BINDURA UNIVERSITY OF SCIENCE EDUCATION

DEPARTMENT OF ENVIRONMENTAL SCIENCE

Microbial drinking water quality assessment of hand-dug shallow wells and health risk assessment for Redcliff town, Zimbabwe.

By

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A research project submitted in partial fulfilment of the requirements of a Bachelor of Environmental Science Honours Degree in Safety Health and Environmental Management

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DECLARATION

To be compiled by the student

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I, Nyasha T Madhobha, solemnly declare that this work-related project is my own original creation and has never been submitted previously. Any content sourced from external references has been properly acknowledged within the project.

Signature of the student  Date 28 May 2025

To be compiled by the supervisor

This dissertation is suitable for submission to the faculty and has been checked for conformity with the faculty guidelines.

Signature of the supervisor  Date 30 May 2025

Signature of faculty chairperson  Date 10 June 2025

DEDICATION

I dedicate this research project to the Madhobha family, whose unwavering support, encouragement and inspiration made this journey possible.

ACKNOWLEDGEMENTS

I give glory to the Lord Almighty for his divine guidance and strength to persevere until the end. I extend my deepest gratitude to my supervisor, Dr. A. Kanda, for his invaluable guidance, constructive feedback and patience throughout this journey. To my family, I owe endless appreciation for their unconditional love, emotional support and sacrifices that kept me motivated. A special thanks to my colleagues for their encouragement and understanding which made this journey lighter.

ABSTRACT

This research evaluated microbial water quality of the hand-dug shallow wells and assessed the related health risks in Redcliff town, Zimbabwe. There were 25 functioning wells that were purposively selected in high-, medium-, and low-density suburbs by using a stratified sampling strategy. Water was sampled and the membrane filtration method was used to identify Escherichia coli and faecal coliforms. 84% of the wells had over World Health Organization (WHO) hazardous concentrations of E. coli, with the highest levels of contamination in high-density suburbs. Only one well was in conformity with WHO safety standards. A Kruskal-Wallis H test established statistically significant differences among suburb densities in contamination levels ($p < 0.001$). Health Risk Assessment (HRA) model showed high-density dwellers to be at severe risk for infection with 12.7 disability-adjusted life years (DALYs) for each 1000 population. The evidence confirmed a definite relationship between microbial contamination, unhygienic sanitation, and population density. The research concluded that Redcliff hand-dug wells constitute a public health risk, particularly in the urban setting, and suggested adopting intervention strategies such as water treatment, protection of wellheads, and monitoring of water quality.

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CHAPTER 1: INTRODUCTION

1. Introduction

1.1 Background of the study

Hand-dug shallow wells are a vital water source in many parts of the world, yet they are often susceptible to microbial contamination. According to Smith et al. (2020), poor sanitation and inadequate well protection are significant contributors to unsafe drinking water. Similarly, Johnson and Taylor (2021) argued that microbial contamination in groundwater sources, including hand-dug wells, poses health risks such as diarrheal diseases. Effective monitoring and treatment are essential for ensuring water safety.

In sub-Saharan Africa, the reliance on hand-dug wells remains high, especially in peri-urban and rural areas. According to Nkosi and Dlamini (2022), poor construction and maintenance practices exacerbate contamination risks. A study by Okonkwo et al. (2023) highlighted the need for proper sanitation and well protection measures to improve water quality. These interventions are necessary to reduce microbial contamination and protect public health in regions with limited access to piped water.

In Zimbabwe, shallow wells are commonly used as domestic water sources. Moyo and Chikodzi (2019) asserted that inadequate well protection and proximity to waste disposal sites contribute to microbial contamination. A recent study by Banda et al. (2024) identified coliform bacteria in over 70% of tested shallow wells, highlighting significant health risks. Further research is needed to explore sustainable solutions for ensuring the microbial safety of water from hand-dug wells.

1.2 Problem statement

Access to safe drinking water remains a critical challenge in many developing countries, including Zimbabwe, where 66% of the rural population relies on unprotected water sources like hand-dug wells (Chiweshe, 2021). In Redcliff town, shallow wells are prone to microbial contamination due to poor sanitation, posing severe health risks such as diarrheal diseases, responsible for over 4% of deaths annually (UNICEF, 2022). Limited studies exist on microbial quality associated health risk assessment through consumption of contaminated water. This study aims to assess contamination levels and do a human health risk assessment due to consumption of contaminated water from shallow-hand-dug wells.

1.3.1 Aim

To assess the microbial water quality of hand-dug shallow wells in Redcliff town, Zimbabwe and determine potential health risk.

1.3.2 Objectives

- To determine the level of microbial contamination of drinking water in hand-dug wells by estimating quantities of selected indicator organisms total coliforms, and faecal coliforms (e. coli) using the membrane filtration method.
- To determine the potential health risk associated with consuming microbially-contaminated drinking water using health risk assessment (HRA) model.

1.4 Significance of the study

Findings from this study may be used to inform local authorities and health practitioners in developing training and resources focused on safe water handling and sanitation which may reduce incidence of water related illnesses. Additionally, the study will contribute to the body of knowledge by enhancing understanding of water contamination in urban settings and may serve as a basis for future research on waterborne diseases and health risk assessment models.

1.5 Research questions

What is the level of microbial contamination of drinking water from hand-dug wells in Redcliff using selected indicator organisms?

What is the potential human health risk associated with drinking microbially-contaminated water from hand-dug wells in Redcliff.

1.6 Assumptions

- Hand-dug shallow wells in Redcliff town are accessible for sampling and testing of microbial contamination.
- Microbial testing methods used in the study will accurately reflect the contamination levels in the sampled wells.
- Residents and local authorities will cooperate in providing access to the hand-dug shallow wells and necessary information for the study.
- Drinking water from polluted hand-dug shallow wells presents health risk to the community.

