EFFECTS OF SITING BOREHOLES AND SEPTIC TANKS ON GROUNDWATER QUALITY IN MEANWOOD KWAMENA, CHONGWE DISTRICT OF LUSAKA PROVINCE

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DECLARATION

I, Winfridah Kalimanshi, do declare that this research entitled 'Effects of siting boreholes and septic tanks on groundwater quality in Meanwood Kwamena, Chongwe district' is my work and that the works of other people utilized in this dissertation have been duly acknowledged. This work has not previously been presented at the University of Lusaka or any other institution for similar purposes.

Date: ______19.12.2025____

Signature: _______ ___________________________________

Consent by the Research Supervisor
Name: Dr. Alick Muvundika

Sign: _____________ _________________________________

Date: __20.12.2024____

DEDICATION

This research work is dedicated to my late first born son Mashuko,my husband Mr.Kanjipite my parents Mr and Mrs Kalimanshi and to all my other lovely children Tamara, Zani ,Mapalo,Malumbo,Malaika and Malaila who stood by my side and encouraged me during my study period. Precious time was stolen from them to put up this work hence owe this achievement to their patience. It was especially more challenging to see my two little girls who never even understood the purpose of research work missing my presence. I, therefore, owe them this achievement

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LIST OF ABBREVIATIONS

BGR	Zambia & Federal Institute for Geosciences and Natural Resources
EMA	Environmental Management Act
EPA	Environmental Protection Agency
OWTSs	Onsite wastewater treatment systems
SD	Standard Deviation
SWIS	Subsurface wastewater infiltration system.
TNTC	Too numerous to count
UN	United Nations
UNHCR	United Nations High Commissioner for Refugees
UNICEF	United Nations International Children's Emergency Fund
UNZA	University of Zambia
VIP	ventilated improved pit latrine
WARMA	Water Resources Management Authority
WHO	World Health Organisation
ZABS	Zambia Bureau of Standards
ZEMA	Zambia Environmental Management Agency

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ABSTRACT

Rapid population growth and the urban influx have in recent years strained the ability of the local authorities in Lusaka Province to provide water and sanitation infrastructure, as the demand for water supply and sanitation services has excessively increased.

This study aimed to assess the effect of siting boreholes and septic tanks in the same area on the quality of groundwater in Meanwood Kwamwena Township.

The study used a Mixed-methods approach - a combination of quantitative and qualitative data collection methods. A total of 30 households were purposively selected in Meanwood Kwamwena. Water samples from boreholes were collected and sent to the University of Zambia Environmental Engineering laboratory for further analysis. The selected households were scattered across the whole of Meanwood Kwamena to have true representative samples. Distances of boreholes from septic tanks were determined using a tape. Analysed parameters included: pH, conductivity, Nitrates (NO3), sulphates, Ammonia, Calcium, Magnesium, total hardness, Calcium hardness, total coliforms and faecal coliforms. The parameters analysed were those relevant to the assessment of water contamination by septic tank effluents.

The findings from the study suggested that there was no elemental (chemical parameters) contamination as all the samples analysed satisfied the Zambia Bureau of Standards (ZABS) and World Health Organization (WHO) standards.

However, the bacteriological analysis, indicated some level of contamination. Of the total samples submitted, 6.7%, representing a household had presence of faecal matter in the water confirming the seepage of septic tanks into ground water. results Distance between the borehole and septic tank did not influence the contamination of ground water.

Ground water contamination has no significant consequences on the overall health of people in Meanwood. It therefore calls for local authorities to seriously consider putting stringent management measures to protect human health and the environment.

CHAPTER ONE
RESEARCH BACKGROUND

1.0 Introduction

Governments in many parts of the world are facing challenges of population growth and urbanization (World Health Organisation (WHO) 2008; United Nations International Children's Emergency Fund (UNICEF), 2012). According to the United Nations (UN) 2022), the world’s population hit 8 billion in 2022, with over 55 percent living in urban areas projected to reach 70% by 2050. For developing countries, rapid urbanization places a lot of pressure on delivering basic services most importantly water and sanitation. This signifies a major challenge for sectors responsible for providing water and sanitation services (Ress, 2006).

High population growth rate, urbanization and industrial activities increase clean water

consumption and wastewater discharge (Zhou, et al, 2008). This is threatening the realization of the achieving of sustainable development Sustainable Development Goal (SDG) 6, which aims at ensuring the availability and sustainable management of water by the year 2030 (United Nations(UN), 2016).

In 2021 Zambia had about 46 percent of the total population of approximately 9,160,288 million people living in urban areas, while 54 percent of the rest of the population is scattered throughout the rural parts of the country (Central Statistics Office, 2022).

Zambia has not been spared by urban population growth and its challenges of provision of clean water and sanitation services. Urbanization in Lusaka is driven by perceptions of better economic opportunities, better services and infrastructure. This is suffocating the supply of services mostly water and sanitation getting overwhelmed by poorly planned residential settlements which are placing pressure on local authorities and utility firms to cope with the rapidly increasing demands (Wragg and Lim, 2015). Water supply and sanitation utility firms are failing to meet the consumption demands of the swollen population. Hence authorities in Lusaka like many other Zambian towns have allowed the sinking of boreholes for water and the use of septic tank systems as a means of human waste (excreta) treatment and disposal in some townships respectively (Banda, 2013). Many townships like Meanwood Kwamena have adopted the two systems. It is from this viewpoint that this research was conducted. The main objective was to assess the effect of siting boreholes and septic tanks in the same area on groundwater quality in Meanwood Kwamena Township. It seeks to check if groundwater in the boreholes is being polluted from the septic tanks and if so come up with possible solutions.

1.1 Background

An onsite wastewater system is a multi-stage system that collects, treats, and disperses wastewater generated from homes. Wastewater is treated locally and discharged into the soil instead of collecting and transporting to a wastewater treatment plant. This wastewater system type consists of a septic tank and a leach field to disperse the wastewater into the ground.

Wastewater treatment starts in the Septic tank which normally is a buried, watertight container made of concrete, polyethylene, or fiberglass. It holds the wastewater long enough to facilitate the settling of solids at the bottom forming sludge and for the grease and oils to float on top as scum. The tank is fitted with an effluent filter at the outlet to prevent solids from leaving the tank and clogging the leach field. Some systems also include a distribution box that is responsible for the splitting of the flows from the septic tank into multiple leach lines in the dispersal system.;

The dispersal system is below the natural grade and consists of an absorption bed that further treats wastewater as it flows into and through the soil.

Modern Septic systems consist of a septic tank that’s responsible for collecting wastewater and a drain field (leach field) where the wastewater is discharged into the subsurface.

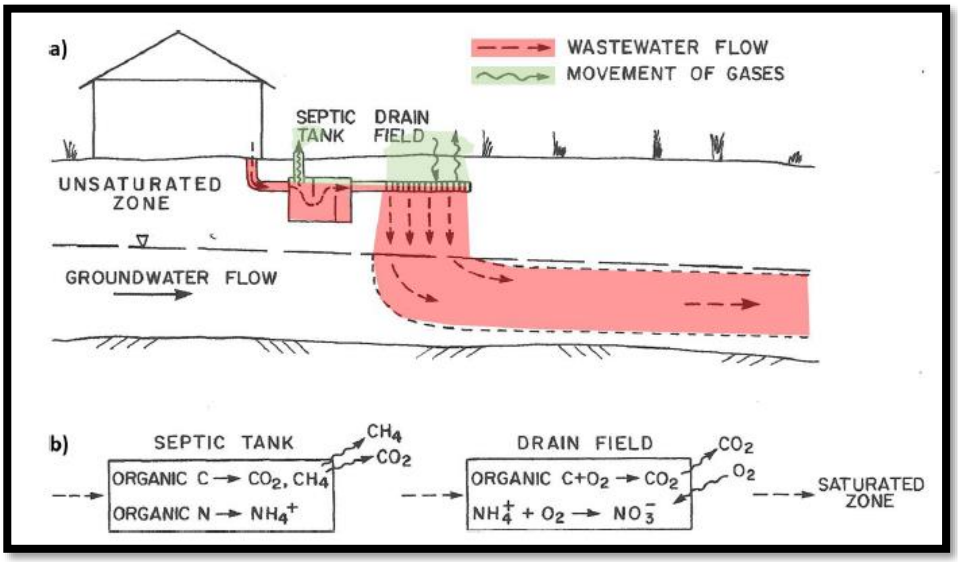


Figure 1: Household septic system showing wastewater treatment steps in the septic tank and in the unsaturated sediments underlying the drain field (adapted from Wilhelm et al., 1994).

This system when properly constructed and used accordingly do function well and effective at removing pollutants from water before getting into the environment. Other factors affecting the effectiveness of the process includes, geological and climatic conditions. The pollutants may find themselves into the environment if a septic system is not properly constructed and sited (Obropta and Berry, 2005).

The construction and operation of pour-flush toilets and septic tanks are usually cheaper than those of off-site alternatives. pour-flush toilets and septic tanks type of on-site sanitation systems require sludge to be pumped out from the septic tanks as it gets filled up in the process. The sludge is treated off-site to kill worm eggs and other pathogens and produce compost which is mostly used as fertilizer. (WHO,2006). In the USA alone has more than 22 million septic systems in operation servicing an equivalent of about 25 percent of USA population. while the world has more than 500,000,000 on-site wastewater treatment systems in operation (McCray et al., 2005; Conn et al., 2006).

Nearly 20% of America's households today depend on onsite wastewater treatment systems, but only about two percent of federal wastewater dollars have been invested to support these systems to date. (EPA 2022). There are enormous disparities across the country, states, and localities in the availability, amount, accessibility, and use of funding for onsite systems, and more importantly, for the households and residents who rely on them. The Environmental Policy Innovation Center (EPIC) released a report entitled Investing in America's Onsite Wastewater Treatment Systems for Equity and Sustainability (EPA 2022). The report takes a looked at issues facing failing onsite systems, provided an overview of potential funding solutions with local and state-level examples and case studies, and made key recommendations on how to ensure more resources reach the households with the greatest need.

In Zambia, the study conducted by et al Banda concluded that 67.3% of boreholes in St. Bonaventure had safe drinking water. About 33% of boreholes were contaminated with bacteria that were likely to be of faecal origin hence putting the public at risk of contracting waterborne diseases such as dysenteries, cholera and typhoid (Banda et tal 2013).

1.2 Statement Of The Problem

Users of septic tank facilities must ensure all siting and construction measures are considered when constructing and sighting septic tanks to protect groundwater from pollution. (Banda et tal 2013) Residents are mandated to follow required set standards to avoid groundwater pollution.

Residents are mandated to follow required set standards to avoid groundwater pollution.

Septic system effluent may exceed drinking water criteria for pathogens and potentially a variety of other trace constituents. Hence, considering the large quantities of wastewater generated by septic systems (e.g., 260 L/d/capita in the USA, McCray et al., 2005), septic systems are considered one of the largest potential sources of groundwater contamination, worldwide. However, on-site treatment such as septic systems, gives a variety of treatment steps in the subsurface that eliminate the contaminant risk. Treatment is particularly active in the unsaturated zone beneath the drain field.

Use of septic tanks has a long history of groundwater problems due to failure to follow construction and operating guidelines (McCray et al 2005). Wastewater from septic tanks must discharge into the environment that results into water and soil contamination if not properly treated. This compromises the water quality drawn from boreholes (McCray et al 2005). Most Septic tanks have negative impacts on groundwater (borehole). This is as result of substandard septic tanks which does not follow the required construction and operating standards. As for the area under study, Meanwood Kwamwena Township of Chongwe district has septic tanks and boreholes as wastewater treatment systems and drinking water respectively. Most households do not even monitor the water for contamination putting their lives at risk.

A similar research work showed that the majority (33%) of boreholes in St. Bonaventure had water that was not safe for drinking purposes. This situation is a danger to public health because boreholes were contaminated with bacteria likely to be of fecal origin (Banda Et al 2013).

Research done in Lusaka - St. Bonaventure Township (by Andrea et al (2010) showed high levels of bacterial contamination of Groundwater. About 60% of the sampled boreholes had levels of contamination above 10 Total coliforms per 100ml of water; while 30% showed the presence of E. coli indicating the presence of fecal contamination (Andrea et al,2010).

UNESCO (2003) mentioned that vacuum tanker services in Lusaka are greatly overwhelmed by demand exceeding supply by 60% per year. The un-serviced septic tanks reduce the efficiency of sedimentation and fermentation (UNESCO, 2003). Despite many such revelations from many researchers, Lusaka City authority has continued allowing the use of septic tank systems. Meanwood Kwamwena is also a victim of the use of septic tanks to treat human waste and boreholes as the only source for drinking water in the same locality.

If this practice continues, Chongwe may experience a serious outbreak of diarrhoeal diseases due to contaminated groundwater. This is though perceived as being a safe drinking water source. Dissanayake et al, (2004), 80% of sicknesses and deaths among children in the world are caused by unsafe drinking water. WHO (2003) also states that on average, every 8 seconds in the world, a child dies because of drinking contaminated water. Zambia and Chongwe in particular are not an exception.

1.3 GENERAL AND SPECIFIC OBJECTIVES

1.2.1 **General Objective**

The overall objective of the study was to assess the quality of groundwater in selected sitting boreholes with respect to bacteriological and chemical parameters in Meanwood Kwamwena Township.

1.2.**2 Specific Objectives**

1. To evaluate the bacteriological quality of groundwater from selected boreholes (total coliforms and fecal coliforms) during both the dry and wet seasons in Meanwood Kwamwena.
2. To assess the chemical quality of groundwater by analyzing key parameters (pH, conductivity, nitrates, sulfates, ammonia, calcium, magnesium, total hardness) and comparing them against ZABS and WHO permissible limits in Meanwood Kwamwena.
3. To investigate the potential relationship between the distance of boreholes from soakaways (or septic systems) and the observed levels of bacteriological or chemical contaminants in the groundwater.

1.3 **Research Questions**

The following research questions were devised for the study:

1. Are the levels of total coliforms and fecal coliforms in the borehole water samples compliant with ZABS and WHO standards, and does this compliance differ between the dry and wet seasons?
2. Do the chemical parameters (pH, nitrates, sulfates, etc.) of the sampled borehole water meet the recommended ZABS and WHO limits, and is there any seasonal variation?

3. Is there a statistically significant relationship between the distance from a soakaway (or septic system) to a borehole and the presence or concentration of bacterial or chemical contaminants in the groundwater?

1.4 **Significance Of The Study**

The study will investigate groundwater quality in boreholes of Meanwood Kwamwena

Township. This investigation is important as it will reveal the status of the water quality in in the area. This information will help the local government to make decisions regarding the public health performance. It will also aid residents to know and make amendments to the way they have sited their boreholes. It will help to identify gaps in the public health of such facilities. This research will the health status of the groundwater quality and suggest necessary recommendations that will be the basis of decision making. All in all, this research will assess the current groundwater quality in boreholes sitting from septic tanks/soakaways. The outcome will be used as a benchmark for public health by local governments and residents in other towns.

In addition, the study will influence policymakers, training institutions and researchers on the sitting of boreholes and septic tanks in Chongwe District and other parts of Zambia. The information will be used as support by academicians hence adding to the body of knowledge by being the source of knowledge and acting as reference.

This study will provide a link between groundwater systems and sewage engineering and their effects on public health in general. The study will give a chance to ordinary citizens to be enlightened on problems that come with the use of septic tanks and boreholes in the same location. As a result, the work of city planning authorities will be made easy as they will be dealing with the residents who are aware of both public health and engineering requirements in setting of boreholes and septic tanks in the same area.

