DETERMINATION OF WATER QUALITY FROM SHALLOW WELLS OF SELECTED PARTS OF KITUI COUNTY, KENYA

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A Thesis Submitted in Partial Fulfilment of the Requirements for the Degree of Master of Science in Environmental Management of South Eastern Kenya University

2025

DECLARATION

I understand that plagiarism is an offense and therefore declare that this thesis report is my original work and has not been presented to any other institution for any other award.

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ACKNOWLEDGEMENT

This far, I thank the Almighty God for the gift of life and knowledge to undertake this study. Second, I would like to express my deepest gratitude to my supervisors and lectures, Dr. Moses Mwangi and Dr. Charles Ndung'u for their tireless guidance to this end. To my family, I am grateful for your unwavering support, time and encouragements. Finally, I am grateful to my classmates and friends for their input.

DEDICATION

This study is dedicated to my cherished family. May God keep blessing you.

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LIST OF ABBREVIATIONS AND ACRONYMS

ASALs	**:**	Arid and Semi-arid Lands
Al^+	**:**	Aluminium
BOD	**:**	Biological Dissolved Oxygen
Ca^+	**:**	Calcium
$CaCO3^-$	**:**	Calcium carbonate
Cl^-	**:**	Chlorides
EC	**:**	Electrical Conductivity
Fl^-	**:**	Fluorides
GIS	**:**	Geographic Information System
GoK	**:**	Government of Kenya
GPS	**:**	Geographic positioning system
JICA	**:**	Japanese International Corporation Agency
K^+	**:**	Potassium
KEBS	**:**	Kenya Bureau of Standards
mg/l	**:**	Milligrams per litre
Mg^+	**:**	Magnesium
Mn^+	**:**	Manganese
NO_2^-	**:**	Nitrates
pH	**:**	Hydrogen Potential
SO_4^-	**:**	Sulphates
TDS	**:**	Total Dissolved Solids
WHO	**:**	World Health Organization
Zn^+	**:**	Zinc

ABSTRACT

Groundwater sources supply water for many people living in dry areas for agricultural, household purposes among others. Increased population has resulted in changes in land use, including deforestation, agricultural activities, and livestock rearing, among others. The residents of Kauwi and Zombe locations make use of agricultural chemicals and manure in their farms which are later washed in the water sources, degrading its quality. These human activities are likely to introduce contaminants in the shallow groundwater sources. In addition to these human activities there are also natural pollutants such as weathering of rocks, soils and minerals that also affect the water quality. The activities have potential to introduce contaminants in the groundwater sources which affect the water quality possibility of negative health implications to human beings and the environment. This study was undertaken to establish the physiochemical contamination of shallow groundwater sources. It looked at the elements that impact groundwater quality in Kitui County's Kauwi and Zombe locations throughout both the rainy and dry seasons. Samples were collected from randomly selected 30 shallow wells during the wet season of December 2021 and the dry season of October 2022 and analysed for physical chemical parameters using a portable laboratory kit in the field.From the findings, all parameters of interest complied with the recommended standards except for turbidity, chloride, calcium carbonate, nitrates and sulphates. Therefore, the shallow wells water quality in Kauwi and Zombe locations is suitable for domestic use except for some of the shallow well water points which contained high levels of sulphates, nitrates and turbidity. The study found significant spatial variation in the physical and chemical and characteristics of shallow groundwater resources in the areas ($p \leq 0.05$) which were attributed to geologic materials and human activities carried out in the study area. Further, statistical significant temporal variations were also observed in the shallow ground water for both the wet and dry seasons. This was associated to surface runoff. The study results also revealed a significant statistical association between the water quality parameters in the studied areas which implies that the parameters have a similar source of origin in the environment. Based on the findings, the study proposes training programs to be conducted on farmers on applying the required quantities of farm in puts. The shallow wells should also be protected by fencing to restrict watering of animals. Finally, conducting regular water quality analysis on the shallow wells in the study area will provide vital information on water quality and help identify potential issues early. The results offer a baseline for future research on groundwater quality in semi-arid regions affected by both natural and anthropogenic factors. The study provides evidence to inform local water governance and regulatory frameworks. It calls for the development and enforcement of water protection policies, particularly in rural and agricultural zones. Policies should support capacity-building programs for local communities, focusing on safe agricultural practices and groundwater protection.

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background of the Study

Many regions of the world rely on groundwater as their primary water supply utilized for their various water needs (Gautam *et al.*, 2015). The accessibility of sufficient, clean and adequate water resources is critical for growth of any country. The world's population is steadily increasing, which has pressurized the available water sources: increasing water demands for household, industrial and agricultural purposes. As the population expands, the demand and amount of safe and clean water for consumption per person also increases (Marshall, 2011). Despite the fact that access to clean and safe drinking water is a basic human right, many third-world countries are now experiencing acute water shortages (Bouwer, 2000).

The primary water sources include wells and boreholes as well as reservoirs, rivers and lakes (Katsanou & Karapanagioti 2017). According to Goswami & Bisht 2017, groundwater is a significant, treasured and renewable natural resource that accounts for 95% of the Earth’s freshwater supplies that is critical for human survival and socioeconomic growth. It accounts for 85% water demands in rural areas and 50% of urban water demands (Kumar & Shah 2006), and most people living in rural areas fetch water from shallow wells, boreholes, and springs as they are relatively cheap to drill. Rural area populations across the world extract water from shallow wells for household, agricultural and industrial use (Pavelic *et al*., 2012). Carrald *et al.* (2019) discusses groundwater as a valuable source worldwide since it is extensively utilized in homesteads for domestic chores, agricultural, industrial production purposes. Shallow wells are generally inexpensive when excavating and they are either owned by individuals in the community or the entire community (Kimani *et al*., 2007). People in several developing nations rely only on groundwater sources, such as shallow wells, because public water delivery infrastructures are insufficient (Pritchard *et al.*, 2008).

According to Mumma *et al*. (2011), groundwater demands will continue to rise as the population grows, potentially leading to depletion of accessible water resources. Kenyan Arid and Semi-arid Lands (ASALs) dwellers rely on groundwater sources to supply their water needs because surface water supplies are sparse owing to erratic rainfall patterns. However, surface water sources tend to be contaminated, pushing water demands to exploiting sources of groundwater (Katsanou & Karapanagioti, 2017).). However, groundwater sources are not much safer than surface water sources as it percolates through several rocks and microbes that came with it are sieved (Mwamati, 2017). According to Barakat *et al.* (2019), although being geologically protected, groundwater is just as prone to contamination as surface water. This is due to overexploitation of accessible groundwater sources. This scenario is projected to deteriorate in ASALs with only seasonal water supplies and a reliance on shallow groundwater sources. Land use activities, such as farming with irrigation, are likely to exert strain on groundwater. The lack of water during drought seasons causes significant concern in supply of safe and clean water, its salinity being compromised (Marshall, 2011). Because arid and semiarid lands experience water stresses, pastoralists and agropastoralists prioritize water quantity above quality when watering their livestock and crops. Surface water tends to have less dissolved salts when compared to groundwater because surface water has not interacted with rock minerals as groundwater. WHO (2011) stated that water is considered safe when it doesn't cause considerable damage to those utilizing it after long-term usage. Groundwater is claimed to be more resistant to pathogen contamination than surface water, however it is not always accessible in adequate quality due to chemical content (WHO, 2005).

Shallow groundwater supplies are under threat of contamination due to natural and anthropogenic undertakings. Hassan (2006) appreciates water contaminated to be through both point and non-point sources. Untreated human and animal wastes, agrochemicals, herbicides, pesticides, and inorganic fertilizers, effluent from industries, mines, over exploitation of the available scanty water resources bring pollutants into water supplies, including bacteria, heavy metals, nitrates, sulphates, phosphates, and salts (Singh, 2003). Harmful compounds from the ground surface gets swept into shallow wells by seepage and runoff. Additional water contaminants include various salts, heavy metals and nitrates that tend to be washed into water systems.

The Sustainable Development Goals (SDGs) of the United Nations established in 2015 seek to address the most urgent issues facing the world, such as water contamination and scarcity. Goal 6 is specifically concerned with making sure that everyone has access to clean water and can sustainably manage water and sanitation by 2030. Target 6.3 focuses on enhancing water quality by lowering pollution and minimizing the discharge of harmful chemicals into water sources, while Target 6.1 specifically seeks to provide universal and equitable access to safe and reasonably priced drinking water for everyone by 2030. These goals are in line with the continued need to address groundwater contamination, particularly in areas where this resource is vital. The difficulties encountered in ASALs and other susceptible areas highlight how crucial it is to put sustainable water management techniques into place in order to guarantee that everyone has access to enough clean, safe water and to lessen the detrimental effects of pollution and overexploitation on groundwater supplies. Effective legislation, international collaboration, and the incorporation of climate resilience techniques into water management are all necessary to achieve these SDGs.

Consumption of polluted water may have major health consequences for people and animals. The majority of ASALs dwellers use out-dated techniques to treat their water. These include filtration, boiling, sedimentation, storing for extended periods of time or even exposing it to sunlight for some time; with minimal or no use of modern and advanced treatment techniques like use of water treatment chemicals. To determine the level of groundwater contamination, the water is assessed based on their biological, chemical and physical parameters. These include biological oxygen demand, ammonia, conductivity, chemical oxygen demand, pH, sulphates, magnesium, nitrates, phosphates, heavy metals (Zinc and Lead) and turbidity. When the analysis results don't meet the requirements specified by the WHO and the KEBS requirements, the water is not safe for human use and may have major health consequences.

Seasonal variations tend to affect the quality of water in the same resource (Likambo, 2014), this is particularly prevalent in areas with higher levels of rainfall. Heavy downpours increase the amount of storm moving towards water resources, polluting them in the long run hence requiring proper treatment before consumption (Georgakakos, 2014). Pollutants from non-point sources of pollution tend to increase as a result of runoff and seepage. They originate from agricultural fields, poorly designed waste management systems in residential areas and from petroleum products leakage points. This tends to affect the water's chemical and physical parameters, thereby reducing quality. Climate change studies suggest that rainfall and runoff have a significant influence on supplies of water (Wang *et al.*, 2012). Rainfall inadequacy decreases water movements, hence, reducing the quantity of dissolved oxygen, thereby having an impact on the survival of aquatic species such as fish. Low dissolved oxygen levels can cause the sediment to release nutrients and metals into the water, compromising its quality. In addition, fluctuations in temperature have an impact on groundwater quality. Under high temperatures, salts and minerals in rocks surrounding water tends to be dissolved at a higher rate that under low temperatures, this tends to affect the electrical conductivity of the water. The main objective of this study was to determine the spatial and seasonal variation of shallow well water quality in Kauwi and Zombe locations of Kitui County. The drive for the study was driven by observed growth in population coupled with adoption of new land use practices of varied magnitudes expected to have an impact on water quality.

1.2 Problem Statement

Population growth, along with land use changes such as deforestation, agricultural operations, livestock rearing, and sand mining, has occasioned the decline of water quality in shallow groundwater sources in Kauwi and Zombe locations. There are intensive agricultural activities carried out near the shallow wells which include the use of fertilizers, pesticides, and manure in farming in these locations, and this may cause contamination of their water. In addition, livestock keeping is also practiced and there is a lot of grazing near the wells and the animals are also watered at the wells. Most of the wells are not covered hence their water is prone to contamination. This poses a threat to the well-being of the residents who fetch water for domestic and other uses from these wells since only a few of them treat their water before consumption.

Consumption of water containing physicochemical parameters levels above the recommended WHO and KEBS standards is likely to cause health problems among water users. It is consequently critical to analyse the physicochemical properties of the shallow wells water. The purpose of this study was to analyse the current state of shallow wells water quality in the Zombe and Kauwi locations of Kitui County, with the goal of determining the spatial and temporal differences in their physical and chemical features.

1.3 Study Objectives

1.3.1 Main Objective

The main objective of this research was to assess the quality of shallow groundwater sources in Zombe and Kauwi locations in Kitui County.

1.3.2 Specific Objectives of the Study

The specific objectives were

i. To determine the spatial variations in physical and chemical characteristics of shallow wells in the research locations.
ii. To determine the temporal variations in physical and chemical characteristics of shallow wells in the research locations.
iii. To determine the correlation between the water quality parameters in the research locations.

1.4 Null Hypothesis

i. There is no significant spatial differences in physical and chemical characteristics of shallow wells in the research locations.
ii. There is no significant statistical temporal variations in physical and chemical characteristics of shallow wells in the research locations.
iii. There is no significant statistical correlation between the water quality parameters in the research locations.

1.5 Significance of the Study

The findings will be beneficial to fellow scientists in this field, land use and water planners, and policymakers who monitor the quality of water for various uses. Findings of this research provide an essential foundation for directing governments, general public, owners of various industries on actions related with damaging water resource and, eventually, groundwater resources. If different human actions linked with water system contamination are decreased, the degree of water system and groundwater pollution and degradation will decrease, lowering the expenses of water treatment before use, drinking and even the accompanying health risks.

This study has provided the necessary statistics for future monitoring of the various physical and chemical variations in the water sources at the locations. This data is critical for the establishment and updating of shallow groundwater sources, as well as maps used in community water supply planning. Finally, the findings of this study can be used to warn the public about the possible health risks of consuming contaminated water for domestic purposes, as well as to advise the governments and likely donors on the establishment of watering points for the communities and appropriate areas for investment.

1.6 Justification of the study

Kauwi and Zombe locations have realized tremendous increase in population which has led to changes in land use such as deforestation, agricultural operations, livestock keeping, mining among other human activities. With increased population there is a possibility of groundwater pollution as the land use activities in addition to the natural pollutants are likely to introduce impurities in ground water sources in the study locations through seepage and runoff.

Some shallow wells are situated in agricultural zones and hence, susceptible to pollution by surface runoff containing fertilizers, pesticides, and herbicides. Other wells are used to water cattle, but are not protected. Continuous intake of contaminated water is damaging to human health, whereas the availability of good quality water aids in illness prevention and promotes a healthy lifestyle, highlighting the need of being aware of the quality of water used.

In this regard, the setting and inadequate supervision of some of the shallow wells of Zombe and Kauwi locations need to be checked for its quality due to the scanty or unavailability of statistics about quality of water in these resources. Also, temporal fluctuations in relation to geographical point of water resources in the two locations is unavailable, which is why this study was conducted.

1.7 Scope of the Study

The study was done in Zombe and Kauwi locations of Kitui County. There are slight climatical differences between these locations: Zombe experiencing semi-arid conditions while Kauwi having semi-humid conditions. The study aimed to identify the spatial and temporal changes in water characteristics and it involved purposive sampling of ground water from the shallow wells were that are closer to homesteads. The water samples were collected during the rainy season of 2021 and the other during the dry season of 2022. The study considered the physical properties of water quality that included electrical conductivity and turbidity. It also measured the chemical characteristics involving parameters such as pH, Calcium, Aluminium, Magnesium, Manganese, Potassium, Chloride, Sulphates, Nitrates, Total Dissolved Solids, Fluoride, Zinc, Calcium carbonate and Salinity.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Spatial Variations in Physical and Chemical Properties of Groundwater

Water quality analysis is of great importance as it ensures that people consume water that meets the WHO and KEBS standards. Kisaka & Mato (2018) investigated the influence of geographical differences on groundwater quality; this investigation was conducted in Dodoma, Tanzania. The water quality differed from one location to another. Findings of this study indicated that all of the sample parameters of interest were within acceptable WHO criteria, with the exception of two boreholes with very high levels of TDS, electrical conductivity, and overall hardness. Similar research was conducted in Kenya's Yatta plateau, Kitui County, to investigate the impact of regional differences on groundwater quality. Findings exposed that all the parameters were below the satisfactory WHO range, with the exception of turbidity, which was beyond the suggested level (Mwamati, 2017). The results revealed regional and temporal variability in the many water parameters studied. The author ascribed this to the geological strata that comprise the aquifers.