1.7 Limitations

- Sampling and analysis timeframe may miss seasonal contamination fluctuations.
- Study is limited to Redcliff Town, reducing generalisability to other Zimbabwean regions.

- Some hand-dug wells may be inaccessible due to security or logistical constraints.
- Secondary health data may be imprecise due to underreporting or data gaps.
- Microbial contamination testing may have sensitivity limitations.

1.8 Delimitations

- Study focuses on hand-dug shallow wells in Redcliff town, excluding other water sources.
- Study only examines health risks related to microbial contamination, excluding chemical or heavy metal contamination.
- Data collection is limited to January to May 2025, excluding seasonal variations.

CHAPTER 2: LITERATURE REVIEW

2. Literature review

2.1 Introduction

This chapter explores findings from other similar studies on microbial water quality in hand-dug shallow wells, examining contamination sources, associated health risks, and strategies for ensuring water safety and public health.

2.2 Microbial contamination of ground water

Microbial contamination of groundwater is a significant public health concern, particularly in areas with inadequate sanitation. According to Bagordo et al. (2024), a systematic review of field-scale studies identified factors such as well depth, well type, and proximity to pollution sources as critical determinants of microbial contamination. Similarly, a study by Sorensen et al. (2021) found that 66% of groundwater sources in urban Kisumu, Kenya, were contaminated with E. coli, highlighting the widespread nature of this issue.

The depth and construction quality of wells significantly influence microbial contamination levels, especially in high-risk areas. Bagordo et al. (2024) reported that shallow wells without proper lining are more vulnerable to contamination due to their exposure to surface pollutants, including runoff from agricultural and domestic activities. Additionally, Sorensen et al. (2021) found that unprotected hand-dug wells showed significantly higher contamination rates compared to protected ones, attributing this to the lack of barriers preventing the infiltration of fecal matter and other microbial pathogens.

2.3 Water-borne diseases associated with contaminated water

Waterborne diseases, such as cholera, typhoid, and dysentery, remain significant public health concerns globally. According to the World Health Organisation (WHO, 2021), microbiologically contaminated drinking water can transmit these diseases, leading to approximately 505,000 diarrheal deaths each year. Similarly, the Centers for Disease Control and Prevention (CDC, 2022) reported that between 2015 and 2020, there were 214 outbreaks associated with drinking water, highlighting the ongoing risks of waterborne illnesses.

Table 1: Common water-borne diseases associated with contaminated water

Disease	Causative agent
Cholera	*Vibrio cholerae* bacteria from contaminated water.
Typhoid fever	*Salmonella Typhi* bacteria from fecal-contaminated water.
Dysen	*Shigella* bacteria *or Entamoeba histolytica amoeba* from contaminated water.
Giardiasis	*Giardia lamblia* parasite from contaminated water.
Hepatitis A	*Hepatitis* virus from contaminated water or shellfish.
Cryptosporidiosis	*Cryptosporidium* parasite from contaminated water.
Trachoma	*Chlamydia trachomatis* bacteria, spread through unclean water sources.
Leptospirosis	*Leptospira* bacteria from contaminated water with animal urine.

2.4 Microbial contamination of hand-dug shallow wells in small towns of developing countries

Microbial contamination tests for the shallow hand-dug wells in small villages (Table 2) show a staggering frequency of dangerous pathogens. The most frequently analyzed microbes are fecal coliforms, total coliforms, and E. coli, and membrane filtration and multiple tube fermentation are among the frequent methods utilized. Key findings state that wells located in close proximity to septic tanks, dumping sites, and farming fields are usually contaminated, and thus the necessity for proper water management and sanitation measures. Microbial health risk assessment is suggested in such research, requiring improved well maintenance and sanitation facilities to enable fewer health risks. These investigations, as shown in Table 2.2, highlight the global nature of the issue, since the same contamination patterns are reported in numerous developing countries.

Table 2: Studies on microbial contamination of hand-dug shallow wells in small towns

Country (Town)	Microbes analysed	Method used	Key findings	Reference
Uganda (Lukaya)	E. coli, total coliforms	Membrane Filtration	57% of wells showed fecal contamination; E. coli counts exceeded 10^3 cfu/100 ml.	Nabuya et al. (2020)
Ghana (Fiapre)	Total coliforms, Fecal coliforms	Multiple Tube Fermentation (MTF)	Wells near pit latrines had microbial levels surpassing WHO/EPA guidelines.	Osei et al (2021)
Nigeria (Awka Metropolis)	Coliforms, Vibrio cholerae	Standard Plate Count	All sampled wells contaminated due to proximity to septic tanks and poor waste management.	Nwankwo et al. (2019)
Ghana (Kamasi)	E. coli, total coliforms	Membrane Filtration	Contamination due to inadequate sanitation infrastructure in urban communities.	Addai et al. (2022)
Kenya (Kisumu)	Salmonella, Shigella, E, coli	Molecular Analysis (PCR)	Wells lacked protection, leading to bacterial contamination from runoff and latrine leachate.	Odhiambo et al. (2023)
India (Kerala)	E. coli, total coliforms	MPN (Most Probable Number)	Wells near agricultural zones showed high microbial contamination due to fertilizer runoff.	Prakash et al. (2022)
Bangladesh	E. coli, Vibrio	Standard Plate Count,	Poor sanitation infrastructure caused persistent	Alam et al.

