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EFFECTS OF HOUSEHOLD DRINKING WATER STORAGE CONTAINERS AND USER PRACTICES ON WATER SAFETY IN RUSHINGA DISTRICT

BY

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Abstract

Diseases related to contamination of drinking water constitute a major burden on human health and are a major cause for concern in public health. The challenge is even more pronounced in developing countries where safe water sources are limited. Drinking water can be contaminated at various stages along the water handling chain thereby presenting a public health risk to consumers. In communities where drinking water is not connected to the home, the common practice is storing drinking water in containers so that it is conveniently accessed for drinking. However, poor household drinking water handling and storage practices can reduce the gains in water quality at point of use and increase risks of water-borne illnesses. Common water storage container attributes like design, container covers, and cleaning frequency impact contamination levels. The aim of the study was to evaluate the effects of various aspects of household drinking water storage practices, including container design, material, and cleaning frequency, on levels of E. coli and total coliform count. The study's aim was to determine the effect of type of material, design and characteristics of different household drinking water storage containers, and water user practices on microbial water quality in rural communities of Rushinga district. A cross-sectional study was conducted surveying 217 households across 3 wards in Rushinga district, Zimbabwe. Multi-stage cluster sampling was done. Boreholes from which households that were surveyed drew water from were purposively sampled on condition of their water quality (not contaminated as per the WHO guidelines) whilst the wards and households were conveniently sampled. Data on storage container characteristics was collected through interview schedules. Stored drinking water in containers were sampled and analyzed for E. coli and total coliform counts. Strengths and associations between variables were measured through univariate and multivariate analyses. Overall, 91.0% of the participants in Rushinga district used plastic-made household water storage containers. Covering of storage containers was significantly associated with drinking water contamination (OR = 15.2; 95% CI 6.16 - 37.7; $p < .001$) for participants in Rushinga district. The design of storage container mouth was as well associated with household drinking water contamination (OR = 8.6; 95% CI 1.70, 48.18; $p = .009$). Generally, wide mouth and uncovered containers had higher total coliforms and E, coli levels. Therefore, promotion of hygienic practices such as using narrow-mouthed, covered containers, regular cleaning and use of appropriate cleaning materials can significantly reduce water-borne microbial exposure through simple, affordable behavioral interventions. However, further research with larger sample sizes is required to establish the strength and the significance of the relationship between storage container characteristics and microbial contamination.

Key words: water storage, drinking water contamination, E.coli, total coliform count

Declaration

I declare that this dissertation is my original work except where sources have been cited and acknowledged. The work has never been submitted, nor will it ever be submitted to another university for the award of a degree.

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Dedication

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List of acronyms and abbreviations

CDC	Centers for Disease Control and Prevention
CFU	Coliform Forming Units
MPN	Most Probable Number
NTU	Nephelometric turbidity Units
POC	Point of Collection
POU	Point of Use
UNICEF	United Nations Children’s Emergency Fund
WASH	Water, Sanitation and Hygiene
WHO	World Health Organisation

Definition of key terms

Coliforms a group of bacteria used as indicators of sanitary quality and safety of water. High levels of coliforms suggest contamination.

Container material the material the storage container is made of like plastic, metal, ceramic and clay.

Microbial quality level of microorganisms like bacteria, viruses and protozoa in drinking water

pH a measure of acidity or alkalinity of the drinking water.

Retention time the length of time water is stored in a container.

Turbidity cloudiness of water caused by suspended particles in drinking water. This can indicate contamination and promote microbial growth.

Water contamination presence of harmful substances in drinking water that makes the water harmful for drinking. Contaminants can include microorganisms, heavy metals and organic pollutants.

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CHAPTER 1 INTRODUCTION

1.1 Introduction

The deterioration of drinking water quality is the key cause of water-borne infections in the world. At the same time, drinking water has been found to be more contaminated in rural areas with 41% than in urban areas (12%) with Africa (53%) and South-Asia (35%) having the biggest prevalence of contamination (Alemeshet, Baraki, & Mekbib, 2021).

Again, data from WHO and UNICEF indicates that two billion people lack access to safely managed drinking water with eighty percent of people who lack basic drinking water services living in rural areas (Centres for Disease Control and Prevention[CDC], 2022). As a result, there are 1.7 billion cases of diarrhoea among children younger than five years and an estimated 446000 children younger than five years die from diarrhoea commonly in low and middle income countries significantly contributing to their mortality (Centres for Disease Control and Prevention[CDC], 2022). Consequently, because of the microbial deterioration of drinking water there are three million cases of cholera and an estimated 95000 deaths annually whilst there are eleven million cases of typhoid and an estimated 129000 deaths due to typhoid fever experienced every year.

By and large, the greatest microbial risks are linked to ingestion of water that is contaminated with faeces from humans or animals (including birds). Faeces can serve as a source of pathogenic bacteria, viruses, protozoa and helminths and as a result faecally derived pathogens are the primary concern in microbial water quality (World Health Organisation [WHO], 2017).

In developing places where clean water is not piped into dwelling or into yard, point-of-use water storage containers are commonly used in the home. People fetch water from water points and store it in the home so that it is readily available as need arises. However, the containers used can impact on the quality of the water.

The global burden of diseases related to consumption of contaminated water points out to the importance of preserving the quality of drinking water. It also indicates the significance of investing in water, sanitation and hygiene (WASH) programming.

1.2 Background of the Study

Studies have found out that drinking water is contaminated along the distribution chain from source to the point of use where it may be stored in the household. Findings from WASH programmes in World Vision programming areas in rural Zimbabwe have indicated that microbial household water quality was markedly lower than water at the source with 34% of household drinking water meeting the WHO water quality standards compared to 70% of the quality at water points (World Vision International, 2019c). A number of studies have concentrated on identifying faecal indicator bacteria found in drinking water but not necessarily highlighting exactly where the contamination has happened either at source, transportation or point of use. In many parts of the world including rural Zimbabwe where drinking water is not connected into dwellings or is not brought on site, people adapt by storing water in containers. However, storing water in containers increases the chances of the water being contaminated making the water of low quality.

There are several factors associated with the microbial quality of drinking water and one vital factor is of the water storage containers. In the search for answers about microbial water quality challenges, past studies have identified factors related to water storage containers like container materials, cleaning practices and exposure to contaminants as influencing the microbial quality of stored water. However, there still remain a gap to determine relative impact of different container types and storage conditions on key microbial water quality parameters.

Study findings by UNICEF Zimbabwe have shown that the country has experienced a decline in the coverage of basic drinking water and sanitation from 72% to 63% between 2000 and 2020 (World Health Organisation [WHO] and United Nations Children's Education Fund [UNICEF], 2017). Despite efforts to improve and address water access and coverage through water, sanitation and hygiene (WASH) programs, the country has faced a number of challenges towards achieving the provision of safe and clean water. Studies by WHO/UNICEF presented that only 42% of households have basic hygiene services while the access to basic water in urban communities is 45% higher than in rural areas. Water challenges in both urban and rural areas have presented major problem in the increase of waterborne related disease.

Majority of rural communities in Zimbabwe, lack water distribution systems within their homes. As a result, drinking water is acquired from external sources and stored until consumption. A common practice in Zimbabwe, as well as in other countries, involves using containers for water collection and storage. Study findings in Murewa, have revealed that over 60% of water samples taken from household storage containers were found to be contaminated with E. coli bacteria (Makokove, 2022).

Thus, the study aims to fill the gap by determining how microbial contamination levels of drinking water are distributed within various containers of different characteristics that are used in the home and the water user practices in Rushinga district. Understanding these relationships can help inform guidelines for safer water storage and handling practices, especially in resource-limited settings

1.3 Statement of the Problem

A lot of efforts are being made to improve access to drinking water through various interventions that include protection of boreholes and installation of safely managed water systems. However, despite having safer water sources poor drinking water storage and handling practices can result in increased water-borne health conditions and inevitably increased health costs and mortality. Access to clean drinking water has always been a problem in rural areas of Zimbabwe with some communities taking more than 30 minutes round trip to get water. As a coping practice, more and more families obtain drinking water from water sources and water points then store the water in household containers made of different materials, designs and characteristics. Use of household water storage containers has become a progressively popular method of ensuring that drinking water is readily available in the home where access to clean water is limited as in not piped to the dwelling or yard. Data collected from the Ministry of Health and Child Care reports for Rushinga district in 2022 indicate that microbial drinking water quality was significantly lower at point of use in the households with 43% of the households' sampled water meeting the WHO quality standards as compared to 83.5% of the quality of water at protected water points. However, there is not much that has been studied on the effects of household drinking water storage containers and water user practices on microbial quality of stored water in Rushinga district. Therefore, the aim of the study was to assess the effects of different drinking water storage containers on microbial levels of household stored water as this has become a sector-wide challenge with diseases related to contamination of drinking water constituting a major burden on human health. This is because by the time microbial contamination is detected, many people may have been exposed to the pathogens. For that reason, interventions to improve and preserve the quality of drinking water provide significant benefits to health.

1.4 Broad Objective

The main objective of this study was to determine the effect of type of material, design and characteristics of different household drinking water storage containers, and water user practices on microbial water quality in rural communities of Rushinga district.

1.4.1 Specific objectives

The specific objectives of the study were;

1. to characterize the different household drinking water storage containers used by communities in Rushinga district communities in 2023
2. to assess the risk of water contamination levels on different household water storage containers used in Rushinga district communities in 2023
3. to determine associations between material type, design, characteristics of the different household water storage containers, water user practices, and the levels of microbial contamination in stored drinking water in Rushinga district communities in 2023

1.5 Research Questions

- What are the characteristics of the different household water storage containers used by communities in the Rushinga district in 2023?
- How are the levels of microbial contamination of household drinking water different in relation to characteristics of storage containers and user practices for communities in Rushinga district in 2023?
- What are the relationships between the type, design and characteristics of drinking water storage containers, user practices, and the microbial loads of the stored water in Rushinga district communities in 2023?

1.6 Hypothesis

H_0: The level of microbial contamination levels of drinking water does not vary with characteristics of storage containers.

H_1: The level of microbial contamination levels of drinking water varies with characteristics of storage containers.

1.7 Significance of the study

Drinking water in the household can be contaminated at various stages along the water handling process thereby presenting a public health risk to consumers. The purpose of this study was to assess the proportionate effects of household drinking water storage containers and the related water user practices on microbial water quality levels in rural communities of Rushinga district. Rural communities often store drinking water in containers for extended periods before use and then the type, design and characteristics of storage containers can influence microbial growth in the water. The study compared microbial loads in different containers assessed by measuring total coliforms and E. coli counts in stored water. An understanding in the different concentration levels of microbial water contamination in different characteristic household storage containers provided evidence and was used to recommend more hygienic household water storage containers. The study sought help in the development of practical solutions to preserve drinking water quality in the home and inherently improve health for people in Rushinga district.

1.8 Delimitations of the Study

The study looked at microbial quality (E. coli and total coliforms), pH and turbidity of drinking water for different characteristics of containers because chemical water quality monitoring requires huge amounts of resources and is also largely as a result of either geological formations, type of materials used for drilling or type of materials used in water distribution networks other than the characteristics of the household storage containers and user practices. The parameters (pH and turbidity) are important in microbial water analysis because they can influence growth of microorganisms in drinking water.

Secondly, the study assessed drinking water storage in the home and study was focused on rural communities in Rushinga district. The essence behind studying only the household water storage aspect is to ascertain whether controlling contamination right at the point of use can be a major component in dealing with challenges of drinking water quality. To further delimit, the study was focused on the World Vision Zimbabwe operational wards in Rushinga district and study populations that draw water from the same sources with zero faecal coliforms per 100ml and zero total coliform count per 100ml results at the source.

The study analysed data for predominant containers and not cover the full range of possible types of containers and was not studied further to ascertain what influences the variation in microbial loads for different container materials thereby reducing the scope of the study. Exposure duration for sampling and testing was also considered whereby samples were collected and tested over a one month period so that longer exposure periods do not impact on the results. Last of all, the target microbes were total coliforms and E. coli and did not comprehensively identify all microbes that are present in the water.

1.9 Limitations of the study

The conclusions of the study could be affected by some factors. The water samples collected at point of use could be subjected to various water treatment methods that the community practice. This could cause skewed results. The design lacked a control group and the impact of specific variables on outcome cannot be isolated. More can be done to establish cause-and-effect relationships since associations do not mean causality. Lastly, some of the behaviours were self-reported and may not be actual behaviours.

CHAPTER 2 REVIEW OF RELATED LITERATURE

2.1 Introduction

This chapter outlines related literature with regards to water quality at point of use specifically looking at the different characteristics of household water storage containers, user practices, and their coherent relationship to levels of microbial contamination of water. It also reviews findings from other studies that are in relation to drinking water handling in the home.

