

**AKENTEN APPIAH-MENKA UNIVERSITY OF SKILLS TRAINING AND
ENTREPRENURIAL DEVELOPMENT**



**RISK ASSESSMENT OF WATER FROM HAND-DUG WELLS: A CASE STUDY
IN AFLAO IN THE KETU-SOUTH MUNICIPALITY IN THE VOLTA REGION
OF GHANA**

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DECLARATION

CANDIDATE’S DECLARATION

I, Sumaila Abdul, declare that this thesis, except quotations and references contained in published works which have all been identified and duly acknowledged, is entirely my original work, and it has not been submitted, either in part or whole, for another degree elsewhere.

SIGNATURE DATE.....

SUPERVISORS’ DECLARATION

I hereby declare that the preparation and presentation of this work were supervised in accordance with the guidelines for supervision of thesis/dissertation/project as laid down by the Akenten Appiah-Menka University of Skills Training and Entrepreneurial Development.

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DEDICATION

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LIST OF ABBREVIATIONS

ADD: Average Daily Dose

APHA: American Public Health Association

CF: Conversion Factor

Cm: Mean Concentration

CSF: Cancer Slope Factor

DL: Detection Limit

ED: Exposure Duration

EF: Exposure Frequency

IAH: International Association of Hydrogeologists

IR: Intake Rate

MOFA: Ministry of Food and Agriculture

NGWA: National Ground Water Association

PHC: Population and Housing Census

RfD: Reference Dose

SDGs: Sustainable Development Goals

WASH: Water, Sanitation and Hygiene

WHO: World Health Organization

ABSTRACT

Numerous peri-urban and rural areas in developing countries like Ghana face challenges with access to quality potable water due to reliance on contaminated groundwater sources. This study assessed the quality of hand-dug wells in Aflao using a cross-sectional survey. The data collection involved sanitary inspections and a survey of 400 household wells based on the WHO standard observation checklist. Water samples from 20 wells were analysed for microbial and heavy metal contaminants (Pb, Cd, Cr, Ni & As) using membrane filtration technique and atomic absorption spectrometry respectively. We found 37.3% of wells were within 10 meters of the latrine location, 98% lacked concrete floors, 98.3% lacked covers, and 88.5% had poor or no drainage systems, 31.8% were under trees, and all wells (100%) had shallow depth (<30 m). Microbial loads exceeded WHO guidelines: all samples (100%) contained total coliforms (32 – 1209 cfu/100 ml), while faecal coliforms and specifically *E. coli* were in 90% (18/20) of samples (0 – 186 and 0 – 93 cfu/100ml, respectively). Sanitary risk factors (latrine proximity, absence of concrete floors and well covers, inadequate drainage, wells under trees, and shallow depth) strongly correlated ($p < 0.05$; OR >1) with microbial contamination. All the heavy metals tested (As, Cd, Cr, Ni & Pb) were below minimum detection limits (0.001 – 0.01mg/L. Majority (70.3%) of well users perceived the water quality to be acceptable. Failed microbial quality and correlation with sanitary risk factors confirmed that unprotected hand-dug wells were unsafe water source for consumption without treatment.

CHAPTER ONE

INTRODUCTION

1.1 Background

High population expansion, rapid economic development, and urbanization have frequently contributed to pressure on the water supply system in recent decades, particularly in developing nations with inadequate water treatment facilities and piped water supply (Amin *et al.*, 2019; Klassert *et al.*, 2018). Around 17% of people worldwide do not currently own a safe source of water (WHO, 2021). This pressing issue highlights the urgent need for concerted efforts to address and improve global water accessibility. Most towns have sought alternate water sources due to the lack of pipe-borne water, and Groundwater is often regarded as the most optimal option available (Lu *et al.*, 2018).

Groundwater is derived from a variety of sources, including precipitation that infiltrates the ground, replenishing underground aquifers, surface water, springs, lakes, and rivers (Rauf *et al.*, 2021). Additionally, human activities, such as irrigation or wastewater disposal, can contribute to the recharge of groundwater. Although it is commonly considered that groundwater is devoid of bacterial pathogens, assessments conducted over the past few decades suggest that a large proportion of the groundwater supply is contaminated (Changsheng *et al.*, 2022; Mooney *et al.*, 2022; Thaniem *et al.*, 2022; Amin *et al.*, 2019). Similarly, groundwater contamination is influenced by some variables including soil hydraulic conductivity, water table depth and closeness of contaminants toward water sourced (Elangovan *et al.*, 2018; Kayembe *et al.*, 2018). The absence of a centralised sewage and wastewater treatment system in Ghana has led to the rise of private on-site sanitation facilities (Asumadu *et al.*, 2023; Appiah-Effah *et al.*, 2019). Considering

that a potable water facility and a sewage facility are essential, both are frequently constructed close distance having the potential to cause contamination.

Infiltration of septic and other waste water into groundwater could lead to the spread of disease-causing organisms that have the potential to negatively affect the health of consumers (Ferrer *et al.*, 2020; Ndoziya *et al.*, 2019). It can be concluded that very few empirical data exist on the effect of possible contamination factors and sources of groundwater quality in Ghana. The purpose of the current study stands to establish the risk associated with hand-dug well water contamination and potential sources and factors of contamination in the Aflao in the Ketu-South Municipality.

1.2 Statement of the problem

Groundwater contamination can occur when contaminants seep into the ground and percolate into shallow aquifers (Khan & Charles, 2023; Hasan *et al.*, 2021). Hand-dug wells (HDWs) are most common in low-income communities or places that lack access to pipe-borne water (Duncan *et al.*, 2020). HDW requires less excavation to reach the water source which makes it highly susceptible to microbial and chemical contamination (Famose & Olajuyigbe, 2023).

However, Beyraki *et al.* (2021) and Akhtarpour and Soleimani (2021) also discovered that high permeability in sandy soils was also known to produce high infiltration rates and effective drainage, which added up to factors that contributed to the contamination of groundwater. In a study conducted in a rural area of Ghana, it was discovered that onsite sanitation systems were a major source of groundwater contamination with high levels of faecal coliforms and nitrates detected (Abanyie *et al.*, 2022; Lutterodt *et al.*, 2021; Quamar

et al., 2019). A similar study conducted by Zume *et al.* (2021) found that groundwater contamination due to contaminant sources from industrial and agriculture activities, urban runoff, refuse dumping, onsite sanitation, and mining were widespread and posed a significant threat to public health.

On the other hand, the Ketu-South Municipal Assembly Environmental Sanitation Strategic Action Plan (2022) and the Population and Housing Census by the GSS (2021) 70% of the people of Aflao depend on shallow wells as their main source of water. The quality of hand-dug well water sourced from shallow aquifers is of concern due to potential contamination risks. This raises a similar concern as the major source of water for the people of Aflao is hand-dug well water posing a potential health risk (Baloch *et al.*, 2021). The high-water table and the sandy nature (MOFA, 2020) of the area are also possible factors that can facilitate the contamination of underground water.

1.3 Aim and specific Objectives

1.3.1 Aim

The main aim of the study was to determine the quality of water supply from hand-dug wells (HDWs) used by the inhabitants of Aflao in the Ketu-South Municipality.

1.3.2 Specific Objectives

The specific objectives were to:

- i. determine Knowledge, Attitude and Practice (KAP) of water safety among hand-dug well users.
- ii. determine sanitary risk condition of hand-dug wells using the WHO assessment framework.

- iii. determine microbial organisms and heavy metals in water from hand-dug well.
- iv. determine the association between sanitary risk factors and microbial contaminants
- v. determine health risks associated with hand-dug well water sample.

1.4 Significance of study

The study's contributions span various domains, beginning with health safeguarding. By unravelling contamination pathways, communities gain knowledge to implement targeted interventions, reduce health risks and alleviate burdens on healthcare systems. Empowerment through knowledge emerges as a key outcome, particularly for residents in Ketu-South Municipal, armed with a deeper understanding of their water sources, communities can take proactive measures, adopting sanitation practices and collaborating with local authorities for sustainable water solutions. In policymaking, the study becomes a valuable resource, offering insights for informed decisions on land use, waste disposal, and industrial activities. Scientific advancement is another significant outcome, contributing to the broader understanding of contamination and refining water quality assessment methodologies. Effective policies, guided by the study's outcomes, become crucial for lasting clean water access. This includes the establishment of water quality standards, robust monitoring programs, and pollution prevention measures, ensuring adaptability to evolving contamination challenges. The socioeconomic progress linked to enhanced water quality is undeniable. Clean water directly contributes to higher productivity, lower healthcare costs, and improved living standards, aligning with broader sustainable development goals.

1.5 Scope of the study

The study aimed to evaluate the health risks linked to hand-dug well water sources primarily utilized by the inhabitants of Aflao in the Ketu-South Municipality. Laboratory analysis was conducted to assess the presence of bacteria, organisms, and other contaminants.

1.6 Limitations of the Study

Water samples were collected only once, limiting the study's ability to capture variations in water quality over time. Also, seasonal variations (wet/rainy and dry) were not considered in the study design. Geographically, the study focused solely on Aflao within the Ketu-South Municipality, where the result cannot be generalized to other locations where variations in water quality may not have been considered. Furthermore, the investigation exclusively centered on HDWs, excluding consideration of other water sources, which may result in findings that do not fully represent the overall water quality in the area.

CHAPTER TWO

LITERATURE REVIEW

2.0 Introduction

This part presents reviews of existing works relating to the research study from various journals, published and unpublished academic work and other internet sources. From most of the reviewed literature, several scholars identified several sources and factors that influence groundwater quality notably among them are: the lateral distance of the water source from the onsite facility, the composition of the soil matrix, the depth to the water table, depth of the well, mode of construction, type of water source and the sanitary risk level of the water source. The chapter also reviews the pathways of ground water contamination, water safety plans and standards for drinking water, and detection of microbial and heavy metals contaminants in water.

2.2 Determination of possible factors that facilitate well-water contamination

2.2.0 Mode of construction of well

Proper well construction is widely regarded as a critical determinant of water quality. Scholars like Divya and Joji (2023) and Fileccia (2023) argued that adhering to established engineering and construction standards is essential to prevent contamination. However, while these standards provide a blueprint for safeguarding water quality, their effectiveness is contingent upon consistent enforcement and contextual adaptation. For instance, inadequate grouting or sealing due to resource constraints in low-income regions compromises the protective barriers around wells, despite adherence to general construction guidelines (Chaudhry *et al.*, 2019). This raises questions about the feasibility of universally applying such standards without addressing national limitations. Ngasala *et al.* (2019) highlighted the critical role of well location in minimizing contamination risks,

advocating for safe distances from septic tanks and agricultural runoff. However, this approach has been criticised for oversimplifying the complex interplay of local hydrogeological conditions. For instance, Viban *et al.* (2021) noted that in some rural areas, adherence to such distance recommendations is impractical due to land scarcity or competing land uses, thereby necessitating alternative solutions, such as localized water treatment systems.

The role of maintenance in mitigating contamination was well documented, with Ahmed *et al.* (2020) and Scaeteanu Vasile and Madjar (2018) underscoring the need for regular inspections and timely repairs. However, their emphasis on maintenance overlooked the systemic issues that prevent its implementation, such as a lack of financial and technical resources in underdeveloped nations. The WHO (2019) acknowledges this gap, advocating for community-driven initiatives to enhance maintenance practices. Yet, such initiatives remain under-explored in the literature, signaling a need for research into their long-term viability and scalability. Islam *et al.* (2016) highlighted the impact of poor well design on microbial contamination, linking improper construction to the infiltration of faecal matter. While this reinforces the argument for stringent construction standards, it failed to account for the socio-economic realities that often compel communities to prioritize immediate access to water over safety concerns. Yazdan *et al.* (2020) extended this critique by comparing pollution levels between shallow hand-dug wells and boreholes, concluding that the previous were more prone to contamination due to their construction characteristics. Their findings advocated for a shift towards borehole construction, yet this approach may not be economically feasible for all communities. Nayebare *et al.* (2020) further complicated the narrative by demonstrating that even improved wells can exhibit gross contamination, primarily due to local environmental conditions. This challenges the

notion that improved construction alone guarantees water safety, highlighting the need for an integrated approach that includes both construction and ongoing environmental monitoring. Consequently, while best practices in well construction remain fundamental, the persistence of contamination in "improved" wells underscores the need for research into complementary strategies, such as decentralized water treatment and education initiatives.