(Dhaka)	cholerae	PCR	contamination in peri-urban wells.	(2020)
Zimbabwe (Bulawayo)	Total coliforms, Fecal coliforms	Membrane Filtration	High contamination levels in wells close to dumping sites.	Zingoni et al. (2023)
South Africa (Limpopo)	Coliforms, Cryptosporidium	Fluorescent Microscopy	Wells in rural areas showed contamination due to livestock grazing and poor hygiene practices.	Mothetha et al. (2021)
Ethiopia (Addis Ababa)	Total coliforms, Giardia lamblia	ELISA, Membrane Filtration	Microbial risks linked to poorly maintained wells and insufficient water treatment.	Assefa et al. (2022)
Pakistan (Karachi)	E. coli, Salmonella	MPN, PCR	High contamination in densely populated areas lacking sanitation services.	Ahemed et al. (2020)
Nepal (Kathmandu)	Total coliforms, fecal streptococci	Membrane Filtration	Hand-dug wells contaminated due to poor sewage systems and surface runoff.	Silva et al. (2019)

2.5 Potential health risk assessment

Commonly used models for microbial health risk assessment include the Health Risk Assessment (HRA) model, Quantitative Microbial Risk Assessment (QMRA), and Hazard Quotient (HQ) approach. Key variables include contaminant concentration (cfu/100 ml), ingestion rate (L/day), body weight (kg), and exposure frequency (days/year).

Health Risk Assessment model equation (World Health Organization, 2021).

$$Risk = \frac{C \times IR \ \times EI}{BW \ \times AT}$$

Where:

C = Contaminant concentration (cfu/100ml)

IR = Ingestion rate (L/day)

EF = Exposure frequency (days/year)

BW = Body weight (kg)

AT = Averaging time (days)

This study uses the Health Risk Assessment (HRA) model due to its reported application in the estimation of microbial contamination of drinking water, especially in low-resource settings. It has been used in Ugandan and Ethiopian settings to identify risk from hand-dug wells, with efficiency in similar settings (World Health Organization, 202). The model quantifies health risks by combining exposure data and contaminant concentrations, to guide targeted public health interventions. Its capacity to incorporate local conditions such as fluctuating rates of exposure and contamination levels makes it appropriate for Redcliff town, Zimbabwe. It does, however, assume steady ingestion rates and lacks variability in individual health, a point noted.

2.6 Theoretical framework

Bronfenbrenner's (1979) Social Ecological Model (SEM) would be appropriate for application in this study as it takes into consideration the way individual, interpersonal, community, and societal factors combine to affect microbial contamination. In contrast to one-level models, SEM facilitates multi-layered analysis of sanitation practice, socio-economic status, and government. McLeroy et al. (1988) exemplified its application in public and water research in developing settings such as rural Uganda and Ethiopia. It directs this research by pointing out intervention points at levels, directing strategies like education in hygiene, infrastructure development, and policy enforcement in Redcliff Town.

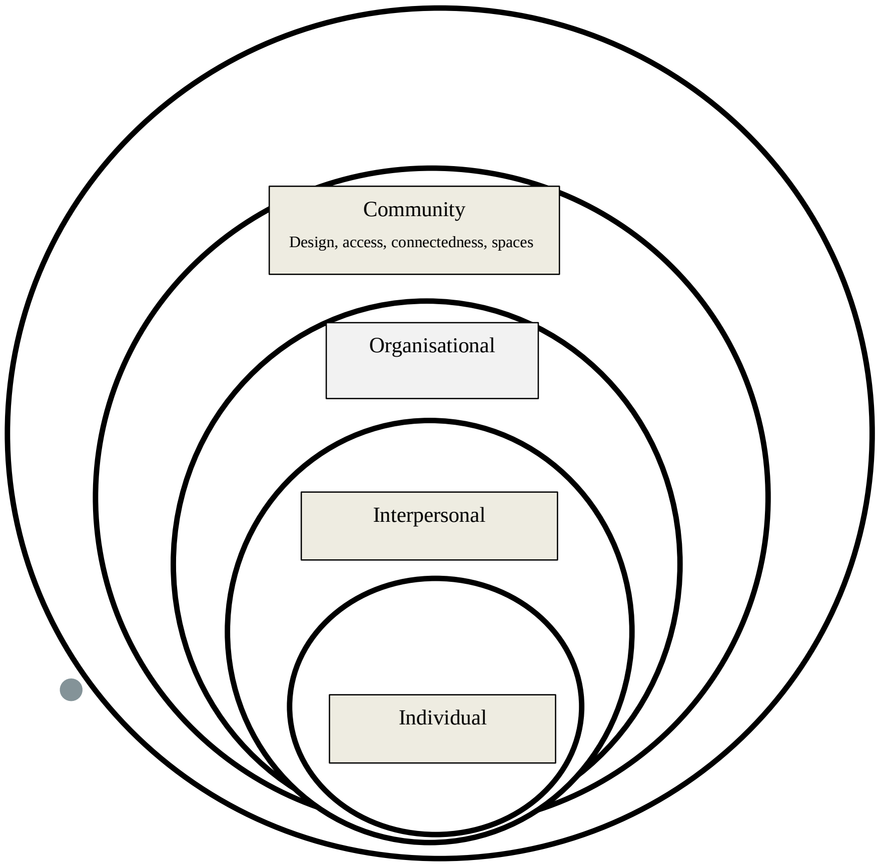

Figure 1: The social ecological model (Bronfenbrenner, 1979)

2.7 Summary

This chapter consolidated evidence that shallow well microbial contamination is accounted for by socio-economic and environmental factors. Biases in early studies tend to overlook community behavior and policy loopholes. Existing emphasis is on water quality, but the solutions to behavioral and governance issues are still absent, making this study's public health and theoretical focus worthwhile.

CHAPTER 3: METHODS AND MATERIAL

3. Methods and material

3.1 Description of the study area

Redcliff is a is a mining town in Midlands province of Zimbabwe (19.017°S, 29.798°E), is approximately 18 km south of Kwekwe (Fig. 2). The area experiences a semi-arid climate with annual rainfall averaging between 650 – 800 mm, predominantly during the November–March rainy season (Madyiwa et al., 2020). The Kwekwe and Sebakwe Rivers are key water sources for Redcliff. However, many residents rely on hand-dug shallow wells (HDSWs) which often lack treatment and are prone to contamination from nearby space latrines and waste disposal sites (Nyikadzino & Mutema, 2021). This is due to erratic municipal water supply. Inadequate treatment facilities and irregular distribution systems have been observed to exacerbate reliance on unsafe water sources (Moyo et al., 2023). Population growth has increased water demand, but demand management strategies remain limited, worsening access challenges.