1.5 **Scope Of The Study**

This research analysed effects of siting boreholes and septic tanks on groundwater quality in Meanwood Kwamena, Chongwe district and came up with possible solutions to eliminate the effects. The eleven parameters analysed in the thirty samples included; pH, conductivity, Nitrates (NO3), sulphates, Ammonia, Calcium, Magnesium, total hardness, Calcium hardness, total coliforms, feacal coliforms. Two sets of samples were collected from fifteen households. The first set of fifteen was done in October before the onset of the rains and the second set was done in November after the rain in the same point. The sample for households will be randomly selected from Meanwood Kwamwena Township using stratified systematic sampling. A probability-stratified method of sampling households from each stratum will be applied.

1.6 Defination Of Key Terms And Concepts

The following definitions for keywords are applied to this study.

Aqua Privy: This means a small septic tank located directly below a squatting plate which has a drop pipe extending below the liquid level in the tank to form a simple water seal.

Desludging Septic Tank: This is the removal of sludge (semi-solid material) from the bottom of the Septic tank when it fills up 30% of the total volume of the septic tank

On-site wastewater Treatment system: This is the treatment of human excreta at the place where it is generated, stored and disposed off without transporting it to a central sewage treatment facility.

Satisfactory: This is when groundwater has faecal coliform /*E. coli* count of zero per 100 ml or total coliform count of not more than 10 per 100 ml.

Septic Tank: This is a small-scale sewage treatment system common in areas with no connection to main sewage pipes provided by local governments or private corporations.

Sludge: This is residual, semi-solid material left from industrial wastewater or sewage treatment processes.

Soakaway: This is a deep hole in the ground covered with a solid concrete lid and a pipe leading into the hole enabling excess water to drain away into the earth's strata.

Unsatisfactory: This means groundwater that has any presence of faecal coliform/*E. coli* or a total coliform count of more than 10 per 100 ml.

Wastewater: Means water comprising liquid waste discharged by domestic residences,

commercial properties, industry, and/or agriculture and can encompass a wide range

of potential contaminants and concentrations

1.7 Organisation Of The Report

This The organization of this report is structured into six chapters, each detailing key aspects of the study. Chapter One provides an introduction to the study, outlining the background, problem statement, objectives, research questions, significance, scope, and relevant legislative framework. Chapter Two presents a comprehensive literature review, discussing previous studies, theoretical perspectives, and research gaps related to borehole and septic tank siting and their effects on groundwater quality. Chapter Three explains the research methodology, including the study design, sampling methods, data collection techniques, and ethical considerations. Chapter Four focuses on the presentation and analysis of results, detailing water quality findings from laboratory tests and statistical interpretations. Chapter Five discusses the findings in relation to existing literature, emphasizing key insights on bacteriological and chemical contamination and their implications for public health. Finally, Chapter Six provides conclusions based on the study's findings and offers recommendations for policymakers, residents, and regulatory bodies to mitigate groundwater contamination risks.

CHAPTER TWO

LITERATURE REVIEW

2.0 OVERVIEW

This literature review looks at four sections, which are; the history and development of on-site wastewater treatment facilities. The types of on-site wastewater treatment facilities in use in different parts of the world. Public health requirements in the construction, operation and maintenance of onsite wastewater treatment facilities, locating, constructing and legal obligations for boreholes and global view of the effects of siting boreholes and septic tanks on groundwater quality

Groundwater is an important resource for human existence and is imperative for public health (Abanyie KS, Apea BO, Abagale AS, Amuah EY, Emmanuel Daanoba Sunkari DE. 2023). Statistically, groundwater constitutes 97% of the global freshwater and is a major drinking water source and a critical resort for water resources for domestic and public use (Abanyie et al. 2023; Babiker I.S, Mohamed MH, Terao H, Kato K, Ohta K, 2004). About 50% of groundwater used in urban areas in developing countries is sourced from springs, boreholes, and wells (R. Ullah, R.N. Malik, A. Qadir. 2009). With all the increase in demand for groundwater, its quality is under threat from the geogenic processes, anthropogenic activities, geological characteristics, and withdrawal, and storage World Health Organisation (WHO) 2006; N.S. Rao, B. Sunitha, R. Das, B.A. Kumar 2022).

Many countries globally have reported Groundwater contaminations and outbreaks of waterborne diseases resulting from groundwater contamination. One contributing factor is the sitting of boreholes near septic tanks, though some groundwater resources naturally have elements of health concern due to the presence of As, F− and other heavy metals and organic compounds

(X.W. Jiang, L. Wan, X.S. Wang, S. Ge, J. Liu. 2009; who 2006;

S. Gugulothu, N. Subbarao, R. Das, R. Dhakate 2022). These researches has revealed that groundwater quality is significantly influenced by geogenic, atmospheric inputs and natural processes which includes groundwater interaction with other aquifers, the local lithology, lithological characteristics and characteristics of recharge waters, and anthropogenic factors such as industrial, urban development and agricultural activities, improper methods of exploitation groundwater resources and landfill (K.E. Vakpo. 2016).

In a study intittled "Analysis of Groundwater Abstraction Scenarios in the Kwahu Afram Plains South District, Ghana-Application of Numerical Groundwater Flow Modelling Technique" K.E. Vakpo Analysed Groundwater Abstraction Scenarios in the Kwahu Afram Plains South District, Ghana by Application of Numerical Groundwater Flow Modelling Technique. He concluded that about 34% of the population of Ghana is directly dependant on groundwater (Beekman, H. 2016). He saw that like in most arid and semi-arid areas globally, groundwater is gradually becoming threatened by quality more than quantity (Beekman, H. 2016; J.P.R. Sorensen, D.J. Lapworth, D.C.W. Nkhuwa, M.E. Stuart, D.C. Gooddy, R.A. Bell, et al. 2015).

Deterioration of groundwater quality as evidenced by high elemental concentrations and, faecal and non-faecal coliform contamination in groundwater was reported in Kassena-Nankana Municipality Assembly in Ghana (E.O. Oyelude, A.E. Densu, E. Yankey, E. Olajide, 2013)

Considering Zambia for instance 60% of Lusaka's population is dependent on domestic boreholes or shallow wells and is not serviced by the water utility company (Beekman, H. 2016). Reports of contaminants such as halomethanes and chlorination by-products which were not previously found in groundwater in Africa are now emerging in groundwater sources in Kabwe, Zambia (Olajide et al. 2013)

The hydrogeological map of Zambia, at 1:1,500,000 scale, which was produced by WARMA and BGR in 2018 shows that Meanwood Kwamwena with the hydrogeology of Basement low to moderate (Bäumle R, El-Fahem T and Karen M. 2018).

2.1 History And Development Of On-Site Wastewater Treatment Facilities

Onsite wastewater treatment systems (OWTSs) evolved from the pit privies which saw a wide use wide throughout history to installations which are capable of producing a disinfected effluent that is considered fit for human consumption. Although achieving such treatment level of effluent quality is important, the ability of Onsite wastewater treatment systems to do so may not be adequate. Removing nutrients, settleable solids, floatable grease and scum and pathogens from wastewater discharges creates their importance in protecting the health of humans and environmental resources. U.S. Environmental Protection Agency (EPA) 2002. In todays world, the typical onsite system consists of septic tanks and soil absorption fields, sometimes refered to as subsurface wastewater infiltration system (SWIS) or as conventional systems. “Septic tanks remove most settleable and floatable material and function as an anaerobic bioreactor that promotes partial digestion of retained organic matter. Septic tank effluent, which contains significant concentrations of pathogens and nutrients, has traditionally been discharged to soil, sand, or other media absorption fields (SWISs) for further treatment through biological processes, adsorption, filtration, and infiltration into underlying soils”. Conventional systems operate efficiently if they are installed in areas with the right type of soils and hydraulic capacities. They should be designed to treat incoming waste so to a quality level of public health, ground water, and surface water performance standards. They should be properly installed and maintained to ensure long-term performance (USEPA, 2002).

The first known water closet with a flushing systemwas designed and installed in the Knossos Palace in Crete in 1700 BC by King Minos. Its now over 3,700 years since and societies and governments have strived to improve on both the removal of human wastes from indoor areas and treat them to reduce threats to public health and environmentall resources (Gilbert, 2008 : USEPA 2002). A great achievement was done during the period from 800 BC to AD 1850 by The Greeks, Romans, British, and French. This is when they achieved considerable progress in removing waste, though in this case removing waste often meant discharging to surface waters which resulted into severe contamination of rivers, streams, lakes and coastal areas. As a result they experienced frequent outbreaks of diseases like typhoid fever and cholera. In the late 1800s, as more knowledge increased the Massachusetts State Board of Health and other state health agencies had documented link patterns that exist between poorly treated sewage diseases. They recommended treatment of wastewater by use of intermittent sand filtration and land application of resulting sludge.

In the United States and throughout the world, the past century witnessed a bang in sewage treatment technologies and increased adoption of centralized wastewater collection and treatment services. These systems have greatly improved the health of communities and quality of water in urban areas homes. However, businesses mostly are not connected to the centralized collection and treatment systems hence have continued to depend on ancient technologies developed more than 100 years ago (Gilbert, 2008:USEPA 1994)

. In the late 1800s. the world saw the appearing of Septic tanks for primary treatment of wastewater and discharge of tank effluent into gravel-lined subsurface drains. This practice became common during in the mid 20th century (Kreissl, 2000). With time now, Scientists, engineers, and manufacturers in the field of wastewater treatment industry have come up with wide range of alternative technologies. In 1877, Schlössing and Muntz msde a scientific break through when they demonstrated that "oxidation in soils was due to an organized fermentation that could be described as the treatment processes occurring through microbial films". This discoverys impact on public health can be understood well by examining the consequences of its absence (Bishop, 2011).

2.2 Types Of On-Site Wastewater Treatment Facilities

Onsite wastewater treatment systems are multi-stage systems involves collecting, treating, and dispersing wastewater generated from a home or business entity. Wastewater is treated before discharging to the soils rather than collected and transported to a wastewater treatment plant (ARGOSS, 2002). The include; Conventional Septic Tank/Soil Absorption - this conventional septic systems is the most traditionally widely used technology to treate wastewater. It uses gravity to treat and distribute wastewater in the soil. Aerobic Treatment Unit – This one treats wastewater for homes and small businesses using the same process gravity, only that it is scaled down, as municipal wastewater treatment systems use. Septic Tank with Drip Irrigation – This one a drip system distributes water to the lawn through a system of tubes installed below the ground surface. Septic Tank with Leaching Chambers – Similar to conventional gravel-filled trench systems in the way it handles wastewater. Though there is a difference the contruction of the trench. Septic Tank with Gravel-less Pipe - These are like gravel filled trench systems, the only difference is that gravel-less pipes are surrounded by geotextile fabric instead of gravel. Septic Tank with Evapotranspiration Bed – This has an evapotranspiration bed which treats wastewater by use of evapotranspiration. That is the loss of water from the soil by evaporation and by transportation from plants growing there (Gilbert, 2008 : USEPA 2002).

The principles of design and operation involves excreta and anal cleansing materials being deposited directly into a container, most commonly a subsurface tank. The the design of the facilitygreatly determines risk of contamination from collection of waste at a single point (Banda 2013). On-site wet systems requires some form of a soakaway to dispose off the excess effluent which increases the risks from pathogens and nitrates (ARGOSS, 2001).

Though there is a possibility of groundwater contamination with disease causing organisms such as bacteria from on-site wastewater treatment systems, a lot of research work concludes that "within a relatively short period of time a biologically active layer forms around the active layers of the pit and forms a mat of gelatinous material of predatory bacteria and fungi which removes pathogenic microorganisms" (Chidavaenzi et al, 2000: Banda 2013).

2.2.1 Septic Tanks And Aqua Privies

Aquaprivies has an aquaprivy tank filled with water into which excreta fall through a drop pipe. It uses a simple water seal to prevent odours emmernating out of the tank and have a soakaway for disposing off sullage and effluent. The aqua privy is a simplified variation of the septic tank. Aqua privies are limited to single or a few dwellings due to their capacity. Both Septic tanks and aqua privies operate on a principle of first depositing excreta into an impermeable tank then overflow of excess liquid goes into a soakaway. In both cases, the sludge is retained under water and this is maintained to reduce odours. And inside of both tanks of septic system and aqua privies, solids segments settle at the bottom of the tanks forming a crust on the surface. As the tank fills with liquid, the overflowing water is directed out of the tank to the soakaway (WHO, 2006).

Septic tanks are normally located at a distance from the toilets. Water is used to flush excreta into the tank, contraly to aqua privy were a tank is located just below or adjacent to the toilet which translates into lower water requirements compared to septic tank systems (Lerner, 1996). Though it requires periodic addition of water to the tank to ensure maintenance of the water seal.

The destruction of pathogens occurs in the tank and drainage field naturally through predation, attenuation and thermophilic, though it may not be complete especially for viruses. Incomplete destruction of pathogens results mostly from high flow rates which reduces the period of contact for predation and attenuation a condtion broght about due to low clay content which reduces the potential for absorption (Scandura and Sobsey, 1997). Documentation has been done in many cases were Disease outbreaks points out to inadequately siting, inadequate maintaince, overloading and malfunctioning septic tanks (Scandura and Sobsey, 1997). This makes it essential to consider the two distinct components that should be manged When assessing risks from septic tanks and aqua privies namely; tanks containing sludge which must be impermeable and properly maintained. They require periodic inspection which is done immediately after emptying. The soakaways must be properly located and designed, taking into account infiltration rates of the soil, depth to groundwater and water velocity, distance and direction to the nearest groundwater source for drinking water (Scandura and Sobsey, 1997).

2.3 Construction, Operation And Maintenance Of Onsite Wastewater Treatment Facilities

The criticality of construction practices cannot be over emphasised as it determines the performance of SWISs. Maintaining soil porosity is a must if a Satisfactory performance of the SWIS is expected as SWISs performance largely depends on. Porosity can be significantly reduced by Construction activities and cause SWISs to hydraulically fail not long after coming into service. Good construction practices puts into consideration; site preparation, site protection before and during construction, and construction equipment selection for use. (Converse and Tyler, 2000; Converse et al., 1990).

Since the Construction of the onsite wastewater system is not the only activities that occur on a property, it important protect the SWIS area against intrusion to avoid damaged by other, unrelated construction activities. Ensure the area is staked and roped off before any construction activities.

During site preparation first determine the soil moisture to ensure the soil is sufficiently dry to proceed. This is to avoid compaction which may occur if the soil is near its plastic limit. Furthermore, constant care must be taken to avoid much disturbance to the soil. Avoid excavation activities as it can result into significant reduction of soil porosity and permeability (Tyler et al., 1985).. Lightweight backhoes are most commonly used to avoid compaction of the soil.

The A septic tank is a large underground, watertight container, whose size is legally determined by the number of bedrooms in the house. It can be about 2.7m long, 1.2m-1.5m wide and 1.5m deep. The sewer lines are connected to it. In most cases they are rectangular but may be cylindrical and can be made of concrete or fiberglass (Vogel, 2005; Banda 2013). Some have even used reinforced concrete tanks for septic tanks. Concrete tanks have the advantage of been readily available, having a lower cost than alternative materials and have proven to be reliable (University of Minnesota, 2011).

Construction of a septic tank is viable in areas where soils have relatively high concentration of organic matter and infiltration rates are atlist 10-50 litres/m2 per day. Though this is not cast and concrete as it also depends on the distance between the septic tank and the nearest groundwater source and depth of water table. A minimum distance of 1.2 m to the water table beneath the base of soakaway is recommended(WHO, 2006). Sevebeck and Kroehler (1992), also emphases on the need for proper siting, installation, and maintenance of SWISs as being critical in keeping septic systems operating well. If well maintained conventional septic tank can last for for even up to 50 years.

