineral rights and recognized viable lead and zinc in Kabwe. By 1939, the country had become the world's primary source of copper, demonstrating its potential as a wealthy nation. During this period there was significant rural-urban migration of people, as they sought to capitalize on employment opportunities in urban areas (Chisulo, 2013). Housing for Africans at the time was inadequately designed and constructed from substandard materials, making it unaffordable for them to secure proper accommodation. Consequently, the proliferation of slums characterized the early stages of urban expansion (Knauder, 1982).

Ipusukilo settlement was established illegally in the early 1970s. The name Ipusukilo means "a place of prosperity" in the local Bemba language. The initial inhabitants arrived in

1971. During that period, local leaders, commonly referred to as chairmen, delineated and distributed plots. The subsequent settlers mainly comprised of retirees and individuals relocating from settlements within Kitwe and other Copperbelt districts. In 1990, the settlement was designated for upgrading, leading to the commencement of the numbering exercise and the issuance of Occupier's Permits by the Kitwe City Council. The settlement is segregated into three distinct sections. Although the land falls under the jurisdiction of the Kitwe City Council, all plots have been delineated and either allocated or sold to land seekers by the local leaders of the area (Macwani *et al.*, 2009). The settlement lacks proper road network and improved water sources such as piped water, people living in Ipusukilo settlement mostly rely on individual shallow wells for their water.

2.11 Water and sanitation regulation system in Zambia

In Zambia, the responsibility for providing water and sanitation services lies with the government, as outlined in the Local Government Act No. 281. To regulate and oversee this sector, the National Water and Sanitation Council (NWASCO) was created. Despite its efforts, NWASCO's services currently reach only about 65% of the population, leaving many residents in informal settlements dependent on unsafe alternatives such as shallow wells. These facilities are particularly inadequate in peri-urban and low-income areas, where a significant portion of the urban population lives (Sichilima *et al.*, 2015; UNDP, 2011).

Although the National Water Policy seeks to promote fair and inclusive access to clean water and sanitation, its implementation often falls short in informal settlements. Weak enforcement of water and sanitation laws has resulted in more than half of slum residents lacking adequate access to these essential services. As a consequence, many rely on unprotected groundwater sources and sanitation methods that contribute to groundwater contamination, including pollution from pit latrines into nearby shallow wells (Bulaya *et al.*, 2017).

2.12 Theoretical framework

The Health Belief Model (Figure 2.3) is a theory used in understanding behavior change and preventive behaviors related to fear and risk perception. The model was used in this study to assess whether households are likely to change their behavioural practices based on what they perceive as the health benefits (Hochbaum, 1958).

The model involves perceived susceptibility, referring to whether households recognize the risk of consuming contaminated water. Those who perceive a highly may be more likely to adopt protective measures such as boiling or chlorination, whereas those who believe their water is safe may be less cautious. Perceived severity influences whether households take contamination threats seriously, such that, respondents who understand that polluted water can lead to severe health are more motivated to improve water handling practices (Straub *et al*., 2014). The observed benefits relate to households belief that specific interventions, such as safe water storage or treatment, effectively reduce microbes. However**,** the barriers include cost, time constraints and inadequate disinfection methods that may hinder the implementation of these practices, thereby increasing the hazard of bacteria. Cues to action, prior experiences with waterborne diseases, health education programs, or community awareness initiatives, may trigger households to adopt safer handling behaviors (Tajeri moghadam *et al.,* 2020). In this model, self-efficacy, or the individual's confidence in the ability to treat and store water safely, plays a key role in determining whether protective behaviors are consistently practiced.

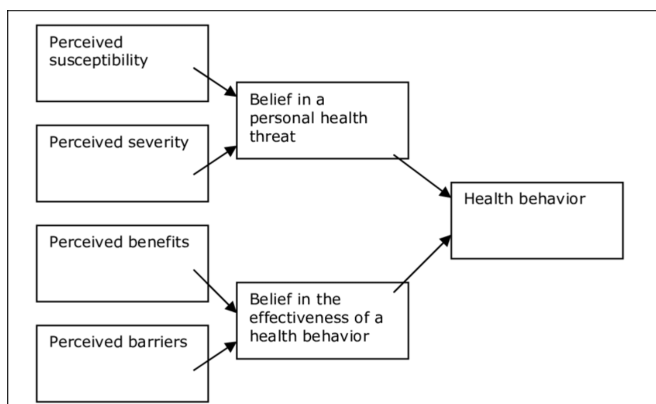

Figure 2.3: The health belief model adopted from Orji and Mandryk (2014)

2.13 Conceptual framework

This is a structure that helps researchers understand and visualize the relationships between the different elements of the study. It includes independent and dependent variables as well as intervening variables that affect the outcome of the research (Ager & Strang, 2008). For this study, it is represented as shown in Figure 2.4.

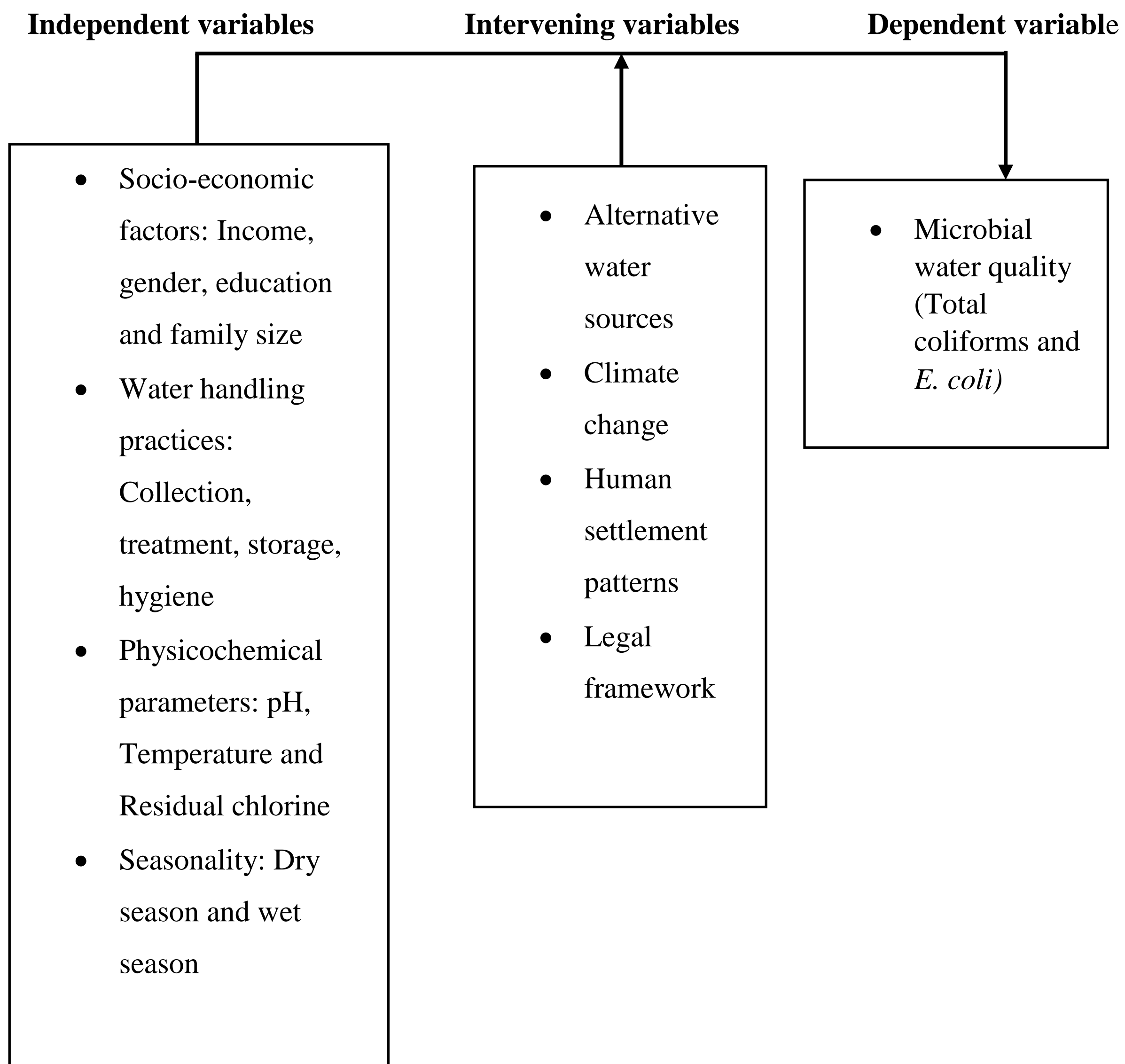

Figure 2.4: Conceptual framework guiding the study

CHAPTER THREE
MATERIALS AND METHODS

3.1 Description of the study area

3.1.1 Location and size

The study was carried out on the Copperbelt province in Kitwe district, with latitude 12°45'S, and longitude 28°20'E. Kitwe district has five constituencies. Ipusukilo settlement belongs to Kwacha constituency (IDP, 2023) and lies in the peri-urban areas of Kitwe stretching along the Kafue River basin (Figure 3.1). According to the census conducted in 2022, the present population of Ipusukilo settlement stands at 31,405 (ZAMSTAT, 2023) with an estimate of 4,800 households (Kitwe City Council, 2024).