Redcliff has an estimated population of 41 526 (ZIMSTAT, 2022) and comprises 6 156 high-density, 162 medium-density, and 1 075 low-density residential properties (UCaz, 2023). The town's economy is largely driven by mining and steel industries, notably ZISCO Steel (UCaz, 2023). Poor sanitation systems and a weak solid waste management framework contribute to environmental degradation (Moyo et al., 2023). In many areas, open defecation and unregulated waste dumping near wells heighten microbial contamination risks (Nyikadzino & Mutema, 2021). The close proximity of pit latrines to water sources in low-income areas especially presents a significant public health concern. These conditions highlight the urgent need for water safety assessment and management.

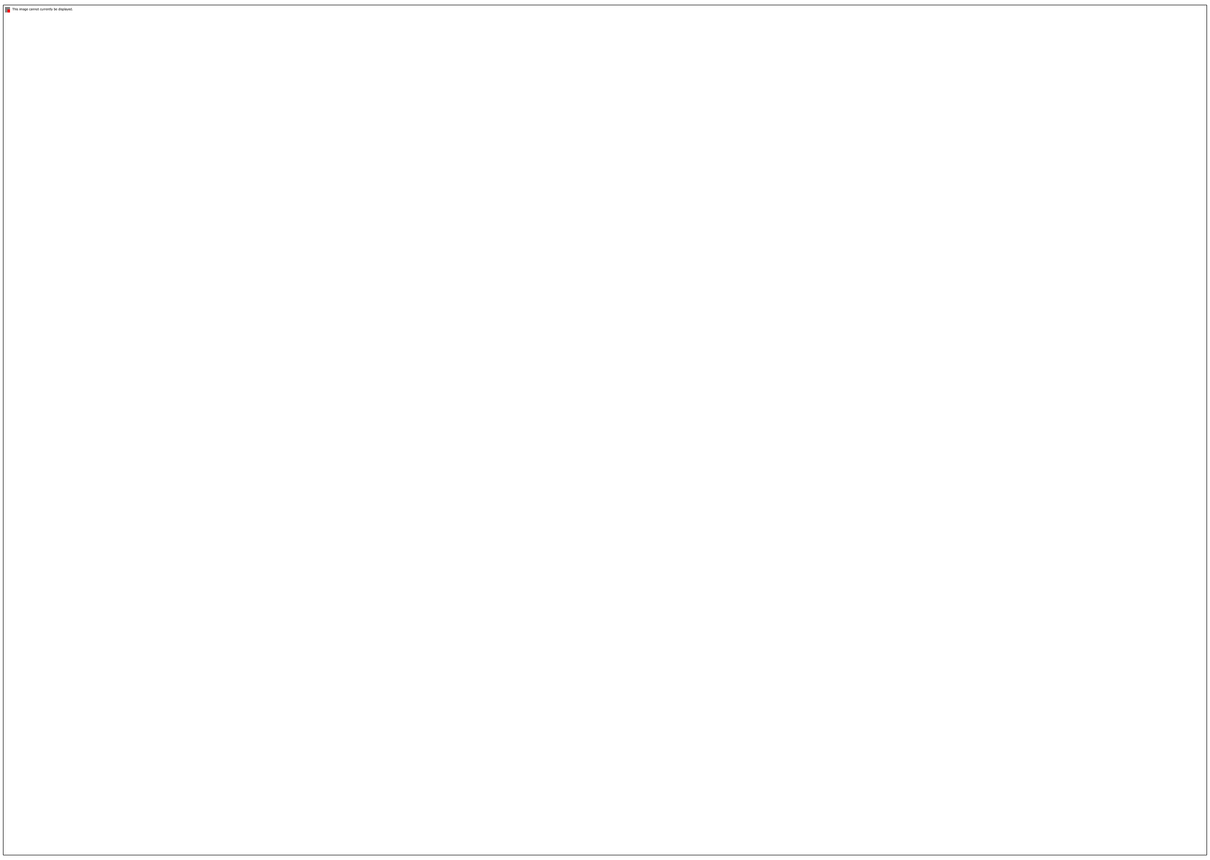

Figure 2: Map of Redcliff Urban showing all sampling points.

3.2 Research design

This study employed a quantitative, cross-sectional design to assess microbial contamination in hand-dug shallow wells in Redcliff. Cross-sectional designs collect data at one point in time, ideal for describing contamination patterns without long-term follow-up (Setty et al., 2019). It allows for rapid comparison across sites and is cost-effective (Levin, 2006). The study used primary data through membrane filtration, a standard method for quantifying faecal bacteria (WHO, 2021). Though cross-sectional designs cannot capture seasonal variation, this was addressed by sampling multiple locations. Similar approaches have been used in Nigeria and Kenya for groundwater contamination studies (Oremo et al., 2020; Adewuyi & Awoyemi, 2019).

3.3 Establishment of sampling sites

Sampling points were purposively selected employing a stratified sampling method in order to represent the medium-, low-density residential suburbs and the high-density residential suburbs (Etikan et al., 2016). A walk-through survey revealed 38 shallow hand-dug wells (SHDWs) within the suburbs. Only 25 SHDWs were functional, accessible, and included in the selection criteria. They were used in this study. Proportional sampling was established using the number of SHDWs observed in each suburb: 12 in high-density, 8 in medium-density, and 5 in low-density suburbs. This was done to maintain representativeness while not altering the pattern of distribution as observed during field survey. This method ensured equitable representation of socioeconomic and environmental conditions. Stratified sampling allows for spatial equity in water quality assessments (Ncube & Abrams, 2019; Moyo & Worster, 2020). Masocha et al. (2018) recommend sample sizes of 20–50 SHDWs for urban water quality studies. Sampling enables suburb-specific health risk assessments (Dube et al., 2020).