2.2 Conceptual framework

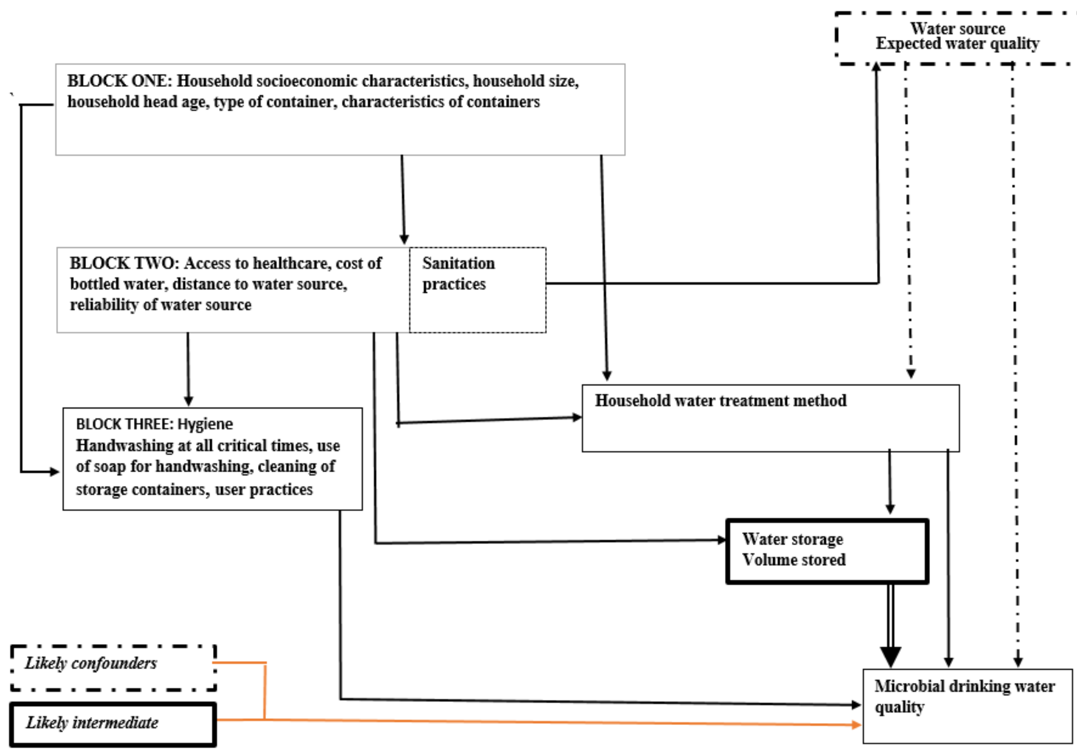

Figure 1. Conceptual framework, adapted from (Cohen, et al., 2015)

There are intermediate variables that lie between the independent variable and the dependent variable and can help explain the relationship between the two. In this instance, pH, turbidity and temperature of stored water can influence the survival and growth of microorganisms and these parameters should be monitored in parallel with microbial testing. Therefore, it can help explain the results. Again, at point of use water treatment for example with chlorine can have an effect on microbial water quality.

At the same time, there are likely confounders that should be controlled for which include initial microbial loads. Baseline levels of water contamination for water from different sources should be controlled. Another confounder could be of container cleaning. How thorough the storage containers are cleaned before use can affect the results. The length of time water is stored in the container is also an important factor. Comparisons should be made at similar time points. Lastly, handling of storage containers is also a confounder. How the containers are filled, handled and sampled can introduce differences in microbial contamination between container groups and this should be controlled through standardized protocols.

2.3 Water, Sanitation and Hygiene (WASH) related challenges

Water, Sanitation and Hygiene (WASH) remain a key component towards the achievement Sustainable Development Goal 6 on ensuring the availability and management of clean water and sanitation for all (WorldHealthOrganization, 2021). The WHO has projected that approximately 4.2 billion people globally lack access to safely managed sanitation facilities.

Reports on the progress on household drinking water, sanitation and hygiene over the past five years from 2000-2020 have shown that only 74% of the global population used safely managed drinking water services in 2020. Safely managed water service is one that is located on premise which is conveniently available and free from contamination. This therefore presented a positive mark towards the achievement of the SGD 6. However, questions remained on how the remaining 26% of the global population is accessing and managing the use of clean water.

Study findings from the Sustainable Development Goals baseline report that 892 million people were still practicing open defecation worldwide by 2015 and that 2.3 billion lacked even a basic sanitation service (WHO, 2021a). Such evidence, showed the need for extensive WASH interventions to reduce the health risks associated with open defecation. Abubakar (2018) posit that open defecation contaminates water sources, including surface water and groundwater, compromising the quality of drinking water supplies. Fecal matter and pathogens from open defecation can enter water bodies, making them unsafe for human consumption. This poses significant health risks, especially in communities reliant on contaminated water sources.

At the same time, WHO & UNICEF, (2017a) state that coverage of basic hand washing with soap and water was low in other regions varying from 15% in sub-Saharan Africa to 76% in Western Asia and Northern Africa. Combined together, unclean water and poor sanitation and hygiene are the principal causes of child death (World Health Organisation [WHO], 2022). Study evidence from the Sub Saharian region have presented an association between diarrhoea in children and inadequate water supply, inadequate sanitation, water contaminated with transmittable disease agents and poor hygiene practices (Clasen, et al., 2014).

According to a report by the WHO in 2022, it is estimated that 2.2 billion people worldwide are exposed to drinking water contaminated with fecal matter (WHO, 2022a). This represents a significant risk to the safety of drinking water due to potential microbial contamination. As a result, 297 000 under the age of five and an estimated 829 000 people die from health-related conditions linked to unsafe drinking water, sanitation and hand hygiene. The Zimbabwe Multiple Indicator Survey findings also indicate challenges with access to drinking water safety at point of use which included limited infrastructure, water quality, inadequate treatment and storage (Zimbabwe National Statistics Agency and United Nations Emergency Fund , 2019).

Survey by MICS in 2019, has shown that only 10% of Zimbabweans have access to safe drinking water on their premises whilst around 60% rely on water sources that are within 30 minutes of walking distance including waiting time. Consequently, 83.7% of stored drinking water samples in the households tested positive for E.coli compared to 59% of the source water samples. This suggest pronounced water contamination away from the source and inherently high risk of waterborne diseases for the population. Similar findings were raised by the Center of Disease Control as they the need for positive WASH intervention measures to address health risks related to water contamination.

To demonstrate the impact of improved access to WASH services, the (CDC, 2022) report that there was a significant decrease (15%) of deaths linked to diarrhoea in Southeast Asia, East Asia and Oceania whilst globally diarrhoeal deaths reduced by 10%. This indicated the importance of investing in WASH interventions.

2.4 Drinking water quality

Drinking water parameters are grouped into three large categories that include: physical, chemical and bacteriological. The physical and chemical parameters are often refered to as the physio-chemical parameters. The three categories have several parameters but of ultimate importance are the microbes, salts and metals such as lead and arsenic. These have captured global attention and have resulted in countries developing protocols to guide WASH programming. The WHO has designed guidelines for drinking water quality based on internationally accepted procedures for risk assessment (World Health Organisation [WHO], 2017). These are neither regulations nor standards but are meant to guide individual countries as they develop their national standards on drinking water quality.

Domestic water storage is an important component of many households without adequate and constant supply of water. Hence, most households have resorted to storing water for domestic use in different containers or utensils which tend to reduce water quality and promote the growth of microbial and bacteria or viruses. Studies in the rural communities of Napal have shown the deteroration in water quality in relation to the domestic water storage containers or facilities, and the time taken before the water is used (Molerhofer, 2015).

When water is stored for a prolonged duration, it provides an environment conducive to microbial growth. Bacteria, viruses, and other microorganisms can multiply in the water, leading to potential contamination and an increased risk of waterborne diseases (Coffey, Paul, Stamp, & Hamilton, 2019). Study findings have shown the continued accumulation of biofilm on the inner surfaces of storage containers, such as tanks, barrels, or buckets. Hence, the accumulation of biofilms provide the necessary conditions for the microbilogical bacterial contamination. In their studies (Coffey, Paul, Stamp, & Hamilton, 2019) pointed out that the slimy layers consisting of microorganisms and organic matter that adhere to the container's walls harbor harmful bacteria and provide a breeding ground for further microbial growth.

Findings from the studies conducted in Ecuador have presented that drinking water quality has a possiblilty deteriorate with a prolonged exposure to different factors such as temperature fluctuations, exposure to light, and the presence of organic matter (Moreno, et al., 2020). This degradation can facilitate microbial activity and compromise the safety of the stored water. A review of published literature was conducted to evaluate established water quality risks and impacts associated with domestic water storage.

Numerous studies have demonstrated the tendency for disinfectant residual levels, such as free chlorine, to decrease during. Factors such as large storage volumes, slow flow rates, high surface area-to-volume ratios, and long stagnation times in storage cointainers were shown to accelerate the accumulation of microbial and other water contaimination organisms (Moreno, et al., 2020). The loss of disinfectant residual increases the risk of microbial regrowth during storage.

2.4.1 Bacteriological and physical parameters for drinking water

Bacteriological and physical parameters play a crucial role in assessing the quality of drinking water. Despite advancements in measurement techniques, challenges persist in accurately monitoring and interpreting these parameters. Jakositz, et al., (2020) alluded that the prioritizition of research, collaboration, and innovation on water quality management needs to be strengthened to ensure the safeguarding of public health and promoting sustainable development. As such, bacteria and viruses have been used as indicators in drinking water quality monitoring.

However, (Goh S. S., 2019) argued that the use of bacteria and viruses as indicators can become pathogenic when they are present in higher doses. More commonly used bacteria and viruses in drinking water quality monitoring are the total coliform and the E.coli or faecal coliform (WHO, 2017a). The total coliform occurs naturally in the environment but when present in drinking water, it is an indication that there may be harmful bacteria in the water. On the other hand, the existence of E.coli in food or water points out to recent faecal contamination that could be due to poor sanitation measures and poor storage conditions.

Furthermore, Odonkor & Mahami (2020) claim that the occurrence of E.coli in water or food does not necessarily imply the presence of pathogens but suggests high chances of faecal-related microorganisms which include *Salmonella* and *Hepatitis A*.

For this reason, E.coli has been used as an indicator microorganism when examinations of food and water samples are done to detect levels of faecal contamination. Accordingly, WHO guidelines posit that for drinking water to be considered safe for consumption, it should have zero total coliforms per 100ml and zero E.coli per 100ml (World Vision International, 2019a). Low risk drinking water should have E.coli counts from 1-10MPN/100ml, medium risk has 11-100MPN/100ml whilst high risk has more than 100MPN/100ml (WHO, 2017b).

It is in line with these guidelines that WHO recommendation for pH drinking water quality ranges from 6.5 to 8.5. while a pH less than 6.5 can be corrosive. Turbidity is recommended at less than 5NTU. High turbidity can shield pathogens and make disinfection less effective.

Physical parameters, including turbidity, color, odor, and taste, provide information about the aesthetic quality of drinking water. While they may not directly pose health risks, their presence can indicate potential issues with the water supply. Turbidity, caused by suspended particles, is a critical physical parameter as it affects disinfection efficiency and can serve as a harbinger of microbial contamination. The use of turbidity as an early warning indicator should be emphasized, and real-time monitoring systems can provide timely information for immediate corrective actions.

2.5 Zimbabwean standards for bacteriological parameters of drinking water

Similarly, in Zimbabwe the total coliform and E.coli standards for drinking water quality are the same with the WHO guidelines (zero total coliform and zero E.coli/faecal coliforms) as set by the Food and Food Standards regulations and the Guidelines for Drinking Water Quality, Zimbabwe (Gombiro, et al., 2014).

Zimbabwe implements strictier standards than those of WHO on chemical parameters. The total coliform count and the E. coli/faecal coliform count are the prime parameters of concern for bacteriological water quality monitoring in most WASH programmes. More oftenly, water contamination is detected when many people have been exposed and this is the reason why routine sampling and testing of drinking water is central and has been made mandatory in Zimbabwe.

It is noteworthy that particular consideration should be given to water safety framework and comprehensive water safety plans in order to ensure that drinking water is safe and inherently protect the health of the public. Table 1 shows standards on bacteriological parameter and maximum permissible limit of microorganisms for drinking water in Zimbabwe.

Table 1. Drinking water bacteriological parameters and maximum permissible limits for Zimbabwe

Parameter	Unit	Maximum Permitted Level	Health Impact
Total Coliform Count	CFU/100ml	Should not be detectable. However, if detected should be less than 10/100ml	Indicate contamination from soil, human or animal waste
E. coli or thermos-tolerant coliform bacteria	CFU/100ml	Must not be detectable in any 100ml sample	Indicate recent faecal contamination due to cross-contamination

Source (Gombiro, et al., 2014a)

Ensuring safe drinking water quality for communities is a prerequisite for every government and in turn, communities have the role of ensuring that good drinking water quality are kept within the permissible limits of the WHO or the country's national water quality standards. WHO standards regard a zero count of E. coli per 100ml of water as safe for drinking. However, the 2017 World Vision WASH14-country evaluation noted discrepancies in the way drinking water is handled among countries involved in the implementation of water supply programmes. The assessment of microbial water quality at the point of use has shown that water quality was a significant problem as caused by problems at the water point, but more importantly problems with safe water collection, transportation and household storage (World Vision International, 2019b).

Adopting WHO standards provides Zimbabwean communities' confidence that their water meets international health-based targets. However, implementation challenges were noted between some countries in a large evaluation (World Vision International, 2019c). Inconsistent adherence to guidelines could undermine protection in some locations. Comprehensive water safety planning is advised to reinforce standards through multiple barriers from the point of collection to the point of use. Continual surveillance and system reviews are important for sustained safety given infrastructure limitations (WHO, 2017). Community engagement reinforces handling and maintenance behaviors critical to maintaining water quality.

2.6 Water Safety Plans

Inadequate domestic water handling is a major contributor to illness globally. Implementing WHO guidelines through community programs presents a cost-effective public health strategy for improving access to safe drinking water by reducing recontamination risk at the point-of-use.The WHO Guidelines for Drinking-Water Quality establish the international standard for ensuring drinking water safety worldwide. Following a rigorous evidence-based protocol, the guidelines provide guidance to manage a comprehensive range of health hazards and support national standards development.

Reports from WHO have shown that the most effective way to consistently ensure the safety of a drinking-water supply is through the implementation of a comprehensive risk assessment and risk management approach that covers all stages of the water supply, from catchment to consumer (WHO, 2017a). As such, Baum & Bartram, (2018) outlined that water safety plans (WSPs), have been developed to systematize and organize best practices in managing drinking-water quality. Therfore, WSPs represent an evolution of traditional sanitary surveys and vulnerability assessments, as they encompass the entire water supply system and its operation.