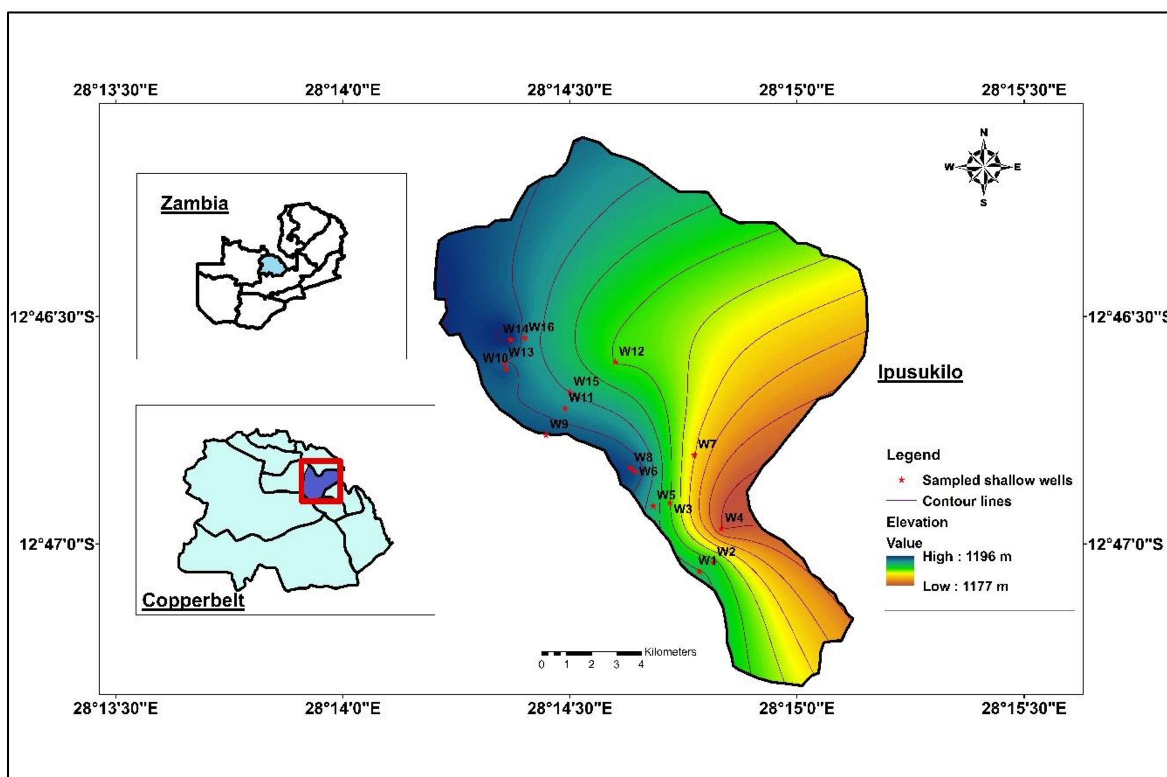

Figure 3.1: Location map of the study

3.1.2 Geology

The area is characterized by a variety of rocks such as limestone, granite and metamorphic rocks. The soil types prevailing in the area are clay to loam soils, which are reddish to brown, having a texture of coarse to loamy topsoil, derived from the underlying rocks (Kitwe District State of Environment Outlook Report, 2010).

3.1.3 Topology

The settlement has an altitude of 1195 m. Ipusukilo settlement has no mature forests or woodlands, but it has grasslands of sparse distribution and ant hill mounds (Kasali *et al*., 2017).

3.1.4 Climate

Temperatures in Kitwe range annually between 9°C and 31°C, with July being the coolest month and October the hottest, recording average temperatures of 9°C and 31°C, respectively. According to the Zambia Meteorological Department, Kitwe records an annual mean rainfall of 1,258 mm with the majority of precipitation occurring during the months of December to March. The driest month for the city is October (SDF Report, 2023). According to Kasali *et al.* (2017), the location of the settlement in the flood plain makes it vulnerable to experience riverine and flash floods.

3.1.5 Socio-economic activities

The area has moist and fertile soils that are suitable for growing crops such as vegetables and sugarcane throughout the year. Homestead gardening is a common feature in the settlement due to the availability of river water. The residents grow crops such as cassava, sweet potatoes, sugarcane, vegetables and pumpkins. Farm plots are also rented out to residents of Ipusukilo by the Ministry of Agriculture and some co-operatives. The cultivated crops on these plots are for both consumption and sale (Macwani *et al*., 2009).

3.2 Research design

A cross-sectional study design was utilised for this research, characterized by the collection of data at one specific point in time (Blumenthal *et al*., 2001). The proposed design was able to effectively meet the study objectives.

3.3 Household sample size

Household sample size determination was guided by the Nassiuma formula (Nassiuma, 2000).

$$n = \frac{NC^2}{C^2 + (N-1)e^2} \quad \text{...Equation 1}$$

Where: n: desired sample size, N: represents the total number of households (4,800) C: coefficient of variation (30%) e: margin of error (2%)

Using the values provided;

$$n = \frac{4800*(0.3)^2}{(0.3)^2 + (4717-1)(0.02)^2} = 215 \text{ households}$$

3.4 Sampling procedure

Administratively, Ipusukilo settlement has been divided into three distinct sections called zones (southeast, southwest and northwest regions) (Macwani *et al*., 2009). The focus areas were zones where residents rely on shallow wells for their drinking water. Based on this selection criteria, the three zones were purposively selected as strata.

According to Kitwe City Council (2024), there are 200 households in zone one, zone two has 1,800 households and 2,800 households in zone three. The proportionate sampling technique (Kish, 1995) was utilized to establish the sample size of households to be included in the study from zones one, two and three from a sample size of 215 households as per equation 2.

$nh = (Nh/N) * n$ ……………………………………………………………..Equation 2

Where Nh is the population size for the stratum, N is the entire population size and n is the desired sample size.

The number of targeted households in each stratum was 4% (9 households) from stratum one, 38% (81 households) from stratum two and 58% (125 households) from stratum three. The selection of households was carried out using a simple random sampling method. First, a list of blocks and the number of households per block was obtained from the local administration office. Each household in the selected blocks was assigned a number. Households in the block were listed and numbered in a sequence. Listed houses in each block were identified through the administrative codes labeled as IP 1023 (IP means Ipusukilo, 10= block 10, 23= household number). A random sample generator (RANDBETWEEN function in Excel) was then used to select the required number of households from each stratum until the desired sample size was reached. This ensured that that all households had an equal opportunity for selection.

3.5 Data collection

3.5.1 Household survey

To obtain data on household practices, a semi-structured questionnaire was used during the survey and administered to heads of households in the study area (Appendix 1). The survey focused on collecting information related to the socio-economic aspects of the sampled households, water handling practices and sanitation practices.

3.5.2 Water sample collection

A sample size ranging from 44 to 100 households is generally considered sufficient to obtain representative data on water quality in areas with a total household population between 4,000 and 6,000 (CAWST, 2013). The study involved proportionate sampling of 132 water samples from 44 households (2 from zone one, 17 from zone two and 25 from zone three), conducted during the dry season (October 2024) and the wet season (December 2024). The 44 households were part of the household assessment of socio-economic factors and water handling practices. Additionally, 16 water samples were also collected at the source (1 from zone one, 6 from zone two and 9 from zone three) following USEPA (2009) guidelines. To ensure that contamination of water samples does not occur during transportation and storage before laboratory analysis, sterile 500 mL containers were used to collect water samples using high-density polyethylene (HDPE) bottles, which are durable and non-reactive, minimizing the risk of contamination. These bottles are ideal for microbial water sampling and were tightly sealed to prevent external contaminants. Sterile gloves were used during sample collection, ensuring no contact with the interior of the bottles. At each site, polyethylene bottles were rinsed and shaken 3 times with the sampled water before it was collected. After filling the bottles they were labeled, and put in a cooler box (4 °C). Samples were taken to the Environmental Engineering Laboratory at Copperbelt University, Zambia, for microbial analysis within 6 hours.

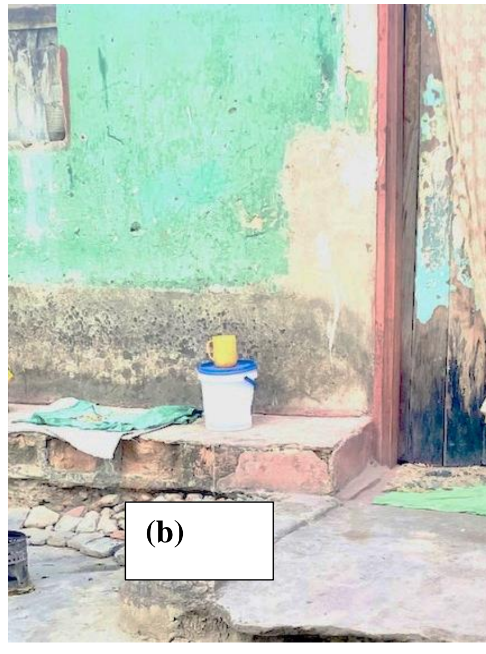

Plate 3.1: Water sample collection from the source (a) and at the point of use (b)

A multi-parameter probe was used in the field to measure physicochemical parameters, including temperature and pH. A color comparator, employing N,N-diethyl-p-phenylenediamine (DPD) as the reagent, was used to measure residual chlorine levels.

Plate 3.2: On-site measurement of physical parameters using a multi-parameter probe

3.5.3 Laboratory analysis

In the laboratory, the membrane filtration method was used to analyze the house stored water and the source. The setup included a filtration unit consisting the filter holder, a membrane filter and a vacuum pump. A sterile membrane filter of 0.45 micrometers was utilized to capture the microbes. The water sample of 100 ml volume was poured through

the membrane filter using a vacuum to draw the sample through. Coliform bacteria retained on the surface of the membrane. After filtration, the membrane was placed on selective growth medium by use of sterile forceps (APHA, 2005). M-Endo les agar was used for total coliform and incubated at 35°C - 37°C for 24 hours. HiChrome for *E. coli* was used and incubated at 35°C for 24 hours.

Plate 3.2: Incubating water samples

Following the incubation period of 24 hours, the Petri dishes were retrieved from the incubator and inspected for microbial growth. Bacterial colonies present on the membrane surface were counted using a digital colony counter. On m-Endo agar, the total coliforms were identified by their characteristic red to pink coloration with a metallic sheen, while the *E. coli* colonies appeared blue on HiChrome.

The total bacterial count in every 100 ml was recorded as Colony Forming Units per 100 ml calculated using the formula:

$$\frac{\text{CFU}}{\text{100ml}} = \frac{\text{No.CFU colonies}}{\text{Volume of water filtered}} \times 100\text{ml} \quad \text{.............................Equation 3}$$

For confirmatory testing, a representative bacterial colony was isolated and biochemical tests were done using urease, citrate, SIM (sulphur, indole, motilility) and TSI

(triple sugar ions), and subsequent Gram staining using thr gram staining kit showed the characteristic appearance of Gram-negative rod-shaped bacteria.