Table 3: Distribution of Selected Households Using Shallow Hand-Dug Wells (SHDWs) Across Residential Settlements in Redcliff Town

Type of Residential Settlement	**Selected Residential Areas**	**Households with Used SHDWs**	**Selected Households with Used SHDWs**	**Proportion (%)**
Low-density	Redcliff Suburb	35	5	20.0
Medium-density	Torwood	60	8	32.0
High-density	Rutendo,	90	12	48.0

	Silobela			
Total	3	185	25	100.0

3.4 Sampling, sample preparation and analysis

Water samples were collected using standard procedures for water sampling, (APHA, 2017). Water samples were drawn early in the morning between 6:00 and 8:00 a.m before significant water use. Sterilized glass bottles of 250 ml were washed, rinsed with distilled water, and autoclaved at 121°C. Pre-disinfected 10-litre buckets and nylon ropes were used when collecting water; separate shallow wells had individual, sterilized equipment to prevent cross-contamination. Field assistants used disposable gloves that were exchanged between sites. Mid-depth samples were taken to mirror real well water quality. Bottles were closed, labeled, and placed at 4°C in an ice-packing cooler. Samples were packed and taken to Bindura University and examined within six hours, safely within the recommended 8-hour holding time.

In the laboratory, MacConkey Agar was prepared by measuring 25g of agar into 500 ml of demineralised water as stated by Cheesbrough (2010). The mixture was warmed under stirring to complete dissolution, followed by autoclaving at 121°C for 15 minutes. Water samples were prepared following standard analytical procedures for the analysis of *Escherichia coli* and Faecal coliforms using the membrane filtration method as outlined by APHA (2017) (Appendix 1). A conical membrane filtration unit was used to filter 100 ml of each water sample through sterile 0.45 µm cellulose PVDF membrane. Filter was plated on solid MacConkey Agar in petri plates and incubated at 37°C for 24 hours. Colonies were counted by hand and reported as cfu/100 ml.

3.5 Ethical consideration

This study adhered to the APA (2017) Ethical Principles for research involving human participants. Informed consent was obtained verbally after clearly explaining the study's purpose, procedures, and their right to withdraw at any time. Confidentiality was maintained by anonymising all data and ensuring no personal identifiers were recorded. Participation was entirely voluntary, with no coercion or undue influence. The study respected the principle of beneficence by minimizing any risk to participants and ensuring the findings would inform public health improvements. Ethical clearance was granted by the Bindura University of Science Education through the Department of Environmental Science.

3.6 Data Management

Health risks were determined by the Health Risk Assessment (HRA) model, which estimates the likelihood of infection by microbial levels of water exposure by ingestion. The Escherichia coli daily dose (D) was estimated as: $D = C \times V$, where C is E. coli concentration (cfu/100 mL) and V is the volume ingested per day. 2 litres/day and 1 litre/day were consumed by adults and children, respectively, from the Zimbabweans' water use habits (Nhapi, 2009; Chidavaenzi et al., 2000).

Although generic E. coli only was used for testing, the infectivity constant of E. coli O157:H7 ($r = 0.0019$) was used as a conservative estimate. The method is justified by research in similar low-resource environments (Momba et al., 2018) under the lack of species-specific dose-response models. The exponential model, $P\_inf = 1 – \exp(−r \times D)$, was used to calculate the infection probability per exposure event.

Laboratory test data was entered from template-adjusted Microsoft Excel with cell ranges frozen and validation rules enabled. Categorical data (suburb type) was handled through drop-down list fields, and variables entering numbers were limited within valid ranges of values (0-1,000,000). The =COUNTIF (range, criteria) function was utilized in detecting duplicate entry. Outliers, values ±3 standard deviations from the mean, were detected using =ABS((value–mean)/stdev)>3 and double validated compared to raw lab values.".

Missing values, totaling below 5% of data, were imputed using median imputation. This was done by finding the median of the variable using Excel's =MEDIAN (range) formula, and then entering the missing values by hand. Median imputation was done because it is not influenced by outliers and maintains the distribution of the data, as asserted by Acuna and Rodriguez (2004).

Data were analyzed in Excel. Normality was tested using histograms and Q–Q plots. Since the data did not seem to be normally distributed, non-parametric analysis was employed. Visual analysis and descriptive statistics were employed for comparing the microbial counts among different residential suburbs. The measured values were compared with WHO (2017) microbial risk values using the non-parametric version of the one-sample t-test, which is the Wilcoxon Signed-Rank Test.

Table 4 WHO Risk Classification for Microbial Water Quality

Indicator	Safe	Intermediate Risk	Hazardous/High Risk

E. coli (cfu/100 mL)	<1	1–10	>10
Faecal coliforms (cfu/100 mL)	<10	10–100	>100

CHAPTER 4: PRESENTATION OF RESULTS

4. Results

4.1 Spatial Distribution of Hand-Dug Shallow Wells

The spatial distribution of the 25 hand-dug shallow wells was successfully sampled during the study. The wells were located across three residential suburbs in Redcliff, selected using a stratified sampling technique to reflect high, medium, and low-density areas. The proportional allocation resulted in 12 wells from high-density (Torwood), 8 from medium-density (Rutendo), and 5 from the low-density suburb.

4.1 Levels of Microbial Contamination of Drinking Water from SHDWs

Table 5 indicates mean microbial contamination levels in residential settlements. E. coli levels were not significantly different among low-, medium-, and high-density settlements ($p > 0.05$), but faecal coliforms were more in high-density compared to other settlements ($p < 0.05$). The trend was the rise in microbial loads from low- to high-density settlements, particularly for faecal coliforms. Such a distinction indicates the possible effect of settlement density and sanitation infrastructure on water quality.