According to Baum & Bartram, (2018) the adoption of the WHO WSP approach ensures that water supply systems either private or public observe key principles and concepts from other risk management approaches, such as the multiple-barrier approach and hazard assessment and critical control points. Thus the concepts seeks to reduce water quality deterioration at all points either at the point of collection or at the point of use. WHO outlines the need to identify areas that pose the risk of water contaminantion and employ effective measures or interventions at different stages to effectively reduce risks (WHO, 2022). By applying this approach, WSPs identify and implement multiple barriers throughout the water supply system, including source protection, treatment processes, distribution system maintenance, and consumer awareness.

Furthermore, the WSP approach emphasizes hazard assessment and critical control points, which involve identifying potential hazards, assessing their risks, and establishing control measures to mitigate these risks. Hazards can include physical, chemical, and microbiological contaminants that may enter the water supply at various stages.

Identifying critical control points which are key points in the water supply system control measures can be implemented to prevent or reduce risks, and ensure a systematic and proactive approach to water quality protection (Baum & Bartram, 2018).Study findings Baum & Bartram (2018) have also presented that the strength of the WSP approach lies in its comprehensive and systematic nature, as it considers the entire water supply system from source to consumer.

By integrating risk assessment, hazard identification, and critical control point analysis, water safety plans provide a structured framework for managing and reducing risks associated with drinking-water quality. They enable water utility operators and regulatory authorities to proactively identify potential risks, implement appropriate control measures, and monitor the effectiveness of these measures over time.

Regular review and revision of water safety plans based on ongoing monitoring and surveillance ensure continuous improvement and adaptation to changing circumstances.

2.7 Characteristics of water storage containers

There are several aspects that describe the characteristics of water storage containers that are used in the home. The characteristics of household water storage containers can be defined by either the type of material that makes the storage vessel, the carrying capacity of the storage vessel, the size of the vessel's opening (mouth) or the technology that is used to draw water from the vessel. Household water storage containers can be made of calabash, metal, clay, glass, plastic or metal material.

Then, water storage containers can have a small carring capacity or a big carrying capacity, narrow or wide mouthed, or can have a spigot/tap or water is withdrawn through the opening that it is filled through using a cup or a ladle. This points to various aspects that can be studied to ascertain discrepancies in microbial concentration of water (Levy K., 2008).

Domestic water storage is especially prevalent in rural areas where centralized water distribution systems are lacking and individual households must store water collected from wells, rainwater catchment or hand pumped boreholes. However, the decentralized nature of water storage in rural settings presents unique microbial risks that can negatively impact the quality of drinking water supplies if not properly managed (Al-Bahry, Al-Hinai, Mahmoud, & Al-Musharafi, 2013). Microbial contamination poses one of the greatest threats to public health in such resource-limited areas with poor sanitation and lack of water treatment.

Abubakar (2018) posited that the bulk water source in many rural localities is already susceptible to fecal contamination from agricultural runoff, open defecation, or wildlife. Community members in the rural areas are exposed to multiple risks assosciated with water contamination from the source to the point of use. In the same light, Moreno, et al., (2020) pointed out that microbial growth can be facilitated by the multi-day water storage within household containers, especially when temperatures regularly exceed 20°C, creating an ideal thermal environment for microbial proliferation.

On the other hand, most families collect large volumes of water to reduce the frequency to the watering point which may promote prolonged storage of water further promoting the regrowth of coliform bacteria and other opportunistic pathogens introduced into the storage system. Further more, Slavik, Oliveira, & Cheung, (2020) highlighted that water storage containers used over time can contribute to the leaching of harmful materials that provide an additional food source supporting rapid bacterial growth within the confined storage environment.

However, given the limited resources for water treatment for rural communities failure to disinfect water at the point-of-collection, water stored over long periods of time allows pathogens to increase to potentially infectious concentrations and also facilitates the establishment of resilient biofilm communities lining domestic container walls (Budeli, Moropeng, & Mpenyana-Monyatsi, 2018). These biofilms harbor elevated bacterial populations that continually shed pathogens back into the bulk water. Attempts to treat water prior to drinking often fail to inactivate mature biofilms, rendering stored water unsafe indefinitely once contaminated. Slavik, et, al., (2020) reiterates that entry points for microbes through open tops, cracked lids or imperfect seals are also commonly encountered in rural domestic tanks constructed with low-cost local materials.

The consequences of microbial water quality deterioration during rural domestic storage include a greater incidence of waterborne diseases, especially to vulnerable populations like young children and the elderly. Waterborne illnesses and outbreaks linked to stored drinking water have been well-documented in developing nations, where water-related deaths remain a leading cause of mortality.

2.8 Effects of materials used in production of water storage containers

Sobsey et al, 2003 as cited in ((Duru, Amadi-Mgbenka, Amadi, Nsofor, & Nze, 2013) state that due to lack of access to safely managed water services, a large population of the world drink untreated non-piped water. As a result of lack of safe piped water connected into dwellings, storage of water for future drinking is a common practice by households. People collect water from sources and store it in the home for drinking by family members.

Duru, Amadi-Mgbenka, Amadi, Nsofor, & Nze, (2013) found out that storage containers used to store water at home have an effect on water quality. The stored water quality may deteriorate further as a result of contamination by users and production of disease causing pathogens when stored in a vessel that is not properly treated or cleaned (Andrew, 2004; Sobsey et al, 2003; Trevett, 2003, Trevett et al, 2001; Simangoet et al, 1992; Sutton and Mabiana, 1989 as cited in Duru et al, 2013). In corroboration with these findings, it has been recommended that exposures to health risks can be reduced by bringing piped water into dwellings to improve drinking water quality (Ahmad, Haq, & Sattar, 2010).

These findings highlight the importance of container disinfection, cleaning protocols and safe handling practices emphasized in WHO guidelines to minimize deterioration during domestic storage (WHO, 2017). Contamination risks are significantly reduced through regular hygiene interventions (Ahmad, Haq, & Sattar, 2010). Given such risks, bringing treated piped water directly into homes as recommended by Ahmad et al. (2010) would not only improve access but also help ensure water quality is maintained by avoiding storage-related contamination. Piped systems can more reliably deliver drinking water meeting safety targets with minimal risk of recontamination compared to provision requiring household storage (WHO, 2017).

Domestic storage plays a critical role in either protecting or compromising drinking water quality through hygienic practices. Strategies that avoid reliance on household storage such as in-home piped supplies are preferred to maintain the health gains of improved source water quality interventions.

A systematic review of literature established more in material of the water storage containers as traditional water storage materials such as copper, brass and clay were found to have some antimicrobial properties which were highly efficient as compared to those made of aluminium, plastic and steel (Manga, et al., 2021). The same review revealed that occurrence of coliforms meaningfully increases when temperature of water rises to above $15^{o}C$ and as a result, containers made of polyethylene material may have higher microbial activity than fibre glass and fibre cement.

Duru, Amadi-Mgbenka, Amadi, Nsofor, & Nze, (2013) note comparable findings and state that total viable bacteria and faecal coliforms were highest in calabash material and decreased in clay pot, metal vessel, plastic vessel and lastly glass vessel in descending order. Similarly, certain bacteria have been found to stick to plastic surfaces promoting growth of the bacteria.

However, these results can be best suited for specific areas depending with most common type of material that make the water storage vessels for a community since they usually buy from same service providers. Studies by Al-Bahry, et al., (2013) substantiate findings by Manga et al., (2021) and state that total coliforms were found to be high depending on the type of water storage containers for households. Drinking water was found to have low microbial contamination from the beginning of water distribution system but increased as water is stored in tanks.

While these studies hold the view that storage of water in containers can give rise to deterioration, other researchers' views disputes these views. Agbede and Morikayo, 1995; Agebede, 1991 as cited in (Obianyo, 2020) argues that storage improve the microbial quality of water based on the premuse that upon storage suspended impurities flocculate and settle at the bottom of the storage container where it can be subjected to ultraviolet radiation from sunlight near the water surface. Eventually bacteria are partly destroyed by the ultraviolet light.

Obianyo, (2020) notes increased microbial contamination in water stored in steel, plastic and clay container over a period of one month which was attributed to unhygienic user practices rather than type of container. However, the study did not observe any particular container as the best for water storage. It nonetheless identified dependability on the parameter of interest.

2.9 Water retention time/time taken using stored water

The systematic review, also found highest effect on stored water quality in retention time. Microbial growth increases as retention time increases (Manga, et al., 2021b). When there are large water storage containers and a few users in the home, contact time with the water also increases increasing the probability of contamination. Stored water is subject to deterioration in quality as a result of sediments later settling or sticking on the container surfaces.

The study by (Duru, Amadi-Mgbenka, Amadi, Nsofor, & Nze, 2013) on biological characteristics of surface water and increased number of storage days showed that storage containers for water in the home have an effect on water quality. Bioload estimate for fungi was found to be high in the order of calabash, claypot, metal vessel and plastic vessel having the least bioload. For faecal coliforms, the calabash vessel had the highest bioload followed by the claypot, metal, plastic and glass bottle vessels with the glass vessels being the control.

Momba and Kaleni, (2002) found similar results and state that storage of drinking water for 48 hours result in the regrowth of total coliforms. This meant that quality of water decreases with retention time in storage containers.

However, other researches disputes these findings as they found no statistically significant association between the amount of time that water was stored and the water quality as this is dependable on user frequency or per capita (Graham, 2007)

2.10 Storage container age, colour, design and location

Above and beyond retention time and vessel material, there is a significant association between the age of the water storage vessels and the quality of drinking water that is stored in the home (Chia, Oniye, & Swanta, 2013). In a different study of the impact of colour of storage container on bacteria flora in water, decrease in bacterial counts was more pronounced in the colourless and blue buckets stored outdoor and were recommended for best choice for use in water storage tanks (Adetitun & Olugun, 2020). This suggests the disinfection action that can be as a result of ultra violet radiation on the colourless containers. In the systematic review, Manga, et al., (2021c) found out that microbial quality of stored water can be improved when storage containers are cleaned.

Chia, Oniye, and Swanta, (2013a), found a significant relationship between the age of the storage tank and the availability of microbes related to water contamination.

However, a study by Schafer & Mihelcic, (2012) found no meaningful relationship between the age of storage container and presence of microorganisms in water. The author argues that the effect is hinged on maintenance of the storage containers because where they are well-maintained biofilms are removed.

Storage container designs can also affcet microbial water quality of drinking water. A review by Schafer, (2010) revealed that storage container design idirectly affect microbial water quality by affecting user practices. Schafer found more in that household storage containers can complicate the cleaning techniques like complete emptying and washouts. This also affects user practices on how water is drawn at point of use. Water that is stored in wide mouth containers may be subjected to contamination more often than those with narrow mouths whilst water stored in containers with spigots or taps may limit contact of water with user hands at point of use.

As well, Schafer, (2010a) found that storage containers location affects water quality through temperature. When storage containers are placed under direct sunlight, the temperature of the water increases giving better chances of disinfection through ultra violet radiation.

Manga et al., (2021d) found an association between water storage containers and user practices such as cleaning and hygiene. The review included user practices such as container cleaning and covering. Similarly, Chalchisa, Mergesa, & Beyene, (2018) hold the same view and note that storage containers impact on water quality when good hygiene such as covering of the container is not emphasised. Stored water is exposed to contamination by animals and airborne particulates when not covered.

Furthermore, when water is stored for an extended period, it increases the duration during which the collected water is exposed to potential faecal contaminants. Plastic containers are generally not suitable for prolonged storage as they can contribute to the formation of a slimy layer on the inner surface of the container. This slimy layer, along with the water source itself, can adversely affect the taste and palatability of the stored water.

While narrow-mouthed storage containers have been found to offer better protection against faecal contamination compared to wide-mouthed containers, they are still considered inappropriate for extended water storage due to difficulties in effectively cleaning the inner surface. This limitation raises concerns about the potential for microbial growth and contamination over time.

Studies have reported challenges with algal growth in jerry cans, with one possible explanation being the accumulation of small sediments during storage and the subsequent formation of a biofilm. Suspended particles and bacteria can adhere to the inner surface of the plastic casing, creating an environment conducive to the growth of microorganisms.

It is worth noting that inappropriate washing and rinsing practices have been identified as significant factors contributing to algal growth. Insufficient cleaning provides favorable conditions and an environment for the proliferation of microorganisms. These findings highlight the importance of considering the material, design, and maintenance of storage containers when it comes to water storage. Exploring new literature in this area can provide further insights into the best practices for ensuring the safety and quality of stored water.

Furthermore, the duration of water storage has been found to increase the risk of exposure to possible faecal contaminants. Plastic containers, commonly used for water storage, are generally not suitable when storing domestic water for a long of time. Study findings of water stored in plastic containers over a long period have shown, the formation a slimy brown layer on the inner surface of the containers, which may negatively impact water quality and promote microbial growth.

Similar views were recorded in a study by Makokove, (2018) as it was discovered that water stored in plastic containers over a long period of time changed in both colour and teste worsening the palatability of the water. Further evidence showed that after water sample tests water quality decreased with an increase of microorganisms.

While narrow mouthed storage containers have shown better protection against faecal contamination compared to wide-mouthed containers, they are still considered inappropriate for extended water storage due to the difficulty in effectively cleaning their inner surfaces.

Studies have reported challenges related to algal growth in jerry cans, as documented by (Sharma, et al., 2013). One possible explanation for this phenomenon is the accumulation of small sediments during storage, leading to the formation of a biofilm on the inner surface of the plastic casing. This biofilm can result from suspended particles and bacteria adhering to the plastic, creating an environment conducive to algal growth. Inadequate washing and rinsing practices have been identified as major contributors to algal growth, as they create favorable conditions for the proliferation of microorganisms (Sharma, et al., 2013).

2.11 Multiple use of water storage containers

Combining collection and storage promotes cross-contamination increasing microbiological risks incompatible with achieving drinking water safety targets.The practice of using the same container for water collection, transport and storage is common in many communities but poses unique risks to drinking water quality (Gizachew, Admasie, & Wegi, 2020). Studies on WASH have presented that the use of the same containers for water collection and storage pose the risk of transferring pathogens from the water source to the home.