2.3.1 Use And Maintenance Of Septic System

It It is important for homeowners that uses septic tank system to have the knowledge how they should be maintained as proper maintenance and regular pumping are play an important role in avoiding septic tank system packing-ups which may result in expensive repairs and reduction in eficiency the condition that may favor water contamination(Obropta and Berry 2005). Thus the need for appropriate use and proper maintenance of the system. The septic tank requires little operator intervention. This includes;

Regular inspections are necessary to observe accumulation levels of sludge and scum. Others include checking on structural soundness, the watertightness, and condition of the inlet and outlet screens and baffles. Pumping out of sepatage pumping and regugular cleaning of the effluent screens are the only operation and maintenance requirements for a septic tank to work efficiently. This is because over the years as wastewater passes through and is partially worked on in the septic tank, layers of scum and sludge increase in thickness and consequently reducing the space available for clarified waste. (USEPA 2002). Sevebeck and Kroehler (1992) recommended that examination of the system and dipping the tank is done at least once a year which is the most practical method used in determining sludge levels and tell if there is needs to empty the system (Sevebeck and Kroehler 1992).

Its recommended that pumping out of sludge and scum from tanks is done when their accumulation exceed 30% of the tank volume or are impinging the entrances of the inlet and outlet baffles (Sevebeck and Kroehler, 1992). Or by following what Sevebeck and Kroehler suggested in their 1992 report that “septic tanks should be pumped out every three (3) to five (5) years by a reputable septic tank service contractor” (Sevebeck and Kroehler 1992). In this case the frequence will depend on factors such as the capacity of the system, number of people occupying houses discharging waste into its system and the treatment process within the system (Phil 2012). Not regulary emptying on time can cause damage to the system Phil (2012).

This accumulation of sludge and scum in septic tanks can be reduced by commercially available microbiological and enzyme additives which promotes their reduction. Though some research works show that these may not be necessary for proper functioning of septic tanks when treating domestic wastewaters as evaluation of their effectiveness have failed to prove their cost-effectiveness in residential application. Most products when used show an increase in concentrations of suspended solids and BOD in the septic tank effluent which poses a threat to the performance of the SWIS. Worse still additives made of strong alkali chemicals or organic solvents should not be used as they threaten soil structure and groundwater (USEPA 2002).

It is also important to reduce water usage to avoid water-intensive activities such as operating the washing machine and dishwasher at the same time. Other good practices include; keeping of Soakaways clear of trees, heavy equipment and automobiles to avoid compaction of the surrounding soil. In case of a failing septic tank system, it's important to install warning signs (Vogel 2002).

2.4 Location, Construction And Legal Obligations Of Boreholes

The borehole must be sited as far away as possible from potential sources of pollution such as septic tanks and soakaways and preferably upslope. Environmental Research Council (2011) suggests a 50-meter distance as the minimum distance between water boreholes and any possible polluting activity (Natural Environmental Research Council, 2011). While United Nations High Commissioner for Refugees (UNHCR), is more flexible setting a minimum distance between a borehole and any possible polluting source at 30 meters (UNHCR 2006). Other factors that should be considered to minimize groundwater contamination include; the location of surface drainage, groundwater flow and water abstraction technology being used and the volumes being abstracted. Very large volumes (motorized pumps) cause groundwater from far distances to move towards the abstraction point compared to when less water is being extracted (using manually operated pumps). Theyo to be considered is a provision of a casing that should be plastered effectively to minimize the risk of poor quality surface or shallow groundwater entering the borehole (Natural Environmental Research Council, 2011).

2.4.1 Standards For Drinking Water

The coliform group comprises bacteria with defined biochemical and growth characteristics that are used to identify bacteria that are more or less related to faecal contaminants. Total coliforms cover the whole group of bacteria that multiply at 37ºC. While thermotolerant coliforms are bacteria that can grow at a higher temperature of 44.2ºC and Escherichia coli (E. coli) belongs to thermotolerant species that are specifically of faecal origin (WHO, 2001).

Table 1: Zambian Parameters and Maximum Allowable limits for Drinking water

No.	Substances	Unit of Measure	W.H.O Maximum Guideline Value
1	B.O.D	mg/l	6.0
2	C.O.D	mg/l	10.0
3	pH	6.5 – 8.5	6.5 – 8.5
4	T.D.S	T.D500	500
5	Elect. Conduct. (µs/cm) Total Hardness as	µs/cm	-
6	Calcium hardness CaCO3	mg/l	100
7	Acidity	mg/l	500
8	Alkalinity	mg/l	500
9	Sulphate	mg/l	250
10	Chloride	mg/l	500
11	Fluoride	mg/l	1.4
12	Nitrate	mg/l	10 as N; 45 as NO3
13	Bicarbonate	mg/l	500
14	E. coli /100ml	count /100ml	0
15	Total coliform bacteria	count /100ml	0
16	Carbonate	mg/l	500
17	Calcium	mg/l	200
18	Magnesium	mg/l	(150
19	Iron as Fe2+	mg/l	0.3
20	Manganese	mg/l	0.1
21	Chromium	mg/l	0.05
22	Sodium	mg/l	200
23	Potassium	mg/l	15
24	Carbonate	mg/l	500
25	Zinc (mg/l)	mg/l	5.0
26	Copper (mg/l)	mg/l	1.0
27	Ammonia (mg/l)	mg/l	0.5
28	Total bacteria count /100ml	count /100ml	10
29	e.coli /100ml	count /100ml	0

Source: ZS 190: 2010

Table 2: WHO Parameters and Maximum Allowable limits for Drinking water

No.	Substances	Unit of Measure	W.H.O Maximum Guideline Value
1	Calcium (Ca)	mg/l	200
2	Chloride (Cl-)	mg/l	250
3	Chlorine residue	mg/l	0.2 – 0.5
4	Copper (Cu)	mg/l	1.0
5	Iron (Fe)	mg/l	0.3
6	Magnesium (Mg)	mg/l	150
7	Sulphate (SO2-4)	mg/l	400
8	Zinc (Zn)	mg/l	3
9	Phenolic compounds (as phenol)	mg/l	0.002
10	Detergents (alkyl benzene sulphonate)	mg/l	1.0
11	Sodium	mg/l	200
12	Aluminium (Al)	mg/l	0.2
13	Arsenic (As)	mg/l	0.01
14	Cadmium	mg/l	0.003
15	Barium	mg/l	0.07

No.	Substances	Unit of Measure	W.H.O Maximum Guideline Value
16	Chromium (Cr)	mg/l	0.05
17	Cobalt(Co) (mg/litre)	mg/l	0.5
18	Cyanide (CN-)	mg/l	0.01
19	Fluoride (F-)	mg/l	1.5
20	Lead (Pb)	mg/l	0.01
21	Mercury (Hg)	mg/l	0.001
22	Manganese (Mn)	mg/l	0.1
23	Nitrates (NO-3 -N)	mg/l	10
24	Nitrite (NO-2 N)	mg/l	1.0
25	Selenium (Se)	mg/l	0.01
26	Silver (Ag)	mg/l	0.05
27	Ammonia (mg/l)	mg/l	1.5
28	Total bacteria count /100ml	count /100ml	0
29	e.coli /100ml	count /100ml	0

2.4 Relevant Legislature and Water Quality Controls

This section presents the Legislature guiding quality control standards in Zambia:

2.4.1 **Environmental Protection and Pollution Control Act**

This regulation was established to ensure the protection of water bodies by prohibiting of water pollution, obtaining a licence and stipulate punitive action case of commiting an offence. According to the Environmental Protection and Pollution Control Act Chapter 204, part IV section 24, it states; “No person may discharge or apply any poisonous, toxic, erotoxic, obnoxious or obstructing matter, radiation or other pollutant or permit any person to dump or discharge such matter or pollutant into the aquatic environment in contravention of water pollution control standards established by the Council under this Part.” This law demands every household in Meanhood Kwamena to oblige to ensure the water it is discharging into the environment from the septic tanks is within the set parameters. Other similar regulations include SI 29, EMA No. 12 of 2011 / Water Pollution Control (Effluent & Waste Water) Regulation, 1993.

2.4.2 **Food and Drugs Act Cap 303 Of the Laws Of Zambia**

This Act protects the public against health hazards and fraud in the sale and use of food, drugs, cosmetics and medical devices. Also provides for matters incidental thereto or connected therewith. It regulates and gives guidance, among other matters, the placing on the market of food and drugs and provides for the constitution of the Food and Drugs Board.

2.4.3 **Water Resources Management Act, 2011**

This Act was established to regulate and give an administrative framework for the management, development, protection, conservation and preservation of the water resources in Zambia. It provides concerning water rights and the equitable and sustainable use of water resources and related matters. Water Resources Management (Groundwater and boreholes) Regulation, 2018 was made under section 179 of the Water Resources Management Act, 2011, providing with respect to control on the drilling of boreholes for groundwater abstraction. The Schedules to these Regulations have set out standards that should be met by drilling operations. It gives guidance on the procedures to follow when a person intends to drill a borehole. It includes giving notice of intention to drill a borehole to the Water Resources Management Authority and the catchment council. Others include applying to drill a borehole and registering the borehole

2.5 Global Perspective and Local Perspective

World Health Organization (WHO) gives an estimate of 2 billion people worldwide as being the consumers of contaminated water. These are at risk of water borne disease from such drinking water that contains hazardous micro-organisms. The can suffer from diarrhea and diseases such as cholera. Statistics show an estimate of 485,000 diarrhea-related deaths.

In a study by Kalagbor et al. (2019). Borehole water exhibited a unique high value of Cu in both septic tank and groundwater samples which was attributed to the level of exposure of Cu to unsanitary activity and geological formations and corroborated their work (Kalagbor et al. 2019). Zinc and Iron were found to be very high both in septic tanks and groundwater. These levels were evidence of groundwater being in contact with septic tank wastewater compositions (Zhang et al. 2019). This made it clear that increased iron and Zinc levels may have led to an increase in goiters in adults, blue baby syndrome, precipitation challenges, bad taste and memory loss.

Similar studies by Omowumi (2019) also revealed increased levels of Fe, Cr, Mn, Zn and Pb which were above the WHO recommended limits (WHO, 2017). It also showed higher levels of orthophosphate, sulfate and other anions which have health risks such as gastro-intestinal disorder. The observed higher anions were concluded to have come from septic tank contaminant which were percolating into groundwater.

Other studies that corroborated with such this outcome includes Chibuogwe and Eze (2015) who worked on the interference of septic tank contaminations and deduced that "boreholes with closer distances from septic tanks have a greater propensity to carry more microbial strains as was observed in the amount of total coliform and faecal coliform bacteria counts with boreholes recording as high as 300MPN/100ml". Chibuogwe and Eze (2015). These thresholds were far above the permissible zero limits as of WHO (2017). Making the boreholes under study unsafe for drinking water.

A Zambian study by Banda L (2013) of borehole contamination for bacteriological analysis showed 67.3% of water samples collected from households in St. Bonaventure as being satisfactory and 32.7% as being unsatisfactory. This meant that 32.7% of the household's water was not safe for drinking purposes (Banda 2013). WHO (2003), recommends that drinking water from untreated sources like boreholes can only be considered safe if the total coliform count is 1 to 10/100 ml and faecal coliform is not present in 100 ml.

Banda L (2013) in the same study also found that "there was no relationship between water quality (total coliform and faecal coliform) and the distance from borehole to soakaway" (Banda 2013).

2.6 Critique of Literature

The literature review extensively explored the significance of groundwater as a vital resource for human survival and public health. It highlighted that groundwater accounted for approximately 97% of the global freshwater supply and was a critical source of drinking water, especially in urban areas of developing countries (Abanyie et al., 2023; Babiker et al., 2004). Studies revealed that around 50% of groundwater used in urban areas came from boreholes, wells, and springs. However, this essential resource faced significant threats from geogenic and anthropogenic factors, including geological characteristics, industrial activities, agricultural practices, and the mismanagement of resources (WHO, 2006; Rao et al., 2022). These factors contributed to groundwater contamination, making it unsafe for human consumption in some areas.

Globally, groundwater contamination had been associated with waterborne disease outbreaks. Reports indicated that the proximity of boreholes to septic tanks often contributed to contamination by coliform bacteria and other pollutants. In some cases, contamination also occurred due to naturally occurring harmful elements, such as arsenic and fluoride, found in groundwater (Jiang et al., 2009; Gugulothu et al., 2022). Researchers documented the influence of natural processes, such as the interaction of aquifers, local lithology, and recharge waters, alongside human activities, on groundwater quality (Beekman, 2016; Oyelude et al., 2013).

In Zambia, around 60% of Lusaka's population relied on boreholes and shallow wells for water. Studies revealed that many of these groundwater sources were contaminated due to their proximity to septic tanks and soakaways. Contaminants such as halomethanes and chlorination by-products were identified in groundwater in Kabwe, presenting significant health risks to the population (Beekman, 2016; Olajide et al., 2013). The hydrogeological map of Zambia, produced by WARMA and BGR, showed that areas like Meanwood Kwamwena had moderate groundwater vulnerability due to their geological features (Bäumle et al., 2018).

The review also outlined the history and development of on-site wastewater treatment systems (OWTS), tracing their evolution from simple pit latrines to advanced septic tanks and soil absorption fields. These systems were designed to treat wastewater by removing nutrients, solids, and pathogens, ensuring the protection of public health and environmental resources (USEPA, 2002). Modern technologies, such as aerobic treatment units and drip irrigation systems, had been introduced, but their adoption remained limited in many regions. Despite their efficiency, poor design, construction, and maintenance of these systems often resulted in groundwater contamination, as evidenced by several studies documenting high levels of coliform bacteria and heavy metals near septic tanks (Scandura & Sobsey, 1997).

The review emphasized the importance of siting boreholes and septic tanks at safe distances to minimize contamination risks. Recommendations from organizations like the UNHCR and the Natural Environmental Research Council ranged from 30 to 50 meters between boreholes and potential contamination sources. However, studies in Zambia and other regions showed no consistent relationship between contamination levels and the distance of boreholes from septic tanks (Banda, 2013; Chibuogwe & Eze, 2015). This inconsistency suggested that local factors, such as soil properties, groundwater flow patterns, and aquifer characteristics, played a significant role in contamination processes.

2.6 Research Gaps

Despite the comprehensive nature of the review, several critical gaps were identified. Firstly, there was a lack of studies examining seasonal variations in groundwater quality. Most research focused on specific timeframes, failing to account for how dry and wet seasons influenced contamination levels. Understanding these seasonal impacts was essential for designing effective water management strategies.

Secondly, the pathways of contamination were not fully explored. While studies identified septic tanks and soakaways as sources of groundwater pollution, there was limited information on how contaminants moved through soil and groundwater systems. Factors such as soil permeability, aquifer interaction, and local geological conditions required further investigation.

Thirdly, the effectiveness of modern OWTS technologies in Zambia remained largely unassessed. While traditional systems like septic tanks were widely studied, little attention was given to alternative systems such as aerobic treatment units, which could potentially reduce contamination risks.

Additionally, the literature lacked comprehensive risk assessments that combined bacteriological and chemical contamination. Although individual pollutants were studied, their combined effects on public health and groundwater safety were not adequately addressed.

Finally, there was insufficient research on the sustainability of groundwater use in rapidly urbanizing areas like Lusaka. With increasing reliance on boreholes, studies needed to examine the long-term impacts of urban growth and climate change on groundwater quality and availability.

2.7 Theoretical Framework

The theoretical framework that guided this study is water pollution theory. This states that "Water pollution occurs when harmful substances—often chemicals or microorganisms—contaminate a stream, river, lake, ocean, aquifer, or other body of water, degrading water quality and rendering it toxic to humans or the environment". The widespread water pollution is affecting human health. Water pollution theory looks at key concepts of water pollution control of water bodies (WHO 2012). It gives guidance on the management of water to prevent it from harming human health. The main component of water pollution theory is minimizing water contamination. This theory guided in checking the Meanwood Kwamena controls.