Table 4: Variation of Mean (±SD) E. coli and Faecal Coliforms in Drinking Water Collected from SHDWs Across Residential Settlements (n = 25)

	Low-density	Medium-density	High-density
E. coli	$24±5.4^{a}$	$26±4.9^{a}$	$30±6.2^{a}$
Faecal coliforms	$12±3.1^{a}$	$15±3.5^{a}$	$38±9.4^{b}$

Similar superscripts (^{a}, ^{b}) across a row indicate no significant difference ($p > 0.05$); different superscripts indicate significant difference ($p < 0.05$), based on the Kruskal-Wallis H test.

4.2.1 Microbial Contamination in Sampled Wells by WHO Risk Category

Table 6 shows the distribution of sampled SHDWs by WHO microbial risk category. Hazard wells dominated the largest category: 84% for E. coli and 60% for faecal coliforms. Only 4% of wells were safe for E. coli and 12% for faecal coliforms. Intermediate levels of risk were found in 12% and 28% of wells, respectively. The trends reflect the extensive contamination of SHDWs in the study area.

Table 5: Categories of Drinking Water Based on Microbial Contamination (WHO, 2017)

Microbe	Safe (0)	Intermediate (1–10)	Hazardous (>10)
E. coli	1 (4%)	3 (12%)	21 (84%)
Faecal Coliform	3 (12%)	7 (28%)	15 (60%)

4.3 Comparison of Microbial Concentrations in Drinking Water with WHO (2017) Safety Limits

Table 7 shows the comparison of mean microbial concentrations in SHDWs from various residential suburbs with WHO (2017) safe drinking water guidelines. WHO recommended standard for E. coli drinking water is 0 cfu/100 ml and for faecal coliforms is <10 cfu/100 ml. The results show that all the three types of residential low-, medium- and high-density suburbs had E. coli and faecal coliforms concentrations exceeding WHO safe standards. Of particular interest, high-density suburbs experienced the highest exceedances, most significantly for faecal coliforms, whose mean value was over three times the acceptable value. Superscripts show significant differences between observed means and WHO standards.

Table 6: Mean Microbial Concentrations in SHDW Water Compared to WHO (2017) Drinking Water Guidelines

Microbe	WHO Safe Limit (cfu/100	Low-density	Medium-density (Mean	High-density

	ml)	(Mean ± SD)	± SD)	(Mean ± SD)
E. coli	0	24 ± 5.4[a]	26 ± 4.9[a]	30 ± 6.2[a]
Faecal coliforms	<10	12 ± 3.1[b]	15 ± 3.5[b]	38 ± 9.4[c]

Superscripts ([a], [b], [c]) denote significant differences between observed values and WHO thresholds at $p < 0.05$ using the one-sample Wilcoxon signed-rank test.

4.4 Quantitative Microbial Health Risk Assessment (HRA)

The Health Risk Assessment (HRA) model was used for this study to quantify the health effects of drinking SHDW water with E. coli. Risk estimations for children and adults were conducted separately using locally applicable rates of ingestion, which are 2.0 L/day for adults and 1.0 L/day for children (ZINWA, 2023). The parameters used were EDD, P_inf, and DALYs per 1,000 population.

Table 8 shows risk levels for suburb density. In the high-density suburbs, the highest risk was found in both adults and children, who were above critical values. Children consistently had higher DALY estimates because of the lower body weight and greater vulnerability and further indicating the necessity for age-specific interventions.

Table 7: Health Risk Assessment for Adults and Children by Suburb Density Using HRA Model

Suburb Density	Group	E. coli (Mean cfu/100ml)	Ingestion Rate (L/day)	EDD (cfu/day)	P_inf	DALYs/1000Risk Category
High Density	Adults	30	2.0	600	0.34	12.7 Critical
High	Children	30	1.0	300	0.28	14.3 Critical

Density						
Medium Density	Adults	26	2.0	520	0.25	6.2 High
Medium Density	Children	26	1.0	260	0.19	7.6 High
Low Density	Adults	24	2.0	480	0.18	1.1 Moderate
Low Density	Children	24	1.0	240	0.14	2.8 Moderate

EDD (Estimated Daily Dose) calculated as: EDD = C × IR (cfu/day)
P_inf estimated using: P = 1 – exp (-r × EDD); where r = 0.001 for generic E. coli (WHO, 2017)
DALY values based on burden estimation formula adapted from Havelaar et al. (2010)

CHAPTER 5: DISCUSSION

5. Discussion

5.1 Introduction

This chapter describes the key findings regarding microbial contamination of SHDWs in comparison to the existing literature and WHO guidelines. It outlines public health risks, consolidates study limitations and countermeasures, and uses the Social Ecological Model to conceptualize individual, environmental, and societal factors related to water quality and their corresponding health consequences.

5.2 Levels of Microbial Contamination of Drinking Water from SHDWs

The research showed extensive microbial pollution throughout SHDWs in Redcliff, where E. coli concentrations were not diverse among low-, medium-, and high-density suburbs. Faecal coliforms were considerably greater in high-density suburbs. The trend is with a research study by Bagordo et al. (2024), where they showed that poor hygiene and access to pollution sources in high-density urban centers promoted microbial contamination. Along the same line, Nwankwo et al. (2019) established that all the wells in Awka Metropolis were septic tank and poor waste disposal-contaminated, affirming the correlation of human density of activities to water quality degradation.

Progressive rise in faecal coliform counts from low- to high-density suburbs are observed to be explained by poor waste disposal infrastructure and high surface runoff in high-density suburbs. This is in agreement with Odhiambo et al. (2023), who indicated Kisumu bacterial contamination by runoff and leachate from latrines. The high microbial concentrations in

SHDWs indicate the necessity of better sanitation and well capping, which was reported by Addai et al. (2022) that also recorded the same trend in Ghana.