In Kenya, a study was conducted in Makueni County to investigate the physicochemical properties of streams, shallow wells, tap water and boreholes samples from the dry season in the southern, northern, and central areas. The findings found that fluoride, chloride, calcium, magnesium, electrical conductivity, hardness and TDS levels surpassed WHO and KEBS guidelines (Gevera *et al.*, 2020). High concentrations of the dominating factors were found in the northern area. The study ascribed the geographical trend to the existence of softer rocks of the northern than those of the southern regions. Similarly, Muthini *et al.* (2014) investigated the ASALs of Marsabit County. This research assessed the quality of the area's numerous water sources, which included shallow wells, boreholes, dams, and pans. This study found that that all of the parameters investigated were within the approved WHO and KEBS standards, with the exception of turbidity, which exceeded the acceptable WHO and KEBS limits.

The location of water sources exhibited immense effect on their quality. Makhokha (2019), investigated the groundwater quality throughout the shoreline in Kilifi, Kenya, during both the dry and rainy seasons. The investigation discovered that the pH levels were within the satisfactory WHO and KEBS parameters, except the shallow wells in Malindi, where the water was acidic. This was the effect of industry positioned near water sources. It was also discovered that wells near salt mining sites had electrical conductivity levels greater than the WHO and KEBS guidelines. TDS levels under the permissible range in drinking water were only discovered during the rainy season. Chloride and salinity levels surpassed WHO and KEBS guidelines. This was linked to salt intrusion along the coastline. Further, research conducted in South Africa in an area near a mining basin indicated groundwater pollution. This was observed through measuring of the physical and chemical parameters, which included nitrates, sulphates, and dissolved minerals among others. The results revealed a declined trend in water quality in many locations of the basin (Alexander, 2017).

Silva *et al. (2021)* embraced the art of Principal component analysis and GIS technology to evaluate the quality ground water quality of 22 monitored wells in the Araripe Sedimentary Basin (ASB), located in the Brazilian semiarid region. Probability curves were used to identify the critical variables and a regional Water Quality Index. The National Sanitation Foundation index (WQINSF) was adapted using multivariate statistical analyses. Further, the Principal Component Analysis (PCA) was used to determine the principal water quality parameters and their weights. GIS technology was used to build geospatial behaviour maps for the hydro geochemical variables. The study findings indicated that phosphorus, Nitrate, coliforms, pH, and turbidity exceeded the water quality standards. This was attributed to anthropogenic activities, as the affected wells were located in agricultural areas.

The study of spatial variation of ground water quality based on an integrated analysis of physico-chemical parameters and use of Geographic Information System was done in Dhanbad coal mining area of India. According to Chatterjee *et al.* (2010), the overall ground water quality is difficult due to the spatial variability of multiple contaminants and wide range of indicators that could be measured. The water quality was good and suitable for drinking despite the location of the ground water sources near a mining site. In a similar study, Machiwal *et al.* (2010) focused on a GIS-based assessment and characterization of groundwater quality in a semi-arid hard-rock terrain of Rajasthan, western India using long term and multi-site post-monsoon groundwater quality data. Spatio-temporal variations of water quality parameters in the study area were analysed by GIS techniques. GIS analysis revealed that sulphate and nitrate ions exhibit the highest (CV>30%) temporal variation, but groundwater pH was stable. Hardness, EC, TDS, and magnesium govern the spatial pattern of the GWQI map. The groundwater quality of the study area is generally suitable for drinking and irrigation.

2.2 Temporal Variations in Physicochemical Properties of Groundwater

Many studies have been conducted globally, across the regions and locally on temporal variations in ground water quality. Makwe *et al*. (2013) studied the seasonal variation in physicochemical characteristics of groundwater contamination in Karu Abattoir, in Ethiopia. Results of this study showed that entirely of the parameters studied were highly concentrated during the rainy season that during the dry season, apart from Sulphate and Iron. Olonga *et al*. (2015) did a similar study on the periodic differences of physicochemical and biological characteristics of groundwater quality in Ruiru in Kenya. This study delved on the quality water of both boreholes and shallow wells during both dry and wet seasons. Results of this study showed significant differences between the seasons except for sodium and magnesium.

Comparable research done in Kenya's Keiyo Highlands in Elgeiyo Marakwet County, aiming at assessing seasonal differences in physicochemical and biological water quality characteristics in shallow wells throughout both rainy and dry seasons (Mbaka *et al*., 2017). In both seasons, pH was lower below the permissible WHO and KEBS standards, indicating acidic water. During the dry season, the water was softer, high turbidity and more acidic than when compared to parameters during rainy season. Kanyaru (2012) investigated the physicochemical parameters of shallow wells in Kamanyaki, Tharaka Nithi County, Kenya, throughout dry and wet seasons. Findings of this study indicated that chemical characteristics differed considerably between the dry and rainy seasons. Research on seasonal fluctuations in physicochemical qualities of water in chosen areas was conducted in Lagos Lagoon throughout the dry and wet seasons. Salinity, EC, and TDS all indicated significant seasonal fluctuations, which were attributable to evaporation (Ladipo *et al*., 2011).

Deshpande *et al.* (2012) evaluated the quality of groundwater in Warora tehsil, District Chandrapur, India for its suitability for drinking purposes. Sixty groundwater samples were collected during pre-monsoon period of the year 2011 and analysed for various parameters. Physical and chemical parameters of groundwater such as electrical conductivity, pH, total dissolved solids, Ca^{2+}, Mg^{2+}, Na^{+}, K^{+} , Cl^{-} , CO_3^{2-}, HCO_3^{-} and Sulphates , Nitrates , Phosphates , and Fluoride were determined. The value of TDS, Cl^{-} and SO_4^{-} ion concentration was within the limits in majority of the samples. The excess amount of Calcium, Magnesium, Total Hardness, Nitrates and Fluorides in the groundwater was linked to human activities and geological composition of the aquifer.

The ground water quality is likely to be affected by climate in ephemeral and long-term ways. These are driven by changes in hydrogeological processes, which include precipitation, ground water recharge, and storage and seawater intrusion. Zahid (2023) studied the potential impacts of climate change on ground water quality in New Jersey. The findings of the study indicated that long-term and seasonal fluctuation in both anthropogenic and geogenic pollutants would likely result from modifications in hydrogeological and biogeochemical processes brought on by climate change. Similarly, Dams *et al.* (2010) projected the potential impact of climate change on quantitative groundwater characteristics determining GWDTEs (Groundwater Dependent Terrestrial Ecosystems). The groundwater recharge and river heads were estimated with the WetSpa model using a daily time step to incorporate the impact of changes in rainfall intensity. For each of these scenarios, recharge, river stage, groundwater head and groundwater flow are estimated for 32 years with half monthly time steps. Future precipitation shows an increase in precipitation during winter and a decrease during summer. Future groundwater recharge decreases on average with 20 mm per year, the highest decreases are simulated from July until September. Average groundwater heads indicate an average decrease of 7 cm. Precipitation in the future indicates a rise in the winter and a fall in the summer. The average groundwater head shows a 7 cm average decline. In interfluves, groundwater levels typically drop by up to 30 centimeters. The average drop in the lowest groundwater level is 6 cm, whereas the average decrease in the highest groundwater level is approximately 3 cm.On average, the groundwater discharge reduces with 4%, from 5 to 4.8 m^3/s. GWDTEs that currently receive a low groundwater discharge, are likely to disappear due to future climate changes.

2.3 Correlation between Water Quality Parameters

The relationship between water quality parameters is of greater interest as it provides crucial information on how to control parameters that are related to one another, as you only need to control one of them. Kothari *et al*., (2021) studied the link between several water quality measures and indices in Uttarakhand, India. In this study, TDS exhibited the strongest link with conductivity, sulphate, and chloride, whereas turbidity had a significant correlation with nitrate in drinking water. The study linked the association between turbidity and nitrate to the presence of nitrate-rich residential and animal waste in the soil, which gets carried into water sources via run-off during rainy seasons. Similarly, correlation research was conducted in Nagpur, India and its findings revealed that total hardness, electrical conductivity, chlorides, sulphates, magnesium, calcium, dissolved oxygen and pH exhibited a strong correlation, unlike chlorides and total dissolved solids that were greatly related with electrical conductivity (Chaubey & Patil 2015).

Most parameters seem to correlate with one another. A study undertaken in Tamil Nadu, India, on the association of drinking water quality found a substantial link between TDS, total hardness, calcium, magnesium, and chloride and electrical conductivity (Stanley *et al*., 2021). There was also a strongly positive link between total dissolved solids and electrical conductivity, in addition to a highly negative correlation between pH and total alkalinity. The study of correlation on the quality of drinking water from Kashan City, Iran shallow wells did not reveal any meaningful association (Heydari *et al*., 2013). TDS and EC showed a substantial positive association, as did calcium and total hardness. The study discovered that heavy and trace metals behaved independently of physical characteristics, anions, and major cations in the water of Kashan City.

In another study, Kumar *et al*. (2011) conducted a correlation study on the quality of groundwater in and around Shahzad District, Uttar Pradesh. The findings revealed a strong positive association between electrical conductivity and sulphates, sodium, magnesium, calcium, total hardness, TDS. Total basicity also correlated positively and significantly with calcium, magnesium, sulphates, chlorides, and fluorides. Mwamati (2017) investigated groundwater quality on the Yatta plateau. In the research, various water parameters were correlated. The results showed a strong link between fluoride and total alkalinity, pH and TDS, pH and total hardness, and pH and EC.

A correlation study conducted in Gujarat India by Shroff *et al.* (2015) to determine the pH, colour, Ec, Total hardness, Calcium, Magnesium, Total Alkalinity, TDS, Chloride, Sulphate, Fluoride and sodium the results indicated that EC was found to be correlated with eight out of the seventeen parameters studied. It was suggested that if Ec was controlled the other parameters would definitely be controlled. A similar study was conducted in Gulbarga city where water samples were analysed for electrical conductivity (EC), pH, total dissolved solids, Total Hardness, Calcium, Magnesium, Sodium, Potassium, Sulphates and Nitrates. The findings of the study indicated a significant correlation among many of the tested parameters. The correlation between Ec and other water quality parameters was found to be positive (Abdul *et al.,* 2012).

Gabriel & Donatus (2010) studied ground water quality from Yola area of North-eastern Nigeria. Correlation study was conducted on the parameters studied. The study findings indicated a high correlation between the EC and TDS, Na, and Cl .Mg, Ca, NO3, Cl and Fe indicated a high correlation with EC in surface water samples. In another study carried out to determine the interrelationship between TDS,EC, sodium, potassium, Calcium, magnesium and Chloride, EC seemed to be strongly correlated with TDS (Alhumoud *et al.* (2010).Ranjan *et al.* (2006) assessed the impacts of climate change on fresh groundwater resources. The focus was on salinity intrusion in water resources stressed coastal aquifers. The results did not show any correlation between precipitation and temperature with fresh groundwater loss. A strong negative correlation was observed between the aridity index and fresh groundwater.

2.4 Factors affecting ground water quality

The quality of water in shallow wells is influenced by a variety of factors, both natural and human-induced. Geological characteristics, human activities, microbial contamination, seasonal variations, and land use practices all contribute to the overall water quality in shallow wells. The geological characteristics of the area where a shallow well is located are fundamental in determining water quality. The permeability of the soil and the type of aquifer (e.g., fractured or unfractured) influence the flow and storage of groundwater. In shallow wells, the geological formations near the surface can directly impact the contamination risk, as surface water and contaminants easily infiltrate the shallow aquifer (Moore, 2003). According to a study by Bouwer (2002), shallow wells in areas with sandy and loamy soils tend to experience faster contamination due to their higher permeability compared to wells located in regions with clay-rich soils. These findings were corroborated by Pettyjohn & Wenzel (2003), who demonstrated that shallow wells in urban and agricultural regions are more vulnerable to contamination from surface pollutants due to their proximity to the surface.

Human activities in the vicinity of shallow wells, such as agriculture, industrial operations, waste disposal, and urbanization, play a significant role in deteriorating groundwater quality. The application of fertilizers and pesticides in agricultural areas is a major source of nitrate contamination, while the improper disposal of waste leads to microbial contamination. Urbanization, particularly unregulated construction and poor sanitation systems, exacerbates the contamination of shallow wells (Ali *et al*., 2017). The risks of contamination are higher in shallow wells because they are closer to surface water sources, which may carry pathogens or pollutants from anthropogenic activities. A study by Bhat *et al.* (2014) highlighted the vulnerability of shallow wells to microbial contamination, especially in areas where sanitation practices are inadequate. The study found that shallow wells near urban or rural settlements are prone to contamination from septic tanks and wastewater runoff. A review by Rock *et al.* (2015) indicated that shallow wells in agricultural areas tend to have higher concentrations of nitrates and pesticides, particularly in regions where agricultural practices are intensive and groundwater recharge is low.

One of the most significant concerns for shallow well water quality is microbial contamination, which poses a direct health risk. Shallow wells are highly susceptible to contamination by bacteria, viruses, and protozoa, primarily from human and animal waste. The proximity to surface water and the lack of effective filtration mechanisms in the aquifer make shallow wells ideal conduits for pathogens, especially in areas with inadequate sanitation infrastructure (Tse *et al.*, 2012). A study by Rizzo *et al.* (2013) found that shallow wells near agricultural land and urban areas are highly prone to fecal contamination. Their research emphasized the importance of proper waste management and sanitation systems to reduce the microbial load in shallow wells. Similarly, a study by Adefolalu *et al.* (2016) on microbial contamination in rural shallow wells in Nigeria found that many shallow wells were contaminated with coliform bacteria, highlighting the vulnerability of such wells to pollution from nearby latrines and open waste disposal practices.

Seasonal changes can have a significant impact on the quality of water in shallow wells. During the rainy season, the risk of contamination increases due to surface runoff, which can carry pollutants such as chemicals, pathogens, and waste into the shallow aquifers. In contrast, during dry periods, evaporation can lead to a concentration of salts and other dissolved solids in the water. Additionally, dry season can result in a decrease in groundwater recharge, which may lead to increased contamination as the well water becomes more exposed to the surface (Sivakumar, 2015).Research by Hutton *et al.* (2011) found that shallow well water quality deteriorates significantly during heavy rainfall events, which can result in flooding and contamination from surface runoff. Their study in sub-Saharan Africa revealed that well contamination is more prevalent during the rainy season due to the influx of contaminants from agricultural fields and waste disposal sites. Similarly, a study by Ahmed *et al.* (2017) concluded that shallow wells in semi-arid regions showed increased salinity and higher concentrations of dissolved solids during dry periods, as limited rainfall reduced the dilution of contaminants in the groundwater.

The surrounding land use is another critical factor influencing the water quality of shallow wells. Improper land management practices, such as deforestation, poor waste disposal systems, and unregulated industrial activities, can introduce contaminants into shallow wells. In areas where agriculture and livestock farming are prevalent, runoff containing fertilizers, pesticides, and animal waste can infiltrate the groundwater, compromising water quality (Srinivasan *et al*., 2010). According to a study by Khosravi *et al.* (2011), shallow wells located in agricultural areas are at high risk of contamination from fertilizers and animal waste. The study emphasized that the implementation of proper land-use regulations and wastewater treatment systems is essential to mitigate the risks to shallow well water quality. Similarly, a study by Postigo *et al*. (2017) found that the lack of proper environmental management practices, such as sustainable agriculture and waste disposal, is a significant factor in the contamination of shallow wells, particularly in developing countries where regulatory measures are weak.

2.5 Groundwater Quality Assessment Methods

Groundwater quality assessment is essential for the management of water resources, particularly in regions where groundwater is the primary source of drinking and irrigation water. Various methods and techniques have been developed over time to assess the quality of groundwater, ranging from traditional field-based methods to modern analytical and computational techniques. The choice of assessment method depends on the specific objectives of the study, the resources available, and the nature of the contaminants. The primary goal of groundwater quality assessment is to identify the presence, concentration, and source of contaminants, as well as to understand the spatial and temporal variation of groundwater quality.