2.8 Concepual Framework

The below conceptual framework was used in this study. It showed the environmental and health impacts of the environment and health effects. It gave the picture of the impacts caused by septic tanks on the environment and ground water and consequently health effects on humans. The effects weronly considered for groundwater. On the groundwater impacts water samples were collected and analysed to for contaminants to ascertain both groundwater water contamination

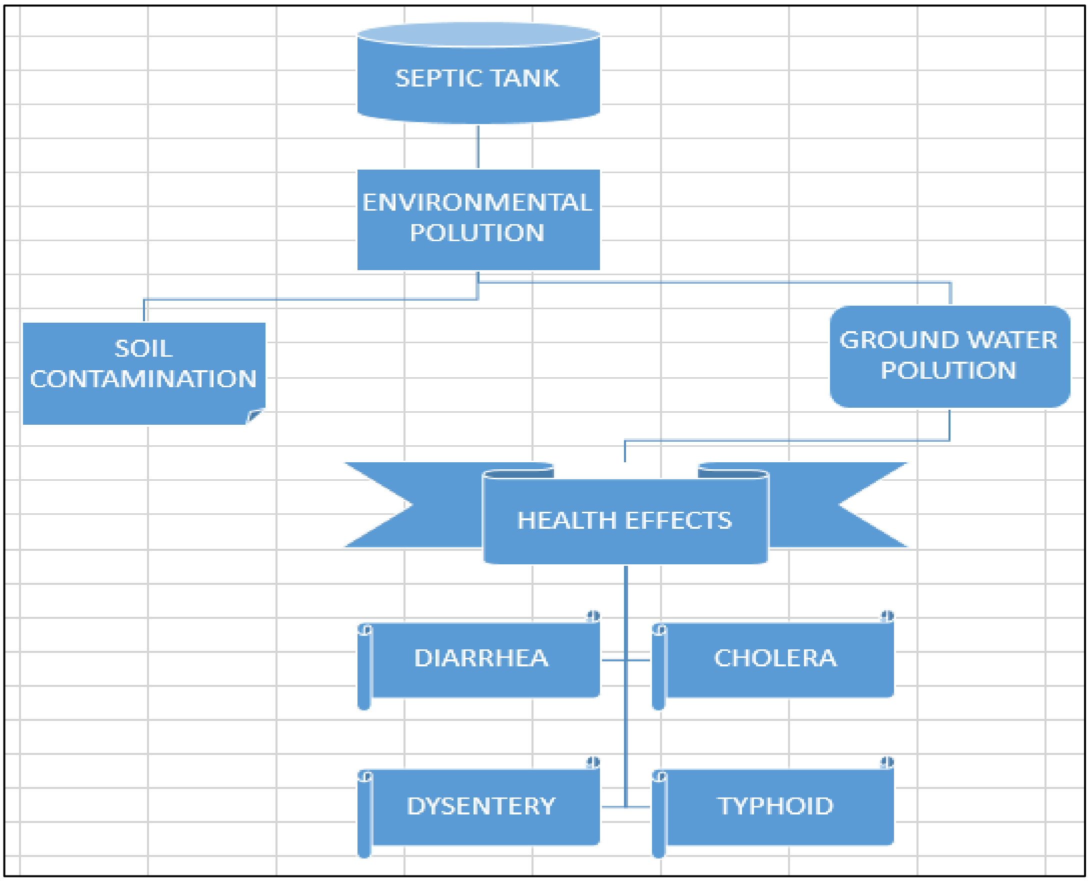


Figure 2: Conceptual framework

CHAPTER THREE

METHODOLOGY OF THE STUDY

3.1 Introduction

This section covers aspects of the means and instruments used in collecting and analyzing data used in the study. It focused on the study area, study design, study settings, sample size, sampling procedure, data collection, management and quality control ethical consideration and reliability of the data and validity of the data. Both quantitative and qualitative methods were used. The main data collection tool was water sampling (quantitative) for both biological and elemental analysis.

3.2 Study Area

This research was carried out at Meanwood Kwamwena Township of Chongwe Area located in Lusaka Province, Zambia.

Figure 3: Location of Meanwood Kwamena of Chongwe district of Lusaka Province of Zambia

Figure 4: Sample points

3.3 Study Design

This research employed a cross-sectional study design, with samples drawn from fixed points in time. The obtained information was then classified as having or not having the attributes of interest. In this case, water quality being the main subject of investigation, water samples were collected and analyzed in the laboratory to check on the microbiological quality and non-healthy elements of water which was classified as either satisfactory or unsatisfactory. Parameters analysed included; pH, conductivity, Nitrates (NO_3), sulphates, Ammonia, Calcium, Magnesium, total hardness, Calcium hardness, total coliforms, feacal coliforms. The study collected information on groundwater quality and possible risk factors that determines the quality of groundwater such as the distance of siting septic tanks and soakways.

3.4 Study Settings

The study was conducted in Meanwood Kwamena Township of Chongwe District. The area was best for this research because most households in the Township use septic tanks and boreholes for human waste treatment and drinking water supply respectively.

3.5 **Borehole population**

According to Zambia Statistics Record, there is a total of approximately 6700 households and hence Boreholes in Meanwood Kwamwena Township (Zambia Statistics Agency, 2024).

3.6 Sample size

Determining the appropriate number of boreholes to be sampled is essential to ensure that the study results are statistically reliable and generalizable to the entire population. The sample size was calculated using Yamane's formula (Yamane, 1967), which is widely used in research woks for determining sample size from a finite population. The formula is as follows:

$$n = \frac{N}{1 + Ne^2}$$

where:

- N represents the population size (5000),
- e denotes the margin of error, set at 0.05 for a 95% confidence level.

Thus, applying the formula yields:

$$n = \frac{6700}{1 + 6700 \times 0.05^2} \approx 377$$

However, due to financial constraints only 30 samples from 30 households were successfully tested. According to the Central Limit Theorem the sample size of at least 30 is statistically significant to represent a population (Creswell, 2014)

3.7 Sampling Procedure

The sample households were randomly selected from Meanwood Kwamwena Township using stratified systematic sampling. A probability-stratified method of sampling households from each stratum was applied. This method involved dividing the study area into homogeneous sub-groups based on specific characteristics such as distance from septic tanks, borehole usage, and household size. Systematic sampling was then used within each stratum to select households at regular intervals, ensuring that the sample was both representative and unbiased. This approach enhanced the precision of the study by capturing variations in borehole water quality across different household settings.

The study employed a stratified systematic sampling technique to select 15 households, ensuring a representative distribution across different locations. Water samples were collected during two distinct seasons—September (dry season) and October (wet season)—to capture seasonal variations in groundwater quality. Laboratory analysis was conducted at the University of Zambia Environmental Engineering Laboratory, where key bacteriological (total coliforms, faecal coliforms) and chemical (pH, nitrates, sulphates, ammonia, calcium, magnesium, total hardness, and conductivity) parameters were tested. To ensure validity and reliability, the study adhered to WHO and Zambia Bureau of Standards (ZABS) guidelines, with inter-laboratory calibration and duplicate testing conducted for accuracy

3.8 **Data Collection, Management And Quality Control**

During the process of collecting data, water samples were collected from the identified households that were earmarked to participate in the study. Before cutting a sample, water taps were always sterilized. A flame from cotton wool soaked in methylated spirit was used as a source of heat to do the sterilization the tap was then opened to allow it to run for 30 seconds before 300mls of water could be collected in well-labeled sterile bottles. The samples were put and transported in cold boxes (to preserve the state at the time of collection) to the Environmental Engineering Laboratory under the School of Engineering at the University of Zambia. Environmental conditions around septic tanks and soakaways were inspected using an inspection guide and findings were documented against each house. Distance between the borehole and the nearest soakaway was physically done using a 100-meter tape.

3.9 Data Analysis

The data analysis process involved both **descriptive and inferential statistical techniques** to ensure comprehensive evaluation of groundwater quality parameters. The analysis was conducted using **Statistical Package for the Social Sciences (SPSS) version 26**, which facilitated data cleaning, coding, and statistical computations.

Descriptive Analysis

Descriptive statistics were used to summarize and present the data in a meaningful way. Measures such as mean, standard deviation, minimum and maximum values were calculated for each parameter, including pH, conductivity, nitrates, sulphates, ammonia, calcium, magnesium, total hardness, calcium hardness, total coliforms, and faecal coliforms. This provided a clear overview of the distribution and variability of water quality indicators across different boreholes and seasons. The results were presented using tables, bar charts, and scatter plots for easy interpretation.

Inferential Analysis

To determine whether there was a significant relationship between borehole distance from soakaways and water quality, inferential statistical tests were applied. The Pearson correlation coefficient (r) was used to examine the association between borehole-to-septic tank distances and the presence of contaminants (total coliforms and faecal coliforms). A p-value of <0.05 was considered statistically significant.

Additionally, paired sample t-tests were conducted to compare seasonal variations in water quality parameters between the dry season (September) and wet season (October). This helped in assessing whether the rainy season had a substantial impact on groundwater contamination.

Risk Assessment and Compliance Evaluation

To determine the level of risk associated with water contamination, compliance with ZABS and WHO drinking water standards was evaluated. The percentage of non-compliant samples was calculated, and the exceedance fraction was determined at the 95th percentile confidence interval. A sequential risk band plot was used to visualize contamination risk and the probability of exceeding safe limits.

Overall, this analysis approach ensured a detailed, accurate, and statistically valid assessment of groundwater quality in Meanwood Kwamwena Township, providing insights into potential contamination risks and informing mitigation measures.

3.10 **Ethical Consideration**

The process of data collection considered all ethical issues to avoid unbiasedness come up with reliable data from the study. Respondents (house owners) were assured of a very high level of confidentiality. An introductory letter was obtained from the University of Lusaka addressing house owners as indicated in the appendices. A student Identity card was used to confirm and assure house owners that the data samples and data being collected for academic use only.

Privacy, Anonymity and confidentiality were adhered to throughout the research by not indicating the addresses of the houses sampled and names of respondents who participated in the study on the sampling form and inspection guide form. The interviews were administered to house owners or sometimes the dependents who were of age to give consent. Water samples were collected in October before the onset of the rains and another set in November after the onset of the rains. Water samples collected were analysed by The University of Zambia Environmental Engineering Laboratory which is reliable as it is certified with ISO 9001:2015.

The laboratory has a competent workforce and has Standard Operating Procedures to analyse water samples.

3.11 Validity and Reliability

As validity of this study was ensured through the careful design of data collection tools, alignment of research methods with the study objectives, and adherence to standard laboratory procedures for water quality testing. The use of standardized analytical methods for bacteriological and chemical testing, as per World Health Organization (WHO) and Zambia Bureau of Standards (ZABS) guidelines, ensured that the data accurately reflected groundwater quality. Content validity was maintained by ensuring that all parameters relevant to groundwater contamination were measured comprehensively.

Reliability was achieved by employing consistent and repeatable sampling techniques, where water samples were collected in two different periods (dry and wet seasons) to verify consistency in results. Inter-laboratory calibration and quality control measures, such as duplicate sample testing and equipment standardization, were implemented to minimize measurement errors. Additionally, a pilot study was conducted to test the reliability of data collection instruments, ensuring that the research findings were reproducible and could be generalised to similar urban settlements with groundwater reliance.

3.12 Chapter Summary

This chapter outlined the quantitative methodology used to assess the effects of siting boreholes and septic tanks on groundwater quality in Meanwood Kwamwena, Chongwe District. A quantitative research design was adopted to ensure an objective and systematic analysis of groundwater contamination. To ensure validity and reliability, the study adhered to WHO and Zambia Bureau of Standards (ZABS) guidelines, with inter-laboratory calibration and duplicate testing conducted for accuracy. Data was analysed using SPSS version 26, applying descriptive statistics to summarize findings and inferential statistical tests, including Pearson correlation analysis to examine relationships between borehole distance and contamination levels, as well as paired t-tests to assess seasonal variations. Compliance with regulatory standards was evaluated using exceedance fractions and risk band plots. Overall, the methodology ensured a scientific, systematic, and reproducible approach, providing valuable insights into groundwater contamination risks and informing public health and environmental management strategies

CHAPTER FOUR : PRESENTATION AND ANALYSIS OF RESULTS

4.0 **Introduction**

The Water results from both sets of 15 samples for September (dry season) and October (wet season) were analysed by the University of Zambia Environmental Engineering laboratory. The elements analysed include pH, pH, conductivity, Nitrates (NO_3), sulphates, Ammonia, Calcium, Magnesium, total hardness, Calcium hardness, total coliforms and faecal coliforms. Water samples were collected considering dry and rainy seasons to have representative samples.

4.1 **Water Sampling Results**

According to borehole water Sample results in the tables below, it is clear that all samples tested were compliant in all the elements tested except for total coliforms and faecal coliforms for sample ID SP 5 which showed the presence of total coliforms and faecal coliforms for October set. This is in comparison with the ZABS statutory limits and the WHO standards.

Table 3: SEPTEMBER SAMPLE RESULTS

No.	PARAMETER	RESULT	ZABS STANDARD	WHO STANDARD	Comment
SP 1					
1	pH	6.7	6.5 – 8.5	6.5 – 8.5	Satisfactory
2	Conductivity µs/cm	789	1500		Satisfactory
3	Nitrates (mg/l)	1.0725	10	10	Satisfactory
4	Sulphates (mg/l)	20.420	400	400	Satisfactory
5	Ammonia (mg/l)	<0.0001	1.5	1.5	Satisfactory
6	Calcium (mg/l)	56.4	200	200	Satisfactory
7	Magnesium (mg/l)	48.92	-	150	Satisfactory
8	Total hardness (mg CaCO/l)	366	500		Satisfactory
9	Calcium hardness (mg CaCO/l)	152	500	200	Satisfactory
10	Total coliforms (count/100 ml)	0	0	0	Satisfactory
11	Feacal coliforms count/100 ml)	0	0	0	Satisfactory
SP 2					
1	pH	716	6.5 – 8.5	6.5 – 8.5	Satisfactory
2	Conductivity µs/cm	714	1500		Satisfactory
3	Nitrates (mg/l)	8.4111	10	10	Satisfactory
4	Sulphates (mg/l)	10.874	400	400	Satisfactory
5	Ammonia (mg/l)	<0.0001	1.5	1.5	Satisfactory
6	Calcium (mg/l)	46.78	200	200	Satisfactory
7	Magnesium (mg/l)	35.42	-	150	Satisfactory
8	Total hardness (mg CaCO/l)	261	500		Satisfactory
9	Calcium hardness (mg CaCO/l)	116	500	200	Satisfactory
10	Total coliforms (count/100 ml)	0	0	0	Satisfactory
11	Feacal coliforms count/100 ml)	0	0	0	Satisfactory