5.3 Microbial Concentration in Water from SHDWs Compared to International Guidelines

All the mean levels of E. coli and faecal coliform in all the subtypes of suburbs exceeded the WHO (2017) cut-off levels, and highest deviations were in high-density suburbs. WHO's standard for E. coli is 0 cfu/100 ml and <10 cfu/100 ml for faecal coliform. The same results were earlier reported by Nabuya et al. (2020) in Uganda, where among 57% of wells that were sampled, the level was above 10^3 cfu/100 ml of E. coli. Similarly, Alam et al. (2020) in Bangladesh have documented the sustained contamination owing to inadequate sanitation.

Higher levels of contamination in high-density suburbs indicate the lack of access to sanitation and protection of well infrastructure. This trend was also reported by Prakash et al. (2022), where wells near agricultural runoff and settlements in India were above safety levels. In summary, it is verified that most of the SHDWs in Redcliff are a public health risk upon consumption, especially in the high-density suburbs.

5.4 Quantitative Microbial Health Risk Assessment for Exposed Populations

According to the Health Risk Assessment (HRA) model used in this study, children and adults living in densely populated suburbs were at a high level of health risk through exposure to E. coli. Children were at greater risk with greater DALYs because their bodies are lighter and have weaker immunity. This finding is consistent with WHO (2021) concerns that link contamination with microbes and heavy diarrhoeal disease burdens.

Risk assessments here align with those for Uganda and Ethiopia, where Assefa et al. (2022) and Nabuya et al. (2020) applied HRA to show increased microbial risks in poorly treated wells. Although DALYs in low-density suburbs were reduced, they remained higher than desirable, meaning that no suburb was free from risk. Findings demand targeted public health interventions like household water treatment and hygiene promotion, especially among children in high-density areas.

5.5 Limitations of the Study

This research had various limitations. Firstly, its findings cannot be applied to every Zimbabwean town given difference within regions in water and sanitation infrastructure. The HRA model, while previously used in Uganda and Ethiopia, was initially deployed and validated in the USA, and this could restrict its applicability to Zimbabwe. To mitigate this, local parameters were utilized, including ingestion rates based on ZINWA (2023) and age-based exposure. Besides, microbial identification was restricted to generic E. coli only, not other pathogens like Salmonella or Cryptosporidium.

5.6 Summary

This chapter emphasized critical microbial contamination of Redcliff's shallow hand-dug wells, with correlation to population density, and accompaniment with increased health risks. This contributes by quantifying local risks by the HRA model, filling gaps in Zimbabwean data.

CHAPTER 6: CONCLUSION AND RECOMMENDATIONS

6. Conclusion and recommendations

6.1 Conclusion

The contamination analysis in this study revealed high microbial contamination of Redcliff's hand-dug shallow wells (SHDWs), where 84% of samples were above WHO hazardous E. coli levels and 100% contamination levels in high-density suburbs. The results validate a serious public health risk, especially in high-density settlements. Unlike most of the reviewed studies, this research used a stratified sample design to allow for observation of density-based contamination patterns and a locally calibrated Health Risk Assessment (HRA) model for quantification of risk. This work is important as it provides Zimbabwe-specific microbial risk data to support targeted interventions and policy. Seasonal variation should be assessed and pathogen-specific virulence profiles included in future research for increased accuracy.

6.2 Recommendations

- Immediate water treatment**:** Distribute chlorine tablets or household water filters in high-density suburbs where microbial contamination and health risks are highest.
- Well infrastructure improvement: Upgrade SHDWs in high- and medium-density areas by improving construction (e.g., installing concrete aprons and sanitary seals) to minimize contamination from surface runoff and latrines.
- Targeted water quality monitoring: Conduct quarterly microbial testing of SHDWs, especially in low-density suburbs with intermediate risk levels, to detect and respond to emerging contamination trends in time.
- Community hygiene education: Launch public awareness campaigns on safe water handling, sanitation practices, and well protection, especially in informal settlements.

- Policy and planning integration: Integrate findings into local council water safety plans and guide zoning policies that limit residential development near wells and pit latrines.

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Appendices

Appendix1. Laboratory procedure for determining *E.coli* and *Faecal coliforms* in water collected from shallow hand dug wells.

1. Cleaning of sample bottles

Glass water bottles were thoroughly rinsed with tap water to remove debris

Bottles and cans were scrubbed with lab detergent using brush to remove in-organic compounds

Bottles were rinsed thrice with distilled water to eliminate detergent traces

2. Sterilisation

Bottles and cans were autoclaved at 121 degrees for 15 minutes to ensure complete sterilisation

3. Storage before use

Sterilised bottles were stored in a clean, dust free environment and sealed until sample collection.

4. Sample collection procedure

Hand-washing with soap and ethanol

Wearing sterile gloves to avoid introducing external bacteria

Drawing and discarding 3-5 bucket volumes to remove stagnant water

Sterile bottle was opened before collection to avoid contact with any sterile surface

Sample was collected, each bottle labeled with date and time, location and sample number

Samples were paced in cooler ice packs

Samples were transported to lab within 4 hours for analysis

Preparation of MacConkey nutrient agar

<u>Materials used:</u>

Mac Conkey agar powder	Tripod stand
Distilled water	Sterile petri dishes
Balance scale	Bunsen burner
Measuring cylinder	Autoclave
500ml beaker	Stirrer

Steps

- Measure 25g of macconkey agar per 500ml of distilled water
- Add powder to 500ml of distilled water and stir thoroughly
- Heat the mixture while stirring until completely dissolved
- Autoclave the medium at 121 degrees for 15 minutes. Allow it to cool to 45-50 degrees before solidification
- Working near a flame, pour 15ml into sterile petri dishes

- Agar to solidify at room temperature

Filtration membrane materials used

Measuring cylinder	-filtration unit clamp
Filtration unit	- mellipore pump
Membrane filter	-autoclave
Sterile forceps	- sterile dilution blanks