2.2.1 Geology, Well Depth and Aquifer Protection

The relationship between geology, well depth, and aquifer protection is central to understanding groundwater contamination (WHO, 2019). Gunjyal *et al.* (2023) and Rao *et al.* (2023) observed that deeper vadose zones lead to reduced contamination levels, primarily due to anoxic conditions that promote denitrification. These findings aligned with Ferrer *et al.* (2020), who noted that as water infiltrates the ground, natural processes such as filtering and adsorption significantly reduce contaminants. However, this natural filtration is not universally effective. Sepehrnia *et al.* (2023) argue that the soil's water repellency and its microscopic distribution properties can complicate the filtering process, allowing pathogens to persist under certain conditions. The impact of geological characteristics on contamination risks is further highlighted in a study by Hinfelaar *et al.* (2020), which identified pit latrines as a significant contributor to groundwater degradation. Their findings underscored the importance of geological features, such as soil porosity and permeability, in dictating the extent of contamination. Ferrer *et al.* (2020) and Martínez-Santos *et al.* (2017) argued that clayey soils, with their low permeability, provide natural protection by slowing microbial transport. However, these advantages are not universal. Urbanization, as noted by Karon *et al.* (2017), can disrupt natural filtration processes, rendering even "protective" geological conditions inadequate.

Nitrate contamination, often linked to wastewater and shallow water tables, remains a significant concern. Gunjyal *et al.* (2023) observed that shallow aquifers were particularly vulnerable during periods of heavy wastewater application, highlighting the interplay between human activities and geological susceptibility. Similarly, Rawlins (2019) emphasized the long-term risks posed by onsite sanitation systems, arguing that protective measures such as aquifer capping and increased well depth are critical to mitigating these impacts. Deeper wells are often assumed to be safer, Ferrer *et al.* (2020) cautioned that this assumption does not hold in all cases. They found that viral pathogens, due to their smaller size, are less effectively filtered than bacteria and protozoa, even in deeper wells. This finding is echoed by Rao (2023), who suggested that well depth must be coupled with other protective measures, such as effective grouting and aquifer sealing, to ensure water safety. In areas where geological protection is compromised, measures such as vertical sealing with materials like cement or bentonite clay, as suggested by Mooney *et al.* (2023), become essential. However, the practicality of these measures depends on local resource availability and technical expertise. Martínez-Santos *et al.* (2017) noted that while clay-rich soils can adsorb contaminants, prolonged exposure to pollutants may eventually degrade these natural defences.

2.2.2 Distance between a well and sanitary facility

The WHO (2022) recommended a minimum distance of 30 meters between wells and potential contamination sources to reduce groundwater pollution. A study by Sekgobela *et al.* (2024), emphasized that while this guideline is vital, local conditions such as soil type, topography, and hydrogeology significantly influence its effectiveness. Pouye *et al.* (2023) argue that in areas with frequent heavy rainfall, leaching of contaminants can occur even at greater distances, suggesting that the recommended distance alone may not suffice to

protect groundwater. Yousuf *et al.* (2021) and Contreras *et al.* (2020) highlighted that proximity to sanitation facilities often correlates with contamination risks, particularly in areas with inadequate sanitation infrastructure. Their findings aligned with earlier observations by Bhallamudi *et al.* (2019) and Dodos *et al.* (2017), who revealed that groundwater contamination frequently occurs even when facilities are beyond the recommended 30-meter threshold. This underscores the need to address additional factors, such as construction quality and sanitation practices, rather than relying solely on physical separation.

Ercumen (2018) conducted extensive research in Bangladesh and India, providing robust evidence of high faecal contamination levels when sanitation facilities were located less than 30 meters from water sources. However, Jenifer and Jha (2022) argue that while distance is crucial, the design and maintenance of sanitation systems play an equally vital role. This perspective is supported by Othoo *et al.* (2020), who emphasized that poorly designed sanitation systems exacerbate contamination risks, regardless of proximity. Escobar (2021) and Xiang *et al.* (2019) demonstrated that soil characteristics significantly impact the effectiveness of distance guidelines. For instance, highly permeable soils allow contaminants to infiltrate groundwater even at distances exceeding 30 meters, while clay-rich soils provide better filtration. Brooks *et al.* (2020) add that environmental factors, such as heavy rainfall, can compromise these usual barriers, making local geological assessments essential in determining safe distances. Improved sanitation technologies, as proposed by Yousuf *et al.* (2021), offer promising solutions to reduce contamination risks. Sealed pit latrines and other innovations can mitigate groundwater pollution even when facilities are relatively close to water sources. However, these technologies often require significant financial and technical investments, which may not be feasible in resource-

limited settings. Ismaeel and Khalil (2022) stressed the importance of tailoring sanitation designs to the specific environmental and socio-economic contexts of a region. Contreras *et al.* (2020) and WHO (2022) argue that while the 30-meter guideline remains a crucial benchmark, its effectiveness depends on complementary measures, including proper site assessments and improved sanitation infrastructure.

2.3 Water, Sanitation and Health

According to a report by the WHO (2023), Sustainable Development Goal (SDG) 6 is not expected to be achieved by the global community by 2030. In 2020, two billion people worldwide were still without access to safely regulated water services. Attaining universal coverage by 2030 in objectives SDG 6.1 demands a quadrupling of present progress rates in properly managed drinking water systems. In Ghana, 12.7 percent of families use unsafe drinking water, 80.6 percent have outdated restrooms, and 18.8 percent practice open defaecation. (Guzmán & Stoler, 2018). As a result, one of the most common illnesses in Ghana's medical establishments is diarrheal sickness brought on by drinking polluted water. Additionally, diarrhoea contributes to about 25% of all under-5 mortalities in Ghana (Afrifa-Anane *et al.*, 2022). Safe drinking water accessibility and availability, as well as suitable sanitation, are accordingly of the highest importance to one's health and well-being. They are vital to the prevention of disease and enhance nutrition (Momberg *et al.*, 2021).

Accordingly, following Sustainable Development Goal (SDG) 6 again, which aims to "Ensure availability and sustainable management of water and sanitation for all," the government of Ghana has set goals for improving sanitation by 2030 and achieving universal access to safe drinking water by 2025 (Oppong *et al.*, 2022; WHO, 2019). These

aims are part of various global and national actions that aim to enhance access to water and sanitation systems worldwide. Unfortunately, over 80% of Ghanaian households still use unimproved sanitation, and attaining the sanitation target by 2030 looks to be a mirage despite attempts to make sanitation accessible to everyone by 2030 (Bankole *et al.*, 2023; Mwenje, 2021). These challenges to attaining the objective are caused by certain factors, including inadequate sanitation infrastructure and a deficit of sanitation technology, among others (Oppong *et al.*, 2022; Karon *et al.*, 2017). In the end, better access to water, sanitation, and hygiene should be considered one of the most important components of health because they considerably help to avoid disease (Chaminé *et al.*, 2021).

2.4 Indicator parameters

2.4.1 Total and faecal coliforms

Bacteria such as total and faecal coliforms are frequently employed as water quality indicators (WHO, 2023). These are a diverse range of bacteria that are present in warm-blooded animals' intestines as well as the soil, plants, and other elements of the environment. Faecal coliforms (FC) are a subset of total coliforms (TC) and are found specifically in the intestines and faeces of animals. Both types of bacteria are used to assess the level of contamination in water sources, as their presence indicates potential faecal contamination (Vahith & Sirajudeen, 2016). Monitoring these indicators helps determine whether water is safe for consumption and recreational use.

2.4.2 E. coli

E. coli is a distinct bacterium typically found in well water and warm blooded animals. It serves as an indicator of water pollution and sanitation, with its presence indicating recent faecal contamination and the potential for disease-causing pathogens (WHO, 2023). To

evaluate well water quality and pinpoint the origins of *E. coli* contamination, numerous investigations have been carried out. One study found a significant relationship between the amount of *E. coli* found in drinking water and other sources, including soil samples, animal faeces, and human stools (Sruthi *et al.*, 2022). Another study by Khan & Gupta (2020) recognized and described biofilm-producing *E. coli* in drinking water, demonstrating unsuitable treatment of the water supply system. Continuous monitoring of water quality is crucial, as *E. coli* can survive in water for several weeks and serves as an indicator of faecal contamination.

2.5 Health risk assessment

2.5.1 Hazard Identification

Heavy metals, characterized by high atomic weight and density at least five times greater than water, are elements with chemical properties that impact humans, animals, and the environment (Goswami & Neog, 2023; Ismanto *et al.*, 2023). Their extensive use in various industries, agriculture, medicine, and technology has led to widespread distribution, prompting concerns about possible negative effects on the environment and human health (Belcik *et al.*, 2023; Sharma *et al.*, 2023). The sources of environmental heavy metal contamination are diverse, including industrial waste from activities such as metal plating, mining, smelting, battery manufacturing, tanning, petroleum refining, paint production, pesticide use, pigment manufacturing, printing, photographic industries, and fertilizer production (Thaniem *et al.*, 2022).

2.5.2 Hazard Characterization

There can be serious health concerns from drinking water contaminated with heavy metals. Studies have identified the presence of various heavy metals in drinking water,

including Lead (Pb), Cadmium (Cd), Chromium (Cr), and Arsenic (As) (Bojago *et al.*, 2023; Ogoko *et al.*, 2023; Younas *et al.*, 2023; Bai *et al.*, 2022; Chahal *et al.*, 2022; Marufi *et al.*, 2022). Some of these metals, such as Cd and As have been found to exceed the permissible limits set by the WHO and other standards. The concentration of these metals in drinking water can lead to both carcinogenic and non-carcinogenic health effects.

2.5.3 Exposure Assessment

Exposure assessment, as defined by Cordier *et al.* (2023) is the construction of individual exposure estimates to produce a valid and precise classification of subjects. According to the Codex Alimentarius Commission (CAC, 1981), exposure assessment can be defined as the process of applying qualitative and/or quantitative techniques to analyze potential exposure to biological, chemical, and physical substances, including exposure connected to food. . It focuses on gauging human exposure to toxic elements, considering the prevalence and concentrations of these elements in the diet, consumption patterns of foods containing them, and the probability of consuming contaminated food (Rai *et al.*, 2019).

2.5.4 Risk Characterization

Risk characterization is defined as the evaluating the probability and severity of known or possible harmful health impacts in a population using qualitative and/or quantitative methods while taking uncertainties into consideration (Thomsen *et al.*, 2021). It relies on hazard identification, hazard characterization, and exposure assessment (CAC 1981). This final step in risk assessment integrates information from intake/exposure assessment and hazard characterization to provide decision-making advice in risk management, offering estimates of potential health risks under various exposure scenarios (WHO, 2023). Several

studies have explored the non-carcinogenic and carcinogenic risks associated with heavy metal exposure through water consumption.

Similarly, a study conducted in Nigeria, focused on the Riruwai mining area in Kano State, indicated high levels of heavy metals in water samples that surpassed WHO and NSDWQ recommendations (Badamasi *et al.*, 2021). Children exhibited higher non-carcinogenic risk (HQ) values than adults, though all values remained below one. Carcinogenic risk assessment showed acceptable total cancer risk (TCR) for some metals but exceeded tolerable limits for Arsenic and Cadmium in specific sources. In Gombe State, a study on hand-dug wells indicated generally safe health and cancer risk indices for the exposed population, with negligible carcinogenic risk through drinking water ingestion and dermal routes (Balogun *et al.*, 2023). A study in Iran assessed levels of arsenic As, Cr, and Pb in groundwater from Noshahr and Ramsar using ICP-MS. Average metal concentrations were within standard ranges. As, Pb, and Cr all have minimal non-carcinogenic risk according to their Hazard Quotients (HQs), with Cr having the highest risk. The United States Environmental Protection Agency's permissible limit was exceeded by the Lifetime Cancer Risk (LTCR) values for Cr compared to As (Niknejad *et al.*, 2023).

Furthermore, a study in Ethiopia by Mohammed *et al.* (2023), assessed heavy metal concentrations in river water samples, finding that except for cadmium, average concentrations were below international and national permissible limits (WHO, EPA, USEPA). Pearson's correlation indicated common sources for chromium (Cr) and cadmium (Cd). Hazard quotient (HQ) and total hazard index (THI) results deemed Cu, Cr, Cd, and Pb safe, suggesting no adverse public health effects. However, concerning carcinogenic risk, elevated Cr and Cd concentrations suggest a potential risk of cancer in

the future. Thaniem *et al.* (2022) indicated that dug wells lacking proper protection were prone to contamination, influenced by residential, municipal, commercial, industrial, and agricultural activities. Elevated levels of lead, iron, cadmium, chromium, and pH were found in all water samples. While chronic daily ingestion and hazard quotient for heavy metals were generally normal, Cd and Cr in children showed concerns. Pesticides, fertilizers, and livestock dung introduce heavy metals, posing health risks. Drinking water with anions and heavy metals negatively impacts health, but treatment can ensure safety. Groundwater contamination stems from anthropogenic activities, land use changes, and chemical compounds, including organic compounds from agriculture and wastewater treatment plants. While some cited studies focused on untreated underground and surface water, the present study assessed water from hand-dug wells specifically examining arsenic, cadmium, lead, nickel, cadmium and chromium. This choice was driven by available data indicating concentrations of these six heavy metals surpassing recommended levels by the Ghana Standards (Opoku *et al.*, 2020).

