ASSESSMENT OF SEASONAL AND SPATIAL VARIATIONS IN GROUNDWATER QUALITY OF KAMITI-MARENGETA SUB-CATCHMENT IN KIAMBU COUNTY, KENYA

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DECLARATION

This thesis is my original work and has not been presented for any other degree award in any other university.

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DEDICATION

I dedicate this research work to my parents, Christine Achieng Miruka and Andrew Okeyo Ojwang, my partner Jacob Ochieng Odhiambo, and our beloved son Jami Adrian Ochieng.

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ABBREVIATIONS AND ACRONYMS

ACA	Athi Catchment Area
ANOVA	Analysis of Variance
APHA	American Public Health Association
AQL	Aqualytic Laboratories
BH	Borehole
CL	Confidence Level
DO	Dissolved Oxygen
DPSIR	Drivers, Pressure, State, Impact, and Response
EC	Electrical Conductivity
EDTA	Ethylenediaminetetraacetic acid
EN-ISO	European Union International Organization for Standardization
GIS	Geographic Information System
GPS	Global Positioning System
GVA	Groundwater Vulnerability Assessment
HCL	Hydrochloric acid
HSD	Honest Significant Difference
IQR	Interquartile Range
KEBS	Kenya Bureau of standards
KNBS	Kenya National Bureau of Statistics
KS 459-1:2007	Kenya Standard
KU	Kenyatta University
MAM	March. April, and May
MS	Mean Squares
NACOSTI	National Commission for Science, Technology and Innovation
NAS	Nairobi Aquifer System
NEMA	National Environment Management Authority
NO	Nitrate
NS	Not Specified
NTU	Nephelometric Turbidity Units
OND	October, November, and December
pH	Pondus Hydrogenii
SHW	Shallow Well
SO	Sulphate
SPADNS	2-(parasulfophenylazo)-1,8-dihydroxy-3,6-naphthalene-disulfonate
SPSS	Statistical Package for Social Sciences
SS	Sum of Squares
TA	Total Alkalinity
TDS	Total Dissolved Solids
TH	Total Hardness
WHO	World Health Organization
WRA	Water Resources Authority
WRMA	Water Resources Management Authority

WSP	Water Service Provider

ABSTRACT

The rise in population within Kamiti-Marengeta Sub-Catchment significantly increased the need for essential services such as residential houses and water supply. However, the service delivery of these critical services, especially water supply in the area, has not progressed with the demand. This has forced many housing investors and institutions to turn to groundwater extraction to meet the population's needs. The main objective of the research was to assess variations in the physical and chemical parameters of groundwater in the Kamiti-Marengeta sub-catchment by assessing the following specific objectives: 1. Physical and chemical characteristics of the boreholes and shallow wells, 2. Spatial variations of selected groundwater quality parameters, 3. Effect of seasonal variations on the select groundwater quality parameters, and 4. Perception and opinions of the residents regarding water quality and demand and supply issues. Forty-seven groundwater samples, 30 from deep wells (boreholes) and 17 from shallow wells, were sampled in May 2016 and September 2017 to represent the wet and dry seasons, respectively. Standard methods were used for onsite and laboratory analysis of the physical and chemical characteristics of the samples. The results obtained from sample analysis were compared to the KEBS and WHO standard values to determine the potability of groundwater. The spatial variation of the physical and chemical parameters in the sub-catchment was determined through a one-way analysis of variance (ANOVA) and mean separation procedure with the Turkey test. The kriging gridding methodology in Surfer 13 Golden Software was used to interpolate the spatial water quality parameters and generate thematic contour maps for the tested parameters. The student's t-test performed at a 95% confidence interval was adopted in determining variation in groundwater quality across the two seasons and SPSS and excel to analyze descriptive statistics and the relationship between multiple variables from the social survey. The concentration of turbidity, $Ca^{2+,}$ K+, $Fe^{2+,}$ and F^- in some borehole samples and pH units, $Ca^{2+,}$ Na^+, and Fe^{2+} concentration in some shallow wells did not meet the required standard for drinking water by KEBS and WHO. There was a significant difference in levels of DO between Kiwanja and Kenyatta University (p = 0.13) and Kenyatta University and Kahawa Wendani (p = 0.00), total hardness between Bypass and Membley (p = 0.018), and Bypass and Kahawa Wendani at (p=0.041); and turbidity between Kiwanja and Membley (p = 0.011) and between Membley and Kahawa Sukari (p = 0.024). Contour maps for concentration and units of tested parameters in borehole and shallow well samples showed the variation in the physical and chemical characteristics of the groundwater. A significant difference was registered in the mean concentration of EC, Turbidity, Total Hardness, Ca2+, and Fe2+ in boreholes and mean concentration in all parameters in shallow wells except for Mg2+ during the dry and wet season. The social survey revealed that the boreholes were the primary sources of domestic water within Kamiti-Marengeta sub-catchment. Poor water quality was highlighted as the major problem with the water supply by 44% of the respondent, followed by broken water supply by 39% and cost of water by 10%. 7% of the residents did not cite any problem with the water supply. 50% percentage of the residents perceived the taste of water as the most critical water quality attribute, followed by odour at 36% and appearance at 14%. Fifty-six percent of the respondents considered the water safe for drinking, 39% perceived the water unsafe for drinking, and 5% could not gauge whether water was safe or not. The scientific findings on the assessment of the physical and chemical characteristics of groundwater and the social survey findings indicate that groundwater in some parts of the six regions is chemically unfit for drinking. The findings of this study provide baseline information on the quality of the groundwater systems of the area. It also contributes to knowledge of the seasonal variation of groundwater quality of volcanic aquifers like the Nairobi Aquifer System (NAS), which is vital for water quality monitoring.

CHAPTER 1 : INTRODUCTION

1.1 Background of study

Freshwater of good quality and quantity is at the core of sustainable development (Dodds et *al.*, 2013). Water quality is a significant aspect of this finite resource as it affects human and ecological health. According to Knox and Marston (2014), the global increase in the human population has stressed the global, regional, and local environment. It has become a challenge for the world to meet the ecological and human demands for freshwater. The rapid increase in human population coupled with urbanization, poor waste management, living standards, and environmental degradation have continued to put pressure on freshwater resources worldwide. Urbanization and rapid population increase have resulted in the constraint of water resources simultaneously; climate change has also led to a significant reduction in surface water. The high population density in an area can result in depletion of groundwater through over-abstraction and degradation of its quality from the intrusion of wastewaters from the septic tanks and sewerage systems (Wada *et al.*, 2010).

Annually 502,800km3 of water evaporates from ocean surfaces and 74,200km3 from land. The 577,000 km3 of water falls back in the form of precipitation, with 79% (458,000 km3) falling on the ocean and 19% (109,630 km3) on land, and the remaining 2% (9370km3) falling on lakes (Koutsouris *et al.,* 2016). Of this 9370km3 that falls on the land surface, only 2% (187.4 km3) can infiltrate the soil as the rest is lost through surface runoff and evaporation (World Bank, 2010). 70% of freshwater is contained in the icecaps and glaciers; however, groundwater is by far the most abundant and readily available source of fresh water globally and remains the most exploited resource (Zeng *et al.*, 2017). Groundwater is considered important for the security of water supply and significant in cases where the available surface water is scarce or not fit for human consumption. However, the recharge rate for the groundwater aquifers is very slow (Famiglietti, 2014). This means that the human demand for the resource exceeds its natural replenishment.

The increasing water demand coupled with the availability of drilling and pumping technologies has contributed to the intensification of groundwater extraction worldwide. A study conducted by World Bank (2010) showed that, groundwater use worldwide has significantly improved agricultural growth. According to the study's report, India, the United States, and China, are the leading countries in groundwater abstraction, accounting for more than 50% (442 km3/yr of an estimated 840 km3/yr) of global abstraction (World Bank, 2010).

In Kenya, management and monitoring responsibility of all water resources is done by the state. According to the Constitution of Kenya 2010, the responsibility to manage water resources rests with the national government, whereas the provision of water service is a function of the county government (GoK, 2010). Water Resources Authority, as established by the Water Act 2016, regulates water resources. Water use depends on approval and a water permit which clearly states the water use, the amount approved for abstraction, and how long the permit will be valid. Despite the conditions of the law, groundwater management in Kenya is influenced by people’s perception of groundwater as a private resource owned by the landowner. Groundwater is therefore treated and perceived as a resource with great benefits to everyone, with most users exploiting it and ignoring the likely consequences of unregulated use.

In 2009, The Ministry of Water and Irrigation found that, of the 1.04 billion cubic meters of groundwater resource available in Kenya, only 0.18 is utilized. According to the Integrated Water Resource Management and Water Efficiency Plan (MoWI, 2009 and Olago, 2019), the exploitation of groundwater resources has significant potential to improve water supplies in Kenya. The challenge, however, is that groundwater use is reduced by inadequate knowledge of its occurrence, its overexploitation, saline intrusion along the coast, and the poor quality of some aquifers in the country.

The population of Kiambu County, in central Kenya, with a landmass of 2538.6 Km2, has significantly grown from 914,412 in 1989 (Kiambu County, 2013) to 2,417,735 in 2019 (KNBS, 2019). Similarly, population of Kenyatta University has grown from about 17,538 in the 1987/88 academic year to a student population of over 70,000 by 2017 against a hostel capacity of only 10000 beds (Integras, 2015). This continuous increase in population and accommodation crisis has subsequently increased housing settlement within the university surrounding, such as Kahawa Wendani, Kahawa Sukari, Membley, Kiwanja, and Bypass areas, as well as increased demand for water supply services.

The delivery of water supply by the municipality has failed to keep pace with the increasing demand. Ruiru-Juja Water and Sewerage Company, the main WSP, is only capable of meeting 14% of the water demand (Naomi *et al.,* 2018), making most of the housing developers resort to the exploitation of groundwater. Groundwater in this region is that of the Nairobi Aquifer System (NAS) (WRMA, 2010), and the quality challenge with the water from this aquifer is high levels of fluoride and alkalinity, which often is above the KEBS/WHO recommended standards for drinking purpose (KEBS, 2010). Even though Water Resources Management Authority is obliged to monitor and regulate the use of groundwater resources, the groundwater quality monitoring activity is limited to a few areas. In the entire Athi Catchment Area (ACA), which is inclusive of Nairobi, Kiambu, Mombasa, Loitoktok, and Machakos sub-regions, there are only 40 dedicated groundwater monitoring networks (WRA Strategic Plan 2018 -2022), none of which is located within the study area.

1.2 Statement of the problem

Urbanization and rapid population increase have resulted in the constraint of water resources simultaneously; climate change has also led to a significant reduction in surface water. Kenya's water resources are under pressure from rapid population growth, urbanization, industrial waste, and agricultural activities (Wada *et al.*, 2010). With the continuous growth in population and rapid urbanization; increasing groundwater contamination has become an urgent concern globally because it endangers public health. According to Shukla and Saxena (2021), eighty percent of diseases in developing countries are related to water and sanitation issues. In Kenya, however, the challenges of water scarcity and poor sanitation account for nearly 10% of all water and sanitation-related illnesses (Harvey, 2011).

Kamiti-Marengeta Subcatchment is an area that has experienced a significant population increase in the recent past. This continuous increase in population and accommodation crisis has subsequently increased housing settlement within Kenyatta university surroundings such as Kahawa Wendani, Kahawa Sukari, Membley, Kiwanja, and Bypass areas increased demand for water supply services. The municipality's water supply and solid waste management has failed to keep pace with the increasing demand. Ruiru-Juja Water and Sewerage Company, the main WSP, is only capable of meeting 14% of the water demand (Naomi *et al.*, 2018), making most of the housing developers resort to the exploitation of groundwater. Currently, major parts of this area do not have adequate solid waste management and sanitation systems, which threatens public health. Some residents in these areas also practice small-scale agriculture, using synthetic chemicals such as pesticides and fertilizers on farms.

In the entire Athi Catchment Area (ACA), which includes Nairobi, Kiambu, Mombasa, Loitoktok, and Machakos sub-regions, there are only 40 dedicated groundwater monitoring networks none of which is located within the study area (WRA Strategic Plan 2018 -2022). Additionally, there are no studies on seasonal and spatial variation in the quality of boreholes and shallow wells of the NAS within Kamiti-Marengeta sub-catchment. Consequently, the hydrochemical composition of the groundwater systems of the area and their spatial distribution are not well known.

Despite all these threats to groundwater quality and weak quality monitoring structures, residents have continued to use the water for domestic purposes including for drinking purposes without undertaking water quality assessment. A study on the predominance of waterborne diseases in Kahawa Wendani, Kahawa Sukari, and Githurai areas of Kiambu by Kaluli *et al.,* (2017) revealed that once every three months, a resident of this area is treated for water-related illnesses and browning teeth is a major dental problem for the areas' residents visiting dentists clinics. These water related health problems have seen a number of residents shifting their preference to getting drinking water from drinking water refilling shops that continue to grow in demand.

Data on groundwater quality is needed so that we can be sure to solve the health-related problems. Therefore, this study aims to assess the quality of borehole and shallow well waters of Kamait-Marengeta sub-catchment and determine its suitability for drinking purposes. The findings of this study will assist the residents, developers, the Water Resources Authority, and the municipality in developing the most appropriate strategies to deal with the challenges of groundwater quality.

1.3 Justification of study

Given the long stretch of the Nairobi Aquifer, it is notable that it is subjected to varying stress levels with various distinguished hotspots where the intensity of abstraction has resulted in a considerable decline in water level, change in water quality, and conflict among groundwater users. Given the significance of water resources to human activities in the Kamiti-Marengeta sub-catchment, it is important to regularly monitor the groundwater quality to ensure that the water poses no threat to people's health. Mapping groundwater quality, understanding the relationship between the area’s geology and quality of the groundwater, and how water quality varies across seasons is important because it can help not only identify the major threats to water quality but also help in effective management of water quality.

1.4 Research questions

The proposed research seeks to address the questions listed below:

1. What are the physicochemical characteristics of boreholes and shallow wells in Kamiti-Marengeta sub-catchment?
2. What is the spatial variability of the selected groundwater quality parameters in Kamiti-Marengeta sub-Catchment?
3. What effect do seasonal variations have on the physicochemical parameters of boreholes and shallow wells of Kamiti-Marengeta sub-catchment?
4. What are the perceptions and opinions of residents of Kamiti-Marengeta sub-catchment regarding water quality and supply issues, e.g odour, taste, appearance, interrupted supply, and cost?

1.5 Study objectives

1.5.1 General objectives

The overall objective of this study was to determine the spatial and seasonal variations in the physical and chemical parameters of groundwater in Kamiti-Marengeta sub-catchment.

1.5.2 Specific objectives

The proposed research seeks to address the following specific objectives.

1. To determine the physicochemical water quality parameters of boreholes and shallow wells of Kamiti-Marengeta sub-catchment.
2. To evaluate the spatial variability of the selected groundwater quality parameters in Kamiti-Marengeta sub-catchment.

iii. To establish the effects of seasonal variations on the physicochemical water quality parameters in boreholes and shallow wells of Kamiti-Marengeta sub-catchment.

iv. To investigate the perception and opinions of residents of Kamiti-Marengeta sub-catchment about water quality and supply issues, e.g., odour, taste, appearance, interrupted supply, and cost.

1.6 Hypotheses

The proposed study will test the following hypotheses.

Ho1 There is no statistically remarkable difference in chemical and physical water quality parameters in boreholes and shallow wells across the six zones of the study area.

Ho2 There is no statistically significant seasonal variation in the tested parameters from borehole samples.

Ho3 There is no statistically significant seasonal variation in the tested parameters from shallow well samples.

1.7 Scope and limitation of study

The study was carried out within Kenyatta University and surrounding estates providing settlements for the Kenyatta University community, limiting it to Kahawa Wendani, Kahawa Sukari, Eastern Bypass, Membley, and Kiwanja. The study focused on areas where groundwater has been explored for domestic purposes. It was limited to determining the physical and chemical parameters of groundwater used for drinking purposes. The selected water-quality properties for analysis included Temperature, pH, Chloride, Dissolved Oxygen, Total Hardness, Electrical Conductivity, Potassium, Turbidity, Magnesium, Total Dissolved Solids, Nitrate, Total Alkalinity, Calcium, Sodium, Fluoride, Sulphate, and Iron. The limitation in this study area was the difficulty in locating the boreholes. Most of the boreholes in the study area are not registered with Water Resources Authority; the borehole water in most residential areas is directly piped to the houses, and the owners completely seal some after drilling and a structure put up to cover it.

1.8 Conceptual framework

DPSIR (Drivers, Pressures, States, Impacts, responses) is a framework through which one can identify and analyze the significant associations between environment and social factors. The framework is based on a series of causative links beginning from "driving forces" (human, economic and environmental activities) through "pressures" (over-abstraction, pollution, saltwater intrusion), resulting in "states" (chemical, biological and physical) and "impacts" on targets such as human health and aquatic or terrestrial ecosystems, ultimately requiring technical and political "responses." Effective responses can alter the framework's elements: addressing pressures through prescriptive and technological actions, state by remedial actions, and impacts by compensation for the damages.

This study used a modified version of the European Environment Agency DPSIR framework (Kristensen, 2004). The DPSIR model explicitly explains the issues behind the deterioration in groundwater quality within the Kamiti-Marengeta sub-catchment resulting from the pressures and drivers, as shown in Figure 1-1.

The main **driving forces** identified and affecting Kamiti-Marengeta sub-catchment are population growth, urbanization, unregulated abstraction of groundwater, scarcity of freshwater sources, and the geologic unit, which makes the water high in fluoride concentration. These factors, together with the inadequate supply of water by the water and sewerage companies, threaten both the quantity and quality of groundwater systems. The continuous growth in population in the sub-catchment from 914,412 in 1989 (Kiambu County, 2013) to 2,417,735 in 2019 (National Population Census, 2019) has increased the demand for housing and water supply. Most of the rivers and streams within the sub-catchments are highly contaminated, increasing the scarcity of freshwater sources. Consequently, most housing developers have resorted to groundwater exploration with so much disregard for the Water Resources Authority's guidance for groundwater abstraction.

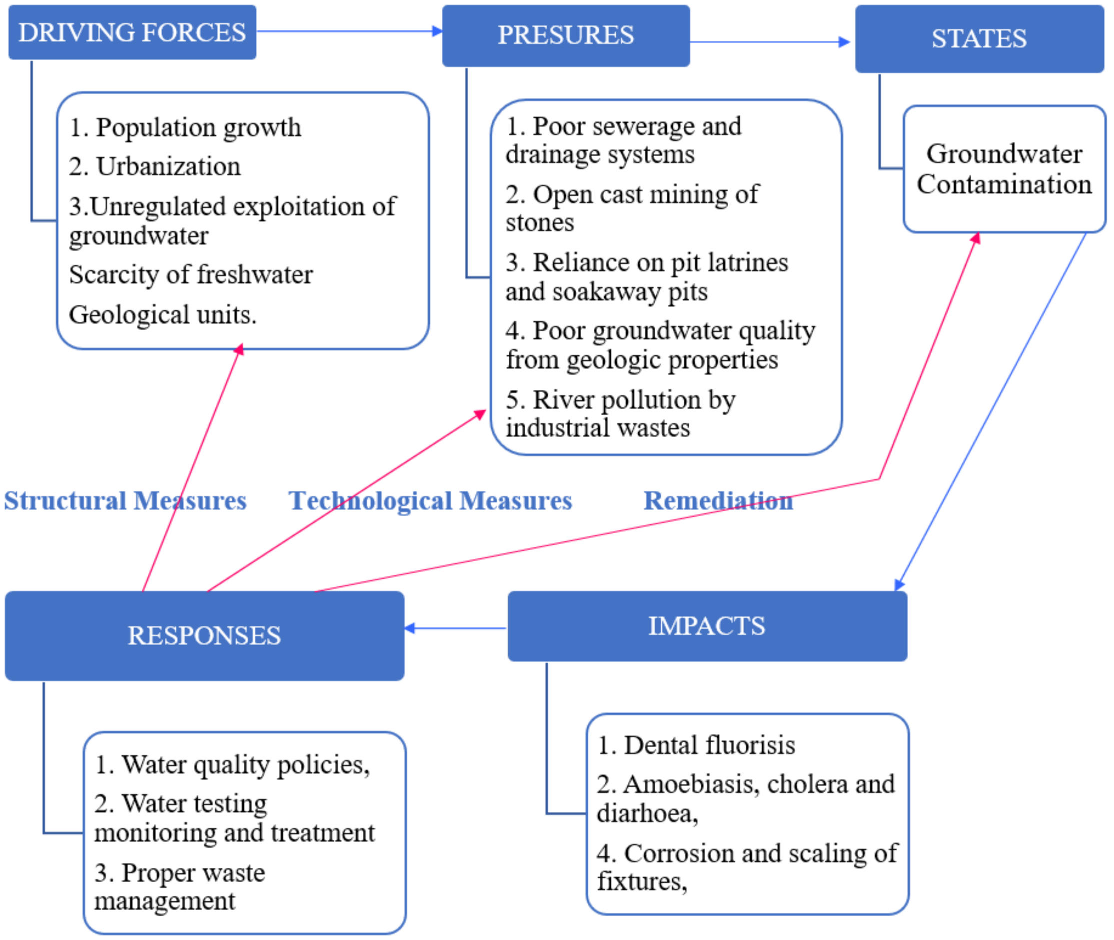


Figure 1-1: Conceptual framework

The chemicals and nutrient contaminants generated by the driving forces and reaching the groundwater through infiltration, surface run-off, and ground and surface water interactions denote the main **pressures** on quality. Kamiti-Marengeta sub-catchment is subjected to poor sewerage and drainage systems, with some households fully relying on pit latrines and soak pits. The groundwater quality in this area may be compromised by the intrusion of contaminants from the various sources mentioned above, as well as from landfills, small-scale agricultural activities, and industrial discharge from factories within the sub-catchment.

For the current **state**, reports by WRMA (2010), Onyancha and Getenga (2013), Olonga et al. (2015), and Muraguri (2016) have concluded that the quality status and quantity of borehole and shallow well waters in different parts of Nairobi aquifer systems are compromised by the drivers mentioned above and pressures. Consumption and use of poor-quality groundwater can lead to diseases such as amoebiasis, dental fluorosis, diarrhea, and cholera when it contains biological and chemical contaminants. These **impacts**, however, can be reduced if the pressures prompting them are addressed.

Addressing the pressures and drivers would require normative-based and structural **responses** such as ensuring the availability of well-managed sewer systems, increased supply of water by the water and sewerage company to the area, enforcing restrictions on borehole drilling, establishing more water monitoring networks, and strengthening groundwater monitoring. In addition, technological actions can be applied to prevent, contain, or remove pollutants from groundwater. At the outset, the only groundwater remediation technologies were the pump and treat approach. Through the years, new groundwater remedial options have evolved, creating flexibility in groundwater treatment (Siegrist *et al.*, 2011). Using the DPSIR framework in this study, it will be possible to determine the responses such as plans, actions, or programs that need to be in place to address the drivers and pressures on groundwater quality.

CHAPTER 2 : LITERATURE REVIEW AND CONCEPTUAL FRAMEWORK

2.1 Introduction

The purpose of conducting a literature review is to understand the topic of study broadly and consider some studies that other scholars had done. This chapter aims to provide an insight into the subject of groundwater quality. The literature review is conducted in line with the study objectives through different sub-topics. These sub-topics comprise the effects of seasonal variation on the physical and chemical composition of groundwater, spatial variability in groundwater quality, mapping of groundwater quality, and users' perceptions of drinking water quality, and lastly the conceptual framework as discussed in the sections below:

2.2 Geochemistry of groundwater resources and geochemical processes

The geochemical attributes of aquifers vary and are highly dependent on the composition of mineral rock found in the flow path of the groundwater. Groundwater can mimic a combination of the geochemical properties as it gradually flows through different rock units. Intricate geochemical exchanges might result in either precipitation or dissolution of some elements. According to Gu *et al.,* (2020), water flowing below the ground to some degree reacts with the surrounding rock minerals. Through these interactions, the water acquires its specific chemistry.

2.2.1 Carbonate reactions

Carbonates are constituents of several rocks including metaphoric and igneous rocks. Carbonates provide a suitable condition or the geochemical evolution of groundwater. Dissolution of calcite occurs when it meets water and carbon dioxide as shown in equation 2.1 below.

$CaCO_3 + CO_2 (g) + H_2O = Ca^{2+} + 2HCO^{3-}$……………………………………………Equation 2-1

At the initial stage, Carbon dioxide reacts with water and produces the hydrogen ions, which reflects the water's acidic condition as shown in equation 2.2 below.

CO_2 (g) + H_2O = H^++ HCO^{3-}………………………………………………………..Equation 2-2

This acidic condition stimulates calcite dissolution through this reaction $CaCO^{3+}$ H^+ = Ca^{2+}+ HCO^{3-} The first reaction reveals that calcite solubility significantly depends on quantity of carbon dioxide available. Similarly, in the last reaction it is evident that solubility of calcite depends on the hydrogen ions, the lower the pH the higher the solubility of calcite. Hydrogen ions that enhance the solubility of calcite are also produced when sulphide minerals are oxidized or other chemical reactions of sulphur in the air.

Despite the presence of enough carbon dioxide in the air for calcite dissolution, there is usually an overload of carbon dioxide in the soil owing to the biological processes occurring in the soil. Consequently, as water from the surface gradually flows through the soil, it absorbs more carbon dioxide that hastens calcite dissolution. When all the carbon dioxide dissolved in water is used up and there is no other source for carbon dioxide the water becomes saturated and cannot dissolve the calcite rock.

2.2.2 Oxidation-reduction reactions

These chemical reactions comprise electron transfer from one element to the other. Normally, the direction and rate of the process are controlled by the oxidation state of the immediate environment. In a natural environment, the vital oxidant is oxygen, whereas organic matter is the vital reductant. Other reductants are Ferrous Iron and Sulphide. The reaction between oxygen and organic matter reduces the carbon element to methane.

When water infiltrates the ground, it is no longer at equilibrium with atmospheric air. Dissolved oxygen in water is gradually reduced as the water reacts with the reducing agents present in the soil. Various elements can occur in different oxidation states, which differ in solubility under normal conditions. For example, iron occurs in two forms in a highly soluble state, ferrous iron (Fe2+), and in an insoluble state, ferric iron Fe3+. For most elements occurring in more than one state, the oxidized form is always highly soluble compared to their reducing forms.

2.2.3 Ion-exchange processes

Due to the electrical charge of ions in water, they tend to be attracted to solid materials such as mineral grains. The ion exchange process involves both cations and anions, and clay is known to be very effective at adsorbing cations owing to their constantly negatively charged surfaces. According to Langmuir (1997), the propensity for major cations adsorption in natural waters varies. The Ca^{2+} are the most strongly adsorbed onto surfaces, followed by Mg^{2+}, K^+, and Na^+. This absorption relationship enables water softeners to work effectively because as hard water is passed through the softening system, Ca^{2+} and Mg^{2+} ions are, to a greater degree, adsorbed onto a chemical that is being modified. As this process continues, the ion exchange sites are completely occupied by the Ca^{2+} and $Mg^{2+,}$ and it reaches a point where the system stops working.

At this point, sodium chloride brine is added to the system. This increases sodium concentration in the solution, which replaces the $Ca2^+$ and Mg^{2+}, thus, recharging the ion exchange substrate (Arden, 2012). According to Langmuir (1997), the base exchange softening process also works in nature. So long as there are sodium ions reserved in clay minerals, Ca^{2+} and Mg^{2+} ions in the water will to a greater degree, attach to the substrate the Na+ ions will be released into the water. The ion exchange process is remarkably critical for trace metals with cation properties.

2.3 Characteristics of groundwater quality

Groundwater quality is of great significance as its quantity since it is an important telluric component of the hydrological as well as most bio-geological processes. In totality, groundwater resources consist of various salts in solution forms resulting from their location and previous flow directions. According to Todd and Mays (2005), groundwater in natural systems contains dissolved solids of not more than 1000 mg/l. However, this number can be exceeded when there are high evaporation rates, groundwater is geothermally heated, or groundwater encounters highly soluble minerals such as gypsum. Groundwater acquires dissolved constituents naturally by dissolving aquifer salts, gasses, and minerals. Thus, information on the natural quality of groundwater can provide significant insights into the nature of groundwater resources (Belkhiri and Mouni, 2012). Assessing the natural chemistry of groundwater is important because it makes available information on the reactions leading to natural water chemistry, movement, mixing, and groundwater recharge (Kumar *et al.*, 2014).

2.3.1 Physical characteristics

Water has a substantial ability to hold heat compared to air. According to Palmer *et al.* (2004), human activities, climate, and other structural features of the catchment area significantly influence the thermal conditions of groundwater. Water temperature is important because it impacts the dissolved oxygen water contains. High water temperature decreases the ability of oxygen to dissolve in water and increases the level to which some chemicals in water can damage an organism (Palmer *et al.*, 2004). Temperature also affects various parameters such as alkalinity, salinity, and electrical conductivity.

Turbidity is the quantity of microscopic solids or liquid matter hovering in the water. In other words, it is a measure of the cloudiness of water. According to Estlander (2012), the cloudiness of water results from colloidal and floating substances. Turbidity is measured by passing a shaft of light through the water and photometrically measuring the light dispersed at right angles to the beam. This measures the actual quantity and quality of microscopic solids or liquid matter hovering in the water. Electrical conductivity, also known as electrical resistivity, is a significant water quality parameter. It refers to water’s ability to carry on electric current. The value of water’s electrical conductivity significantly depends on the concentration of magnesium, calcium, and bicarbonate ions (Todd and Mays, 2005). Electrical conductivity of water changes with temperature changes.

“pH” is an abbreviation for pondus hydrogenii and means the weight of hydrogen. Water pH varies from 0 to 14 and is considered neutral when the pH is 7.0 (Palmer *et al.*, 2004). High pH levels mean the water is alkaline or basic, while low pH means the water is acidic. According to Perrin (2012), the pH of pure water should be 7.0; however, precipitation and other water sources are likely to be a little acidic owing to contaminants present in the water. pH is a vital determinant of several biological functions; for instance, very high pH or extremely low pH can cause harm to living organisms by interfering with their metabolic processes.

2.3.2 Chemical characteristics

Groundwater derives its chemical properties from the geologic nature of the underlying rock. Apart from the geologic environment, the chemical properties of groundwater also depend on its movement. According to WHO (2011), high concentrations of some chemicals in water easily alter the water's natural chemical properties, posing risks for water users. For example, high concentrations of fluoride and iron are major groundwater quality issues, especially in developing countries, due to the associated health impacts. Most minerals in the soil and underlying rocks are soluble but have different water solubility. The solubility of these minerals also varies with pH, water depth, and amount of dissolved oxygen. As surface runoff gradually flows through the soil, it carries soluble minerals, which find their way into the aquifers through leaching.

Total dissolved solids significantly affect the taste of water, which is key in drinking water test analysis. According to Virkutyte and Sillanpaa (2006), high TDS concentration can alter the taste and quality of drinking water and industrial technicalities such as increasing water hardness which leaves films and deposits in boilers and water pipes and makes water filters to wear out sooner. High concentrations of TDS may also indicate that the water is high of inorganic salts such as calcium, magnesium, potassium, sodium, bicarbonates, chlorides, sulphates, and dangerous contaminants such as arsenic, manganese, bromide, sulphate, and iron.

The level of DO in water varies over the day and seasonally. DO also vary with altitude and temperature. Singh *et al.* (2014) highlighted some of the importance of DO in water: DO is often used to gauge the steadiness of trace metals such as zinc, copper, magnesium, chromium, and iron; organic pollutants, poisonous complexes, and radionuclides. It can also assess the stability of various trace metals, radionuclides, toxic anionic complexes, and organic contaminants in water. DO is also an important geochemical oxidant. DO is consumed as the result of oxidation of the ferrous silicates, a significant weathering molecule at low temperatures. To a great extent, dissolved oxygen controls the solubility of various naturally occurring polyvalent trace elements in groundwater and the fate of dissolved organic contaminants by limiting the type and nature of microorganisms present within the aquifer.

For several years, water hardness has been characterized by encrustations left by heated water or soap. Water hardness results from the existence of divalent metallic cations. In groundwater, these are in abundance attributable to the existence of calcium and magnesium in the water (Todd and Mays, 2005). Alkalinity is a function of various solutes such as dissolved carbonates, bicarbonates, and carbon dioxide. These solutes make alkalinity have a high correlation with the hardness (Zhuang *et al.*, 2010).