In the same light Whitley, et al., (2019) posit that contamination of water collection containers can be caused by direct contact of animal feaces with the containers from the collection points, bringing pathogens from the environment into the home.

Similar views were raised by Duru, Amadi-Mgbenka, Amadi, Nsofor, & Nze, (2013) as they argued that most people tend not to clean or wash containers at the water point a behaviour that propagates microbial contamination.

Collection surfaces also accumulate deposited materials during transport that slough off into stored water. Biofilm growth on walls concentrates microbes resisting disinfection. Remnants of collection environments like animal fecal matter, soil and debris support continued bacterial regrowth during stagnation (Ahmad, Haq, & Sattar, 2010). Intermittent extraction exposes stored water to potential recontamination. Hands contacting water frequently introduce thermotolerant coliforms and curb residual disinfectant effectiveness. Storage-collection conduits become vectors disseminating pollution within premises (Ahmad, Haq, & Sattar, 2010).

Strict separation of collection, transport and storage functions through dedicated cleaning of each component is necessary to interrupt disease transmission routes. Following WHO guidelines on multi-barrier protection and hygienic practices prevents contamination amplification through domestic water handling (WHO, 2017).

2.12 Household water handling practices

Household handling practices play a critical role in water storage management and can significantly impact the quality of stored water. Empirical evidence from studies by Kassie & Hayelom, (2017) posited that good hygienic practices in managing domestic water by ensuring cleanliness of the domestic water storage containers is vital to prevent contamination. Studies have shown that using containers that are not thoroughly cleaned can increase the risk of water contamination and promote microbial growth.

Similar views were also echoed by Makokove, (2018) as he pointed out that poor unhygienic practices promote microbial growth to safe water as water contamination is not only associated with collection or through the use faecally contaminated water but can be a direct product of poor handling and storage management.

Hence, Makokove, (2018) and Adetitun & Olugun, (2020) highlighted that it is essential to wash containers before collecting water at the source and when drawing water from storage containers. Failure to clean containers properly can lead to the accumulation of sediments, the formation of biofilm, and algal growth, which can affect water quality.

According to Guchi, (2015) using appropriate containers, can help prevent the introduction of harmful microorganisms and maintain the integrity of the stored water. He argued that the use of wide-mouthed in household water storage containers, which allow for the dipping of hands, cups, and other utensils, is associated with increased levels of microbial contamination.

Guchi, (2015) in addition placed the possibility of water contamination as wide mouthed containers provide an opportunity for faecal matter to come into contact with the stored water, potentially introducing harmful microorganisms. The act of dipping hands or utensils can transfer bacteria or other contaminants from the external environment into the water, compromising its safety and quality.

In a study conducted by Kirby, et al., (2016) in Lesotho, it was disscorved that majority of the households in rural areas neglect to clean their water containers before collecting water or utensils when drawing water from storage containers. These practices have been linked to water contamination at the point of use. Furthermore, Onigbogi & Gunyemi, (2014) and Guchi, (2015) confirm a strong correlation between the use of wide-mouthed storage vessels and microbiological contamination. This indicates that the design of storage containers plays a crucial role in the potential for contamination.

2.13 Summary

The chapter reviewed related literature and identified a variety of household water storage containers that are used by other communities that have been studied before including their characteristics. The chapter also outlined the common practices around the use and maintenance of these containers. Overall, the chapter emphasises the importance of understanding and improving household water storage practices to enhance drinking water quality and public health. It suggests that interventions should not only be centred on providing safe water but also on how water is stored and used in the home.

CHAPTER 3 METHODOLOGY

3.1 Introduction

This chapter outlines the research methodology used in the study to investigate the effects of household water storage containers on microbial water quality. The aim of the research was to understand the relationship between the types of storage container used and the quality of water stored within, specifically focusing on microbial contamination. The methodology was designed to ascertain the following; the types of commonly used household water storage containers, the material and the design of the containers and their influence on microbial quality of stored water, and the common practices around the use and maintenance of these containers, and how do these practices impact the microbial water quality.

To answer these gaps, the study was designed considering three main aspects; research design, data collection, and data analysis.

3.2 Research design

The research adopted an observational cross-sectional study to allow for the observation of behaviours of the individuals and households at the point of use. The application of an observational cross-sectional study in this study was to allow for a clear and ideal system that provide a snapshot of the current water quality in households that use different storage vessels. More so, the use of an observational cross-sectional study allowed the research team not to intervene in any way but rather observe and record the day to day activity in water storage and use in the home.

Cross sectional studies allow for the useful comparison of data as in this case the research design was useful in comparing different contamination levels or microbial loads between different characteristic containers. Data was therefore be collected and analyzed at one particular point to reduce bias. This had an edge over longitudinal studies that require repeated sampling over time which could be difficult to conduct because it would be difficult to hold drinking water practices constant. Also, sampling all households at once was considered as a way to control seasonal effects and ensure that any differences noticed are largely as a result of the storage containers characteristics and limited external factors.

3.3 Population and sampling

3.3.1 Study site

The study was conducted in Rushinga district in Zimbabwe. Rushinga is located some 241km north-east of Zimbabwe from Harare in Mashonaland Central province. It borders with Mt Darwin district to the north-western side whilst it also borders with Uzumba Maramba Pfungwe district to the south and Mudzi district to the south-eastern part. It is located in the agro-ecological region 5 where there is dry climate with seasonal rainfall patterns with an average annual rainfall of 750mm-800mm. However, there is significant variability from year to year. A greater part of the community in the rural areas of the district obtain drinking water boreholes fitted with handpumps. Drinking water is not piped into yards and dwellings in rural areas and water is stored in containers in the home. Figure 2 below shows the map of Rushinga district and the administrative wards studied.

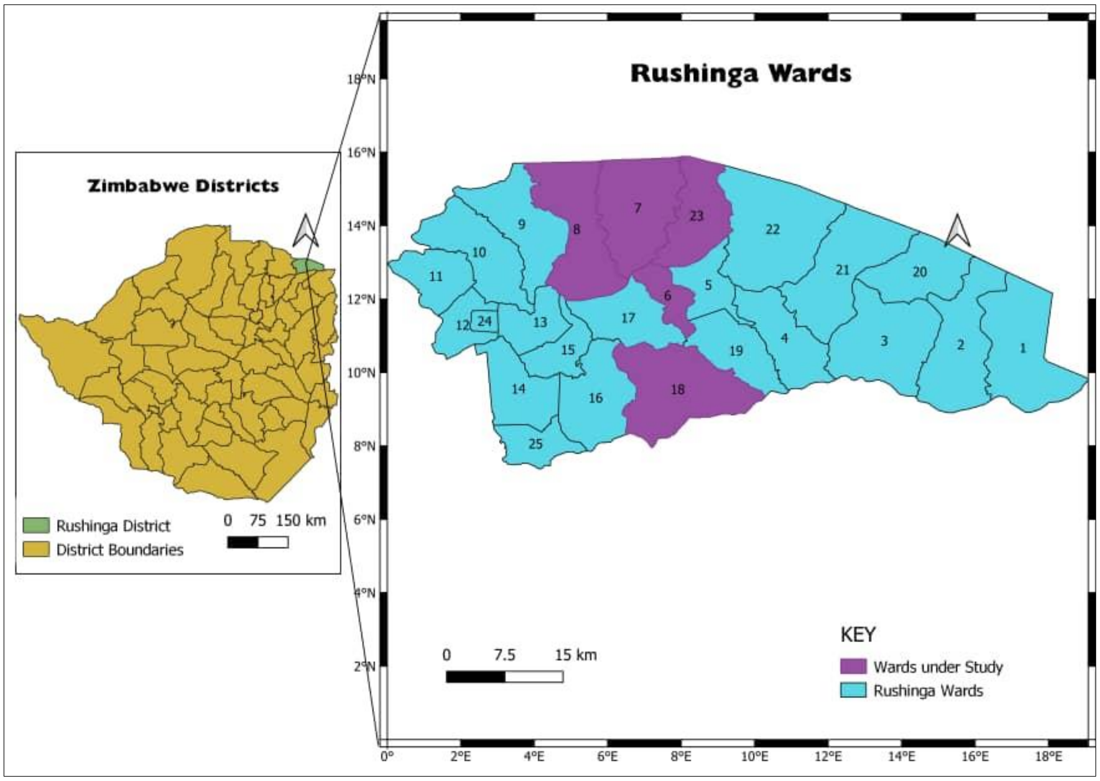

Figure 2. Administrative wards under study

3.3.2 Study population

The study was conducted in World Vision operational wards in Rushinga where bacteriological water quality has been found to be lower in the home than at the source. These include wards 6, 7, 8, 18 and 23 were World Vision Zimbabwe has been operating and programming in WASH. For the purpose of this study only, households that draw drinking water from sources that tested zero total coliform count and zero E. coli were included. This was done to control for initial microbial loads of sampled water as a confounding factor of the quality of water at the sources so as to ensure validity of the results.

3.3.3 Sampling procedure

The sampling design adopted followed a multi-stage cluster design approach which divided large populations into groups or clusters so as to ensure that the sampling process is more practical. In this, regard the first stage involved the systematic selecting of targeted wards/clusters from the survey area with a probability proportional to size (PPS) technique whereby the population was divided into 5 wards which were wards 6, 7, 8, 18 and 23.

The second step selected 3 wards out of the 5 administrative wards from which World Vision Zimbabwe has programming presence. These were wards 7, 8 and 23. Convenient sampling has been preferred as a result of limited financial resources and time constraints. More so, convenient sampling ensured that actual and up to date data on the total number of the household in each ward and village are obtained from the database.

The third stage involved a purposive selection of boreholes with zero E. coli characteristics. In this study, the researcher purposively sampled 2 boreholes per ward which is more than 10% of the total boreholes of the conveniently selected wards. Each borehole is estimated to serve 50 households. It gave a total estimated population of 300 households for the study. PPS sampling reduced the amount of sampling error because probability of selection was related to the population size of the ward/cluster hence providing results in more precise estimates.

At the fourth stage, a fixed number of households was systematically chosen from each selected ward/cluster. This involved sampling of targeted households that draw water from the boreholes that would have tested zero E.coli. The multi-stage cluster sampling approach when combined with PPS selection at the first stage offered some key advantages whereby larger wards/clusters had a higher probability of selection compared to smaller ones. This therefore ensured that bigger units had a better chance of inclusion in the sample.

A multi-stage design involving clustering at ward/area level and then sampling households within clusters reduced fieldwork costs and logistical challenges compared to simple random sampling of individual households.

In summary, the multi-stage cluster sampling design along with PPS selection at the primary sampling unit (ward/cluster) level helped in obtaining a representative sample and generated estimates with less sampling error and variance in a cost-effective manner. Figure 3 below illustrates the sampling strategy that was followed up until the sample was drawn;

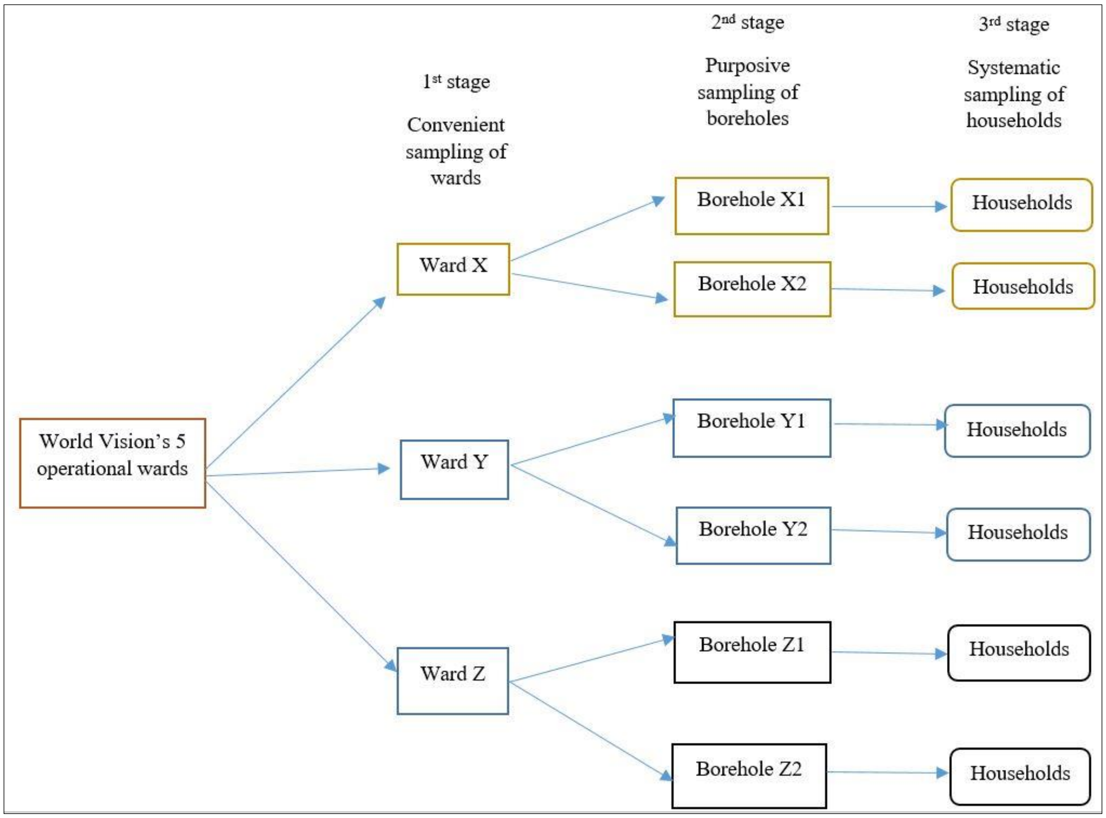

Figure 3. Sampling procedure flow diagram

3.3.4 Sample size

The study sample consisted of boreholes and households within the 3 selected wards and the sample was representative of households served by the water points in the 3 wards of Rushinga district. Each targeted household was therefore interviewed and had a water sample collected. However, to ensure an effective way of sampling households that participated in the survey, a sample size was therefore calculated using the Dobson formula;

$n = (z/\Delta)\ 2p\ (1-p)$

Where $\boldsymbol{n}$ = the expected sample size

p = the prevalence from a similar study

Δ = 0.05, is the level of precision, and z is the value from the standard normal distribution reflecting the confidence level that was used. Using the statistical formula above, the sample was calculated at 95% Confidence Interval and 0.05 level of significance. Based on previous study by (Alemeshet, Baraki, & Mekbib, 2021) prevalence of households with contaminated drinking water;

$p = 835 = 0.83$; $q = 0.17$; $z = 1.96$; $\Delta = 0.05$

$n = (z/\Delta)\ 2p\ (1\text{-}p)$

$$n = \frac{(1.96)}{0.05}\ 2(0.83)\ (1-0.83)$$

$n = 1536.64 \times 0.1411$

$n = 216.8$

n = 217

Therefore, a total of 217 households was therefore selected for the study and respondents were adults found at the households at the time of data collection.