Field-based methods for groundwater quality assessment are direct and widely used, particularly for initial assessments. These include:
Water Sampling and Laboratory Analysis: This is the most common and accurate method for assessing the quality of groundwater. Water samples are collected from wells, filtered, and transported to laboratories for detailed chemical, physical, and microbial analysis. Parameters such as pH, dissolved oxygen, electrical conductivity, total dissolved solids (TDS), major ions (e.g., nitrate, fluoride, calcium, magnesium), heavy metals, and microbial contaminants are typically analyzed (US EPA, 2006). The study by Güler *et al.* (2002) used field sampling methods to assess the groundwater quality in urban and agricultural areas, demonstrating how high levels of nitrates and pesticides could be detected through laboratory analysis. Similarly, Sharma *et al.* (2006) employed water sampling to evaluate the contamination of shallow groundwater in the Indo-Gangetic plain, finding elevated concentrations of arsenic.

In-situ Water Quality Sensors: Recent advancements have led to the development of portable in-situ water quality sensors. These sensors measure various parameters, including pH, turbidity, temperature, dissolved oxygen, and electrical conductivity, directly at the sampling point. They offer real-time monitoring and can significantly reduce the time and cost of analysis. García-González *et al*. (2017) used portable sensors to assess the temporal variability in groundwater quality, particularly in regions with high agricultural activity. This approach allowed them to detect rapid changes in key water quality parameters like nitrate levels following rainfall events.

Geophysical methods have been increasingly used in groundwater quality assessments, especially in areas where direct sampling is challenging due to limited access or contamination concerns. These methods include:
Electrical Resistivity Tomography (ERT): ERT is used to map the distribution of contaminants and aquifer characteristics by measuring the electrical resistance of the ground. It can help identify zones of contamination, such as areas of high salinity or areas with high concentrations of certain ions (Loke & Barkers, 2017). Zhou *et al*. (2014) applied ERT in an urban environment to study groundwater contamination. Their

research showed how this method could be used to trace contamination plumes of heavy metals, providing a spatial understanding of contamination in shallow aquifers.

GPR is another geophysical method that is used for mapping the subsurface in three dimensions. It can identify the depth and structure of aquifers, which is critical for understanding groundwater flow and potential pathways for contaminants. Milanesi *et al.* (2013) used GPR to assess groundwater quality in an industrial area, identifying high-risk zones of contamination linked to industrial waste disposal sites.

Geospatial technologies, such as remote sensing and Geographic Information Systems (GIS), are increasingly employed in groundwater quality assessments. These tools allow for the analysis of large-scale spatial patterns of groundwater quality across regions, integrating data from different sources, including field measurements, satellite imagery, and geophysical surveys. Remote sensing technologies, such as satellite-based sensors, can help assess surface conditions, land use changes, and vegetation, which indirectly influence groundwater quality. For instance, satellite imagery can be used to identify areas of high agricultural activity, urbanization, or industrial activity that may correlate with contamination risks. Zhao *et al.* (2015) used remote sensing to assess land use changes and its relationship with groundwater contamination in an agricultural region of China. Their findings highlighted that changes in agricultural practices were strongly correlated with increases in nitrate levels in local aquifers.

GIS-based Modeling: GIS tools are widely used to integrate data from various sources and perform spatial analysis, such as mapping areas of contamination risk and identifying vulnerable aquifers. GIS can also be combined with water quality data to model and predict contamination patterns under different land use scenarios. Chakraborty *et al.* (2014) developed a GIS-based model to evaluate groundwater quality in a highly industrialized region. The study demonstrated how GIS-based tools could help predict areas at high risk of contamination from industrial effluents and waste.

Statistical methods, including multivariate analysis and geostatistics, are powerful tools for understanding complex relationships in groundwater quality data. These methods are used to analyze large datasets, identify patterns, and determine the sources of contamination. PCA is commonly used to reduce the dimensionality of large water quality datasets and identify major factors influencing groundwater quality. It helps in determining the source of contaminants, such as agriculture, industrial activities, or natural sources. Zhang *et al.* (2007) used PCA to assess groundwater contamination in a large agricultural region, identifying fertilizers and pesticides as the primary contributors to contamination. The study emphasized the importance of PCA in simplifying complex groundwater quality data and identifying key contaminant sources.

Kriging is a geostatistical method used to predict groundwater quality based on spatially correlated data. It is widely used to interpolate groundwater quality parameters and create detailed contamination maps. Batu *et al.* (2015) applied Kriging to model nitrate contamination in groundwater, demonstrating how geostatistical tools could provide valuable insights into the spatial distribution of contaminants across large geographic areas.

Groundwater Flow and Contaminant Transport Models simulate the movement of groundwater and the dispersion of contaminants. They are particularly useful for understanding how contaminants migrate through aquifers and how interventions, such as groundwater treatment or land use changes, might reduce contamination. Sanchez-Vila *et al.* (2010) used a groundwater flow and contaminant transport model to assess the impact of land use changes on groundwater quality in a coastal region. The model successfully predicted the spread of saltwater intrusion and other contaminants, providing key insights for water management strategies.

2.6 Potential Impacts of Climate Change on Groundwater Quality

Climate change is a global phenomenon with profound effects on environmental systems, including groundwater resources. Although groundwater is often considered a more stable and reliable source of water compared to surface water, it is not immune to the impacts of climate change. Changes in temperature, precipitation patterns, evaporation rates, and extreme weather events all have the potential to affect groundwater quality, either by altering the natural processes that govern water quality or by introducing new contamination risks. In this review, we examine the research on the potential impacts of climate change on groundwater quality, highlighting both direct and indirect effects, and comparing the findings with other relevant studies.

2.6.1 Changes in Precipitation Patterns and Groundwater Recharge

One of the most significant ways in which climate change can affect groundwater quality is by altering precipitation patterns, which in turn influence groundwater recharge rates. A shift toward more intense rainfall events, combined with longer periods of drought, could lead to reduced groundwater recharge during dry periods and rapid infiltration of contaminants during heavy rains. Taylor *et al.* (2013) investigated the impact of altered precipitation patterns on groundwater recharge in Australia. The study found that reduced recharge during drought periods led to a higher concentration of salts and other dissolved minerals in groundwater, which in turn compromised water quality. Chiew *et al.* (2009) also highlighted that increased rainfall variability could affect both the quantity and quality of groundwater resources, particularly in regions that rely on shallow aquifers. Their research suggested that more extreme weather patterns could lead to faster contamination of groundwater resources, especially in agricultural areas.

2.6.2 Temperature Increases and Groundwater Contamination

The increasing global temperature associated with climate change can also influence groundwater quality by affecting the physical and chemical properties of aquifers. Higher temperatures can increase the rate of evaporation, thereby concentrating dissolved solids and contaminants in groundwater. Furthermore, temperature changes can affect the solubility of certain substances, leading to higher concentrations of minerals such as arsenic, fluoride, and iron in groundwater**.** Ahmed *et al*. (2015) assessed the effect of rising temperatures on groundwater quality in arid regions and concluded that higher temperatures could increase the concentration of certain contaminants, such as salts and heavy metals, due to evaporation and enhanced leaching from soils. Smedley &

Kinniburgh (2002) discussed how temperature increases could affect the release of naturally occurring contaminants like arsenic from mineral-rich sediments into groundwater. They highlighted that warming could lead to an increase in arsenic concentrations, particularly in areas with high geological arsenic concentrations.

2.6.3 Extreme Weather Events and Groundwater Quality

Extreme weather events such as floods, hurricanes, and storms are expected to become more frequent and intense due to climate change. These events can have both direct and indirect impacts on groundwater quality. Wilhelmi *et al.* (2004) studied the impact of extreme weather events on groundwater quality in the Midwest United States and found that intense flooding resulted in increased pathogen levels and contamination from agricultural runoff in shallow wells. Doll *et al.* (2003) conducted a study on the impacts of climate-induced extreme weather events in coastal aquifers. Their research showed that rising sea levels and intensified storms could lead to an increase in salinity in coastal groundwater resources, threatening the quality of drinking water.

2.6.4 Changes in Land Use and Vegetation Cover

Climate change can also indirectly impact groundwater quality by altering land use and vegetation cover. Changes in vegetation, whether due to rising temperatures, changes in precipitation, or human activities, can affect the infiltration of water into aquifers and the types of contaminants that reach groundwater. Graham *et al.* (2011) explored the relationship between climate change, land use, and groundwater quality. They concluded that climate-induced land use changes, such as increased agricultural activity or deforestation, could lead to higher levels of nitrate and pesticide contamination in groundwater.

Foley *et al.* (2017) analyzed the interaction between climate change and land use changes in agricultural regions, finding that increased agricultural intensification due to climate change led to higher nutrient loads in groundwater, particularly in shallow aquifers.

2.6.5 Sea-Level Rise and Saltwater Intrusion

In coastal areas, sea-level rise due to climate change presents a significant threat to groundwater quality. Rising sea levels can result in saltwater intrusion into coastal aquifers, rendering groundwater undrinkable due to high salinity levels. Taniguchi *et al.* (2002) conducted a study on saltwater intrusion in coastal aquifers and concluded that rising sea levels could lead to significant salinization of freshwater aquifers, particularly in low-lying coastal regions. Their research emphasized the need for groundwater management strategies to mitigate the effects of saltwater intrusion. Bakker *et al. (*2013) reviewed the impacts of climate change on groundwater resources and discussed how saltwater intrusion in coastal aquifers could significantly affect the quality of groundwater in regions experiencing both rising sea levels and increased water demand.

2.7 Research Gap

Several research have been undertaken on shallow groundwater quality in ASALs (Kanyaru, 2012; Mbaka *et al*. 2017; Makhoka, 2019), but few have investigated the influence of spatial temporal changes on shallow groundwater quality. Even though Mwamati (2019) investigated the impact of spatial and temporal variability on quality of groundwater, the study only looked at boreholes.

CHAPTER THREE

3.0 METHODOLOGY

3.1 Location of the Study Area

The research was conducted in Kauwi and Zombe Locations, Kitui West and East, respectively. Figure 3.1 and 3.2 shows the specific study locations of the study.

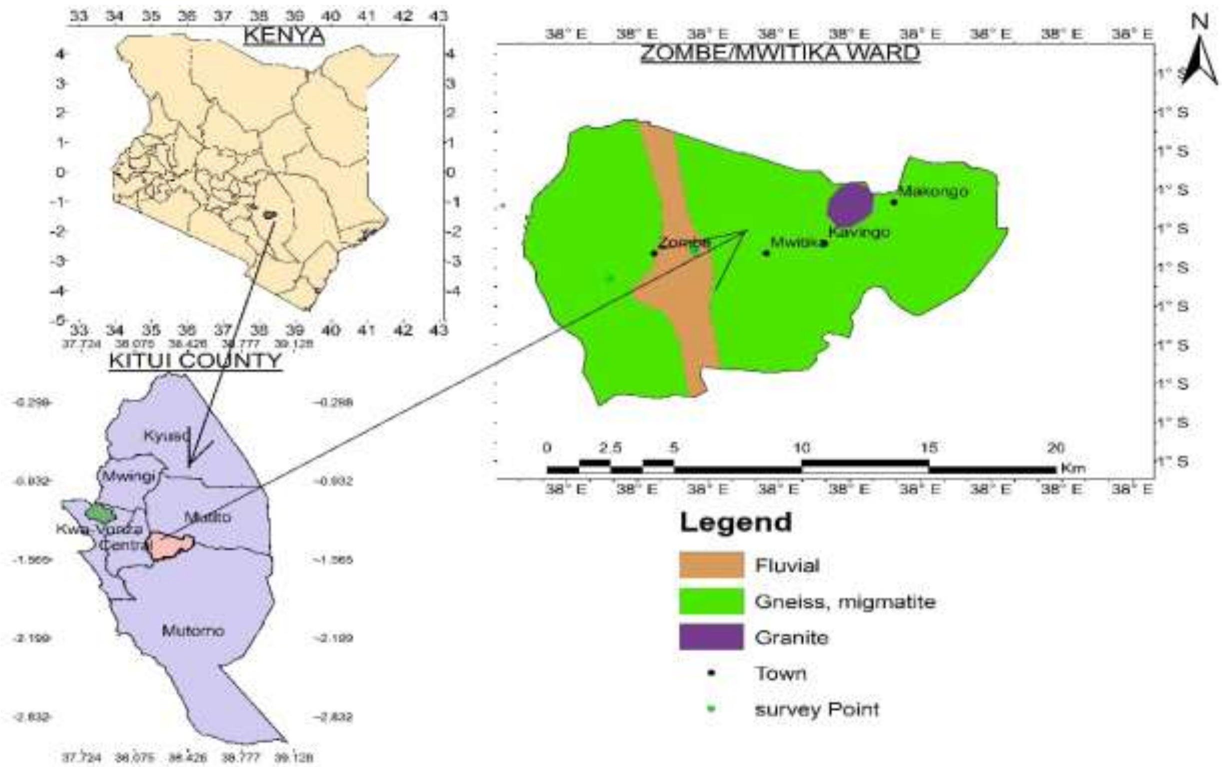


Figure 3.1: A map showing the location of Zombe in Kitui County (ArcGIS Database, 2022)

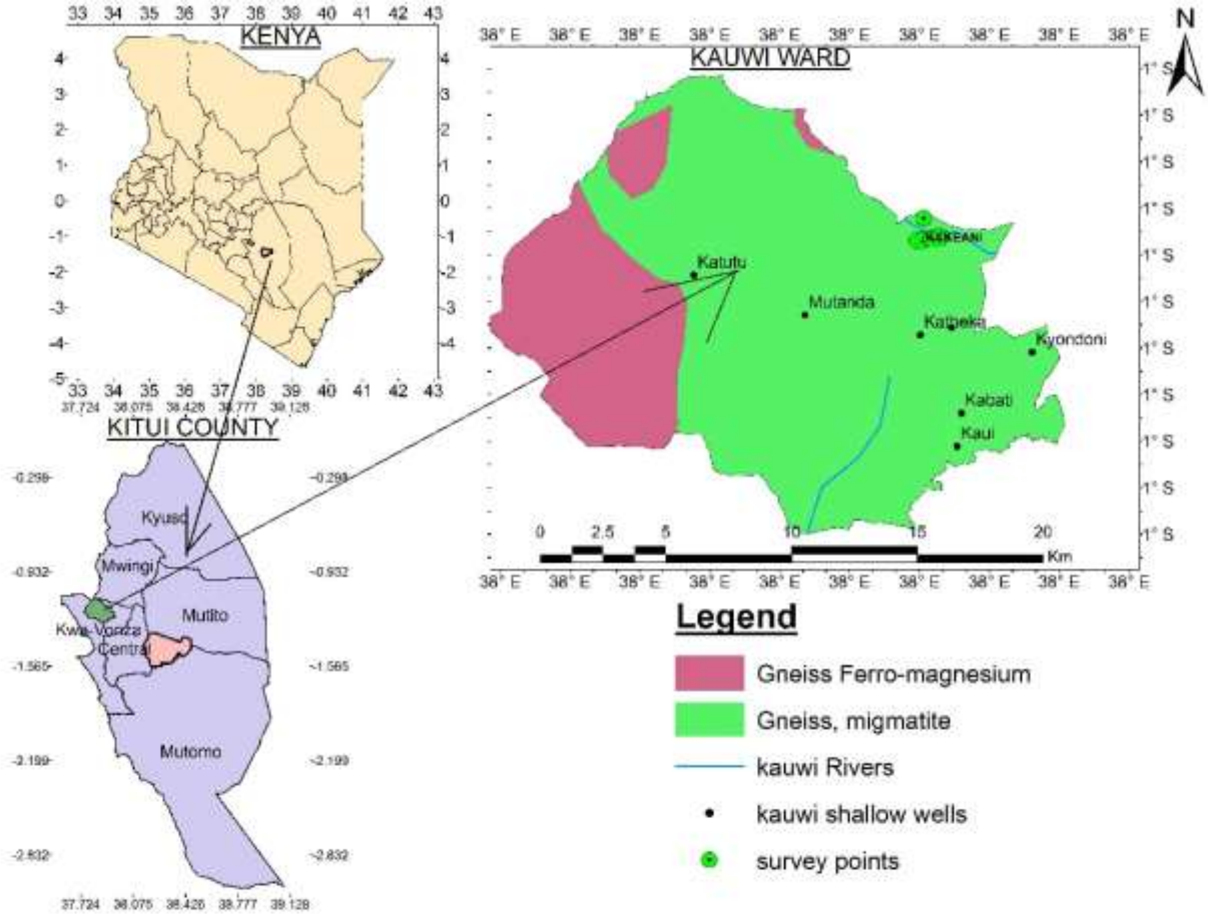


Figure 3.2: A map showing the location of Kauwi in Kitui County (ArcGIS Database, 2022)

3.2 Climatic Conditions

The research location is characterized by a hot and dry environment with unpredictable precipitation. The climate is divided into two zones: Kauwi is semi-humid while Zombe is semi-arid and temperatures ranges between from 14 to 34°C all year round. July is known to be the coldest month of the year whereby the temperatures fall up to 14°C while the month of September is normally the hottest with high temperatures of 34°C. There are two rainy seasons, which are erratic and unreliable. The long rains occur from March to May and short rains falling between October - December. The remaining months of the year are often dry and rainfall patterns fluctuate from year to year, making it impossible to anticipate.