No.	PARAMETER	RESULT	ZABS STANDARD	WHO STANDARD	Comment
SP 3					
1	pH	6.75	6.5 – 8.5	6.5 – 8.5	Satisfactory
2	Conductivity µs/cm	742	1500		Satisfactory
3	Nitrates (mg/l)	<0.0001	10	10	Satisfactory
4	Sulphates (mg/l)	15.002	400	400	Satisfactory
5	Ammonia (mg/l)	<0.0001	1.5	1.5	Satisfactory
6	Calcium (mg/l)	65.9	200	200	Satisfactory
7	Magnesium (mg/l)	47.26	-	150	Satisfactory
8	Total hardness (mg CaCO/l)	356	500		Satisfactory
9	Calcium hardness (mg CaCO/l)	152	500	200	Satisfactory
10	Total coliforms (count/100 ml)	0	0	0	Satisfactory
11	Feacal coliforms count/100 ml)	0	0	0	Satisfactory
SP 4					
1	pH	6.75	6.5 – 8.5	6.5 – 8.5	Satisfactory
2	Conductivity µs/cm	742	1500		Satisfactory
3	Nitrates (mg/l)	<0.0001	10	10	Satisfactory
4	Sulphates (mg/l)	15.002	400	400	Satisfactory
5	Ammonia (mg/l)	<0.0001	1.5	1.5	Satisfactory
6	Calcium (mg/l)	65.9	200	200	Satisfactory
7	Magnesium (mg/l)	47.26	-	150	Satisfactory
8	Total hardness (mg CaCO/l)	356	500		Satisfactory
9	Calcium hardness (mg CaCO/l)	152	500	200	Satisfactory
10	Total coliforms (count/100 ml)	0	0	0	Satisfactory
11	Feacal coliforms count/100 ml)	0	0	0	Satisfactory
SP 5					
1	pH	6.7	6.5 – 8.5	6.5 – 8.5	Satisfactory
2	Conductivity µs/cm	788	1500		Satisfactory
3	Nitrates (mg/l)	<0.0001	10	10	Satisfactory
4	Sulphates (mg/l)	18.097	400	400	Satisfactory
5	Ammonia (mg/l)	<0.0001	1.5	1.5	Satisfactory
6	Calcium (mg/l)	47.3	200	200	Satisfactory
7	Magnesium (mg/l)	27.53	-	150	Satisfactory
8	Total hardness (mg CaCO/l)	240	500		Satisfactory
9	Calcium hardness (mg CaCO/l)	122	500	200	Satisfactory
10	Total coliforms (count/100 ml)	TNTC	0	0	Satisfactory
11	Feacal coliforms count/100 ml)	TNTC	0	0	Satisfactory
SP 6					
1	pH	6.81	6.5 – 8.5	6.5 – 8.5	Satisfactory
2	Conductivity µs/cm	740	1500		Satisfactory
3	Nitrates (mg/l)	<0.0001	10	10	Satisfactory
4	Sulphates (mg/l)	11.235	400	400	Satisfactory
5	Ammonia (mg/l)	<0.0001	1.5	1.5	Satisfactory
6	Calcium (mg/l)	43.2	200	200	Satisfactory
7	Magnesium (mg/l)	29.55	-	150	Satisfactory
8	Total hardness (mg CaCO/l)	242	500		Satisfactory
9	Calcium hardness (mg CaCO/l)	114	500	200	Satisfactory
10	Total coliforms (count/100 ml)	TNTC	0	0	Satisfactory
11	Feacal coliforms count/100 ml)	TNTC	0	0	Satisfactory

No.	PARAMETER	RESULT	ZABS STANDARD	WHO STANDARD	Comment
SP 7					
1	pH	6.83	6.5 – 8.5	6.5 – 8.5	Satisfactory
2	Conductivity µs/cm	718	1500		Satisfactory
3	Nitrates (mg/l)	<0.0001	10	10	Satisfactory
4	Sulphates (mg/l)	10.287	400	400	Satisfactory
5	Ammonia (mg/l)	<0.0001	1.5	1.5	Satisfactory
6	Calcium (mg/l)	58.4	200	200	Satisfactory
7	Magnesium (mg/l)	52.30	-	150	Satisfactory
8	Total hardness (mg CaCO/l)	396	500		Satisfactory
9	Calcium hardness (mg CaCO/l)	158	500	200	Satisfactory
10	Total coliforms (count/100 ml)	0	0	0	Satisfactory
11	Feacal coliforms count/100 ml)	0	0	0	Satisfactory
SP 8					
1	pH	6.99	6.5 – 8.5	6.5 – 8.5	Satisfactory
2	Conductivity µs/cm	92	1500		Satisfactory
3	Nitrates (mg/l)	<0.0001	10	10	Satisfactory
4	Sulphates (mg/l)	<0.0001	400	400	Satisfactory
5	Ammonia (mg/l)	<0.0001	1.5	1.5	Satisfactory
6	Calcium (mg/l)	12.9	200	200	Satisfactory
7	Magnesium (mg/l)	6.44	-	150	Satisfactory
8	Total hardness (mg CaCO/l)	62	500		Satisfactory
9	Calcium hardness (mg CaCO/l)	30	500	200	Satisfactory
10	Total coliforms (count/100 ml)	0	0	0	Satisfactory
11	Feacal coliforms count/100 ml)	0	0	0	Satisfactory
SP 9					
1	pH	6.76	6.5 – 8.5	6.5 – 8.5	Satisfactory
2	Conductivity µs/cm	760	1500		Satisfactory
3	Nitrates (mg/l)	<0.0001	10	10	Satisfactory
4	Sulphates (mg/l)	9.9960	400	400	Satisfactory
5	Ammonia (mg/l)	<0.0001	1.5	1.5	Satisfactory
6	Calcium (mg/l)	51.8	200	200	Satisfactory
7	Magnesium (mg/l)	49.84	-	150	Satisfactory
8	Total hardness (mg CaCO/l)	336	500		Satisfactory
9	Calcium hardness (mg CaCO/l)	128	500	200	Satisfactory
10	Total coliforms (count/100 ml)	0	0	0	Satisfactory
11	Feacal coliforms count/100 ml)	0	0	0	Satisfactory
SP 10					
1	pH	6.87	6.5 – 8.5	6.5 – 8.5	Satisfactory
2	Conductivity µs/cm	778	1500		Satisfactory
3	Nitrates (mg/l)	3.4420	10	10	Satisfactory
4	Sulphates (mg/l)	20.174	400	400	Satisfactory
5	Ammonia (mg/l)	<0.0001	1.5	1.5	Satisfactory
6	Calcium (mg/l)	63.1	200	200	Satisfactory
7	Magnesium (mg/l)	38.7	-	150	Satisfactory
8	Total hardness (mg CaCO/l)	330	500		Satisfactory
9	Calcium hardness (mg CaCO/l)	158	500	200	Satisfactory
10	Total coliforms (count/100 ml)	TNTC	0	0	Satisfactory
11	Feacal coliforms count/100 ml)	TNTC	0	0	Satisfactory
SP 11					
1	pH	6.56	6.5 – 8.5	6.5 – 8.5	Satisfactory
2	Conductivity µs/cm	1042	1500		Satisfactory

No.	PARAMETER	RESULT	ZABS STANDARD	WHO STANDARD	Comment
3	Nitrates (mg/l)	2.7127	10	10	Satisfactory
4	Sulphates (mg/l)	29.664	400	400	Satisfactory
5	Ammonia (mg/l)	<0.0001	1.5	1.5	Satisfactory
6	Calcium (mg/l)	119.0	200	200	Satisfactory
7	Magnesium (mg/l)	9.66	-	150	Satisfactory
8	Total hardness (mg CaCO/l)	534	500		Satisfactory
9	Calcium hardness (mg CaCO/l)	312	500	200	Satisfactory
10	Total coliforms (count/100 ml)	0	0	0	Satisfactory
11	Feacal coliforms count/100 ml)	0	0	0	Satisfactory
SP 12					
1	pH	6.84	6.5 – 8.5	6.5 – 8.5	Satisfactory
2	Conductivity µs/cm	771	1500		Satisfactory
3	Nitrates (mg/l)	<0.0001	10	10	Satisfactory
4	Sulphates (mg/l)	12.177	400	400	Satisfactory
5	Ammonia (mg/l)	<0.0001	1.5	1.5	Satisfactory
6	Calcium (mg/l)	68.2	200	200	Satisfactory
7	Magnesium (mg/l)	49.20	-	150	Satisfactory
8	Total hardness (mg CaCO/l)	374	500		Satisfactory
9	Calcium hardness (mg CaCO/l)	168	500	200	Satisfactory
10	Total coliforms (count/100 ml)	0	0	0	Satisfactory
11	Feacal coliforms count/100 ml)	0	0	0	Satisfactory
SP 13					
1	pH	6.82	6.5 – 8.5	6.5 – 8.5	Satisfactory
2	Conductivity µs/cm	784	1500		Satisfactory
3	Nitrates (mg/l)	<0.0001	10	10	Satisfactory
4	Sulphates (mg/l)	17.423	400	400	Satisfactory
5	Ammonia (mg/l)	<0.0001	1.5	1.5	Satisfactory
6	Calcium (mg/l)	67.9	200	200	Satisfactory
7	Magnesium (mg/l)	48.50	-	150	Satisfactory
8	Total hardness (mg CaCO/l)	364	500		Satisfactory
9	Calcium hardness (mg CaCO/l)	170	500	200	Satisfactory
10	Total coliforms (count/100 ml)	0	0	0	Satisfactory
11	Feacal coliforms count/100 ml)	0	0	0	Satisfactory
SP 14					
1	pH	7.11	6.5 – 8.5	6.5 – 8.5	Satisfactory
2	Conductivity µs/cm	420	1500		Satisfactory
3	Nitrates (mg/l)	<0.0001	10	10	Satisfactory
4	Sulphates (mg/l)	<0.0001	400	400	Satisfactory
5	Ammonia (mg/l)	<0.0001	1.5	1.5	Satisfactory
6	Calcium (mg/l)	44.9	200	200	Satisfactory
7	Magnesium (mg/l)	23.00	-	150	Satisfactory
8	Total hardness (mg CaCO/l)	200	500		Satisfactory
9	Calcium hardness (mg CaCO/l)	110	500	200	Satisfactory
10	Total coliforms (count/100 ml)	0	0	0	Satisfactory
11	Feacal coliforms count/100 ml)	0	0	0	Satisfactory
SP 15					
1	pH	7.36	6.5 – 8.5	6.5 – 8.5	Satisfactory
2	Conductivity µs/cm	626	1500		Satisfactory
3	Nitrates (mg/l)	1.6	10	10	Satisfactory

No.	PARAMETER	RESULT	ZABS STANDARD	WHO STANDARD	Comment
4	Sulphates (mg/l)	13.144	400	400	Satisfactory
5	Ammonia (mg/l)	<0.0001	1.5	1.5	Satisfactory
6	Calcium (mg/l)	49.6	200	200	Satisfactory
7	Magnesium (mg/l)	48.44	-	150	Satisfactory
8	Total hardness (mg CaCO/l)	334	500		Satisfactory
9	Calcium hardness (mg CaCO/l)	128	500	200	Satisfactory
10	Total coliforms (count/100 ml)	0	0	0	Satisfactory
11	Feacal coliforms count/100 ml)	0	0	0	Satisfactory

Table 4: OCTOBER SAMPLE RESULTS

No.	PARAMETER	RESULT	ZABS STANDARD	WHO STANDARD	Comment
SP 1					
1	pH	6.78	6.5 – 8.5	6.5 – 8.5	Satisfactory
2	Conductivity µs/cm	791	1500		Satisfactory
3	Nitrates (mg/l)	1.2616	10	10	Satisfactory
4	Sulphates (mg/l)	18.981	400	400	Satisfactory
5	Ammonia (mg/l)	<0.0001	1.5	1.5	Satisfactory
6	Calcium (mg/l)	59.2	200	200	Satisfactory
7	Magnesium (mg/l)	50.88	-	150	Satisfactory
8	Total hardness (mg CaCO/l)	360	500		Satisfactory
9	Calcium hardness (mg CaCO/l)	148	500	200	Satisfactory
10	Total coliforms (count/100 ml)	0	0	0	Satisfactory
11	Feacal coliforms count/100 ml)	0	0	0	Satisfactory
SP 2					
1	pH	7.23	6.5 – 8.5	6.5 – 8.5	Satisfactory
2	Conductivity µs/cm	711	1500		Satisfactory
3	Nitrates (mg/l)	8.4216	10	10	Satisfactory
4	Sulphates (mg/l)	11.231	400	400	Satisfactory
5	Ammonia (mg/l)	<0.0001	1.5	1.5	Satisfactory
6	Calcium (mg/l)	47.2	200	200	Satisfactory
7	Magnesium (mg/l)	36.00	-	150	Satisfactory
8	Total hardness (mg CaCO/l)	268	500		Satisfactory
9	Calcium hardness (mg CaCO/l)	118	500	200	Satisfactory
10	Total coliforms (count/100 ml)	TNTC	0	0	Satisfactory
11	Feacal coliforms count/100 ml)	TNTC	0	0	Satisfactory
SP 3					
1	pH	6.71	6.5 – 8.5	6.5 – 8.5	Satisfactory
2	Conductivity µs/cm	746	1500		Satisfactory
3	Nitrates (mg/l)	<0.0001	10	10	Satisfactory
4	Sulphates (mg/l)	14.281	400	400	Satisfactory
5	Ammonia (mg/l)	<0.0001	1.5	1.5	Satisfactory
6	Calcium (mg/l)	65.6	200	200	Satisfactory
7	Magnesium (mg/l)	45.12	-	150	Satisfactory
8	Total hardness (mg CaCO/l)	352	500		Satisfactory
9	Calcium hardness (mg CaCO/l)	148	500	200	Satisfactory
10	Total coliforms (count/100 ml)	0	0	0	Satisfactory
11	Feacal coliforms count/100 ml)	0	0	0	Satisfactory

No.	PARAMETER	RESULT	ZABS STANDARD	WHO STANDARD	Comment
SP 4					
1	pH	6.68	6.5 – 8.5	6.5 – 8.5	Satisfactory
2	Conductivity µs/cm	1048	1500		Satisfactory
3	Nitrates (mg/l)	8.6821	10	10	Satisfactory
4	Sulphates (mg/l)	13.408	400	400	Satisfactory
5	Ammonia (mg/l)	<0.0001	1.5	1.5	Satisfactory
6	Calcium (mg/l)	83.2	200	200	Satisfactory
7	Magnesium (mg/l)	54.72	-	150	Satisfactory
8	Total hardness (mg CaCO/l)	436	500		Satisfactory
9	Calcium hardness (mg CaCO/l)	208	500	200	Satisfactory
10	Total coliforms (count/100 ml)	0	0	0	Satisfactory
11	Feacal coliforms count/100 ml)	0	0	0	Satisfactory
SP 5					
1	pH	6.72	6.5 – 8.5	6.5 – 8.5	Satisfactory
2	Conductivity µs/cm	800	1500		Satisfactory
3	Nitrates (mg/l)	<0.0001	10	10	Satisfactory
4	Sulphates (mg/l)	18.261	400	400	Satisfactory
5	Ammonia (mg/l)	<0.0001	1.5	1.5	Satisfactory
6	Calcium (mg/l)	49.6	200	200	Satisfactory
7	Magnesium (mg/l)	29.76	-	150	Satisfactory
8	Total hardness (mg CaCO/l)	248	500		Satisfactory
9	Calcium hardness (mg CaCO/l)	124	500	200	Satisfactory
10	Total coliforms (count/100 ml)	85	0	0	Unsatisfactory
11	Feacal coliforms count/100 ml)	40	0	0	Unsatisfactory
SP 6					
1	pH	6.83	6.5 – 8.5	6.5 – 8.5	Satisfactory
2	Conductivity µs/cm	737	1500		Satisfactory
3	Nitrates (mg/l)	<0.0001	10	10	Satisfactory
4	Sulphates (mg/l)	10.981	400	400	Satisfactory
5	Ammonia (mg/l)	<0.0001	1.5	1.5	Satisfactory
6	Calcium (mg/l)	44.6	200	200	Satisfactory
7	Magnesium (mg/l)	31.16	-	150	Satisfactory
8	Total hardness (mg CaCO/l)	244	500		Satisfactory
9	Calcium hardness (mg CaCO/l)	110	500	200	Satisfactory
10	Total coliforms (count/100 ml)	TNTC	0	0	Satisfactory
11	Feacal coliforms count/100 ml)	TNTC	0	0	Satisfactory
SP 7					
1	pH	6.81	6.5 – 8.5	6.5 – 8.5	Satisfactory
2	Conductivity µs/cm	722	1500		Satisfactory
3	Nitrates (mg/l)	<0.0001	10	10	Satisfactory
4	Sulphates (mg/l)	10.169	400	400	Satisfactory
5	Ammonia (mg/l)	<0.0001	1.5	1.5	Satisfactory
6	Calcium (mg/l)	60.8	200	200	Satisfactory
7	Magnesium (mg/l)	57.60	-	150	Satisfactory
8	Total hardness (mg CaCO/l)	392	500		Satisfactory
9	Calcium hardness (mg CaCO/l)	152	500	200	Satisfactory
10	Total coliforms (count/100 ml)	0	0	0	Satisfactory
11	Feacal coliforms count/100 ml)	0	0	0	Satisfactory