Steps

Assemble filtration unit

Connect to vacuum pump with sterile tubing

Place the membrane filter

Secure the funnel using clamp

Filtration of water samples

Shake the sample bottle to distribute bacteria evenly

Intriplicate highly contaminated water samples

Pour 100ml of water sample

Apply vacuum pump to draw liquid through the membrane

Rinse the funnel to remove residual bacteria

Transfer filter using sterile forceps amd place on selective agar, ensuring filter is in full contact with agar surface

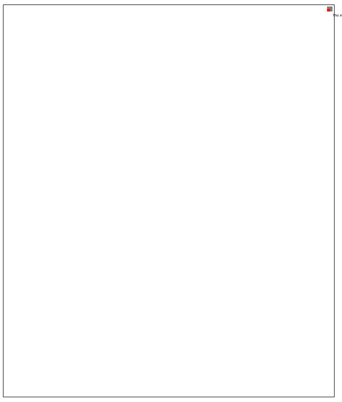
Incubate the plates at 37 degrees for 24 hrs

Fecal coliforms produced pink colonies

Record counts as cfu per 100ml

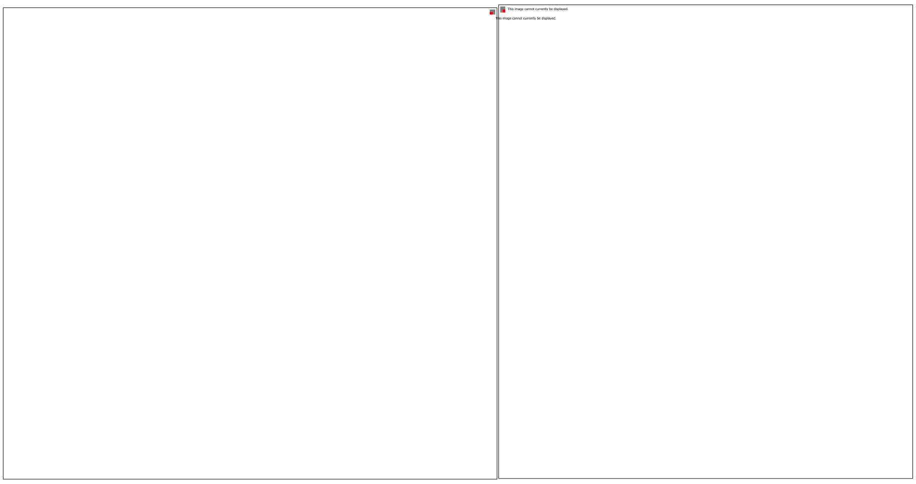
Appendix 2: Sampling Procedure

1. Collection of water samples from hand-dug shallow wells using sterile sampling bottles



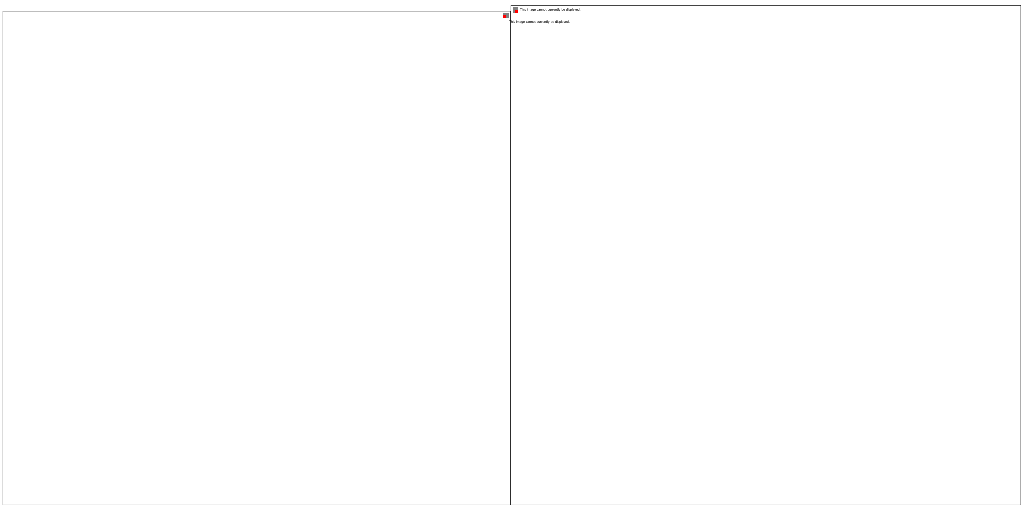
Sterile sampling bottles

2. Nutrient agar was prepared by mixing 25g of Mac-Conkey agar into 500ml of distilled water; heat the mixture while stirring for it to dissolve. The agar was then put in sterile bottles and autoclaved at 121ºC for 15 minutes.



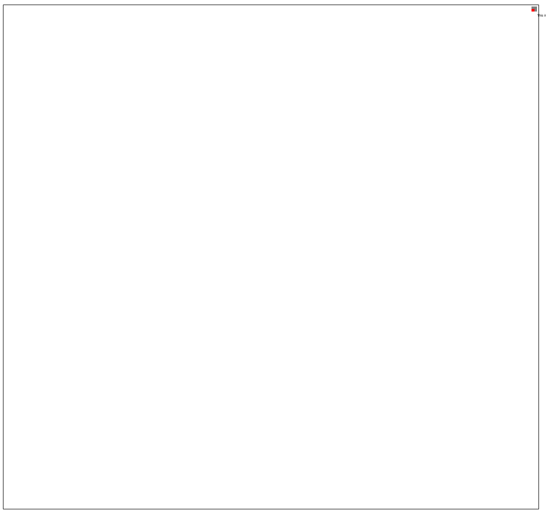
Preparation of MacConkey nutrient agar

3. Assembling the membrane filtration unit



Showing the filtration unit

4. Filter paper transfer to petri dish containing nutrient agar and incubation of petri dish



Petri dish ready for incubation

5. Counting and recording of visible colonies


Bacterial count