3.3 Land Use

Land is used for small-scale farming of livestock and food crops. In Kauwi majority of the farmers apply animal manure and few of them use fertilizers on their farms. The case is different in Zombe where majority of farmers use fertilizers on their farms and only a few of them who use animal manure.

3.4 Hydrogeology

The geology of the study area is mostly Precambrian rocks of 540 Ma BP and older crystalline. These rocks exhibit a regional structural North-South drift in formation. The geographical context is consistent with the geology of the Mozambique belt, where Proterozoic (2500 - 540 Ma Bp) and Quaternary (2 Ma Bp till now) deposits are found on hill slopes and in river beds. The metamorphic and volcanic rocks in this region dissolve in water sources, resulting in a high salt content in drinking water. Tana River Drainage Basin encompasses almost the whole region of Kitui County. Only a short stretch along the south and southwest border flows into Athi River. Kitui County has no permanent rivers other than the great Tana River. The majority of the ephemeral rivers draining into the Tana River become dry in a month after the rains (Borst & De Haas, 2006).

3.5 Crop Farming

The food crops grown in the area include: cereals (maize, millets, and sorghum), legumes (green grams, beans, cowpeas, pigeon peas), root crops(cassava), vegetables (kale-sukuma wiki, spinach), fruit crops(pawpaws, mangoes).Some of these crops like green grams and cassava are widely grown for food security and income generation because they are more drought tolerant than the other food crops.

3.6 Research Design

The research used a descriptive research design. The study covered physicochemical water parameters such as pH, TDS, Turbidity, EC, Calcium (Ca^+), Aluminium (Al^+), Magnesium (Mg^+), Manganese (Mn^+), Potassium (K^+), Salinity, Chlorides (Cl^-), Sulphates (SO_4^-), Nitrates (NO_2^-), Fluorides (Fl^-), Zinc (Zn^+) and Calcium carbonate ($CaCO3^-$). The parameters were chosen depending on anthropogenic activities and geology of these areas, which included deforestation, sand harvesting, livestock husbandry and agricultural operations.

3.7 The Sampling Technique

Two study sites (Kauwi location and Zombe location) were purposively selected in Kitui West and Kitui East sub-counties respectively. The shallow wells were purposively selected. The wells were selected based on their accessibility and also the human activities taking place around such as farming, animal grazing, irrigation, sand mining among others.

3.8 The sample size determination

Two study sites (Kauwi location and Zombe location) were purposively selected in Kitui West and Kitui East sub-counties respectively. The shallow wells were purposively selected. The wells were selected based on their accessibility and also the human activities taking place around such as farming, animal grazing, irrigation, sand mining among others.

3.9 Data Collection Procedure

Field surveys were conducted to collect primary data. Observations like abstraction methods, activities carried out near the wells, and methods of shallow well protection were made at the sampling sites. The local community members helped in the identification of the shallow wells. Global Positioning System (GPS) coordinates of each shallow well were recorded.

3.10 Water Sampling

Composite water samples were collected from 30 shallow wells,15 in Kauwi and 15 in Zombe locations during the wet month of December 2021 and dry month of October 2022. Triplicate samples were collected and location of the sampling points are indicated in Figure 3.3.

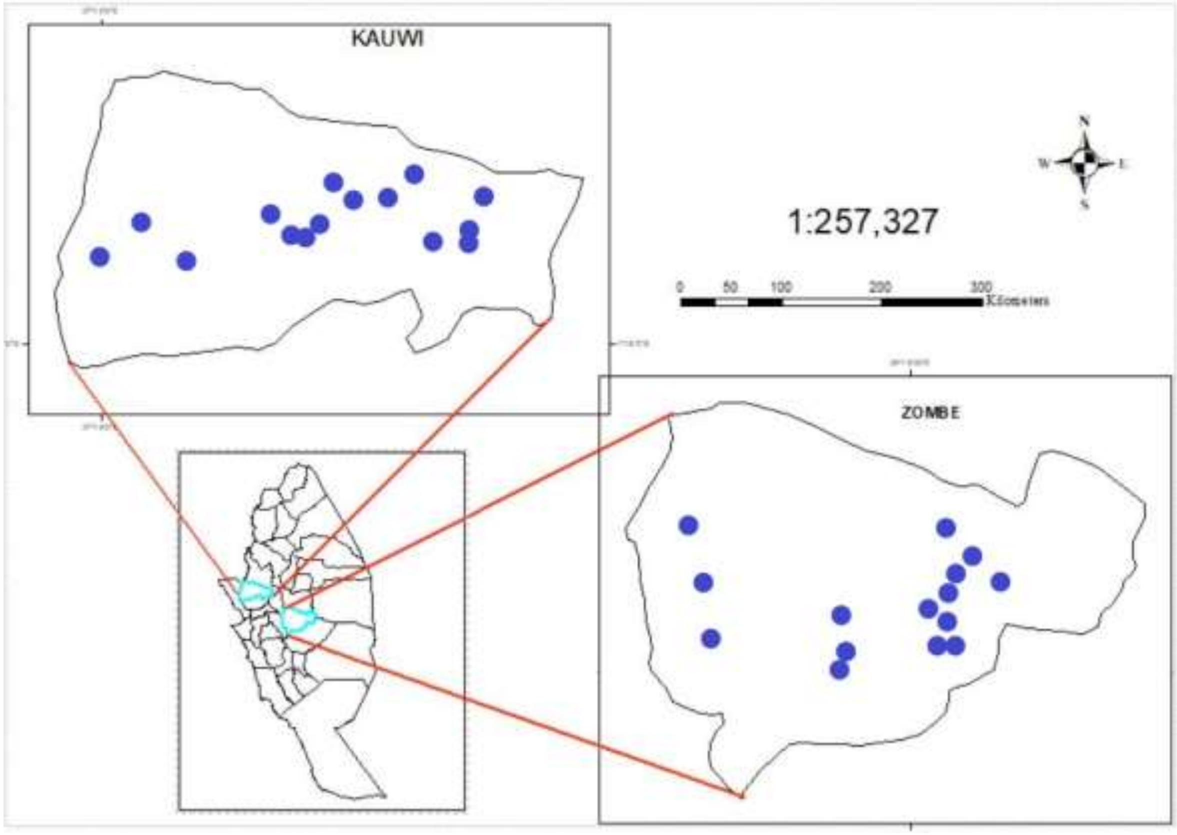


Figure 3.3: Location of the sampling sites (ArcGIS Database, 2022)

3.10.1 Frequency of Sampling

Water sampling was done in December 2021 for the rainy (wet) season and in October 2022 for the dry season.

3.10.2 Analysis

The water samples were analysed using portable water testing equipment at the site.

The following parameters were analysed;

a) pH was analysed using a Portable pH meter
b) TDS was analysed by use of a Portable TDS meter
c) EC was analysed using a Portable EC meter
d) Turbidity was analysed using a turbidity meter standardized to 0.00 NTU using distilled water
e) Ca, Mg, Mn, K, Cl, Sulphates, Nitrates, Fluorides, Zinc, and Calcium carbonate were analysed by use spectrometric methods

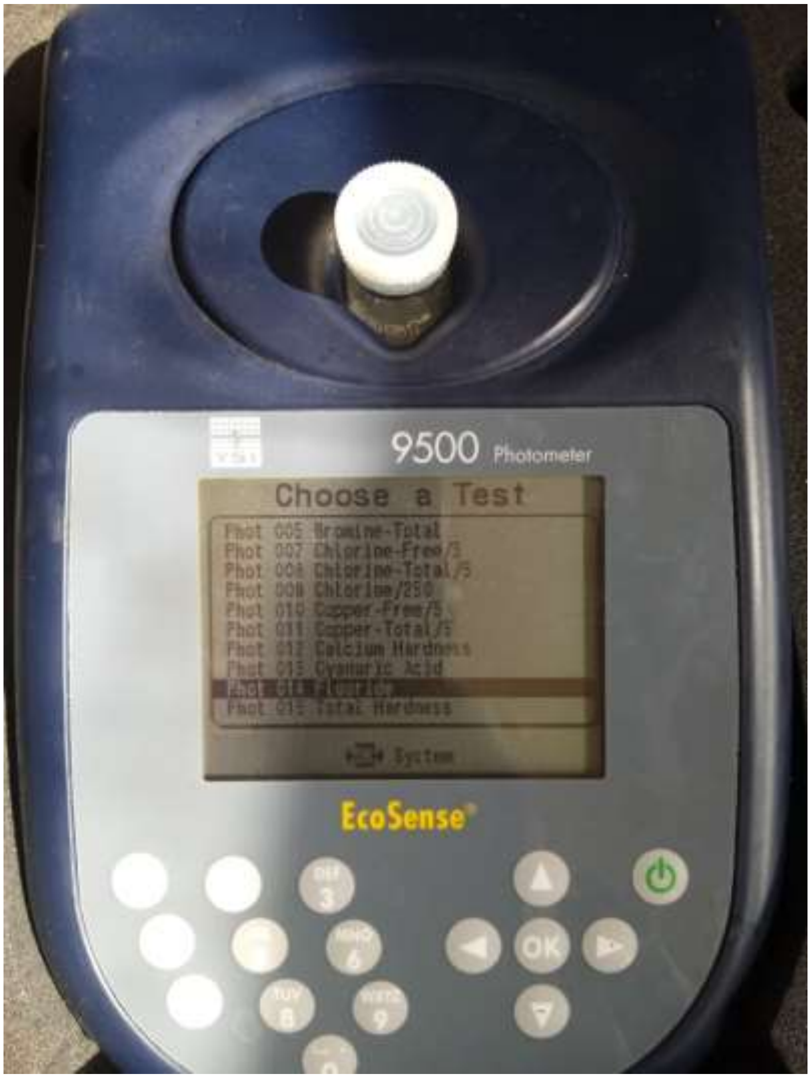


Plate 3.1: A photo showing a portable spectrophotometer

Plate 3.2: Turbidimeter used to measure turbidity in the field

3.11 Statistical Data Analysis

Using Microsoft Excel, the data file was reviewed for accuracy and completeness as part of the data cleaning process. It was then analysed using SPSS to calculate the mean values, students' t-test and to compute Pearson correlation.

3.11.1 Independent *t-test*

An independent t-test with a 95% confidence interval was used to determine the geographical and temporal fluctuations in the physical and chemical properties of groundwater in the research areas.

3.11.2 Correlation

The Pearson's correlation coefficient (r) was utilized to assess the relationship between groundwater quality measures. According to Kothari & Garg 2014, the correlation coefficient varies from -1 to +1. When the coefficient is -1, it indicates a strong negative correlation in which the Y variable declines as the X variable increases, whereas +1 indicates a strong positive linear correlation in which the Y variable increases as the X variable grows.

Table 3.1: Interpretation of the Pearson's correlation coefficients (Kothari & Garg 2014)

'r' value	**Correlation level**
$\pm0.70 \leq n$	Very strong relationship
$\pm0.40 \leq +0.69$	Strong relationship
$\pm0.30 \leq +0.39$	Moderate relationship
$\pm0.20 \leq +0.29$	Weak relationship
$\pm0.01 \leq +0.19$	No or negligible relationship
0	No relationship

CHAPTER FOUR

4.0 RESULTS

4.1 Spatial Variations in Physicochemical Properties of Groundwater

A comparison was made using independent *t-test* on mean levels of physicochemical properties of shallow wells in Zombe and Kauwi Locations and the results are presented in Table 4.1. Most of the physicochemical parameters of ground water in the study area were significantly different between Kauwi and Zombe locations ($p \leq 0.05$). These included Calcium, Magnesium, Electrical conductivity, Sulphates and Chlorides (Table 4.1).Calcium levels in water differed significantly between Kauwi and Zombe locations. The mean levels were 148.33 mg/l in Kauwi and 203.32 mg/l in Zombe; which did not comply with the KEBS and WHO standards. Mg in water was also characterised by significant spatial variations ($p \leq 0.05$) between Kauwi and Zombe locations. Kauwi location recorded a mean of 35.25 mg/l while Zombe location recorded 45.67 mg/l which was within acceptable levels according to KEBS and WHO standards. Electrical conductivity was found to be 452.13 mg/l in Kauwi and 342.21 mg/l in Zombe which was also within the acceptable levels according to KEBS and WHO standards. Sulphates recorded a mean value of 186.58 mg/l while Zombe recorded 252.43 mg/l. The mean values showed compliance to KEBS and WHO standards.

Table 4.3: Mean Values of Water Quality Parameters of shallow wells in Kauwi and Zombe Locations

Parameter	Kauwi mean	Zombe mean	P Value	WHO	KEBS
pH	7.09*(0.08)*	7.09(*0.08*)	0.62	6.5-8.5	6.5-8.5
Calcium (mg/l)	148.33*(77.39)*	203.32(*65.38*)	0.004*	100	100
Magnesium (mg/l)	35.25(*16.32*)	45.67(*14.01*)	0.01*	50	50
Aluminium (mg/l)	0.13(*0.05*)	0.18(*0.18*)	0.13	0.2	0.2
Manganese (mg/l)	0.10(*0.07)*	0.14*(0.13*)	0.12	0.5	0.1
Electrical conductivity (mg/l)	452.13(*149.10*)	342.21(*147.28*)	0.006*	1000	1000
Potassium (mg/l)	7.48(*8.57*)	7.02(*3.88*)	0.80	50	50
TDS (mg/l)	455.37(*172.28*)	540.78(*172.28*)	0.06	500	500
NaCl (mg/l)	36.62(*96.59*)	61.95(*96.59*)	0.17	-	-
Sulphates (mg/l)	186.58(*88.57*)	252.43(*88.57*)	0.002*	250	250
Nitrates (mg/l)	61.02*(20.26)*	66.47(*14.92*)	0.24	10	50
$CaCO_3$ (mg/l)	137.30(*121.76*)	144.87(*107.03*)	0.80	300	300
Chlorides (mg/l)	184.11(*78.99*)	238.17(*112.04*)	0.04*	250	250
Fluoride (mg/l)	0.52(*0.38*)	0.50(*0.39*)	0.86	4.0	4.0
Zinc (mg/l)	1.56(*2.13*)	1.12(*1.12*)	0.31	5.0	5.0
Turbidity (NTU)	5.76(*6.01*)	7.26(*10.28*)	0.49	5	5

Note: The variables in parentheses are standard deviation

* P values are significant ($p \leq 0.05$)

4.2 Temporal Differences in Physical and Chemical Characteristics of shallow wells

The mean levels of physicochemical properties of shallow wells during the wet and dry season in both Kauwi and Zombe are represented in Table 4.2 and table 4.3 respectively. The mean values for the pH, Ca, Ec, salinity, Sulphates, CaCo3 and Chlorides indicated statistical temporal differences ($p \leq 0.05$).The t-test results at 95% confidence level indicated that there was significance difference in the concentration of the pH, Ca, Mg, Sulphates, CaCo3, and chlorides between the wet and dry season($p \leq 0.05$).The water pH varied significantly between the wet and dry seasons ($p \leq 0.05$).It was noted that the water had a higher pH in the wet season as when compared to the dry season in both Kauwi and Zombe. The pH of the water was adequate under KEBS and WHO standards for both seasons. Significant differences were also observed in calcium levels between the wet and dry seasons ($p \leq 0.05$). It was found to be 177.77mg/l and 180.17 mg/l in the dry season in Kauwi and Zombe respectively. In the wet season a mean of 118.91 mg/l was recorded in Kauwi while a mean of 226.47 mg/l was recorded in Zombe. The mean values were higher than the acceptable WHO guidelines.