Table 2.1 *Permissible* values for *natural* potable water

Parameters	Ghana level	Acceptable WHO Acceptable level
<i>E. coli</i> (cfu/100ml)	0	0
Total coliforms (cfu/100ml)	0	0
Salmonella (cfu/100ml)	0	0
Shigella (cfu/100ml)	0	0
As (mg/L)	0.01	0.01
Cadmium (mg/L)	0.003	0.003
Chromium (mg/L)	0.05	0.05
Lead (mg/L)	0.01	0.01
Nickel (mg/L)	0.02	0.02

Source:(GDWQMF,2015)

2.6 Construction types

2.6.1 Shallow Wells

These wells are typically dug or drilled to a shallow depth, usually less than 30 meters (100 feet). Shallow wells are often used for domestic purposes like drinking and irrigation, but their water quality might be more vulnerable to surface-sourced pollution (IAH, 2016; Kan-Uge *et al.*, 2023).

2.6.2 Deep Wells

Deep wells are drilled to greater depths, often hundreds of meters (or more) into the ground. The water from deep wells is usually of higher quality and less prone to surface contamination (IAH, 2016; Misstear *et al.*, 2017).

2.7 Protection status of wells

2.7.1 Protected wells

These wells are typically constructed with a lining, a concrete cover, a windlass to raise water, and a drainage platform. They are designed to prevent surface materials from polluting or contaminating the water source. Protected wells can include tube wells, boreholes, and protected dug wells (WHO 2023; Thaniem *et al.*, 2022). These wells are typically deep and closed, which helps to protect the water from contamination by people and animals.

2.7.2 Unprotected wells

Unprotected wells, can be a public health hazard and may act as direct conduits for surface materials to pollute or contaminate the water source (Misstear *et al.*, 2017). They are more vulnerable to bacterial and chemical contamination, especially if they are situated in areas

with poor sanitation practices, runoff from agricultural fields, or other potential sources of pollution (WHO, 2019; GSS, 2017).

2.8 Groundwater Contamination Routes

A pathway refers to the specific course that a potential hazard follows to access a water source within the natural surroundings (WHO, 2023; Krishnan, 2011). Groundwater contamination manifests through two distinct types of pathways: localized pathways and aquifer pathways. In the case of localized pathways, the intrusion of pathogens into the water supply intake is a consequence of human oversight, such as deficient design or the utilization of substandard construction materials. Consequently, bacteria experience a shorter duration of presence within the saturated zone. Conversely, aquifer pathways involve the migration of pathogens through the underlying soil from the contamination source to the groundwater via the process of infiltration (Lapworth *et al.*, 2017). It is important to note that protected wells can become contaminated if they are not properly maintained or if the water source itself becomes contaminated.

Water sources that exhibit elevated sanitary risk scores have been connected to substandard water quality. Penakalapati *et al.* (2017) posit that unhygienic conditions catalyze both faecal and chemical contamination, particularly in instances where human and animal waste are present. As a result, the level of cleanliness surrounding groundwater sources has a profound impact on water quality. Studies by Ghosh *et al.* (2023), and Quarmar *et al.* (2017), have identified a strong correlation between increased sanitary hazards and faecal pollution in groundwater sources in both Agra city and India. Similarly, Engström *et al.* (2015), in their investigation of microbiological pollutants and associated

risk factors in groundwater sources in Juba, South Sudan, underscore the critical importance of local cleanliness practices.

2.9 The Legal and Institutional Frameworks for Drinking Water

The legal and institutional frameworks concerning drinking water encompass a comprehensive array of laws, regulations, agencies, and organizations tasked with governing the access, distribution, quality, and management of safe drinking water (Sancin & Juhart, 2023). These frameworks exhibit variations across countries but generally encompass provisions for maintaining water quality standards, ensuring government oversight, promoting infrastructure development, encouraging community involvement, and preparing for emergencies (Sancin & Juhart, 2023; Wuijts *et al.*, 2021). Dokmanović's research (2022) underscored the notion that access to water is an inherent human right managed by the state in the collective interest, with UN recognition reinforcing this stance. However, his study reveals shortcomings in Serbia's safeguards against water pollution and the privatization of water resources, which jeopardize the nation's sovereignty over its natural assets.

Mechlem's work (2012) accentuates the indispensability of robust legal frameworks for effective groundwater governance. These frameworks should be buttressed by complementary policies, heightened awareness, technological solutions, and administrative and financial structures for successful implementation. Gunnarsdottir *et al.* (2015) investigation examined Iceland's national framework for ensuring safe drinking water. Although largely in place, the framework reveals certain inadequacies necessitating attention, such as enhanced central government guidance, more robust water supply

system surveillance, and better implementation of water safety plans by Local Competent Authorities.

2.9.1 Global Institutions and Agencies

- i. World Health Organization (WHO): WHO sets international guidelines and standards for water quality and health, including drinking water safety. It provides technical support and guidance to countries to ensure access to safe drinking water (Goryushina, 2022).
- ii. United Nations Children's Fund (UNICEF): UNICEF works to provide clean and safe drinking water to children and communities around the world, particularly in developing countries (Verma *et al.*, 2023).
- iii. United Nations Environment Programme (UNEP): UNEP addresses environmental issues, including water quality and sanitation, to promote sustainable water management globally (Taşeli & Iyer-Raniga, 2023).
- iv. World Bank: The World Bank provides funding and support for water-related projects, including those aimed at improving access to clean drinking water in developing countries (Rodríguez *et al.*, 2021).

2.9.2 Institutions and Agencies in Africa

- i. African Ministers' Council on Water (AMCOW): Through the management of water resources, AMCOW is an international organization that encourages collaboration, security, social and economic growth, and the eradication of poverty among African nations (Kgatle & Qiki, 2023).

- ii. African Water Facility (AWF): AWF is a financial mechanism established by the African Development Bank to support water resources development and management projects in African countries (Mutschinski & Coles, 2021).

2.9.3 Institutions and Agencies in Ghana

- i. Ghana Water Company Limited (GWCL): GWCL is the state-owned utility in charge of supplying drinkable water to urban and peri-urban areas in Ghana. It manages water treatment, distribution, and billing (Aigbavboa *et al.*, 2023).
- ii. Water Resources Commission (WRC): WRC is the regulatory body responsible for managing water resources, including quality and allocation, in Ghana (Tetteh *et al.*, 2023) . It works to ensure sustainable and equitable use of water resources.
- iii. Environmental Protection Agency (EPA) - Ghana: EPA monitors and regulates environmental issues, including water quality, to ensure that standards are met and environmental degradation is minimized (Aboagye *et al.*, 2022).
- iv. Community Water and Sanitation Agency (CWSA): CWSA is responsible for rural water supply and sanitation in Ghana, aiming to improve access to clean water and sanitation facilities in rural communities (Osarfo *et al.*, 2023).
- v. Ministry of Sanitation and Water Resources: This ministry in Ghana oversees policies, strategies, and programs related to sanitation and water resources management, including drinking water (Azupogo *et al.*, 2023).

2.9.4 Drinking water standards and guidelines

Regulatory bodies establish Drinking Water standards as rules to guarantee the security and purity of drinking water (WHO, 2023). These standards specify acceptable levels of various contaminants and parameters in water, such as bacteria, chemicals, and minerals,

to protect public health. Different countries and organizations have their standards, like the World Health Organization (WHO) and the Environmental Protection Agency (EPA) in the United States (Grison *et al.*, 2023).

2.9.5 Framework for safe drinking water

The WHO has developed a comprehensive framework for ensuring the safety of drinking water worldwide. This framework encompasses several key elements that work together to guarantee the availability of safe and clean drinking water (Mustapha *et al.*, 2021). It begins with establishing health-based targets for microbial, chemical, and radiological contaminants in drinking water, to safeguard public health and reduce the risk of waterborne diseases.

2.9.6 A Water Safety Plan (WSP)

The core of this approach involves adopting Water Safety Plans (WSPs), which provide a systematic method for assessing hazards, evaluating risks, implementing control measures, and continually monitoring water systems for ongoing safety (WHO, 2023). This strategy manages drinking water safety from source to consumption, ensuring quality by identifying and mitigating potential risks throughout the supply system. A WSP serves as a proactive and systematic tool to recognize, prevent, and address contamination concerns within water supply systems (Baracho *et al.*, 2023). It includes strategies for operations, monitoring, management, system evaluation and design, communication, and record-keeping. The World Health Organization (WHO) supports the use of this risk assessment tool for all water suppliers to oversee the quality of drinkable water. Roeger & Tavares (2018) also added that WSPs are an important public policy tool to ensure water quality

and safety and successful WSPs require leadership commitment, technical knowledge, governance, and interagency collaboration.

2.9.7 Elements of Water Safety Plans (WSPs)

According to WHO (2023), notable elements of WSPs comprise

- i. Developing strategies to safeguard sources of drinking water from potential contamination risks.
- ii. Implementing precautions to eliminate any possibility of contamination in facilities dedicated to producing safe drinking water.

By amalgamating these components, a Water Safety Plan empowers water suppliers and providers to proactively manage potential contamination risks, ensuring the consistent provision of safe drinking water while staying adaptable to evolving circumstances and emerging threats (Burlingame & Bartrand, 2023).

Continuous monitoring and surveillance are integral to the framework, involving regular testing of water samples to detect various contaminants and ensure compliance with established water quality standards (Javed *et al.*, 2022). Alongside technical measures, capacity building and training are emphasized to empower water providers and stakeholders with the knowledge and skills necessary to implement effective water safety measures. Clear and enforceable legislation and regulation are vital aspects of the framework, providing the legal foundation and mechanisms needed to ensure adherence to water quality standards and safety practices (Dieter & Chorus, 2023).

CHAPTER THREE

METHODOLOGY

3.0 Introduction

In this chapter, the study explores the intricacies of research methodology, detailing the design, techniques, and methods employed for data collection and analysis. A focal point is the determination of sample size, a critical factor influencing the study's reliability and generalizability.

3.1 Study area

3.1.1 Population

According to the Ghana 2021 Population and Housing Census (PHC), the population of Aflao is 38,097 with 9,070 households. The rapid population growth in the Municipality can be partly due to the influx of immigrants, primarily from Togo, Benin, Nigeria, and Niger, who participate in commercial operations in the district. The population consists of 52.9 % females and 47 % males. A little more than half (53.4%) of the Municipals' population resides in rural areas (GSS, 2021). 37.8 % of the municipality's population is comprised of individuals under 15 years of age, indicating that the municipality's population is predominantly young. The overall age dependence ratio for the municipality is 78.1, and the ratio for men is greater (84.0) than that for females (73.4) (GSS,2021).

Similarly, it was noted that homes in the municipality rely on a variety of drinking water sources, but the four most important sources are wells (both protected and unprotected), boreholes, standing pipes, and sachet water (GSS, 2021). In the Municipality, unprotected wells are the most common source of drinking water for households (34 %), followed by protected wells (17.8 %), sachet water (16 %), and borehole/pump/tube wells (11.9 %)

(GSS, 2021). At the locality level, unprotected wells are the predominant source of drinking water for homes in both urban and rural regions (34.9%) (33.3%) (GSS,2021).

3.1.2 Topography and drainage

Ketu South District is a rather low-lying region, with elevations ranging from less than 15 metres near the seashore to 66 metres inland. The coast is rather smooth and dotted with sandbars (MOFA, 2020). The district's drainage system is dominated by seasonal streams and drains southward. Approximately 30 kilometres of the lagoon, ranging from the Keta lagoon at Blekusu to the vicinity of Aflao, offer the possibility of aquaculture and salt mining (MOFA, 2020).