3.5.4 Sanitary inspection

A sanitary survey was carried out at each sampling site when taking the sample. The survey is done to assess the environmental conditions of an area that may led to contamination. All the 16 shallow wells were inspected. This was done by following a standardized format that was adopted from Misati *et al.* (2017). The sanitary scores from shallow wells were plotted against *E. coli* counts to evaluate their relationship.

3.5.5 Prevalence of water related diseases

Health records from Ipusukilo main clinic were examined to determine the most common water-related diseases reported during the year preceding the study period. The data collected included information on age and the type of disease, disaggregated by season. The prevalence of water-related diseases was then calculated with the formula provided below:

$$PR = \frac{P}{N} \times 100 \quad \text{..........Equation 4}$$

Where PR denotes the Prevalence rate, P denotes all individuals with a specific condition at one point in time, and N means the population in the target area.

3.6 Validity and reliability

To ensure the questionnaire accurately captured the intended characteristics, it was reviewed to confirm its relevance and appropriateness by subject matter experts (including environmental health specialists) and the principal investigator, following approval from the Institutional Ethical Review Committee. Additionally, verification of responses from household participants was carried out to ensure all questions were answered correctly and consistently during data collection.

Before conducting the main study, a pilot test was undertaken by administering twenty questionnaires to household respondents in a similar settlement called Chipata. The pre-test results indicated that respondents had a clear understanding of the questionnaire. As part of the reliability assessment for the questionnaire, a Cronbach alpha reliability test was done on the pre tested questionnaire. In this study, a Cronbach alpha of 0.715 was realized and the instrument was entered into the Kobo Toolbox for field data collection.

The equipment utilized for measuring the physicochemical parameters underwent calibration before measurements. To ensure the reliability of laboratory procedures, repeated bacteriological analyses were conducted on water samples.

3.7 Ethical consideration

The questionnaire and the study protocol were approved by the Ethics Committee of Egerton University EUISERC/APP/364/2024 and that of the Tropical Diseases Research Centre TDREC237/10/24. Permission to carry out the study was obtained from the Zambia National Health Research Council NHRA-1612/05/10/2024 and the Zambia Provincial District Health Office. Before participation, respondents provided written consent to participate in the study and were fully informed about the study's purpose.

3.8 Data analysis

Microsoft Excel was employed for data cleaning, while the Statistical Package for the Social Sciences (SPSS), version 24, was used for statistical analysis. R Studio was utilized to generate in-depth graphical outputs and bar charts, which were used to present and interpret the data. The data analysis summary is shown in Table 3.1.

Table 3.1: Data analysis summary

Research objective	Variables	Statistical model
To measure the concentration of Total coliforms and *E. coli.*	**Independent:** Season **Dependent:** Microbial water quality (total coliforms and *E. coli*)	-Descriptives -Paired t-test / -Wilcoxon signed-rank test
To determine the relationship between physicochemical parameters and microbial water parameters.	**Physicochemical parameters** (PH, Temperature and Residual chlorine) **Microbial water parameters** (Total coliforms and *E. coli*)	-Correlations (Spearman / Pearson)
To assess the socio-economic factors that influence microbial water quality.	**Independent:** Income, gender, family size, education **Dependent**: *E. coli*	-Chi-Square -Binary logistic regression

To determine the relationship between water handling practices and microbial water quality.	**Independent:** Water handling practices and season (dry, wet) **Dependent:** *E. coli*	-Chi-Square -Binary logistic regression

CHAPTER FOUR
RESULTS

4.1 Microbial water quality

Microbial contamination levels were particularly higher in the wet season, with total coliforms at 124 ± 40 CFU/100 mL and *E. coli* at 55 ± 20 CFU/100 mL. Detailed findings are provided in Table 4.1 Temperature varied slightly between seasons, measuring 27.2 ± 0.5°C during the wet season and 27.5 ± 0.3°C in the dry season. Mean pH values remained within the WHO guideline range, (6.6 ± 0.5) in the dry season and (7.2 ± 0.5) in the wet season.

Table 4.1: Water quality parameters in water source samples

	Parameter	Dry season	95% CI	Wet season	95% CI
Point of use	Total Coliforms (CFU/100 mL)	27±14	23-32	32±11	29-37
	E. coli (CFU/100 mL)	12±11	9-16	18±13	13-22
	Temperature (°C)	28.1±0.4	27.9-28.2	26.7±0.8	26.5-26.9
	pH	6.4±0.7	6.2-6.6	6.7±0.6	6.5-6.9
	Residual Chlorine (mg/L)	0.1±01	0.11-0.15	0.1±01	0.12-0.15
Source	Total Coliforms (CFU/100 mL)	79 ± 24	67-92	124 ± 40	103-146
	E. coli (CFU/100 mL)	26 ± 16	18-35	55 ± 20	44-66
	Temperature (°C)	27.5±0.3	27.4-27.7	27.2±0.5	26.9-27.4
	pH	6.6±0.5	6.3-6.9	7.2±0.5	6.8-7.4

Microbial contamination at the POU was also a concern with 26 CFU/100 mL in the wet season and 55 CFU/100 mL in the wet season.Water stored at the point of use was slightly warmer in the dry season (28.1°C) compared to the wet season (26.7°C). Chlorine levels were low, with 68% in the dry and 75.3% in the wet seasons.

For the risk levels, results revealed that during the dry season, shallow wells were categorized as having a very high contamination risk, with 75% in the high-risk classification (11-100 CFU/100 mL) (Figure 4.1). Water drawn from point of use was classified as high risk 47.7% falling into this category in the dry season and 65.9 in the rain season. The study found that shallow wells were entirely in the high-risk level, with 100% in the wet season.

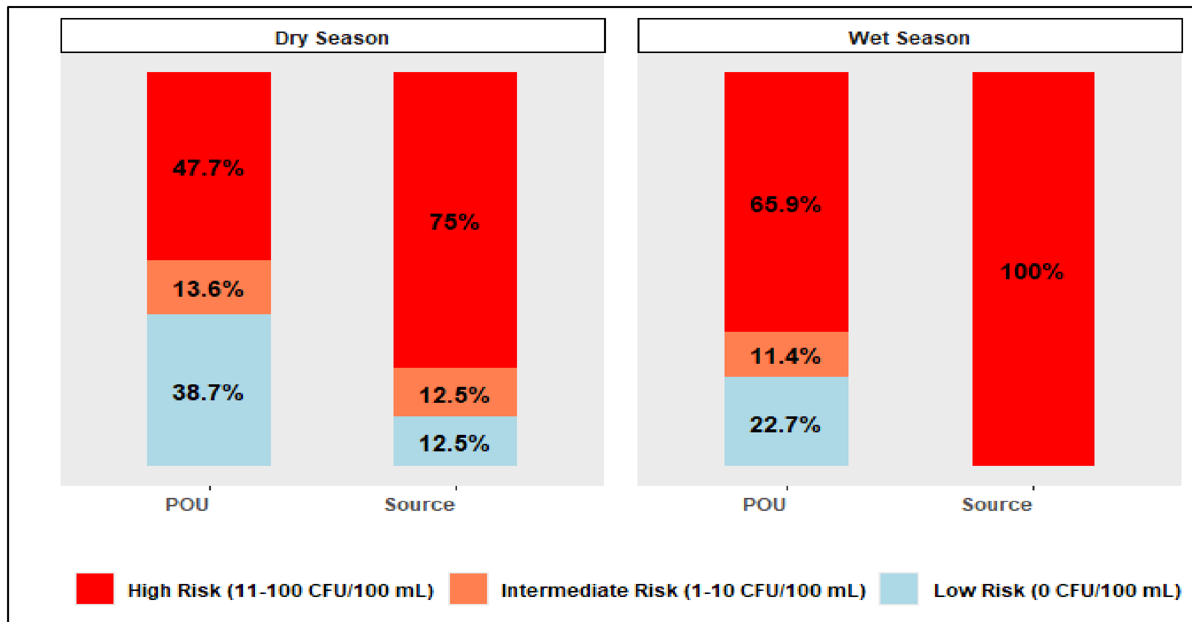

Figure 4.1: Percent distribution of *E. coli* contamination risk levels

4.1.1 Seasonal variation in mean bacteria counts

The study observed notable differences in microbial contamination between the two seasons for both shallow wells and household drinking water. Analysis with the Wilcoxon signed-rank test showed a significant seasonal variation in microbial contamination at the POU, with total coliforms ($Z = -8.061$, $p = 0.001$) and *E. coli* ($Z = -6.582$, $p = 0.001$) both showing higher levels during the wet season.

4.1.2 Sanitary risk survey

A sanitary survey was carried out for every selected shallow well through the use of a sanitary survey questionnaire (Lloyd & Bartram, 1991). The total risk scores obtained were compared to the established risk categories (Etang, 2000; WHO, 2017) and are presented in Table 4.2. These scores remained unchanged throughout the period of study. The results indicated that 50% of the wells were classified as high risk, while 12.5% were categorized as very high risk, with scores ranging from 9 to 10. Additionally, 18.75% of the wells were categorized as intermediate risk, whereas the remaining 18.75% were classified as low risk.

Table 4.2: Sanitary survey of sampled shallow wells in the area of study

Risk	Frequency (%)	Remedial action
Very high	2 (12.5)	Urgent
High	8 (50)	High
Intermediate	3 (18.75)	
Low	3 (18.75)	Low
No risk	0 (0)	No action

The sanitary risk scores from shallow wells were plotted against *E. coli* counts, revealing a positive non-significant correlation in both the dry season (p = 0.106) and the wet season (p = 0.434) (Figure 4.2). These findings indicate that there was no significant correlation between *E. coli* counts and sanitary risk scores.