Magnesium levels differed significantly ($p \leq 0.05$) between the wet and dry seasons in Zombe. It was determined to be 40.56 mg/l during the wet season and 50.78 mg/l during the dry season, both of which are within the KEBS and WHO standards. Sulphate concentrations also varied greatly between the wet and dry seasons. The wet season recorded 233.25 mg/l, while the dry season recorded 139.93 in Kauwi($p \leq 0.05$). In zombe a mean of 298.23 mg/l was recorded during the wet season and 206.62 mg/l during the dry season. The sulphate mean levels were within the KEBS and WHO requirements. There was a significant difference in calcium carbonate concentrations between the wet and dry seasons ($p \leq 0.05$). In Kauwi, it was found to be 220.18 and 54.43 mg/l during the rainy and dry seasons, respectively. The wet season in Zombe recorded a mean of 229.71mg/l while dry season recorded a mean of 60.02 mg/l. Chloride concentrations in water varied significantly between the wet and dry season ($p \leq 0.05$). It was found to be 138.87 mg/l during the wet season and 229.34 mg/l during the dry season in Kauwi. In Zombe the wet season recorded 177.03 while the dry season recorded 299.31. There was also a substantial difference in salinity between Kauwi's wet and dry seasons ($p \leq 0.05$). In the wet season, it was 28.67, while in the dry season, it was 43.61.

Table 4.4: Mean Values of Selected Seasonal Water Quality Parameters of Water Resources in Kauwi Location

Parameter	Wet season mean	Dry season mean	P Value
pH	7.14(*0.07*)	7.03*(0.05)*	0.00*
Calcium(mg/l)	118.91(*77.81*)	177.77(*67.04*)	0.03*
Magnesium(mg/l)	36.57(*12.73*)	44.35(*18.04)*	0.379
Aluminium(mg/l)	0.21(*0.28*)	0.15*(0.06)*	0.372
Electrical conductivity(mg/l)	390.11(*74.64*)	514.15(*179.68)*	0.020*
TDS (mg/l)	419.57(*129.38*)	491.18(*225.91*)	0.26
Nacl(mg/l)	28.67(*14.03*)	43.61*(23.46)*	0.04*
Sulphates(mg/l)	233.25(*42.64*)	139.93(*57.59*)	0.00*
Nitrates(mg/l)	67.52(*10.70*)	54.52(*25.41)*	0.08
CaCO3(mg/l)	220.18(*125.60*)	54.43(*14.79)*	0.00*
Chlorides(mg/l)	138.87(*88.42*)	229.34(*26.89*)	0.001*
Fluoride(mg/l)	0.67(*0.64*)	0.61(*0.37*)	0.12
Zinc(mg/l)	1.41(*2.42*)	1.70*(1.87)*	0.76
Turbidity (NTU)	5.71*(6.90)*	5.80*(5.22*)	0.42

Note: The variables in parentheses are standard deviations

* P values are significant ($p \leq 0.05$)

Table 4.3: Mean Values of Selected Seasonal Water Quality Parameters of Water Resources in Zombe Location

Parameter	Wet season mean	Dry season mean	P Value
Ph	7.15(*0.07)*	7.04(*0.53)*	0.00*
Calcium(mg/l)	226.47(*62.31*)	180.17(*61.83*)	0.05*
Magnesium(mg/l)	40.56*(9.71)*	50.78(*16.02)*	0.04*
Electrical conductivity(mg/l)	452.52(*96.94*)	231.89(*97.23*)	0.00*
TDS (mg/l)	537.09(*139.0*)	544.48(*205.27*)	0.91
Nacl(mg/l)	83.09(*131.56*)	39.31(*19.72*)	0.22
Sulphates(mg/l)	298.23(*86.47*)	206.62(*69.40*	0.003*
Nitrates(mg/l)	68.52(*9.44*)	64.41(*19.06*)	0.46
CaCO3(mg/l)	229.71(*89.67*)	60.02(*16.19*)	0.00*
Chlorides(mg/l)	177.03*(82.89)*	299.31(*105.46*)	0.001*
Fluoride(mg/l)	1.71*(2.48*)	0.67(*0.29*)	0.12
Zinc(mg/l)	1.27*(1.53*)	1.40(*1.79*)	0.41
Turbidity (NTU)	9.08(*14.35)*	5.43(*2.38*)	0.42

Note: The variables in parentheses are standard deviations

* P values are significant ($p \leq 0.05$)

4.3 Statistical Correlation between the Water Quality Parameters

Correlation analysis was performed to assess whether there is a statistical correlation between the water quality parameters, and results are shown in Table 4.4The table clearly indicates that there exists a positive correlation between SO_4 and CL^{-}, TDS and $CaCO_3$, Mg and $CaCO_3$, $CaCO_3$ and TDS, Salinity and $CaCO_3$ among others. A negative correlation exists between Mg and pH, Ca and F-, Ca and pH, Ca and Zn, Ca and K, AL and F-. As a result, the physicochemical parameters correlate with one another, both positively and negatively.

Table 4.4 : Correlation results for selected water quality parameters

	Mg (mg/L)	Ca (mg/L)	Al (Mg/L)	EC (mg/L)	TDS (Mg/L)	Turbidity (NTUs)	Salinity (mg/L)	CaCO3 (mg/L)	NO_3 (mg/L)	SO_4 (mg/L)	Cl^- (mg/L)	F^- (mg/L)	PH	Zn (mg/L)
Mg (mg/L)	1													
Ca (mg/L)	.394**	1												
Al (Mg/L)	.177	.132	1											
EC (mg/L)	.065	.327*	.266*	1										
TDS (Mg/L)	.479**	.445**	.180	.424**	1									
Turbidity (NTUs)	.014	.037	-.027	.088	-.026	1								
Salinity (mg/L)	.252	.446**	.032	.309*	.434**	-.011	1							
CaCO3 (mg/L)	.469**	.226	-.153	.079	.409**	-.012	.476**	1						
NO_3 (mg/L)	.377**	.391**	.271*	.178	.375**	.062	.294*	.163	1					
SO_4 (mg/L)	.256*	.376**	.274*	.166	.457**	.010	.174	-.240	.423**	1				
Cl^- (mg/L)	.234	.278*	.228	.302*	.445**	.079	.190	-.229	.415**	.691**	1			
F^- (mg/L)	.276*	-.020	-.001	.044	.390**	.012	.374**	.563**	.002	-.089	-.166	1		
PH	-.092	-.003	.248	.048	-.143	.068	-.239	-.503**	.201	.399**	.409**	-.314*	1	
Zn(mg/L)	.134	-.147	.033	.151	-.076	.020	-.030	-.147	.081	-.038	-.056	-.009	.076	1

**Correlation is significant at the 0.01 level (2-tailed)

*Correlation is significant at the 0.05 level (2-tailed)

Note: The other values without * are not significant

4.4 Comparison of the Mean Values with KEBS and WHO Standards

4.4.1 Calcium

The Calcium levels ranged from 43.6 mg/l to 283.2 mg/l during the wet season and 0 mg/l to 283.2 mg/l in the dry season with a mean of 172.69 mg/l and 178.97 mg/l respectively (Figure 4.1). High Calcium levels were noted in the dry season compared to the wet season. During the dry season 19 wells did not comply with the WHO and KEBS standards and 18 wells did not comply during the wet season.

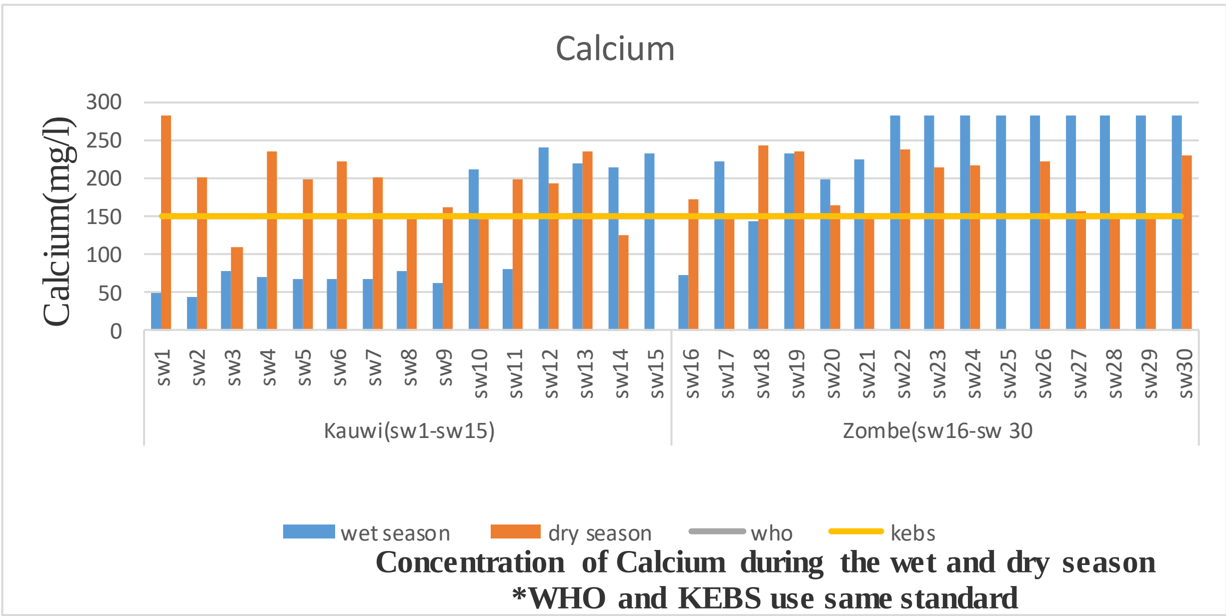


Figure 4.1: Calcium concentration during the dry and wet seasons

4.4.2 Sulphates

During the rainy season, the concentrations varied from 143.2 mg/l to 553 mg/l, and 0 to 255.7 mg/l, with an average of 265.74 mg/l and 173.27 mg/l, respectively. The rainy season had higher sulphate concentrations than the dry season (Figure 4.2). One well during the dry season and 12 wells during the wet season did not meet the WHO and KEBS standards.

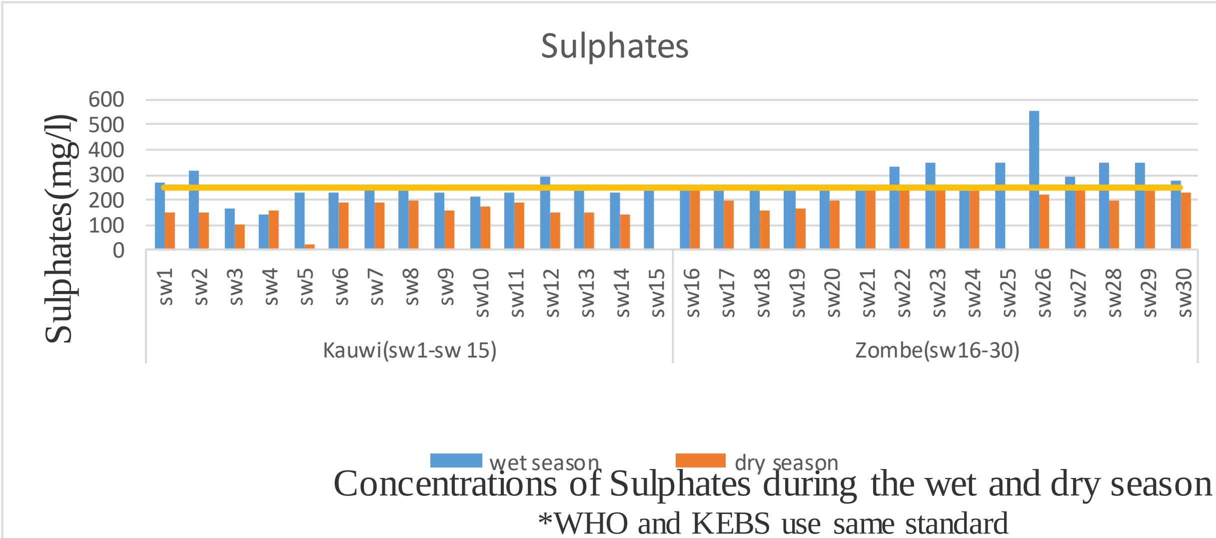


Figure 4.2: Sulphates concentration during the dry and wet seasons

4.4.3 Nitrates

The mean nitrate levels varied from 42.7 mg/I to 87.9 mg/l during the rainy season and from 0 mg/l to 76.8 mg/l during the dry season, with an average of 68.02 mg/l and 59.47 mg/l, respectively (Figure 4.3). Only six wells during the dry season and one during the wet season met WHO and KEBS standards.

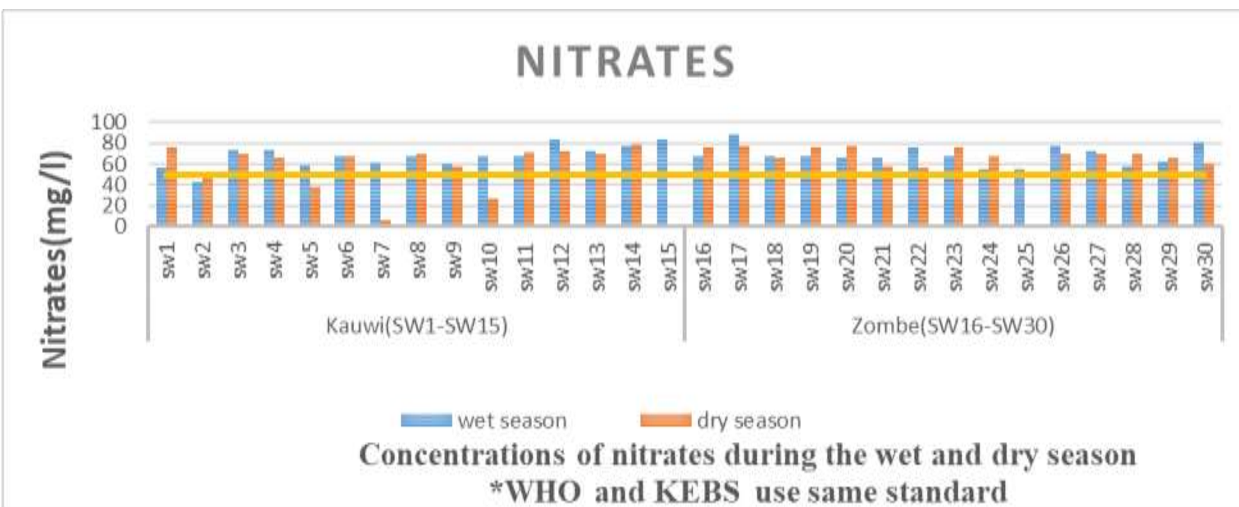


Figure 4.3: Nitrates Concentration during the dry and wet seasons

4.4.4 Total Hardness (Calcium carbonate)

$CaCO_3$ concentrations varied from 28.6 mg/l to 80.9 mg/l during the dry season and 0 mg/l to 350 mg/l during the rainy season, with mean values of 53.7 mg/l and 228.47 mg/l, respectively (Figure 4.4).).Ten shallow wells during the wet season did not meet the WHO and KEBS standards.