3.1.3 Climate

According to the Ministry of Food and Agriculture (2020), the district has a dry equatorial climate. The typical monthly temperatures range between 24°C to 30°C, which are optimal for plant growth year-round. The average annual precipitation for the district is 850 millimetres at the coast and 1,000 millimetres inland. From April to July and September to October, the rainfall is characterised by a double maximum. From December through February, the dry season is dominated by the harmattan winds. During the minor season, rainfall in the district is typically low and unpredictable, notably along the coastal strip between Agbozume and Aflao (MOFA, 2020)

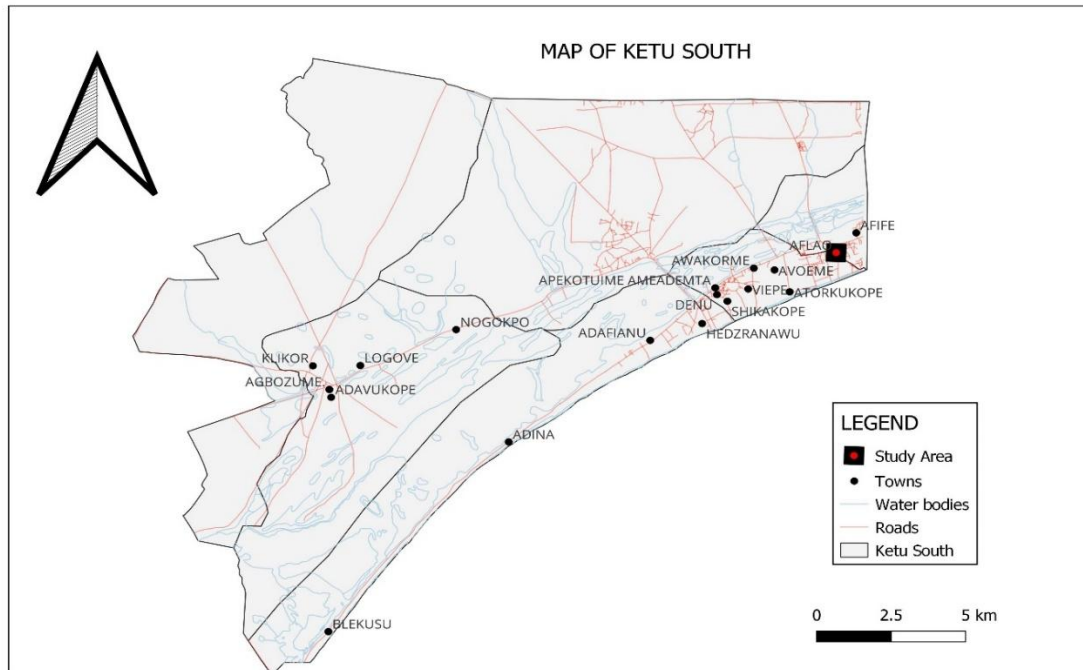


Figure 3.1 Study site map

3.2 Sampling technique

3.2.1 Research Design

The research utilized a cross-sectional study design, employing a questionnaire method of data collection. Additionally, a sanitary risk assessment of hand-dug wells was conducted, along with laboratory analysis of well water.

3.2.2 Sampling size

Given a total of 6,046 HWDs a sample size of 375 was determined using the Yamane's 1967 simplified sampling formula with the assumptions of 95% confidence level, 5% desired level of precision, and 50% maximum variability (Israel, 1992). However, the sample size was approximated to 400 for improvement in reducing sample error (Etikan & Babtpe, 2019). The sample size (385) was approximated to 400 for a uniform sample

across the study area. This allowed for an even distribution of samples despite the slightly varying number of wells in each zone (Zone A: 1,501; Zone B: 1,561; Zone C: 1,536; Zone D: 1,448) but also contributed to reducing sample error (Etikan & Babtope, 2019). Therefore, a sample size of 400 was deemed appropriate, with 100 samples allocated to each of the four zones in the Aflao community for sanitary risk assessment (SRA).

Additionally, the study purposively collected 20 samples of hand-dug well water, with 5 samples obtained from each of the four designated zones. The selection criteria for these well water samples were based on the location of the wells. (1) Two wells from each zone were chosen from waterlogged areas, and (2) three wells from each zone were selected from dry up land areas. This approach aimed to capture a spectrum of well water quality across different locations within the sampled zones, contributing to a more understanding of the study's findings in the context of water quality as adopted from Ogham *et al.* (2023).

3.3 Data collection

3.3.1 Knowledge, Attitude and Practice (KAP)

Responses on KAP from participants were coded as follows: correct responses were assigned a code of 1, while incorrect responses received a code of 0 (Wierzbiński *et al.*, 2014). These codes were then used to construct a composite variable. By calculating the mean of this composite variable, a pivotal threshold was established. Respondents scoring below this mean were categorized as having a low perception of water quality, whereas those scoring above it were categorized as having a high perception.

3.3.2 Sanitary inspections

A sanitary risk survey was conducted to determine the contamination risk of 400 hand-dug wells in Aflao, using WHO guideline which involved identifying potential factors and sources of contamination (WHO, 2023). The sanitary inspection technique was adopted from the WHO Guide for Drinking Water Quality standard having a systematic checklist of a small number of specific inquiries. These checklists addressed the 10 most fundamental and potential factors of well water contamination. Household scores 9-10 risk factors indicated a "very high risk," while 6-8 signifies "high risk," 3-5 denotes "moderate risk," and 0-2 suggested "low risk," (Kirori *et al.*, 2022).

The method involved a systematic assessment of water sources and their surroundings, incorporating both physical inspections and measurements. It encompassed determining distances between potential sources of contamination and wells, as well as measuring the total depth of the wells using a calibrated instrument. The scoring of supposed risk factors, denoted by the presence (yes) or absence (no) was conducted according to guidelines provided by authoritative bodies such as the World Health Organization (WHO), International Association of Hydrogeologists (IAH), and National Ground Water Association (NGWA) which stipulated that wells should maintain a minimum distance of 30 meters from potential contaminant sources (Zhao *et al.*, 2020) . Wells with depths or water tables closer to the land surface, within the 30m threshold, were categorized as shallow wells, while those exceeding 30m were classified as deep wells.

3.3.3 Water sample collection

In October 2023, 20 well water samples were collected and transported to the CSIR-Water Research Institute lab in Accra using 500ml plastic bottles. Adopting of WHO

recommended method/protocol of collecting well water, a 20-meter length of sanitized string, coiled around a cylindrical spool, was affixed to a representative sampling container. The sampling container was deployed into the well through the unwinding action induced by the gravitational force, ensuring that it did not come into contact with the well's inner walls to minimize potential contamination. Submergence of the sampling container was executed such that it achieved complete immersion below the water surface without touching the well bottom or causing disturbance to sedimentary layers. Upon reaching the judgment of adequate water collection, the sampling container was meticulously hoisted, and the twine was reeled back onto the spool, facilitating the retrieval of the container. Subsequently, the container was securely sealed.

3.4 Laboratory analysis

3.4.1 Indicated organisms

Membrane filtration was used, employing a sterile 0.45µm Millipore filter, Erlenmeyer flask, and vacuum source. Samples were filtered and placed on selective media, including Xylose Lysine Deoxycholate (XLD) Agar for *Shigella* and *Salmonella*, M-FC for faecal coliforms (FC), total coliforms (TC) and Hi-Chrome agar for *E. coli*, all in separate Petri dishes (Erkmen, 2021). Incubation occurred at 37±2 °C for 18-24 hours for the analysis. Clamps and forceps were sterilized before each use.

3.4.2 Heavy metals analysis

Atomic absorption spectrometry a sample solution was aspirated into flame and atomized. Through the flame, a light beam was focused, passing through a monochromator and onto a detector that determined how much light the flame absorbed. Because each metal has its characteristic absorption wavelength, a source lamp composed of that metal was used. The

amount of energy at the characteristic wavelength of 279.5nm absorbed in the flame was proportional to the concentration of the element in the sample over a limited concentration range.

3.5 Data analysis

In conducting the analysis, a dual approach was employed, encompassing both descriptive and inferential statistics. Descriptive statistics, involving the use of frequencies, graphs, and tables, provided a comprehensive overview of the data, offering insights into the distribution and central tendencies of the variables under examination. Additionally, the inferential aspect of the analysis involved rigorous testing for associations, aiming to unveil meaningful relationships between various factors. In the analysis of data, Poisson regression model was employed to assess the relationship between contamination parameters identified in well water samples and potential sources and factors of contamination, as outlined in *Table 4.2*. This involved the use of odds ratios and significant level at 0.05. An odd ratio below one suggested no significant difference in line with WHO-recommended sanitary practices, which are anticipated to enhance water quality. Conversely, an odds ratio exceeding one indicates an association with the specific contamination factor under consideration, while a ratio of one implies no discernible difference between contamination and either faulty or improved practices. Additionally, a statistical analysis was conducted to investigate the relationship between identified organisms and observed risk factors. Regression analysis, specifically employing the beta poisson model, was utilized for this purpose. This was achieved through coding "No" responses, as the absence of a risk factor, utilizing as reference categories in the statistical analysis. This allowed for the comparison of the "Yes" responses, which indicated the presence of a risk factor, to determine their relative impact on contamination levels. The

sanitary risk assessment was also performed, utilizing counts to categorize wells into distinct risk levels namely, very high (9-10 risk factors), high (6-8 risk factors), moderate (3-5 risk factors) and low (0-2 risk factors). The statistical software utilized for this in-depth data analysis was SPSS IBM version 27.

3.5.1 Validity and reliability

The research employed a meticulous approach to both validity and reliability, incorporating content validity in questionnaire development and utilizing Cronbach's alpha for internal consistency reliability assessment. The sampling strategy further strengthened the study's validity by capturing a diverse range of variables, contributing to the comprehensive understanding of the multifaceted aspects of the research topic. Moreover, the validity and reliability of the laboratory methods employed for microbial and heavy metals analysis align with the research objective, ensuring that the results accurately reflect the microbial loads and concentration of heavy metals in water sourced from hand-dug wells (Osuagwu, 2020). The rigorous and standardized procedures contribute to the overall robustness and trustworthiness of the research findings.

3.5.2 Health risk assessment

The likelihood that exposure to environmental contaminants will have a negative impact on a person's health is measured as their health risk (Kukreja *et al.*, 2023). The purpose of the risk assessment is to forecast the risks both carcinogenic and non-carcinogenic that could result from exposing adults and children to heavy metals in drinking water. The following equations and parameters as employed by Balogun *et al.* (2023) and Nawaz *et al.* (2023) were adopted.

$$\text{Average Daily Dose (ADD}_{\text{ingestion}}) \text{ (mg/kg/day)} = \frac{C_m \times IR \times ED \times EF \times UCF}{BW \times AT} \dots\dots\dots(1)$$

$$\text{ADD}_{\text{(dermal)}} = \frac{C_m \times SA \times D_p \times ABS \times EF \times ED \times UCF}{BW \times AT} \dots\dots\dots(2)$$

$$\text{Target Hazard Quotient (THQ)} = \frac{\text{ADD}_{\text{ingestion/dermal}}}{\text{RfD}_{\text{ingestion/dermal}}} \dots\dots\dots(3)$$

$$\text{Hazard Index (HI}_{\text{ingestion/dermal}}) = \sum_{i=1}^n (\text{ingestion/dermal}) \dots\dots\dots (4)$$

$$\text{CRI}_{\text{ingestion, child}} = \text{ADD}_{\text{ingestion, child}} \times \text{CSF} \dots\dots\dots (5)$$

Where,

- i. ADD (ingestion) stands for the exposure through ingestion
- ii. C_m (average concentration of the element in water).
- iii. IR (Intake Rate) accounts for both direct and indirect consumption, which is 2 liters per day for adults and 1 liter per day for children.
- iv. EF (exposure frequency) to the pollutant is 365 days per year for both adults and children.
- v. Body weight (BW) is considered to be 70 kg for adults and 15 kg for children.
- vi. Exposure Duration (ED) is 30 years for adults and 6 years for children.
- vii. Unit conversion factor (UCF) of 0.001 L/cm³ is used.
- viii. Average lifetime expectancy (AT) is calculated as ED multiplied by 365 for both adults and children (for non-carcinogenic exposure), and 70 multiplied by 365 for both adults and children (for carcinogenic exposure).
- ix. ABS (Dermal absorption factor) is 0.1 for both adults and children.
- x. SA (Skin surface area) is 18,000 cm² for adults and 6,600 cm² for children. Lastly,
- xi. D_p (dermal permeability coefficient in water (Table 3.1).

Table 3.1 WHO Standards: RfD and CSF for Heavy Metals

Metal	RfD (ingestion)	CSF (ingestion)	RfD (dermal)	Dp	WHO
Copper (Cu)	3.70E-2	2.00E-2	2.40E-2	0.001	2.00
Lead (Pb)	3.60E-3	8.50E-3	4.20E-4	0.0001	1.00E-2
Cadmium (Cd)	5.00E-4	6.10	5.00E-4	0.001	5.00E-3
Chromium (Cr)	3.00E-3	5.00E-1	7.50E-5	0.002	5.00E-2
Nickel (Ni)	2.00E-2	1.70	5.60E-3	0.0002	7.00E-2
Arsenic (As)	0.0003	1.50	0.000123	0.001	0.01

Source: (Balogun *et al.*, 2023; Nawaz *et al.*, 2023)

CHAPTER FOUR

RESULTS AND DISCUSSION

4.0 Introduction

This chapter presented findings and discussions into factors contributing to hand-well contamination and residents' knowledge, attitude and practice (KAP) of water safety. It included an analysis of microbial and heavy metal content in well water, sanitary risk assessment, and established connections between contamination parameters and potential sources. The discussion highlighted health risks associated with consuming water from hand-dug wells, supported by a critical review of existing literature. Drawing upon scholarly sources, the chapter contextualized the findings, examined both supportive and opposing perspectives within the realm of well water safety.