3.4 Data collection instruments

3.4.1 Interview schedule

Data on different aspects of user practices was collected from respondents through a face-to-face administered interview schedule with mainly close-ended than open-ended questions. The structure of the questions made responses more consistent and easy to analyse statistically across interviews. The few open-ended questions allowed the interviewer to for follow up for clarification or elaboration.

3.4.2 Observation

Observations of certain behaviours related to drinking water handling was done. The interview schedule had provision to record direct observations on user practices and state or characteristics of water storage containers and other water handling utensils in the home. Interviewees or any household member were asked to draw water from the storage containers whilst the enumerator observed.

Data that was obtained through observations included for example, type of storage container, characteristics of container, method of withdrawal from the storage container and user practices such as either covered or uncovered containers. Enumerators therefore, would observe and record household behaviors in managing and handling stored drinking water.

3.4.3 Water quality results

Water quality results were recorded in a water quality results log in the spaces that were provided in the interview schedule.

3.5 Pilot study

Data collection instruments were tested on 10% of the study sample (n = 22) households before the upscaling the study. The pilot ward was purposively sampled based on the rationale that the ward was not participating in the main study. This ensured that the data collection instruments were appropriate, effective and yielded valid and reliable data as the pretesting of the data collection instruments identified flaws and omissions in the tools before upscaling the research. Necessary adjustments were done.

3.6 Data collection procedure

Data collection involved household survey and laboratory testing. The process began with training of enumerators who were Environmental Health Technicians from the MoHCC with skills in water quality testing. The enumerators were recruited from wards that were not participating in the study to reduce researcher biases. Data for household surveys was be collected using mobile phones loaded with kobo collect tool and saved in the Open Data Kit (ODK) server in an editable form so that microbiological water quality results can be entered and saved at a later stage after analysis of collected water samples in the laboratory.

The study collected data on the bacteriological and physio-chemical quality of drinking water sources and water from household storage containers using a water quality results log. Samples from drinking water sources were collected on the same day as the interviews with the participating households, while samples from household storage containers were also collected immediately after the interviews were completed.

The utensils commonly used by households to draw water from the storage containers were used to collect the samples. Sterilised 100 ml bottles with tight-fitting lids were used for packaging the water samples from both sources and household storage containers. Water samples were collected from both the main drinking source and storage containers using sterile sample bottles and technique, properly labelled and preserved for microbial analysis. Water samples from the source were collected after sterilizing the spout by flame heating and by allowing the water to flow undisturbed for one minute in order to cool the spout.

The water samples were then taken to the laboratory within 6 hours of collection where they were analysed through the Membrane Filter Technique (MFT) which involved passing a volume of water through a membrane filter to capture and isolate microorganisms. The membrane was then placed on a nutrient medium and incubated to detect colony forming units (CFU).

The membrane filtration technique is recommended by the WHO for low-income countries. This technique is simple, cost-effective, and suitable for microbiological contamination testing of drinking water samples. Specifically, the membrane filter technique using mFC agar and incubation at 44.5°C for 24 hours will be employed to enumerate faecal coliforms, which are commonly used as indicators of unacceptable microbial water quality. The presence of faecal coliforms suggests the possible presence of other pathogenic bacteria such as *Salmonella spp, Shigella spp,* pathogenic *E. coli, and V. cholera*, which are associated with waterborne diseases. This test identified E.coli and Total Coliforms.

Likewise, pH and turbidity tests were conducted in the field using the Nepherometer (test turbidity) and the pH meters. Data obtained on water quality was logged on the spaces provided in the interview schedule where it was linked to the source of water and household sampled through a code.

3.7 Analysis and organization of data

Collected data from households was served in the Open Data Kit (ODK) server and then transferred to Ms Excel and analysed using STATA. Quantitative data was be presented in tables, cross tabulation, pie charts and bar graphs. Linear regression analysis were performed to determine relationships between independent variable and the dependent variable. This established the effect of household drinking water storage containers and water user practices on the microbial quality of the water.

First, simple linear regression was be conducted to predict the outcome (dependent variable) that is contaminated water or concentration of faecal coliform presence using dependent variables for instance container type.

Linear regression was then be followed by multiple regression to establish the effects of multiple predictors on the outcome and lastly logistic regression to estimate the probability of water being contaminated in characteristic containers. In multiple regression, the associations was analysed holding all other independent variables constant thereby adjusting for confounding that may skew the relationships.

For the logistic regression, the outcome was binary (contaminated or not contaminated) whilst the predictor was categorical for example container A, container B, container C and container D.

The logistic regression model was then be used to estimate the probability of contamination given a particular storage container type after controlling for other variables for example pH, household income and duration of water storage. The process then determined which container types had significantly higher or lower odds of contamination compared to a referenced category.

The data analysis of the bacterial tests conducted on the water samples followed the most common international standards to determine microbiological quality and safety. One such key standard was testing for E. coli presence. As per guidelines, any detectable amount of E. coli in a 100ml water sample indicated faecal contamination, rendering the water unsafe for drinking. The analysis involved comparing the bacterial test results for each water sample against the following criterion to determine one of two outcomes. Where there was absence of E. coli or coliforms the sample was classified as compliant with standards and when there was the presence of E. coli or coliforms, even one colony detected in the 100ml of sampled water was classified as unsafe.

Table 2. WHO risk levels for microbial contamination of drinking water

***E. coli per* 100ml of water**	**WHO risk level**
<1	Low risk
1≥10	Medium risk
11-100	High risk
>100	Very high risk

Source: WHO, (2017)

Similarly, the total coliform counts were also assessed against acceptable and permissible limits specified in the standards. The results were categorised as either safe if zero counts per 100ml of water sampled were detected or unsafe if the counts exceed zero but with low risk categorised for counts between 1-10CFU/100ml.

Overall, this approach helped to evaluate the safety and quality of drinking water sources in a standardized, unbiased manner.

3.8 Ethical considerations

Ethical considerations were observed at all stages of the research from the planning, implementation and dissemination of study results. Water quality studies come with ethical issues which should be held with caution. The researcher obtained approval to conduct study from the District Medical Officer and the Africa University Research and Ethics Committee.

Community leaders were also asked to authorise the study to go ahead. Asking for authorization from community leadership showed respect and facilitated cooperation from community members since there were complex issues that involved water sampling from participating households. Besides providing support in terms of active community participation, local community leadership also helped with identify potential issues or concerns that informed research design and procedures thereby improving cultural appropriateness of the research protocols.

Secondly, the researcher obtained written informed consent that enables the enumerators to go to the next stage of the aspect of data collection after explaining the purpose of the study, the procedures which were to be followed, and potential risks and benefits of the study.

Noteworthy, the principle of beneficence and maleficence was also considered. The researcher made it clear that knowledge that shall be gained from the study was expected to help improve household water safety and public health. Respect for participants was also ensured by not coercing coerced, persuading or pressuring them to participate in the study but voluntarily agree to contribute and assured the right to withdraw from the study at any given time if they felt necessary.

Similarly, confidentiality and anonymity of data collected from participants was assured. Data and findings have been kept confidential and solely used for the purpose of the research. At the same time, the data was be kept as soft copy with a password, encrypted when sending online. The researcher plans to communicate results in a way accessible to the participants and the wider community.

Furthermore, the questionnaire went through examination and review by the WASH governance structure for the district who are knowledgeable in the field of water supply and water quality. This process was carried out to ensure that the questions align with the content of the study and are appropriate for the research objectives.

Last of all, the researcher shall not put participants at any form of risk either physically or emotionally, discriminate in any way due to their participation by means of disclosing findings of the study responsibly. To avoid stigmatization, the researcher shall be careful on how results are communicated especially related to certain container types. Results shall be communicated in a way that is accurate and does not cause undue concern by focusing on technical issues, suggesting solutions or recommendations where possible.

3.9 Summary

The chapter outlined the methodology used to examine the relationship between drinking water storage containers, user practices, and water quality in the rural community of Rushinga district. A cross sectional study design was employed to collect data at one point in time. The study was conducted in 3 wards and a total of 217 households were randomly selected to participate in the study. Data collection took 2 weeks where household interviews were conducted using a standardized interview schedule. This chapter provided details on the methodology used, including study design, study site, sample size calculation, data collection instruments, laboratory analyses, and statistical analysis.

CHAPTER 4 DATA PRESENTATION, ANALYSIS AND INTERPRETATION

4.1 Introduction

The quality of drinking water is an important concern for human health. While much attention is given to the source of water and treatment methods, the storage container used to hold drinking water in the home is an important factor influencing water quality that often does not receive enough attention. The aim of this chapter is to investigate how different household drinking water storage container types affect water quality.

Water storage containers vary greatly in their material, design and capacity. Common materials used include plastic, clay, glass, metal and ceramic. Designs are different in the inlets/outlets varying from narrow to wide mouths whilst some are fitted with taps. All these factors makes the storage containers interact with the water and the user practices in different ways potentially affecting the quality of water that they hold.

This comprehensive study therefore, how variables such as container materials and design, container age, duration of water storage, and user practices influence water quality. The aim is to provide guidance to households on choosing optimal containers and help ensure drinking water safety.

4.2 Data Presentation and Analysis

4.2.1 Completion rate for interview schedules

The data in Table 3 below shows that 217 interview schedules were targeted to be administered in households participating in the study. All the 217 interview schedules were administered and completed (with all requested data provided).

Table 3. Participation or completion rate of surveyed households

Instrument	Interview schedules administered (n)	Interview schedules completed (n)	Number of valid interviews (n)	Participation or Completion Rate%
Interview schedule	217	217	217	100

As shown in Table 3 above, the participation and completion rate was 100% and this is a very high completion rate suggesting that the data collection tool was effective at engaging the participants and getting the needed data. As a result, the 100% completion rate provides a good level of data for analysis to understand water storage and handling practices among participating households.

4.2.2 Participation rate for water quality analysis

The study planned to collect and analyse 217 household water samples. Therefore, 100% (n = 217) originally recruited households participated fully in the study by providing a water sample as requested. Table 4 below displays the participation rate of surveyed households in water quality sampling and analysis.

Table 4. Completion rate for water quality log

Instrument	Water quality log planned (n)	Water quality log completed (n)	Number of valid water quality results (n)	Participation rate%
Water quality log	217	217	217	100

The extremely high participation rate presented in Table 4 suggests the study protocols and engagement of participants was very successful in obtaining water samples from all households surveyed. The high participation rate submit that the water quality data obtained allows for very robust analysis and conclusions about household drinking water storage containers, water handling practices, and quality among these households. The obtained data is likely very representative of the target population.

4.2.3 Sex of respondents

Figure 4 below compares the participation males and females as respondents. Out of 217 households that were surveyed 22% (n = 48) were male respondents whilst 78% (n = 169) were female. The data suggests that more female respondents (78%) compared to male respondents (22%) can be effective of traditional household water collection or storage roles. The female dominated participation supports generalisability of results to represent practices where women often manage these tasks.

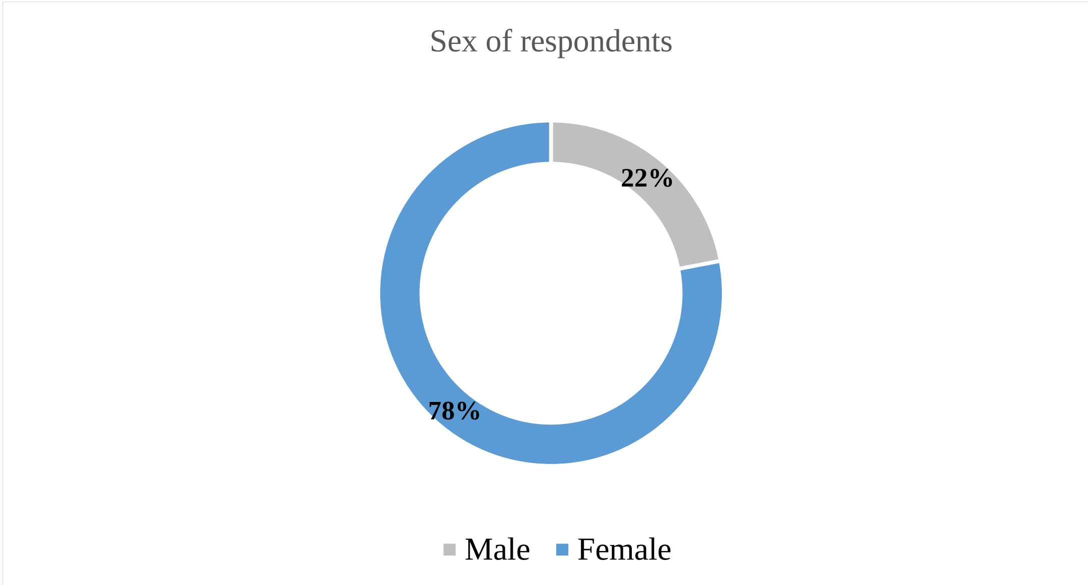

Figure 4. Sex of respondents

However, from Figure 4, having input from some male respondents (22%) helps provides more well-rounded insights not limited to just female views.