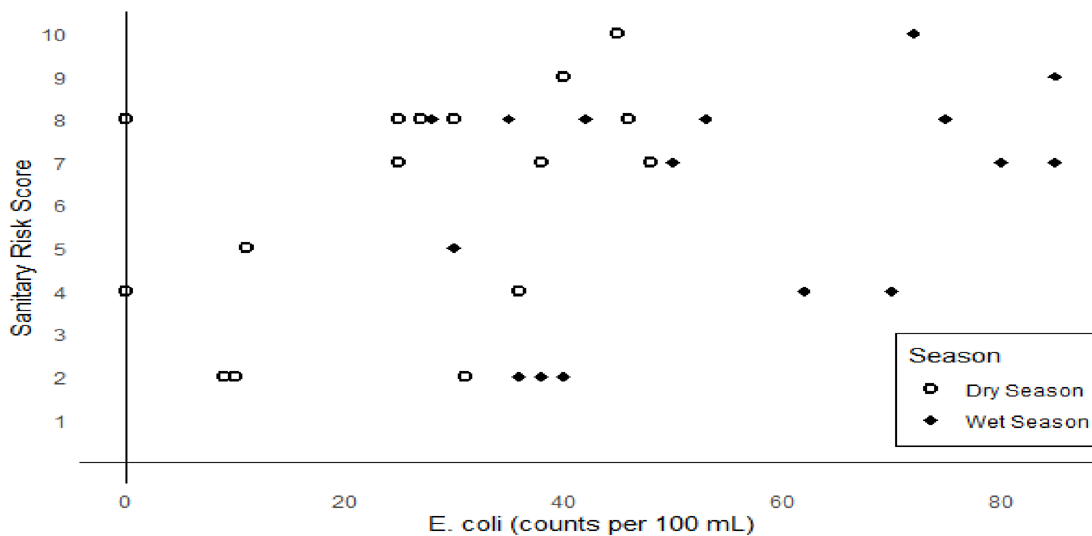

Figure 4.2: Scatter plot of *E. coli* counts versus sanitary scores

4.2 Relationship between physicochemical parameters and microbial water quality

Spearman correlation analysis revealed significant relationships between physicochemical characteristics and microbial contamination in household water. During the dry season, water temperature showed a moderate positive correlation with *E. coli* (r = 0.52, p = 0.001) and total coliforms (r = 0.43, p = 0.003), suggesting that higher temperatures favor microbial growth through enhanced metabolic activity and prolonged bacterial survival. In the wet season, temperature showed weak and non-significant correlations with *E. coli* (r = 0.19, p = 0.173) and total coliforms (r = 0.23, p = 0.132). Similarly, pH had a positive correlation with *E. coli* in the dry season (r = 0.69, p = 0.001). Residual chlorine revealed a

moderate and statistically significant negative correlation with *E. coli* in both seasons (r = -0.42, p = 0.004), underscoring its important role in reducing microbial contamination in household water (Figure 4.3).

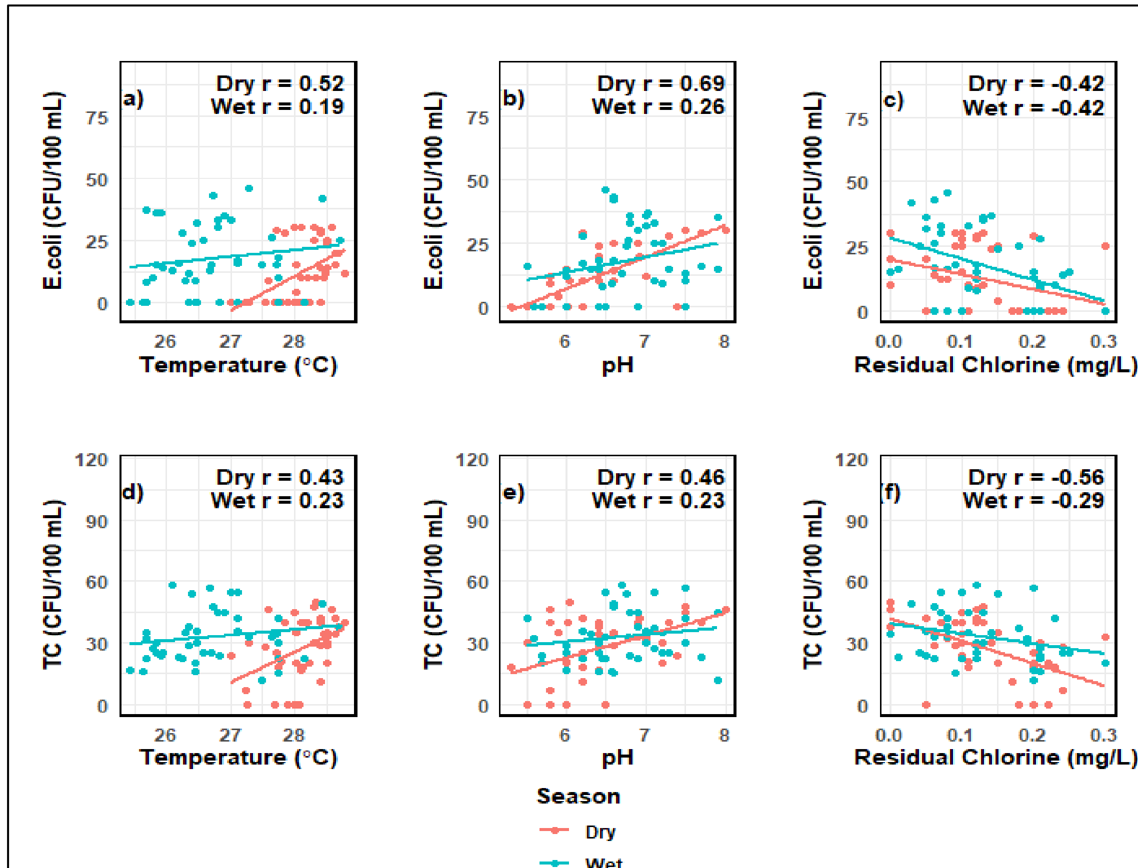

Figure 4.3: Correlations of physicochemical parameters at POU

The analysis showed significant correlations between microbial water quality and physicochemical parameters. Temperature showed a positive correlation with *E. coli* (r= 0.72, p = 0.002) in the dry season, and wet season (r= 0.86, p 0.001). Additionally, pH was positively correlated with *E. coli* in the dry season (r = 0.54, p = 0.032) as shown in Figure 4.4

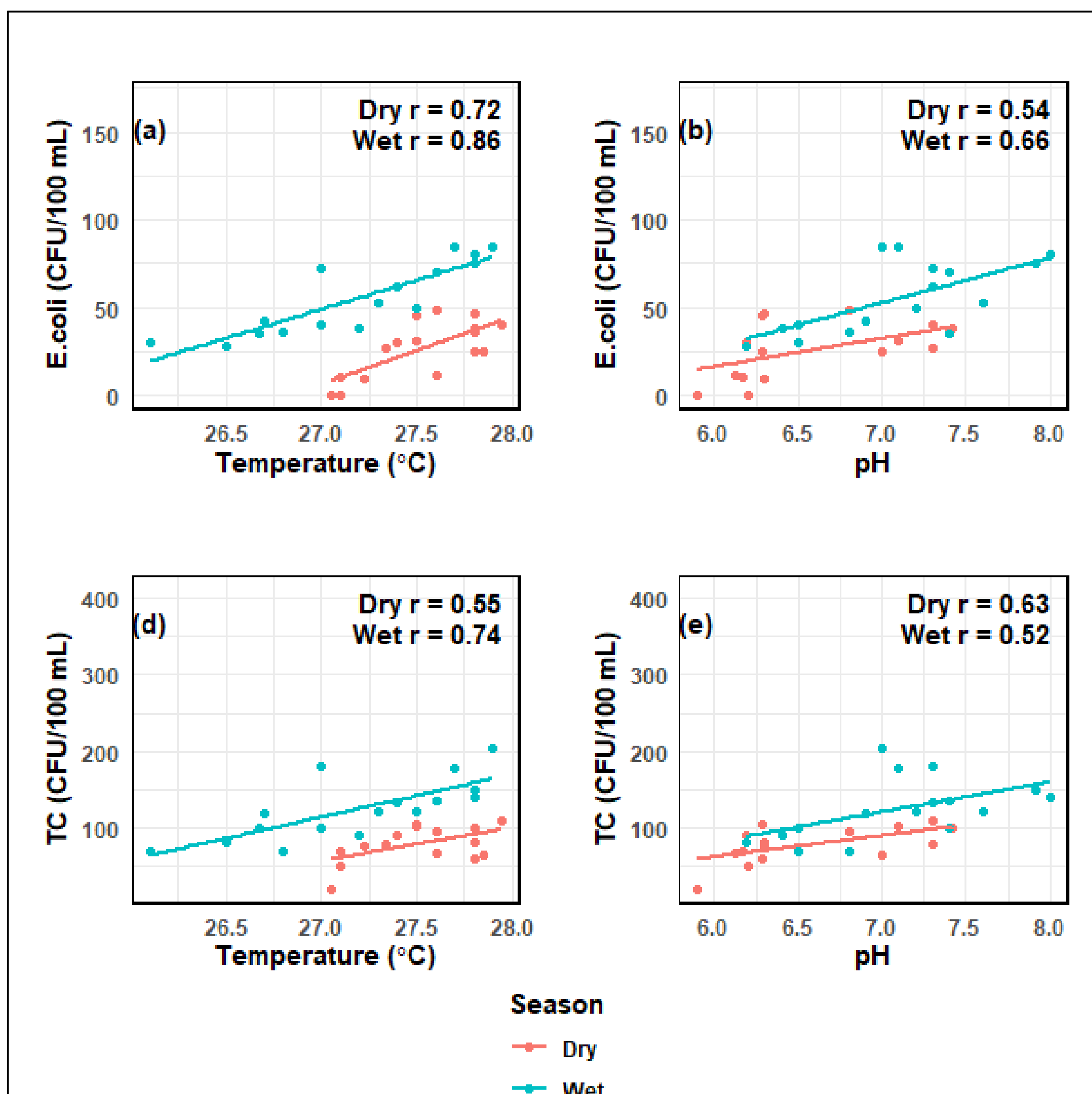

Figure 4.4: Correlations of physicochemical parameters at the source

4.3 Socio-economic factors associated with *E. coli* contamination

Among the sampled households, 65.1% (n=140) were female, while male respondents comprised 34.9% (n=75). Household sizes were predominantly in the range of 6-10 members and consisted 49.3% (n=106) and a smaller proportion of 5.1% (n=11) had more than 10 members. The age of the respondents varied among the sampled households. Most respondents were aged between 29-39 years and constituted 38.6% (n=83), followed by those aged 40-50 years comprising 34.9% (n=75). The education levels are presented in Table 4.3.