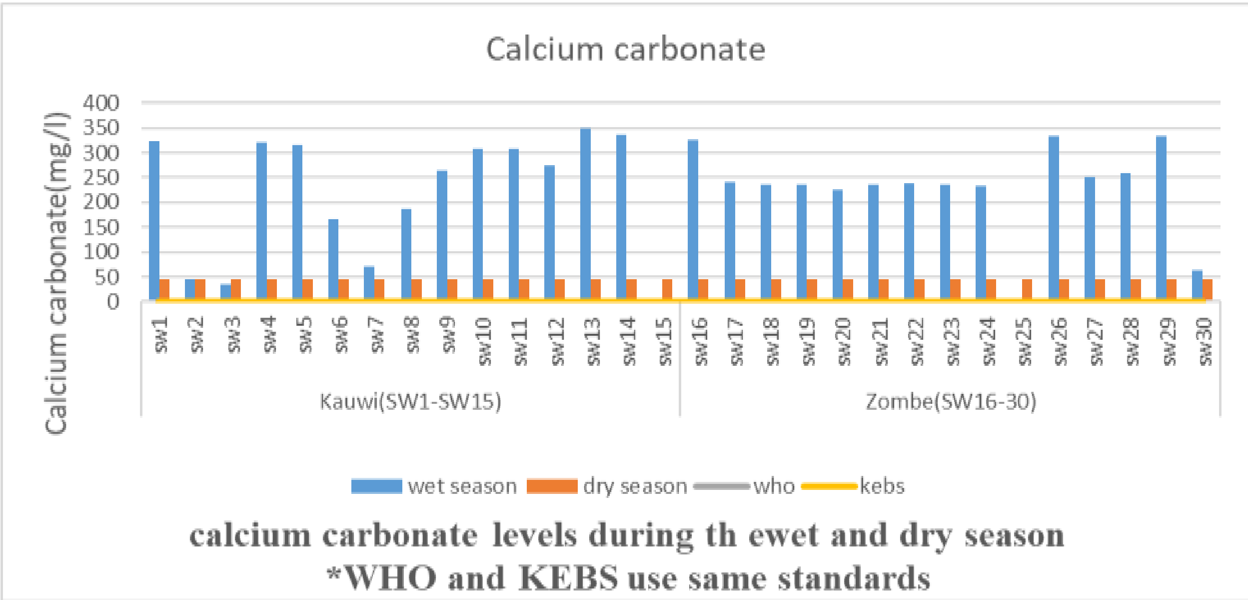
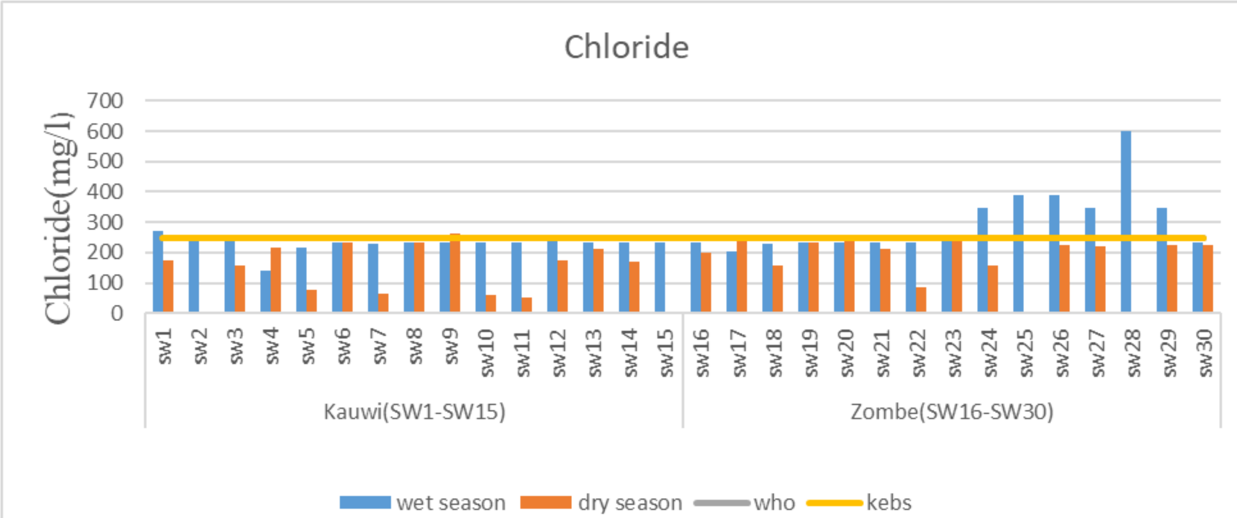


Figure 4.4: Calcium carbonate Concentration during the dry and wet seasons

4.4.5 Chlorides

Chloride concentration varied from 141.1 mg/l to 598 mg/l during the rainy season and from 0 mg/l to 240.9 mg/l during the dry season, with means of 264.32 mg/l and 157.95 mg/l, respectively (Figure 4.5). Seven wells during the wet season and one well during the dry season did not comply to the WHO and KEBS standards.



Concentrations of Chloride during the wet and dry season
***WHO and KEBS use same standard**

Figure 4.5: Chloride during Concentration the dry and wet seasons

4.4.6 Turbidity

The mean turbidity levels during the rainy season ranged from 1.8 NTU to 45.3 NTU, while during the dry season it ranged from 0 to 23.44 NTU respectively (Figure 4.6). The rainy season had higher turbidity levels than the dry season. During the dry season, 13 wells did not comply to the set WHO and KEBS standards while during the wet season, 5 wells did not comply.

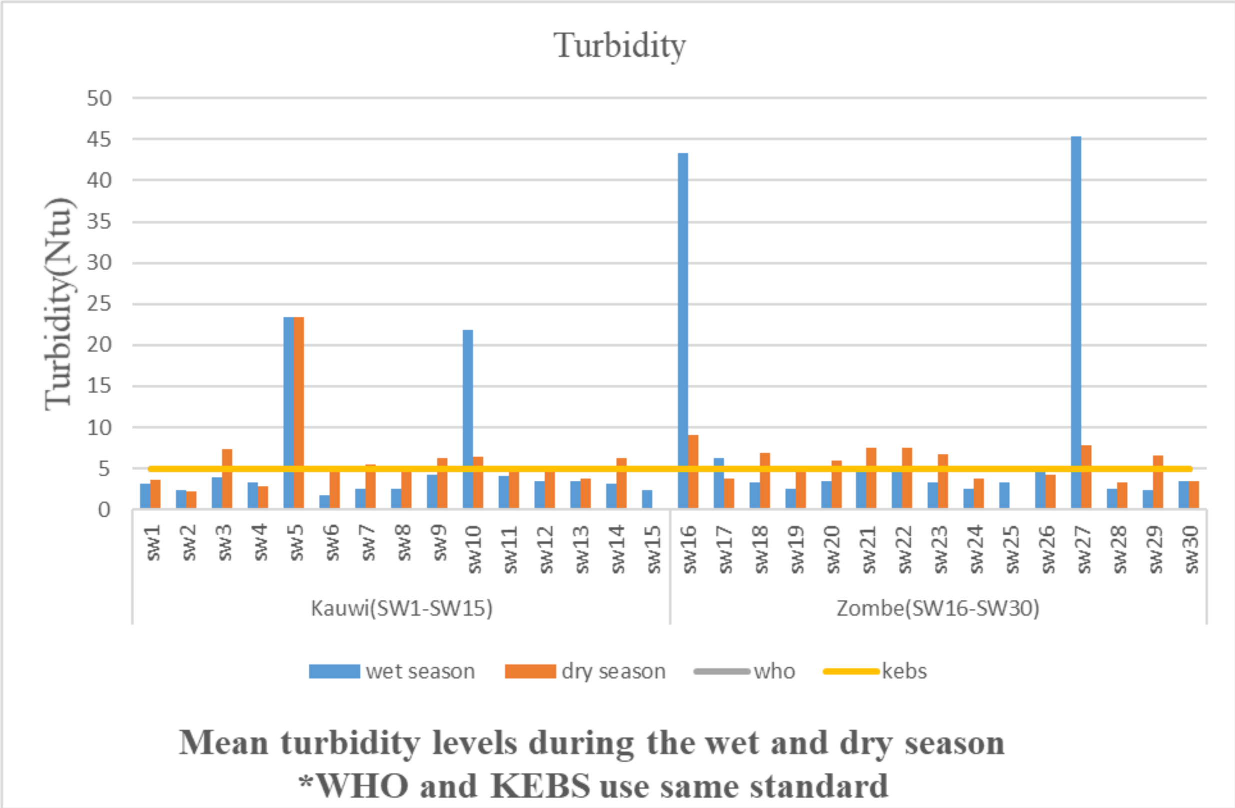


Figure 4.6: Mean levels of turbidity during the dry and wet seasons

CHAPTER FIVE

5.0 DISCUSSION

5.1 Spatial variations in physicochemical properties of shallow wells

The observed significant spatial differences on chlorides, Sulphates, Electrical conductivity, Magnesium and Calcium could be attributed to weathering of gneiss, migmatite and fluvial rocks occurring in the area of study. Additionally, different land use practices like fertilizer application, when farming, animal grazing and sand harvesting carried out in the study area may also enhance these spatial variations. Studies by Gevera *et al.* (2020) established spatial differences in the parameters studied whereby he attributed the differences to rock weathering and evaporation. Further, Mwamati (2017) observed spatial variations in the parameters studied. He attributed the differences to the geologic formations and composition of rocks. The lack of significant differences in the rest of the parameters is probably due to similar anthropogenic activities affecting the changes in these parameters being carried out in the research locations.

5.1.1 Calcium

The presence of spatial variations on Calcium may be due to the dissolution of carbonates like calcite, dolomite, gypsum, and marble (Sulpis *et al.*, 2021). These findings are consistent with the findings of Gevera *et al.* (2020) who reported that there were spatial Calcium differences in ground water of Makueni This was associated to weathering of rocks. Rocks and minerals in contact with water determine the chemical composition or the concentration rates of different parameters in water (Tavassoli *et al.*, 2002).

5.1.2 Magnesium

The observed spatial differences could be attributed to the varying types of magnesium-bearing minerals found across the study areas. Gevera *et al.* (2020) who noted spatial differences in Mg indicated similar findings. The study attributed the differences to dissolution and weathering of silicate rocks.

5.1.3 Electrical Conductivity

The spatial variations observed in Electrical conductivity might be credited to the geological rock formations of the study area. Kauwi consists of gneiss and migmatite rocks while Zombe is characterized by fluvial rocks. The electrical conductivity may be affected by dissolution of various anions and cations by different chemical materials. Makhokha (2019) made similar observations where the electrical conductivity values differed between different locations where the salt mining areas recorded a high electrical conductivity. Gevera *et al*. (2020) also observed spatial differences in electrical conductivity of shallow wells of Makueni. The differences were linked to the geology of the study area.

5.1.4 Sulphates

In the study areas, the significant difference in sulphate mean levels of Kauwi and Zombe might be linked to the various human activities conducted in the study areas. Consumption of water containing sulphates above the recommended levels can cause a laxative effect (Olonga *et al.*, 2015). Similar observations were made by Alexander (2017) where intensive agricultural and mining activities are carried out in the area with high levels of sulphates. Further, Gevera *et al. (*2020) attributed the spatial variation in sulphates to weathering of rocks.

5.1.5 Chlorides

The regional disparities observed in chloride mean levels might be related to geological variables as well as differences in human activity in the studied locations. This concurs with the findings by Makhokha (2019) who observed spatial differences on chloride levels. The differences were associated with geologic formations and surface run-off of leachates. In contrast, findings by Jain *et al*. (2005) also pointed spatial chloride variations which was linked to industrial pollution. Similar observations on chloride variations were also made by Mani & Kannan (2015) where they associated the variations to domestic sewage.

5.2 Temporal variations in physicochemical properties of groundwater

5.2.1 pH

The observed significant seasonal differences in Kauwi and Zombe could be attributed to run-off and deposits with acidic components such as sulphuric or nitric acid from the atmosphere in the rainy season which may cause an increase in pH. The results are in agreement with Mwangi (2014) who noted higher pH of water in Kiambu County during the wet than the dry season. A high pH was attributed to dissolved substances. Further, similar studies by Kanyaru (2012) on assessment of shallow wells in Tharaka Nithi indicated a higher pH during the wet season compared to dry season. This study associated the high pH levels during the wet season to organic matter decay while during the dry season there is reduced water volume which may lead to decrease in pH level. At low pH, heavy metals are easily dissolved in water and the water may lead to gastrointestinal disorder especially hyperacidity and ulcers. High pH may lead to scale formation in heating systems.

5.2.2 Calcium

Calcium is very useful in human health as it helps in strengthening of teeth and bones and plays a part in muscle movement. Excess Calcium in water may cause kidney stones and hypercalcemia which can cause stomach upsets nausea, vomiting and constipation. The significant seasonal variations observed in both Kauwi and Zombe location could be attributed to groundwater recharge containing calcium ions during the rainy season. The results are in agreement with research carried out in Chuka town by Ombaka *et al.* (2013), who found out that calcium levels were greater in the rainy season than in dry season. Calcium levels were higher than acceptable WHO and KEBS guidelines in both seasons.

5.2.3 Electrical Conductivity

The significant differences in electrical conductivity concentrations between the wet and dry seasons in both study areas can be attributed to water evaporation, which increases ion concentrations. During the rainy season, however, the influx of rainwater dilutes the ions, reducing their concentration. This study's results are consistent with those of

Ngabirano *et al.* (2016) who reported greater electrical conductivity values during the rainy season.

5.2.4 Salinity

The observed difference in salinity between the wet and dry seasons in Kauwi could be attributed to the reduced dilution effect during the dry season. This is comparable to the findings of a research by Ladipo *et al.* (2011) that found significant seasonal variations in salinity with the dry season recording higher salinity than the wet season. This was attributed to high rate of evaporation during the dry season leading to increased concentration of salinity. Further, the findings of this study has also been supported by Dan *et al. (2014) and* Regina *et al. (2021)* who noted higher salinity levels during the dry season. This was due to high evaporation rates, poor water flow, and saltwater intrusion.

5.2.5 Sulphates

The observed significant temporal variations in sulphate was attributed to run-offs carrying fertilizers into the shallow wells during the rainy season as there is intensive agriculture carried out near the shallow wells. This concurs with findings of Mwangi (2014) who noted higher sulphate levels during the wet season. The higher levels were associated with run-off from fertilizers, fungicides, chemicals and insecticides. Similarly, Ombaka *et al.* (2013) related high sulphate levels during the wet season to leaching from gypsum and other common minerals.

5.2.6 Total Hardness (Calcium carbonate)

The temporal fluctuations in $CaCO_3$ revealed considerable differences between the wet and dry seasons. The mean $CaCO_3$ levels were greater during the rainy season than in the dry season. The changes might have been caused by groundwater replenishment with calcium and magnesium ions. Previous investigations in Tharaka nithi by Kanyaru (2012), Ombaka *et al*. (2013), Makwe *et al*. (2013), and Olonga *et al*. (2015) found greater levels of $CaCO_3$ during the rainy season compared to the dry season. The studies attributed the high levels to groundwater recharge with Calcium and Magnesium ions which result from leaching from the rocks.

5.2.7 Chlorides

The observed variation in chloride concentrations between the rainy and dry seasons can be attributed to the diluting effect of rainwater during the rainy season, which likely lowers the concentrations of chloride ions. Similar results were obtained by Mwangi (2014) in Kiambu. The introduction of the chloride in the shallow wells could be from natural minerals or leaching of salts from the soil to the wells. High levels of Chloride gives water a salty taste. It also causes damage to home appliances and if consumed in excess it may cause hypochloraemia.