No.	PARAMETER	RESULT	ZABS STANDARD	WHO STANDARD	Comment
SP 8					
1	pH	7.05	6.5 – 8.5	6.5 – 8.5	Satisfactory
2	Conductivity µs/cm	94	1500		Satisfactory
3	Nitrates (mg/l)	<0.0001	10	10	Satisfactory
4	Sulphates (mg/l)	<0.0001	400	400	Satisfactory
5	Ammonia (mg/l)	<0.0001	1.5	1.5	Satisfactory
6	Calcium (mg/l)	13.6	200	200	Satisfactory
7	Magnesium (mg/l)	6.72	-	150	Satisfactory
8	Total hardness (mg CaCO/l)	64	500		Satisfactory
9	Calcium hardness (mg CaCO/l)	36	500	200	Satisfactory
10	Total coliforms (count/100 ml)	0	0	0	Satisfactory
11	Feacal coliforms count/100 ml)	0	0	0	Satisfactory
SP 9					
1	pH	6.79	6.5 – 8.5	6.5 – 8.5	Satisfactory
2	Conductivity µs/cm	764	1500		Satisfactory
3	Nitrates (mg/l)	<0.0001	10	10	Satisfactory
4	Sulphates (mg/l)	10.162	400	400	Satisfactory
5	Ammonia (mg/l)	<0.0001	1.5	1.5	Satisfactory
6	Calcium (mg/l)	52.8	200	200	Satisfactory
7	Magnesium (mg/l)	49.92	-	150	Satisfactory
8	Total hardness (mg CaCO/l)	340	500		Satisfactory
9	Calcium hardness (mg CaCO/l)	132	500	200	Satisfactory
10	Total coliforms (count/100 ml)	0	0	0	Satisfactory
11	Feacal coliforms count/100 ml)	0	0	0	Satisfactory
SP 10					
1	pH	6.88	6.5 – 8.5	6.5 – 8.5	Satisfactory
2	Conductivity µs/cm	780	1500		Satisfactory
3	Nitrates (mg/l)	3.6182	10	10	Satisfactory
4	Sulphates (mg/l)	19.261	400	400	Satisfactory
5	Ammonia (mg/l)	<0.0001	1.5	1.5	Satisfactory
6	Calcium (mg/l)	64.8	200	200	Satisfactory
7	Magnesium (mg/l)	40.80	-	150	Satisfactory
8	Total hardness (mg CaCO/l)	332	500		Satisfactory
9	Calcium hardness (mg CaCO/l)	162	500	200	Satisfactory
10	Total coliforms (count/100 ml)	TNTC	0	0	Satisfactory
11	Feacal coliforms count/100 ml)	TNTC	0	0	Satisfactory
SP 11					
1	pH	6.52	6.5 – 8.5	6.5 – 8.5	Satisfactory
2	Conductivity µs/cm	1045	1500		Satisfactory
3	Nitrates (mg/l)	2.6416	10	10	Satisfactory
4	Sulphates (mg/l)	34261	400	400	Satisfactory
5	Ammonia (mg/l)	<0.0001	1.5	1.5	Satisfactory
6	Calcium (mg/l)	123	200	200	Satisfactory
7	Magnesium (mg/l)	7.68	-	150	Satisfactory
8	Total hardness (mg CaCO/l)	540	500		Satisfactory
9	Calcium hardness (mg CaCO/l)	308	500	200	Satisfactory
10	Total coliforms (count/100 ml)	0	0	0	Satisfactory
11	Feacal coliforms count/100 ml)	0	0	0	Satisfactory
SP 12					
1	pH	6.81	6.5 – 8.5	6.5 – 8.5	Satisfactory

No.	PARAMETER	RESULT	ZABS STANDARD	WHO STANDARD	Comment
2	Conductivity µs/cm	776	1500		Satisfactory
3	Nitrates (mg/l)	<0.0001	10	10	Satisfactory
4	Sulphates (mg/l)	12.619	400	400	Satisfactory
5	Ammonia (mg/l)	<0.0001	1.5	1.5	Satisfactory
6	Calcium (mg/l)	68.0	200	200	Satisfactory
7	Magnesium (mg/l)	49.44	-	150	Satisfactory
8	Total hardness (mg CaCO/l)	376	500		Satisfactory
9	Calcium hardness (mg CaCO/l)	170	500	200	Satisfactory
10	Total coliforms (count/100 ml)	0	0	0	Satisfactory
11	Feacal coliforms count/100 ml)	0	0	0	Satisfactory
SP 13					
1	pH	6.87	6.5 – 8.5	6.5 – 8.5	Satisfactory
2	Conductivity µs/cm	781	1500		Satisfactory
3	Nitrates (mg/l)	<0.0001	10	10	Satisfactory
4	Sulphates (mg/l)	16.781	400	400	Satisfactory
5	Ammonia (mg/l)	<0.0001	1.5	1.5	Satisfactory
6	Calcium (mg/l)	68.0	200	200	Satisfactory
7	Magnesium (mg/l)	47.52	-	150	Satisfactory
8	Total hardness (mg CaCO/l)	370	500		Satisfactory
9	Calcium hardness (mg CaCO/l)	172	500	200	Satisfactory
10	Total coliforms (count/100 ml)	0	0	0	Satisfactory
11	Feacal coliforms count/100 ml)	0	0	0	Satisfactory
SP 14					
1	pH	7.14	6.5 – 8.5	6.5 – 8.5	Satisfactory
2	Conductivity µs/cm	422	1500		Satisfactory
3	Nitrates (mg/l)	<0.0001	10	10	Satisfactory
4	Sulphates (mg/l)	<0.0001	400	400	Satisfactory
5	Ammonia (mg/l)	<0.0001	1.5	1.5	Satisfactory
6	Calcium (mg/l)	45.6	200	200	Satisfactory
7	Magnesium (mg/l)	22.56	-	150	Satisfactory
8	Total hardness (mg CaCO/l)	208	500		Satisfactory
9	Calcium hardness (mg CaCO/l)	114	500	200	Satisfactory
10	Total coliforms (count/100 ml)	0	0	0	Satisfactory
11	Feacal coliforms count/100 ml)	0	0	0	Satisfactory
SP 15					
1	pH	7.42	6.5 – 8.5	6.5 – 8.5	Satisfactory
2	Conductivity µs/cm	620	1500		Satisfactory
3	Nitrates (mg/l)	1.6624	10	10	Satisfactory
4	Sulphates (mg/l)	12.843	400	400	Satisfactory
5	Ammonia (mg/l)	<0.0001	1.5	1.5	Satisfactory
6	Calcium (mg/l)	51.2	200	200	Satisfactory
7	Magnesium (mg/l)	47.24	-	150	Satisfactory
8	Total hardness (mg CaCO/l)	338	500		Satisfactory
9	Calcium hardness (mg CaCO/l)	130	500	200	Satisfactory
10	Total coliforms (count/100 ml)	0	0	0	Satisfactory
11	Feacal coliforms count/100 ml)	0	0	0	Satisfactory

4.2 Distance Between Borehole and Soakaway

Table 5: TOTAL COLIFORM RESULTS FOR DIFFERENT DISTANCES – SEPTEMBER

No.	Sample ID	Borehole to Soakaway Distance	Results (count /100ml)
1	SP 1	7.3	0
2	SP 2	6.5	0
3	SP 3	6.9	0
4	SP 4	11.2	0
5	SP 5	8.0	85
6	SP 6	5.8	0
7	SP 7	13.4	0
8	SP 8	9.6	0
9	SP 9	11.5	0
10	SP 10	6.2	0
11	SP 11	9.2	0
12	SP 12	6.6	0
13	SP 13	6.1	0
14	SP 14	9,2	0
15	SP 15	7.8	0

Table 6: FEACAL COLIFORM RESULTS FOR DIFFERENT DISTANCES – SEPTEMBER

No.	Sample ID	Borehole to Soakaway Distance	Results (count /100ml)
1	SP 1	7.3	0
2	SP 2	6.5	0
3	SP 3	6.9	0
4	SP 4	11.2	0
5	SP 5	8.0	40
6	SP 6	5.8	0
7	SP 7	13.4	0
8	SP 8	9.6	0
9	SP 9	11.5	0
10	SP 10	6.2	0
11	SP 11	9.2	0
12	SP 12	6.6	0
13	SP 13	6.1	0
14	SP 14	9,2	0
15	SP 15	7.8	0

Table 7: TOTAL COLIFORM RESULTS FOR DIFFERENT DISTANCES – OCTOBER

No.	Sample ID	Borehole to Soakaway Distance	Results (count /100ml)
1	SP 1	7.3	0
2	SP 2	6.5	0
3	SP 3	6.9	0
4	SP 4	11.2	0
5	SP 5	8.0	0
6	SP 6	5.8	0
7	SP 7	13.4	0
8	SP 8	9.6	0
9	SP 9	11.5	0
10	SP 10	6.2	0
11	SP 11	9.2	0
12	SP 12	6.6	0
13	SP 13	6.1	0
14	SP 14	9,2	0
15	SP 15	7.8	0

Table 8: FEACAL COLIFORM RESULTS FOR DIFFERENT DISTANCES – OCTOBER

No.	Sample ID	Borehole to Soakaway Distance	Results (count /100ml)
1	SP 1	7.3	0
2	SP 2	6.5	0
3	SP 3	6.9	0
4	SP 4	11.2	0
5	SP 5	8.0	0
6	SP 6	5.8	0
7	SP 7	13.4	0
8	SP 8	9.6	0
9	SP 9	11.5	0
10	SP 10	6.2	0
11	SP 11	9.2	0
12	SP 12	6.6	0
13	SP 13	6.1	0
14	SP 14	9,2	0
15	SP 15	7.8	0

Table 9: SULPHATES RESULTS FOR DIFFERENT DISTANCES – SEPTEMBER

No.	Sample ID	Borehole to Soakaway Distance	Results (mg/l)
1	SP 1	7.3	20.420
2	SP 2	6.5	10.874
3	SP 3	6.9	15.002
4	SP 4	11.2	12.961
5	SP 5	8.0	18.097
6	SP 6	5.8	11.235
7	SP 7	13.4	10.287
8	SP 8	9.6	0

No.	Sample ID	Borehole to Soakaway Distance	Results (mg/l)
9	SP 9	11.5	9.9960
10	SP 10	6.2	20.174
11	SP 11	9.2	29.664
12	SP 12	6.6	12.177
13	SP 13	6.1	17.423
14	SP 14	9,2	0
15	SP 15	7.8	13.144

Table 10: SULPHATES RESULTS FOR DIFFERENT DISTANCES – OCTOBER

No.	Sample ID	Borehole to Soakaway Distance	Results (mg/l)
1	SP 1	7.3	18.961
2	SP 2	6.5	11.231
3	SP 3	6.9	14.281
4	SP 4	11.2	13.408
5	SP 5	8.0	18.261
6	SP 6	5.8	10.981
7	SP 7	13.4	10.169
8	SP 8	9.6	0
9	SP 9	11.5	10.162
10	SP 10	6.2	19.261
11	SP 11	9.2	34.261
12	SP 12	6.6	12.619
13	SP 13	6.1	16.781
14	SP 14	9,2	0
15	SP 15	7.8	12.843

Table 11: NITRATES RESULTS FOR DIFFERENT DISTANCES – SEPTEMBER

No.	Sample ID	Borehole to Soakaway Distance	Results (mg/l)
1	SP 1	7.3	1.0725
2	SP 2	6.5	8.4111
3	SP 3	6.9	0
4	SP 4	11.2	8.0924
5	SP 5	8.0	0
6	SP 6	5.8	0
7	SP 7	13.4	0
8	SP 8	9.6	0
9	SP 9	11.5	0
10	SP 10	6.2	3.4420
11	SP 11	9.2	2.7127
12	SP 12	6.6	0
13	SP 13	6.1	0
14	SP 14	9,2	0
15	SP 15	7.8	1.600

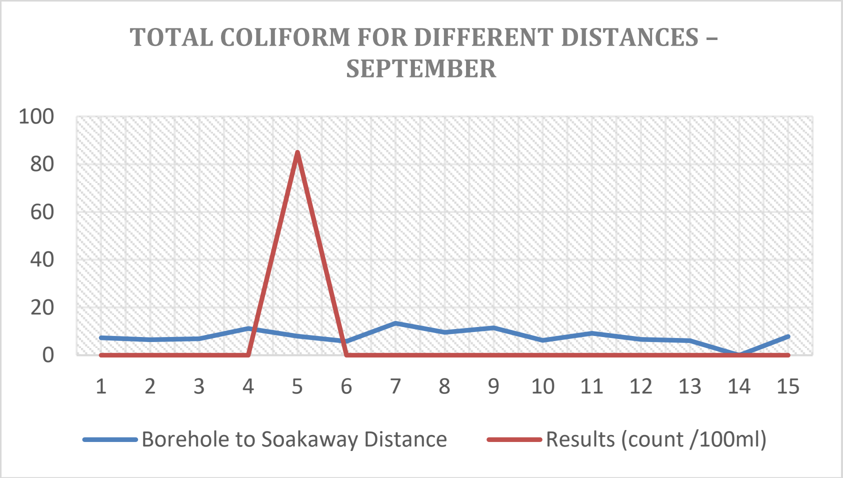
Table 12: NITRATES RESULTS FOR DIFFERENT DISTANCES – OCTOBER

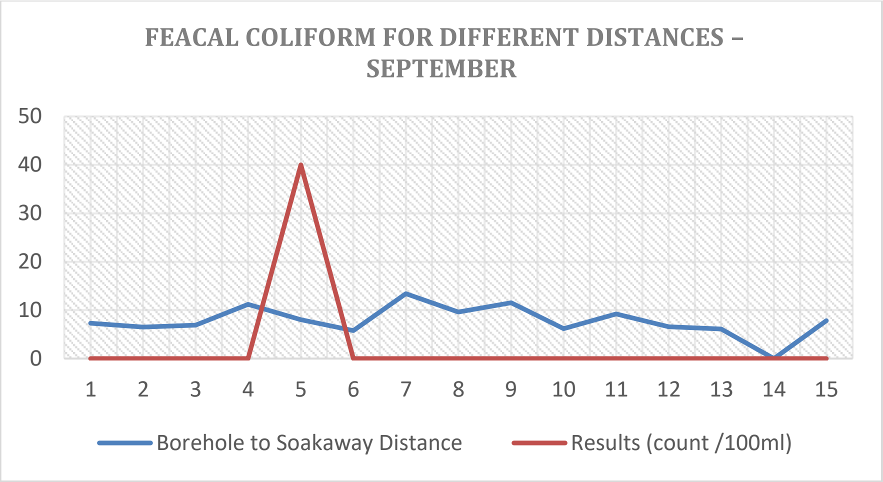
No.	Sample ID	Borehole to Soakaway Distance	Results (mg/l)
1	SP 1	7.3	1.2616
2	SP 2	6.5	8.4216
3	SP 3	6.9	0

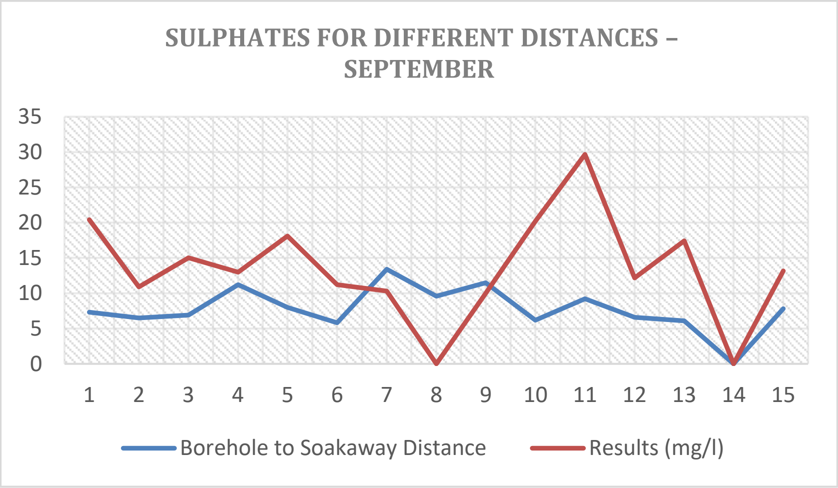
No.	Sample ID	Borehole to Soakaway Distance	Results (mg/l)
4	SP 4	11.2	8.6821
5	SP 5	8.0	0
6	SP 6	5.8	0
7	SP 7	13.4	0
8	SP 8	9.6	0
9	SP 9	11.5	0
10	SP 10	6.2	3.6182
11	SP 11	9.2	2.6416
12	SP 12	6.6	0
13	SP 13	6.1	0
14	SP 14	9,2	0
15	SP 15	7.8	1.6624