Table 4.3: Education levels completed by household heads

Education level	Frequency	Percent
No formal education	51	23.7
Primary	92	42.8
Secondary	63	29.3
Tertiary	9	4.2
Total	**215**	**100**

Most household heads had completed primary education (42.8%), followed by 29.3% who had completed secondary education. Only 4.2% reported attaining tertiary education and 23.7% had no formal education. Regarding income, nearly half of the households (48.4%) earned between USD 3.8 - USD 19, while 43.7% reported incomes between USD 22.8 - USD 38, and only 7.9% earned above USD 38 (Table 4.4).

Table 4.4: Monthly income levels among households

Monthly income[#]	Frequency	Percent
USD 3.8 – USD 19	104	48.4
USD 22.8 – USD 38	94	43.7
>USD 38	17	7.9
Total	**215**	**100**

[#]1 USD =26.269 Zambian Kwacha (ZMW) (2024)

The study assessed the influence of socio-economic factors on microbial water quality (Table 4.5). The results reveal significant associations for several variables, such as, household size, monthly income and education level.

Table 4.5: Multivariable analysis of socio-economic predictors of *E. coli*

Variables	Contamination of water with *E. coli*		COR 95% CI , p value	AOR 95% CI, p value
	Absence %	Presence %		
Household size				
1 - 5	82.3	29.6	0.090 (0.020- 0.403), 0.002*	0.076 (0.006 – 1.001), 0.050*
6 - 10	17.6	70.4	1	1
Monthly income				
USD 3.8-USD 19	5.9	66.7	1	1
USD 22.8-USD 38	52.9	25.9	0.043 (0.005- 0.407), 0.006*	0.075 (0.005 – 1.210), 0.068
>USD 38	41.2	7.4	0.016 (0.001- 0.204), 0.001*	0.019 (0.001 - 0.534), 0.020*
Education level				
No formal education	5.9	51.9	1	1
Primary	29.4	29.6	0.114 (0.011- 1.158), 0.066	0.356 (0.023 – 5.391), 0.456
Secondary	29.4	14.8	0.057 (0.005- 0.641), 0.020*	0.092 (0.003 – 2.936), 0.177
Tertiary	35.3	3.7	0.012 (0.001- 0.223), 0.003*	0.009 (0.000 – 0.545), 0.025*

Abbreviations:*Statistically significant, COR, crude odds ratio; AOR, adjusted odds ratio; 95% CI, 95% confidence interval; Hosmer and Lemeshow p value = 0.7 indicating the model fits well; 1, reference category

The findings revealed significant associations between *E. coli* contamination in drinking water and household size, monthly income, as well as the education level of the head of house. Household size was significantly associated with microbial water quality (p

= 0.001). Larger households with 6-10 members recorded higher *E. coli* contamination rates (70.4%) compared to smaller households with 1-5 members (29.6%). Based on the multivariable logistic regression results, smaller family sizes were linked with a decreased risk of presence, with an adjusted odds ratio (AOR) of 0.076 for households with 1–5 members compared to larger households.

Education level was another key factor influencing microbial water quality (p = 0.008). Households with no formal education had the highest *E. coli* contamination rates (51.9%), while those with tertiary education recorded the lowest contamination rates (3.7%). The logistic regression results further reinforced this trend, showing that individuals with tertiary education had considerably lower odds of water contamination (AOR = 0.009; 95% CI: 0.000-0.545; p = 0.025) compared to those with no formal education. Similarly, household income was found to have a strong relationship with *E. coli* contamination (p = 0.001). Contamination rates were highest (66.7%) among households earning between USD 3.8 and USD 19, while those earning above USD 38 had the lowest contamination rates (7.4%). The logistic regression results (Table 4.5) confirmed this association, with households earning over USD 38 showing (AOR = 0.019; 95% CI: 0.001-0.534; p = 0.020) compared with households having lower incomes USD 3.8 and USD 19.

4.4 Water handling practices associated with *E. coli*

Water handling practices, which includes the type of container utilised for storing drinking water, varied among households. The majority 59.5% (n= 128) used wide-mouth plastic buckets, while 40.5% (n= 87) stored water in narrow-mouth plastic containers (Figure 4.5).

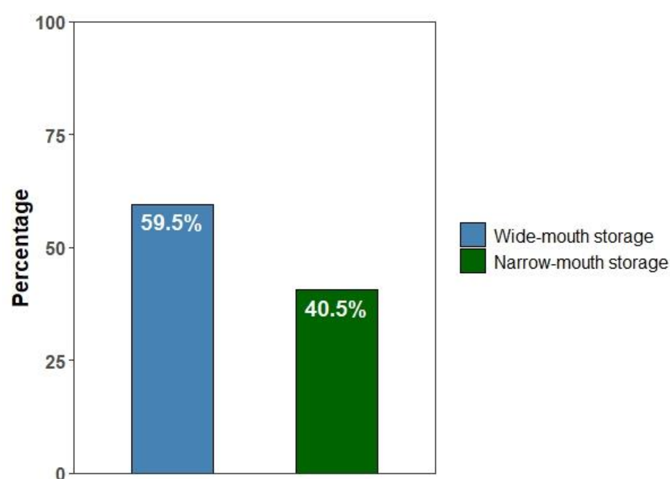

Figure 4.5: Water storage containers utilized among households

In terms of storage time, over half of the households (54%, n = 116) kept drinking water for more than 24 hours, while 7.9% (n = 17) stored it beyond 48 hours. Placement of drawing utensils also differed, with 40% (n= 86) keeping them inside the storage container, 30.2% (n= 65) on the floor, 16.3% (n= 35) hanging on the wall and 13.5% (n= 29) placing them on a kitchen table. For water withdrawal practice**s**, 59% (n = 128) of respondents reported using the dipping method, where a cup is inserted directly inside the storage container to collect drinking waterr, while 40.5% (n = 87) obtained water by tilting the storage container to pour water. Among the 215 interviewed households, 41% (n= 88) of respondents who treated their drinking water, 32% (n= 68) used chlorine-based treatment and 9% (n=20) relied on boiling (Figure 4.6).

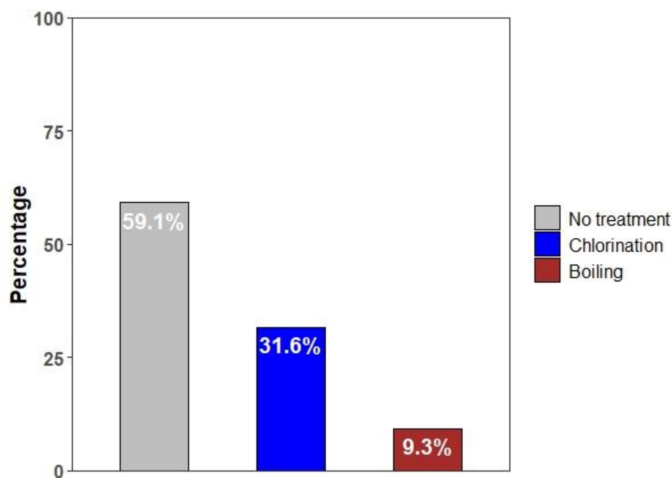

Figure 4.6: Household water treatment methods

The research results indicated that 38% (n=82) reported cleaning their storage containers using soap and water (Figure 4.7), whereas most of the households consisting 57% (n=122) used only water and smaller percentage 5% (n=11) used mud. The findings indicated that 13.5% of respondents stated washing hands with soap and water before meals, while a majority (86.5%) used water only. After defecation, 40% practiced handwashing with soap and water. In terms of sanitation, the facilities were predominantly latrines (92.1%) (n=198) while 7.9% (n=17) of households had ventilated pit latrines. When it comes to waste disposal, majority said they burn 72.1% (n=155), while others bury 20.9% (n=45) and a few reported to throw in the open 7.0 (n=15). Awareness of hygiene practices varied among respondents, 47.0% were aware of the importance of drinking safe water, 30.7% recognized handwashing with soap and 19.5% identified safe water storage at home, and only 2.8% aware of the need for safe disposal of babies feces.

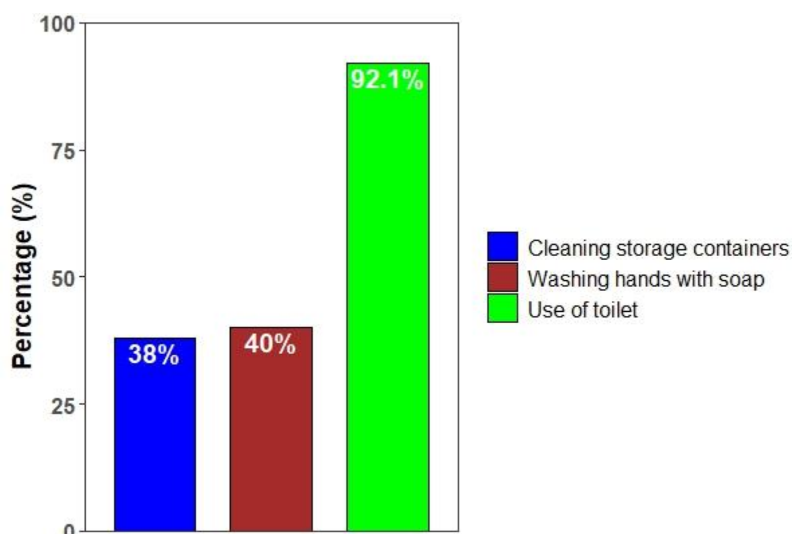

Figure 4.7: Summary of hygiene and sanitation practices

A significant association was established between water handling practices and *E. coli* in drinking water among households (Table 4.6). The odds of contamination were higher through the wet season, with households having 8.726 times greater odds of *E. coli* presence likened to the dry season (AOR = 8.726; 95% CI: 1.450-52.515, p = 0.018). Narrow-mouthed storage containers were associated with lower odds of contamination (AOR = 0.090; 95% CI: 0.014-0.580, p = 0.011) compared to wide-mouthed storage containers. Covered containers also had reduced odds of contamination compared to uncovered ones (AOR = 0.113; 95% CI: 0.014-0.889, p = 0.038).