5.3 Statistical Correlation between the Water Quality Parameters

The significant positive correlation between magnesium and calcium carbonate suggests that higher magnesium concentrations are associated with increased levels of calcium carbonate. This is expected, as both magnesium and calcium are major cations found in water and are involved in processes such as water hardness. The formation of calcium carbonate ($CaCO_3$) typically occurs in hard waters, and magnesium is often found alongside calcium in such systems, leading to their concurrent increase. This aligns with study findings by Liu *et al. (*2005) who found a direct relationship between these cations and calcium carbonate saturation in ground water. Similarly Rapant *et al*. (2017) documented that calcium and magnesium concentrations in groundwater significantly influence health outcomes, indicating their pivotal role in water chemistry and quality.

The positive correlation between TDS and calcium carbonate suggests that higher TDS concentrations are linked to elevated levels of calcium carbonate. TDS includes various dissolved salts, and a significant portion of these may be contributed by calcium and magnesium salts, both of which are components of calcium carbonate. Therefore, higher TDS levels often correspond to harder water, which typically contains more calcium carbonate. The positive correlation between TDS and calcium carbonate is also consistent with other research. According to the World Health Organization (WHO, 2017), TDS in natural waters is largely composed of calcium, magnesium, and bicarbonate ions—key constituents of calcium carbonate. Tiwari & Singh (2014) also reported a significant relationship between TDS and calcium carbonate in rural groundwater, showing that elevated TDS typically signals increased hardness.

TDS is a measure of the total concentration of dissolved solids in water, including ions such as calcium, magnesium, and sodium. The positive correlation between TDS and magnesium concentrations indicates that as the total concentration of dissolved solids increases, so does the concentration of magnesium, which is a major contributor to TDS. This is consistent with the understanding that higher TDS levels often reflect higher concentrations of divalent cations like magnesium and calcium. Srinivasamoorthy *et al.* (2008), who demonstrated that magnesium significantly contributes to the TDS load, particularly in regions with dolomite or basaltic geology. Subba Rao (2006) also reported a strong link between magnesium and TDS in hard rock aquifers of India, noting that geogenic processes such as rock-water interaction and weathering of magnesium-bearing minerals were key contributors.

Salinity and calcium carbonate also show a significant positive correlation Salinity in water is primarily due to the presence of dissolved salts, which may include compounds like sodium chloride, calcium chloride, and magnesium sulfate. As salinity increases, calcium carbonate levels tend to increase as well, likely due to the common presence of calcium and carbonate ions in saline environments. Appelo & Postma (2005) described how saline water introduces not only sodium and chloride but also calcium and bicarbonate, leading to increased calcium carbonate precipitation.This relationship is further supported by findings from Mazor (2004) who observed that groundwater systems in semi-arid climates often exhibit co-enrichment of salinity and calcium carbonate due to prolonged water-rock interaction and dissolution of carbonate-bearing minerals

A strong positive correlation between sulphate and chloride suggests that these two ions often occur together in water. Both sulphate and chloride are commonly found in groundwater and surface water, often originating from natural sources like mineral deposits or from human activities such as industrial processes. This correlation may indicate the presence of both ions in certain water sources, reflecting common geochemical processes or pollution sources. Jalali (2005) identified similar co-occurrence in groundwater affected by agricultural runoff and evaporative concentration, suggesting a shared origin or transport pathway. Similarly, Sarin & Chatterjee (2014) observed a significant positive correlation between sulphate and chloride in the groundwater of the Indo-Gangetic Basin, noting that these ions often co-occur in regions with heavy irrigation and industrial contamination. Their study emphasized that both sulphate and chloride can be leached from soils or industrial effluents, where they may mix with naturally occurring groundwater constituents. Additionally, Smedley & Kinniburgh (2002) highlighted the role of geogenic processes, such as the dissolution of evaporite minerals (e.g., halite and gypsum), in promoting the co-occurrence of these ions, especially in arid and semi-arid regions where evaporation exceeds precipitation.

A slight negative correlation between magnesium and pH indicates that higher magnesium concentrations are associated with a slight decrease in pH (Zubair *et al*., 2002). This may be due to the fact that magnesium salts, when dissolved in water, can slightly lower the pH, especially in waters with high mineral content. However, the correlation is weak, suggesting that other factors may also influence the pH levels in the water. The correlation between calcium and pH is negligible, suggesting that there is no significant relationship between calcium concentration and pH in the analyzed samples. This could imply that pH variation is governed by other factors, such as the presence of acidic or basic compounds, rather than calcium alone (Mazor, 2004).

A negative correlation between aluminum and fluoride suggests that as the concentration of aluminum increases, the fluoride concentration tends to decrease. This relationship may be due to the fact that aluminum can form complexes with fluoride, reducing the available fluoride ions in the water. This is particularly relevant in natural waters, where aluminum and fluoride may interact to form insoluble compounds. For instance, Pillai *et al. (*2007) demonstrated that aluminum and fluoride ions can interact in water systems, where aluminum ions, particularly in the form of aluminum hydroxides, have a high affinity for fluoride, leading to the formation of stable complexes that reduce free fluoride concentrations. Similarly, Liu *et al.* (2011) investigated the interaction between aluminum and fluoride in groundwater samples from industrial areas in China, finding that aluminum fluoride complexes contributed to lower free fluoride concentrations, especially in waters with high aluminum content. The study also indicated that under acidic conditions, the formation of aluminum-fluoride complexes is more prominent, further reducing the fluoride available in the solution.

The observed significant correlation between SO_4 and Cl^-; $CaCO_3$ and TDS; Mg and $CaCO_3$; TDS and SO_4; $CaCO_3$ and Salinity implies that if the concentration of any of these variable increases, the concentration of the other variables increases. It is also an implication that they originate from similar sources in the environment. This means that to control ground water quality you only need to control either of them. This is in agreement with the results obtained by (Daraigon *et al ., 2011*; Jothivenkatachalam *et al.,* 2010.; Patil and Patil 2010).

5.4 Comparison of Mean Levels to WHO and KEBS Standards

Calcium, Sulphates, nitrates, Chlorides, turbidity and Calcium carbonate did not comply to the KEBS and WHO standards in both seasons. This could be attributed to the geology and anthropogenic activities carried out in the study area.

5.4.1 Calcium

The high calcium levels observed during both the wet and dry season can be attributed to the geology of the study area. Comparable results were obtained by Rajesh *et al*. (2015) where he attributed the source of the high calcium levels in shallow aquifers in Southern India to minerals. Calcium is very useful in human health as it helps in strengthening of teeth and bones and also plays a part in muscle movement. Excess Calcium in water may cause kidney stones and hypercalcemia which can cause stomach upsets, nausea, vomiting and constipation.

5.4.2 Sulphates

The high sulphate levels observed in Zombe shallow wells that did not comply to WHO and KEBS standards could have originated from fertilizers containing sulphates. These study results concur with Rajesh *et al.* (2015) where sulphate levels did not comply to WHO standards in some of the wells. The source of the sulphates was attributed to minerals such as feldspars and pyroxene. Further, a study by Nguyen and Huynh (2023) also recorded sulphate levels higher than the WHO standards. This was attributed to leaching from landfills.

5.4.3 Nitrates

The observed nitrate concentrations failing to meet WHO and KEBS standards could potentially be linked to agricultural run-off, a concern that has been raised in previous studies. For instance, Yu *et al.* (2020) noted that several shallow wells did not comply with WHO standards, attributing this non-compliance to both geological factors and the use of chemical fertilizers. Intake of excess nitrate can affect how blood carries oxygen and lead to a condition known as blue baby syndrome (WHO, 2011).

5.4.4 Total Hardness

According to the results of the study the ten shallow wells that did not comply during the wet season could be attributed to run-off containing magnesium and calcium ions. Similar results were obtained by Kanyaru (2012). According to the study, groundwater is highly soluble especially for rocks containing gypsum, calcite and dolomite which are responsible for water hardness. Similarly, Makhoka (2019) observed similar results. He attributed the water hardness to heavy agricultural activities carried out in the study areas.

5.4.5 Chlorides

The observed high chloride levels could be from natural minerals or leaching of salts from the soil to the wells. Similar results by Makhoka (2019) indicated chloride levels higher than WHO and KEBS standards especially for the groundwater sources that were near the sea. This was attributed to geologic formations. Further, Muraguri (2016) also observed chloride levels higher than WHO standards. He attributed the high levels to the total dissolved solids. High levels of Chloride in water give it a salty taste. It also causes damage to home appliances and if consumed in excess it may cause hyperchloremia.

5.4.6 Turbidity

The high turbidity levels in shallow wells noted from the study findings can be attributed to water runoff. Ombaka *et al.* (2013) found similar results, with turbidity levels during the rainy season that did not meet WHO and KEBS requirements. This was attributed to surface run-off as a result of heavy rains. Further, Adongo *et al.* (2022) also observed high turbidity levels in shallow wells which did not comply to the WHO standards during both the wet and the dry season. This was linked to silt, organic matter and microscopic organisms. High turbidity levels provide a shelter to microorganisms and this prevents disinfection.

CHAPTER SIX

6.0 CONCLUSION AND RECOMMEDATIONS

6.1 Conclusion

The study concluded that geological differences, land use practices, and anthropogenic activities were the key contributors to spatial variations in water quality. The temporal variations were primarily influenced by factors such as rainfall, evaporation and ground water recharge during the wet season. Finally, the correlation between water quality parameters indicated significant associations between certain ions and compounds, implying that controlling one parameter could help manage others.

6.2.1 Recommendations

To ensure the sustainability and quality of groundwater resources, it is crucial to adopt a diversified approach. First, protection of shallow wells should be prioritized to prevent contamination and ensure their long-term sustainability. This can be achieved through well covering and fencing to restrict access by grazing animals. Secondly, training programs to be conducted on farmers on applying the required quantities of farm in puts. Finally, conducting regular water quality analysis on the shallow wells in the study area will provide vital information on water quality and help identify potential issues early. Through the integration of these practices we may effectively safeguard shallow wells water quality and promote sustainable agricultural practices.

6.2.2 Recommendations for further studies

We recommend for further research to be done on bacteriological quality of shallow wells since the study only covered the physical and chemical quality.

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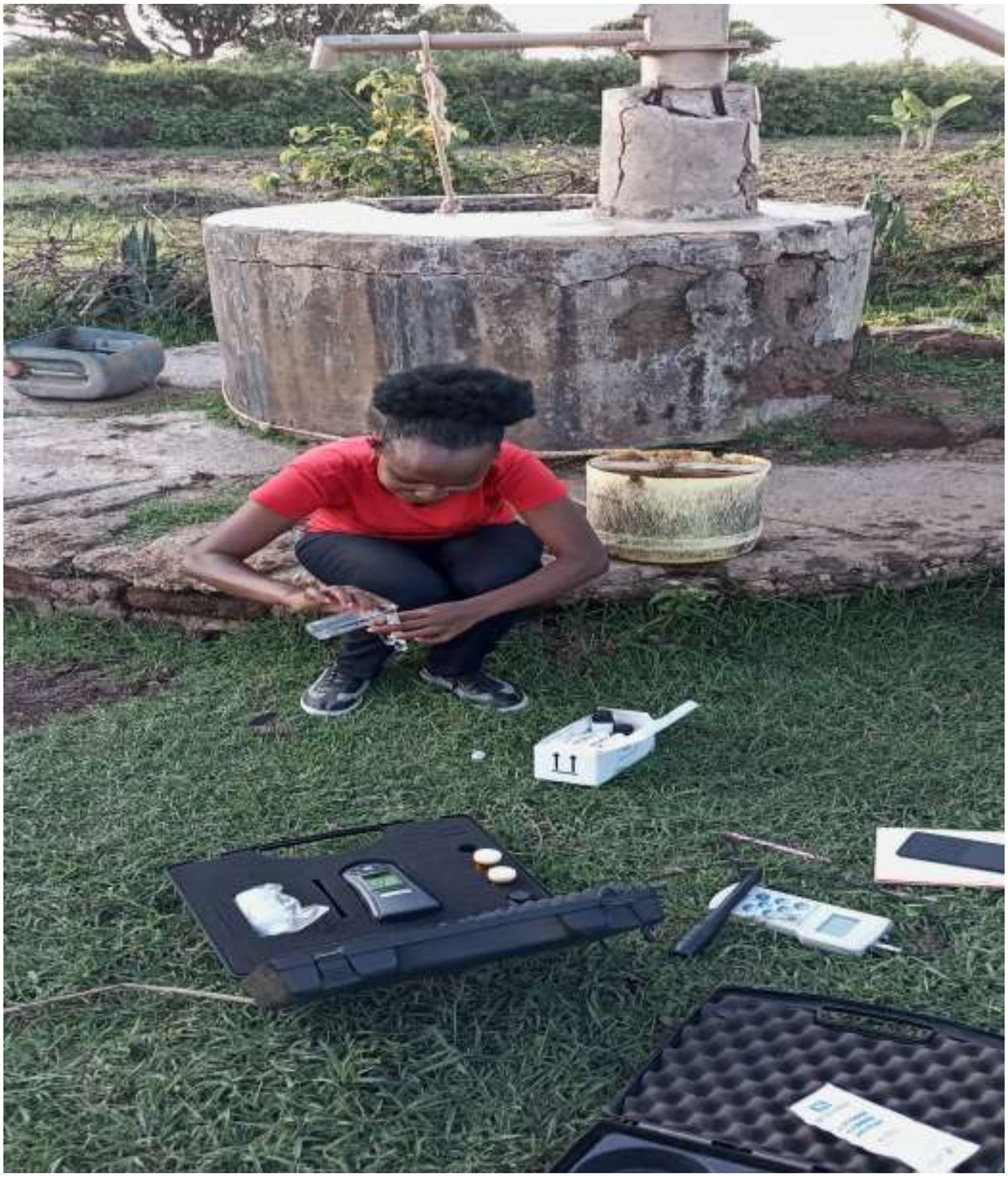
LIST OF APPENDICES

Appendix i: Water quality analysis in the field (Dorcas, 2024)



Appendix ii: Uncovered well in the study area (Dorcas, 2024)