2.4 Urbanization and groundwater quality

Provision of water supply, drainage systems, and sanitation are major components of handling the rapidly increasing urban environment. In providing all these, significant underground infrastructure is required. The subsurface urban infrastructure, including tunnels for roads, sewer pipes housing foundations, and basements, indirectly interferes with shallow groundwater. The rapid increase in urban population through rural-urban migration and natural growth is a major driver of the changes in the environment. According to Nath *et al.* (2021), as much as the global rural population doubled during the twentieth century, the population in towns and cities amplified more than tenfold. As the population grows and cities expand, water infrastructure increasingly depends on groundwater or surface water transferred into the urban area from outside (Agrawal *et al.*, 2021). Urbanization radically changes the rates and patterns of groundwater recharge, prompts new abstraction regimes, and significantly affects groundwater quality (Sharp, 2010).

Groundwater recharge can be affected by alteration of the natural routes and sources of infiltration by any adjustment that reduces the permeability of the land surface, such as the construction of buildings, roads, and car parks. To drain these areas, the natural drainage system is altered through the construction of stormwater drains, stream canalization and soak ways to collect the stormwater from the impermeable surfaces, thereby producing concentrated infiltration in the vicinity (Bricker *et al.,* 2017). Additionally, leakages from sewerage networks and water mains constructed below the ground increase the infiltration volume. Other sources of urban recharge include irrigation, onsite sanitation cesspits, septic tanks, and non-sewered sanitation. Groundwater in many large cities and towns in shallow aquifers is highly polluted and unsuitable for drinking.

Elisante and Muzuka (2017) and Wagh *et al.* (2017) confirm the deterioration of groundwater quality from pollution from the above sources through studies on nitrate concentrations in groundwater. Xu and Usher (2006) also reported this correlation in studies conducted in Mombasa, Kenya, and Niamey, Niger. The state of water sources in rapidly developing urban areas often drives water service providers and private users to explore unpolluted water in the deep aquifers, which are further affected by over-abstraction to provide daily water requirements of the mushrooming population.

2.5 Groundwater vulnerability and effects of rainfall variability

Technical reports and literature from various studies have shown that agricultural activities and on-site sanitation systems generally pollute groundwater in Kenya Even with this knowledge, it is evident that there are still no sustainable measures that are being put in place to reduce contamination of groundwater systems from anthropogenic activities. The groundwater vulnerability assessment (GVA) approach has been used worldwide to prevent and protect against groundwater contamination. According to Rendilicha *et al.* (2018), the GVA approach translates information on impact into pertinent guidelines on practice and policy formulation to detect and implement practicable adaptation measures. Nevertheless, for a country like Kenya, which highly depends on groundwater systems for industries, urban and rural development, and agriculture, the significance of groundwater vulnerability assessment is yet to be considered.

The first review of the vulnerability and pollution status of Kenya's groundwater conducted by Rendilicha *et al.* (2018) revealed several challenges in groundwater management in the country, thereby envisaging increased chances of the resource's vulnerability to both climate change and pollution unless the situation is corrected. In Kenya, land use management is still addressed through different uncoordinated policies and legal frameworks that have not been able to solve the many issues affecting land use management and further management of groundwater resources. The review also pointed out the lack of cross-sectoral coordination and linkages among relevant government agencies in managing groundwater resources. Management decisions at different agencies are often carried out without considering the likely impact of those decisions on groundwater resources.

Since 2006, Kenya's laws and regulations have had provisions for identifying and mapping groundwater protection and vulnerability zones, but this is yet to be done. Vital law provisions for groundwater conservation, for instance, Groundwater Conservation Act that requires recharge areas for groundwater and zones that protect the aquifers to be identified, mapped, and gazetted to protect them against pollution, have also not been done. In 2006, Water Resource Authority formulated a proposal for a Policy for Protection of Groundwater (WRMA, 2006). This was to foster discussions on groundwater conservation through balancing national development with sustainable groundwater use and quality protection by reducing the risks posed by pollution, unfortunately, it was never implemented (Rendilicha *et al.,* 2018).

Addressing these groundwater management challenges requires reduction of pressure on a single resource through the integration of management of ground and surface water resources; aquifer recharge and soil and water conservation; enforcement and implementation of the various provisions of laws and regulations on groundwater resources; and creation of awareness on risks of mismanagement of groundwater.

A few researchers have attempted to assess the effects of varying rainfall amounts over time and area on Kenya's groundwater systems. Nyakundi *et al.* (2016), in their study on the effects of rainfall variability on groundwater levels, found that groundwater levels increased in boreholes within Ruiru during the wet season. Another study done in the same area by Olonga *et al.* (2015) revealed a remarkable difference in mean concentrations in water quality properties of samples from boreholes and shallow wells. Fluoride, Nitrate, Turbidity, and Iron levels were higher than the required limits of both KEBS and WHO standards, and all the sampled boreholes and shallow wells were contaminated with faecal coliform.

Muraguri (2016) assessed groundwater quality in six administrative zones within Nairobi County and found that the groundwater's chemical and physical parameters varied from one zone to another despite its source being from the same aquifer. All sampled boreholes recorded high concentrations of lead (Pb) and Nickel (Ni) above maximum permissible limits for drinking water in the two seasons. Cadmium (Cd) and Chromium (Cr) were also detected in boreholes within Dagoreti/Kawangware, Kasarani/Roysambu, and Industrial Area.

2.6 Spatial variability of groundwater quality

Groundwater quality mapping over large areas is the first water resource management step (Taghizadeh-Mehrjardi, 2014). The groundwater's physical, chemical, and microbial characteristics are of key importance as the groundwater quality characteristics are established (Ashun, 2014). Two main stages are involved in mapping groundwater quality (Taghizadeh-Mehrjardi, 2014); (a) A sampling stage in which the environmental variables are measured at various field locations. (b) The prediction stage, during which the results of the previous measurements are interpolated to a fine grid. Water quality parameters under investigation include TDS, pH, Chloride, Turbidity, EC, Sodium, Temp, Fluoride, DO, Total Alkalinity, Sulphate, Total Hardness, Potassium, Nitrate, Magnesium, Calcium, and Iron.

Mathematical models that show spatial correlation can be created from the geostatistical data and variograms is established to identify spatial correlation (Taghizadeh-Mehrjardi, 2014). Interpolation techniques include the Kriging method, which provides the "best," unbiased, linear estimate of a variable of interest at an unsampled question through the use of least squares. The Kriging method is utilized in this study using Surfer software. The Kriging method is most effective in spatial interpolation studies of heavy metals concentration in groundwater. Other studies have found that the spherical model is most useful in fitting the environmental variables of Cl^-, EC, and SO_4^2. Some studies have found the CoKriging method to provide better fitting results for groundwater nitrates.

2.7 Users' perceptions of drinking water quality

Esthetic quality is an essential and significant part of the consumers' experience with water supply systems. Irrespective of the source of drinking water, the first thing a consumer perceives is how it looks, smells and tastes. It is these sensory experiences that influence a person's response. A general hypothesis of health-related comportment theories is that people are more likely to embrace protective health comportments when perceiving risks. According to de França *et al*. (2009), groundwater wells owners who recognize high pollution risks are likely to undertake a quality assessment to ensure they are avoiding negative health impacts. More often than not, well waters are assumed to be of good quality, thus the owners' propensity to underestimate pollution risks (Colley *et al.*, 2019; Hooks *et al.*, 2019).

Additionally, some believe groundwater is always of good quality because it is natural and free of chemicals. According to Hooks *et al.* (2019), the natural perception tends to conjure positive responses in consumers with products labeled "natural." Positive attributes are associated with groundwater as it is obtained underground without additional chemical input. On the other hand, recycled or treated water can conjure strong affective negative retorts simply because these are perceived as unnatural and linked to harmful chemicals (Smith *et al.*, 2018).

Users rely on their senses to determine the quality status of drinking water. However, physical, chemical, and microbiological components of water can influence its taste, smell, and appearance of water (Gray, 2008; WHO, 2008; and Gray, 2011). Even though colored or high turbid water may not necessarily have a direct negative health impact, it can have some oduor or unpleasant taste which is likely to be perceived by the consumer as unsafe (WHO, 2011). Perceptions about drinking water arise from various factors and are also influenced by many variables (Araral, 2010). Understanding processes that influence public perception of drinking water can, among other things, influence public policy on water management and improve consumer services. Professionals in the water sector, including technicians and policymakers, may have difficulty integrating general public perceptions into their frameworks. In developing countries, integrating public perceptions into water policy is even more difficult compared to developed countries where stringent quality standards already exist.

Tussupova *et al.* (2016) note in their study done in Kazakhstan that perceived characteristics of the water source, including water safety and quality, and time spent to collect the water, is important in forming public perceptions of drinking water. In this study, public perception of tap water relating to quality is quite high due to the perceived high quality and convenience of tap water compared to other sources such as boreholes and wells. Araral (2010) discusses the main factors that modulate public perceptions of water and how these factors combine to shape the overall public opinion of drinking water quality. Sensorial information refers to drinking water organoleptic, which is related to such factors as taste, odor, color, and turbidity. Organoleptic is the main factor paramount for drinking water perception, including quality, service satisfaction, willingness to pay, and choosing a water source. Araral (2010) notes that the perception of sensorial information is almost psychological, and people expect such water quality attributes to be consistent. In some countries, taste may be considered more important than odor or color, perhaps because the taste can detect changing chemical compositions at lower concentrations, much better than these two other senses.

Risk perception is another key factor related to drinking water quality; tap water is generally regarded as less risky than other sources, with chemical and microbial factors that are expected to be within set limits (de França *et al*., 2009). Contextual indicators also inform public perception of water quality, including the characteristics of the area where the water is being consumed, cultural impacts and historical issues that have arisen, trust in the service providers such as water companies, and prior personal experience. Previous experience is key to consumers' assessment of water quality since it is how users form impressions about how good drinking water should look and taste. Impersonal and interpersonal information and the exchange are key influencers of public perception (de França *et al*., 2009). This mostly includes the media (television, radio, newspapers, brochures, and advertisements by service providers) and sources in the community such as friends and relatives, local town councils and schools, among others.

Similarly, the public seems to trust certain groups more than others. For example, politicians and bureaucrats are less trusted than Community Based Organizations, environmental groups, and NGOs. Demographics, cultural backgrounds, and education level also affect user perceptions of drinking water quality. However, Araral (2010) notes that education and income are inversely related to trust risk of drinking water quality and recommend that policymakers and water service providers use public and consumer surveys to gain useful information about public perceptions of water quality.

Gaps from literature

Among all studies that have been conducted on the Nairobi Aquifer Systems, none has focused on this study area. From the studies that have been done, very few have made efforts to determine the effect of seasonal variability on the quality of borehole and shallow well waters. The link between groundwater and land use changes over time in this study area has not been done, and neither has any comparison of the scientific evidence and consumer's perception of water quality of boreholes and shallow wells in the area. Studies on the Nairobi aquifer system are also limited by choice of parameters for investigation. Some researchers have only investigated trace metals; some have specifically focused on select physical and chemical parameters, while others have done only a few physical, chemical, and microbiological parameters. By 2016, only one study had focused on groundwater quality in Kahawa Wendani area; however, this was also limited by the parameters assessed, and it had no linkage with the impact of seasonal variability on groundwater. This one study is not enough to assess the groundwater quality distribution for the Kahawa, Kenyatta university, Membley Kiwanja, and Bypass region, which evoked this study, so that reference data on physical and chemical quality as well as spatial variation be availed for the area.

CHAPTER 3 : MATERIALS AND METHODS

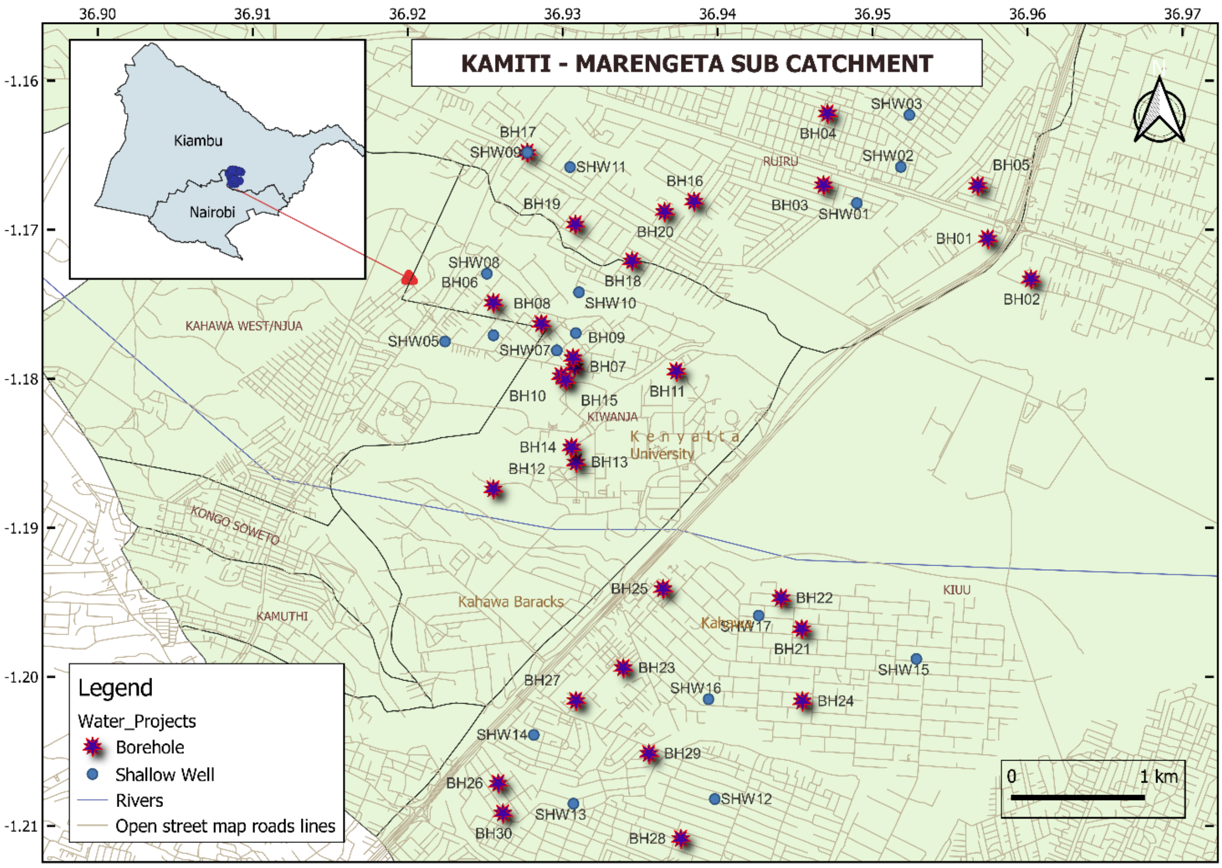
3.1 Introduction

Chapter three provides details of the study area, the research design, and techniques and procedures adopted for the study. The chapter comprises the following elements, the study area, research design, data analysis procedure, and ethical considerations.

3.2 Study area

Geographically the study area is bounded by the following coordinates 36.90' E and -1.21 and 36.97 and -1.16 as illustrated in Figure 3.1.

Figure 3-1: Map of the study area



Source: Generated from GIS by Author, Feb 2022.

The study area is an outskirt settlement across Nairobi County and Kiambu County borders along Thika Road. Irrespective of its proximity to Nairobi's central business district, most of its areas fall within the administrative boundaries of Ruiru constituency in Kiambu County. The study area is a residential area characterized by a significant number of residential developments, hence no significant variation in land use. The study area is divided into six distinct estates: Kahawa Wendani, Kahawa Sukari, Kenyatta University, Eastern Bypass, Membley, and Kiwanja.

3.2.1 Temperature and rainfall

The area enjoys warm climate with the annual average temperatures ranging between 13°C and 25°C as in Table 3.1. It experiences the long (March, April, May [MAM]) and short (October, November, December [OND]) rainy seasons. The mean rainfall per year in the area varies each year with annual rainfall ranging between 15.9mm and 45.4mm over a six-year period of 2010 to 2015 as illustrated in Table 3.2.

Table 3-1: Temperature for Ruiru County

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Total	Ave
Av. high in °C	26	28	27	25	24	23	22	23	25	26	24	25	298	24.83
Av. low in °C	12	13	14	15	14	12	11	12	12	13	14	13	155	12.92

Source Ruiru County, (2016)

Table 3-2: Rainfall data form KU weather station

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total	Ave.
2010	57.7	41.3	67.5	25.5	57.8	12.2	2.7	6	1	41.5	23.5	27.5	364.2	30.4
2011	3.3	36.8	31	24.2	30.8	18	0	5.6	18.6	20.5	46	23	257.8	21.5
2012	0	2.2	4.2	41.0	38	32.3	5.3	22	28.9	102	20.8	75.5	372.2	31.0
2013	17.7	0	12.6	52.5	16	13.6	8.8	11.5	8.2	0	20.4	29	190.3	15.9
2014	8	46	63.3	19	13	29	9	1.6	0	27.8	56.8	13.6	287.1	23.9
2015	8	40.8	15.5	58.6	28.8	44	3.9	7.1	0	49.5	148.7	140	544.9	45.4

Source: Kenyatta university weather station

3.2.2 Geology

The surface rocks of the area utterly consist of Pleistocene and Tertiary volcanic material. The intense tectonic activity linked to Great Rift Valley formation resulted to a sequence of widespread eruptions and lava flows during Mid-Miocene and Upper Pleistone times (Kuria, 2013). At greater depths (more than 700mm) beneath the thick volcanic sheet lies metamorphic rocks of the basement complex (gneisses and schists) of the Mozambican System.

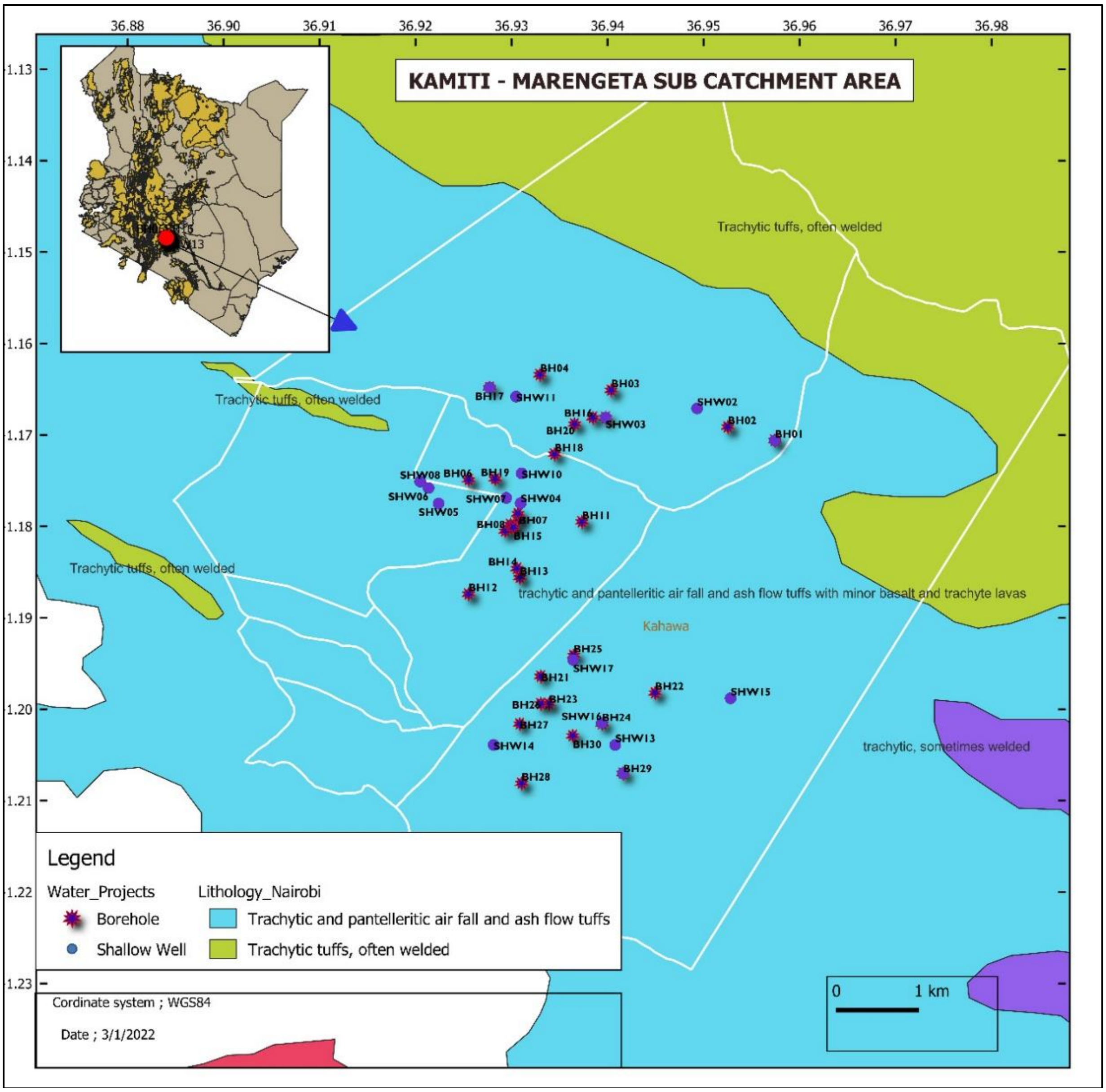


Figure 3-2: Geology map of study area

Source: Generated from GIS by Author, Feb 2022.

The tertiary volcanic period took about 13 million years and was characterized by cyclic eruptive occurrences. This consisted of the expulsion of lava flows, pyroclastic bombs, and ashes (Onyancha and Getenga, 2013). During these times of relative latency: the old land surface was formed and has become the water-bearing rocks within the volcanic sequence.

The study area predominantly lies on the Middle and Upper Kerichwa Valley Tuffs, which are underlain by the Kiambu Trachytes and further underlain by Nairobi Phonelites, Nairobi

Trachytes, and the Undifferentiated Crystalline rocks of the Mozambique Belt. Figure 3.2 shows the lithology of the study area.

3.2.3 Hydrogeology

The physiography of the area is undulating terrain and well-drained by Kamiti River and its three tributaries—Marengeta and Kiu River. The climate of Kamiti-Marengeta sub-catchment is generally warm and temperate, with the main vegetation cover of long and short grass maintained by local precipitation of 900 millimetres per year. The surface geology is composed of reddish to brownish soils and marram derived from the in-situ weathering of volcanic rocks. These soils are underlain by the Athi, upper and lower series, which mainly comprise sediments and tuffs. The probable aquifers in this area are struck within the Athi Series. These aquifers are replenished through vertical infiltration and lateral percolation of surface water. The aquifer's transmissivity ranges from 0.1 to 160 m^2/d and the hydraulic conductivity from 0.01 to 1.3 m/d. Storativity values range from 1.2 x 10-4 to 4.2 x 10-1 (Mumma *et al.*, 2011).

3.3 Research design

Both quantitative and qualitative research methods were used in this study. A quantitative experimental research approach was adopted for onsite and laboratory determination of water quality parameters and the use of standardized measures to compare the water quality parameter figures (Creswell, 2013). On the other hand, a qualitative research approach was used to determine the research participant's perceptions and lived experiences (Ritchie *et al*., 2013) regarding water demand, supply, and quality in the study area. The qualitative aspect of the study provided the researcher with information that would otherwise not be acquired by the objective measurement requirements of the quantitative approach. Using the two research approaches, the researcher obtained holistic research results (Creswell, 2013).

3.3.1 Data collection

The study applied both primary and secondary data to realize its objectives. Primary data in this study included borehole water samples, groundwater quality data, and a social survey on the perception of consumers on the supply and quality of water. The collection of groundwater samples was carried out in May 2016 and September 2017 to illustrate the effects of seasonal variations on groundwater quality. The social survey data addressing consumers' perception of water supply and quality issues were collected through structured questionnaires and interviews.

3.3.2 Sampling technique and procedure for groundwater samples

During reconnaissance, a total number17 shallow wells and 125 boreholes were identified some from WRMA records and some from a snowballing exercise. Kish's (1974) formula, n = k/1 + N/k, which provides a procedure for obtaining the minimum sample size was adopted for the study. Where: n represents the Sample size, N represents the overall population size, S represents highest standard deviation in the population factor (total error = 0.1 at a confidence level of 95%), and V represents the standard error of sampling distribution = 0.05, P = the population elements, and $k = s^2/v^2$

$$\mathbf{n} = \frac{k}{1} + \frac{N}{k} \text{ ……………………………………………………………………Equation 3-1}$$

$k = s^2/v^2$ where $S = P(1-P) = 0.5(1-0.5) = 0.25^2$ Therefore $S^2 = 0.25^2$

In determining the minimum sample size of the boreholes where:

N = 125,

$k = s^2/v^2 = 0.25^2/0.05^2 = 25$

$n = k/1 + N/k = 25/1 + (125/25) = 25+5 = 30$

All the 17 shallow wells were sampled thereby making the total ground water samples 47. Plastic bottles with one liter capacity were used in collecting and storing water samples from each site on each sampling date. The sampling bottles, which had been sterilized with 10 percent nitric acid and cleaned with deionized water, were thoroughly rinsed with the sampled water before the sample was collected.

Samples from wells with a pumping mechanism were taken after the water had been pumped to waste for about 5 minutes to prevent the collection of non-representative samples of polluted or stagnant water in the pipes. Samples from shallow wells without a pumping mechanism were collected directly from the wells using sterilized bottle fitted with a weight at the base with a lot of care to avoid contamination of the sample by any surface scum.

During sampling, a sufficient air space of 2.5cm was left to enable proper mixing of the samples prior to laboratory analysis. Once the sample was collected, the bottles were capped immediately. Geographically referenced coordinates of sampling sites were also recorded with the help of a hand-held GPS receiver. For analysis, a cooler box was used to store and transport the samples from the sampling sites to the Kenyatta University Laboratories. The samples were then analyzed on the day they arrived in the laboratory and refrigerated overnight in case arrival at the laboratory was too late for processing to be done on the same day.

3.3.4 Sampling procedure for research participants in social survey

The purposive sampling technique was used to sample participants for the social survey. According to Etikan et al. (2016), purposive sampling enables the researcher to handpick participants with good knowledge of the subject matter or people who have had first-hand experience of what is of interest to the researcher. Considering the large population of the study area, Cochran’s formula was adopted to help calculate the suitable number of participants in the social survey (Singh and Masuku, 2014). Since there was not much information on which households were using which water sources, it was assumed that half of the households within the six zones received water from different supply sources and would provide maximum variability.

$n_0 = \frac{Z^2pq}{e^2}$……………………………………………………………Equation 3-2

Where: e = the required precision level, p = the (possible) section of the population which has the characteristics in question, and q = 1 – p. So, with p = 0.5, q =1-0.5, e= 5% ∓ precision. Z value from the distribution table at 95% Cl = 1.96. Therefore; $((1.96)^2$ (0.5) (0.5)) / $(0.05)^2$ = 385 households. The individuals selected were from different households in different locations within the study areas to ensure fair representation of the whole study area. The sample size was split across the six zones of the study area considering the difference in population in the zones. 40, 50, 60, 70, 80 and 85 households were samples in Membley, Bypass, Kiwanja, Kenyatta University, Kahawa Sukari and Kahawa Wendani respectively.

3.4 Data analysis

For this study, only 17 parameters; TDS, pH, Chloride, Turbidity, EC, Sodium, Temp, Fluoride, DO, Total Alkalinity, Sulphate, Total Hardness, Potassium, Nitrate, Magnesium, Calcium, and Iron were determined. Depending on the parameters' properties, the collected water samples underwent field or laboratory analysis. The data obtained from onsite and laboratory analysis were analyzed using Microsoft Excel and Statistical Package for Social Sciences (by the oxidation state of the immediate), and contour maps showing the spatial variation of the groundwater parameters were generated from Surfer 13 software as discussed in sections 3.4.1 to 3.4.4.

3.4.1 In situ analysis

Levels of EC, temperature, pH, and dissolved oxygen were immediately measured at the sampling site using a universal water quality portable field meter because their properties quickly change with time and temperature. Other parameters that were analyzed in the field using the universal water quality portable field meter were turbidity and total dissolved solids, as shown in Plate 3.1.

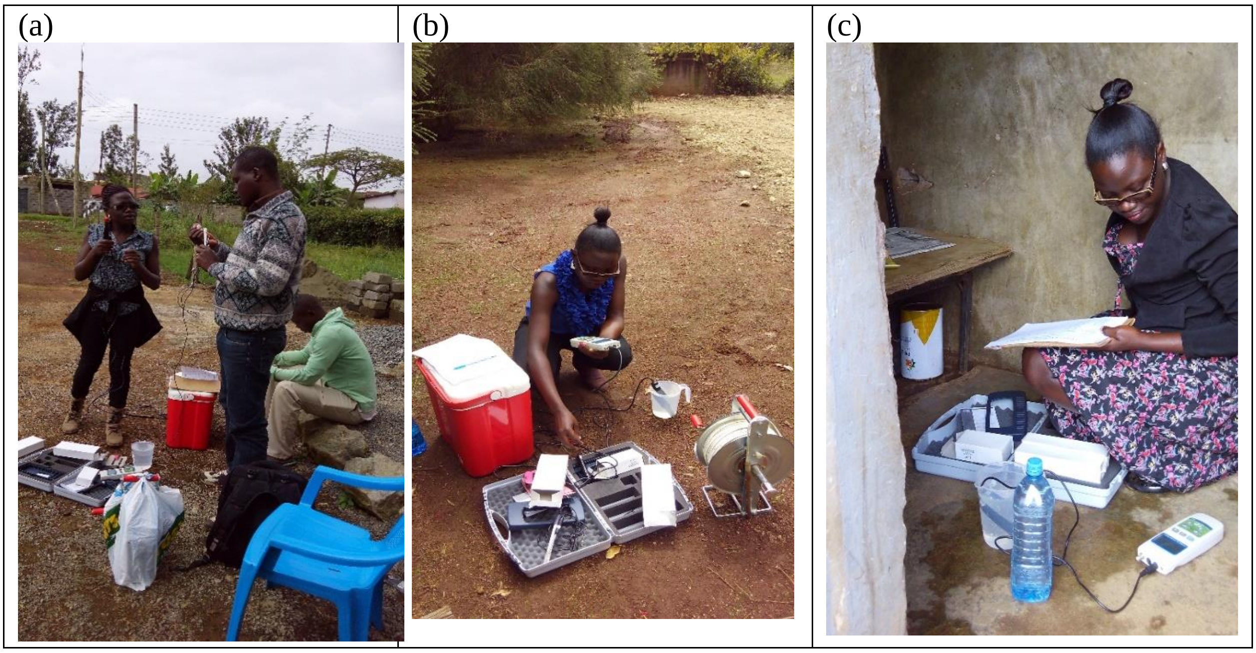


Plate 3.1: Field analysis in (a) Kiwanja, (b) Membley, and (c) Bypass

3.4.1.1 Determination of temperature and pH, DO, TDS and EC

Temperature, pH, DO, TDS, and EC of samples were determined by use of Aqualytic AL15 Multi-Meter Instrument with combined features of various portable meters.

Temperature and pH

The pH electrode and temperature probe were inserted into their socket on the portable meter. The meter was powered on, and the mode button was used to set the meter for pH and Auto temperature indicator. The sensing head of the temperature and pH electrodes were immersed into the sample. The concentration values of temperature and pH were read on the meter's display. The upper display showed the pH value and the temperature by the bottom left display *(*AQL, n.d.).

Total dissolved solids and electrical conductivity

The conductivity probe was attached to the multi-meter by installing it into the conductivity socket. The meter was powered by pressing the power button, and the mode button was used to set the correct display for EC values. The EC probe cap was removed, and while holding the body, the sensing head was immersed into the sample in the jar. The conductivity value recorded in µS/cm was read from the meter's display. A similar procedure was performed to determine the total dissolved solids concentration in the collected samples, except that the meter's display units were changed from µS/ cm to ppm *(*AQL, n.d.).

Dissolved oxygen

The oxygen probe was attached to the multi-meter by installing it into the DO socket. The meter was powered by pressing the power button, and the mode button was used to set the display for % O_2. To provide the correct display for DO, the function button on the meter was pressed once, which enabled the display to show DO units in mg/L. With the meter ready, the protective cover of the oxygen probe was removed, and the head immersed about 10cm deep into the sample to ensure temperature compensation automatically took effect *(*AQL, n.d.). The DO value recorded in mg/L was read from the meter's display.

3.4.1.2 Determination of turbidity

The turbidity of the water samples was determined through the Nephelometric method using an Aqualytic AL450T-IR turbidity meter with an infrared light source. The nephelometric technique draws from comparing the intensity of light scattered by a sample under predetermined conditions. Deionized water was first used to standardize the turbidity meter to zero NTU, followed by another standardization] with 100 and 40 NTU standards (AQL, 2014). 10ml of the samples were transferred into cuvettes after thoroughly mixing the sample by shaking. The turbidity of samples in the cuvettes was consistent with EN ISO 7027 and recorded in Nephelometric units.