4.1 Profile of respondents

The surveyed population, comprised 400 respondents, exhibited a diverse demographic profile with an average age of 46 and a gender distribution of 76% females and 24% males. Education levels varied, ranging from 38% with no formal education to 3% attaining tertiary education. Employment diversity was notable, with 31% not employed, including about 7% retirees, 61% self-employed predominantly traders, and 8% in government positions. The average household size was 3, and residents had, on average, lived in the community for 20 years, occupying houses with an average size of 9 people. This brief profile captured the nuanced characteristics of the study participants.

4.2 Data Presentation

A significant majority, 96 %, utilized well water for cooking, indicating its suitability for culinary needs. Additionally, 97 % relied on well water for washing, encompassing

laundry, dishes, and personal hygiene, underscoring its integral role in daily cleanliness. However, the percentage drops to 73% for drinking purposes, suggesting potential concerns about water quality and safety (*Figure 4.1*).

Out of the 400 households surveyed, the percentage of households reporting the absence of diseases (97%) suggested a difference (95%) compared to those reported having diseases (3%) *Figure 4.2*. While the majority of households expressed satisfaction with their well water (70%), a notable proportion potentially harboured concerns or dissatisfaction (44.8%) (*Figure 4.3*). The average depth of the 400 wells surveyed was 4 meters (*Figure 4.4*).

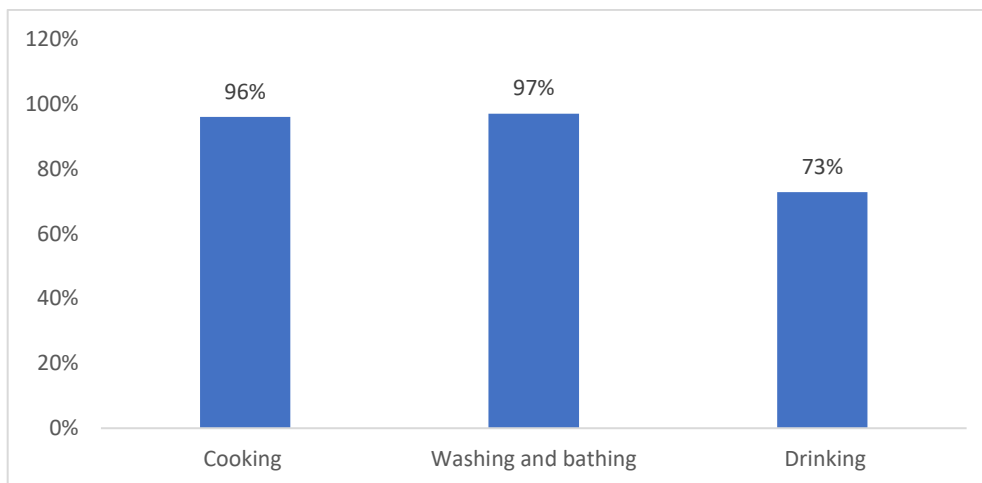


Figure 4.1: Household Water Usage

Source: Field Data (2023)

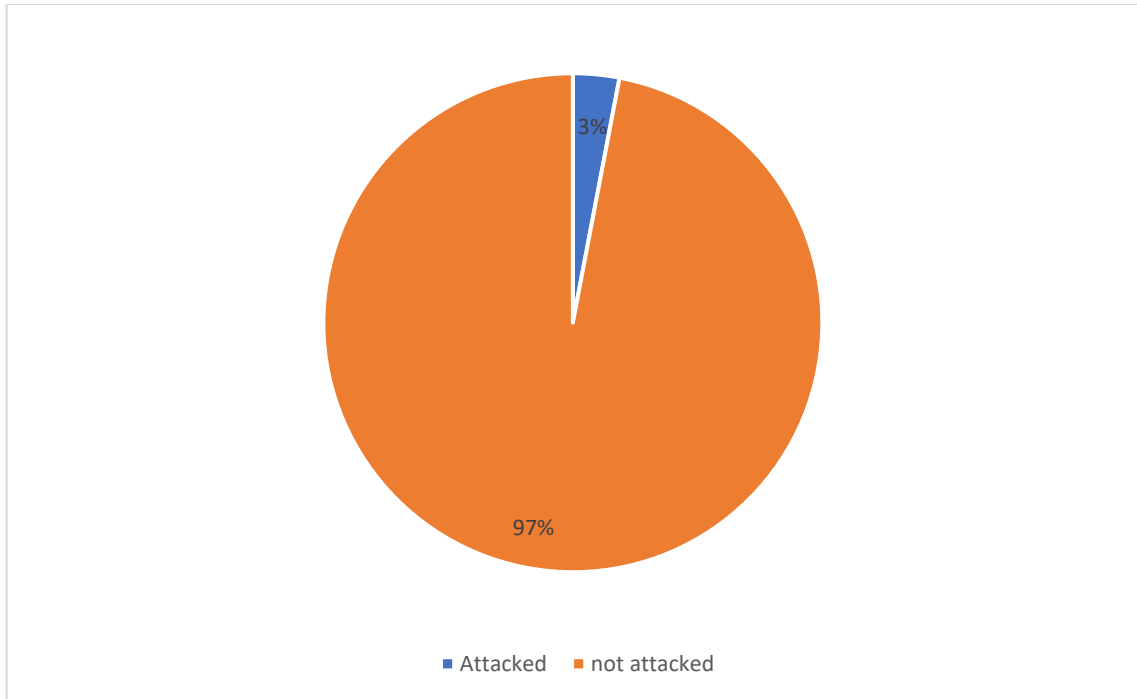


Figure 4.2 Prevalence of Waterborne Diseases

Source: Field Data (2023)

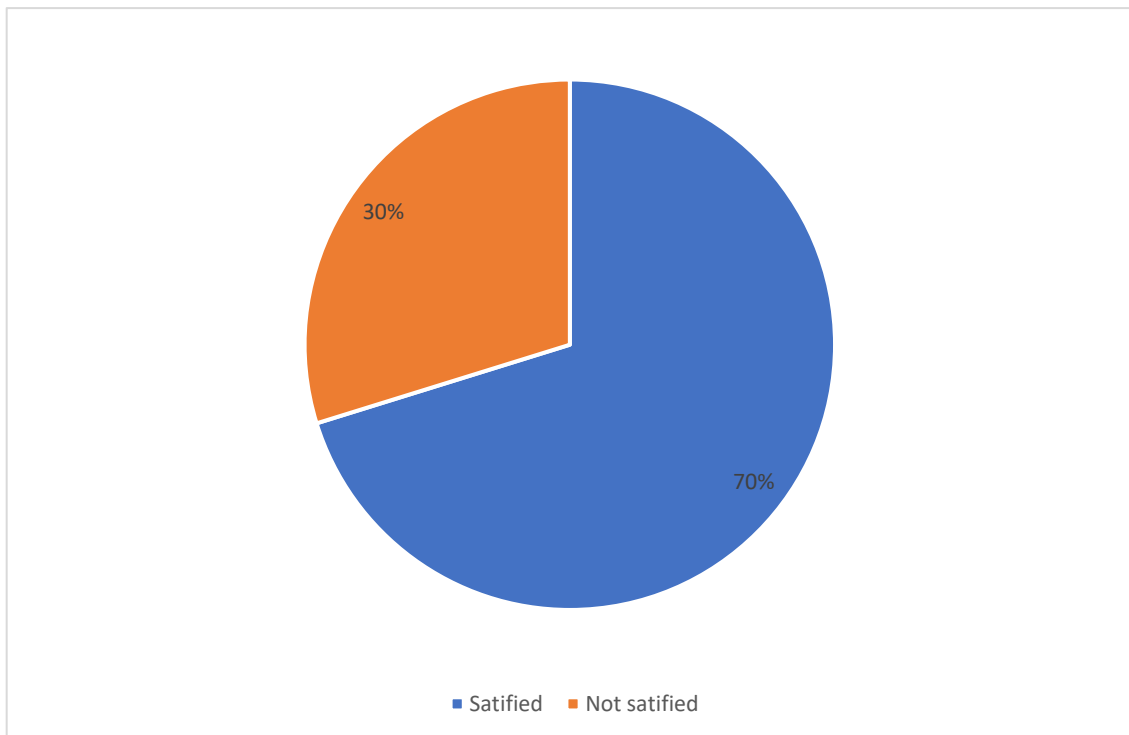


Figure 4.3: Satisfaction Level of Consumers

Source: Field Data (2023)

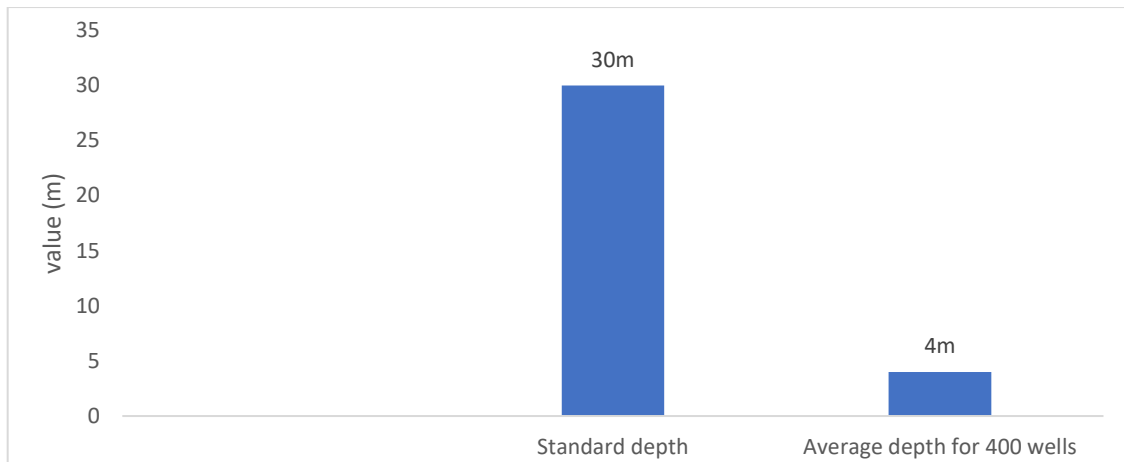


Figure 4.4: WHO Standard and Average Depth Recorded

Source: Field Data (2023)

Examining the results presented in *Figure 4.5*, the majority of respondents (65 %) reported treating their water, indicating a significant awareness of the importance of water treatment for health and safety. Conversely, 35 % of respondents did not treat their water, suggesting potential knowledge gaps or differing attitudes towards water treatment practices.

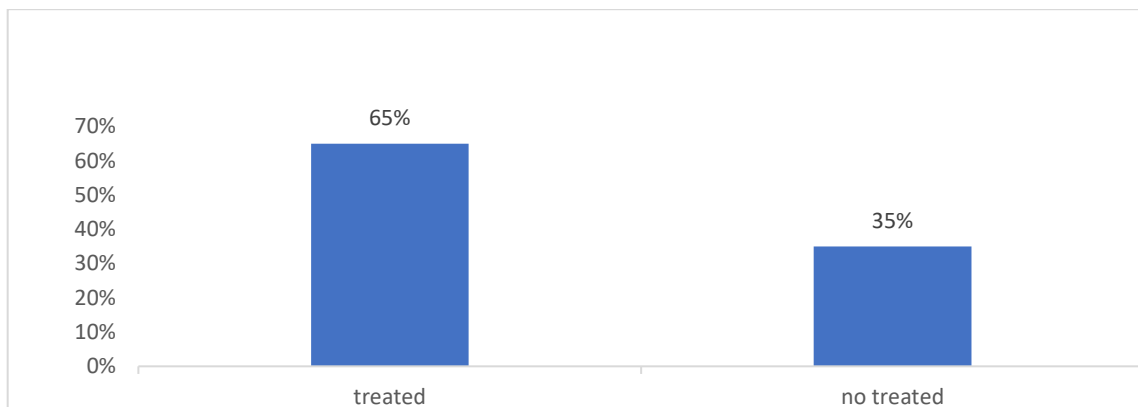


Figure 4.5: Frequency of Water Treatment

Source: Field Data (2023)

4.2.1 Sanitary Risk Factors

The percentage scored on sanitary assessment among 400 households with hand-dug well recorded, 37.3% of wells with latrine within 10 meters, which can pose a potential risk of contamination due to proximity (Table 4.1). Approximately 20.8% of wells had a latrine

uphill or on higher ground, which could increase the risk of contamination from upward flow. Around 35.3% of wells had other pollution sources like animal excreta or rubbish within 10 meters, increasing the risk of contamination. Moreover, as indicated in Table 4.1, the most noteworthy findings are a significant 88.5% of wells did not have drainage systems, indicating a high potential for contamination. About 31.8% of wells were under or close to a tree, which could lead to leaf and debris accumulation. A small percentage (7.8%) of wells had inadequate headwalls, which increased the potential for surface water to enter and contaminate the well. Almost all wells (98.5%) lacked a concrete floor, which could contribute to the risk of contamination from surface water. All wells (100%) had shallow depths, also increasing the risk of contamination. Rope and bucket contamination were possibility in all wells that had been seen because they were left in a position that could permits contact with potential contaminants. Almost 98.25% of wells required a cover, highlighting the need to prevent surface water and other contaminants from entering the well.