4.2.4 Characteristics of drinking water storage containers

The study categorised household drinking water storage containers used by rural communities in Rushinga district in 2023.

4.2.4.1 Material used in production of household drinking water storage container

Figure 5 below shows the containers from which drinking water was sampled for analysis and these were the containers from which the households were drinking at the time of the survey.

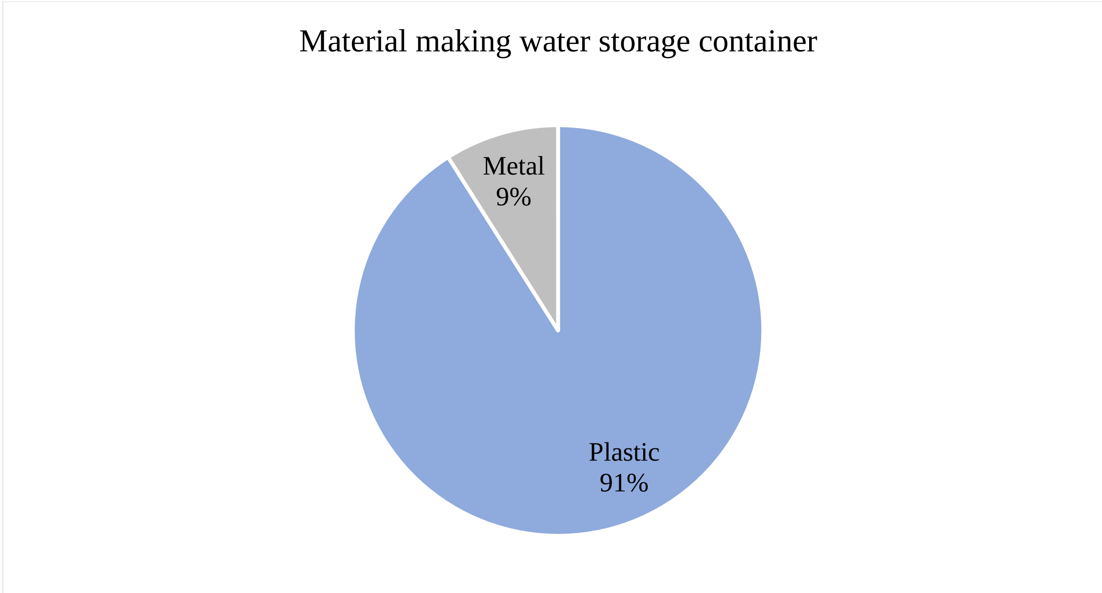

Figure 5. Categories of household drinking water storage containers

As highlighted in Figure 5 above, plastic material make up the vast majority (91%) of the household water storage containers, while metal accounts for a small proportion (9%). Plastic containers are over 10 times more common than metal as household drinking water storage containers.

4.2.4.2 Description of drinking water storage containers

Data in Figure 6 below shows that approximately 94% (n = 204) containers with taps are overwhelmingly more common than containers without taps which had 6% (n = 13). The data suggests that taps are almost a universal feature on drinking water storage containers. Wide mouth containers constituted 93% (n = 202) and dominate over narrow mouth containers which had 7% (n = 15). On the other hand, tightly covered containers with 82% (n = 178) significantly outnumber those left uncovered with 18% (n = 39), showing that covers are a norm.

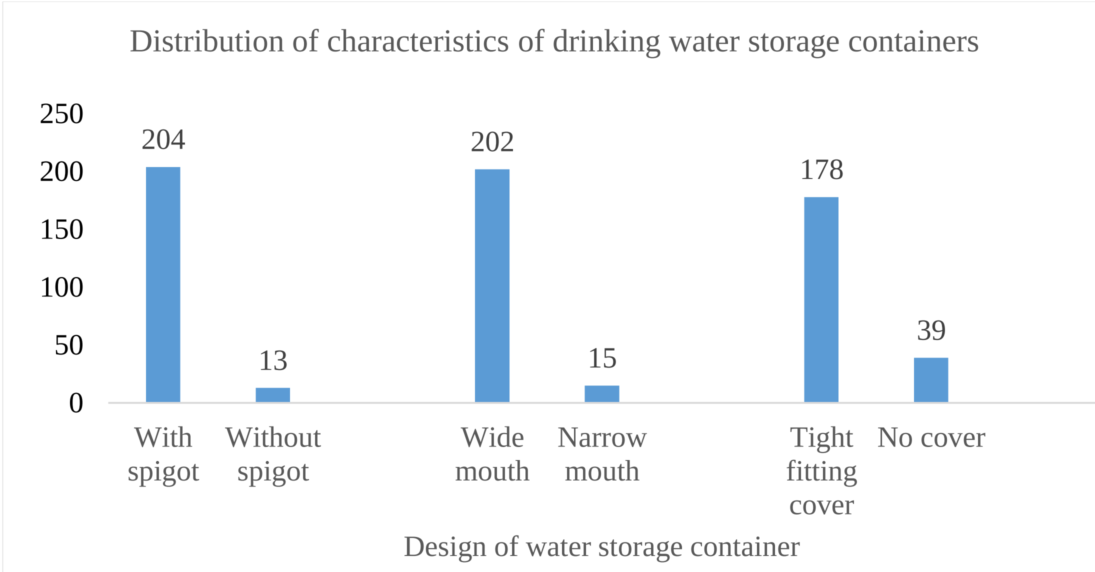

Figure 6. Drinking water storage containers and their features

4.2.4.3 Volumes/capacities of water storage containers identified

The most common containers' volume was 20 litres at 96.8% (n = 210). The 10 litres and 35 litres only accounted for a small proportion at approximately 0.5% (n = 1) and 1.8% (n = 4) respectively. The 25 litres were even less common than the outliers at just 0.9% (n = 2). This indicates that 20 litres is by far the predominant capacity used for household water storage in the surveyed households.

In summary, this distribution highlights 20 litres as the standard capacity, while signaling the need to account for capacity when assessing links to water quality as shown in Table 5 below.

Table 5. Distribution of water carrying capacity of drinking water storage containers

Capacity of water storage container observed at sampling (litres)	Observed (n)	Percent (%)
10	1	0.5
20	210	96.8
25	2	0.9
35	4	1.8
Total	**217**	**100.0**

4.2.5 Averages and variations in household drinking water storage containers

Table 6 below explains further the distribution of water storage containers for the surveyed households.

Table 6. Distribution of commonly used container capacity and how they are spread out from the mean

Water Storage Container Capacity (L)	Frequency	Cumulative Frequency	Mean (L)	Std. Dev (L)
10	1	1	20.1	6.13
20	210	211	20.1	6.13
25	2	213	20.1	6.13
35	4	217	20.1	6.13

Given the data in Table 6 above, the mean of 20.1 explains that, on average household water storage containers held about 20 litres of water. The standard deviation of 6.13 litres suggests that while 20 litres was average, container capacities varied within a relatively narrow range of about 6 liters above and below this mean. Very few containers were significantly larger or smaller than the 20 litre norm, as evidenced by the low standard deviation. Most container capacities lie close to the mean value, falling between 14-26 litres based on the standard deviation. Differences in capacity were minor compared to the average, limiting their ability to impact results.

4.2.6 Risk of drinking water contamination in household water storage containers

For assessing risk of contamination risk for different household drinking water storage containers, the study started by analysing the correlation coefficients before using linear regression. The initial analysis served as exploration of relationships between variables by simply measuring association. This assisted in identifying container characteristics which appear to have either the strongest or weakest correlations to various measures of drinking water contamination. Correlation coefficients analysis gave a first pass indication of container attributes that could pose higher or lower relative risks worth further examining.

4.2.7 Relationships between drinking water storage container characteristics and user practices as related to water contamination

Table 7 below shows associations between container variables and user practices in causing drinking water contamination in a correlation matrix. From the data provided, only withdrawal method from the storage container and water storage/retention time had a fairly strong positive linear relationship (correlation coefficient 0.69) in relation to drinking water contamination at household storage. It suggests that, as the water withdrawal method changes for example from tap to dipping, the associated water storage time tends to change in the same direction.

Table 7. Associations between various drinking water container characteristics in relation to E.coli water contamination

Variable	E coli	Withdrawal method	Container covering	Container mouth	Storage time	Container material	Container capacity	Hygiene status
E coli	1.00							
Withdrawal method	-0.19	1.00						
Container covering	0.19	-0.31	1.00					
Container mouth	0.30	-0.40	0.10	1.00				
Storage time	-0.19	0.69	-0.34	-0.28	1.00			
Container material	0.05	-0.34	-0.35	0.21	-0.19	1.00		
Container capacity	-0.06	0.32	-0.14	0.08	0.33	-0.11	1.00	
Hygiene status	0.29	-0.45	0.30	0.31	-0.40	0.26	-0.20	1.00

Again, findings indicate that there is a weak positive relationship (correlation coefficient 0.31) between the design of the mouth of a container and the hygiene status of the container. As the mouth of the container changes (wide or narrow), the hygiene status of the storage container tends to change in the same direction to some degree becoming either dirty or clean.

As well, with a correlation coefficient of -0.44, the data shows a negative or inverse correlation between water withdrawal method and hygiene status of container. It suggests that as the withdrawal method changes for instance from tap to dipping, the hygiene status of the container tend to change in the opposite direction. It can be inferred that certain drinking water withdrawal methods are more associated with cleaner or dirtier container hygiene statuses.

Water storage time and hygiene status of container had also a negative correlation (coefficient -0.40). It suggests that as length of water storage increases, the reported hygiene status of the container tends to decrease.

In Table 8 below, the correlation coefficients (positive) for container covering, container mouth, container material and hygiene status of containers show that the variables have a positive relationship with total coliform count. However, amongst them all, container materials and hygiene status of containers suggest a moderately and stronger positive relationship with total coliform count with correlation coefficients of 0.61 and 0.55 respectively.

It suggests that certain water storage materials have a much stronger association with higher coliform counts and as the hygiene status of the container increases (becomes cleaner/more hygienic), the total coliform count decreases. In other words, containers that are better maintained and have higher hygiene levels tend to have lower levels of coliform bacteria contamination in the stored water. It also suggests that the choice of container material can substantially impact on coliform levels in stored drinking water.

Table 8. Associations between container characteristics in relation to total coliform count

Variable	Total Coliform Count	Withdrawal method	Container covering	Container mouth	Storage time	Container material	Container capacity	Hygiene status
Total Coliform Count	1.00							
Withdrawal method	-0.57	1.00						
Container covering	0.47	-0.31	1.00					
Container mouth	0.40	-0.40	0.10	1.00				
Storage time	-0.55	0.69	-0.34	-0.28	1.00			
Container material	0.61	-0.34	0.35	0.21	-0.19	1.00		
Container capacity	-0.18	0.32	-0.14	0.08	0.32	-0.11	1.00	
Hygiene status	0.55	-0.44	0.30	0.31	-0.40	0.26	-0.20	1.00

Again, data from Table 8 above show a correlation coefficient of -0.57 between method of water withdrawal and total coliform count indicating a moderate-strong negative relationship. This means that withdrawal methods associated with less direct contact for example pour-out spigots against scooping are linked to lower coliform count.

4.2.8 Analysis and comparison of individual and combined effects of multiple storage container characteristics and user practices on risk of water contamination.

4.2.8.1 Mouth of storage container as a predictor of risk of drinking water contamination

Table 9 below shows the linear regression for E.coli and mouth of container. The coefficient (0.27) show the estimated change in E coli contamination. Holding all other variables constant, E.coli levels were averagely 0.27 units higher. Since $p < 0.001$ and that calculated 95% CI range (0.16 - 0.39) does not include 0 on the model means that the relationship is overwhelmingly statistically significant.

We therefore, reject null hypothesis and conclude that the mouth of a container is an important variable that can be used to predict risk of drinking water contamination. This could suggest that narrow mouth containers perform better at reducing contamination as compared to wide mouth containers.

Table 9. E.coli levels based on mouth of water storage container

Explanatory variable	**Coefficient**	**Std. err.**	**[95% Confidence Interval]**		**p-value**
Mouth of container	0.60	0.09	0.16	0.39	0.000
Cons	0.25	0.09	0.70	0.43	0.007

Table 10 below also show the relationship between mouth of water storage container and total coliform count. The findings from Table 10 above assume that, containers with wider mouths have total coliform counts estimated to be about 0.6 units higher than narrow-mouthed containers on average, holding other factors constant. The $p < 0.001$ indicates that the relationship is overwhelmingly statistically significant. The 95% CI (0.41 - 0.79) does not include zero which confirms that the estimated effect of container mouth type on coliforms is real.

Table 10. Total Coliform Count and mouth of drinking water storage container

Explanatory variable	Coefficient	Std. err.	[95% Confidence Interval]		p-value
Mouth of container	0.27	0.06	0.16	0.39	0.000
Cons	0.69	0.57	0.58	0.80	0.000

4.2.9 Material making storage container as a predictor of risk of drinking water contamination

In Table 11 below, the findings suggest that container material type has a very small estimated effect size on E.coli levels with only a 0.04 increase on average.

Since the p-value = 0.430 > 0.05, it means it cannot be concluded with confidence that the effects of materials are small and that this relationship is real. The 95% CI (-0.07 to 0.15) includes 0 and it cannot be concluded that the relationship is statistically different than 0. Therefore, the null hypothesis cannot be rejected and it can be concluded that the risk of drinking water contamination does not vary with container material.