3.4.2 Laboratory analysis

Laboratory analysis of the remaining parameters was done at the chemistry and civil engineering laboratories. Standard laboratory procedures were applied while using aqualytic

AL400 photometer, ultraviolet spectrophotometric screening, and flame atomic absorption spectrophotometry equipment to perform the analysis.

Plate 3.2: Laboratory analysis at Civil Engineering Laboratory in KU

3.4.2.1 Determination of fluoride

Fluoride levels was determined through the SPADNS colorimetric method. This technique was conducted based on the chemical reaction of fluoride and a zirconium-dye lake. On a 50 mL groundwater sample, the researcher added 5.00 mL of SPADNS solution and zirconyl-acid reagent, mixed it well and then read the absorbance from the Aqualytic AL400 photometer (AQL, 2017).

3.4.2.2 Determination of chloride

Chloride levels in the sampled underground water was determined by use of a mercuric nitrate $Hg(NO_3)_2$ titration due to the formation of soluble slightly dissociated mercuric chloride. The pH of the water samples was first lowered appropriately by adding nitric acid. During titration, the mercuric ions reacted with the chloride ions forming mercuric chloride. The excess mercuric ions in the solution complexed with diphenyl carbonzone to form a purple solution. The change of colour from yellow to purple during the titration process marked the titration's endpoint (Domask, and Kobe, 1952). The number of digits on the counter was recorded and Chloride concentration calculated as product of digits used and digit multiplier.

$$Chloride\ concentration = \frac{(\mathbf{A-B})\ x\ N\ x\ 35\,450}{\mathbf{mL\ sample}} \text{ ………………………………. Equation 3-3}$$

Where: A = mL titration for sample,

B = mL titration for blank and

N = normality of $Hg(NO_3)_{2-}$

Mg NaCl/L = (mg Cl-/L) x 1.65

3.4.2.3 Determination of iron

Determination of iron was done through colorimetric method. 50 mL portion of the groundwater sample was acidified with 2 mL concentrated hydrochloric acid (HCl). After thoroughly mixing the solution, 10 mL $H_4C_2H_3O_2$ was added to 20 ml phenanthroline solution and thoroughly mixed. The colour intensity was then read from the photometer after allowing the thoroughly mixed solution to settle for about 5 to 10 minutes (AQL, 2017).

3.4.2.4 Determination of hardness

Assessment of the level of hardness as mg/l (ppm) calcium carbonate in the collected samples was done through EDTA (ethylenediaminetetraacetic acid) titration. The pH value of the sample was first brought to 10 by use of a buffer solution. The buffer solution reacted with magnesium and calcium ions in the sample and formed a red compound. During the EDTA titration, the metal ions react with it until all the metal ions are complexed. The surplus EDTA removes the complexed metal ions with the indicator to form a blue solution. The colour change from red to blue marked the endpoint of the titration (American Public Health Association, 2005).

Hardness (EDTA) as mg $CaCO3/L = \frac{A\ x\ B\ x\ 1000}{mL\ sample}$…………………………….….Equation 3-4

Where: A = mL titration for sample and;

B = mg $CaCO_3$ equivalent to 1.00 mL titrant.

3.4.2.5 Determination of nitrate (NO_{3-}) and sulphate (SO_4^{2-})

The determination of nitrate (NO_3-) and sulphate (SO_4^{2-}) concentration was done through ultraviolet spectrophotometric screening method. For Nitrate concentration, the samples were first treated by adding and thoroughly mixing 1 ml HCL solution to a 50 ml clear sample. NO_3^- calibration standard was prepared in the range of 0-7mg NO_3^- by diluting 0, 1.0, 2.0, 4.0, 7.0 to 35.0 mL volumes of intermediate nitrate solution by diluting to 50ml. The NO_3^- standard was also treated in the same manner as the samples. This was followed by spectrophotometric measurement by reading the absorbance against deionized water set at a zero absorbance value. 220 nm wavelength was used to get NO_3^- concentration reading and 275 nm wavelength applied to establish interference emerging from dissolved organic matter. The absorbance due to NO_3^- was plotted against the standard concentration to come up with a standard from which the concentration of the sample was directly obtained. The sample concentration was therefore obtained directly from the standard curve (Goldman and Jacobs, 1961).

For Sulphate concentration, 100ml of the sample was thoroughly mixed with 5 ml conditioning reagent in a 250 ml flask. A spoonful of barium chloride ($BaCL_{12}$) was added into the mixture and stirred for another 1 minute. The mixture was then transferred into the absorbance cell and its turbidity recorded at a space of between 30 seconds to 4 minutes. A standard curve was constructed using sulphate solution and the sample concentration read directly from the curve. Consistency of the standard curve was ensured by running the sulphate standard with every 3 or 4 samples. Concentration of sulphate was therefore calculated through the equation 3.3.

Sulphate (SO_4^{2-}) (mg/L) = $\frac{\mathbf{mg\ (Sulphate)*1000}}{\mathbf{Volume\ of\ Sample\ (ml)}}$ ………………………………….Equation 3-5

3.4.2.6 Determination of calcium, magnesium, and sodium

Calcium, Magnesium and Sodium concentrations were determined through flame atomic absorption spectrophometry. Calcium stock solution was made ready by mixing 6 ml hydrochloric acid with 0.252 g of calcium carbonate ($CaCO_3$) in a 100ml volumetric flask. A dilute solution prepared by mixing it with deionized water to the 100ml mark on the volumetric flask. A 500µL pipet was used to add 0.0, 0.5, 1.0, 1.5 and 2.0mL of calcium stock into 5 different beakers containing 250mL distilled water and mixed thoroughly. The flame atomic spectrophotometer was then set up according to the operation instructions and the standards as well as the samples were measured. Samples that recorded absorbance out of the standards' range were further diluted and re-measured (American Public Health Association, 2005).

Magnesium stock solution was made by mixing 0.101g of dry magnesium oxide (MgO) in about 6 ml hydrochloric acid in a 1000ml volumetric flask. Distilled water was added to the solution to the 100 ml mark to further dilute it then thoroughly mixed by shaking volumetric flask. Using a 500µL pipet, 0.0, 0.5, 1.0, 1.5 and 2.0mL of magnesium stock solution was added into 5 different beakers containing 250mL distilled water and mixed thoroughly. The elements of the flame atomic spectrophotometer were changed to measure magnesium after which the emission standards as well as the samples were measured (American Public Health Association, 2005).

Preparation of sodium chloride stock solution was carried out by mixing 0.510 g of NaCl in 100ml deionized water in a 200ml volumetric flask. This was further diluted by adding the distilled water to the 200ml mark and properly mixed. 250ml of distilled water was poured into 6 different 400mL beakers and 0, 0.5, 1.0, 1.5, 2.0 and 2.5mL volumes of the NaCl stock solution was slowly added to the deionized water in the beakers using a pipe and properly mixed. The concentration of NaCl in the standards were all calculated and recorded. The spectrophotometer was set according to the operating instructions for Na measurements. The measurement was set back to zero with distilled water and emission intensity of both standards and the water samples measured (American Public Health Association, 2005). In cases where the emission was high above the range of the calibration curve the water samples were further diluted with deionized water and measurement of the emission intensity repeated.

3.4.3 Mapping of groundwater quality

For mapping purposes, geographical coordinated of the sampling sites were obtained using a Garmin GPS-60. The geographical coordinates and the values of the water quality parameters for each sampling site were uploaded into Surfer 13 Golden Software. Surfer 13 software was used to generate contour maps to show the spatial variation of the groundwater quality parameters in Kamiti-Marengeta sub-catchment as shown in the framework for contour map generation in Figure 3.3.

Kriging gridding method was used to incorporate the spatial water quality parameters. This geostatistical technique helps produce good maps from data that is irregularly spaced (Yang *et al.,* 2004). Kriging gridding method expresses the trends in a data set such that all high points are linked along an elevation instead of being separated contours of the bull’s eye type. The Kriging feature of surfer software serves as an accurate or a levelling interpolator based on the parameters specified by the user. According to Yang *et al.* (2004), the kriging is more accurate as it integrates anisotropy and basic trends in a natural and efficient manner.

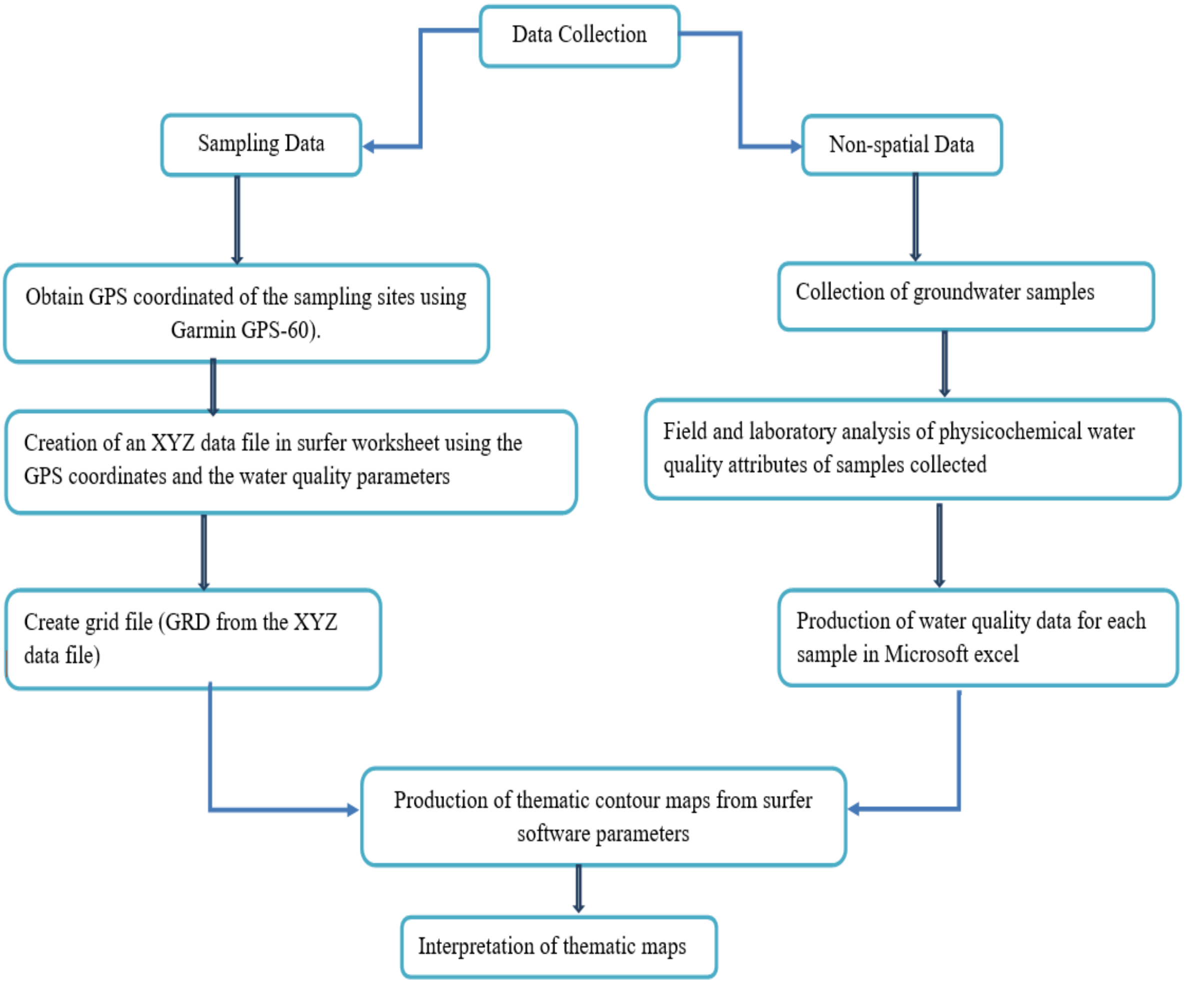
3.4.4 Statistical analysis

One-way analysis of variance (ANOVA) was carried out to establish if there were remarkable differences in concentration levels of the tested water quality attributes across the six zones of the study area (Manly and Alberto, 2016) as illustrated in Appendix V and Appendix VI. After running ANOVA Tukey’s Honest Significant Difference (HSD) test was carried out to collate all possible pairs of means to determine which specific groups’ means were different.

Correlation analysis was conducted for the borehole and shallow wells sets of data for both wet and dry seasons. The correlation matrix showing degree of association was computed between for the 17 tested parameters and a correlation co-efficient (R) was used to gauge which parameters were correlated parameters. Correlation categories of perfect ($R = 1$), very strong ($\pm0.9 \leq R \leq 1$), strong ($\pm0.7 \leq R < \pm0.9$), moderate ($\pm0.5 \leq R < \pm0.9$), and poor ($R^2 < \pm0.5$) were adopted for the study.

The students t-test was performed to establish the mean variations in concentration levels of tested water quality attributes in boreholes and shallow wells during the two seasons. Box and whisker plots were used to provide a clear visual representation of concentration of the water quality parameters and to present the descriptive statistics clearly and accurately.

They were also used to demonstrate the seasonal differences in concentration levels of the assessed water quality attributes. The box and whisker plots described the statistical five number summary, upper and lower extremes, median and upper and lower quartiles as calculated in Appendix II and Appendix III.



3.5 Ethical considerations

The integrity of research needs not only knowledge but also integrity and honesty. The researcher took into consideration the research ethics that regulate the relations between the researcher, the research participants, and the local authority. To conduct the study in Kenyatta University the researcher secured authorization from the registrar administration whereas to collect samples from KU surrounding environs, permission was obtained from the property owners and caretakers of residential areas with boreholes or shallow wells.

As per the regulations governing research studies, the researcher applied for and acquired a research permit from the governing body, National Commission for Science Technology, and Innovation (NACOSTI), to enable smooth running of the research without interference from local authority. Another ethical issue that was considered was confidentiality issue. The researcher ensured privacy of the research participants was maintained. This was achieved by ensuring that the data collected was only used in the study and no third party had access to it.

Lastly, those participating in the research were given a consent form (Appendix XIII) to sign before data collection. The researcher ensured that the consent forms informed the research participants that their participation was voluntary, clearly outlined their rights, potential benefits, and risks associated with the study (Flory and Emanuel, 2004). This helped the researcher to gain the buy in and trust from the participants because they became confident over the security of the information they provided.

CHAPTER 4 : RESULTS AND DISCUSION

4.1 Introduction

The presentation of Chapter 4 of the study is done in four different sections where the results of each objective are presented and discussed according to the study objectives. The first and second objectives are discussed in section 4.2, the third objective in section 4.3, and the fourth objective in section 4.4. The study results are presented in tables, maps, and graphs alongside explanatory and illative statistics.

4.2 Physical and chemical characteristics of boreholes and shallow wells

This section presents the results of objective 1, determination of select physicochemical characteristics of the borehole and shallow well waters, and objective 2, spatial variations of selected groundwater quality parameters in Kamiti-Marengeta Sub-Catchment. Table 4.1 provides the location of each borehole and shallow well to help readers follow the discussion.

Table 4-1: Location of BHs and SHWs

	ByPass	**Kiwanja**	**KU**	**Membley**	**K. Sukari**	**K. Wendani**
Boreholes	BH01	BH06	BH11	BH16	BH21	BH26
	BH02	BH07	BH12	BH17	BH22	BH27
	BH03	BH08	BH13	BH18	BH23	BH28
	BH04	BH09	BH14	BH19	BH24	BH29
	BH05	BH10	BH15	BH20	BH25	BH30
Shallow Wells		SHW04				SHW12
		SHW05				SHW13
	SHW01	SHW06		SHW09	SHW15	SHW14
	SHW02	SHW07		SHW10	SHW16	
	SHW03	SHW08	None	SHW11	SHW17	

4.2.1 Temperature

The water temperature of groundwater has a significant influence on the amount of total dissolved solids. At every groundwater temperature, a concentration of the dissolved mineral element is in contact with the mineral. However, the actual concentration of that mineral is dependent on the groundwater temperature (Nelson, 2002). The temperature of samples of water collected from the borehole had a mean value of 22.99°C for the dry season and 23.03°C for the wet season. In shallow wells, the temperature mean value was 22.37°C and 21.88°C during the dry and wet seasons, respectively, as shown in Appendix I. The highest temperature in boreholes during the dry season was recorded at BH22 in Kahawa Sukari and the lowest at BH26 at Kahawa Wendani. During the wet season, the highest borehole temperature was recorded at BH22 at Kahawa Sukari and the lowest at BH9 at Kiwanja. For the shallow wells, the highest temperature during the dry season was recorded at SHW01 at Bypass and the lowest value at SHW10 at Membley.

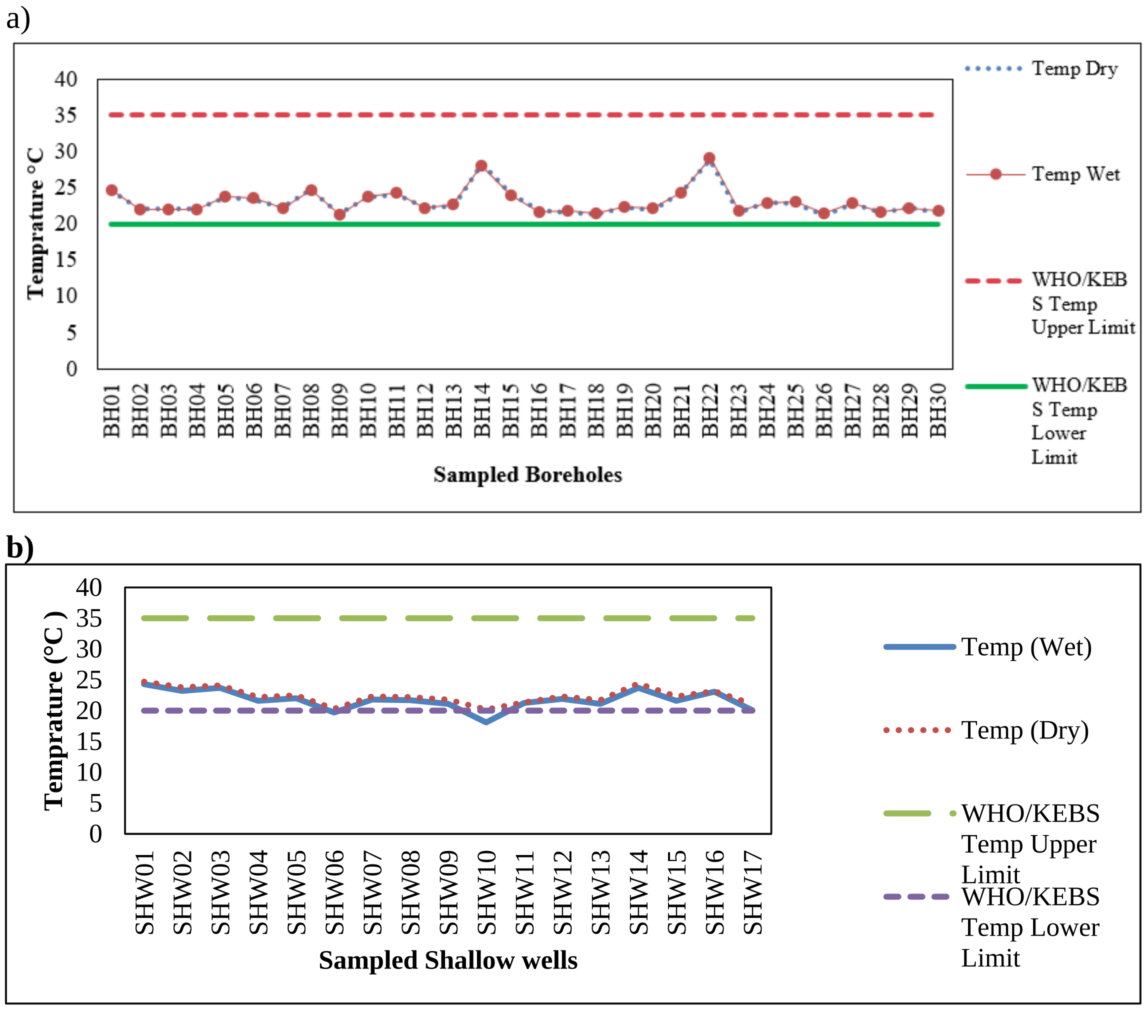


Figure 4-1: Temperature values in BHs and SHWs against WHO and KEBS standards

During the wet season, the highest shallow well temperature was recorded at SHW01 in Bypass and the lowest at SHW6 in Kiwanja. The temperature of samples was within WHO and KEBS allowable limits of 20°C to 35°C, except for SHW06 in Kiwanja. SHW 10 in Membley, recorded a lower value of 19.70°C and 18.09°C during the wet period as shown in Figure 4-1 (a) and (b). The contour map for temperature in boreholes indicated pockets of high-temperature values of between 25.5°C to 28.5°C in Kahawa Sakari and Kenyatta University, while slightly lower temperature values of between 21°C to 22°C were recorded in Membley and Kahawa Wendani. In shallow wells, the contour maps indicated high-temperature values of between 22.4°C to 24°C in Bypass and Kahawa Wendani and pockets of low-temperature values in parts of Kiwanja and Kahawa Sukari, as illustrated in Figure 4-2. On average, the borehole water temperature in the wet season was slightly higher than that of the dry season, probably due to higher thermal gradient during the wet periods. The rate of temperature changes with distance in the earth's crust and according to Timothy and David (2019), heat flows from hot regions to cold regions and during the wet season the upper surface of the earth is wet/cold, meaning there is a high thermal gradient created as the heat moves up the earth surface warming the groundwater. Higher temperature levels of shallow well waters during dry season compared to wet season is attributed to the fact that shallow aquifers responding to

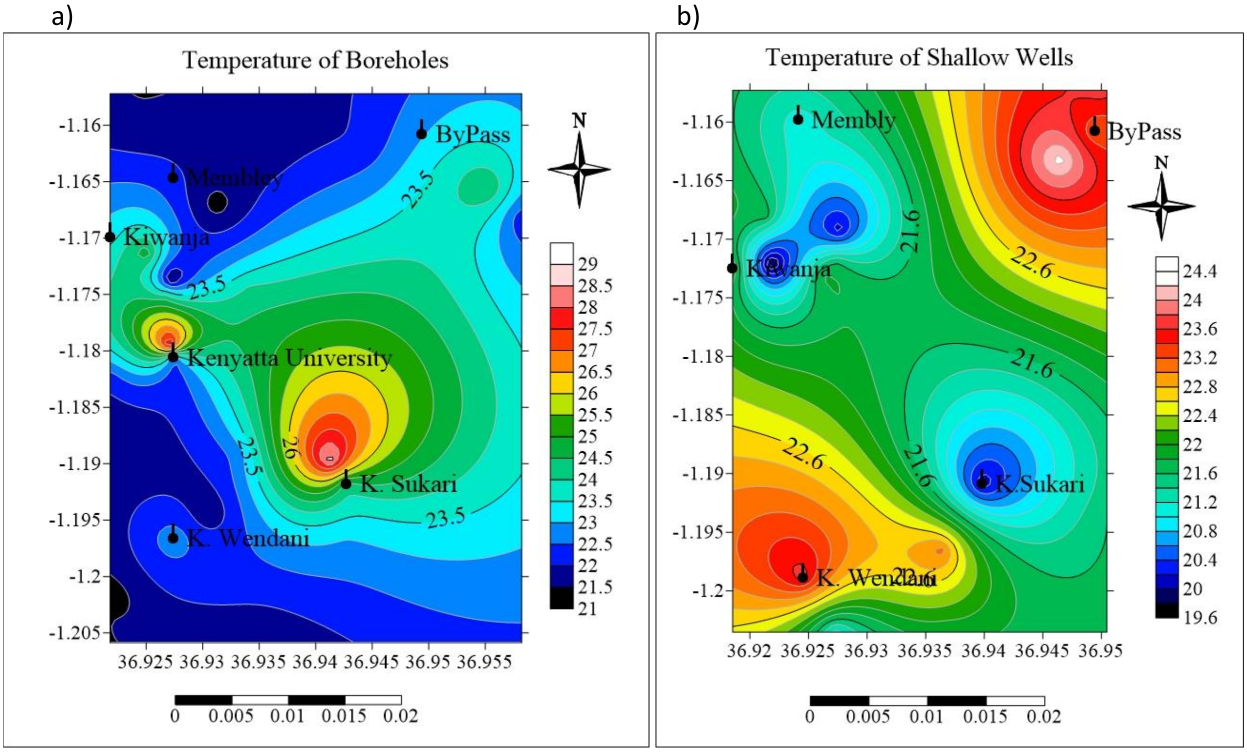


Figure 4-2: Contour map of temperature in BHs and SHWs

ground surface temperatures and land use. The temperature values indicate that the groundwater temperature in the study area is largely ambient and good for water quality considering that, high temperature increases the growth of micro-organisms which may negatively impact the odour, taste and colour of water or even cause corrosion problems (Yilmaz and Koc, 2014).

4.2.2 pH

pH as water quality parameter is important as it shows if the water is acidic or alkaline. According to Nelson (2002), low groundwater pH values below required standards depict the that the water is acidic. Under normal groundwater temperature, a pH value of 7mg/L is considered neutral hence groundwater with pH values less than 7 mg/L is acidic and groundwater with pH values above 7mg/L is alkaline. pH units of water samples from boreholes had a mean value of 7.25mg/l and 7.24mg/l for dry and wet season, respectively. This showed a minor seasonal influence on pH units in the boreholes within the sub-catchment. Further correlation analysis of the parameters in section 4.2.19 showed no strong positive or negative correlation between pH and other tested parameters which also indicated that pH in the boreholes is a function of other minerals or chemical reactions in groundwater.

In Shallow wells, the pH mean values were 6.95mg/l and 7.46/l during the dry and wet season respectively as shown in Appendix I. The pH values of sampled boreholes were within the WHO and KEBS KS 459-1:2007 standards of 6.5mg/l to 8.5mg/l during the wet and dry period as shown by Figure 4-3 (a). The pH values for the 17 sampled shallow wells were within the WHO and KEBS KS 459-1:2007 standards during the wet period. During the dry period three shallow wells, SHW7 in Kiwanja and SHW 9 and SHW 10 in Membley recorded lower pH values than the WHO and KEBS standards as shown in Figure 4-3 (b).

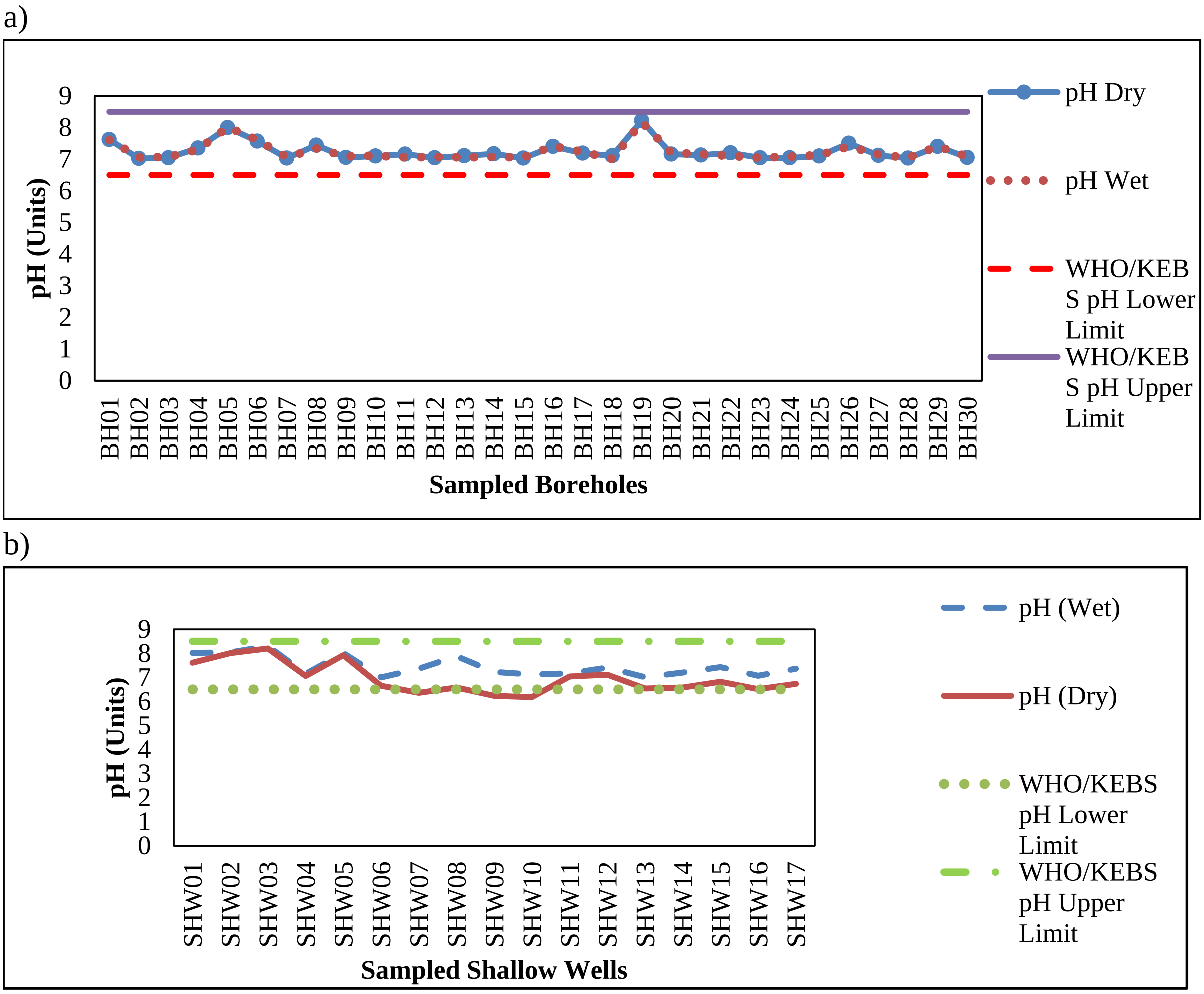


Figure 4-3: pH units in BHs and SHWs against WHO and KEBS standards

The contour map for pH units shown in Figure 4-4 (a) and (b) indicate that water from both boreholes and shallow wells in the greater part of the sub-catchment is alkaline with values ranging between 7.05 units to 7.65 units. There are however pockets of high pH units recorded in Membley and Bypass, in the northwest and northeast parts of the sub catchment, respectively. In general, the sampled boreholes were alkaline during the two seasons. Shallow wells were slightly acidic during the dry season hence supporting Langmuir's (1997) study that found natural waters to be slightly acidic with values ranging from (5.0-7.5mg/l). Additionally, the acidity may have also been caused by presences of organic acids and carbon dioxide within the soil zone or from the biogeochemical processes taking place during decay and leaching of plant materials (Yankey *et al.*, 2011).

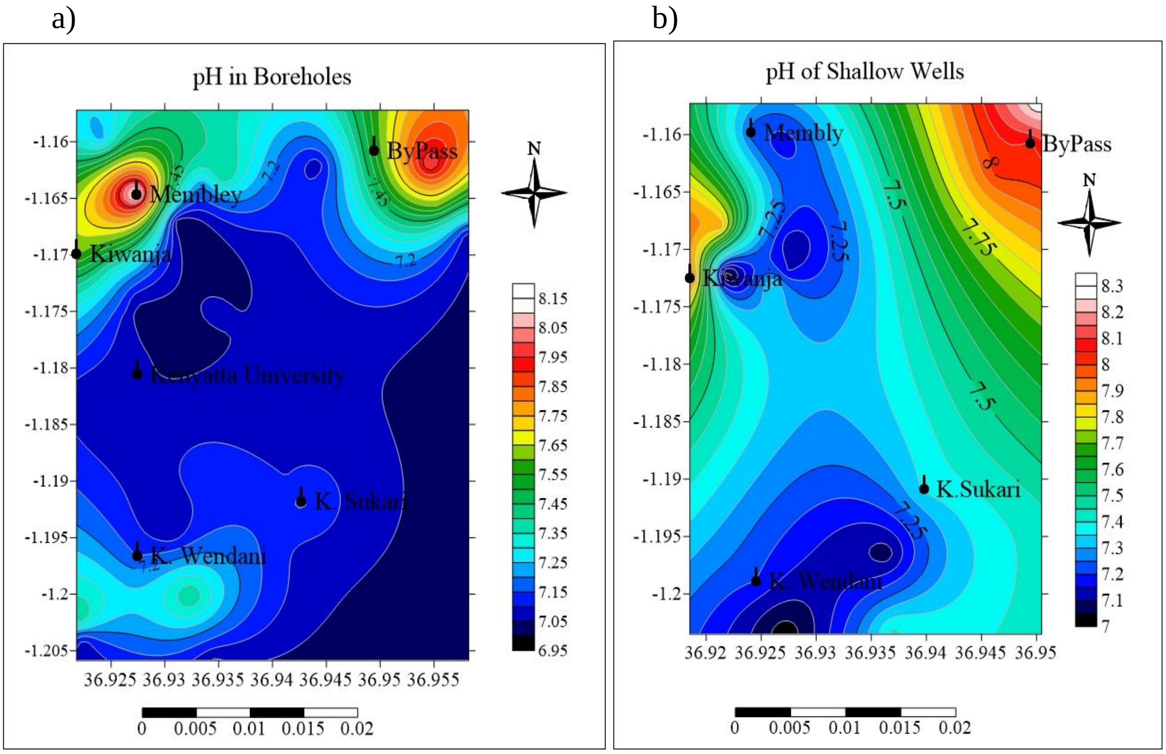


Figure 4-4: Contour map of pH units in BHs and SHWs

4.2.3 Electrical conductivity

Electrical conductivity is the amount of the dissolved ionic constituents responsible for the water’s electrical attributes. The mean values of the EC of water samples from boreholes were 431.97 µS/cm and 432.29 µS/cm during the dry and wet seasons, respectively. In Shallow wells, the pH mean values were 403.59 µS/cm and 474.06 µS/cm during the dry and wet season respectively as shown in Appendix I. The highest EC value in boreholes during the dry season was recorded at BH22 in Kahawa Sukari and the lowest at BH12 in Kenyatta University. For shallow wells, the highest EC value during the dry season was recorded at SHW17 in Kahawa Sukari and the lowest value at SHW10 in Membley. During the wet season, the highest borehole EC value was recorded at BH22 in Kahawa Sukari and lowest at BH12 in Kenyatta University. The highest shallow well EC value was recorded at SHW12 in Kahawa Wendani and lowest value at SHW10 in Membley.