Table 4.1: Sanitary risk assessment

S/N	WHO Sanitary risk factors assessed	Distribution	
		Yes (N=400)	%
1	Latrine within 10 m of the well	149	37.3%
2	Latrine uphill/nearest latrine on higher ground than the well	83	20.8%
3	Animal excreta or rubbish within 10 m of the well	141	35.3%
4	Absence of drainage/poor drainage system	354	88.5%
5	Well under or closer to a tree	127	31.8%
6	The well headwall	31	7.8%
7	Absence of concrete floor around the well	378	94.5%
8	The depth of the well is Shallow (less than 30m)	400	100.0%
9	Poor handle fetching buckets	400	100.0%
10	Well covered	393	98.25%

Source: Field Data (2023)

4.2.2 Sanitary risk scoring

In the graph depicted in Figure 4.6, out of the total number of wells assessed, 2 % (N=400) were categorized as having a very high risk. These wells had multiple severe sanitary risk factors, which increased the likelihood of contamination and pose a serious threat to water quality and safety. About 71% (N=400) fell under the high-risk category. These wells were associated with 6-8 sanitary risk factors presence. Approximately 27 % (N=400) were classified as moderately risky.

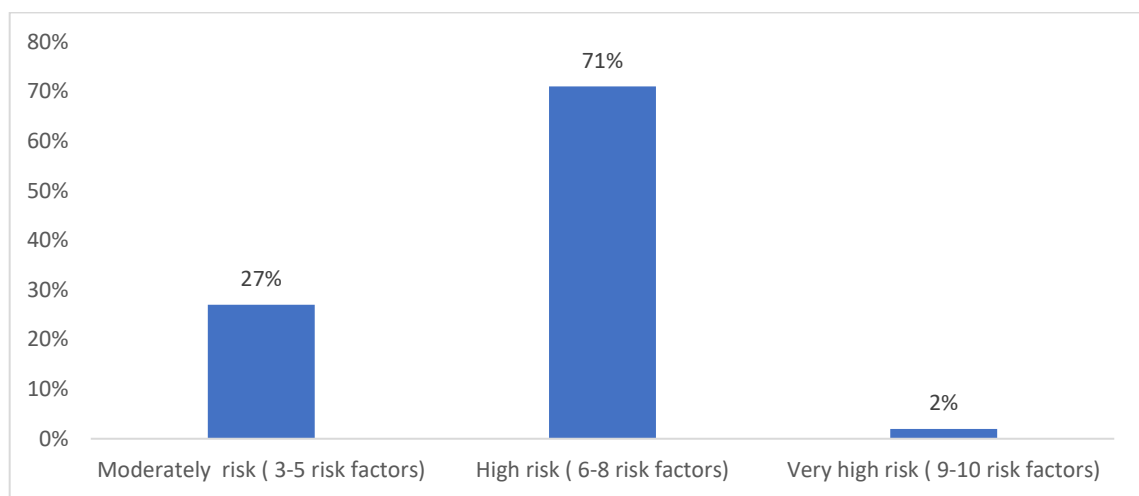


Figure 4.6: Sanitary risk scoring

Source: Field Data (2023)

4.2.3 Observed sanitary risk factors versus microbial loads.

The proximity of latrines within 10 meters of a well, areas prone to flooding, and public toilet areas, as well as wells located under trees, wells designated for public use, latrines situated uphill from wells, the practice of digging and burying faeces within households, and the absence of proper drainage and well covers were significantly associated ($p < 0.05$) with increased levels of microbial contamination (Table 4.2). However, the presence of animal droppings did not show a significant association with contaminant levels ($p > 0.51$, $p > 0.460$, $p > 0.948$), nor did the presence of public toilets correlate with TC levels ($p > 0.590$). Similarly, the absence of well covers ($p > 0.444$), flood-prone areas ($p > 0.493$)

concerning *E. coli*, and the practice of digging and burying feces in relation to *E. coli* ($p > 0.948$) were not significantly associated with contamination ($p > 0.05$).

Key risk factors with higher OR ($OR > 1$) indicating a strong association with contamination included the presence of latrines within 10 meters of a well, which showed significantly increased odds for faecal coliforms ($OR = 5.620$), total coliforms ($OR = 1.247$), and *E. coli* ($OR = 2.699$) contamination. Wells located under trees were also strongly associated with contamination, with OR values of 1.890 for faecal coliforms and 2.806 for *E. coli*. Additionally, wells designated for public use showed 2.516 times likely to contaminate the well water with FC and 3.591 for *E. coli*. Latrines situated uphill from wells exhibited increased odds of contamination with OR values of 3.034 for FC and 1.710 for *E. coli*. The absence of a fence, cover, apron and shallow depth exhibited constant outcomes, with all observations and measurements consistently yielding the same result (risk factor observed). This implied that observed factors did not exhibit variation or fluctuation within the dataset. The unidirectional skewness of these constant observations and measurements suggested a lack of diversity or meaningful variability in the specific attributes assessed within the studied population as indicated in dash (-) in Table 4.2

Table 4.2: Observed sanitary risk factors verse microbial loads

Risk factors	Faecal coliform		Total coliform		<i>E. coli</i>	
	OR	P-value	OR	P-value	OR	P-value
Latrine within 10m to a well =YES	5.620	.000	1.247	.000	2.699	.000
Latrine within 10m to a well =NO	1	-	1	-	1	-
Absence of drainage system =YES	.231	.000	.636	.000	.375	.000
Absence of drainage system =NO	1	-	1	-	1	-
Absence of cover=YES	.475	.000	1.807	.000	.837	.444
Absence of cover=NO	1	-	1	-	1	-
Flooded=YES	.672	.000	1.574	.000	1.102	.493
Flooded=NO	1	-	1	-	1	-
Well within the vicinity public toilet =YES	.315	.000	.986	.590	.423	.000
Well within the vicinity public toilet =NO	1	-	1	-	1	-
Well under tree=YES	1.890	.004	.623	.000	2.806	.001
Well under tree=NO	1	-	1	-	1	-
Animal faeces and refuse =YES	1.364	.051	1.023	.460	1.015	.948
Animal faeces and refuse =NO	1	-	1	-	1	-
Public use=YES	2.516	.000	.564	.000	3.591	.000
Public use=NO	1	-	1	-	1	-
Latrine upward to well=YES	3.034	.000	1.205	.000	1.710	.023
Latrine upward to well=NO	1	-	1	-	1	-
Dig and bury faeces in the house =YES	1.623	.010	.780	.000	.907	.721
Dig and bury faeces in the house =NO	1	-	1	-	1	-
Absence of fence= NO	1	-	1	-	1	-
Absence of apron=YES	1	-	1	-	1	-
Depth (less than 30m) = YES	1	-	1	-	1	-

Source: Field Data (2023)

4.2.4 Comparing indicated parameters among zones

Pointing out the specific trend illustrated in Table 4.3, the analysis of the *E. coli*, Total and Faecal coliform variable discovered that there were no statistically significant ($p > 0.05$) differences observed between any of the zones (A, B, C, and D).

Table 4.3: Comparing indicated parameters among zones

Parameters	ZONES	ZONES	Sig.
Total Coliform	ZONE A	ZONE B	.993
		ZONE C	.997
		ZONE D	.490
	ZONE B	ZONE A	.993
		ZONE C	1.000
		ZONE D	.645
	ZONE C	ZONE A	.997
		ZONE B	1.000
		ZONE D	.607
	ZONE D	ZONE A	.490
		ZONE B	.645
		ZONE C	.607
Faecal Coliform	ZONE A	ZONE B	.913
		ZONE C	.963
		ZONE D	.743
	ZONE B	ZONE A	.913
		ZONE C	.677
		ZONE D	.983
	ZONE C	ZONE A	.963
		ZONE B	.677
		ZONE D	.465
	ZONE D	ZONE A	.743
		ZONE B	.983
		ZONE C	.465
<i>E.coli</i>	ZONE A	ZONE B	.967
		ZONE C	.990
		ZONE D	.246
	ZONE B	ZONE A	.967
		ZONE C	.870
		ZONE D	.462
	ZONE C	ZONE A	.990
		ZONE B	.870
		ZONE D	.150
	ZONE D	ZONE A	.246
		ZONE B	.462
		ZONE C	.150

Source: Field Data (2023)

4.2.5 KAP of respondents on water safety

The assessment of 400 respondents using hand-dug wells and their KAP of water safety, a mean score of 7.7475 was obtained (Figure 4.7). This mean score was a critical threshold for categorizing the respondents' KAP into two groups: those with a score below 7.7475 indicating low KAP, and those with a score above 7.7475 indicating high perception. The findings revealed that the majority (54.3%) of the respondents had a higher KAP with regard to water safety while 45.7% of the respondents having a lower KAP with regard to water safety.

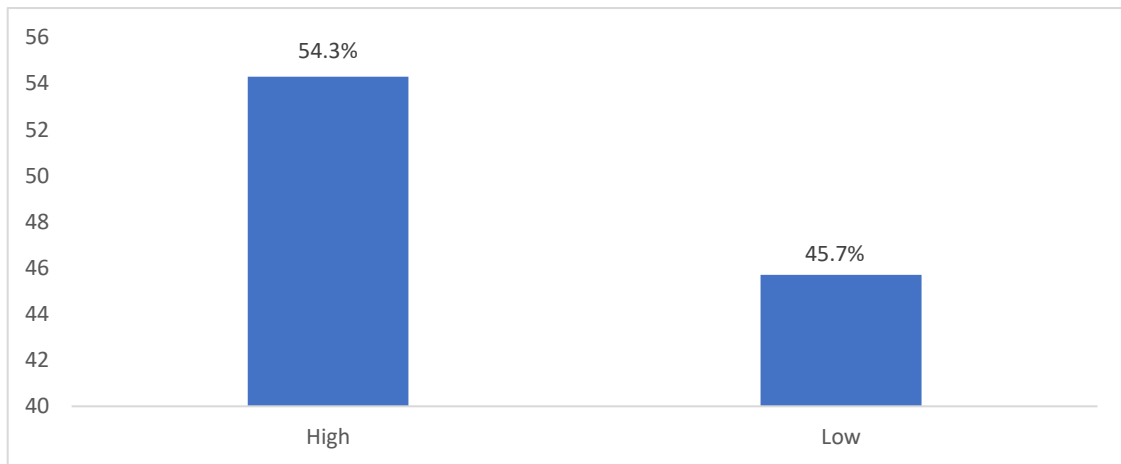


Figure 4.7: KAP of respondents on water safety

Source: Field Data (2023)

4.2.6 Heavy metal lab result

The results of the heavy metal analysis from all 20 samples consistently showed concentrations below the detection limits. The concentrations of Pb, Cd, Cr, Ni, and As were all found to be below the following respective detection limits: <0.005 mg/L, <0.002 mg/L, <0.01 mg/L, <0.01 mg/L, and <0.001 mg/L as indicated in Table 4.4. Furthermore, the WHO standards for drinking water with a permissible limit for (Pb)0.01 mg/L, (Cd)0.003 mg/L, (Cr)0.05 mg/L, (Ni)0.02 mg/L, and (As)0.01 mg/L.

Table 4.4: Health risk assessment of heavy metals

Zones	N	Pb (mg/L)	Cd (mg/L)	Cr (mg/L)	Ni (mg/L)	As (mg/L)
Zone A	5	<0.005	<0.002	<0.01	<0.01	<0.001
Zone B	5	<0.005	<0.002	<0.01	<0.01	<0.001
Zone C	5	<0.005	<0.002	<0.01	<0.01	<0.001
Zone D	5	<0.005	<0.002	<0.01	<0.01	<0.001
DL		0.005	0.002	0.01	0.01	0.001
WHO		0.01	0.003	0.05	0.02	0.01
Drinking Water standards						

DL: Detection Limit

Source: Field Data (2023)

4.3 Discussion of Findings

4.3.1 Sanitary risk assessment

The collected data for this study on sanitary risk factors for the assessed wells offers valuable insights into the possible sources of contamination and health hazards connected with the well water supply. Each risk factor highlights a specific aspect that requires attention and intervention to guarantee the community's access to safe and high-quality water.