Appendix iii: The GPS coordinates of the shallow wells

NAME OF THE WELL	LOCATION	NAME OF THE OWNER		GPS_Coordinates	_GPS_Coordinates_latitude	_GPS_Coordinates_longitu	_GPS_Coordinates_altitude
Kwa Kawilu	KAUWI	Kawilu Musyoki		-1.3086344 37.7556081 1174.6038483192667 91.059	-1.3086344	37.7556081	1174.603848
Kwa Kasumbi	KAUWI	Kasumbi Mbuti		-1.1696293 37.9003811 1183.7501129630853 4.683	-1.1696293	37.9003811	1183.750113
Kwa Mwatu Mbuti	KAUWI	Mwatu Mbuti		-1.1699342 37.8990609 1191.3101611198783 4.883	-1.1699342	37.8990609	1191.310161
Kwa Muli	KAUWI	Muli Mbuti		-1.1701897 37.9011584 1192.6585708824084 4.36	-1.1701897	37.9011584	1192.658571
Kwa musumbi	KAUWI	Kwa musumbi		-1.1685382 37.9077926 1197.7685669258203 4.46	-1.1685382	37.9077926	1197.768567
Kwa Nziaka	KAUWI	Nziaka Kasuva		-1.1693054 37.9073275 1207.0748255681788 4.36	-1.1693054	37.9073275	1207.074826
Kwa Nzeli Kasuva	KAUWI	Nzeli Kasuva		-1.16927 37.9073383 1197.9267101096975 4.94	-1.16927	37.9073383	1197.92671
Kwa Josphat Mwania	KAUWI	Josphat Mwania		-1.1687372 37.9061332 1187.5320998246134 4.7	-1.1687372	37.9061332	1187.5321
Kwa Nyamu Mbiti	KAUWI	Nyamu Mbiti		-1.1683062 37.9066766 1190.501458796427 4.9	-1.1683062	37.9066766	1190.501459
Kwa Peter Mbete	KAUWI	Peter Mbete		-1.169529 37.9069159 1188.6203228972313 4.95	-1.169529	37.9069159	1188.620323
Kwa Patrick Mwania	KAUWI	Patrick Mwania		-1.1685134 37.9054409 1187.2107972912806 4.86	-1.1685134	37.9054409	1187.210797
Kwa Vundi valua	KAUWI	Vundi valua		-1.1694648 37.9043917 1183.908447265527 4.7	-1.1694648	37.9043917	1183.908447
Kwa Olivia	KAUWI	Olivia Mule		-1.1693711 37.9040311 1184.6824077399835 4.66	-1.1693711	37.9040311	1184.682408
Kwa Ndesya kamito	KAUWI	Ndesya kamito		-1.1694388 37.9046563 1187.3236522787995 4.56	-1.1694388	37.9046563	1187.323652
Kwa Justus mwaniki	KAUWI	Justus mwaniki		-1.169463 37.9046111 1188.830260093932 4.66	-1.169463	37.9046111	1188.83026
Kwa Silvester mwami	ZOMBE	Silvester mwami		-1.1619676 37.9016229 1206.8394745056085 5.0	-1.1619676	37.9016229	1206.839475
Kwa Alex John	ZOMBE	Alex John		-1.4100963 38.132848 628.0 4.5	-1.4100963	38.132848	628
Kwa Mwami Mathew	ZOMBE	Mwami Mathew		-1.4454346 38.2601981 557.0 4.983	-1.4454346	38.2601981	557
Kwa John Wambua	ZOMBE	John Wambua		-1.4445695 38.2596778 568.0 4.28	-1.4445695	38.2596778	568
Kwa Mutua Mwania	ZOMBE	Mutua Mwania		-1.4688844 38.2039207 580.0 4.68	-1.4688844	38.2039207	580
Kwa Muli Mutuvi	ZOMBE	Muli Mutuvi		-1.4401743 38.2592472 559.0 4.8	-1.4401743	38.2592472	559
Kwa Wambua ng'etu	ZOMBE	Wambua ng'etu		-1.4446648 38.2598088 563.0 4.78	-1.4446648	38.2598088	563
Kwa Lilian Mutia	ZOMBE	Lilian Mutia		-1.4455839 38.2598674 552.0 3.9	-1.4455839	38.2598674	552
Kwa Musau musimi	ZOMBE	Musau musimi		-1.4484655 38.2612142 543.0 4.78	-1.4484655	38.2612142	543
Kwa Martin Kioko	ZOMBE	Martin Kioko		-1.4485695 38.2610076 559.0 4.32	-1.4485695	38.2610076	559
Kwa Partricia	ZOMBE	Partricia		-1.4691152 38.2034824 577.0 4.26	-1.4691152	38.2034824	577
Kwa Kamene Kimwele	ZOMBE	Kamene Kimwele		-1.4698002 38.2041746 578.0 3.8	-1.4698002	38.2041746	578
Kwa Mueke muli	ZOMBE	Mueke muli		-1.469901 38.2035799 569.0 4.78	-1.469901	38.2035799	569
Kwa Lancaster	ZOMBE	Lancaster		-1.4701785 38.2033613 584.0 4.9	-1.4701785	38.2033613	584
Kwa Alex Wambua	ZOMBE	Alex Wambua		-1.4686106 38.204078 578.0 4.583	-1.4686106	38.204078	578
							0

Appendix iv: Research License

SOUTH EASTERN KENYA UNIVERSITY
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Our Ref: B406/MAC/20004/2017

DATE: 14th June, 2021

Dorcas Mbuli Mutemi
Re g. No B406/MAC/20004/2017
MSc. in Environmental Management
C/O Dean School of Environment, Water & Natural Resources

Dear Mutemi,

RE: PERMISSION TO PROCEED FOR DATA COLLECTION

This is to acknowledge receipt of your MSc. in Environmental Management Proposal document titled: ***"Determination of Ground Water Quality of Different Sources in Kauwi and Zombe Locations, Kitui County".***

Following a successful presentation of your MSc. Proposal, the School of Environment, Water & Natural Resources in conjunction with the Directorate, Board of Postgraduate Studies (BPS) have approved that you proceed on and carry out research data collection in accordance with your approved proposal.

During your research work, you will be closely supervised by Dr. Moses Mwangi and Dr. Charles Ndungu. You should ensure that you liase with your supervisors at all times. In addition, you are required to fill in a Progress Report ***(SEKU/ARSA/BPS/F-02)*** which can be downloaded from the University Website.

The Board of Postgraduate Studies wishes you well and a successful research data collection exercise as a critical stage in your MSc. in Environmental Management.

Prof. David M. Malonza
Director, Board of Postgraduate Studies

Copy to: Deputy Vice Chancellor, Academic, Research and Students Affairs (Note on File)
Dean, School of Environment, Water & Natural Resources
Chairman, Department of Environmental Science and Land Resources Management
Dr. Moses Mwangi
Dr. Charles Ndungu
BPS Office - To file

ARID TO GREEN ISO 9001: 2015 CERTIFIED TRANSFORMING LIVES

Appendix v: Lab analysis results for Kauwi and Zombe during the wet and dry season

Station	Shallow wells	Seasons	PH	Ca	Al	Mg	Mn	EC	K	NaCl	Cl2	SO4	NO3	TDS	F	Zn	TUR	CaCO3
Kauwi	sw1	wet	7.13	48.6	0.1	26.9	0.2	425	5.9	40	270	268	56.3	448	1.3	1.4	3.2	45.2
Kauwi	sw2	wet	7.09	43.6	0.2	42.1	1.3	596	9.6	28	246	315	42.7	500	0.4	4.4	2.3	44.3
Kauwi	sw3	wet	7.13	78.2	0.1	49	0.3	492	9	28.5	238.5	161	74	496	2.5	8.3	4	37.25
Kauwi	sw4	wet	7.21	70.8	0.1	44.7	0.1	350	6.7	26	141.1	143.2	73.5	395.2	0.34	4.54	3.3	65.1
Kauwi	sw5	wet	7.15	67.4	1.2	30.7	0.3	392.7	45.3	30.2	216.6	227.6	58.5	531.5	1.3	0.3	23.4	35.45
Kauwi	sw6	wet	7.07	67.8	0.1	34.2	1.3	335.1	0.3	3.7	233.6	231.5	67.7	476.9	0.3	0.3	1.8	60
Kauwi	sw7	wet	7.26	67.7	0.2	58.2	0.2	345.7	0.1	3.7	228	255.9	61.2	456	0.1	0.1	2.5	71.5
Kauwi	sw8	wet	7.15	77.4	0.1	1.3	0.2	343.4	0.3	47.8	233.6	233.2	67.7	345.5	0.1	0.1	2.5	49.6
Kauwi	sw9	wet	7.25	61.05	0.2	32.7	2.9	344	5.6	5.05	233.1	231.7	60.25	289.2	0.1	0.1	4.2	80.2
Kauwi	sw10	wet	7.15	213.1	0.1	34.1	0.2	334.3	5.7	33.95	232.1	212.9	67.7	290.1	0.4	0.2	21.8	63.3
Kauwi	sw11	wet	7.05	81.15	0.2	33.7	0.2	374.2	5.8	33.95	232.1	231.3	67.5	311.2	0.3	0.1	4.1	38.9
Kauwi	sw12	wet	7.24	240.6	0.1	6.8	0.1	450	0.8	45.5	236.1	290.1	83.4	567.4	0.9	0.2	3.5	77.4
Kauwi	sw13	wet	7.09	219	0.2	34.2	0.2	337.1	6.1	35.4	232.2	234.2	71.9	388.1	0.7	0.8	3.5	38.7
Kauwi	sw14	wet	7.14	214.1	0.1	34.3	1.2	333.2	7.1	33.3	234.5	228.1	77.3	345.1	0.5	0.3	3.2	54.3
Kauwi	sw15	wet	7.05	233.1	0.2	25.8	0.1	399	0.8	35	232.6	235	83.1	453.3	0.8	0.1	2.3	55.2
Kauwi	sw1	dry	7.08	283.2	0.1	59.3	0.3	655.9	9.3	63.3	173.8	152.1	76.5	644.8	0.7	0.7	3.6	324.4
Kauwi	sw2	dry	7.06	200.4	0.2	45.6	0.4	355.6	8.2	2.8	0.2	145	50	325.5	0.3	4.6	2.25	45
Kauwi	sw3	dry	7.02	110.3	0.2	11.2	0.5	500.5	8.5	10	155.3	100	70	465	0.4	4.1	7.3	34
Kauwi	sw4	dry	7.13	234.4	0.1	50.6	0.2	600	9.6	23.7	214.7	155.3	65.6	644.7	0.8	0.8	2.8	321.7
Kauwi	sw5	dry	7.01	200	0.1	43	0.2	535	0.6	44	77	23.2	38	166.2	0.6	0.1	23.44	315.6
Kauwi	sw6	dry	6.95	223.4	0.1	23	0.5	785	1	43	234.4	185.4	67	565	0.1	0.2	5	166.6
Kauwi	sw7	dry	7.01	200.3	0.2	43	0.3	500	3.5	59.7	64	185	5.7	455	0.8	3	5.5	70
Kauwi	sw8	dry	7.02	150	0.2	50	0.2	500	10	45	233	200	70	465	0.7	4.5	4.6	187
Kauwi	sw9	dry	7.01	163.3	0.2	56.2	0.2	600	7.2	73.2	263.8	153.3	57.2	682.3	1.2	0.8	6.2	264.3
Kauwi	sw10	dry	6.96	145.9	0.1	10	0.3	700	10.3	57	62.2	170.2	26.8	763	1.3	0.1	6.37	307
Kauwi	sw11	dry	7.01	200	0.2	47.4	0.2	430	1.5	54	52.1	187.3	70.5	345	0.5	4.7	4.91	307
Kauwi	sw12	dry	7.02	192.3	0.1	46.3	0.2	450.2	15.3	56.2	173.2	150.5	72.2	367.7	0.6	0.8	5.2	273.8
Kauwi	sw13	dry	7.05	236.8	0.2	36.3	0.3	600.1	11.2	57.2	211.2	146.8	70.2	653.3	0.3	0.3	3.7	350
Kauwi	sw14	dry	7.04	126.2	0.2	46.9	0.2	500	19.2	65	168.2	144.8	78.2	825.2	0.9	0.8	6.2	336.2
Kauwi	sw15	dry	7.11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Zombe	sw1	wet	7.14	71.6	0.1	32.3	0.03	343.7	7.2	14.7	234.6	233.7	67.8	403.7	0.2	1.7	43.3	73.9
Zombe	sw2	wet	7.2	222.4	0.3	32.2	0.1	350.2	8.1	166.7	201.7	232.6	87.9	345	0.8	2.4	6.3	28.6
Zombe	sw3	wet	7.13	144.4	0.3	32.2	0.1	345.6	8.5	38	227.7	233.8	67.7	453.4	0.5	1.8	3.3	65.4
Zombe	sw4	wet	7.08	232.7	0.3	34	0.3	455.2	6.6	43.3	232.2	233.3	67.7	543.4	0.7	1.5	2.6	72.4
Zombe	sw5	wet	7.03	199.6	0.1	34.6	0.1	344.5	7.7	33.8	234.5	233.5	66.7	454.5	0.3	0.2	3.4	76.3
Zombe	sw6	wet	7.14	223.95	0.1	24.8	0.2	345.6	6.6	54.5	234.5	234.5	66.4	345	0.6	2.3	5	50.7
Zombe	sw7	wet	7.26	234.5	0.2	49.5	0.5	594.5	15.3	38.5	234.5	333	76.3	501.3	0.2	0.4	5.3	40.95
Zombe	sw8	wet	7.19	279.1	0.4	33	0.4	460	7.6	34	240.6	345.6	67.7	531	0.7	0.3	3.3	68.65
Zombe	sw9	wet	7.23	290.1	0.4	38.5	0.5	499	6.6	44	345.6	234.5	55	504.5	0.7	0.5	2.5	50.2
Zombe	sw10	wet	7.15	290	0.6	45	0.7	444	8	45	389.3	345.6	55	810	8.5	0.5	3.3	50.6
Zombe	sw11	wet	7.05	290.1	1.3	54	6.95	457.5	7.2	543	390.8	553	77.4	814	6.8	1	4.5	76.3
Zombe	sw12	wet	7.17	290.1	2.4	43.3	0.2	543	7.2	38.5	345.6	290.1	71.8	557	2	2.7	45.3	35.85
Zombe	sw13	wet	7.21	165.05	2.5	55	0.9	467.5	1.9	34.5	598	345.6	57	599	1.3	1.3	2.5	65.55
Zombe	sw14	wet	7.22	234.5	0.1	45	14.7	477	1.7	33.8	345.6	345.6	61.9	593.5	1.1	2.7	2.3	80.9
Zombe	sw15	wet	7.16	229	1.1	55	3.8	660.5	5.8	33.5	234.5	279.1	81.5	601	1.2	1.6	3.4	64
Zombe	sw1	dry	7.08	173.3	0.3	50.2	0.2	173.3	12.9	65.2	200.8	263.9	76.3	637.7	0.9	2.8	9.1	325.5
Zombe	sw2	dry	7.16	150	0.2	50	0.2	245.6	10.9	42.4	236.7	200	76.7	376.6	0.8	3.5	3.7	241.3
Zombe	sw3	dry	7.02	244.6	0.4	67.5	0.3	342.3	9.5	37.9	155.6	154.7	65.8	657	0.6	0.8	6.9	234.6
Zombe	sw4	dry	6.95	234.7	0.4	67.8	0.2	343.8	7.6	23	231.5	167.8	75.8	864.6	0.7	0.1	4.8	235.8
Zombe	sw5	dry	7.01	164.7	0.2	50.5	0.2	353.5	10.6	87.8	240.9	197.5	76.8	564.8	0.6	0.6	5.9	225.3
Zombe	sw6	dry	7.04	154.6	0.3	46.7	0.4	235.8	7.9	45.2	212.8	242.5	57.8	754.8	0.5	0.5	7.5	236.4
Zombe	sw7	dry	7.12	237.8	1.5	50.6	0.4	256.8	1.2	23.3	87	245.6	56.8	500.5	0.8	0.7	7.5	237
Zombe	sw8	dry	7.02	214.5	0.4	56.8	0.5	233.7	11.1	34.6	236.7	255.7	75.8	468.9	0.4	0.4	6.8	234.9
Zombe	sw9	dry	7.01	217.2	0.2	54.6	0.1	157.8	10.7	43.8	156.8	236.7	67.4	564.6	0.9	0.8	3.8	233.7
Zombe	sw10	dry	6.98	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Zombe	sw11	dry	7.01	221.3	0.2	69.3	0.3	213.7	0.2	58.8	225.5	221.2	70.2	538.2	0.8	0.5	4.2	333.9
Zombe	sw12	dry	7.03	156.3	0.2	52.3	0.3	241.2	9.2	38.2	221.3	251.2	70.2	582.2	0.3	0.3	7.9	250.6
Zombe	sw13	dry	7.05	150	0.2	50	0.2	105.3	10	28	0.8	200.3	70.3	347.3	1.2	0.4	3.3	260.1
Zombe	sw14	dry	7.05	154.5	0.2	45.4	0.3	345.4	0.6	44.8	223.7	233.7	65.7	764.5	0.9	0.6	6.6	332.6
Zombe	sw15	dry	7.07	229	0.3	50	0.4	230.2	2.3	42.5	225.3	228.5	60.6	545.5	0.6	0.6	3.4	64

Appendix vi: Water abstraction from the shallow wells(Dorcas, 2024)