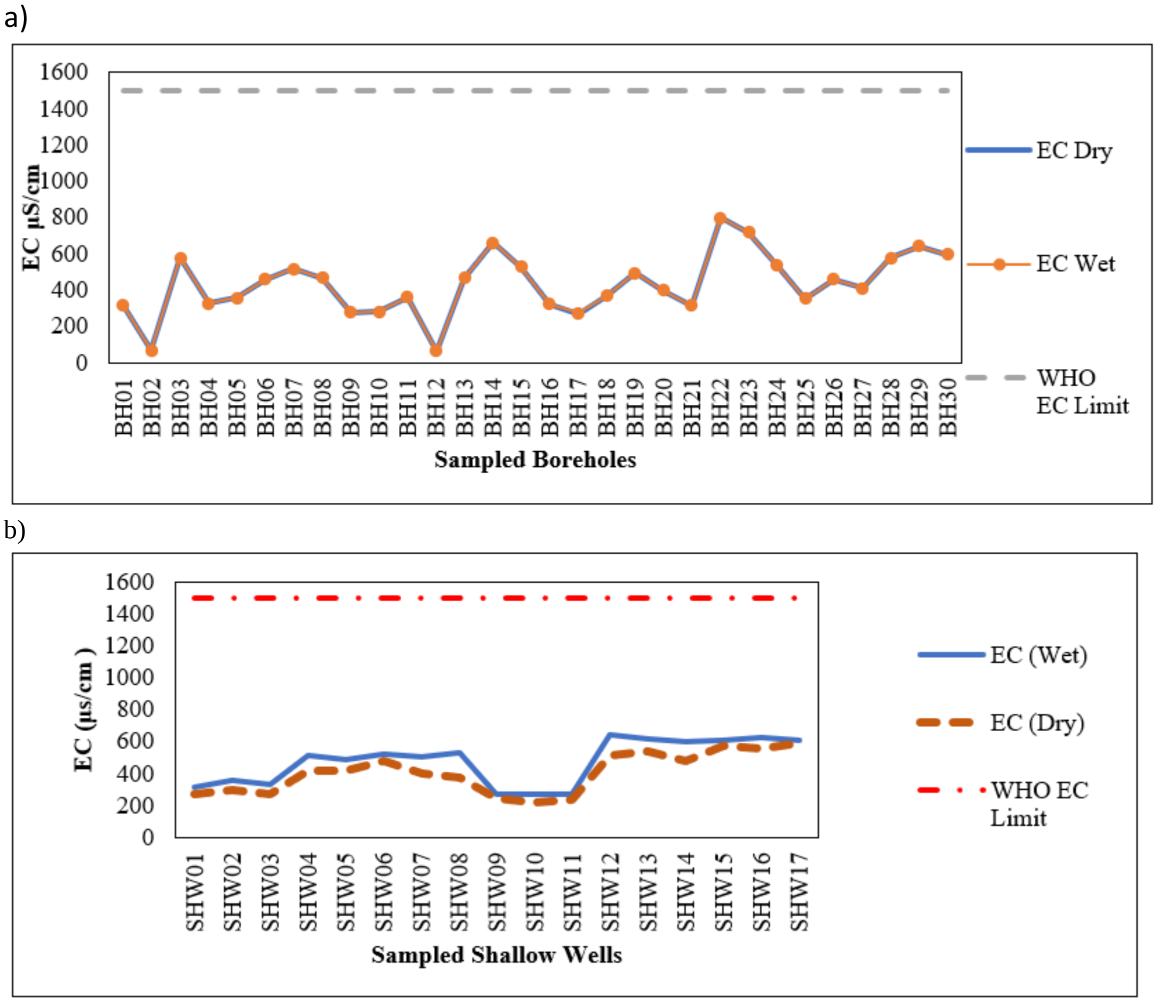


Figure 4-5: EC (µS/cm) in BHs and SHWs against WHO and KEBS standards

The EC values of all samples were found to be below the permissible maximum WHO standards of 1500µS/cm for drinking water as shown in Figure 4-5 (a) and (b). The contour map for EC in boreholes during dry and wet season indicated that, EC was high with values ranging between 650µS/cm and 800µS/cm in the south and southwest areas of Kahawa Wendani, and some small pockets in KU and Kahawa Wendani as shown in Figure 4-6 (a). In shallow wells high EC levels ranging between 520 µS/cm to 620 µS/cm was mainly recorded in southwest and southeast areas of Kahawa Wendani and Kahawa Sukari.

The EC of boreholes and shallow wells of the study area are below the maximum limits of 1500µS/cm, making the water safe for drinking. The high levels of EC in shallow wells are attributed to dissolution of various salts and other chemical elements from surface runoff, agricultural activities, domestic waste, and leachates, located near the wells, and natural phenomena such as soil type, erosion, and high temperature, increasing the charged ions in the shallow well water.

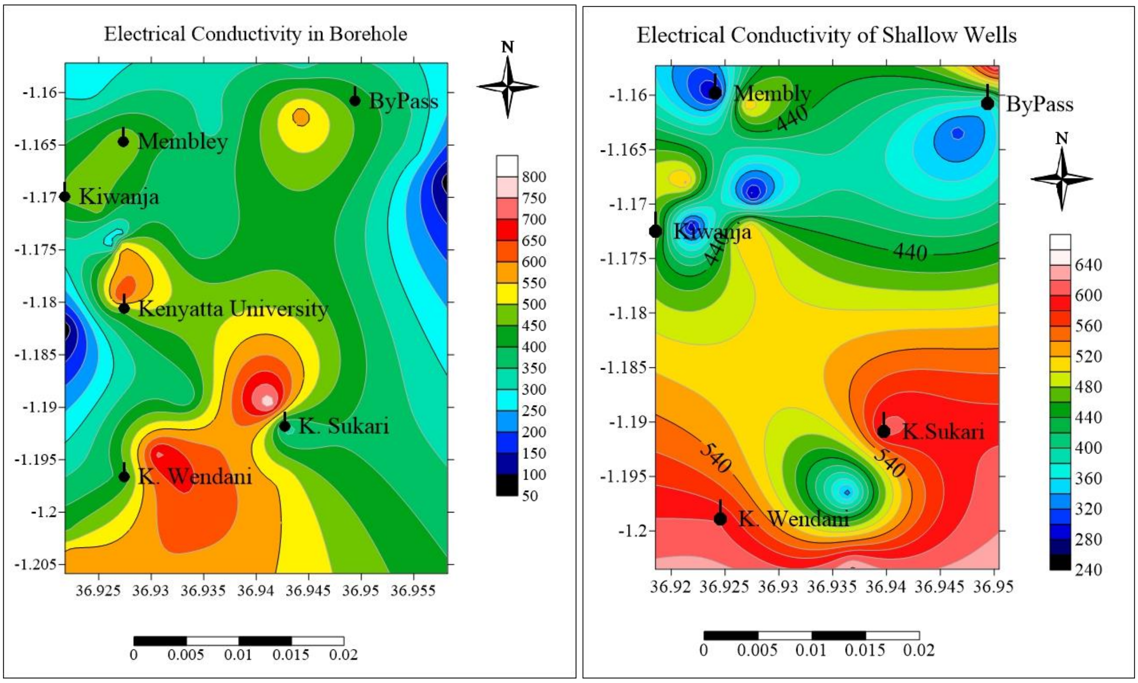

a) b)

Figure 4-6: Contour maps of EC (μS/cm) in BHs & SHWs

This confirms Olonga *et al.* (2015) that the EC levels for shallow wells during the wet season were higher compared to the levels during the dry season, which was attributed to the infiltration of ions from the soil by surface runoff. EC is a water parameter that is associated with total dissolved solids. Generally, an increase in EC and TDS increases the corrosion potential of the water (Seyedmohammadi *et al.*, 2016). From the seasonal plots of EC values of boreholes and shallow wells, it shows that seasonal variation had less effect on the boreholes than on the shallow wells. The results obtained in this study also suggest that the electrical conductivity of boreholes and shallow wells in this area does not follow a particular pattern but rather depends wholly on human activities and the natural geographical formation of a specific area thereby confirming reports by Prasad *et al.* (2018), which attributed high EC values in shallow wells compared to boreholes during the different seasons to the high concentration of dissolved solids such as anions and cations resulting from the geology, soil type, and potential pollution.

4.2.4 Turbidity

Turbidity mean values of water samples from boreholes were 2.77 NTU and 2.79 NTU during the dry and wet seasons, respectively. In Shallow wells, the mean turbidity values were 2.79 NTU and 4.30 NTU during the dry and wet periods, as shown in Appendix I. The highest turbidity value in boreholes during dry season was recorded at BH16 in Membley and the

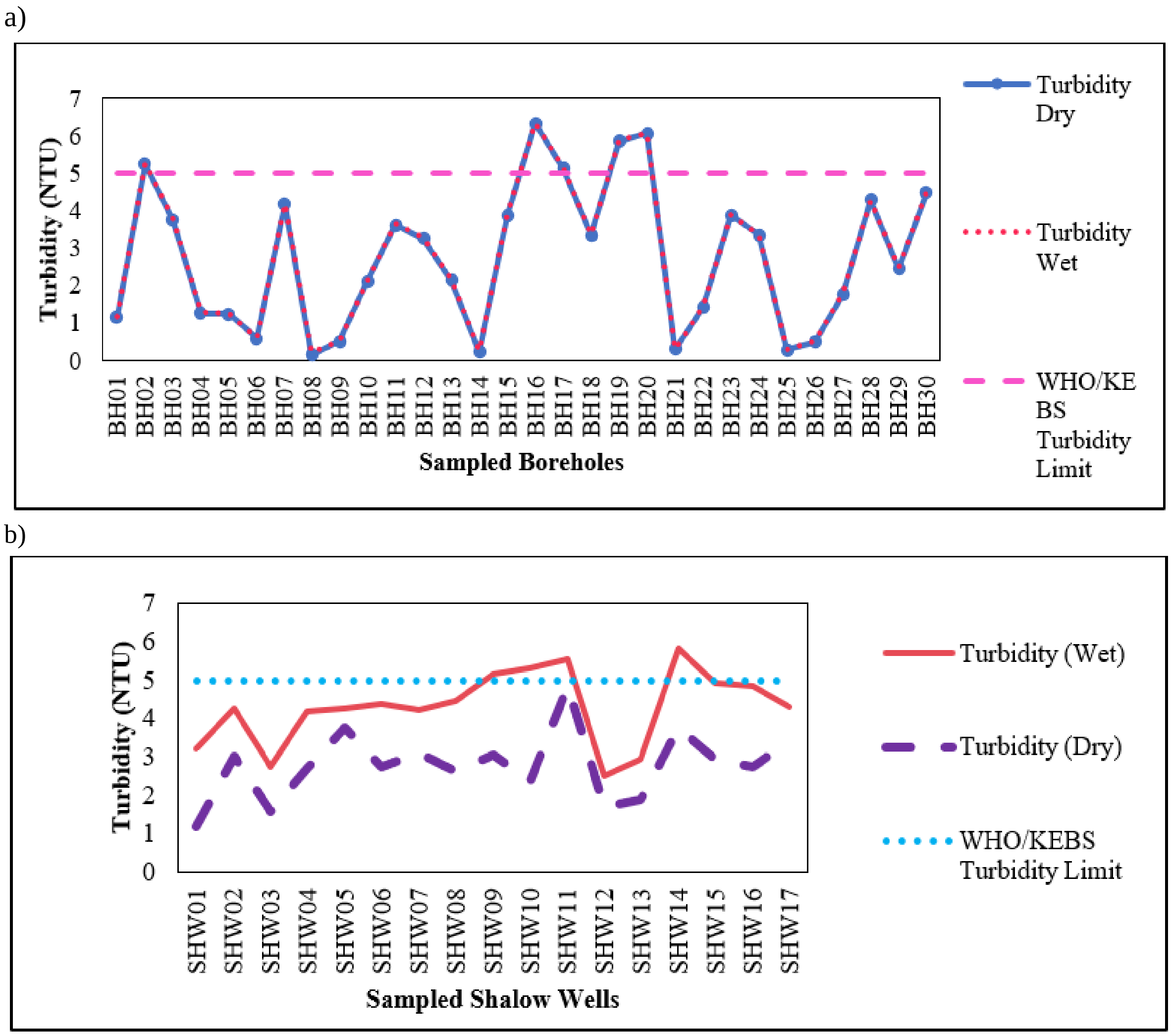


Figure 4-7: Turbidity (NTU) in BHs and SHWs against WHO and KEBS standards

lowest at BH08 in Kiwanja. For shallow wells, the highest turbidity value during the dry season was recorded at SHW11 in Membley and the lowest value at SHW01 in Bypass. During the wet season, the highest borehole turbidity value was recorded at BH16 in Membley and the lowest at BH08 in Kiwanja. The highest shallow well turbidity value was recorded at SHW14 in Kahawa Wendani and lowest value at SHW12 in Kahawa Wendani.

Turbidity values of 25 sampled boreholes and 13 shallow wells were below the WHO and KEBS contaminant limit of 5.0 NTU. BH17, BH19, BH16, and BH 20 in Membley and BH02 in Bypass recorded higher turbidity values above the WHO and KEBS permissible limits of 5NUT during both dry and wet seasons as shown in Figure 4-7 (a). SHW 10, SHW11, SHW12 in Membley, and SHW14 in Kahawa Wendani recorded higher turbidity values above the WHO and KEBS permissible limits of 5NUT during the wet season, as shown in Figure 4-7 (b).

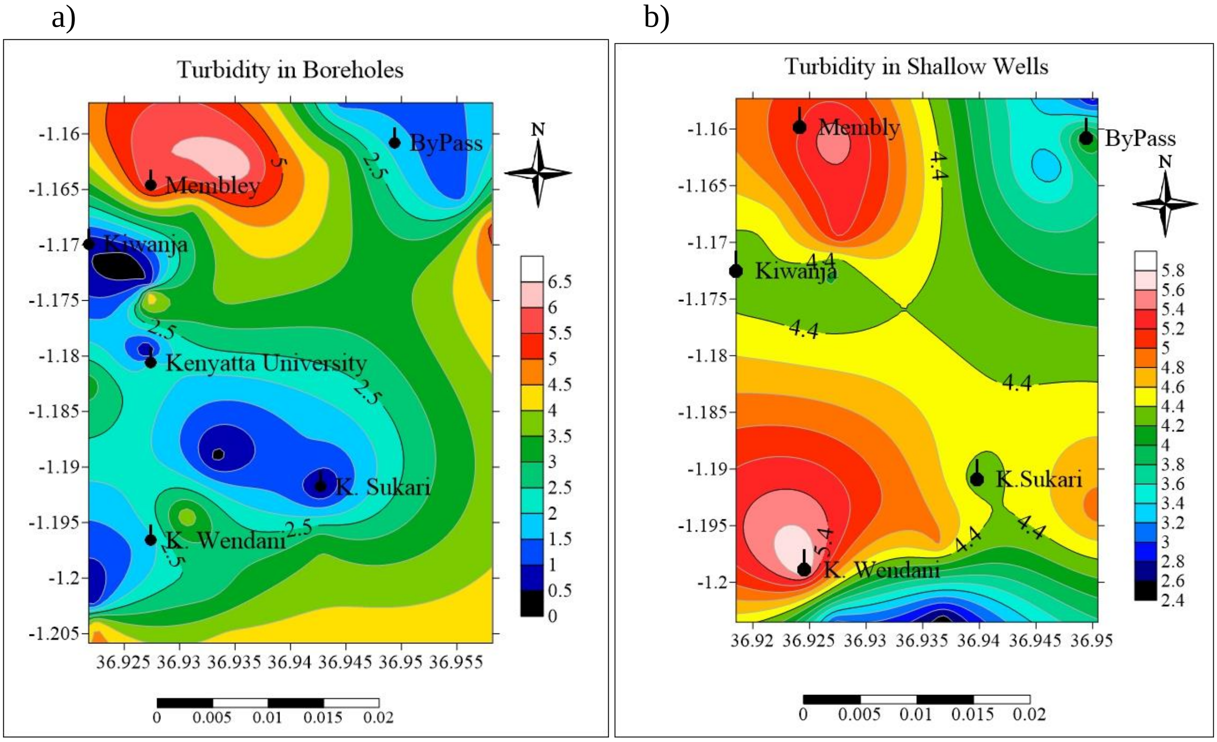


Figure 4-8: Contour map of Turbidity (NTU) in BHs and SHWs

The contour maps for turbidity in borehole water indicated that all boreholes with turbidity values above 5NTU were in Membley in the northeast part of the sub-catchment, as illustrated by Figure 4-8 (a). As illustrated in Figure 4-8 (b), the contour map for turbidity units in shallow wells showed pockets of high turbidity in Membley, Kahawa Wendani, and Kahawa Sukari in the northwest, southwest, and southeast parts of the catchment. Turbidity of water is of significance because the colloidal particles provide hideouts for pathogens. Considering that 5 out of the 30 sampled boreholes and four shallow wells recorded high turbidity values exceeding the permitted limits of 5 NTU by WHO and KEBS for drinking water, the turbidity must be reduced. Turbidity can be reduced through settling, coagulation/flocculation, sedimentation, flotation, adsorption, and filtration.

The high turbidity in borehole water in the north-eastern part of the catchment can be attributed to the thin layer of the upper Athi series, the Nairobi Aquifer’s central supply unit (WRMA, 2010). According to WRMA (2010), the Upper Athi Series is found mainly between 120 and 300 mbgl and thins eastwards. Therefore, boreholes drilled deeper than 120m in the eastern end of the aquifer are likely to have hit mud hence the high turbidity of the water. This could also be because of over-pumping to supply other households without water from the water service provider as typical in the area.

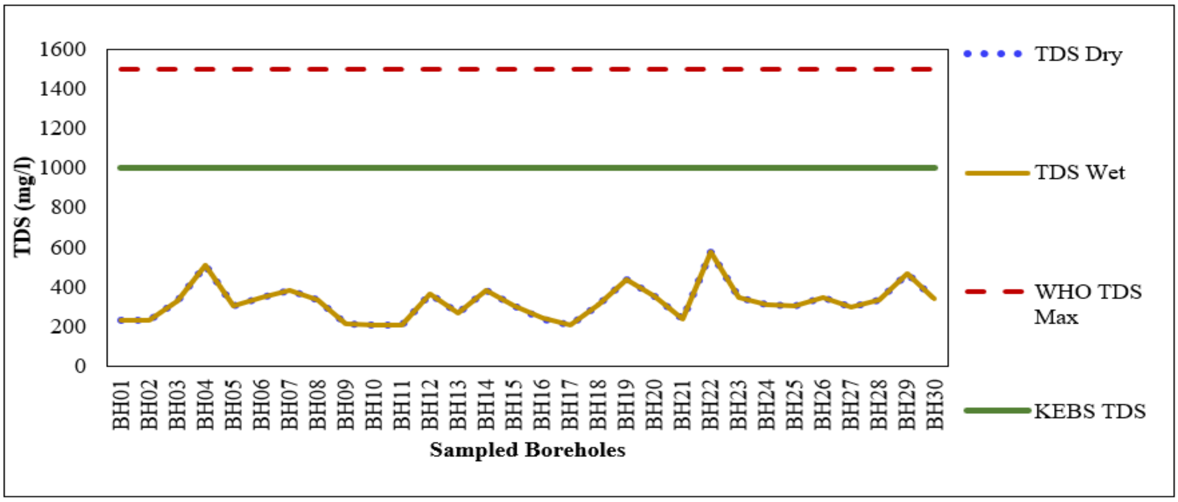
4.2.5 Total dissolved solids

TDS mean values of water samples from boreholes were 323.93mg/l and 323.93mg/l during dry and wet periods, respectively. In Shallow wells, the TDS mean value was 359.89mg/l during the dry season and 505.05mg/l during the wet season, as shown in Appendix I. The highest TDS value in boreholes during the dry season was recorded at BH22 in Kahawa Sukari and the lowest at BH11 in Kenyatta University. For shallow wells, the highest TDS value during the dry season was recorded at SHW12 in Kahawa Wendani and the lowest value at

SHW09 in Membley. During the wet season, the highest borehole TDS value was recorded at BH22 Kahawa Sukari and the lowest at BH11 at Kenyatta University. The highest shallow well TDS value was recorded at SHW07 in Kiwanja and the lowest value at SHW10 in Membley. All the samples were found to have TDS values below the WHO and KEBS standards of 1000mg/l as illustrated in Figure 4-9 (a) and Figure 4-9 (b).

The contour map for total dissolved solids in boreholes indicated high TDS concentrations of between 440mg/l and 560mg/l in Kahawa Wendani, Kahawa Sukari, and Bypass areas in southwest, central, and north areas of the Subcatchment respectively as shown in Figure 4-10. High TDS concentration ranging between 440mg/l and 560mg/l in shallow wells was recorded in Kiwanja, west of the sub catchment area.

a)



b)

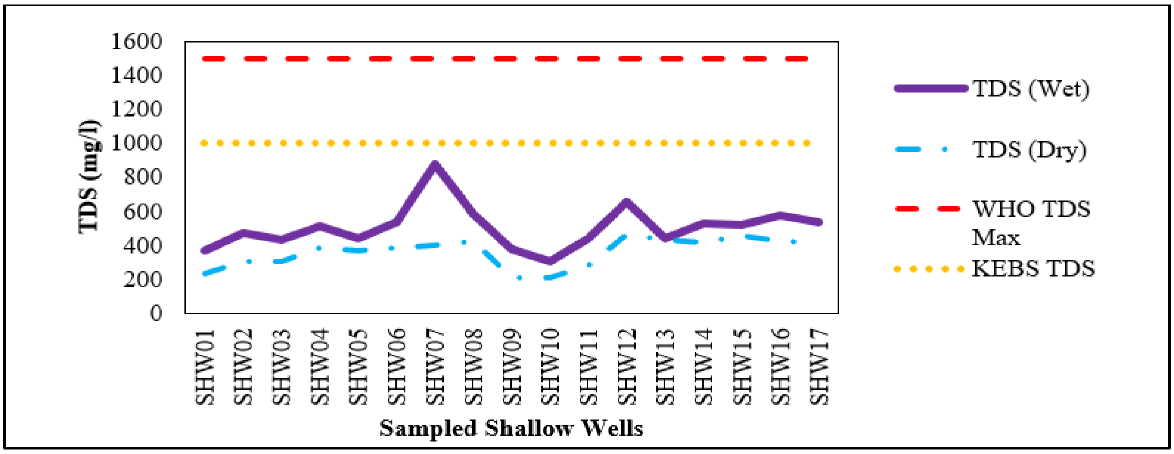


Figure 4-9: TDS (mg/l) in BHs and SHWs against WHO and KEBS standards

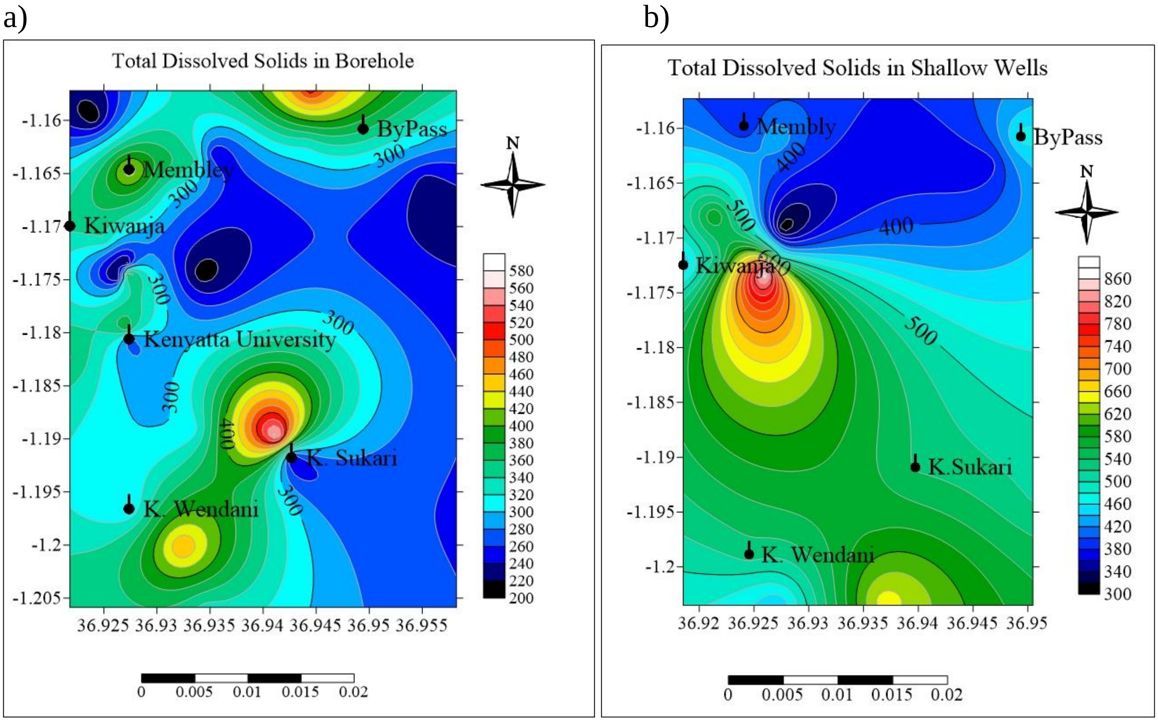


Figure 4-10: Contour map of TDS (mg/l) in BHs and SHWs

Groundwater in the study area has a different concentration of TDS in different areas and at different times due to a couple of reasons such as natural mass circulation, pollution from various sources, and groundwater recharge. According to Ballance and Bartram (2002), TDS from natural sources ranges from below 30mg/l to 6000mg/l based on the ability of different minerals in various geologic regions. The high mean concentration of total dissolved solids in shallow wells during the wet season in this study could be attributed to enhanced groundwater recharge, infiltration of untreated wastewater, and runoff from farms.

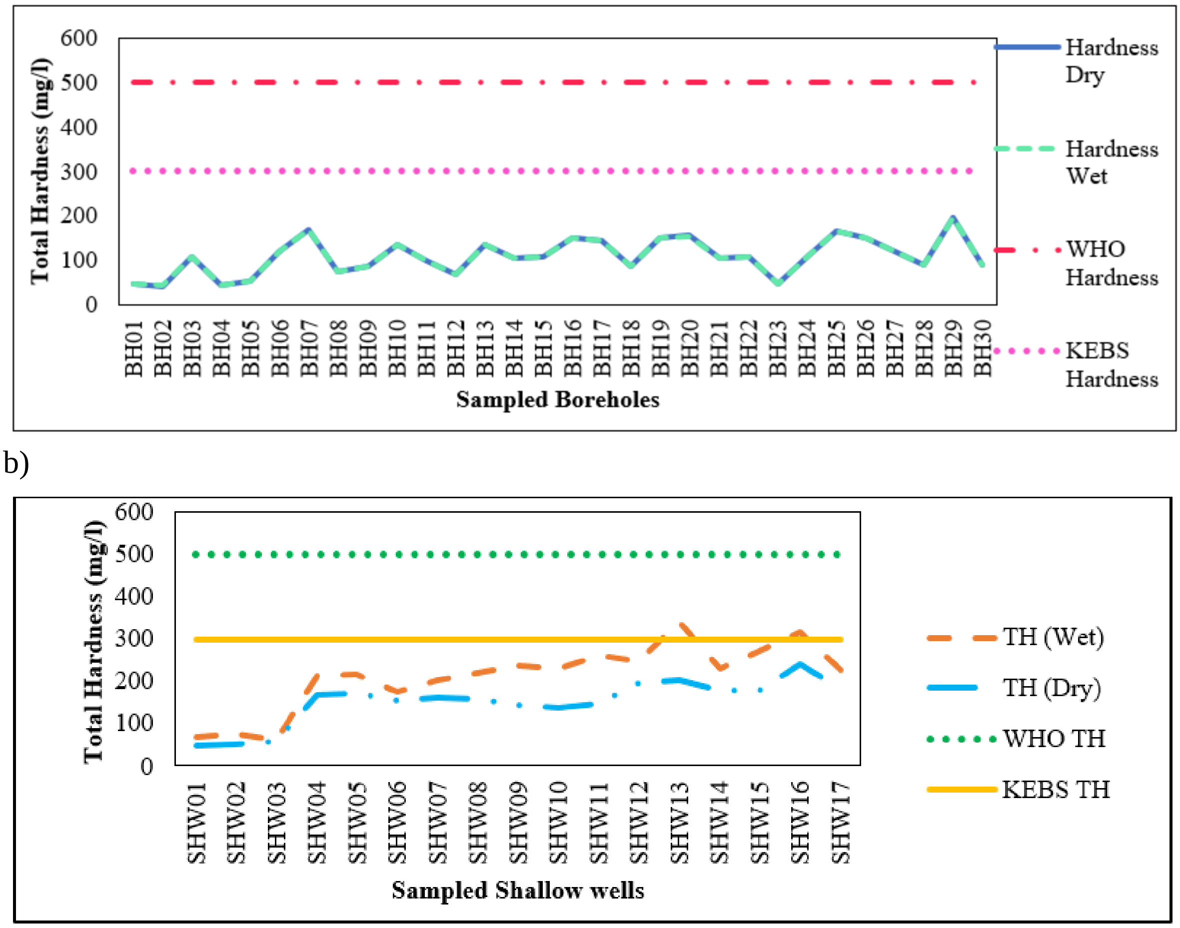
This study confirms the studies of Makwe and Chup (2013) and Olonga *et al.* (2015), which found a higher concentration of mean TDS in shallow wells during the wet seasons compared to the dry season and attributed the results to enhanced weathering and groundwater recharge during the wet season. The slightly acidic pH of rainwater dissolves minerals in the soil and aquifer. According to Nelson (2002), different geologic units such as basalt, sandstone, and limestone have different mineral composition hence it is rational to expect groundwater that interact with these different geological units to be different in terms of composition and taste.

The length of time water spend in an aquifer also determines the amount of mineral solute dissolved in the groundwater. According to Wilson *et al.* (2013), the degree to which water reacts with the aquifer minerals depend on how long it is in contact with the aquifer minerals. This also determines the concentration of dissolved minerals in water.