Table 4.6: Multivariable analysis of water handling practices associated with *E. coli*.

Variables	**Contamination of water with *E. coli***		**COR 95% CI, p value**	**AOR 95% CI, p value**
	Absence %	**Presence %**		
Season				
Wet	37	55.7	2.141 (0.844- 5.427), 0.109	8.726 (1.450-52.515), 0.018*
Dry	63	44.3	1	1
Mouth size of WSC				
Narrow	63	26.2	0.209 (0.080-0.550), 0.002*	0.090 (0.014-0.580), 0.011*
Wide	37	73.8		1
Are WSC covered?				

Yes	51.9	18	0.204 (0.075- 0.554), 0.002*	0.113 (0.014-0.889), 0.038*
No	48.1	82	1	1
Water withdrawal method				
Pouring	81.5	36.1	1	1
Dipping	18.5	63.9	7.800 (2.589-23.497), 0.001*	7.245 (1.440-36.447), 0.016*
Duration of stored water				
< 2 4 hours	74	36	1	1
> 24 hours	26	56	5.065 (1.850-13.864), 0.002*	1.375 (0.241-7.855), 0.720
Practice of HWT				
Always	56	16	0.157 (0.057-0.434), 0.001*	0.120 (0.022-0.656), 0.014*
Sometimes	44	84	1	1
Hand washing with soap				
Yes	66.7	21.3	0.135 (0.049- 0.371), 0.001*	0.038 (0.005-0.281), 0.001*
No	33.3	78.7	1	1

Abbreviations: * Statistically significant, COR, crude odds ratio; AOR, adjusted odds ratio; 95% CI, 95% confidence interval; Hosmer-Lemeshow p-value = 0.826, indicating a well-fitted model; 1, reference category; WSC, water storage container; HWT, household water treatment.

The method of water withdrawal was a significant factor, households using the dipping method were over seven times more likely to have contaminated water compared to those using the pouring method (AOR = 7.245; 95% CI: 1.440-36.447, p = 0.016). Additionally, the duration of water storage influenced microbial quality, with water stored for more than 24 hours showing higher odds of contamination (COR = 5.065; CI: 1.850-13.864, p = 0.002), although this was no longer significant after adjusting for other variables (AOR = 1.375; CI: 0.241-7.855; p = 0.720). Regarding household water treatment, households that regularly treated their water with chlorine had a significantly lower odds of contamination compared to those who did not (AOR = 0.120; CI: 0.022-0.656; p = 0.014).

Furthermore, maintaining hygiene by hand washing with soap significantly reduced the odds of contamination (AOR = 0.038; CI: 0.005-0.281; $p < 0.001$).

4.5 Prevalence of water-related diseases

Seasonal variation in the prevalence of water-related diseases is illustrated in Figure 4.8 Diarrhea was the most frequently reported condition in the dry season, with 245 cases documented. In contrast, the wet season had a higher occurrence of both cholera and diarrhea.

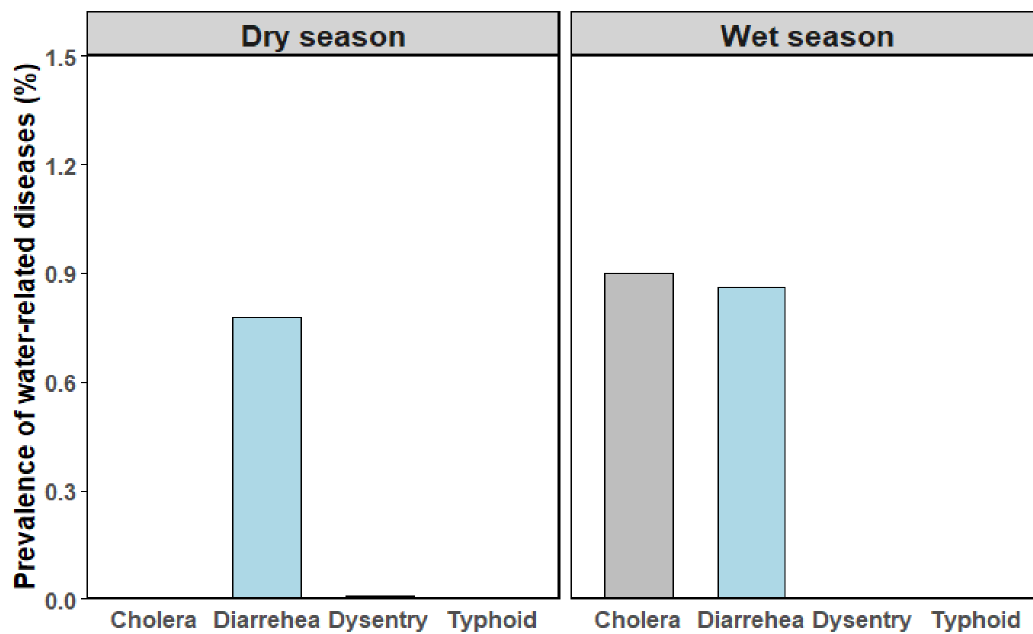

Figure 4.8: Prevalence rates of water related diseases by season in the study area

CHAPTER FIVE
DISCUSSIONS

5.1 Microbial water quality

Microbial contamination showed significant deviations from the WHO limit (0 CFU/100mL). The study found that 61.3% of households had *E. coli* during the dry season and 77.3% in the the wet. These figures are lower than the 90% reported in Ethiopia (Gizachew *et al*., 2020) but higher than 56.5% in India (Gautam *et al*., 2025). Water that falls into the high-risk category is considered unsafe and has a higher chance of causing waterborne diseases (Saima *et al*., 2023; Yang *et al.*, 2025). In order to acces safe water, the World Health Organization recommends disinfecting water to eliminate pathogens (WHO, 2008). Chlorination is the most common way to treat water. In this study, it was found that 68% and 72% had levels below the limit of 0.2–0.5 mg/L during both seasons respectively. This means that the water among them was not being disinfected well enough (WHO, 2017). The percentage was greater than 47% of samples in Panama (Gonzalez *et al*., 2020), but lower than the 85% in Ethiopia that fell below the guideline (Sharma *et al*., 2013).

All the source samples that were tested during the wet season and most of them during the dry season did not meet WHO and ZABS standards. Shallow wells are easily polluted because they are not very deep and are exposed to surface contaminants (Nayebare *et al.,* 2022). This study's results are aligned with earlier studies that have found fecal matter in them. For example Haramoto (2018) research in Nepal discovered that all of the wells they tested had *E. coli*. This is similar to what this study observed. In the same way, Segut *et al.* (2024) found that 80.6% in Kenya tested positive for fecal coliforms. This is higher than the 60% rate that was found in Ethiopia (Gizachew *et al.,* 2020).

5.1.1 Seasonal variation

Microbial water quality varied with seasons. Higher counts were noted during the wet period. At the source, increased recharge rates and water tables moved coliform bacteria from the surface and sanitation facilities (Awuah, 2024; McGill *et al*., 2019). Shallow wells, which often have damaged casings, are susceptible to bacteria pollution. The findings of the study point that the presence of fecal coliforms may result due to proximity to pit latrines. This study is consistent with what was established in other research (Machona *et al*., 2025; Nayebare *et al*., 2022; Segut *et al*., 2024).

The observed counts at the point of use were likely because water at the source was already polluted. Or it may have been stored poorly, and lacked disinfection (Girmay *et al*., 2020). These findings align with Ayeni *et al*. (2023) who reported similar trends but contrasts findings from Ethiopia which identified greater *E. coli* in the dry season (Aydamo *et al*., 2024).

5.1.2 Sanitary survey of shallow wells

The sanitary risk scores from shallow wells were plotted against *E. coli* counts, revealing a positive non-significant correlation in the, dry ($p = 0.106$) and wet ($p = 0.434$). The lack of statistical significance supports the limitation of sanitary surveys in predicting water quality (Misati *et al*., 2017; Snoad *et al*., 2017). Although the the overall sanitary risk score did not correlate with *E. coli* presence, specific risk factors such as proximity of the well to the pit latrine ($p = 0.025$), exposed rope and bucket ($p = 0.025$) and poorly sealed well walls ($p = 0.05$) showed a significant association with *E. coli*. These results differ from those of Luby *et al*. (2008), where individual risk factors did not show a significant association with microbial water quality, but agree with findings of Ercumen *et al*. (2017) in Bangladesh, where individual components of the sanitary risk were were linked to *E. coli* presence. Similarly, Tadele and Tekile (2025) identified five individual risk factors associated with coliform contamination. This suggest that while the combination score did not correlate with *E. coli* presence, specific sanitary risk factors can significantly be associated with microbial water contamination.

5.2 Relationship between physicochemical parameters and microbial water quality

Temperature showed a positive correlation with total coliforms and *E. coli*, suggesting that warmer temperatures are favor microbial growth through enhanced metabolic activity. PH on the other hand also had a positive correlation with microbial growth, suggesting that optimal ph levels between 6.0-7.5 favor microbial growth. Additionally, the negative correlation observed between residual chlorine levels and *E. coli*, suggests that lower chlorine concentrations are associated with higher microbial contamination at the household level. This result aligns with previous research that have indicated that low levels of residual chlorine contribute to the presence of bacteria in stored drinking water (Gillespie *et al.,* 2014; Mao *et al.,* 2018).

5.3 Socio-economic factors associated with *E. coli* contamination

Household heads having education above secondary were less likely to have *E. coli* compared to those with no formal levels. This means that it is an important factor that influences water quality, especially when it comes to having knowledge on water handling for drinking purposes. It also plays a role in perceiving the risks that are associated with consuming contaminated water. The results are similar to studies by Makokove *et al*. (2022) and Mugumya *et al.* (2020) who pointed out that a literate person is more able to recognize the health implications of unsafe water and the perceived benefits of consuming uncontaminated water. Hasan *et al.* (2022) and Yang *et al*. (2025) found similar results, thus, adds to the evidence. The inverse relationship between educational attainment and *E. coli* presence identified in the current study reinforces the idea that improving education can enhance water and promote safer drinking practices.