A notable observation was the relatively high percentage of wells with a latrine located within 10 meters. This proximity raises concerns about the potential for human waste to seep into the well water, necessitating the immediate reevaluation of latrine placement to mitigate contamination risks. Furthermore, the presence of other pollution sources within proximity underscores the need for sanitation strategies that address both latrine placement and the proper disposal of animal excreta and rubbish as discussed in the scholarly work by Brown (2022). An interesting consideration arises from the fact that a substantial percentage of wells have a latrine uphill or on higher ground. As discussed in the scholarly work by Kirori *et al.* (2022) found that the safe separation distance between a latrine seepage point and the well controls the most significant hazard influencing the severity of faecal pollution. It was shown that a safe separation distance cannot be reached because of the current hydro-geological circumstances and the density of the well and sanitation system. Consequently, septic tank effluent quality must be greatly improved. The alarming statistic of poor or absence of drainage system highlights a prevalent challenge that significantly impacts water quality. This can contaminate underground water, emphasizing the urgent need for improved drainage systems and proper maintenance practices. This

finding agrees with similar studies by Allaire *et al.* (2018) who evaluated national trends in drinking water quality violations.

The presence of wells under or near trees raises concerns about potential leaf and debris accumulation, which can compromise water quality. Regular maintenance and tree management are imperative to prevent organic matter from entering the well and contaminating the water supply (Tchórzewska-Cieślak *et al.*, 2022). The high percentage of wells lacking a concrete floor indicates a widespread issue that can contribute to contamination from surface water and other pollutants. Yousuf *et al.* (2021) in their article “A comprehensive review on the loss of wellbore integrity due to cement failure and available remedial methods” discovered that the absence of concrete floors can contribute to contamination from surface water and other pollutants. Implementing concrete floors could be a fundamental step in reducing the risk of contaminants infiltrating the well (Yazdan *et al.*, 2020).

Perhaps the most critical finding was that all assessed wells had inadequate depth. This all-encompassing risk factor underscores the vulnerability of well water to contamination from surrounding soil and water sources. Supporting this finding, Baloch *et al.* (2021) emphasized in their research that, the groundwater raised to the surface and shallow did not meet the current regulatory quality requirements as Adeyeye *et al.* (2020) also discovered that the majority of the wells in their investigation did not match the standard requirements for contemporary hand-dug wells. Therefore, urgent measures, such as well-lining improvements and repairs, are essential to safeguard the community's water supply. As discussed in the scholarly work by Khalifeh and Saasen (2020) the need for well covers (Table 4.2) is another crucial aspect in preventing surface water and pollutants from

entering the well. Installing proper covers should be a priority to ensure the integrity of the well water (Khalifeh & Saasen, 2020).

4.3.2 Sanitary Risk Scoring

The conducted sanitary risk assessment had provided valuable visions into the possible contamination risks associated with the wells in the study area. The results reveal a range of sanitary risk factors that warrant attention and intervention to ensure the safety and quality of the well water supply. Concerning observation from the assessment was the presence of wells categorized as having a Very High Risk. These wells, exhibited multiple severe sanitary risk factors that significantly increase the chance of water contamination. The “High-Risk” category, indicated a prevalent concern for water contamination. While not as severe as the "Very High Risk" wells, these high-risk wells still pose significant health and safety risks to the community. Addressing poor drainage, proximity to pollution sources, and well structure inadequacies are paramount to reducing contamination risks in this group. Referencing relevant publications (Krzyk & Drev, 2023; Suresh *et al.*, 2023), it becomes clear that basic rules of construction of septic tanks e.g. watertight tank linings and tile field construction for effluent treatment are ignored, compounding the problem of direct faecal contamination. Septic tank effluents are almost always close to dug wells, outweighing the impact of all other possible dangers (Ojo, 2022).

The “Moderately Risk” category, suggests a relatively lower but still noteworthy level of contamination risk. Although the risk factors may be less severe in this group, proactive measures should be taken to prevent the situation from deteriorating. Proper maintenance, regular monitoring, and potential improvements to good infrastructure can contribute to reducing contamination risks in these wells (Okoye *et al.*, 2023).

The analysis of the total coliform (TC), faecal coliform (FC), and *E. coli* variables across different zones (A, B, C, and D) indicates that there are no statistically significant differences in these parameters. The comparisons of Zone A with Zones B, C, and D for each variable yielded p-values greater than the customary significance threshold of 0.05. This implied that the observed variations in TC, FC, and *E. coli* levels between Zone A and the other zones were not statistically significant.

4.3.3 KAP on water quality

A lower percentage of respondents indicated that well water treatment did not apply to their situation. Treatment of water was done by private service providers who visit household wells and apply aqua tabs at an unspecific timeframe. According to respondents, understanding the number of aqua tabs per well through considering of volume of water in the well, testing of pH levels, turbidity and possible contaminants surrounding the wells were lost. This could place uncertainty as far as the quality of their well water is concerned. Furthermore, no test has been carried out to ascertain the effectiveness of the applied aqua tabs. Drawing on research by Vargas *et al.* (2021); and Wilson *et al.* (2019), it became clear that in order to prevent both under and over chlorination, residual chlorine must be regularly monitored. Additionally, factors like as pH and temperature must be considered, since these can also alter the disinfection intensity of residual chlorine.

The high percentage of respondents who could not recall their last well water treatment suggests a potential lack of awareness about the importance of regular treatment. Public health agencies and organizations could consider launching educational campaigns to inform well-water users about the risks associated with untreated water and the benefits of

regular treatment. Providing clear guidelines and resources for testing and treating well water can empower individuals to take proactive steps to ensure its safety.

The analysis of well water treatment frequency among respondents highlights both the need for improved awareness and the diversity of practices within this population. By addressing the challenges of recall and understanding individual perspectives on treatment, stakeholders can work together to enhance the safety and quality of well water resources for communities (Decker, 2023).

Among the reasons provided by the respondents who have considered switching to different water source, fewer proportion of respondents mentioned that the taste of the well water was a concern for them. This highlights the significance of water quality beyond just its safety. Taste plays an essential role in the overall acceptability of water for consumption and daily use. Some respondents expressed concerns about the portability of well water. This suggested potential issues with using well water for drinking and other purposes that require water to be easily transportable. Respondents who considered switching didn't provide specific reasons. This lacked of comment could indicate that they were considering switching for various unspecified reasons, or it could reflect a general feeling of dissatisfaction without pinpointing particular concerns. A substantial portion were not having any issues with their well water quality and, for that matter not considering switching to a different water.

4.3.4 Sanitary assessment and well water quality

Hand-dug wells have been implicated in various instances of microbial contamination of groundwater sources (Baia *et al.*, 2022). The results of contamination risk assessments

indicated that the shallow hand-dug wells in the study area exhibited numerous sanitary issues capable of causing contamination (see Table 4.3).

Except Zone A 004 and Zone C 004, which recorded zero results for faecal and *E. coli* presence in this study, all wells were found to be contaminated with high counts of faecal and total coliform, as well as *E. coli* bacteria. Khan (2020) and Odonkor and Mahami (2020) discovered that the presence of *E. coli* in drinking water implies the possible existence of other pathogenic microorganisms. In contrast, a recent study detected *E. coli* in 20 and total and faecal coliform in 18 water samples from shallow wells, highlighting the absence of salmonella and shigella, which are pathogenic organisms in the tested well water samples. In light of this disparity, Mahagamage & Manage (2017) and Olalemi *et al.* (2021) revealed in their study that the absence of salmonella and shigella in the well water samples, despite the presence of *E. coli*, may be attributed to variations in contamination sources, differences in environmental conditions within the well, the prevalence of specific *E. coli* strains, potential sampling variations, the effectiveness of water treatment processes, and the influence of local microbial communities.

Faecal coliforms, a subset of coliform bacteria found in the intestines of warm-blooded animals, serve as indicators of faecal contamination in water sources, signaling potential health risks. Total coliforms, a broader group of environmental bacteria, are also used to assess water quality and potential contamination, warranting further investigation when detected. *E. coli*, a common faecal coliform, is a subject of study in microbiology due to its presence in the intestines of humans and animals, with certain pathogenic strains posing health risks (Oyeniya, 2020). According to Shanker *et al.* (2020), if *E. coli* is absent, but only total coliforms are present in well water, it could mean the layer of bacteria may have

developed within the well, and surface water may be getting into the well increasing the risk of animal waste contaminating water sooner or later and well water may come from an aquifer that contains bacteria. This can happen when groundwater comes from a shallow source.

The high prevalence of these organisms in current study can be attributed to various factors, including the proximity of a latrine within 10m of a well, absence of a drainage system around the wells, well proximity to public toilets, latrines situated above wells, presence of animals' faeces and refuse, the practice of digging and burying of faeces in the house, public use well water in an open space and a path (Xue *et al.*, 2020) as they are significantly associated with contamination (*E. coli*, total and faecal coliform). It is noteworthy that in the majority of these results, the p values less than 0.005 ($p < 0.005$), suggesting a potential significant correlation between the existence of indicated parameters and the observed sanitary risk factors. Since most of the sites had several poor sanitary practices and contaminated water, it was challenging to determine the exact impact of individual practice.

Supporting these results, Ferahtia (2021) and WHO (2019) discovered that these risk factors are core drivers of well contamination. A similar study by Anang *et al.* (2023) indicated in their study that, all water samples had high faecal and total coliform counts, indicating faecal pollution possibly from the proximity to septic sewage. Additionally, the average distance between 8 households with septic tank toilets is 5.7m, with measurements ranging from 10m to 10.67m. Bhallamudi (2019) and Oyeniyi (2020) stated that establishing approved standards in peri-urban communities in developing countries that are characterized by slums or illegal settlements with sanitation conditions and

environmental issues is difficult because of a variety of factors, including hydrogeology and cultural practices regarding environmental sanitation. Consequently, there's a chance that leachate or effluents from onsite sanitation will continuously seep into neighboring wells. This can be connected to the high levels of faecal, total coliform, and *E. coli* as discovered in a recent study. Lutterodt (2018) established that the presence of these bacterial parameters in drinking water was associated with fresh faecal contamination from sewage or animals, making the wells in Aflao unwholesome and posing health risks to consumers. Water safety in homes depends on keeping hand-dug wells a safe distance from on-site sanitation (Anang *et al.*, 2023; Houéménou *et al.*, 2020; Xue *et al.*, 2020; Lutterodt *et al.*, 2018).

Furthermore, the mean depths of the 20 wells sampled for this study were 4m, (Figure 4.4) with water levels at 3.35m. The raised in water levels above the surface was due to the rainy season when this study was conducted. Similarly, as discussed in the scholarly work by Braimah (2021), microbial pathogens originating from onsite sanitation facilities or other potential sources may exhibit a propensity for minimal travel distances as they ingress into the local groundwater system, potentially contaminating nearby wells. This phenomenon is particularly pronounced in regions characterized by a high-water table and shallow well depths, as applied in this study. Furthermore, Cao *et al.* (2021) emphasized in their research that flooding caused by heavy rainfall can exacerbate the rapid transport of such pathogens into groundwater, amplifying the risk of well water contamination. Similarly, Nascimento Santos *et al.* (2023), confirmed in their study that 1,616 (21%) of the contaminated samples were significantly correlated with rainfall amount. Supporting this point, Baloch *et al.* (2021) highlighted in their research that groundwater located near the surface and at shallow depths does not meet the current regulatory quality

requirements, as Adeyeye *et al.* (2020) also found that the sanitary conditions of most of the wells in their study failed to meet the standard requirements for modern hand-dug wells, as discovered in the recent study. This generally increases the pollutant load through surface runoffs and leachates from the surrounding environment, which can be attributed to the presence of faecal and total coliform, and *E. coli*, as discovered in Zone A 001, 002, Zone B 005, Zone C 003, 004, 005, and Zone D 001, 002, 005 in this current study. The study further observed that four sample points (Zone C 003, 004 and Zone D 003, 004) were within the vicinity of a communal toilet, which has the potential to contaminate those wells, as reflected in the study results. On the other hand, an exemplary observation pertained to the deployment of standard well lining and parapet walls at all sample points, functioning as an effective barrier mechanism that delineated a protective interface between hand-dug well water and potential contaminants originating from surface run-off. Furthermore, this observation holds significance in the context of environmental hygiene, particularly given that the majority of these wells are typically situated within household premises and almost every house owned a well which might reduce the risk of contamination from neighbours. Conversely, the results of Othoo *et al.* (2023) investigation showed that 87% of the water sources they examined were shared by several nearby households, which raises the risk of pollution. The utilization of standard well lining and parapet walls assumes a paramount role in preserving the integrity of both the well water quality and the overall environmental cleanliness.

This suggested that, in general, the microbial contamination levels in the samples did not meet the specified criteria. Within each zone, there were variability in microbial contamination levels among the different samples. Local factors within the zones may influence the contamination levels.