4.2.6 Total hardness

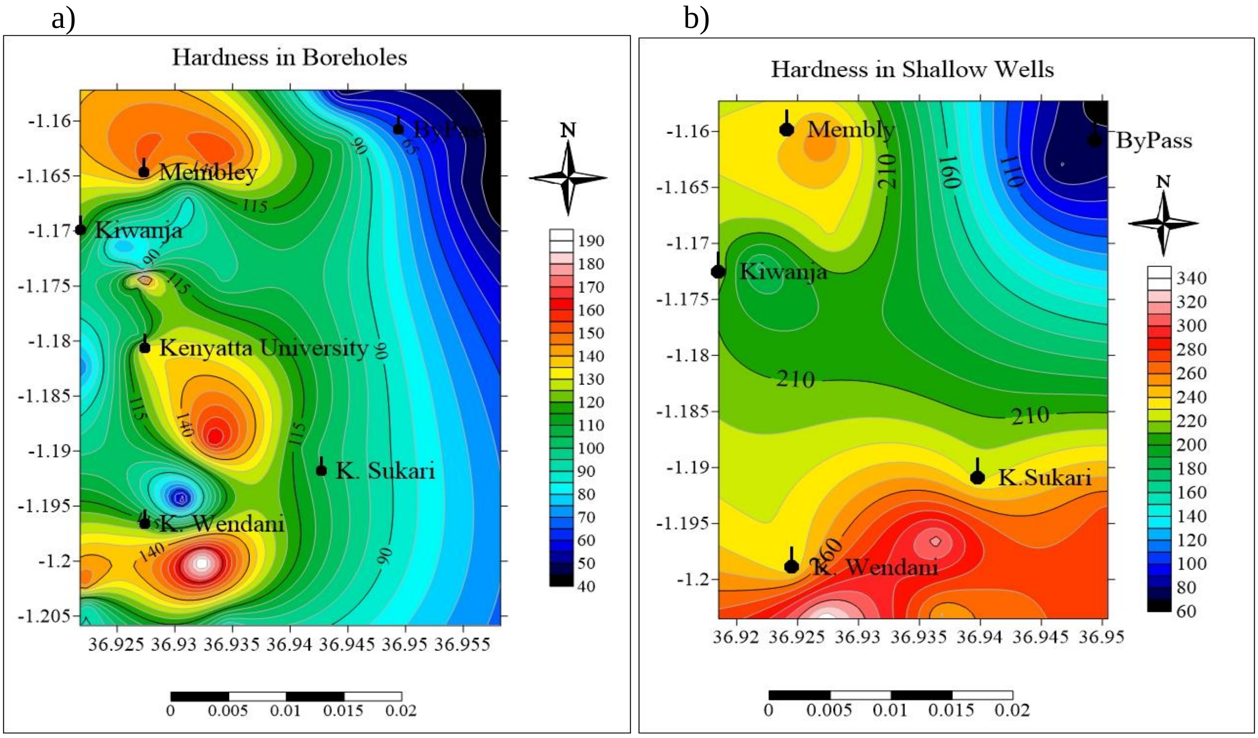
The total hardness mean values of water samples from boreholes were 108.73mg/l during the dry season and 108.75mg/l during the wet season. In Shallow wells, the total hardness mean values were 151.82mg/l and 211.47mg/l during the dry and wet period, as shown in Appendix I. The highest hardness value in boreholes during the dry season was recorded at BH29 in Kahawa Wendani and the lowest at BH02 in Bypass. For shallow wells, the highest total hardness value during the dry season was recorded at SHW16 in Kahawa Sukari and the lowest value at SHW01 in Bypass. During the wet season, the highest borehole total hardness value was recorded at BH29 in Kahawa Wendani and the lowest at BH02 in Bypass. The highest shallow well total hardness value was recorded at SHW13 in Kahawa Wendani and the lowest at SHW03 in Bypass, as shown in Figure 4-11 (a) and (b). All the hardness values of the sampled boreholes and shallow wells were within the WHO and KEBS contaminant limits of 500mg/L and 300mg/l, respectively.

The contour map for total hardness in boreholes during dry and wet seasons highlighted pockets of high hardness values ranging between 140mg/L to 190mg/L in Kahawa Wendani, Membley, and KU, as shown in Figure 4-12 (a). The contour maps for shallow wells recorded high concentration levels of hardness in the southern areas of Kahawa Wendani and Kahawa Sukari 4-12 (b).


a)

b)

Figure 4-12: Hardness in BHs and SHWs against WHO and KEBS Standards


a)

b)

Figure 4-11: Contour map of hardness (mg/l) in BHs and SHWs

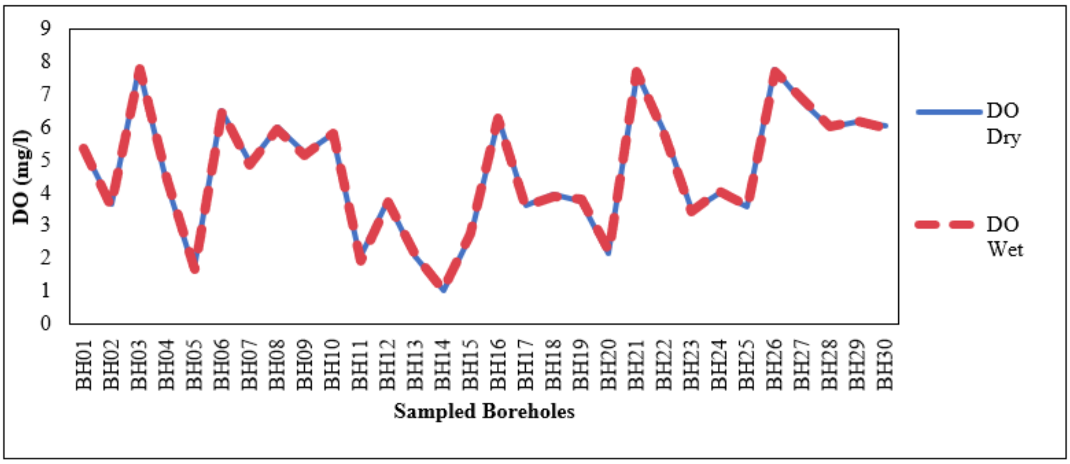
According to Yousefi *et al.* (2015), water hardness naturally occurs because of weathering of calcium-bearing rocks, limestone, and sedimentary rocks. Hardness can also be increased in groundwater through effluent from mining and chemical industries or excessive use of lime in agricultural farms. Groundwater hardness is an aesthetic concern because an elevated concentration level of the responsible ions gives the water an unpleasant taste. The ions also decrease soaps' ability to form lather and scale in plumbing pipes and fixtures. On the other hand, soft water can easily cause corrosion and may also enhance the solubility of heavy metals such as cadmium, zinc, and lead in water (Shyamala *et al.,* 2017).

The concentration of total hardness in shallow wells increased during the wet period. This is contrary to the findings of Yousefi et al. (2019), which showed a reduction in hardness in shallow wells and attributed it to the effect of dilution from increased infiltration of stormwater. The increase in hardness during the wet season could be because of more soluble calcium and magnesium salts, such as calcium chloride, from the farming activities close to the wells. This is further confirmed by the correlation analysis in section 4.2.19 that shows that hardness had a positive correlation with calcium and fluoride in shallow wells during wet season. According to Abanyie *et al.* (2016), a high concentration of total hardness results from the presence of magnesium carbonate ($MgCO_3$) and calcium carbonate ($CaCO_3$), which are dissolved from rocks and leached from agricultural fields that eventually end up in groundwater. It is crucial, however, to note that high hardness concentration does not pose health risks but hinders soap production of lather by soap solutions.

4.2.7 Dissolved oxygen

The mean concentration of dissolved oxygen in water sampled from boreholes was 4.66mg/l during the dry season and 4.66mg/l during the wet season. In Shallow wells, the mean dissolved oxygen concentration was 2.65mg/l during the dry season and 3.72mg/ during the wet season as highlighted in Appendix 1. The highest dissolved oxygen concentration in boreholes during the dry season was recorded at BH03 in Bypass and the lowest in BH14 in KU. For shallow wells, the highest DO value during the dry season was recorded at SHW12 in Kahawa Wendani and the lowest value in SHW02 in Bypass. During the wet season, the highest borehole DO value was recorded at BH03 in Bypass and lowest in BH14 in KU. The highest shallow well DO value was recorded at SHW12 in Kahawa Wendani and lowest value in SHW02 in Bypass as shown in Figure 4-13 (a) and (b).

a)



b)

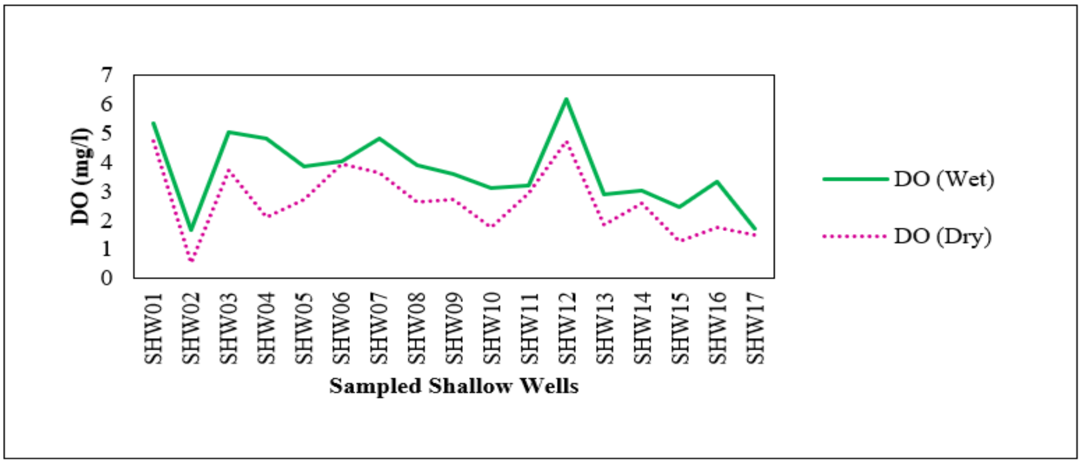


Figure 4-13: DO (mg/l) in BHs and SHWs against WHO and KEBS standards

The contour map for Dissolved Oxygen in boreholes indicated that high DO values ranging between 6.6mg/L to 7mg/L were recorded at Bypass in the north areas, at Kiwanja in northwest area, at Kahawa Wendani in the southwest area and at Kahawa Sukari in southeast areas. The lowest values between 1.2mg/L to 2.1mg/L was recorded at Kenyatta University in Southwest area as shown in Figure 4-14 (a). Pockets of high DO concentration in shallow wells ranging between 4.8mg/l to 6mg/l were recorded at Kiwanja in the west, Bypass in northeast, and Kahawa Wendani in the south and lowest values recorded in Kahawa Sukari as shown in Figure 4-14(b).

Dissolved oxygen in groundwater significantly affects the general groundwater quality as it controls the unifying power of trace metals with other atoms and limits the metabolism of dissolved organic species by bacteria (Longe and Balogun, 2010). According to Schüring *et al.* (2013), the dissolved oxygen concentration in water highly depends on the water's pressure, temperature, and salinity. Oxygen solubility reduces as the water temperatures increase; dissolved oxygen significantly decreases with increased saltiness and increases with a rise in both atmospheric and hydrostatic pressure. There was a minor seasonal influence on DO concentration in sampled boreholes during the dry and wet seasons; however, there was a slight increase in the DO concentration during the wet period in shallow wells. This confirms the

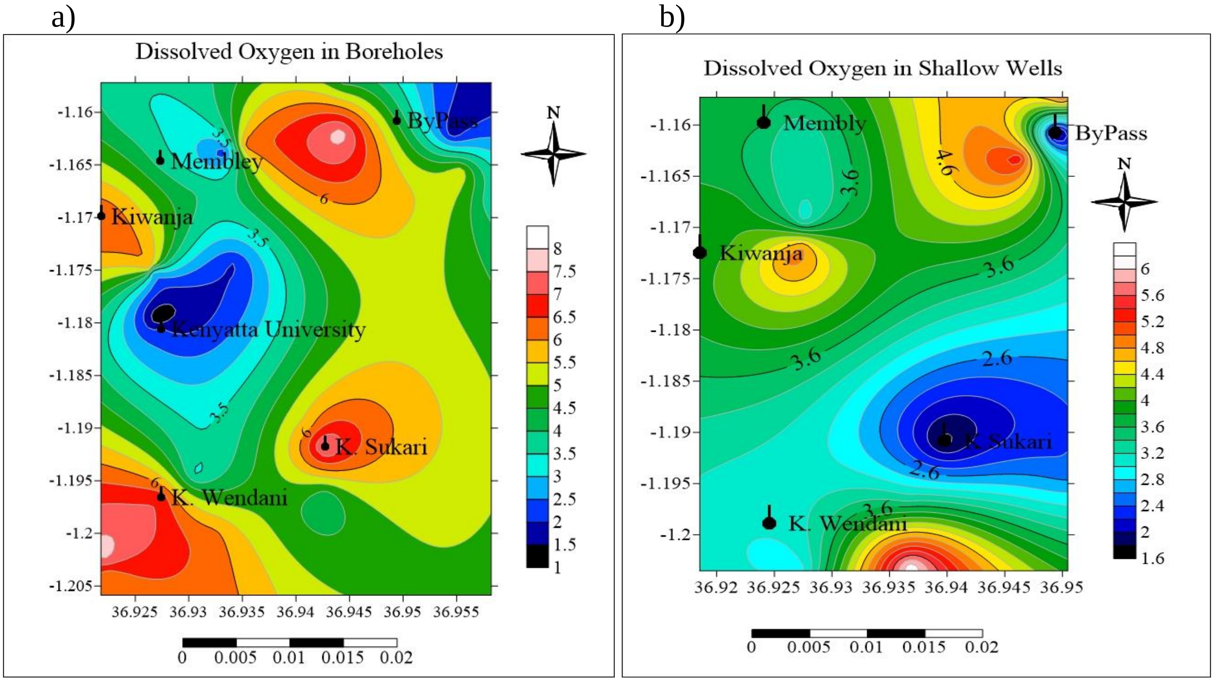


Figure 4-14: Contour map of DO (mg/l) in BHs and SHWs

findings of Schüring *et al.* (2013), who attributed changes in DO concentration in shallow wells in the wet season to increased oxygen solubility resulting from the low temperature or increased water table height in the wet season.

4.2.8 Total alkalinity

The mean total alkalinity concentration in sampled boreholes was 201.90mg/l during the dry season and 202.03mg/l during the wet season. In Shallow wells, the mean concentration of total alkalinity was 146.02mg/l during the dry season and 171.45mg/l during the wet season, as shown in Appendix 1. The highest total alkalinity value in boreholes during the dry season was recorded at BH30 in Kahawa Wendani and the lowest at BH12 in Kenyatta University. For

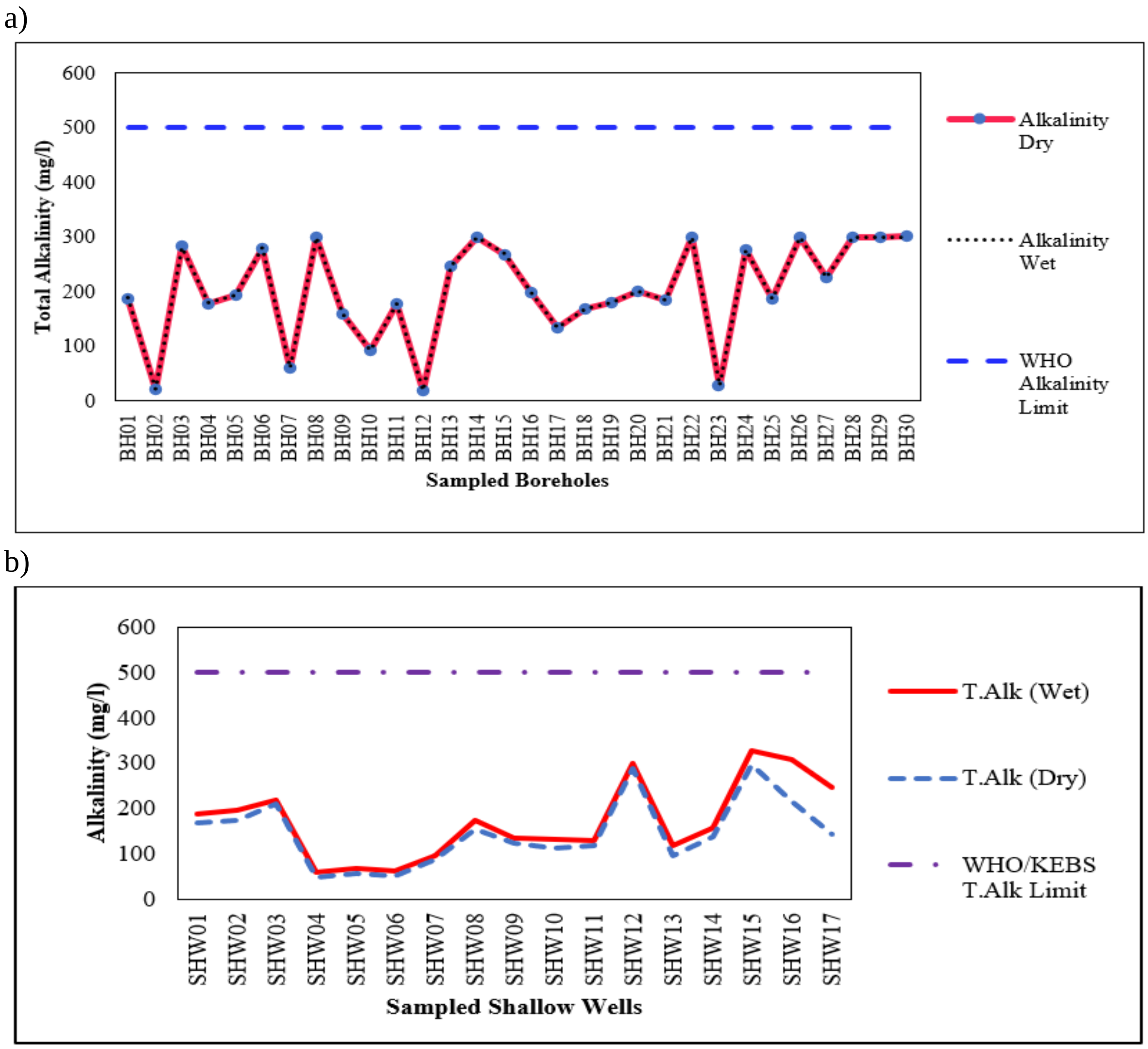


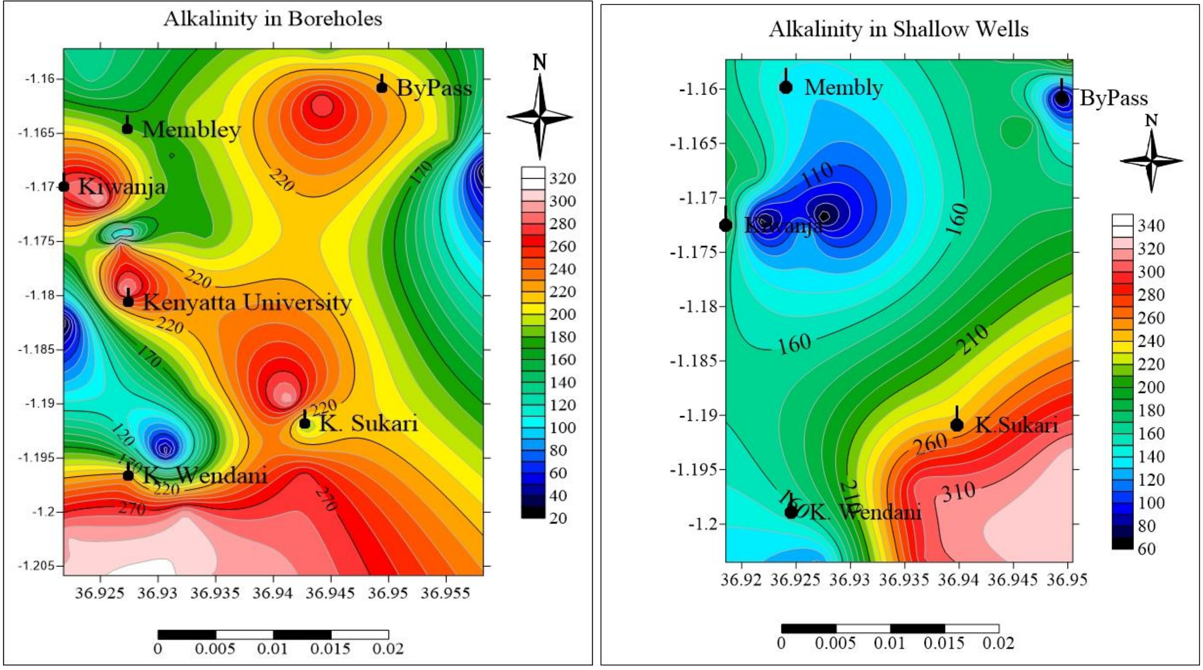
Figure 4-15: Alkalinity (mg/l) in BHs and SHWs against WHO and KEBS standards

shallow wells, the highest total alkalinity value during the dry season was recorded at SHW15 in Kahawa Sukari and the lowest value at SHW04 in Kiwanja.

During the wet season, the highest total alkalinity value in a borehole was recorded at BH08 in Kiwanja and the lowest at BH12 in Kenyatta University. The highest shallow well total alkalinity value was recorded at SHW15 in Kahawa Sukari and the lowest value at SHW04 in Kiwanja, as shown in Figure 4-15 (a) and (b). All the sampled boreholes and shallow wells exhibited alkalinity concentration within the WHO and KEBS acceptable standards of 500mg/L, which is suitable for drinking as it helps stabilize the water's pH.

The contour map for total alkalinity in boreholes indicated high levels ranging between 240mg/l to 300mg/l in the southern areas of Kahawa Wendani, central areas in Kahawa Sukari, the western area in Kenyatta University and Kiwanja, and northeast areas of Bypass as shown in Figure 4-16 (a). In shallow wells, the highest alkalinity levels of between 300mg/L to

327mg/L were recorded in the southeast areas of Kahawa Sukari and Kahawa Wendani and the lowest in Kiwanja, as shown in Figure 4-16 (b).



a)

b)

Figure 4-16: Contour map of alkalinity (mg/l) in BHs and SHWs

Hydroxides, bicarbonates, and carbonates often cause alkalinity in natural waters. The mean concentrations of alkalinity of boreholes were higher compared to the shallow wells in the dry and wet seasons. The alkalinity in shallow wells increased in the wet season, which confirmed the similar findings of Florence *et al.* (2012).

4.2.9 Magnesium

The mean Magnesium concentration of sampled boreholes was 6.40mg/l during the dry season and 6.44mg/l during the wet season. In Shallow wells, the mean Magnesium concentration was 9.39mg/l during the dry season and 6.80mg/l during the wet season, as shown in Appendix I.

a)

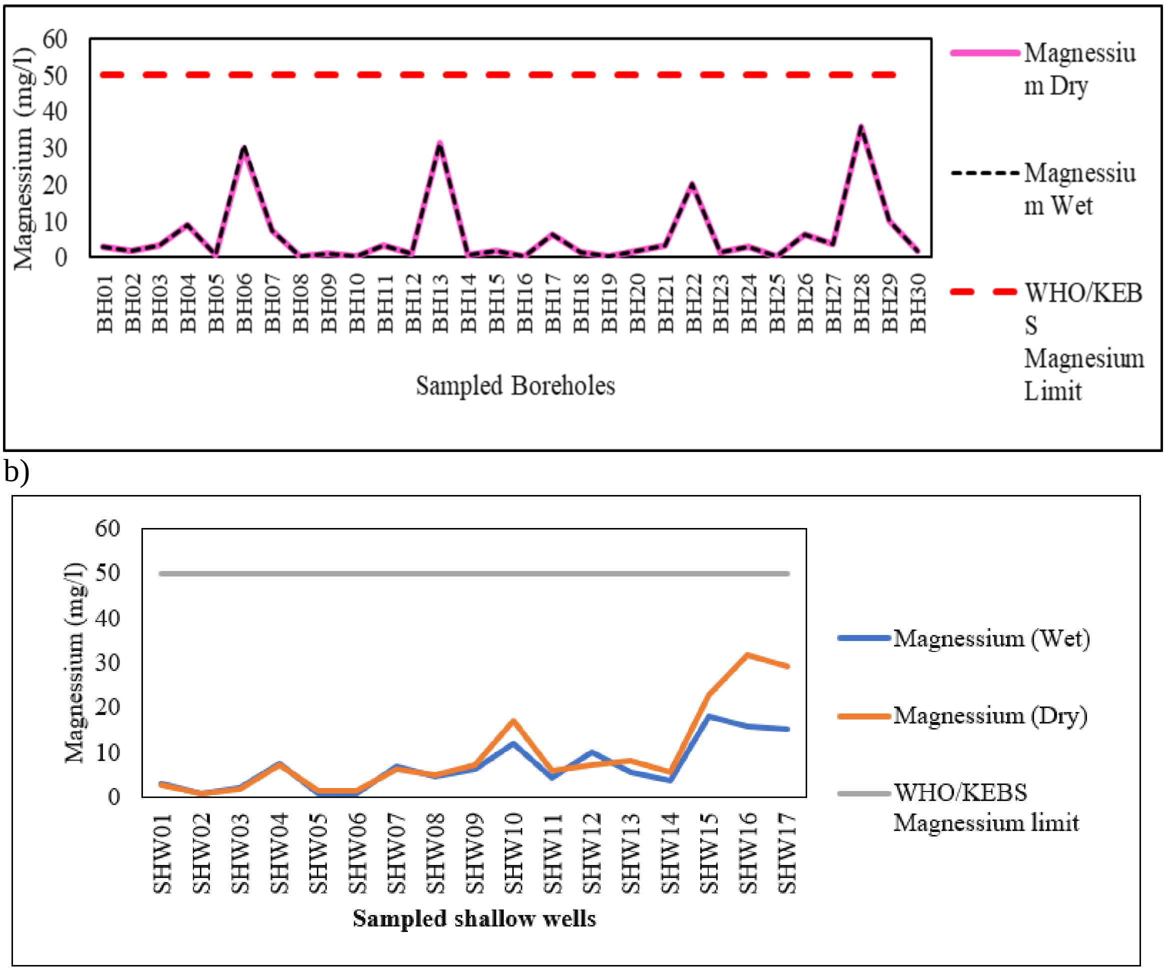


Figure 4-17: Magnesium (mg/l) in BHs and SHWs against WHO and KEBS standards

The highest magnesium concentration in boreholes during the dry season was recorded at BH28 located in Kahawa Wendani, and the lowest value was recorded at BH19 Membley. During the wet season, the highest magnesium concentration in boreholes was recorded at BH 28 in Kahawa Wendani and the lowest at BH19 in Membley, as shown in Figure 4.17(a). In shallow wells, the highest magnesium concentration was recorded at SHW16 in Kahawa Sukari and the lowest at SHW02 in Bypass. During the wet season, the highest magnesium concentration in the shallow well was recorded at SHW15 in Kahawa Sukari and the lowest at SHW06 in Kiwanja, as shown in Figure 4-17 (b) below. All the 47 water samples were found magnesium concentration levels are lower than the WHO and KEBS acceptable limits of 50mg/L. The contour map for magnesium concentration in boreholes indicated low concentration in most parts of the catchment, with values between 0.2mg/L and 22mg/L. However, pockets of high magnesium concentration between 26mg/L and 34mg/L were recorded at Kahawa Wendani and Kenyatta University in the north and east of the sub-catchment, as shown in Figure 4-18a).

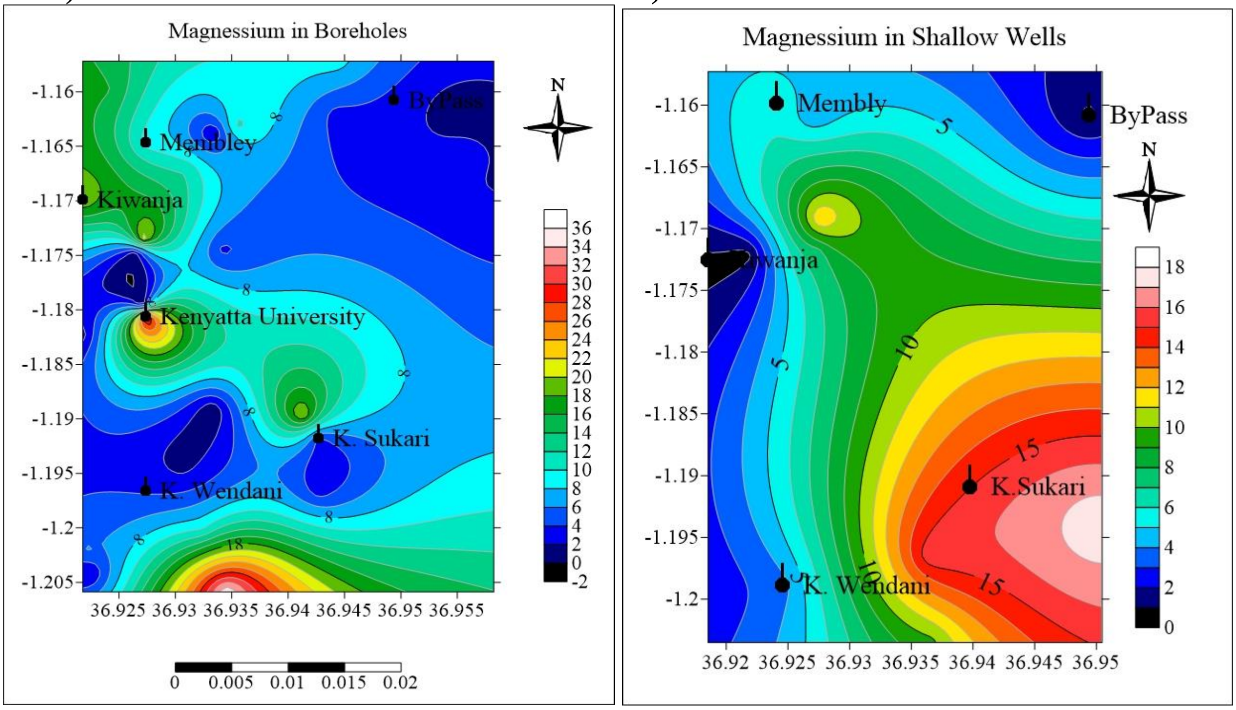

a) b)

Figure 4-18: Contour map magnesium (mg/l) in BHs and SHWs

The contour maps for shallow wells, however, indicated high magnesium concentrations of between 15mg/l to 18mg/l in Kahawa Sukari in the southeast part of the study area and low concentration at Kiwanja and Bypass as shown in Figure 4-18 (a) and (b).

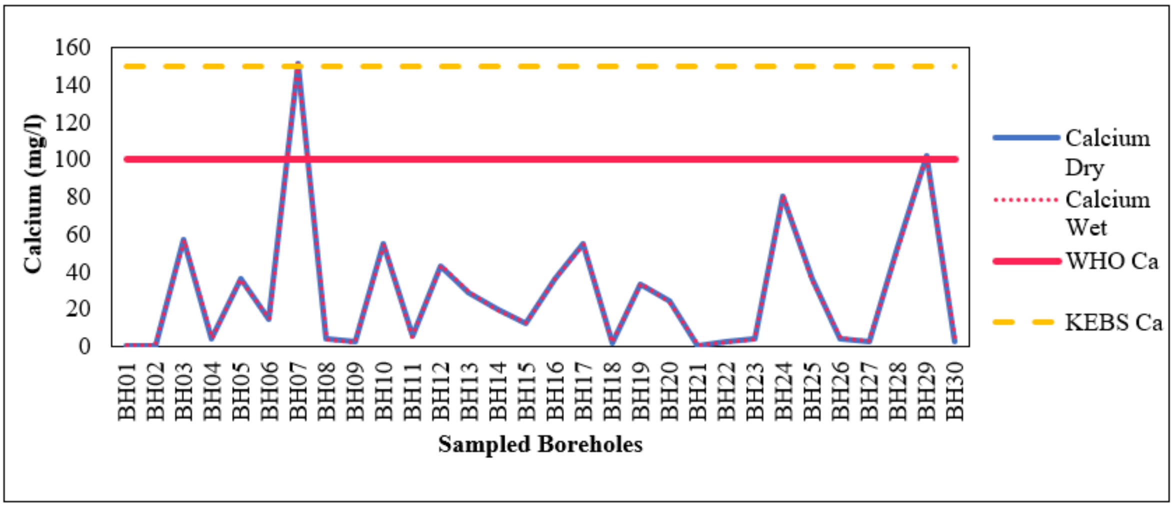
Ashun (2014) highlights magnesium as an alkali earth metal responsible for water hardness. Owing to its role in water hardness, WHO and KEBS drinking water standards have their maximum contaminant level to be 50mg/L. The magnesium concentrations in boreholes and shallow wells of the study area were all below the WHO and KEBS maximum contaminant level for drinking water. The mean magnesium concentrations in shallow wells were higher than in the boreholes during the two seasons indicating that shallow well waters contain more dissolved magnesium ions from the topsoil and pollutants caused by anthropogenic activities. These results are similar to findings of Oparinde *et al.* (2010) and attributed the findings to more dissolved metals from surface soil. The magnesium concentration in shallow wells decreased in the wet season. This decrease in magnesium level could be attributed to the fact that during the wet season, competing cations in the soil and such as Ca^{2+}, H^+, NH_4^{2+}, and Na^+ inhibit dissolution of magnesium by infiltrated rainwater (Kannan and Joseph (2010).

4.2.10 Calcium

The mean Calcium concentration in sampled boreholes during the dry season was 29.08mg/l and 29.08mg/l during the wet season. In shallow wells, the mean calcium concentration during the dry season was 53.07mg/l and 62.74mg/l during the wet season, as shown in Appendix I. The mean calcium concentrations in shallow wells were higher compared to the boreholes during the two seasons. The highest calcium concentration in boreholes during the dry season was recorded at BH07, located in Kiwanja, and the lowest value was recorded at BH01 and BH02 in Bypass, as shown in Figure 4-19(a).