Income was another factor that could have could influence bacteria presence. Households earning more than USD 38 (ZMK 1,200) had a lower odds ratio of *E. coli* contamination. This result is consistent with a study by Hernandez-Vasquez *et al*. (2022) in Peru who reported that higher-income had a lower likelihood of *E. coli* in water. This relationship may arise from better access to safe sources and water handling practices. Several studies have shown this association, which makes it easier to access clean water (Adelodun *et al.,* 2021; Haque *et al.,* 2022; Maniragaba *et al*., 2023). This pattern is evident in developing countries, where households in the lowest wealth quintiles are more likely to have bacteria presence than wealthier ones (Bain *et al*., 2021; Cronin *et al*., 2017).

The study also found that having more people in the house was linked to having *E. coli* water. Families with 1-5 members were 0.076 times less likely to have *E. coli* in their stored water than those with 6-10. This could be because extended homes have increased number of peple accessing water and they may depend more on shared water storage. This can lead to pollution when people handle it, store it incorrectly, or cross-contamination from multiple users. These findings back up what Ondieki *et al*. (2022) found, which was that the size of a household had an influence on the amount of coliforms in drinking water in Kenya. On the other hand Gebremichael *et al.* (2021) observed that larger families in Northwest Ethiopia had better access to improved water than smaller ones.

5.4 Water handling practices associated with *E. coli* contamination

Many of the households in the study area used wide-mouthed containers, such as plastic buckets, to store drinking water. These kinds are easily contaminated because they

have ease of access and provides a large surface area and people typically use utensils to scoop water. Narrow-mouthed containers protect water from pollutants by limiting direct contact, reducing the possibility of bacteria presence. Similar findings were reported in Kenya by Ondieki *et al*. (2022) who reported that buckets as storage puts water at a greater risk of contamination. Similarly, Ali *et al*. (2023) observed comparable results in Ethiopia, where they emphasized the role of the container in reducing bacteria pollution. In this study, households that withdrew water using the dipping method were found to be 7.245 times more likely to have *E. coli* than those who used the pouring way. These results are in line with what Larson *et al.* (2023) observed.

The study also found that, covering storage containers is a good way to decrease the risk of contamination in general. This study indicated that homes that practiced this had less *E. coli* presence than those that did not. But this is different from what a research in Thailand (Vannavong *et al*., 2018), found, that covered containers had more coliforms, either because of cpoor collection practices or inadequate hygiene.

In addition, household water treatment, especially with chlorine, was found to greatly lower the amount of microbes in the water. Regularly treatment of water was 0.120 times less likely to have *E. coli* than inconsistency. This is in line with findings from Nagpur, India Bivins *et al*. (2021), where inadequate disinfection left households exposed to bacteria contamination. Studies conducted in South Africa, Nigeria and Ethiopia (Aydamo *et al.,* 2024; Luvhimbi *et al*., 2022; Okoh *et al.,* 2021) have shown that chlorination is effective in lowering coliform counts in drinking water.

Regular handwashing with soap was protective against water having *E. coli*. Respondents who said they always did this before handling water had a lesser risk of bacterial presence, aligning with the findings of Adhikari *et al*. (2020). Proper hygiene is necessary when it comes to preventing pathogen transmission, because hands can carry *E. coli* and contaminate stored water (Wispriyono *et al*., 2021). Studies, such as those by Rifqi *et al*. (2023) in Indonesia, support this because such practices lead to bacteria being transfered to water. Agensi *et al*. (2019) observed that in Uganda, drinking water had more bacteria, this was due to the fact that people were not using water and soap after using the toilet.

5.5 Prevalence of water-related diseases

There were 245 cases of diarrhea during the dry season, making it the most common water-related disease, while during the wet season, the most prevalent were cholera and diarrhea. This change in the seasons shows how harmful waterborne infections may be for

public health, especially during the wet season when the contamination tends to be higher. Waterborne diseases are a major public health problem, especially in places where there is inadequate water and sanitation. Taking water that is contaminated with microorganisms causes diseases including; cholera, diarrhea, typhoid, and dysentery (Mapingure *et al*., 2024). *E. coli*, a fecal indicator bacterium, is strongly associated with gastrointestinal infections, that can lead to dehydration and in extreme cases, mortality, particularly among young children and older individuals (Okesanya *et al*., 2024). The increased occurrence of *E. coli* contamination during the rainy season is consistent with higher incidences of waterborne disease outbreaks during periods of heavy rainfall, as documented by Battersby *et al*. (2019) and WHO (2024).

CHAPTER SIX

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

6.1 Summary of findings

The study assessed the influence of socio-economic factors and water handling practices on the microbial water quality. The findings of the study showed that, seasonal variations played a role, with higher contamination observed during the wet season. This period led to higher humidity and temperatures favoring bacteria growth. In addition, the socio-economic factors such as income and education levels and poor handling practices increased microbes in water at the point of use. Furthermore, unsafe household practices such as dipping, uncovered containers, and lack of handwashing contributed to elevated *E. coli* levels.

6.2 Conclusions

The following are the conclusions of the study:

i. Shallow wells and point of use water samples were contaminated with bacteria. This renders the wells unfit for human consumption without prior treatment. The contamination at the source was likely due to the proximity with poorly constructed pit latrines, surface runoff and flooding in the study area. These pathways create harmful pathogens leading to an increase in diarrhea diseases, hence explaining the rising contamination levels. As households collected and stored this water, the microbial load at the POU was noticed.

ii. Physicochemical parameters influence microbial growth by providing a favorable environment. Higher humidity plus warmer temperatures may have created condusive conditions for bacteria proliferation in water, especially in cases where households had poor handling and storage practices. On the other hand, residual chlorine levels reduced *E. coli* levels.

iii. Socio-economic factors in this study such as the monthly hosehold income and the education level were associated with microbial water quality. Lower income houses were most likely to rely on untreated water. Limited financial resources may have restricted access to treatment options contributing to higher *E. coli*. Household heads with no formal education had greater odds of bacteria presence, leading to higher contamination. In contrast to those educated, they were more pone to adopt proper storage, regular disinfection and hygienic methods, thereby reducing microbes.

iv. The association between these practices and microbial contamination coupled with the high incidence of water-related illnesses underscores the significant influence of household behaviors on water safety. These findings suggest that improving hygienic water storage and handling methods at the household level is key to decreasing bacteria pollution and the resulting health impacts in the study region.

6.3 Recommendations

1. Household and community level

i. Households must adopt safer water handling and hygiene practices.

ii. People in the community should learn how important it is to store drinking water in narrow mouthed covered containers and avoid direct contact during retrieving.

iii. Furthermore, households need to be trained on the use of chlorine correctly for disinfection. This means knowing the right amount and frequency of application of treatment to make sure the water is treated properly.

iv. Local health facilities should ensure that people get access to disinfectants. Local leaders and health promoters can encourage people to take part in their communities, which can assist in reinforcing these behaviors and contribute to long-term changes in behavior at the home level.

2. Policymakers and implementers (Government authorities and agencies)

i. The Government needs to put a lot of effort into improving water, sanitation, and hygiene (WASH) infrastructure by adding water systems, investing in piped water supply systems, clean sanitation facilities, and good drainage systems.

ii. Environmental health departments, the municipal council, and other government organizations should regularly monitor water quality at both the source and where it is consumed. These assessments should guide the identification of high-risk areas and inform targeted public health interventions.

iii. The Ministry of Health and local governments should also make sure that chlorine disinfectants are always available and include training programs on how to treat household water in their public health outreach initiatives.

iv. National water quality standards need to be enforced more strictly, and service providers and environmental inspectors need to be held clearly accountable. Action plans to address waterborne disease risks should be developed and implemented at district and community levels.

6.3 Suggestion for further research

Further research is needed to expand the understanding of waterborne pathogens and their health risks. For instance, future studies could investigate a wider range of pathogens in water such as *Vibrio cholera Salmonella* and *Shigella*.

Longitudinal studies could offer more insight into causal relationships over time. To achieve a more thorough understanding of microbial contamination.

Future studies should also look into factors like water source distance and environmental factors.

Future research can examine antibiotic-resistant bacteria in water sources. As antimicrobial resistance grows, researchers could look at the antibiotic-resistant bacteria that live in shallow wells and domestic water storage and how they might affect public health.

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APPENDICES

Appendix I. Household survey

My name is Sarah Ng'andwe, I am a student at Egerton University pursuing Masters of Science degree in Environmental Science. I am conducting research on the "**Influence of Socio-economic Factors and Water Handling Practices on the Drinking Water Quality in Kitwe District"**. I am seeking your opinion on water handling practices at the household level. The information provided here will be treated as confidential and will be used for academic purposes only.

Date of Survey ………… Zone…………House Number………………….