Table 11. Linear regression analysis of E.coli levels based on water storage container material

Explanatory variable	Coefficient	Std. err.	[95% Confidence Interval]		p-value
Container material	0.04	0.06	-0.07	0.15	0.430
Cons	0.9	0.05	0.80	1.00	0.000

4.2.10 Container cleaning frequency as related to total coliform count

Another variable that was measured which is related to water user practices was the container cleaning frequency. Findings from the study were as shown in Table 12 below. The coefficient of 0.74 in Table 13 below indicates that as cleaning decreases in frequency (scores increase), total coliform counts are estimated to increase by 0.74 units on average, holding other factors constant. Since $p < 0.001$ and that calculated 95% CI range (0.56 - 0.91) does not include zero on the model means that the relationship is overwhelmingly statistically significant.

From the data, it can be concluded that cleaning frequency of drinking water storage containers strongly correlates with higher levels of total coliform contamination even after accounting for other relevant attributes in the model.

Table 12. Analysis of water storage container cleaning frequency on Total Coliform Count

Explanatory variable	Coefficient	Std. err.	[95% Confidence Interval]		p-value
Cleaning frequency	0.74	0.90	0.56	0.91	0.000
Cons	0.13	0.09	-0.05	0.30	0.151

4.2.11 Effects of different storage containers and user practices on microbial water contamination

The relationship between microbial count and simultaneous container attributes and user practices was analysed. This also helped control for confounding by using multivariate analysis. The unique contribution of each container attribute and user practice to the risk of contaminating drinking water in the home whilst accounting for the effects of the other predictors was determined as shown in Table 13 below.

The data suggest covering the household water storage container and restricted mouth size of water storage containers as being associated with reduced microbial drinking water contamination during storage in the home.

Covering of drinking water storage containers had an odds ratio of 15.2 meaning that people who cover their containers have higher chances of reducing microbial drinking water contamination by 15.2 times than those who do not cover their containers. With the 95% CI (6.16 - 37.7) which does not include 1.0 and $p < 0.001$, this ruled out the null hypothesis that covering of water storage containers had no effect on drinking water contamination in the home. We therefore reject the null hypothesis and conclude that there is statistically significant evidence that covering water storage containers affects microbial water quality at 0.05 level of significance.

Table 13. Logistic Regression Model of predictors of risk of drinking water contamination in storage containers in the home

Covariate	N	Odds Ratio	95% Confidence Interval	p-value
Covered container				
Yes	178			
No	39	15.2	(6.16 , 37.7)	0.000
Storage container mouth narrow/restricted				
Yes	202			
No	15	8.6	(1.70 , 43.18)	0.009
Regular cleaning frequency of storage container				
Yes	201			
No	16	3.4	(0.50 , 23.0)	0.211
Container made of plastic				
Yes	197			
No	20	0.38	(0.45 , 3.2)	0.373
Withdrawal from a storage container with a spigot				
Yes	204			
No	13	1.2	(0.12 , 12.18)	0.875
Small storage container carrying capacity				
Yes	211			
No	6	0.1	(0.94 , 1.06)	0.964

Similarly, Table 13 above shows the results of mouth of storage container and drinking water contamination. The data put forward that containers with wider mouths have over 8 times higher odds of contamination (OR = 8.6) compared to narrow-mouthed containers. The p = 0.009 which is less than 0.05 demonstrates that the relationship is overwhelmingly statistically significant. Overall, the results suggest that restricted or narrow-mouthed containers are significantly associated with reduced microbial drinking water contamination in storage containers.

However, whilst the results suggest a true OR greater than 1, this cannot be said with certainty because the 95% CI (1.70, 43.18) is close to the value of 1.0 indicating the likelihood of no effect. Additional significance testing would be needed. More data would be needed to draw a stronger conclusion.

Taken together, these findings provide exceptionally strong evidence that covering of containers and restricted container mouth width significantly influences microbial drinking water contamination when controlling for other attributes. Even after accounting for various potential confounding variables, covering drinking water storage containers and choice of mouth dimensions remains important predictive factors.

Similarly, results in Table 13 above also point to other factors such as cleaning frequency, hygiene status of container, container carrying capacity, water storage time, and withdrawal method as having weak evidence for a possible relationship with stored household water microbial contamination that require replication given the wide confidence intervals and marginally significant p-values. These may modestly influence drinking water contamination but their effects are less certain compared to container covering and design of container mouth. These require further investigation.

4.3 Discussion and interpretation

The results of the study points out to the important role that water storage containers play in reducing microbial drinking water contamination in the home. Key aspects that have been found from the study include adoption of hygienic water storage practices. The findings also highlight that the hygienic water storage practices could be related to design of the container mouth (narrow or wide) and the storage container capacity which determines cleaning frequency when emptied. Overall, the factors either limit entry of microbial contaminants or remove built up microbes.

4.4 Summary

The chapter presented findings of the study on effects of household water storage containers and user practices on drinking water safety. A total of 217 households were surveyed across 3 administrative wards and 217 water samples collected and tested. The data was analysed and interpreted to understand the relationship between type of storage container and the quality of stored water. The next chapter concludes with the summary and the implications of the findings on public health.

CHAPTER 5 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

This chapter discussed the key findings from the data analysis presented in chapter 4. The results were examined in the context of existing literature on factors influencing household water quality. It then discussed the risk of water contamination as related to various container characteristics, associations of various container characteristics, and recommended or suggested alternatives and strategies to promote safely stored drinking water and to improve container hygiene and water handling practices. Propositions for further areas of research are also outlined.

5.2 Discussion

5.2.1 Characterisation of water storage containers

The study revealed that only 2 types of materials dominated the storage containers that were found. Plastic storage containers constituted about 91% (n=197) whilst metal-made storage containers were found to be 9% (n=20) in Rushinga district communities. Plastic containers were found to be over 10 times more common than metal as household drinking water storage containers.

These findings contradict with study findings by (Levy K., 2008) who found plastics, ceramic, clay, glass, metal and calabash as all common material characterising household drinking water storage containers. The same results were also not consistent with Duru, Amadi-Mgbenka, Amadi, Nsofor, & Nze, (2013) who found the use of calabash as the commonest material for drinking water storage containers.

Similarly, water storage containers with taps were found to be overwhelmingly higher (94%) than storage containers without taps (6%). Likewise, storage containers with wide mouths constituted 93%(n=202) and dominated over narrow mouth storage containers which had 7%(n=15). Tightly covered containers were found to be at 82% (n=178) and significantly outnumbered those containers without lids 18% (n=38), showing covers are a norm.

The study also revealed that 20 litre containers were the most commonly used (96.8%) with a mean of 20.1 and standard deviation of 6.13 and meant that container capacities did not vary much from the mean.

However, the wide use of plastic material in Rushinga district rural communities as drinking water storage containers could be because plastic is likely more affordable than metal. It may also be perceived as more modern and hygienic. The data hints that availability and perceptions around materials influence household choices significantly. This could also have been influenced by WASH programming especially in emergencies where Non-Food Items are given to people.

Taps, wide mouths, and covers are by far the normative designs/practices. The small numbers without these features may reflect lack of alternatives, resources or education. Future analysis should control for these container types, as they may impact water quality differently. Uncovered, narrow mouths especially warrant further investigation as potential risk factors.

In summary, the wide practice of using containers with taps, wide-mouthed, and with covers point to these as standard and presumably safer designs according to local norms and practices. The minority container types may need targeted interventions.

5.2.2 Risk of drinking water contamination in different household water storage containers

5.2.2.1 Drinking water withdrawal method from container

The study found an association between drinking water withdrawal method and microbial contamination (OR = 1.2; 95% CI 0.12 - 12.18; p = 0.880). This means that there is 20% increased odds of contamination for households with storage containers without spigots. However, a p-value of 0.880 and 95% CI (0.12 - 12.18) means that the findings were statistically insignificant and inconclusive. More powered studies would be needed to better understand the relationship.

The result does not necessarily corroborate with results of a study by (Manga, et al., 2021) who found out highest effect in stored water quality in retention time and withdrawal method. Manga et al., (2021) highlights that microbial growth increases with poor withdrawal methods and as retention time increases.

Overall, this correlation hints at an important exposure-outcome linkage between withdrawal behaviors and contamination risks. The relationship could provide insights on simple interventions that discourage withdrawing drinking water from a storage container by scooping. However, more rigorous analyses controlling for other factors would help validate this association and its implications for relative risk assessments.

5.2.2.2 Design of mouth of drinking water storage container

The effect of the design of the container mouth (wide or narrow) was also found to be statistically significant. When controlling for other factors, containers with wider mouths were associated with E. coli contamination (OR = 8.6; 95% CI 1.70, 43.18; p = 0.009;) than narrow-mouthed containers. With a p <0.05, the results were statistically significant.

Overall, the (OR = 8.6) means that wide mouth containers higher odds of contamination than narrow mouths when other attributes are controlled for. They can be contaminated by 8.6 units more than containers with narrow mouths.

The results suggest that the type of mouth of the storage container can be an important predictive factor to consider when seeking to reduce microbial contamination risk through improved container design. The findings by this study does not concur with findings by Schafer (2010) who revealed that storage container design (narrow mouth) can complicate cleaning and affects user pracices.

Schaffer found out that containers with openings that are harder to clean thoroughly (e.g. narrow mouths) may accumulate more hygiene issues over time. The results by Schaffer recommends that easier access to the container interior provided by certain opening designs could facilitate better hygiene practices like scrubbing of interior surfaces.

However, the results of this study are supported the findings by (Chalchisa, Mergesa, & Beyene, 2018) that improved hygiene practices with household water storage containers can help reduce microbial contamination and improve water quality/safety.

Reduced contact with stored drinking water by means of better designs of containers likely limit the contamination of drinking water.

Therefore, while the magnitude and precision of the effect are somewhat reduced, mouth width independently predicts contamination risk even when accounting for other container characteristics measured. This reinforces its importance as a determinant of water safety practices at the household level.

However, other confounding factors beyond just the mouth design also influence hygiene levels. More research is needed to fully understand this association and isolate the specific impact of mouth designs. The relationship provides a modest signal about container attributes that may heighten hygiene challenges requiring mitigation.

In summary, the significant regression analysis reinforces that container mouth attributes may critically impact waterborne disease hazards like E. coli in household stored water.

5.2.2.3 Material making the storage container

On the other hand, the study found a statistically insignificant relationship between type of material making a container and E.coli levels with (OR =0.38; 95% CI: 0.45, 3.2; p = 0.370). These results provide little evidence that choice of material making the storage container has an association with microbial levels after accounting for other variables in the model. The predictor does not appear to be an important factor influencing microbial contamination risk based on this regression analysis.

The findings do not agree with what was found by Duru, Amadi-Mgbenka, Amadi, Nsofor, & Nze, (2013) who found out that deterioration of microbial water quality was highest in calabash material and decreased in clay pot, metal vessel, plastic vessel and lastly glass vessel in descending order.

However, the findings can be explained by results from Obianyo, (2020) who found out increased microbial contamination in water stored in steel, plastic and clay container over a period of one month which was attributed to unhygienic user practices rather than type of container. There may be other factors such as unavailability of cover on metal containers that could have resulted in the chance.

In conclusion, the insignificant association for material type suggests that it may not be a practically or statistically relevant attribute to consider for mitigating microbial contamination. The relationship could be by chance for instance in the case of this study, there were only metals and plastic containers with being the modest type (91%).

5.2.2.4 Cover of water storage container

This study revealed that uncovered containers have over 15 times higher odds of contamination (OR = 15.2; 95% CI 6.16, 37.7; $p < 0.001$) than covered containers. The results concur with findings by (Chalchisa, Mergesa, & Beyene, 2018) as well who found out that storage containers impact negatively on water quality when good hygiene such as covering of the container is not emphasised.

The findings also determines water withdrawal methods and concur with study results by Schafer (2010) which reveal that water stored in containers with spigots or taps may limit contact of water with user hands at point of use.This suggests how water withdrawal method is an important factor impacting microbial quality. Choosing lower –risk withdrawal techniques could significantly improve water safety for households.

In summary, this relationship provides strong support that containers designed with covers influences microbial contamination and should be optimised for health outcomes.

These strong, precise, and statistically significant results provide compelling evidence that lack of covering strongly influences contamination risk. Therefore, this identifies container covering as another highly significant predictor of household water quality.

5.3 Conclusions

The study provided important insights into how common household water storage practices can impact drinking water safety. Several findings indicate that simple aspects of container design and cleaning can significantly increase levels of microorganisms like E. coli and coliforms. Wide mouths on containers, drinking water withdrawal method from storage container, failure to provide cover of container mouth, and infrequent cleaning were all linked to higher odds of contaminants.

A key conclusion is that widespread adoption of basic hygienic storage practices could help reduce water-borne disease risks. Covering containers and keeping mouth openings narrow helps limit the entry of contaminants. More frequent cleaning of containers also helps remove built-up microorganisms. As plastics were the most common material used, emphasizing cleaning of plastic containers specifically could be beneficial.

Overall, the results demonstrate the value of promoting hygienic household water handling and storage. Low-cost changes like using narrow-mouthed containers, covering when not in use, and regular cleaning could go a long way in improving drinking water safety. As water sources themselves may not always be protected, focusing on at point-of-use interventions such as treatment, proper storage, and handling helps ensure good health. The findings provide useful guidance for public health interventions and education programs aiming to reduce waterborne illness burdens.

5.4 Implications of the study

The study has public health, policy, design and research implications. For public health, the findings indicate the need for intervention to promote safe household water handling and storage practices. This can help reduce water-borne diseases. Education programmes should emphasize the importance of proper container design, cleaning, and hygienic use in preventing contamination.

For design implications, the findings suggest public private partnerships that sees water containers manufactures considering designs that makes hygienic use easier. This includes containers with narrower mouths, tight fitting lids or covers, materials easy to clean and designs which discourages dipping at point of use. Subsidies by manufacturers could help most vulnerable households access safer designed containers.

Noteworthy, more studies are required to fully understand risk factors in different community contexts and cultural practices and that the impact of behavioural change interventions promoting safer water handling practices should be evaluated.