In shallow wells, the highest calcium concentration was recorded at SHW04 in Kiwanja and the lowest at SHW01 in Bypass. During the wet season, the highest calcium concentration was recorded at SHW04 in Kiwanja and the lowest at SHW01 in Bypass. The calcium concentration in all sampled boreholes and shallow wells were below the WHO standards of 100mg/l and KEBS standards of 150mg/l except for BH 07 and SHW04 in Kiwanja, and SHW 12, 13, and 14 in Kahawa Wendani during both dry and wet seasons as depicted by Figure 4-19 (a) and (b).

a)



b)

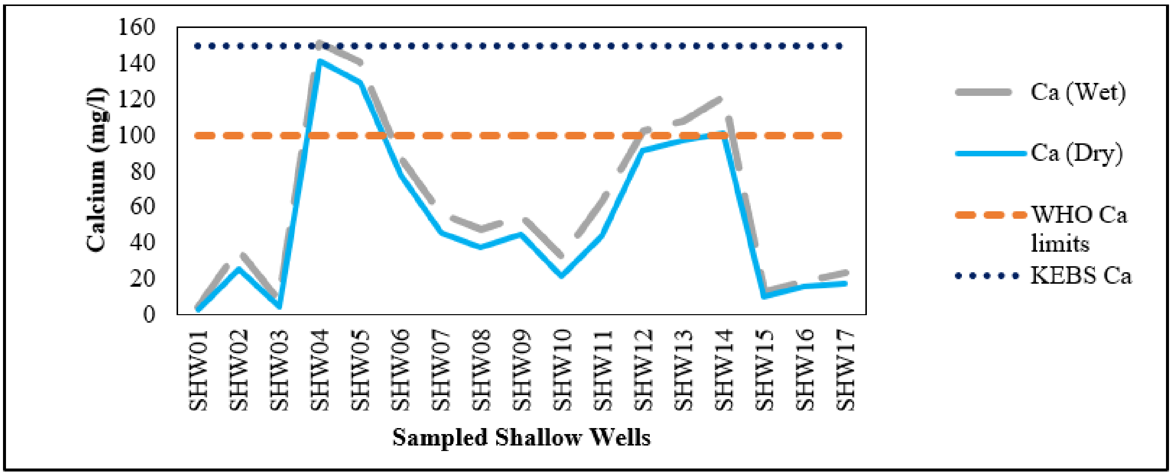


Figure 4-19: Calcium (mg/l) in BHs and SHWs against WHO and KEBS standards

The contour map for calcium concentration in boreholes highlights a pocket of high calcium concentration above 100mg/L in Kiwanja in the northwest part of the study area. Other pockets of high concentrations below 100mg/l are recorded in the central parts of kahawa Wendani and the southern part of the Subcatchment in Kahawa Wendani.

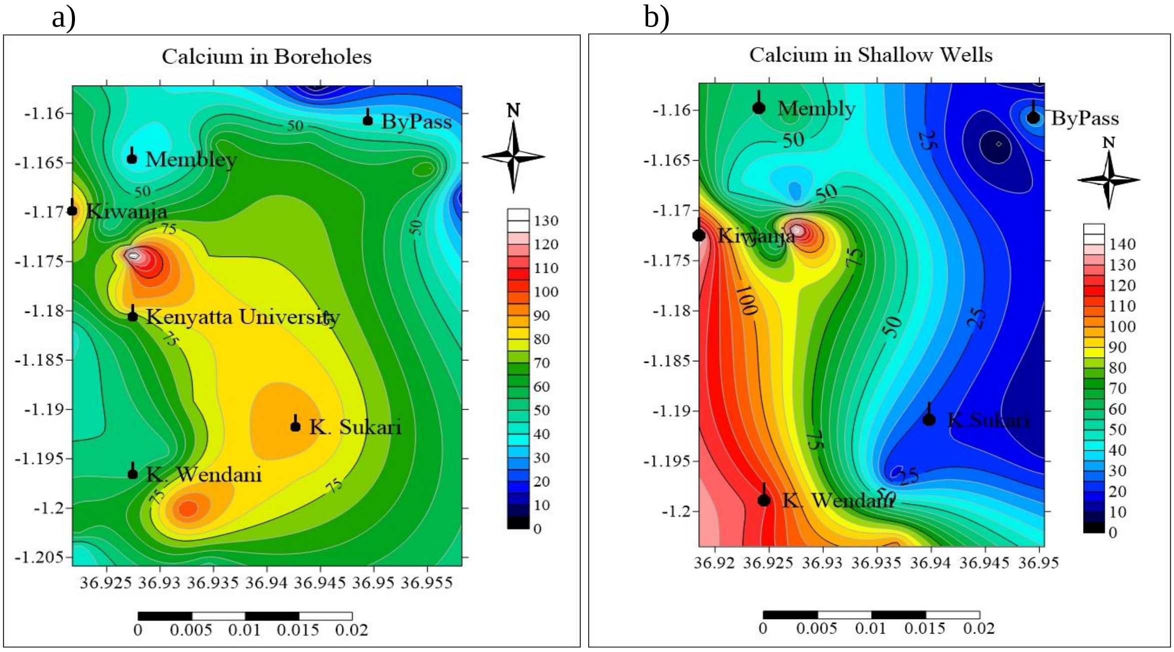


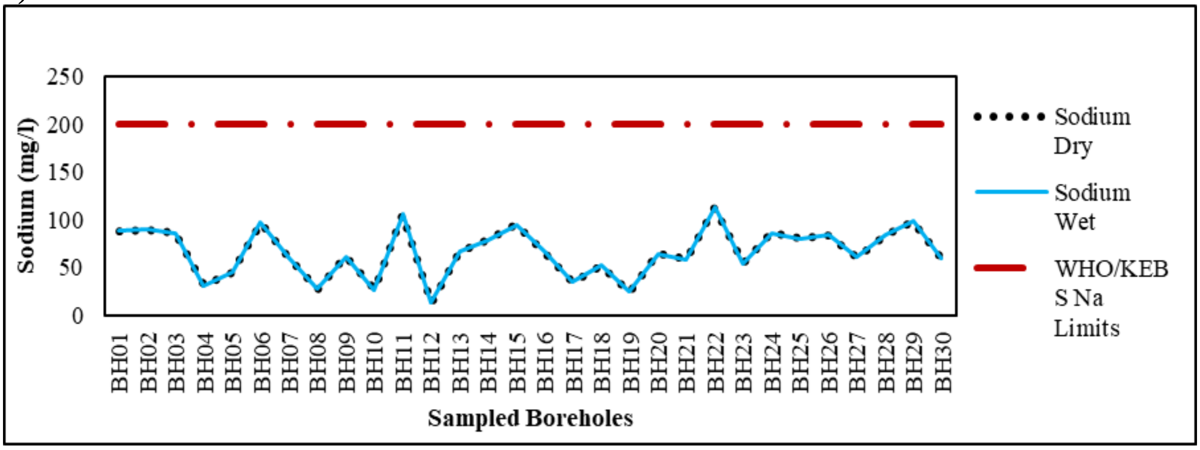
Figure 4-20: Contour map of calcium (mg/l) in BHs and SHWs

Calcium is a significant element of groundwater hardness and significantly stabilizes groundwater pH due to its buffering attributes. Calcium also gives water a better taste. The increase in mean calcium concentrations in shallow wells during the wet period could be associated with storm run-off, which has the potential to increase its concentration. Even though the sources of calcium in aquifer systems are mainly crystalline limestone found in khondalitic rocks (Idoko and Oklo, 2012), the persistent farming activities near some shallow wells in the study could also increase calcium concentration in shallow wells.

4.2.11 Sodium

The mean sodium concentration in sampled boreholes was 66.44mg/l during the dry season and 63.52mg/l during the wet season. In shallow wells, the mean sodium concentration was 59.96 mg/l during the dry season and 85.55mg/l during the wet season (Appendix I). The highest sodium concentration in sampled boreholes during the dry season was recorded at BH22, located in Kahawa Sukari, and the lowest at BH12 KU. During the wet season, the highest sodium concentration was recorded at BH 22 in Kahawa Sukari and the lowest at BH12 in KU, as shown in Figure 4-21 (a). In shallow wells, the highest sodium concentration was recorded at SHW02 in Bypass and the lowest at SHW10 in Membley. During the wet season, the highest sodium concentration in shallow wells was recorded at SHW02 in Bypass and the lowest at SHW09 in Membley, as shown in figure 4.21 (b). The concentration of sodium in all sampled boreholes and shallow wells was below WHO and KEBS permissible limits of 200mg/l except for SHW02 in Bypass during the wet season.

a)



b)

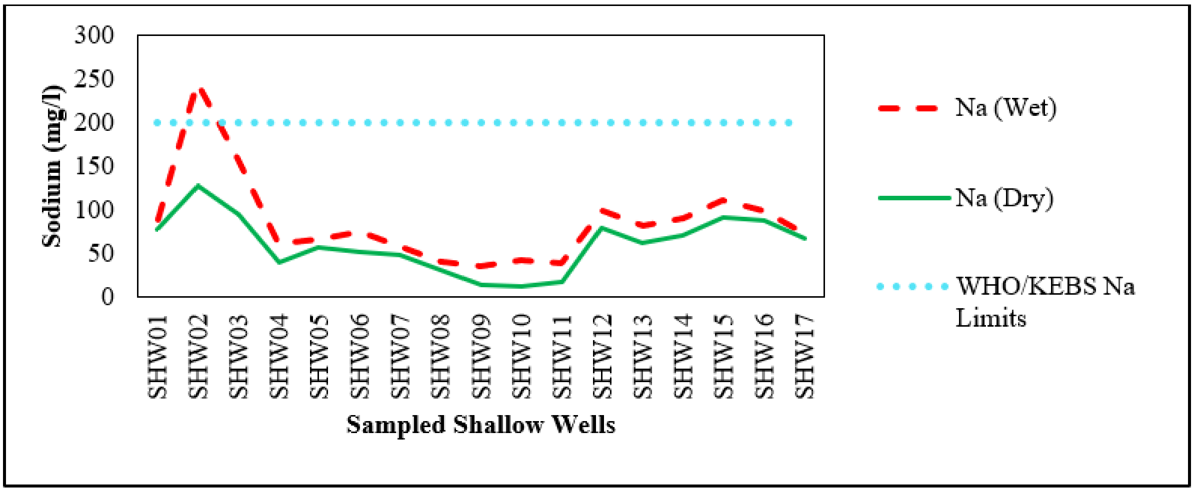


Figure 4-21: Sodium (mg/l) in BHs and SHWs against WHO and KEBS standards

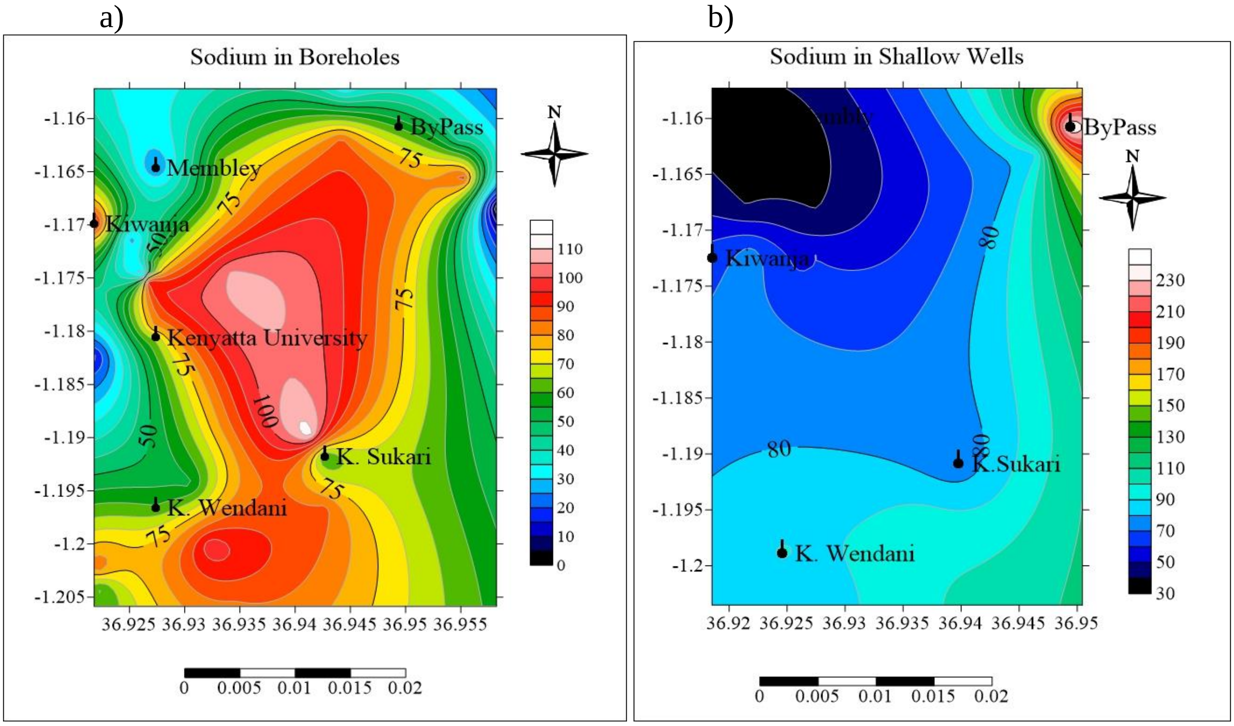


Figure 4-22: Contour map of Sodium (mg/l) in BHs and SHWs

The contour map for sodium in boreholes indicated a high concentration of between 80mg/l to 110mg/l in the southern, central, and northern parts of the Kahawa Wendani, Kenyatta University, and Bypass areas, respectively, as shown in Figure 4-22 (a). The contour map for sodium concentration in shallow wells, as presented in Figure 4.22 (b), showed that sodium concentration was highest in the Bypass area and lowest in the northwest area in Membley. Sodium is a mobile chemical commonly found in rocks and soils and is often used to indicate anthropogenic impacts on groundwater (Sayyed and Bhosle, 2011). Due to its solubility, sodium is always present in groundwater. The high sodium concentration levels in some parts of the sub-catchment could contribute to the salty taste, especially for the borehole water. High concentration levels were recorded in the furthest part of the Bypass area, also indicated that the water is not suitable for irrigation purposes. Sodium is a vital element, but only in concentrations less than 200mg/l. In high values, sodium creates an unpleasant salty taste in drinking water, making it unsuitable for people with hypertension and cognitive heart failure due to salt retention and not suitable for irrigation (Mishra and Dehury, 2017).

4.2.12 Potassium

The mean potassium concentration in sampled boreholes during the dry season was 57.27mg/l and 57.30 mg/l during the wet season. In shallow wells, the mean potassium concentration was 60.33mg/l during the dry season and 86.17mg/l during the wet season (Appendix I). BH08, located in Kiwanja, recorded the highest potassium levels during the dry season and the lowest value at BH02 in Bypass. During the wet season, the highest potassium concentration in boreholes was recorded at BH08 in Kiwanja and the lowest at BH02 in Bypass, as shown in Figure 4-23 (a). In shallow wells, the highest potassium concentration was recorded at SHW04 in Kiwanja and the lowest at SHW11 in Membley.

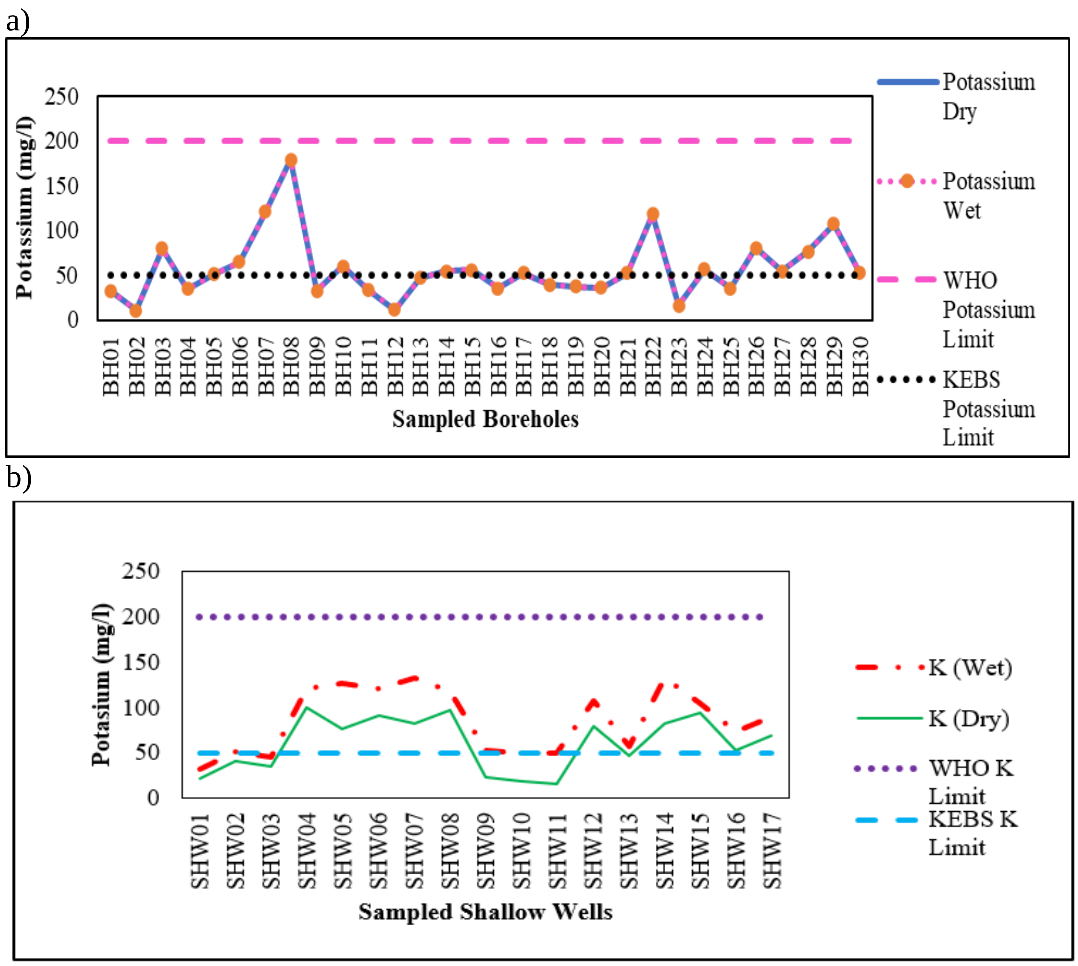


Figure 4-23: Potassium (mg/l) BHs and SHWs against WHO and KEBS standards

During the wet season, the highest potassium concentration in shallow wells was recorded at SHW07 in Kiwanja and the lowest value at SHW01 in Bypass, as shown in Figure 4-23 (b).

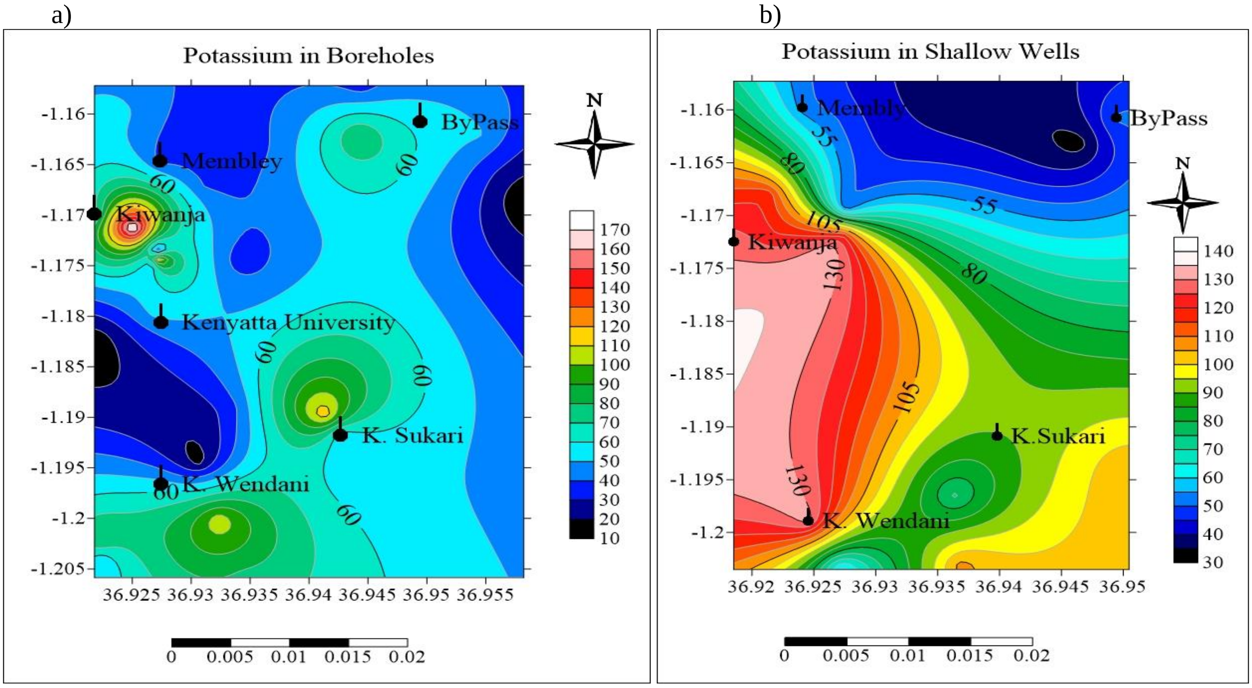


Figure 4-24: Contour map potassium (mg/l) in BHs and SHWs

Of the sampled 30 boreholes, 16 exhibited high potassium concentration above the KEBS permissible limit of 50mg/L during the dry and wet season. 10 out of 17 sampled shallow wells during the dry season and 14 out of the 17 shallow wells during the wet season exhibited high potassium concentrations above the KEBS permissible limit of 50mg/L. The mean potassium concentrations in shallow wells were higher than in the boreholes during the two seasons. Even though higher concentrations were recorded in the shallow wells compared to boreholes, the potassium concentration in all the 30 boreholes and 17 shallow wells was below the WHO potassium limits of 200mg/L. The contour map for potassium exhibited pockets of high potassium concentration values in boreholes ranging between 110mg/l to 120mg/l recorded at Kahawa Wendani in the southwest, Kahawa Sukari in the southeast, and Kiwanja in the northwest of the study area, as shown in Figure 4-24 (a). For shallow wells, high potassium concentration is recorded in the southwestern part of the Subcatchment within Kahawa Sukari and stretches through to the northwest part of the catchment in the Kiwanja area, as presented in Figure 4-24 (b). The increase in potassium in shallow wells during the wet season is consistent with findings by Ashun (2014) that attributed the increase to seepage of agrochemicals and domestic sewage into the wells, considering how close to the wells some of these facilities are located.

4.2.13 Iron

The mean concentration of iron in sampled boreholes was 0.19mg/l during the dry season and 0.20mg/l during the wet season. In shallow wells, the mean concentration of iron was 0.12mg/l during the dry season and 0.18mg/l during the wet season (Appendix I). The highest concentration of iron during the dry season was recorded at BH23, located in Kahawa Sukari, and the lowest concentration was recorded at BH10 in Kiwanja.

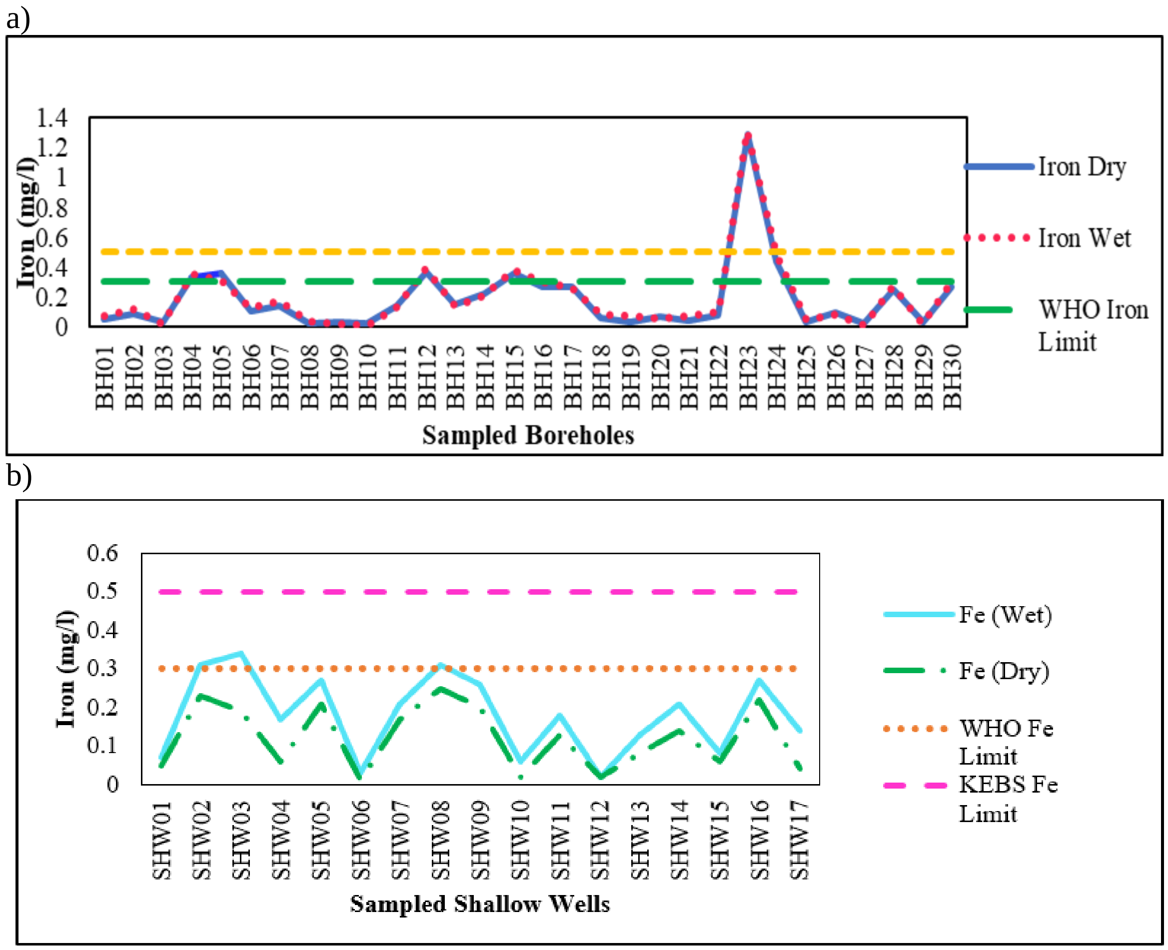


Figure 4-25: Iron (mg/l) of BHs and SHWs against WHO and KEBS standards

During the wet season, BH23 in Kahawa Sukari recorded the highest iron concentration level and the lowest in BH10 and BH27 located in Kiwanja and Kahawa Wendani, respectively, as shown in Figure 4-25 (a). In shallow wells, the highest concentration of iron was recorded at SHW08 in Kiwanja and the lowest at SHW06 in Kiwanja. During the wet season, the highest iron concentration in shallow wells was recorded at SHW03 in Bypass and the lowest value at SHW12 in Kahawa Wendani Figure 4-25 (b). Twenty-four sampled boreholes had iron concentrations within the WHO and KEBS limits of 0.3mg/l and 0.5mg/l, respectively. BH 24 in Kahawa Sukari, BH 12 and BH 15 in Kenyatta University, BH5 and BH4 in Bypass exhibited high iron concentrations above the KEBS standards of 0.3mg/l, and BH23 in Kahawa Sukari exhibited high iron concentration above both WHO and KEBS standards of 0.3mg/l and 0.5mg/l respectively during the dry and wet season.

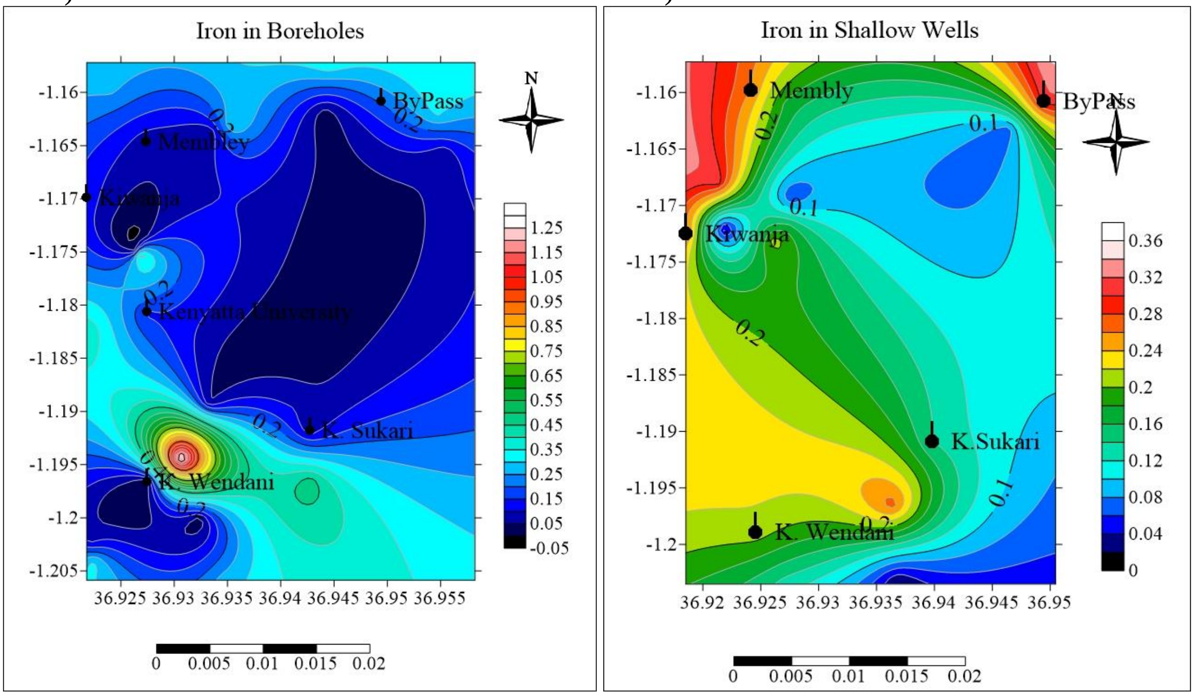

a) b)

Figure 4-26:Contour map of iron (mg/l) in BHs and SHWs

Fourteen sampled shallow wells were below the WHO and KEBS limits of 0.3mg/l and 0.5mg/l, respectively. Three sampled shallow wells, SHW03 and SHW02 in bypass and SHW08 in Kiwanja, exhibited high iron concentrations above the KEBS standards of 0.3mg/l during the wet season. The mean concentrations of iron in boreholes were higher compared to the mean concentration of iron in shallow wells during the two seasons.

The contour maps for Iron (Fe) showed that the more significant parts of Membley, Kiwanja, and Bypass have borehole waters with relatively low iron concentrations. However, concentrations above the permissible limits of 0.35mg/L and 0.4 were recorded in two boreholes, one within Kenyatta University and one within Bypass. The highest iron concentrations between 0.45mg/l and 1mg/l were recorded in western parts of Kahawa Sukari, as shown in Figure 4-26 (a). The contour map for iron concentration in shallow wells indicates pockets of high concentrations in the furthest parts of northwest of the Subcatchment in Membley area and the furthest part of northeast of the sub-catchment in the Bypass area, as shown in Figure 4-26 (b).

Iron concentration is exceptionally high in some parts of the catchment, posing health challenges to residents. According to Chaturvedi and Dave (2012), this can be treated by exposing the water to air and allowing the iron to precipitate, after which ferric hydroxide precipitate can be filtered out and portable water obtained. The other faster, environmentally friendly, and the cost-effective way the iron could also be removed is through treatment with alkaline hydrogen, which does not need external coagulant.