1.0 HOUSEHOLD CHARACTERISTICS

1.1 Gender

1. Male
2. Female

1.2 Respondents' Age

1. 18- 28
2. 29 – 38
3. 39 – 48
4. 49 – 58
5. 59 – 68

1.3 How many people live in your household

1. 1-5 members
2. 6-10 members
3. More than 10 members

1.4. Education level

1. Primary level
2. Secondary level
3. Tertiary level
4. No formal education

1.5 Monthly income

1. ZMW 100-500
2. ZMW 600-1000
3. More than ZMW 1000

WATER HANDLING PRACTICES

2.0 Collection of water

2.1 How many households use the well?

1. One
2. Two
3. More than three

2.2 How do you lift water from the well?

1. Rope and Bucket
2. Wooden stick and Plastic Bucket
3. Jerry can
4. Hand Pump

2.3 Do you wash your hands with soap before collecting water?

1. Always
2. Sometimes
3. Rarely

2.4 Do you wash the collection container before drawing water?

1. Yes
2. No

2.5 Is water transported from the well in closed containers?

1. Yes
2. No

3.0 Storage of household water

3.1 What container do you use to store drinking water in the household?

1. Plastic container
2. Clay pots
3. Plastic bucket
4. Jerrycan

3.2 What is the size of the container you use for storing drinking water in your household?

1. Wide mouth
2. Medium mouth
3. Very small mouth
4. Other specify ………………………

3.3 Do you cover your drinking water storage container?

1. Yes
2. No

3.4 If yes, what do you use to cover the drinking water storage container?

1. Lid of the container
2. Clean cloth
3. Other specify …………………………………….

3.5 How often are the storage containers cleaned?

1. Daily
2. After two days
3. Weekly
4. Monthly
5. Yearly
6. Never

3.6 What do you use to clean your water vessels?

1. Water only
2. Soap and Water
3. Mud and Water
4. Other specify……………………………………………………………

3.7 How long has the water been stored?

1. Less than 24 hours
2. More than 24 hours
3. More than 48 hours

3.8 How is the drinking water from the storage container accessed?

1. Tilting the container to pour the water
2. Dipping with a cup

3. Others specify …………………………………………

3.9 How do children in your household access the drinking water from the containers?

1. An adult fetches for them
2. They fetch it for themselves
3. Others specify. ………………………………………

3.10 Where do you place the utensil used to collect water from the storage container

1. Floor
2. Hanged on the wall
3. Inside the storage container
4. Other

4.0 Treatment of drinking water

4.1 Do you treat your drinking water before use at home?

1. Always
2. Sometimes

4.2 How do you treat your water?

1. Boiling
2. Chlorination
3. Filtration

4.4 Do you believe treating your water can reduce water related diseases

1. Yes
2. No

4.5 What challenges prevent you from treating your drinking water?

1. Costs
2. Time
3. Knowledge

5.0 Hygiene and sanitation

5.1 How do you dispose your waste materials at home?

1. Burn
2. Bury
3. Throw away in the open
4. Others specify..

5.2 Do you wash your hands with soap in a designated hand-washing place?

1. Yes
2. No

5.3 If no, where do you usually wash your hands with soap?

1. At the water source
2. In the latrine
3. Near the latrine
4. In the kitchen area
5. Others specify ……………….

5.4 Do you wash your hands with soap;

1. Before mealtime………Yes/No
2. After using the toilet……..Yes/No

5.5 If yes, what materials do you use to wash your hands for each catergory above?

1. Water only
2. Soap and Water
3. Mud and water
4. Other specify ....

5.7 What type of toilet facility do you have?

1. Flush toilet
2. Pit Latrine
3. Open defecation

5.8 What hygiene advice have you heard before?

1. Use a latrine for defecation
2. Drink safe water
3. Store water safely at home
4. Wash hands

5. Wash hands with soap
6. Eat food prepared under with proper hygiene conditions
7. Safe disposal of babies feces
8. Others Specify …………………………

4.8 From which sources have you heard hygiene advice in the past one year

1. Community meeting
2. Radio
3. Television advertisement
4. Government representative
5. Schools/teachers
6. Religious leaders
7. Others specify ……………….

6.0 Water related diseases

6.1 Has your family member ever suffered from a waterborne disease

1. Yes
2. No

6.2 Do you think your drinking water might be contaminated

1. Yes
2. No

Is there any other information or observation you would like to share regarding the water quality in this area? ....

Appendix II. Health facility questionnaire

Name of the Health facility ………………………… Date of visit ……………………

Name of clinician ………………………….

1. Are there any reported cases of water related diseases for the past one year in this hospital?

    1. Yes
    2. No

Health facility montly reporting form

Disease	**Total reported cases**	**Month**	**Year**

2. What measures are in place to promote safe drinking water quality practices in this area?

    …………………………………………..

Appendix III. Sanitary inspection

Checklist to be filled by the researcher

Date of Survey …………………………

Address/stage……………………………

Water sample taken? .... Sample no. .... Thermotolerant coliform grade ....

Information for assessment

1.	Is the well unprotected by concrete wall?	Yes/No
2.	Is there a latrine within 10m of the well?	Yes/No
3.	Is the nearest latrine on higher ground than the well?	Yes/No
4.	Does the well lack a proper cover?	Yes/No
5.	Is there any other source of pollution (e.g. animal excreta, rubbish) within 10 m of the well?	Yes/No
6.	Is there stagnant water within 2m of the well?	Yes/No
7.	Are the walls of the well inadequately sealed at any point for 3m below ground?	Yes/No
8.	Are the rope and bucket left in such a position that they may become contaminated	Yes/No
9.	Are there any cracks in the concrete floor around the well which could permit water to enter the well?	Yes/No
10.	Were people washing clothes within 2m around the well at the time of the visit	Yes/No
11.	Is the environment around the well dirty?	Yes/No
	Total score of risks…/11	Yes/No

Contamination risk score**.** 9–12 =very high; 6–8 =high; 3–5 =intermediate;0–2 =low

Appendix IV. Egerton university ethical clearance

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EGERTON UNIVERSITY INSTITUTIONAL SCIENTIFIC AND ETHICS REVIEW COMMITTEE

EU/RE/DIR/009
Approval No. EUISERC/APP/364/2024 ***24***

***24th September* 2024**

Sarah Ng'andwe
Egerton University,
P.O. Box 536
Egerton
Telephone.+25470370607
E-mail: sarahngandwe3@gmail.com

Dear Sarah,

RE: ETHICAL APPROVAL: INFLUENCE OF SOCIO-ECONOMIC FACTORS AND WATER HANDLING PRACTICES ON THE DRINKING WATER QUALITY IN KITWE DISTRICT, ZAMBIA

This is to inform you that the ***Egerton University Institutional Scientific and Ethics Review Committee*** has reviewed and approved your above research proposal. Your application approval number is ***EUISERC/APP/364/2024.*** The approval period is ***24th September 2024 – 25th September 2025***

This approval is subject to compliance with the following requirements;

i. Only approved documents including (informed consents, study instruments, MTA) will be used.
ii. All changes including (amendments, deviations, and violations) are submitted for review and approval by ***Egerton University Institutional Scientific and Ethics Review Committee***.
iii. Death and life-threatening problems and serious adverse events or unexpected adverse events whether related or unrelated to the study must be reported to ***Egerton University Institutional Scientific and Ethics Review Committee*** within 72 hours of notification
iv. Any changes, anticipated or otherwise that may increase the risks or affect safety or welfare of study participants and others or affect the integrity of the research must be reported to ***Egerton University Institutional Scientific and Ethics Review Committee*** within 72 hours.

"Transforming Lives through Quality Education"

Appendix V. Zambia national health research authority publication approval

NATIONAL HEALTH RESEARCH AUTHORITY

Lot No. 18961/M, off Kasama Road, Chalala, P.O. Box 30075, LUSAKA
Tell: +260211 250309/0777409076 | Email: znhrasec@nhra.org.zm | www.nhra.org.zm

Ref No: NHRA-1886/21/01/2025 **Date: 19/02/2025**

The Principal Investigator,
Ms. Sarah Ng'andwe
Egerton University
Kenya

Dear Ms. Sarah Ng'andwe,

Re: Request for Authority to Publish Manuscript and Ethical Waiver

The National Health Research Authority is in receipt of your request for authority to publish a manuscript from your study titled **"The Role of Socio-Economic Factors and water handling practices in low-income settings in Kitwe City, Zambia"**

I wish to inform you that following submission of your request to the Authority and our review of the same and in view of ethical waiver, your manuscript has been **approved** for publishing.

Notwithstanding the fact that your request to publish has been approved however, the Health Research Act in section 32 subsection (1) requires that any health research conducted in Zambia shall first be disseminated locally before being disseminated outside Zambia.

This approval is therefore conditional to you abiding by this legal provision. Should you require assistance in facilitating local dissemination of your results, kindly let us know.

Yours Faithfully,

National Health Research Authority

Prof Victor Chalwe,
Director and Chief Executive Officer

All correspondences should be addressed to the Director/CEO National Health Research Authority

Appendix VI. Published articles

Review Article

Environmental Health Insights
Volume 19: 1-12
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DOI: 10.1177/11786302251337563
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Microbial Water Quality at the Point of Use: The Role of Socio-Economic Factors and Water Handling Practices in Kitwe District, Zambia

Sarah Ng'andwe[1,2], George M Ogendi[1], Elizabeth Muoria[1] and Justine Ngoma[3]

Abstract
Background: The scarcity of safe drinking water affects individuals living in low income areas, increasing their vulnerability to waterborne diseases. This study aimed to investigate the relationship between socio-economic factors, water handling practices and microbial water quality in Kitwe District, Zambia.
Methods: A cross-sectional study was conducted among 215 households using a semi-structured questionnaire along with microbiological analysis of water samples during the dry and wet season. A total of 44 water samples (per season) from the point of use and 16 source samples were analyzed for pH, temperature, residual chlorine, total coliforms, and *Escherichia coli*. Multivariable logistic regression analyzed associations between socio-economic factors, water handling practices, and water quality.
Results: The prevalence of *Escherichia coli* contamination was 61.3% during the dry season and 77.3% during the wet season. Key factors associated with household water quality included, household monthly income, education level, family size, season, storage container design, water withdrawal method, covering storage containers, water treatment practices, and hand washing with soap. Notably, households that used narrow-mouthed containers (AOR = 0.090, 0.014-0.580), covered their storage containers (AOR = 0.113, 0.014-0.889), and practiced water treatment (AOR = 0.120, 0.022-0.656) showed significantly reduced risks of *E. coli* contamination.
Conclusion and recommendations: The findings highlight the importance of socio-economic factors and proper water handling practices in improving household water quality. To enhance water safety and reduce water-related diseases, targeted interventions should focus on educating communities about the effective handling of water. Furthermore, addressing socio-economic factors and improving access to safe water are essential for mitigating contamination risks in low-income areas.

Scientific Research Publishing
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Seasonal Variations of Microbial Water Quality from Shallow Wells and Prevalence of Water-Related Diseases

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[2]Department of Agriculture and Aquatic Science, Kapasa Makasa University, Chinsali, Zambia
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Abstract
Microbiological contamination of drinking water remains a critical global health concern, contributing to approximately five million deaths annually. In Sub-Saharan Africa, inadequate access to safe drinking water sources results in over one million deaths each year, with nearly 90% occurring among children. This study investigated the seasonal variation of microbial water quality from shallow wells and the prevalence of water-related diseases. Water samples were collected during the dry and wet seasons and analyzed for total coliforms and