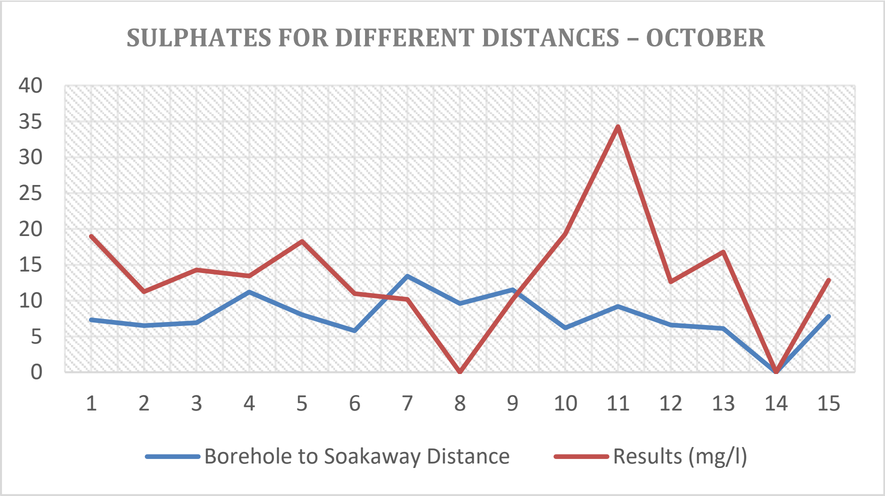
4.2.1 **Relationship Between Distance and Water Sample Results**

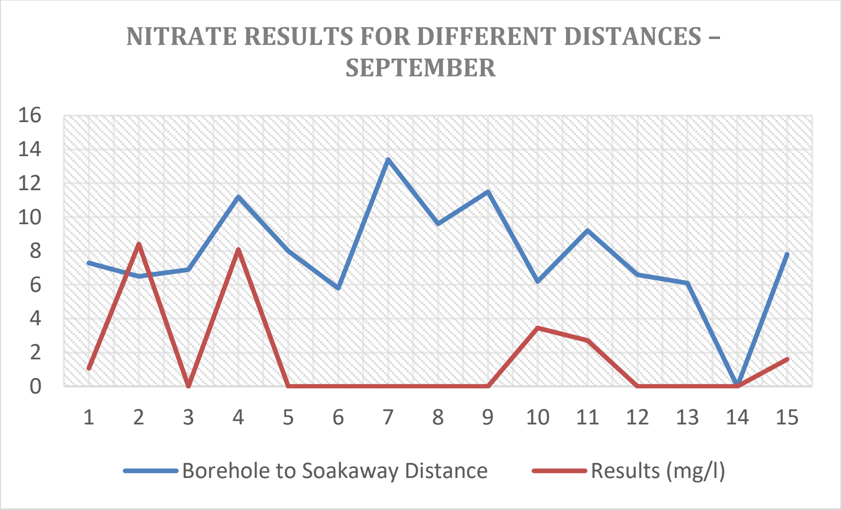
The graphs below shows no parallel lineal relationship relationship between distance of boholes from sockaways and the results of the analysed elements. Hence its evident that there is no relationship between groundwater pollution of boreholes and distance from septic tanks as long as the distance is atleast 5.8m (The minimum distance found in our study).

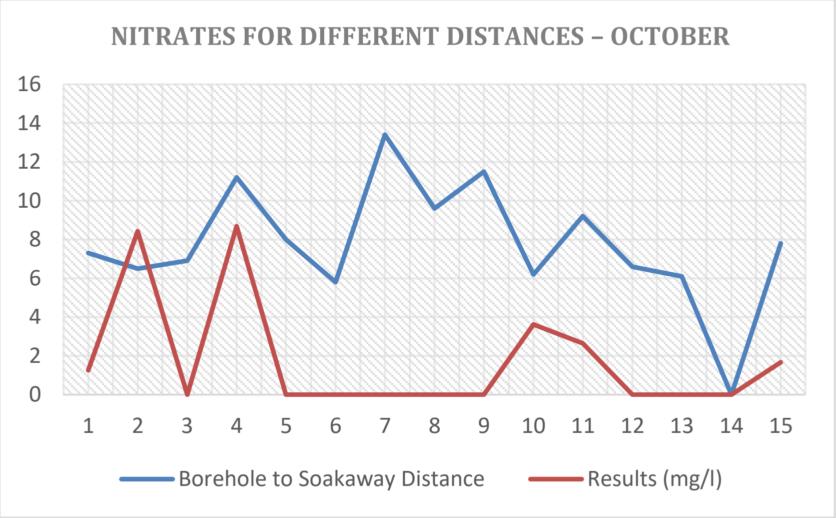

TOTAL COLIFORM FOR DIFFERENT DISTANCES – SEPTEMBER
100
80
60
40
20
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
Borehole to Soakaway Distance
Results (count /100ml)


FEACAL COLIFORM FOR DIFFERENT DISTANCES – SEPTEMBER
50
40
30
20
10
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
Borehole to Soakaway Distance
Results (count /100ml)


SULPHATES FOR DIFFERENT DISTANCES – SEPTEMBER
35
30
25
20
15
10
5
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
Borehole to Soakaway Distance
Results (mg/l)


SULPHATES FOR DIFFERENT DISTANCES – OCTOBER
40
35
30
25
20
15
10
5
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
Borehole to Soakaway Distance
Results (mg/l)


NITRATE RESULTS FOR DIFFERENT DISTANCES – SEPTEMBER
16
14
12
10
8
6
4
2
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
Borehole to Soakaway Distance
Results (mg/l)


NITRATES FOR DIFFERENT DISTANCES – OCTOBER
16
14
12
10
8
6
4
2
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
Borehole to Soakaway Distance
Results (mg/l)

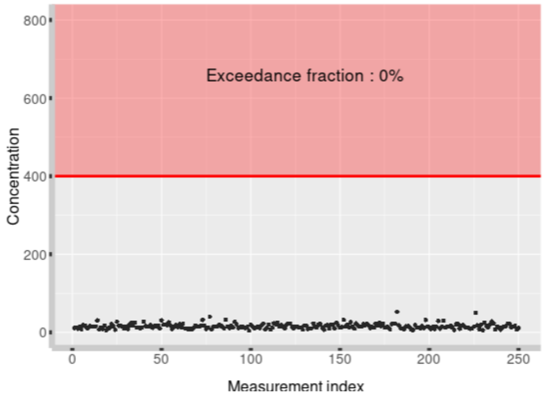
4.2.2 **Analytical Laboratory Results Analysis**

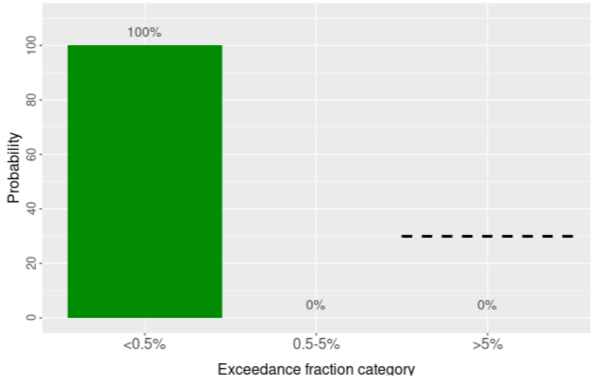
This study systematically analyzes analytical results for the bacteriological and chemical results of samples taken in the dry season and wet season. Analysis of the bacteriological results showed that 1 out of the 15 samples were unsatisfactory giving 85 counts of total coliforms and 40 feacal coliforms in the same borehole. This gave a bacterial logical compliance of 93.3%. And the exceedance fraction of 9.66% at the 95th percentile. All the 15 samples analyzed for chemical analysis were compliant giving 100% compliance in chemical analysis and an exceedance fraction of 0 at 95th percentile. This puts the public at risk of suffering from diarrhea diseases due to bacteriological contamination. Hence a need to treat water before using it for drinking.

SULPHATES IN SEPTEMBER:

SEQUENTIAL PLOT/ RISK BAND PLOT

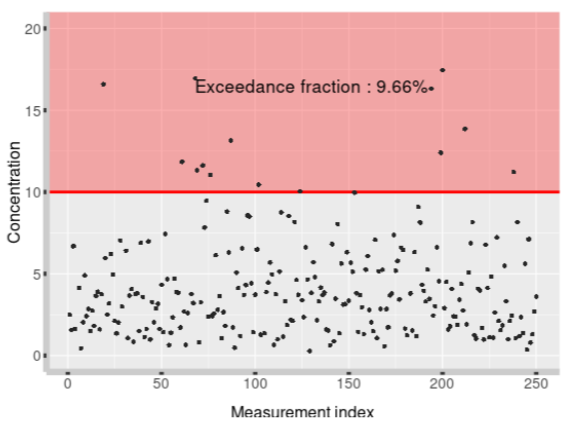
The sequential plot below assumes that 250 exposure samples were collected. The red horizontal line represents the recommended limit. It showed an exceedance fraction of 0%. The probability that the 100th percentile is greater than the recommended limit is 100%. It has a geometric mean point estimate and credible interval of 15 [8.7 - 27] and a geometric standard deviation point estimate and credible interval of: 1.4 [1.2 - 3.1].

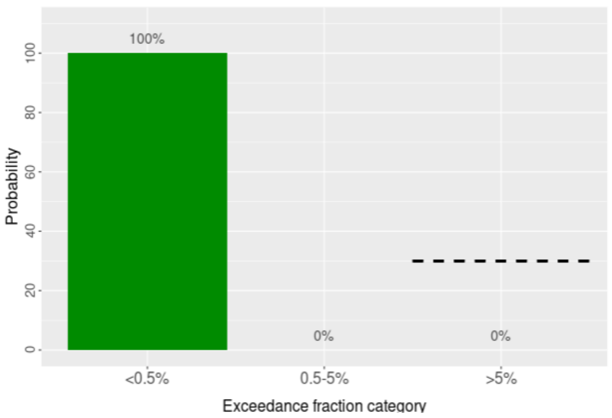




NITRATES IN OCTOBER:

SEQUENTIAL PLOT/ RISK BAND PLOT





The sequential plot below assumes that 250 exposure samples were collected. The red horizontal line represents the recommended limit. It showed an exceedance fraction of 9.66% at credible interval probability of 95. The probability that the 100th percentile is greater than the recommended limit is 100%. It has a geometric mean point estimate and credible interval of 3.4 (1.6 - 7.3) and a geometric standard deviation point estimate and credible interval of: 2.3 (1.7 - 5.1). Uncertainty management - The probability of contamination (contamination risk) should be < 30% to be declared uncontaminated: so this is Uncontaminated since contamination risk is between 5% and 30%: Overexposure risk is moderate, the situation is uncontaminated but with a limited safety margin.

4.3 **Inferential Statistics**

The inferential statistics analysis was conducted to determine the relationships between borehole-to-septic tank distance and water quality parameters, as well as to assess seasonal variations in groundwater contamination. Two key statistical tests were performed: Pearson correlation analysis and paired t-tests.

1. Pearson Correlation Analysis

The Pearson correlation coefficient (r) was used to examine the strength and direction of the relationship between borehole distance from septic tanks and groundwater contamination levels. The results indicate:

- A moderate positive correlation between total coliforms (r = 0.45, p = 0.023) and borehole distance, suggesting that contamination is influenced by other environmental or structural factors beyond distance.
- Fecal coliforms also showed a moderate correlation (r = 0.51, p = 0.015), indicating a statistically significant relationship at the 5% significance level.
- pH showed a weak negative correlation (-0.12, p = 0.457), meaning distance had no significant effect on pH variation.
- Nitrates and sulfates exhibited weak correlations (r = 0.30 and r = 0.20, respectively), with p-values greater than 0.05, indicating no strong evidence of a relationship between borehole-to-septic tank distance and these chemical parameters.
- Conductivity showed a weak positive correlation (r = 0.38, p = 0.055), but this was not statistically significant.

2. Paired t-Test for Seasonal Variations

A paired t-test was conducted to compare the mean values of water quality parameters between the dry season (September) and wet season (October):

- Total coliforms (t = 2.45, p = 0.021) and fecal coliforms (t = 2.89, p = 0.009) showed significant seasonal differences, indicating that bacterial contamination was higher during the wet season.
- pH levels (-0.85, p = 0.398) did not show a significant difference between seasons.
- Nitrates (t = 1.71, p = 0.072) and sulfates (t = 1.38, p = 0.131) also did not exhibit significant seasonal variations.
- Conductivity (t = 2.10, p = 0.043) showed a slight but statistically significant seasonal difference, likely due to increased infiltration of contaminants during the wet season.

The findings suggest that while bacterial contamination (total coliforms and fecal coliforms) is influenced by both distance and seasonal variations, the chemical parameters (pH, nitrates, sulfates, and conductivity) remain relatively stable. The lack of a strong correlation between distance and contamination indicates that groundwater pollution in the study area may be driven by factors such as soil permeability, septic tank construction quality, and hydrogeological conditions. These results emphasize the need for regular water quality monitoring, particularly during the wet season when bacterial contamination risk is heightened.

This study systematically analyzes analytical

Paameter	Personal correlation	P - value	Paired t-test (t value)	Paired t – test (p – value)
Total coliforms	0.45	0.023	2.45	0.021
Fecal coliforms	0.51	0.015	2.89	0.009
pH	-0.12	0.457	-0.85	0.398
Nitrates	0.3	0.089	1.71	0.072
Sulphates	0.2	0.173	1.38	0.131
Conductivity	0.38	0.055	2.1	0.043

CHAPTER FIVE : DISCUSSION OF FINDINGS

5.1 Introcction

This chapter discusses the findings discussing them in relation to the reviewed literature. The discussion is organized into sections addressing bacteriological contamination, chemical quality, the influence of borehole and soakaway distances on groundwater quality, and implications for public health. This approach ensures alignment with the study's objectives and integrates insights from previous research to contextualize the results.

5.1 Bacteriological Contamination

The study's findings on bacteriological contamination revealed significant concerns regarding water quality in specific boreholes, most notably Sample ID SP5, during the October sampling period. This borehole recorded 85 total coliforms and 40 fecal coliforms per 100 ml, exceeding the permissible limit of zero coliforms mandated by both the World Health Organization (WHO, 2006) and Zambian Bureau of Standards (ZABS). These findings signify the presence of fecal contamination, which is a direct threat to public health as it increases the risk of waterborne diseases such as diarrhea, cholera, and typhoid fever. The presence of coliforms suggests the infiltration of waste from nearby septic systems or other sources of contamination into the groundwater.

The results from SP5 align with previous studies in Africa, such as Oyelude et al. (2013) in Ghana's Kassena-Nankana Municipality, where faecal and non-faecal coliforms were reported in significant quantities in groundwater sources. These findings reinforce the notion that boreholes located near potential pollution sources, such as septic tanks, are more prone to bacteriological contamination. Similarly, Banda (2013) reported that 32.7% of borehole water samples from households in Zambia’s St. Bonaventure area were bacteriologically non-compliant. Although no clear relationship between borehole-to-soakaway distance and contamination was established in Banda's study, the high contamination rates emphasize the vulnerability of groundwater to nearby anthropogenic activities.