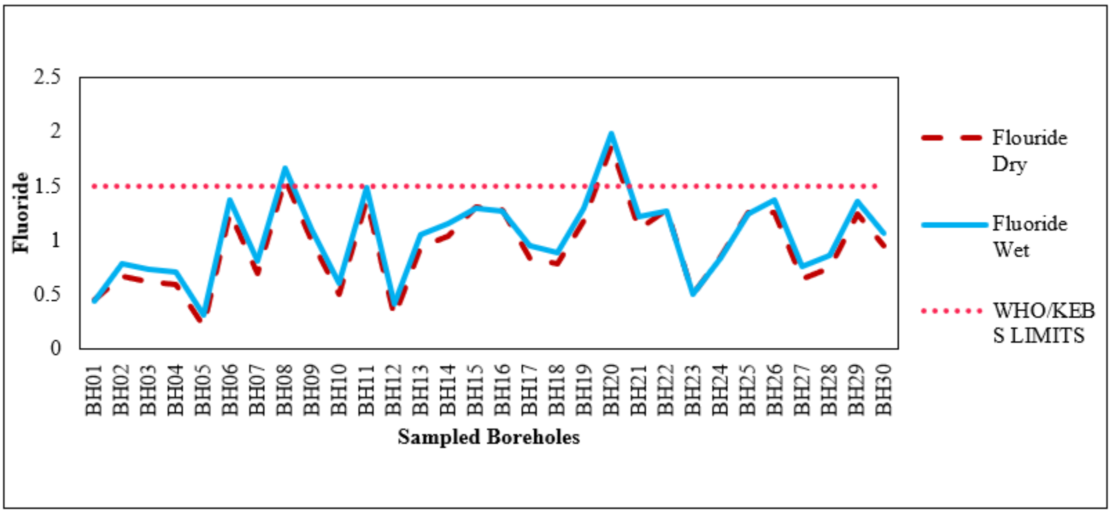
4.2.14 Fluoride

The mean Fluoride concentration in sampled boreholes was 0.95mg/l during the dry season and 1.03mg/l during the wet season. In shallow wells, the mean fluoride concentration was 0.84mg/l during the dry season and 0.91mg/l during the wet season, as shown in Appendix I. The highest fluoride concentration during the dry season was recorded at BH20 located in Membley, and the lowest fluoride concentration was at BH05 in Bypass. During the wet season, the highest fluoride concentration in boreholes was recorded at BH 20 in Membley and the lowest at BH05 in Bypass, as shown in Figure 4-27 (a). In shallow wells, the highest fluoride concentration was recorded at SHW13 in Kahawa Wendani and the lowest at SHW02 in

Bypass. During the wet season, the highest fluoride concentration in shallow wells was recorded at SHW13 in Kahawa Wendani and the lowest value at SHW02 in Bypass, as shown in Figure 4-27 (b). All the Fluoride values of all sampled boreholes and shallow wells were below the WHO and KEBS set standards of 1.5mg/l except for BH20 in Membley and BH08 in Kiwanja during both dry and wet seasons. The mean fluoride concentrations in boreholes were higher than the mean concentration in shallow wells during the two seasons.

The contour map for fluoride concentration in both boreholes and shallow wells showed that the lowest fluoride levels are recorded in Bypass in the northeast part of the catchment. In boreholes, pockets of high fluoride concentrations ranging from 1.3mg/l to 1.9mg/l were

a)



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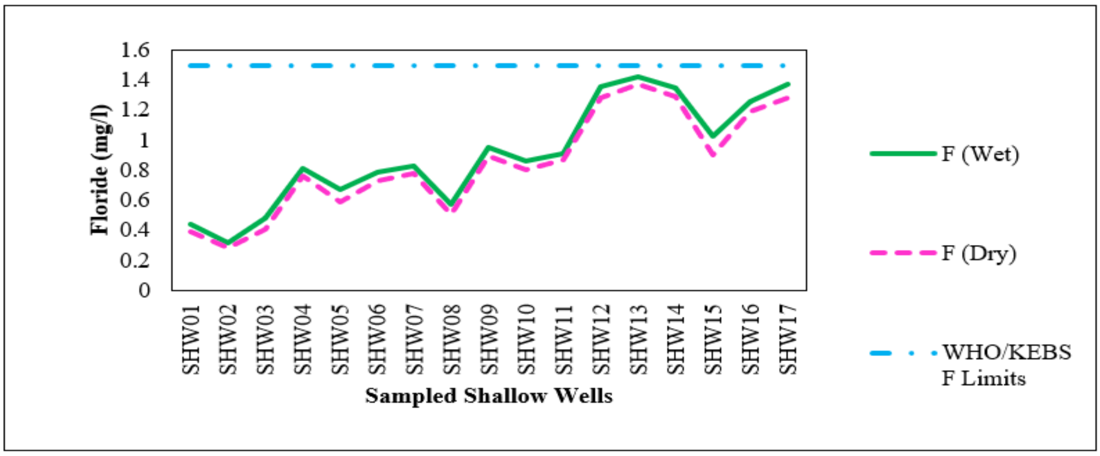
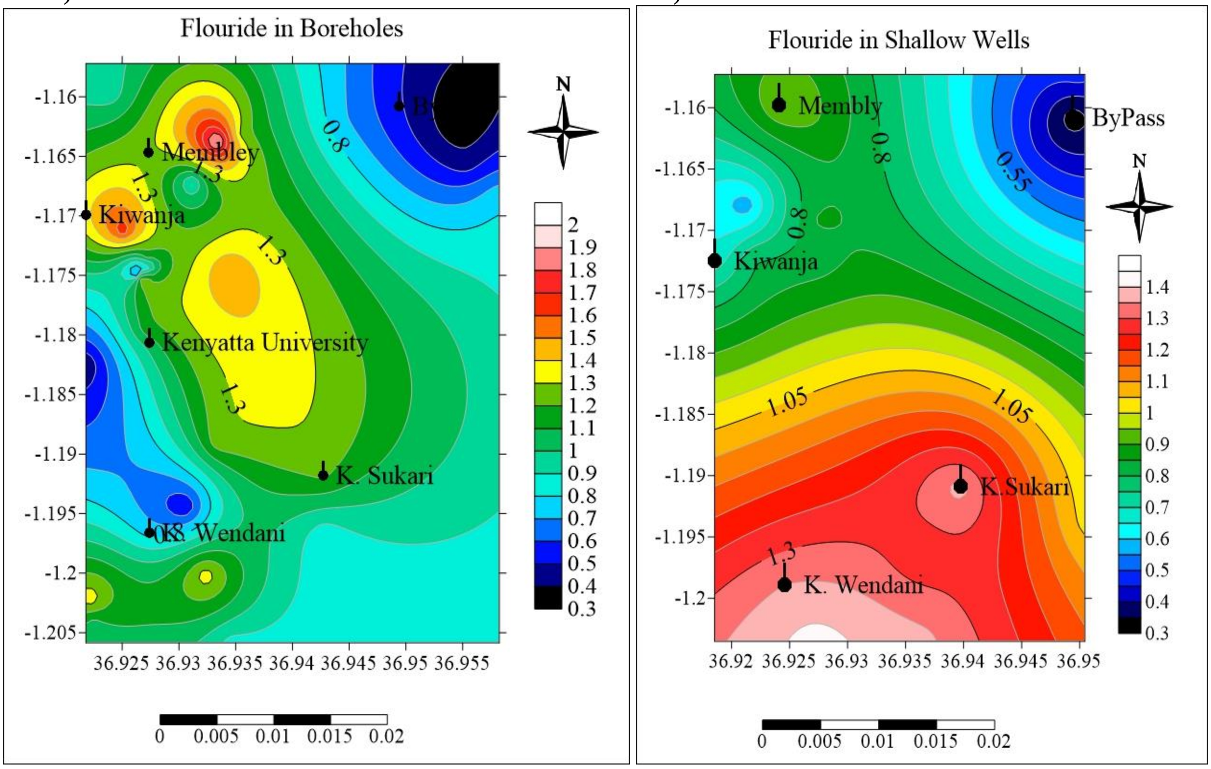


Figure 4-27: Fluoride (mg/l) in BHs and SHWs against WHO and KEBS standards

recorded in Kenyatta University, Kiwanja, and Membley areas, as shown in Figure 4-28. Shallow wells with high fluoride concentrations ranging between 1.1mg/l to 1.4mg/l were in Kahawa Wendani and Kahawa Sukari areas, in the southern part of the sub catchment as highlighted in Figure 4-28 (b).

Fluoride is an essential micronutrient in the lives of both humans and animals, and excess or shortage of the micronutrient can cause severe health and dental problems in humans (Maleki *et al.*, 2014). Fluoride concentration in groundwater varies and is dependent on various factors such as the solubility of the fluorine-bearing rocks and other cations, water pH, and temperature (Mwamati *et al.*, 2017). For that reason, fluoride concentration in groundwater in different areas fluctuate based on the aquifer conditions and water composition.



a)

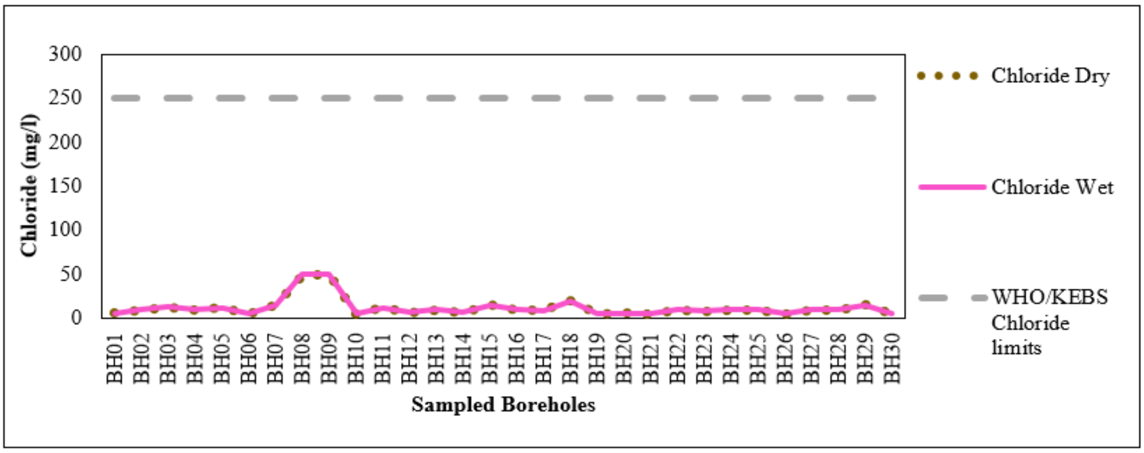
b)

Figure 4-28: Contour map of fluoride (mg/l) in BHs and SHWs

4.2.15 Chloride

The mean chloride concentration in sampled boreholes was 12.15mg/l during the dry season and 12.17mg/l during the wet season. In shallow wells, the mean chloride concentration was 14.53mg/l during the dry season and 27.29mg/l during the wet season (Appendix I). The highest chloride concentration in sampled boreholes during the dry season was recorded at BH08 in Kiwanja, and the lowest chloride concentration was at BH21 in Kahawa Sukari. During the wet season, the highest chloride concentration in boreholes was recorded at BH08 in Kahawa Sukari and the lowest at BH21 in Kiwanja, as shown in Figure 4-29 (a). In shallow wells, SHW17 in Kahawa Sukari recorded the highest level of chloride concentration during the dry period and the lowest in SHW01 in Bypass.

a)



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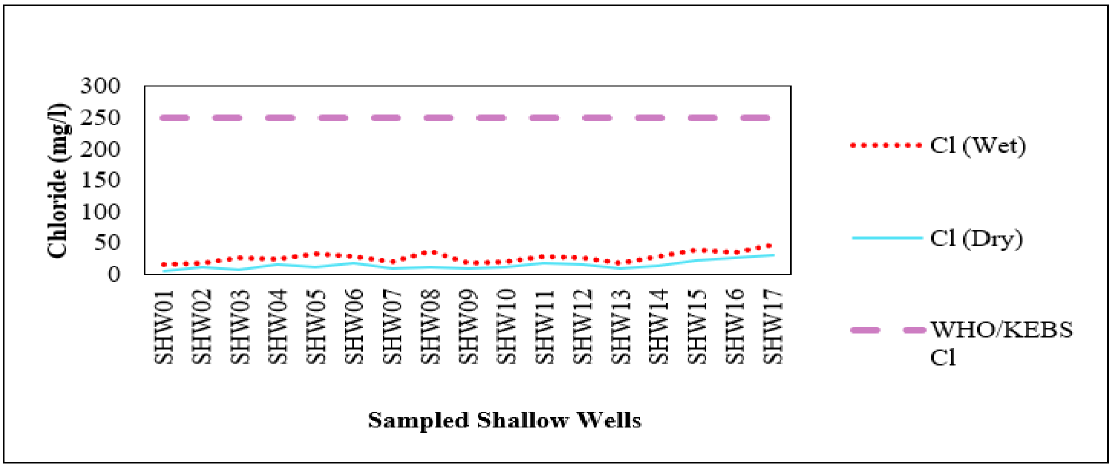


Figure 4-29: Chloride (mg/l) in BHs against WHO and KEBS standards

During the wet season, the highest chloride concentration was recorded at SHW17 in Kahawa Sukari and the lowest at SHW01 in Bypass, as shown in Figure 4-29 (b).The mean chloride concentrations in shallow wells were higher than the mean concentration in boreholes during the two seasons. The chloride concentration in sampled boreholes and shallow wells was below the WHO and KEBS permissible limits of 250mg/l. The contour map for chloride in boreholes, as shown in Figure 4-30 (a), indicated that chloride was predominantly low in the entire catchment except for a small pocket of highest concentrations recorded in Kiwanja in the northwest of the sub-catchment. In shallow wells, high chloride concentration was recorded in Kahawa Sukari in the south-eastern part of the Subcatchment and a small pocket around the Kiwanja area in the northwest part of the sub-catchment, as shown in Figure 4-30 (b).

Chloride ions are present in natural waters in different concentrations. According to Huang *et al.* (2017), there are various ways through which chloride ions get access to natural waters.

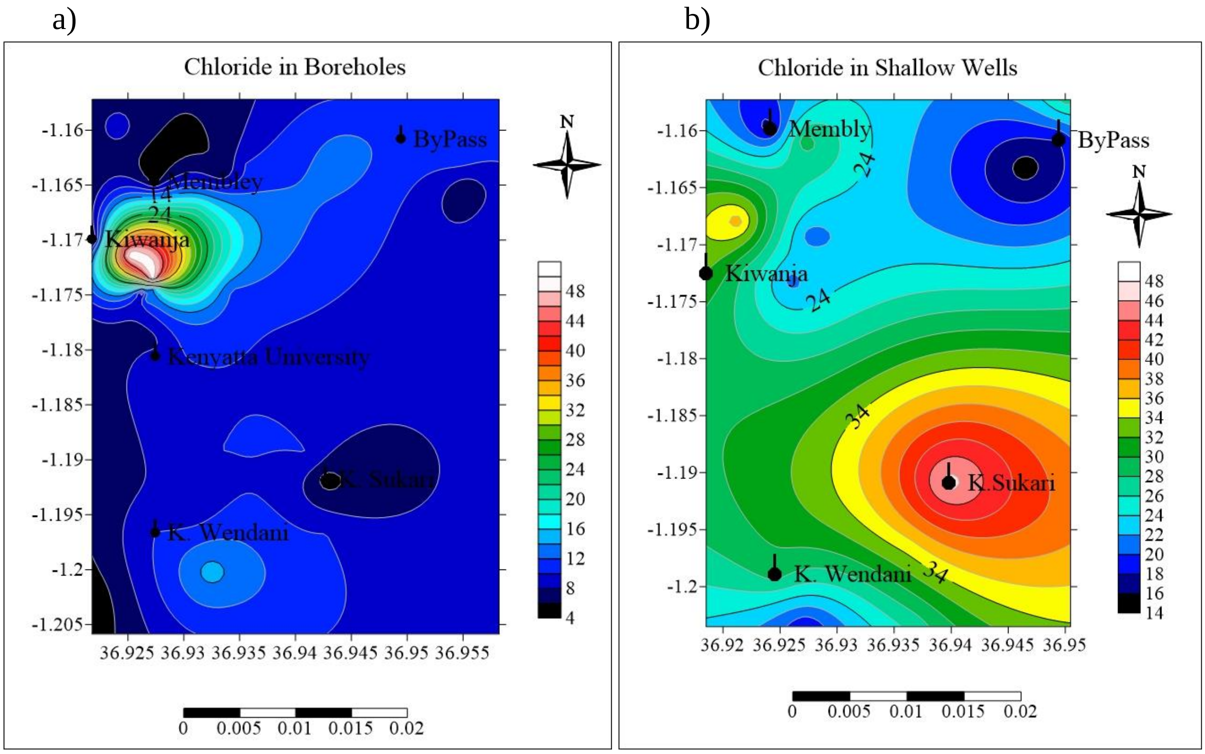


Figure 4-30: Contour map of chloride (mg/l) in BHs and SHWs

Chloride in groundwater can occur naturally or through pollution from domestic or industrial waste, seawater intrusion, and brine. Assessment of chloride concentration in groundwater is vital as it helps detect groundwater contamination by wastewater. High chloride concentration in groundwater points to a high degree of organic pollution.

The natural source of chlorine in water is from dissolved rocks; however, chlorine can also get into natural waters through the infiltration of wastewater into shallow wells, thereby explaining the high concentration of chloride in shallow wells compared to boreholes. Previous studies by Kannan and Joseph (2010) in Kerala, India, and Olonga *et al.* (2015) in Ruiru, Kiambu, Kenya, showed similar trends. Small concentrations of chloride in drinking water do not pose health risks to human life because the human body can endure drinking water with chloride ion concentration of 200mg/l (WHO, 2011). Nonetheless, chloride concentrations above 250mg/l make the water taste salty.

4.2.16 Nitrate

The mean nitrate concentration in sampled boreholes was 0.88mg/l during the dry season and 0.90mg/l during the wet season. In shallow wells, the mean nitrate concentration was 1.59mg/l during the dry season and 3.32mg/l during the wet season. The highest nitrate concentration in boreholes during the dry and wet season was recorded at BH03, located in Bypass, and the lowest value was recorded at BH10 Kiwanja.

During the wet season, the highest nitrate concentration in shallow wells was recorded at SHW08 in Kiwanja and the lowest at SHW05 in Kiwanja, as highlighted in Figure 4-31 (a). In shallow wells, the highest nitrate concentration was recorded at SHW08 in Kiwanja and the lowest value at SHW09 in Membley. During the wet season, the highest nitrate concentration in shallow wells was recorded at SHW08 in Kiwanja and the lowest at SHW05 in Kiwanja, as highlighted in Figure 4-31 (b). The mean concentrations of nitrates in shallow wells were higher compared to the mean concentration of nitrates in boreholes during the two seasons. A comparison with the WHO and KEBS standards indicated that nitrate concentration in all sampled boreholes and shallow wells was below the WHO and KEBS standards of 10mg/l and 50mg/l, respectively.

The contour map for nitrate concentration in boreholes and shallow wells is shown in Figure 4-32 (a) and (b) above. Pockets of the highest nitrate concentration ranging between 1.5mg/l and 1.9mg/l are recorded in Bypass, in the north part of the catchment. In shallow wells, the highest nitrate concentration ranging between 4.6mg/l – 5.8mg/l is recorded in the furthest part of Membley northwest of the Subcatchment.

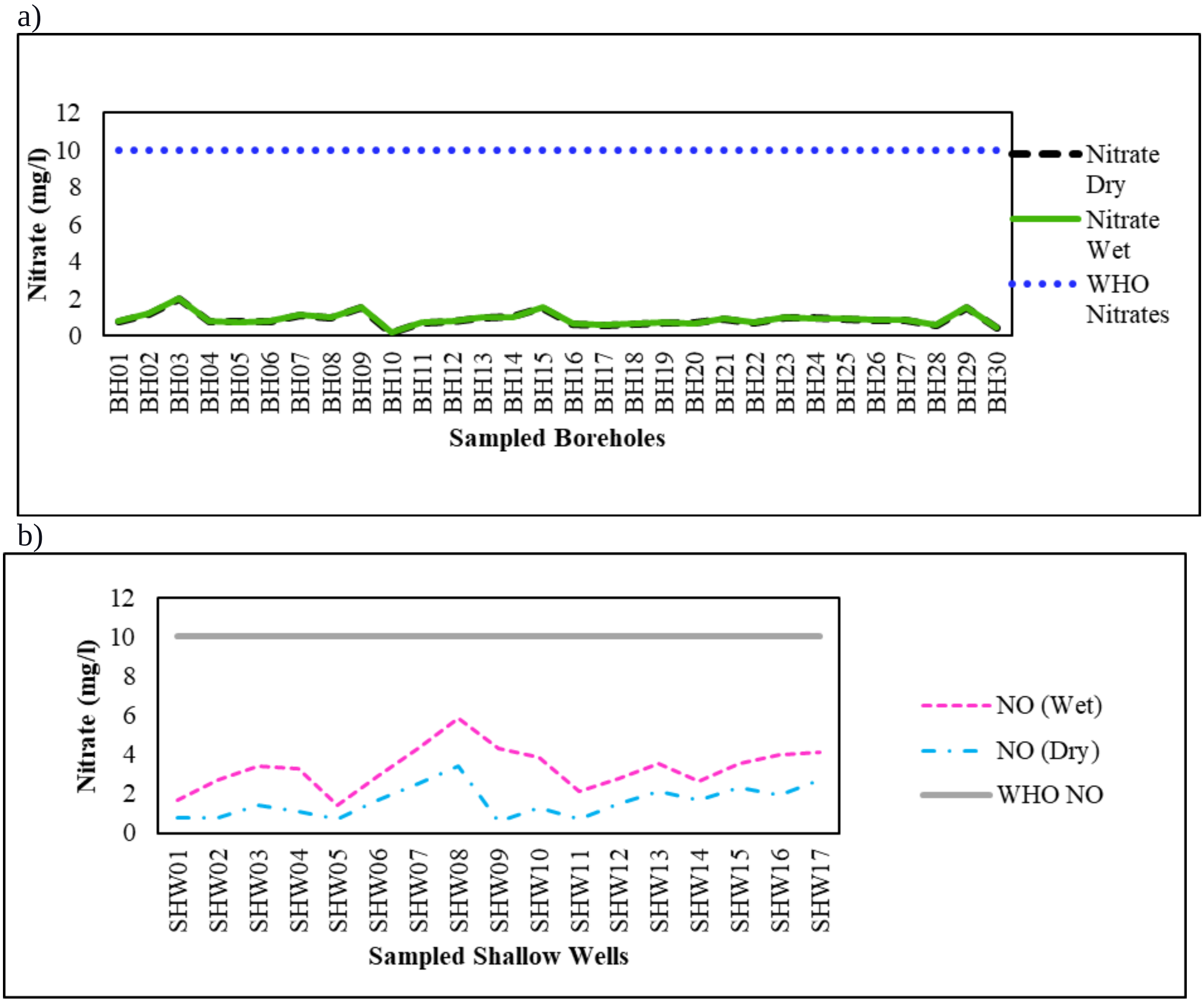


Figure 4-31: Nitrate (mg/l) in BHs and SHWs against WHO and KEBS Standards

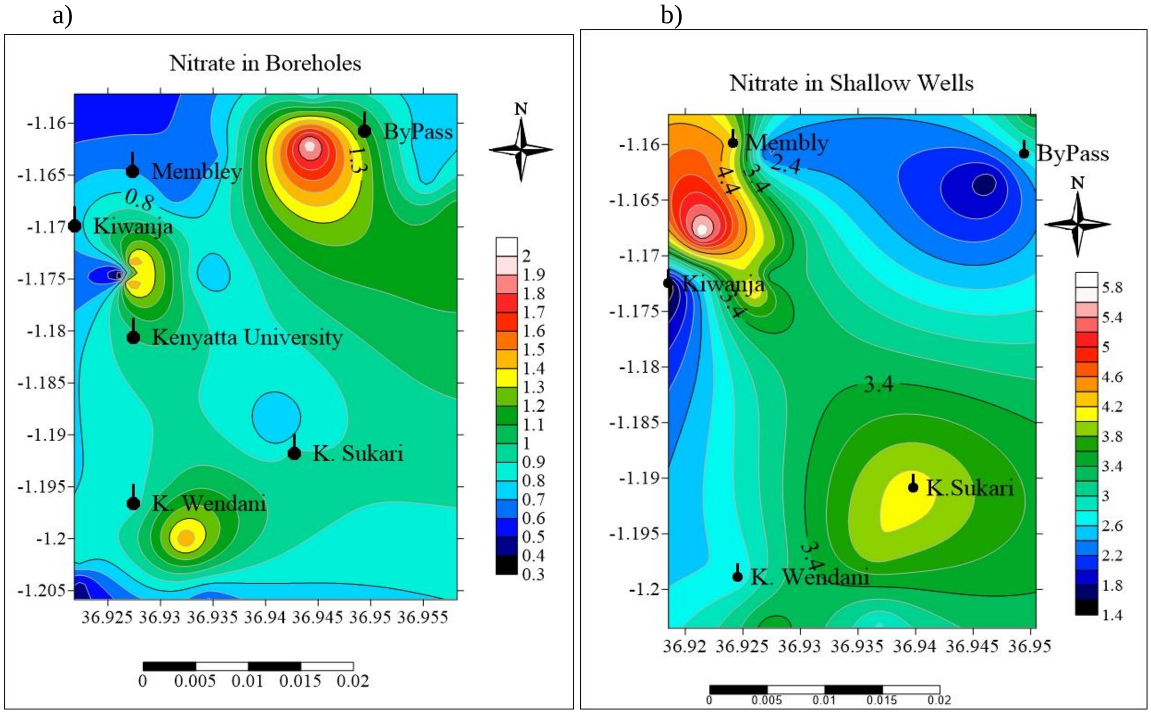


Figure 4-32: Contour map of nitrate (mg/l) in BHs and SHWs

Nitrate is a very mobile compound in both groundwater and soil. According to Sunitha (2013), nitrate does not adsorb aquifer’s geologic material or soil, but it precipitates as a mineral under dry conditions. The nitrate concentration in the study area is generally low, which is an indication that there are no major anthropogenic activities such as infiltration of domestic effluent, use of fertilizers in farms, and effluent from industries that would cause nitrate pollution in greater part of the catchment (Lacasa *et al.*, 2011). This also confirms reports by Sunitha (2013) that natural levels of nitrate in groundwater are typically very low, falling below 10mg/L.

4.2.17 Sulphate

The mean Sulphate concentration in sampled boreholes was 51.13mg/l during the dry season and 51.14mg/l during the wet season. In shallow wells, the mean Sulphate was 37.73mg/l during the dry season and 49.65mg/l during the wet season (Appendix I). The highest sulphate concentration in the borehole during the dry season was recorded at BH22 in Kahawa Sukari, and the lowest sulphate concentration at BH24 in Kahawa Sukari, as shown in Figure 4-33 (a).

In shallow wells, the highest Sulphate value was recorded at SHW13 in Kahawa Wendani and the lowest value in SHW12 in Kahawa Wendani. During the wet season, the highest borehole sulphate was recorded at BH 22 in Kahawa Sukari and the lowest at BH24 in Kahawa Sukari. The highest shallow well sulphate value was recorded at SHW13 in Kahawa Wendani and the lowest at SHW17 in Kahawa Sukari, as shown in Figure 4-33 (b). During the wet season, the highest borehole sulphate was recorded at BH 22 in Kahawa Sukari and lowest at BH24 located in Kahawa Sukari. The highest shallow well sulphate value was recorded at SHW13 in Kahawa Wendani and the lowest value at SHW17 in Kahawa Sukari. The mean concentrations of sulphates in boreholes were higher compared to the mean concentration of sulphate in shallow wells during the two seasons.

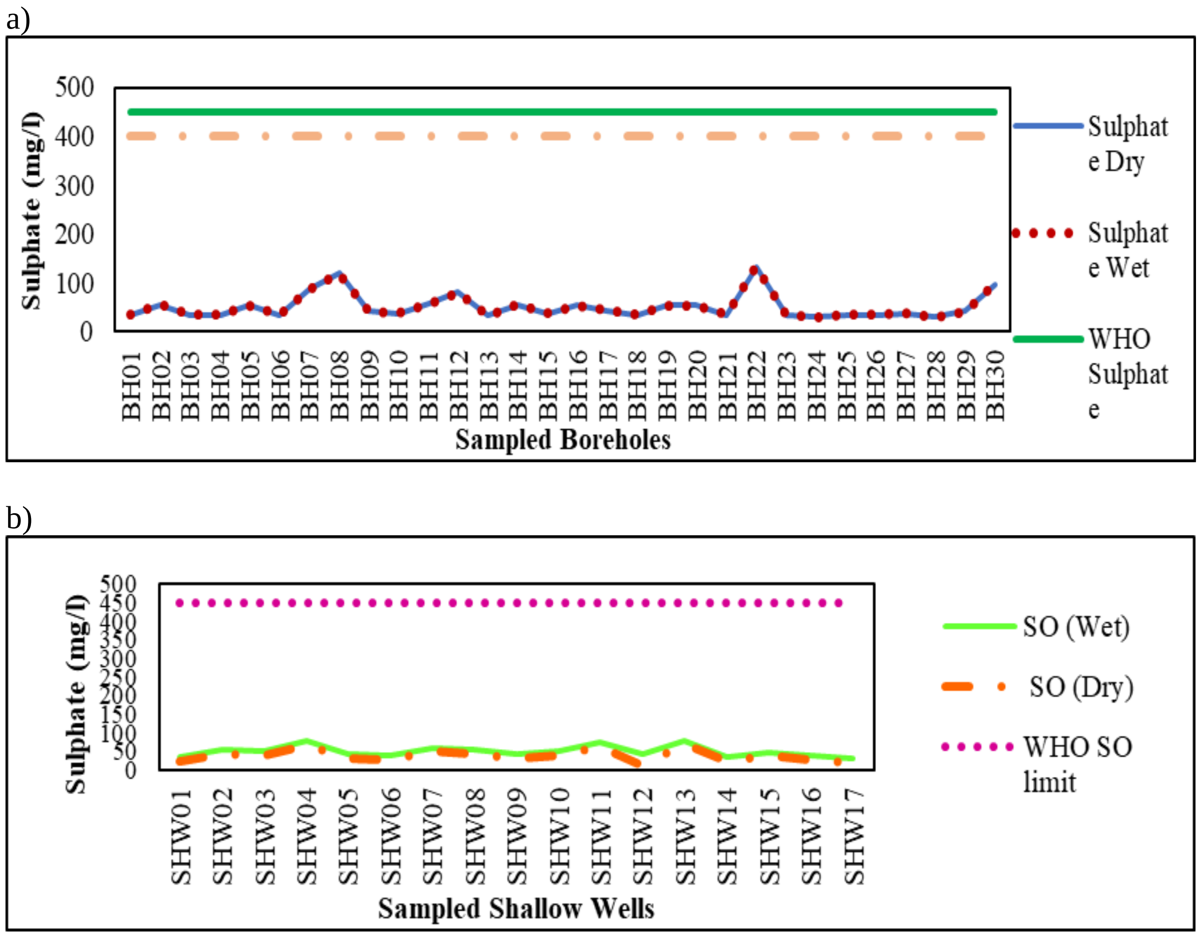
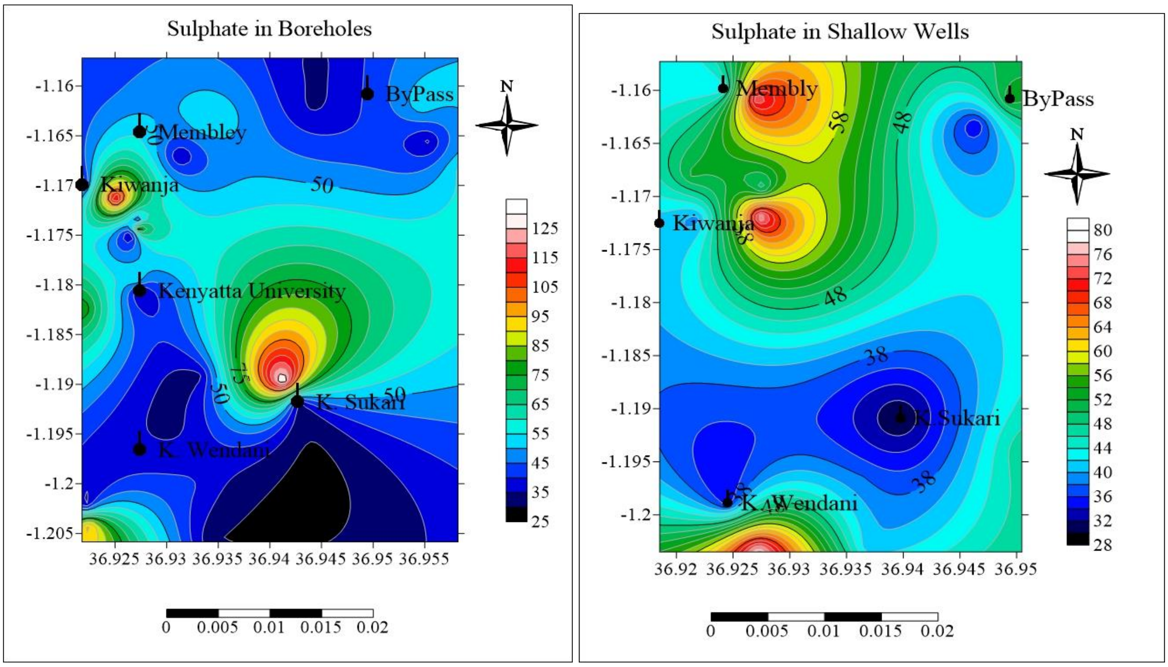


Figure 4-33: Sulphate (mg/l) in BHs and SHWs against WHO and KEBS standards

Despite the difference in sulphate concentration in boreholes and shallow wells all sampled boreholes and shallow wells exhibited sulphate concentration below the WHO and KEBS standards of 450mg/l and 400mg/l respectively. The contour map for sulphate concentration showed predominantly low concentrations across the study area in both boreholes and shallow wells, as shown in Figure 4-34 (a) and (b). However, the highest sulphate concentrations in boreholes ranging between 95 to 125mg/l are recorded in small pockets within Kiwanja in the northwest, Kahawa Sukari in the central part of the sub-catchment and southwest areas of Kahawa Wendani. In shallow wells, pockets of high concentration of sulphate are recorded Kiwanja and Membley areas in northwest and north, respectively, and in Kahawa Wendani in southwest parts of the Subcatchment.



a) b)

Figure 4-34: Contour map of sulphate (mg/l) in BHs (a) and SHWs (b)

Sulphates naturally occur in various minerals but are commonly found in anhydrite ($CaSO4$) and gypsum ($CaSO_4.2H_2O$). High sulphate concentration above the permissible limits can cause laxative effects as well as deficits in trace minerals, suppressing fertility and herds' growth rate (WHO, 2017). Sulphate concentration in groundwater commonly occurs as soluble sodium, calcium, and magnesium salts. It significantly changes during rainfall infiltration or groundwater recharge from surface runoff and pools of water (Belkhiri and Mouni, 2012). During rainwater infiltration or recharge, the water picks up and dissolves sulphates.