5.5 Recommendations

Recommendations for households

- Use narrow-mouthed covered containers to store drinking water. Ensure the lid covers opening completely.
- Clean water containers regularly (at least once a week or at every replenishment). Use soap and water and dry in sunlight.
- Only use containers made of easily cleanable materials.

Recommendations for local public organisations

- Conduct awareness campaigns promoting the three key practices of using narrow containers, covering when not in use, and regular cleaning.
- Provide demonstrations on proper cleaning techniques for water containers. Embed this in programmatic curriculum.
- Partner with schools to integrate hygienic water handling into educational curriculum. If children adopt a good behaviour they will grow up with it.

Recommendations for Non-Governmental Organisations and container manufacturers

- Support distribution of safer container designs that reduce risk of contamination
- Advocate for strengthening national standards and policies recognizing point-of-use risks.

Recommendations for policy makers and government bodies

- Conduct research trials testing interventions like subsidies for safer containers or incentive programmes.
- Develop regulations mandating minimum design standards for marketed containers.
- Integrate hygienic water handling into national health and WASH programs and curriculum.

5.6 Suggestions for further research

The findings of the study suggest the following areas of further research;

- Conduct larger, studies to validate the findings and better understand potential geographical differences.
- Investigate other design factors not captured like container volume and material porosity, and how they influence bacterial growth.
- Assess impacts of containers used for collection/transport of drinking water.

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APPENDICES

APPENDIX 1: Interview schedule

EFFECT OF HOUSEHOLD STORAGE CONTAINERS ON MICROBIAL WATER QUALITY IN RUSHINGA DISTRICT, 2023.

CONSENT STATEMENT

Greetings. I hope I find you well. I am carrying out a study on the effect of household storage containers on microbial water quality. I am kindly asking for agreement to ask you some questions about how your family and community store their drinking water, observe how you store the water and at the same time collect a sample of your water for microbial analysis. Participation in this study is completely voluntary. You may refuse to participate now and if you decide to participate now, you are at liberty to withdraw from the study at any given moment if you feel like without any penalties or forfeiture of benefits. The study assumes that there will be no risks associated with participating in the study whilst at the same time there are no benefits for you for participating. Nonetheless, the findings from the study may provide information about best practices on water storage or overall drinking water handling. All information on this study will be kept strictly confidential. Only a small team will access the data at any point and your personal details will not be linked to any findings from the study. Do you have any questions about this?

If you have any questions about this study in future, please contact the researcher Neckiot Kagodo, contact number +263775789810 or +263715779578

A1. Do you provide your consent to participate in this study?

- (●) Yes
- ( ) No

SECTION A: HOUSEHOLD IDENTIFICATION

A2. Name of Enumerator________________________________

A3. District Name__________________A4. Ward Number__________________

A5. Village Name_______________________________

SECTION B: DEMOGRAPHIC BACKGROUND

B1. Respondent gender

1 = Male

2 = Female

B2. Respondent age____________

Age in completed years

B3. Gender of household head

1 = Male

2 = Female

B4. Highest level of education completed by household head

1 = No formal education

2 = Primary school

3 = Secondary school

4 = Tertiary level

B5. What is the total household size?_____________________________

B6. What is your household's main source of income?

1 = Sale or exchange of own produce (farming)

2 = Labour (self-employed)

3 = Wage employment (working for someone else)

4 = Remittances

5 = Other ***(specify)*****__________________________**

B7. Is the income regular?

A regular income is an income expected at certain intervals that can be relied on for instance; weekly, monthly, quarterly.

1 = Yes

2 = No

B8. What is the average monthly income for the household?

1 = Below US$20

2 = ≥ US$20 < US$50

3 = ≥ US$50 < US$100

4 = ≥US$100

SECTION C: HOUSEHOLD WATER SUPPLY

Ask the following questions or observe the following about the household's water source;

C1. Primary drinking water source for the household (Code)___________________

C2. Primary drinking water source for the household:

1 = Borehole 2 = Protected well

3 = Protected well 4 = Unprotected well 5 = Other ***(specify)***___________________

C3. Description of water source where is the water source located?

1 = Piped into dwelling

2 = Piped into yard

3 = Public

C4. What is the alternatives sources of water supply due to the interruption sources of water sources?

1 = Borehole 2 = Protected well

3 = Protected well 4 = Unprotected well 5 = Other *(specify)*__________________

C5. Approximate distance of water source from household

1 = less than 500m round trip

2 = more than 500m round trip

3 = do not know

C6. Average time taken to travel to the water source and coming back home including queuing time

1 = less than 30 minutes round trip

2 = more than 30 minutes round trip

2 = do not know

C7. What method does your household use to transport water from source to home?

1= Carry by Hands 2= Carry on head

3= Use a wheelbarrow/ scotch cart 4= others

C8. Do you cover container when transporting water from source?

1= Always 2= sometimes 3= not at all

C9. How frequent do you refill your stored drinking water with fresh one from the primary source or how long does your stored water take to be used up?

1 = more frequent 2 = moderately frequent 3 = less frequent 4 = rarely refilled

C10. For how long do you store drinking water in water storage container in your house?

1= Less than 1 day 2= 2-3 days 3= 4-6 days 4= 1 week 5= more than 1 week

C9. Microbial water quality results (E. coli) for the primary drinking water source of the household

1 = 0 CFU/100ml

2 = < 10 CFU/100ml

3 = > 10 CFU/100ml

C10. Microbial water quality results (total coliforms) for the primary drinking water source of the household

1 = 0 CFU/100ml

2 = < 10 CFU/100ml

3 = > 10 CFU/100ml

OBSERVATION CHECKLIST: HOUSEHOLD WATER STORAGE CONTAINER CHARACTERISTICS

Ask and observe about the following from the household;

D1. Linked to water source code________________

D2. Main drinking water storage containers made of?

1 = metal 2 = ceramic 3 = plastic 4 = glass 5 = clay 6 = other (specify)_________________

D3. Carrying capacity of main storage water containers

1 = 2L 2 = 5L 3 = 10L 4 = 20L 5 = 25 L 6 = 30L 7 = more than 30L

D4. What is the design for the main drinking water storage containers?

1 = jerry cans 2 = bucket without spigots 3 = buckets with spigots 4 = drums without spigots

5 = drums with spigots

D5. Container age

1 = very old   2 = relatively old   3 = relatively new   4 = quite new   5 = very new

D6. Are the dominant water storage containers damaged or do they have leaks?

1 = Yes   2 = No

D7. Describe the mouth for the main storage container

1= narrow   2 = wide

D8. Do you cover the container when storing water at home?

1= Yes   2 = No

D9. Do you store water for drinking separately from water for other domestic purposes?

1= Always 2= sometimes 3= not at all

D10. Do you use water for drinking for other purposes?

1= always 2= most of the times 3= sometimes 4= rarely 5= not at all

D11. Do you use the some containers for water collection and water storage?

1= always 2= most of the times 3= sometimes 4= rarely 5= not at all

SECTION E: DRINKING WATER USER PRACTICES

Ask the following questions and closely observe the user practices

E1. If the containers have wide mouths, are they covered with lids?

1 = not at all

2 = partially covered

3 = completely covered

E2. What type of cover do you use to cover water?

1= tight fitting lid   2= Loose lid   3= other

E3. Hygiene status of the containers

1 = very dirty   2 = dirt   3 = clean   4 = very clean

E4. How easy are the containers cleanable by hand?

1 = very difficult   2 = moderately difficult   3 = difficult   4 = moderately easy   5 = easy   6 = very easy

E5. If not easy to clean, what could be the reason?

1 = design has a narrow mouth   2 = it is very big to clean   3 = other **(specify)**

E6. How frequent do you clean the storage containers before refilling?

1 = more frequent   2 = moderately frequent   3 = less frequent   4 = rarely

E7. What is usually used to clean the containers?

1 = water only   2 = water and detergents   3 = sanitizer/disinfectant   4 = water and river sand/mud   5 = other **(specify)**

E8. Storage containers have an effect on microbial water quality

1 = strongly disagree   2 = disagree   3 = neither agree nor disagree   4 = Agree   5 = strongly agree

E9. Do you treat your drinking water at point of use before or after storage?

1 = Yes

2 = No

3 = Refused

E9b. If yes to E9, what method do you use?

1 = boiling   2 = filtration   3 = chemicals   4 = solar disinfection

E10. Ask one household member (most preferably a child) to demonstrate how they withdraw water from container and how they drink the water as you observe. How do you rate the procedure in terms of probability to contaminate the water?

1 = highly probable

2 = moderately probable

3 = unlikely

4 = highly unlikely

***NB: Describe observations*____**

E11. If there are separate utensils used to either withdraw water from the storage container or for drinking, how easily cleanable are they?

1 = very difficult   2 = moderately difficult   3 = difficult   4 = moderately easy   5 = easy   6 = very easy

Describe the type of utensils used in E11________________________

E12. Where do you store your water drawing utensils?

1= on top of the container   2= inside the container   3= table or shelves   4= floor

E13. Describe where the stored water containers are placed?

1 = at floor level in the house

2 = on raised platform in the house

3 = exposed to sunlight outside the house

E14. How often do your household members wash their hands before handling water storage containers or utensils used to withdraw water from the storage containers?

1 = never   2 = rarely   3 = sometimes   4 = usually   5 = always   6 = refused

E15. Has any of your household members experienced any health issues related to the water stored in your home during the last 3 months?

1 = Yes   2 = No   3 = not sure

SECTION F: WATER QUALITY

F1. Kindly ask to take a bacteriological water sample from the storage container from which the household is currently drinking *(kindly ask for consent again)*.

Microbial water quality results (E. coli) for the household sample

1 = 0 CFU/100ml

2 = < 10 CFU/100ml

3 = > 10 CFU/100ml

*Water sample code:*_____ *Date:*______*Time taken:*_____

F2. Microbial water quality results (total coliform) for the household sample

1 = 0 CFU/100ml

2 = < 10 CFU/100ml

3 = > 10 CFU/100ml

F3. pH results of the water sample

1 = below 6.5

2 = 6.5 to 8.5

3 = above 8.5

F4. Turbidity results for the water sample

1 = less than 5 NTU

2 = 5-10 NTU

3 = above 10 NTU

F5. What material makes the type of storage container the sample was collected from?

1 = metal 2 = ceramic 3 = plastic 4 = glass 5 = clay 6 = Other (specify)_______________

F6. Carrying capacity of storage container from which sample was collected

1 = 2L 2 = 5L 3 = 10L 4 = 20L 5 = 25 L 6 = 30L 7 = more than 30L

F7. Water level at the time sample was collected

1 = full   2 = three quarter full   3 = half full   4 = quarter full   5 = almost empty

F8. What is the design for the storage container from which sample was collected?

1 = jerry cans   2 = bucket without spigots   3 = buckets with spigots   4 = drums without spigots

5 = drums with spigots

F9. Age of storage container from which sample was collected

1 = very old   2 = relatively old   3 = relatively new   4 = quite new   5 = very new

F10. Does the storage container from which sample was collected leak or is it damaged?

1 = Yes   2 = No

F11. Describe the mouth for the main storage container

1= narrow   2 = wide

Thank you for taking your time to respond to the questions. I hope this will go a long way in assisting how the country program for Water, Sanitation and Hygiene.

MICROBIAL WATER QUALITY IN RUSHINC

Microbial water tests samples _ KoboToolb

Appendix 1: District Approval Letter to Conduct Study

Phone :
0785489456
0784629810

MINISTRY OF HEALTH AND CHILD CARE
Chimhanda District Hospital
Bag 2087
RUSHINGA

Africa University
College of Health, Agriculture and Natural Sciences
Department of Public Health and Nursing

19 June 2023

RE: PERMISSION FOR NECKIOT KAGODO REG NUMBER 201104 TO CONDUCT A RESEARCH STUDY IN RUSHINGA DISTRICT

I am writing to grant permission for the above mentioned Public Health student of Africa University to carry out his study in Rushinga district. The student has submitted his full proposal titled: ASSESSING EFFECTS OF HOUSEHOLD DRINKING WATER STORAGE CONTAINERS AND USER PRACTICES ON WATER SAFETY IN RUSHINGA DISTRICT.

Thank you

Yours Sincerely

CHIMHANDA DISTRICT HOSPITAL
DISTRICT MEDICAL OFFICER
19 JUN 2023
P. BAG 2087, RUSHINGA
ZIMBABWE

Tembo A
A/District Medical Officer – Rushinga District

Appendix 2: Africa University Research Ethics Committee approval

Investing in Africa's future

AFRICA UNIVERSITY RESEARCH ETHICS COMMITTEE (AUREC)

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

Ref: AU3031/23 16 November, 2023

NECKIOT KAGODO
C/O Africa University
Box 1320
MUTARE

RE: EFFECTS OF HOUSEHOLD DRINKING WATER STORAGE CONTAINERS AND USER PRACTICES ON WATER SAFETY IN RUSHINGA DISTRICT

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

The approval is based on the following.

a) Research proposal

- **APPROVAL NUMBER** AUREC 3031/23
  This number should be used on all correspondences, consent forms, and appropriate documents.
- **AUREC MEETING DATE** NA
- **APPROVAL DATE** November 16, 2023
- **EXPIRATION DATE** November 16, 2024
- **TYPE OF MEETING** : Expedited
  After the expiration date, this research may only continue upon renewal. A progress report on a standard AUREC form should be submitted a month before the expiration date for renewal purposes.
- **SERIOUS ADVERSE EVENTS** All serious problems concerning subject safety must be reported to AUREC within 3 working days on the standard AUREC form.
- **MODIFICATIONS** Prior AUREC approval is required before implementing any changes in the proposal (including changes in the consent documents)
- **TERMINATION OF STUDY** Upon termination of the study a report has to be submitted to AUREC.

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

Yours Faithfully

MARY CHINZOU
ASSISTANT RESEARCH OFFICER: FOR CHAIRPERSON
AFRICA UNIVERSITY RESEARCH ETHICS COMMITTEE