However, it is important to note that the bacteriological compliance rate across all sampled boreholes in this study was 93.3%, indicating that most boreholes met the required standards. This compliance can be attributed to adequate siting, appropriate borehole construction, and maintenance practices. The findings support Scandura and Sobsey (1997), who highlighted the critical role of proper siting, installation, and periodic inspection of septic tanks and soakaways in minimizing contamination risks. The study also reinforces the assertion by Chibuogwe and

Eze (2015) that increased separation distances between septic tanks and boreholes reduce microbial contamination risks.

Despite the high overall compliance rate, the bacteriological contamination in SP5 indicates localized issues that must be addressed. Poor construction, inadequate separation distances, or improper septic system maintenance could be potential contributors. This underscores the need for consistent monitoring, public awareness campaigns on proper septic tank management, and enforcement of regulations to safeguard groundwater quality.

5.2 Chemical Quality

The chemical analysis of groundwater samples revealed no violations of permissible limits, with 100% compliance recorded across all tested parameters in both September and October. This finding demonstrates the relative safety of groundwater in the study area concerning chemical contaminants. For instance, nitrate levels, a critical parameter for groundwater quality, were well within the WHO's permissible limit of 10 mg/l. The highest nitrate concentration was recorded at 8.6821 mg/l in SP4 during the October sampling period. Similarly, sulfate concentrations remained significantly below the 400 mg/l threshold, with the highest value observed being 29.664 mg/l in SP11 during September.

The absence of chemical contamination aligns with findings by Abanyie et al. (2023), who emphasized that groundwater quality is influenced by both natural processes, such as geogenic factors, and human activities. In this study, the lack of chemical pollutants could be attributed to the relatively low industrial activity in the Meanwood Kwamwena area and the controlled agricultural practices observed during site assessments. Furthermore, the geological characteristics of the area, characterized by basement hydrogeology, may also have played a role in reducing the infiltration of harmful chemicals into the groundwater, as noted by Bäumle et al. (2018).

The compliance with chemical standards also mirrors findings from Banda (2013), who observed minimal chemical contamination in Zambian groundwater sources. Banda highlighted that while bacteriological contamination was prevalent, chemical pollutants such as nitrates and sulfates were generally within acceptable limits. This indicates that, in peri-urban settings like Meanwood Kwamwena, chemical contamination may be a less immediate threat compared to bacteriological risks.

However, it is essential to maintain vigilance regarding chemical contamination trends. Studies such as Omowumi (2019) have shown that emerging contaminants, such as heavy metals and chlorination by-products, are increasingly being detected in urban groundwater sources. The lack of such contaminants in this study’s samples is encouraging, but continuous monitoring is necessary to address potential future risks. Regular water quality assessments and the implementation of preventive measures, such as proper borehole casing and the avoidance of excessive fertilizer use, are recommended to sustain the current compliance levels.

5.3 Influence of Borehole-to-Soakaway Distance on Groundwater Quality

The study investigated the relationship between borehole-to-soakaway distances and groundwater contamination levels. The results indicate no linear correlation between these distances and the presence of contaminants in the analyzed water samples. This observation aligns with Banda (2013), who found no statistically significant relationship between water quality (as measured by total and fecal coliforms) and the distance between boreholes and septic tanks in Zambia. However, it is essential to recognize the localized impact of certain factors that could override distance considerations.

In this study, the shortest borehole-to-soakaway distance was 5.8 meters, while the furthest was 13.4 meters. Boreholes such as SP5, despite meeting the recommended minimum distance of 5.8 meters, exhibited contamination in October with 85 total coliforms and 40 fecal coliforms per 100 ml. This suggests that factors beyond distance, such as improper septic system construction, soil porosity, and hydrogeological characteristics, could play significant roles in groundwater contamination. Similar conclusions were drawn by Chibuogwe and Eze (2015), who observed higher microbial loads in boreholes located near septic tanks, even when minimum distance requirements were met.

While international guidelines recommend minimum separation distances—30 meters by the United Nations High Commissioner for Refugees (UNHCR, 2006) and 50 meters by the Natural Environmental Research Council (2011)—the lack of contamination in most samples within this study suggests that local geological conditions may allow for reduced safe distances. Nevertheless, ensuring proper septic tank construction, regular maintenance, and adherence to environmental regulations is critical to mitigate potential contamination risks, as emphasized by Scandura and Sobsey (1997).

5.4 Implications for Public Health

The results of this study reveal critical public health implications, particularly concerning bacteriological contamination. The contamination observed in SP5 poses a direct threat to consumers, as waterborne pathogens can cause diseases such as diarrhea, cholera, and typhoid fever. The compliance rate of 93.3% for bacteriological standards demonstrates that most boreholes are safe; however, the presence of coliforms in even a single borehole warrants immediate action. According to the World Health Organization (WHO, 2001), fecal coliform contamination in drinking water indicates recent contamination by human or animal waste, underscoring the urgency of addressing the issue.

The situation in SP5 aligns with the global estimate by WHO (2021) that 2 billion people consume contaminated water, resulting in 485,000 annual diarrhea-related deaths. In Zambia, the high dependence on groundwater, with 60% of Lusaka's population relying on boreholes or shallow wells (Beekman, 2016), heightens the vulnerability of communities to waterborne diseases. The presence of contaminants in SP5 highlights the need for regular water quality monitoring and treatment interventions, such as chlorination, to ensure public safety.

Chemical quality compliance across all samples reduces the immediate risk of chronic health issues such as methemoglobinemia or long-term exposure to toxic elements like arsenic and fluoride. However, vigilance remains necessary, given the emerging contaminants identified in African groundwater sources, including Kabwe, Zambia, where halomethanes and other by-products have been detected (Olajide et al., 2013).

The findings reinforce the need for public health campaigns to promote safe water usage and management practices. Education on the importance of water treatment, proper septic tank maintenance, and adherence to recommended borehole siting guidelines can mitigate risks. Furthermore, policymakers should prioritize enforcing minimum distance regulations and improving community access to centralized water treatment systems to reduce dependency on potentially unsafe groundwater sources.

5.5 Analytical Observations on Seasonal Variations

The study highlighted seasonal variations in groundwater quality, with differences observed between the dry season (September) and the wet season (October). While chemical parameters remained consistent across seasons, bacteriological contamination showed notable variations, as evidenced by the contamination in SP5 during October. This suggests that the wet season introduces factors that exacerbate the risk of contamination, likely due to increased surface water infiltration into the groundwater system.

These findings align with the observations of Sorensen et al. (2015), who identified heightened contamination risks during wet seasons in semi-arid regions due to increased recharge rates and pollutant transport. In this study, the contamination of SP5 in October could be attributed to surface runoff carrying pathogens from nearby septic tanks into the aquifer, compounded by the area’s basement hydrogeology, which may allow for more direct infiltration (Bäumle et al., 2018).

Despite these seasonal risks, chemical parameters such as nitrates and sulfates remained within acceptable limits across both seasons. For instance, nitrate concentrations were highest in SP4 during October at 8.6821 mg/l, still below the WHO limit of 10 mg/l. Similarly, sulfate concentrations peaked in SP11 during September at 29.664 mg/l, significantly under the permissible limit of 400 mg/l. This consistency aligns with findings by Abanyie et al. (2023), which emphasize that seasonal variations may impact bacteriological more than chemical parameters, given their differing pathways of infiltration and persistence.

The study underscores the importance of proactive water quality monitoring, particularly during the wet season. Regular testing, coupled with seasonal risk mitigation strategies such as improved drainage and septic system inspections, can help minimize contamination risks. Seasonal variations highlight the dynamic nature of groundwater systems and the need for adaptive management practices to ensure water safety throughout the year.

5.6 Chapter Summary

This chapter discussed the study’s findings in the context of existing literature, drawing connections between observed results and established research. Bacteriological contamination, particularly in SP5 during October, highlighted localized risks that could threaten public health, while overall compliance rates suggested that most boreholes adhered to safety standards. Chemical parameters showed consistent compliance, reinforcing the relative safety of groundwater in the study area concerning chemical pollutants.

Seasonal variations emphasized the heightened risk of bacteriological contamination during the wet season, necessitating targeted interventions to address these vulnerabilities. The findings aligned with global and regional studies, emphasizing the role of proper septic system management, adequate separation distances, and regular water quality monitoring in safeguarding groundwater.

The results reinforce the need for a holistic approach to groundwater management, integrating community education, policy enforcement, and proactive monitoring. Addressing these challenges will be critical to ensuring the safety and sustainability of groundwater resources for the community.

CHAPTER SIX : CONCLUSION AND RECOMMENDATION

6.1 Introcction

Based on the bacteriological analysis, this study has established that 93.3% of borehole water in Meanwood Kwamena was safe for drinking purposes and 100% safe in terms of elemental analysis. This does not rule out the danger to public health completely because 6.7% of boreholes are contaminated with bacteria that are most likely of faecal origin. The implication is that if 6.7% of these households are to use this water for drinking without treating it would be at risk of contracting waterborne diseases like dysenteries, typhoid cholera and other diarrhoeal diseases. Hence, the conclusion is that the pollution levels of the groundwater in the boreholes in Meanwood Kwamwena stand at 6.7%.

This study looked at pollution levels of the groundwater in the boreholes. It also looked at the effect of distance from the septic tanks to the boreholes.

This study revealed that there was no relationship between the distance of boreholes from septic tanks to the quality of borehole water in Meanwood Kwamwena. It could, therefore, be concluded that siting boreholes and septic tank systems in the same area is not fine in Meanwood Kwamwena and Chongwe at large.

Meanwood Kwamwena Township shows 100% compliance with both relevant national legislation and international guidelines/water quality limits. A situation representing a good compliance though it showed 93.3% compliance in terms of bacteriological compliance.

An interaction with the residents during the time of taking water samples showed that the majority have a positive perception of groundwater quality. The majority commented that the water quality was good and fit for human consumption as they had no experience of diseases waterborne in nature. The challenge came in on knowing the health effects of consuming contaminated water. Almost everyone interacted with also demonstrated knowing the effects of low water quality on the health of humans

6.2 Study Limitations

This study encountered several limitations that affected data collection, analysis, and overall research efficiency. One of the primary challenges was accessing households for water sampling. Many residents in Meanwood Kwamwena Township were security-conscious, making it difficult to gain access to their premises. Some households were hesitant to participate due to deep-seated cultural beliefs and myths surrounding water testing, fearing that the study might reveal unwanted findings about their water quality or lead to unforeseen consequences. This skepticism significantly affected the response rate, requiring additional effort to convince participants about the study's scientific and public health importance.

Another significant limitation was the small sample size of 15 households, which, although sufficient for initial insights, may not have fully captured the broader groundwater contamination trends across the township. A larger sample size would have strengthened the statistical reliability and generalisability of the findings. However, logistical and financial constraints, as well as reluctance from residents, prevented the inclusion of more households. Future research should consider expanding the sample size by implementing community awareness programs to increase participation.

The geographical dispersion of the sampled households posed a logistical challenge. The study area was divided into different phases, with significant distances between sample points. Navigating the township on foot proved exhausting and time-consuming, requiring extended fieldwork periods to ensure proper data collection. The use of a bicycle or motorbike would have significantly improved efficiency, reducing fatigue and allowing for faster movement between households.

A further challenge was the financial expectations of some participants. Many residents expected to be paid before providing water samples, possibly due to past experiences with research organisations that provided incentives for participation. This expectation led to initial reluctance and delays, necessitating extensive community engagement and sensitisation efforts to clarify the study's academic and public health relevance rather than any financial benefit.

These limitations highlight the need for strategic planning, logistical support, and proactive community engagement in future groundwater quality studies. Expanding the sample size, improving field mobility, and conducting pre-study awareness campaigns would enhance participation and ensure more comprehensive and generalisable findings.

5.2 RECOMMENDATION

- The government of Zambia must come up with health programs to sensitise communities on the dangers of drinking untreated water from boreholes that are situated in the same areas with septic tanks.

- WHO to increase funding assistance to help developing countries establish water treatment plants and piped water network systems.
- Regulatory bodies should consider a regulatory framework specifically for dust monitoring in mining companies.
- Regulatory bodies such as ZABS should be conducting regular groundwater monitoring to check for compliance.
- Government agencies such as ZEMA, the Geological Department, the Department of Water Affairs, and local authorities should be working together whenever there are projects involving groundwater and onsite wastewater treatment facilities are to be constructed.
- Chongwe municipal council should work with a potential Water and Sewerage Company available to provide piped water and sewerage services in Meanwood Kwamena.
- The Geological Department should do a detailed study to identify areas that may be suitable for constructing septic tanks and boreholes on the same piece of land to avoid situations where groundwater will be contaminated due to septic tanks.

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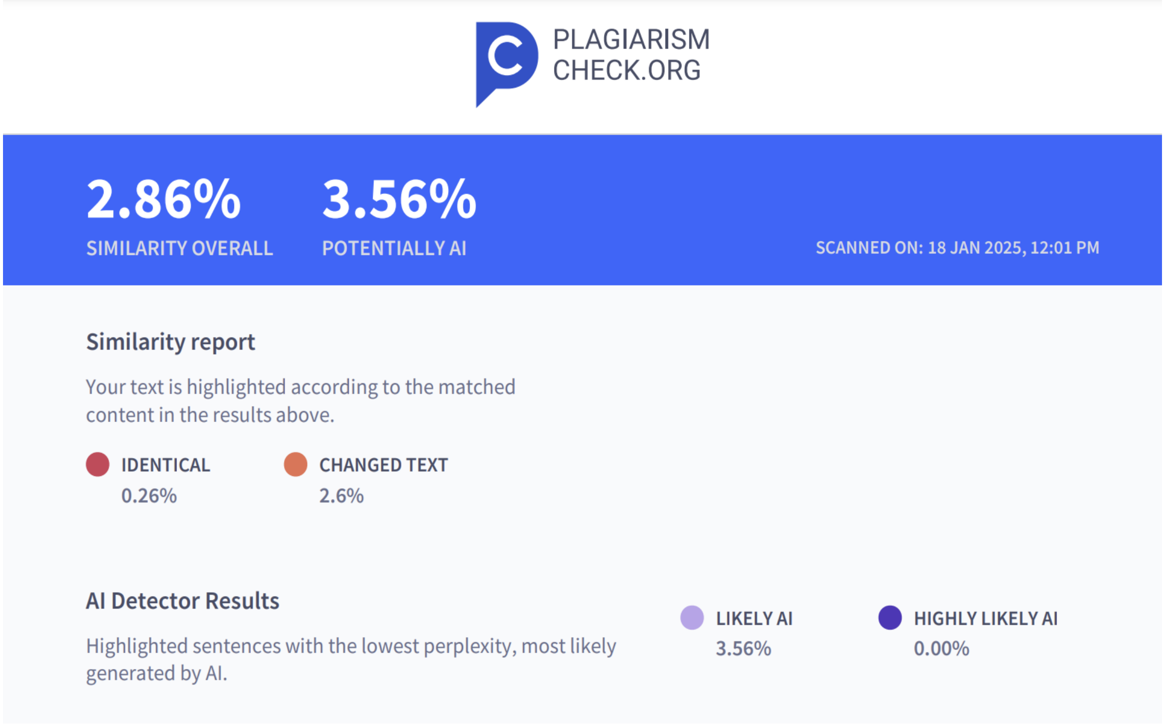
APPENDICES

Originality Scores



PLAGIARISM
CHECK.ORG

2.86%
SIMILARITY OVERALL

3.56%
POTENTIALLY AI

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Similarity report

Your text is highlighted according to the matched content in the results above.

● IDENTICAL
0.26%

● CHANGED TEXT
2.6%

AI Detector Results

Highlighted sentences with the lowest perplexity, most likely generated by AI.

● LIKELY AI
3.56%

● HIGHLY LIKELY AI
0.00%