Despite the comprehensive lab analysis, it was not feasible to calculate the health risk assessment using the provided formulae because the heavy metals concentrations reported suggested the actual concentrations of the metals were lower than the detection limits of lead, cadmium, chromium and nickel, and arsenic, of the analytical methods. As a result, the values required for health risk assessment calculations, such as the Average Daily Dose (ADD) and Cancer Risk Index (CRI), cannot be precisely determined. Furthermore, the absence of specific concentration values prevents the calculation of exposure-related parameters, including Average Daily Dose (ADD) and Cancer Risk Index (CRI) and the inability to quantify contaminant concentrations introduces significant uncertainty in health risk assessments. Moreover, the metal concentrations were consistently reported as below the minimum detection limits, a direct comparison with health-based guideline values, such as those provided by the World Health Organization (WHO), was not possible. The lack of measurable concentrations hinders the evaluation of compliance with established safety standards. In Atonsu, a suburb of Kumasi, Ghana, 12 mechanized boreholes (MBH) and 44 hand-dug wells (HDW) were used in a study by Opoku *et al.* (2020), on the concentration of heavy metals (Cr, Cd, Fe, Zn, Pb, Cu, Zn, and Mn) in drinking water. The study found that the groundwater's chemical composition varies widely in terms of salinity and ionic composition, but it is lowly mineralized (TDS \ll 1000 mg/L). Every physical-chemical parameter was below the corresponding recommended level.

Another study by Balogun *et al.* (2023), found that in certain stations, the HI for children above the safety limit, but the HQ values of heavy metals for combined pathways were below the level for adults. The average values of total carcinogenic risk index (CRI) through exposure to drinking water for children and adults were lower than 10^{-6} , indicating a negligible risk of carcinogenic elements via ingestion and dermal routes. The

characterization of the health index and cancer risk index revealed that the exposed population is generally safe and did not face any significant threat (Balogun *et al.*, 2023). Furthermore, Kulathunga *et al.* (2022) came out that, the concentrations of heavy metal(loid)s in well-water, such as Cd, As, and Pb, were below the World Health Organization (WHO) stipulated allowable limits and discovered in the recent study. In line with established literature of Ethiopia (Mohammed *et al.*, 2023), with the exception of cadmium, the average quantities of heavy metals found in the water samples were below the upper limit allowed by national and international agencies (EPA, USEPA, and WHO). The order of organ specialization for the accumulation of the chosen heavy metals was found to be liver > kidney > muscles. The results of Pearson's correlation showed that the sources of Cr and Cd were similar. Hazard quotient (HQ) and total hazard index (THI) results showed that Cu, Cr, Cd, and Pb contents were safe and might not have adverse public health effects. On the other hand Studies in Nigeria (Yahaya *et al.*, 2022; Badamasi *et al.*, 2021) discovered that the non-permissible concentrations of Pb, Fe, Cd, Cr, and pH were detected in all the water samples and the chronic daily ingestion (CDI) and hazard quotient (HQ) of the heavy metals were normal, except for Cd and Cr in children (Yahaya *et al.*, 2022). The study conducted by Badamasi *et al.* (2021), in the Riruwai mining area in Kano State, Northern Nigeria, analyzed the concentrations of heavy metals (Arsenic, Cadmium, Chromium, Mercury, Lead, and Zinc) in drinking water samples.

The mean concentrations for all metals, except in specific cases like well water samples (RGW5), exceeded the recommended limits by WHO and NSDWQ. In terms of non-carcinogenic risk assessment, Hazard Quotient (HQ) values for children were consistently higher than those for adults at all sampling stations, although they remained below one ($HQ > 1$) for both age groups. For carcinogenic risk assessment, the total cancer risk (TCR)

of Chromium, Mercury, Lead, and Zinc were within acceptable limits across all sites. However, Arsenic and Cadmium exceeded the tolerable limit in underground mining sites, mining ponds, and borehole water samples. Numerous health risk assessment studies on water from diverse sources consistently indicate a significantly elevated risk of carcinogenic effects and these results are primarily attributed to industrial activities (Kulathunga *et al.*, 2022; Badamasi *et al.*, 2021; Raja *et al.*, 2021).

Many studies explore factors influencing heavy metal concentrations in water sources including hand-dug wells. The presence of industrial or anthropogenic activities near the wells or other water sources contributes to heavy metal contamination through storm runoff and also Geological characteristics are identified as contributors to low heavy metal levels, with regions naturally low in metal concentrations yielding water with minimal contamination (Abebe *et al.*, 2023; Hızlı *et al.*, 2023; Hussain *et al.*, 2022). Therefore, the absence of industrial activities (mining, Electronic Waste Recycling, Tannery Operations, Agricultural Practices and Metal Plating and Finishing) could be a possible factor of the low detection limit of targeted heavy metals in the samples result of the recent study.

The present study, along with studies by Liao *et al.* (2021), and Abdiyev *et al.* (2023), reported low concentrations of heavy metals in groundwater from areas with sandy soils. The natural characteristics of sandy soils, including their filtration capability, adsorption capacity, and reduced leaching tendencies, make them beneficial in preventing and reducing the presence of heavy metals in underground water. These properties can contribute to the overall quality of water in regions with sandy soil, acting as a natural filtration system. Sandy soils typically have lower clay content, which reduces the potential for metal leaching. Heavy metals are less likely to be transported downward

through the soil profile, preventing their entry into the groundwater. This explains the characteristic of the soil nature in the recent study which might contribute to the safety of the well water as pointed out by works of literature. Conversely, a parallel case study conducted in the Anloga community a region within the current study area on health hazards of heavy metals in shallow groundwater, is characterized by geological features akin to those in the current investigation, identified certain sample outcomes that surpassed both the established limit and the WHO standard for heavy metal concentrations (Akoto *et al.*, 2019). It was discovered that the health risk from dermal injection of the metals was less than 1, meaning that there was no health danger from dermal absorption of the water samples. The Cd-related cancer risk values ranged from $1.82E-02$ in wells A5 to $9.09E-02$ in wells A1 and A6, suggesting that drinking water from these wells may cause an excess of 2–9 cancer cases for every 100 individuals. Additionally, it was projected that drinking water from wells A1, A2, and A5 would increase one's risk of developing cancer due to lead contamination to $3.69E-06$.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

This study delved into the sanitary conditions of hand-dug wells, community knowledge of water safety, and the presence of bacterial organisms and carcinogenic heavy metals. The results highlighted a substantial number of wells at risk due to potential contaminants, with a noteworthy proportion identified as high-risk. While heavy metal concentrations adhered to WHO standards, the detection of FC, TC and *E. coli* raised concerns about HDW water consumption. Moreover, organisms examined in the samples were noted across zones, indicating uniform contamination parameters without significance difference between study zones. Notably, the study discovered a significant association between HDW well water quality and most potential contamination sources and factors. Addressing these findings is imperative for ensuring the safe consumption of well water in the Aflao community.

5.2 Recommendation

It is recommended to promote and educate the community on effective water treatment, as well as good sanitation and hygiene practices, to prevent source contamination.

5.3 Future research direction

- i. Further studies should involve multiple sampling across different periods to capture temporal variations in water quality, providing a more comprehensive assessment of contamination trends in hand-dug wells.
- ii. Enhance water quality analysis by implementing advanced techniques, such as PCR, for comprehensive microbial detection.

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APPENDICES

Appendix I: Ethical clearance approval letter



Kwame Nkrumah
University of Science
and Technology, Kumasi

College of Health Sciences
SCHOOL OF MEDICINE AND DENTISTRY

COMMITTEE ON HUMAN RESEARCH, PUBLICATION AND ETHICS

Our Ref: CHRPE/AP/569/23

11th July 2023.

Mr. Sumaila Abdul
Department of Public Health Education
Akenten Appiah-Menka University
MAMPONG-ASHANTI.

Dear Sir,

LETTER OF APPROVAL - PROTOCOL AMENDMENT

Original Protocol Title: *"Impact of Biofl Toilet Digester Facilities on Well Water Quality in Aflao in the Ketu South Municipality."*

Amended Protocol Title: *"Risk Assessment of Well Water: A Case Study in Aflao in the Ketu South Municipality in the Volta Region of Ghana."*

Proposed Site: *Ketu-South Municipality.*

Sponsor: *Self-Sponsored.*

Your submission to the Committee on amendment to the above protocol refers.

The Committee has considered the ethical merit of your submission to amend the proposed title and approved it.

Please note that any further amendment to this approved protocol should receive prior CHRPE approval before implementation.

Thank you, Sir for your application.

Yours faithfully,

Rev. Prof. John Appiah-Poku.
Honorary Secretary
FOR: CHAIRMAN

Appendix II: Analytical report (bacterial organisms)



COUNCIL FOR SCIENTIFIC AND INDUSTRIAL RESEARCH WATER RESEARCH INSTITUTE

11th October 2023

Our Ref:

ANALYTICAL REPORT

SUMAILA ABDUL

Tel:
Attn:

Date of Arrival : 02.10.23
Time of Arrival : 09.30 a.m.
Start of Analysis : 02.10.23
End of Analysis : 04.10.23

Journal Number EBHD 10-23-13

Sample Identification	Total Coliform (TC) (cfu/100ml) Method: APHA 9222A	Faecal Coliform (FC) (cfu/100ml) Method: APHA 9222D	<i>E. coli</i> (cfu/100ml) Method: APHA 9260F	<i>Salmonella</i> spp (CFU/100ml) Method: APHA 9260D	<i>Shigella</i> spp (CFU/100ml) Method: APHA 9260D
Zone A 001	588	5	2	0	0
Zone A 002	372	13	3	0	0
Zone A 003	465	48	14	0	0
Zone A 004	558	0	0	0	0
Zone A 005	465	45	20	0	0
Zone B 001	1116	186	48	0	0
Zone B 002	372	25	16	0	0
Zone B 003	186	3	1	0	0
Zone B 004	372	7	2	0	0
Zone B 005	651	4	2	0	0
Zone C 001	32	2	1	0	0
Zone C 002	651	15	10	0	0
Zone C 003	744	6	5	0	0
Zone C 004	930	0	0	0	0
Zone C 005	279	5	3	0	0
Zone D 001	1209	45	35	0	0
Zone D 002	837	24	18	0	0
Zone D 003	744	10	6	0	0
Zone D 004	558	23	15	0	0
Zone D 005	465	186	93	0	0
Ghana Standards GS 175:2017	0	0	0	0	0
WHO Guidelines	0	0	0	0	0

Address: P. O. Box AH 38, Achimota, Ghana
Tel: (+ 233-302) 775352, 779514/5
Fax: (+ 233- 302) 777170. Email: info@csir-water.com
www.csir-water.com

Location: CSIR Premises, Airport Res. Area
Casey Hayford Road
Research Crescent
GPS : GA-018-9651

Appendix III: Analytical report (heavy metals)



Analysis Results

Water Research Institute, Environmental Chemistry Division

CSIR Premises, Airport Res. Area.

Name: Abdul Sumila

P. O. Box M. 32

Accra, Ghana.

SAMPLE	LEAD (Pb) mg/l	Cadmium (Cd) mg/l	Chromium (Cr) mg/l	Nickel (Ni) mg/l	Arsenic (As) mg/l
Z A 001	<0.005	<0.002	<0.010	<0.010	<0.001
Z A 002	<0.005	<0.002	<0.010	<0.010	<0.001
Z A 003	<0.005	<0.002	<0.010	<0.010	<0.001
Z A 004	<0.005	<0.002	<0.010	<0.010	<0.001
Z A 005	<0.005	<0.002	<0.010	<0.010	<0.001
Z B 001	<0.005	<0.002	<0.010	<0.010	<0.001
Z B 002	<0.005	<0.002	<0.010	<0.010	<0.001
Z B 003	<0.005	<0.002	<0.010	<0.010	<0.001
Z B 004	<0.005	<0.002	<0.010	<0.010	<0.001
Z B 005	<0.005	<0.002	<0.010	<0.010	<0.001
Z C 001	<0.005	<0.002	<0.010	<0.010	<0.001
Z C 002	<0.005	<0.002	<0.010	<0.010	<0.001
Z C 003	<0.005	<0.002	<0.010	<0.010	<0.001
Z C 004	<0.005	<0.002	<0.010	<0.010	<0.001
Z C 005	<0.005	<0.002	<0.010	<0.010	<0.001
Z D 001	<0.005	<0.002	<0.010	<0.010	<0.001
Z D 002	<0.005	<0.002	<0.010	<0.010	<0.001

SAMPLE	LEAD (Pb) mg/l	Cadmium (Cd) mg/l	Chromium (Cr) mg/l	Nickel (Ni) mg/l	Arsenic (As) mg/l
Z D 003	<0.005	<0.002	<0.010	<0.010	<0.001
Z D 004	<0.005	<0.002	<0.010	<0.010	<0.001
Z D 005	<0.005	<0.002	<0.010	<0.010	<0.001
WHO GUIDELINE	0.01	0.003	0.05	0.02	0.01