4.2.18 Variations in physicochemical parameters in BHs across the six zones

One-way analysis of variance (ANOVA) ($P > 0.05$) indicated no statistically significant variation in concentration levels in 14 tested parameters: Temperature, pH, EC, TDS, Total Alkalinity, Mg^{2+}, Ca^{2+}, Na^{+}, K^{+}, Fe^{2+}, F^{-} Cl^{-}, NO_3^{2-} and SO_4^{2-} in boreholes in different zones of the study area during both wet and dry season as shown in summary Table 4.2 of Appendix VI. However, there was a statistically significant difference in concentration levels of Turbidity, Dissolved Oxygen, and Total Hardness in boreholes in different zones of the study area during both wet and dry seasons at $p < 0.05$, as shown in summary Table 4.3 of Appendix VII.

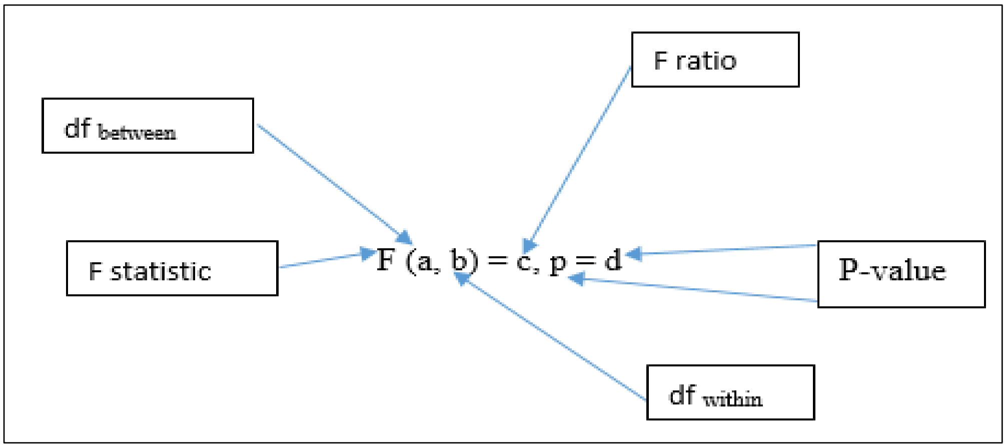
Table 4-2: Variations in physicochemical parameters in BHs across the six zones

Parameter	**Unit**	**Df**	Dry Season		Wet Season	
			F	**p-value**	**F**	**p-value**
Temp	**(^{0}C)**	29	1.97	0.12	1.79	0.15
pH	(mg/l)	29	1.15	0.36	1.4	0.26
EC	(µS/cm)	29	1.49	0.23	1.48	0.23
Turbidity	(NTU)	29	3.5	0.02	3.53	0.02
TDS	(mg/l)	29	0.38	0.86	0.38	0.86
DO	(mg/l)	29	5.15	0.00	5.11	0.00
TH	(mg/l)	29	3.13	0.03	3.13	0.03
TA	(mg/l)	29	1.18	0.35	1.17	0.35
Mg^{2+}	(mg/l)	29	0.56	0.73	0.56	0.73
Ca^{2+}	(mg/l)	29	0.32	0.9	0.32	0.9
Na^{+}	(mg/l)	29	1.09	0.39	1.22	0.33
K^{+}	(mg/l)	29	2.11	0.1	2.11	0.1
Fe^{2+}	(mg/l)	29	1	0.44	1.08	0.4
F^{-}	(mg/l)	29	2.01	0.11	2.04	0.11
Cl^{-}	(mg/l)	29	1.95	0.12	1.95	0.12
NO_3^{2-}	(mg/l)	29	0.84	0.53	0.87	0.52
SO_4^{2-}	(mg/l)	29	0.33	0.89	0.33	0.89

The null hypothesis that concentration of physical and chemical water quality parameters in boreholes across the six zones of the study area are not significantly different was accepted at 95% CL for Temperature, pH, EC, TDS, Total Alkalinity, Mg^{2+}, Ca^{2+}, Na^{+}, K^{+}, Fe^{2+}, F^{-} Cl^{-}, NO_3^{2-} and SO_4^{2} and rejected at 95% CL for turbidity, DO and total hardness.

Table 4-3: ANOVA results for Turbidity, DO and TH

	Dry Season	Wet Season
Turbidity	F(5, 24) = 3.50134, p =0.016	F(5, 24) = 3.53, p = 0.02
Dissolved Oxygen	F(5,24) = 5.14563, P = 0.002	F(5, 24) = 3.53, p = 0.02
Total Hardness	F(5,24) = 3.13349, p = 0.026	F(5,24) = 3.13, p = 0.03



Where df = degrees of freedom.

Post hoc turkey test was run to find precisely which specific regions (compared with each other) the means concentration of turbidity, DO, and total hardness was different. The simultaneous pairwise comparisons by mean separation procedure with Turkey's test at a 95% confidence interval, as shown in Appendix VIII and Appendix IX, revealed that the statistical difference in concentration was placed between:

Kiwanja and Kenyatta University at p = 0.13 and Kenyatta University and Kahawa Wendani at p = 0.001 for Dissolved Oxygen; Bypass and Membley at p = 0.018 and Bypass and Kahawa Wendani at p=0.041 for Total at Hardness; and Kiwanja and Membley at p = 0.011 and between Membley and Kahawa Sukari at p = 0.024 for Turbidity.

The turkey results confirm that despite the water being from the same aquifer, the concentration of these three parameters were not uniform across the aquifer. This could be attributed to different levels of groundwater exposure, pollution from soil and sewage intrusion, and renewed suspension of silt and sediments through breaks within the aquifer. The variation in concentration of these parameters across the mentioned regions is significant in this study because it can help ascertain the source of pollution to the groundwater.

4.2.19 Correlation of the tested parameters

The correlational matrix for borehole samples during the dry and wet seasons, as highlighted in Table 4-4 and Table 4-5, showed that a moderate positive correlation existed in EC with TDS (0.57), total alkalinity (0.59), and sodium (0.6); total alkalinity with potassium (0.51) in the two seasons and with sodium (0.64) during the wet season. These results resonate well with the reports of Kumar et al. (2022), in which sodium and potassium were the most influential parameters and major acid neutralizers.

Total hardness exhibited a moderate positive correlation with Ca (0.54) during the dry season and with calcium (0.54) and fluoride (0.64) during the wet season. This confirms that calcium ions are the major contributing elements to groundwater hardness in the study area. It also corroborates the fact that calcium compounds coupled with various other metals cause hardness in water (Yousefi *et al.*, 2015).

A correlational matrix study of the shallow well parameters highlighted in Table 4-6 and Table 4-7 shows a positive and negative correlation between some parameters. During the dry season, the temperature had a moderate positive correlated sodium (0.64), meaning that an increase in temperature positively contributed to the dissolution of sodium compounds within the aquifer. This confirms reports by Thomas (2021) that an increase in temperature in groundwater gives the water molecules more kinetic energy, thereby increasing the force and frequency of collision with the solutes, which in turn increases their dissolution. A strong positive correlation was recorded between TDS and potassium (0.82), Magnesium and chloride (0.80), and hardness with fluoride (0.81).

Moderate positive correlation was exhibited between: EC with potassium (0.67), fluoride (0.66), chloride (0.64) and nitrate (0.57); TDS with total hardness (0.67), fluoride (0.50) and nitrate (0.68); total hardness with magnesium (0.56) and chloride (0.56); total alkalinity with sodium (0.56), magnesium with fluoride (0.55); and nitrate with potassium (0.57). During the dry season, pH exhibited a moderate negative correlation with hardness (-0.63) and fluoride (-0.56). This indicated that pH values could be a function of genuine relationships with other parameters such as carbon dioxide concentration in water, carbonate and bicarbonate concentrations, temperature, and other environmental factors (Devic *et al.*, 2014). During the wet season, moderate positive correlations were exhibited in hardness and calcium (0.54) and fluoride (0.53): total alkalinity with sodium (0.64) and potassium (0.51); and EC with TDS (0.57), total alkalinity (0.59) and sodium (0.61).

Table 4-4: Correlation for physicochemical parameters of BHs in Dry season

	Temp (^{0}C)	pH	EC (µS/cm)	Turbidity (NTU)	TDS (mg/l)	DO (mg/l)	TH (mg/l)	TA (mg/l)	Mg (mg/l)	Ca (mg/l)	Na (mg/l)	K (mg/l)	Fe (mg/l)	F (mg/l)	Cl (mg/l)	NO (mg/l)	SO (mg/l)
Temp (^{0}C)	1																
pH	0.07	1															
EC (µS/cm)	0.35	0.00	1														
Turbidity (NTU)	-0.45	-0.09	-0.06	1													
TDS (mg/l)	0.28	0.21	0.57	-0.09	1												
DO (mg/l)	-0.16	-0.03	0.09	-0.19	0.06	1											
TH (mg/l)	-0.11	0.03	0.22	0.16	0.10	0.16	1										
TA (mg/l)	0.32	0.16	0.59	-0.30	0.30	0.27	0.25	1									
Mg (mg/l)	0.04	-0.05	0.31	-0.11	0.23	0.14	0.11	0.36	1								
Ca (mg/l)	-0.19	-0.08	0.14	0.28	0.13	0.02	0.54	-0.10	0.10	1							
Na (mg/l)	0.31	-0.20	0.41	-0.09	0.06	0.10	0.16	0.46	0.34	-0.03	1						
K (mg/l)	0.34	0.07	0.49	-0.28	0.38	0.41	0.29	0.51	0.23	0.32	0.11	1					
Fe (mg/l)	-0.15	-0.15	0.25	0.22	0.07	-0.31	-0.39	-0.31	-0.07	-0.03	-0.13	-0.31	1				
F (mg/l)	0.18	0.05	0.26	0.04	0.14	0.02	0.52	0.48	0.06	-0.15	0.34	0.32	-0.33	1			
Cl (mg/l)	-0.02	-0.08	-0.05	-0.27	-0.12	0.07	-0.16	0.08	-0.15	-0.09	-0.14	0.41	-0.18	0.19	1		
NO (mg/l)	-0.02	-0.19	0.18	-0.11	0.07	0.09	0.03	0.15	-0.11	0.17	0.35	0.16	-0.05	0.06	0.39	1	
SO (mg/l)	0.44	0.02	0.20	0.02	0.41	0.03	-0.07	0.06	-0.07	-0.01	-0.10	0.52	-0.11	0.22	0.27	-0.15	1

Table 4-5: Correlation for physicochemical parameters of BHs in wet season

	Temp (^{0}C)	pH	EC (µS/cm)	Turbidity (NTU)	TDS (mg/l)	DO (mg/l)	TH (mg/l)	TA (mg/l)	Mg (mg/l)	Ca (mg/l)	Na (mg/l)	K (mg/l)	Fe (mg/l)	F (mg/l)	Cl (mg/l)	NO (mg/l)	SO (mg/l)
Temp (^{0}C)	1																
pH	0.01	1															
EC (µS/cm)	0.36	-0.05	1														

	Temp (^{0}C)	pH	EC (µS/cm)	Turbidity (NTU)	TDS (mg/l)	DO (mg/l)	TH (mg/l)	TA (mg/l)	Mg (mg/l)	Ca (mg/l)	Na (mg/l)	K (mg/l)	Fe (mg/l)	F (mg/l)	Cl (mg/l)	NO (mg/l)	SO (mg/l)
Turbidity (NTU)	**-0.5**	-0.04	-0.1	1													
TDS (mg/l)	0.28	0.16	**0.57**	-0.09	1												
DO (mg/l)	-0.2	0.01	0.1	-0.19	0.07	1											
TH (mg/l)	-0.1	0.05	0.22	0.16	0.1	0.16	1										
TA (mg/l)	0.32	0.11	**0.59**	-0.3	0.3	0.27	0.25	1									
Mg (mg/l)	0.07	-0.06	0.3	-0.11	0.23	0.15	0.11	0.36	1								
Ca (mg/l)	-0.2	-0.02	0.14	0.28	0.13	0.02	**0.54**	-0.11	0.09	1							
Na (mg/l)	0.34	-0.13	**0.61**	-0.22	0.16	0.14	0.32	**0.64**	0.37	0.05	1						
K (mg/l)	0.32	0.02	0.49	-0.28	0.37	0.4	0.29	**0.51**	0.23	0.32	0.2	1					
Fe (mg/l)	-0.2	-0.14	0.25	0.24	0.08	-0.28	-0.4	-0.32	-0.1	-0	-0.1	-0.31	1				
F (mg/l)	0.14	0.01	0.23	0.03	0.13	0.03	**0.53**	0.48	0.08	-0.1	0.3	0.34	-0.37	1			
Cl (mg/l)	-0.1	-0.11	-0.1	-0.27	-0.1	0.06	-0.2	0.08	-0.2	-0.1	-0.1	0.41	-0.18	0.21	1		
NO (mg/l)	-0.1	-0.17	0.18	-0.1	0.07	0.1	0.02	0.14	-0.1	0.16	0.2	0.17	-0.05	0.05	0.39	1	
SO (mg/l)	0.44	-0.04	0.2	0.03	0.41	0.02	-0.1	0.06	-0.1	-0	-0.1	0.52	-0.09	0.22	0.27	-0.1	1

Table 4-6: Correlation for physicochemical parameters of SHWs in dry season

	Temp (^{0}C)	pH	EC (µS/cm)	Turbidity (NTU)	TDS (mg/l)	DO (mg/l)	TH (mg/l)	TA (mg/l)	Mg (mg/l)	Ca (mg/l)	Na (mg/l)	K (mg/l)	Fe (mg/l)	F (mg/l)	Cl (mg/l)	NO (mg/l)	SO (mg/l)
Temp (^{0}C)	1.00																
pH	**0.56**	1.00															
EC (µS/cm)	-0.09	-0.24	1.00														

Turbidity (NTU)	-0.25	-0.16	0.01	1.00													
TDS (mg/l)	-0.01	-0.15	0.89	0.04	1.00												
DO (mg/l)	0.15	0.14	-0.18	-0.36	-0.08	1.00											
TH (mg/l)	-0.42	-0.63	0.73	0.29	0.67	-0.19	1.00										
TA (mg/l)	0.36	0.16	0.23	-0.33	0.24	0.00	-0.01	1.00									
Mg (mg/l)	-0.26	-0.45	0.52	0.08	0.28	-0.48	0.56	0.37	1.00								
Ca (mg/l)	-0.13	-0.02	0.26	0.20	0.34	0.10	0.41	-0.51	-0.37	1.00							
Na (mg/l)	0.64	0.59	0.36	-0.30	0.33	-0.16	-0.25	0.56	0.06	-0.23	1.00						
K (mg/l)	-0.07	-0.14	0.67	0.09	0.82	-0.01	0.47	-0.03	0.04	0.48	0.11	1.00					
Fe (mg/l)	0.43	0.22	-0.26	0.27	-0.07	-0.22	-0.12	-0.01	-0.18	-0.12	0.13	-0.08	1.00				
F (mg/l)	-0.28	-0.59	0.66	0.15	0.50	-0.12	0.81	0.13	0.55	0.27	-0.11	0.17	-0.35	1.00			
Cl (mg/l)	-0.30	-0.23	0.64	0.38	0.47	-0.42	0.56	0.27	0.80	-0.16	0.16	0.29	-0.19	0.48	1.00		
NO (mg/l)	-0.20	-0.45	0.57	-0.08	0.68	-0.14	0.44	0.17	0.41	-0.17	0.01	0.57	0.00	0.31	0.36	1.00	
SO (mg/l)	-0.18	-0.04	-0.24	0.18	-0.08	-0.31	-0.02	-0.44	-0.22	0.22	-0.29	-0.09	0.14	-0.13	-0.25	-0.03	1.00

Table 4-7: Correlation for physicochemical parameters of SHWs in wet season

	Temp (^0C)	pH	EC (μS/cm)	Turbidity (NTU)	TDS (mg/l)	DO (mg/l)	TH (mg/l)	TA (mg/l)	Mg (mg/l)	Ca (mg/l)	Na (mg/l)	K (mg/l)	Fe (mg/l)	F (mg/l)	Cl (mg/l)	NO (mg/l)	SO (mg/l)
Temp (^0C)	1																
pH	0.01	1															
EC (μS/cm)	0.36	-0.05	1														
Turbidity (NTU)	-0.45	-0.04	-0.1	1													

TDS (mg/l)	0.28	0.16	**0.57**	-0.09	1												
DO (mg/l)	-0.17	0.01	0.1	-0.19	0.07	1											
TH (mg/l)	-0.11	0.05	0.22	0.16	0.1	0.2	1										
TA (mg/l)	0.32	0.11	**0.59**	-0.3	0.3	0.3	0.25	1									
Mg (mg/l)	0.07	-0.06	0.3	-0.11	0.23	0.2	0.11	0.36	1								
Ca (mg/l)	-0.22	-0.02	0.14	0.28	0.13	0	**0.54**	-0.1	0.09	1							
Na (mg/l)	0.34	-0.13	**0.61**	-0.22	0.16	0.1	0.32	**0.64**	0.37	0.1	1						
K (mg/l)	0.32	0.02	0.49	-0.28	0.37	0.4	0.29	**0.51**	0.23	0.3	0.24	1					
Fe (mg/l)	-0.15	-0.14	0.25	0.24	0.08	-0	-0.39	-0.3	-0.06	-0	-0.1	-0.3	1				
F (mg/l)	0.14	0.01	0.23	0.03	0.13	0	**0.53**	0.48	0.08	-0.1	0.34	0.34	-0.37	1			
Cl (mg/l)	-0.05	-0.11	-0.1	-0.27	-0.11	0.1	-0.16	0.08	-0.15	-0.1	-0.1	0.41	-0.18	0.21	1		
NO (mg/l)	-0.09	-0.17	0.18	-0.1	0.07	0.1	0.02	0.14	-0.09	0.2	0.24	0.17	-0.05	0.05	0.39	1	
SO (mg/l)	0.44	-0.04	0.2	0.03	0.41	0	-0.07	0.06	-0.07	-0	-0.1	0.52	-0.09	0.22	0.27	-0.1	1

4.3 Seasonal variations in the physicochemical parameters

4.3.1 Seasonal box and whisker plots for boreholes

The nearly symmetrical seasonal concentration box and whiskers of water quality parameters assessed in boreholes indicated minor seasonal influence on their concentration (Spitzer, *et al.*, 2014) indicating minor seasonal influence on their concentration. Box plots of concentration of Total hardness, Temperature, pH, TDS, Mg^{2+}, Ca^{2+}, K^{+}, Fe^{2+}, F^{-}, $Cl^{-,}$ NO_3^{2} and SO_4^{2-} exhibited long whiskers at the top of the box showing a skewed distribution toward high concentration, whereas long low whiskers of Alkalinity and DO indicated a skewed distribution towards low concentration in boreholes in both dry and wet seasons as shown in Appendix IV and Appendix V.

The large spread (wide interquartile range) exhibited by the Turbidity, Hardness, F^{-}, EC, and DO seasonal box plots indicated high variations in the concentration of the datasets. The significantly low interquartile range (IQR) exhibited by the Temperature, Alkalinity, pH, TDS, K^{+}, Na^{+}, Ca^{2+}, Fe^{2+}, Cl^{-}, SO_4^{2-}, NO_3^{2} and Mg^{2+} box plots in both dry and wet season showed less variation in the dataset. The median concentration for Temperature, pH, Hardness, Mg^{2+}, Ca^{2+}, Na^{+}, Fe^{2+}, NO_3^{2} turbidity and SO_4^{2-} datasets were closer to the lower whisker, except for TDS, K^{+}, and $Cl^{-,}$ where the median values were toward the upper whisker likely due to the higher concentration values in TDS, K^{+}, and Cl^{-}.

4.3.2 Seasonal box and whisker plots for shallow wells

The box and whisker plots for the tested parameters in shallow wells show substantial variations between the two seasons and relatively individual patterns. Figure 4-35 and 4-36 below portrays significant changes in the central tendency of pH, EC, Turbidity, Hardness, K^{+}, Fe^{2+}, $Cl^{-,}$ NO_3^{2} and SO_4^{2-} indicating a substantial influence of the seasons on their concentration.

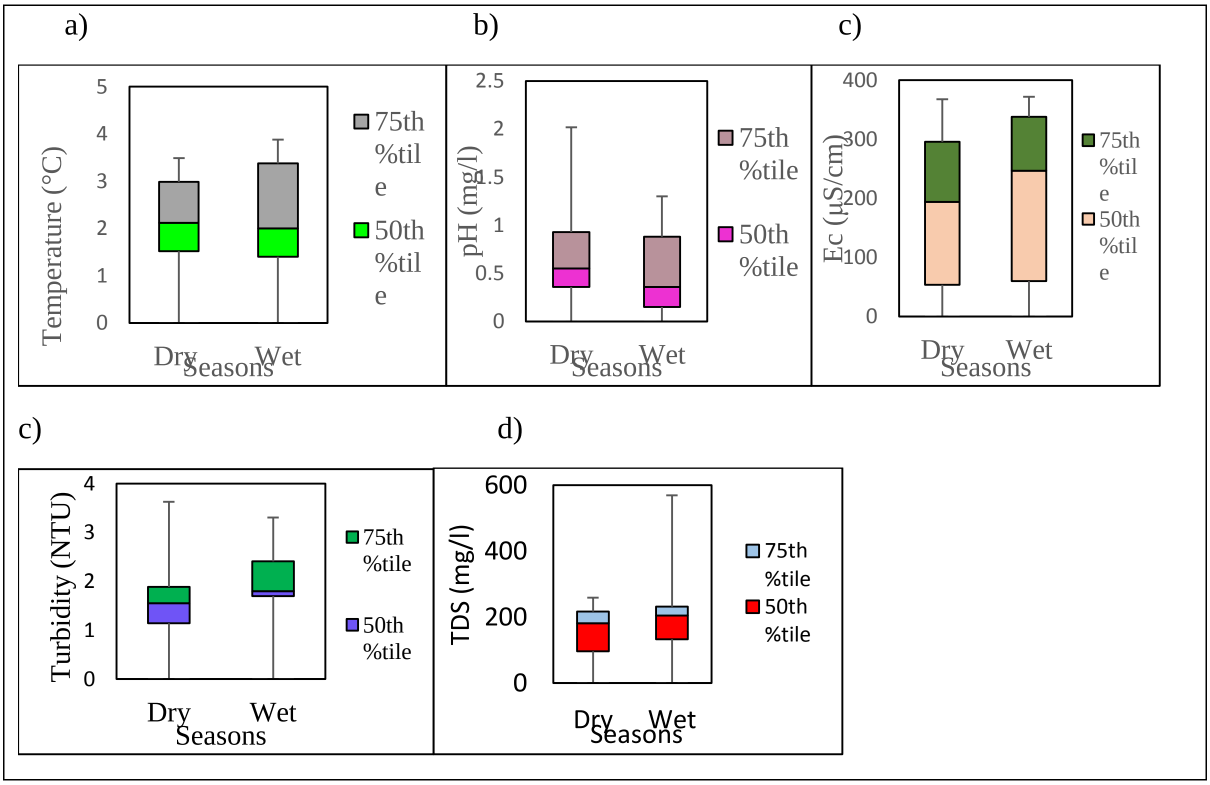


Figure 4-35: Plots for temp, pH, EC, turbidity, and TDS for SHWs

A large spread was displayed by box plots of EC , Temperature, pH, DO and Ca in the two seasons, and K in the dry season indicating high variations in the concentration of the dataset whereas narrow spread in the dataset was displayed in both seasons by TDS, Turbidity, Hardness, Fe, Ca, F, SO, NO, Cl, Na, and K in the wet season indicating low variations in the concentration of the dataset.

The box plots of SO_4^{2-}, NO_3^{2}, $Cl^{-,}$ Mg^{2+}, Na^{+}, Ca^{2+}, and Alkalinity datasets for both seasons, Turbidity and pH dataset for dry season and TDS dataset for wet season exhibited long upper whiskers showing a skewed distribution toward high concentrations. A skewed distribution towards low concentration was however exhibited in the box plots of Temperature, Hardness, and F^{-} datasets of both seasons , TDS dataset of dry season and Turbidity dataset for wet season as shown in Figure 4.36 and Figure 4.37.

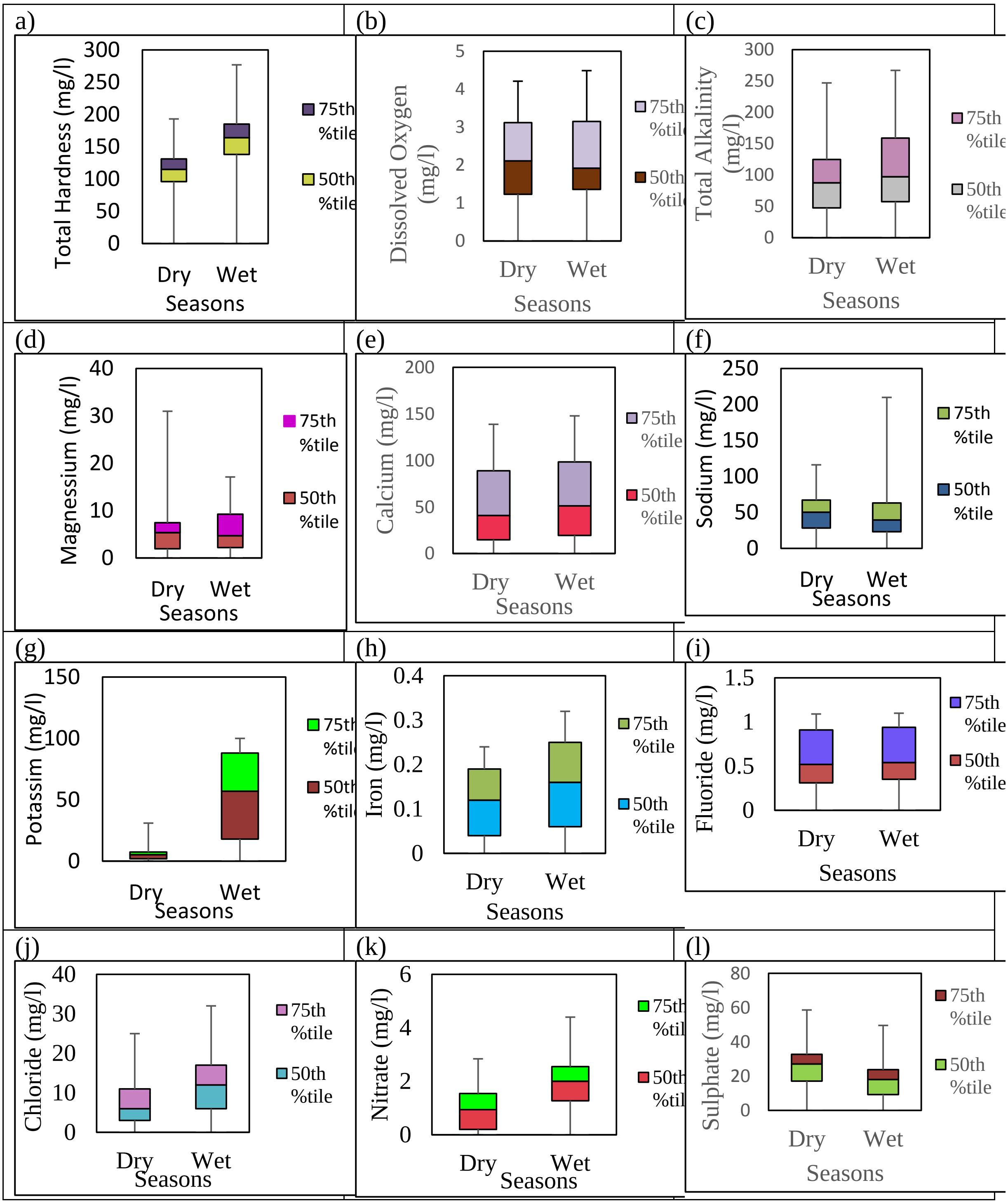


Figure 4-36: Plots of TH, DO, TA, Mg, Ca, Na, K, Fe, F, Cl, NO and SO for SHWs

4.3.3 Seasonal variation in physicochemical parameters

The students t-test was employed to estimate the mean variances in all the tested water quality attributes of both boreholes and shallow wells during the two seasons at 95% confidence interval as show in Appendix X and Appendix XI. The basis of this statistical procedure was that if the probability (p) value is < 0.05 the variance is deemed statistically substantial on the other hand if p value is > 0.05, then there is no arithmetic difference amongst the compared variables.

4.3.3.1 Seasonal mean differences for physicochemical parameters for BHs

The student's t-test analysis executed for the 30 samples at 95% confidence interval showed that there was no remarkable statistical variation ($P > 0.05$) between dry and rainy season for temperature, pH, TDS, DO, Total Hardness, Magnesium, Sodium, Potassium, Fluoride, Chloride, Nitrate and Sulphate in sampled boreholes except for EC, Turbidity, Total Hardness, Calcium, and iron as shown in Table 4-8. The null hypothesis that; mean levels of tested physicochemical characteristics for borehole water during the two seasons do not vary statistically was accepted at 95% CL for temperature, pH, TDS, DO, Total Hardness, Mg^{2+}, Na^{+}, K^{+}, F^{-}, Cl^{-}, NO_3^{2-} and SO_4^{2-} and rejected at 95% CL for EC, Turbidity, Total Hardness, Ca^{2+}, and Fe^{2+}.

Seasonal variation in the mentioned parameters in borehole samples may be due to multiple factors. A higher learning institution (Kenyatta University) within the region and improved transport infrastructure has seen the population of Kamiti Marengeta significantly grow within a short period. Considering that this area suffers from an inadequate water supply by the water and sewerage companies and most people depend on borehole water, there is a possibility that much pumping is done during the dry season to meet the demand. According to Bexfield and Jurgens (2014), dry season pumping of water from boreholes on a vertical hydraulic gradient influences water movement from the unsaturated zones through the aquifer to the supply boreholes. The seasonal variation in the parameters mentioned above could also be attributed to the different depths of the boreholes.

Table 4-8 Seasonal mean differences in physicochemical parameters in BHs

Parameter	**Quality Units**	**Wet Season** Mean ± S.E	**Dry Season** Mean ± S.E	**t**	**df**	**P Value**
Temp	(^{0}C)	22.99 ± 0.33	22.99 ± 0.33	-1.36	29	0.18
pH	(mg/l)	7.25 ± 0.05	7.25 ± 0.05	0.75	29	0.46
EC	(µS/cm)	431.97 ± 30.85	431.97 ± 30.85	-3.85	29	**0.00**
Turbidity	(NTU)	2.77 ± 0.35	2.77 ± 0.05	-7.99	29	**0.00**
TDS	(mg/l)	323.93 ± 16.33	321.93 ± 16.33	0.11	29	0.91
DO	(mg/l)	4.66 ± 0.34	4.66 ± 0.34	-0.49	29	0.63
TH	(mg/l)	108.73 ± 7.43	108.73 ± 7.43	-5.82	29	**0.00**
TA	(mg/l)	201.90 ± 16.27	201.90 ± 16.27	-1.44	29	0.16
Mg^{2+}	(mg/l)	6.40 ± 1.78	6.40 ± 1.78	-1.21	29	0.24
Ca^{2+}	(mg/l)	29.08 ± 6.40	29.08 ± 6.40	-2.35	29	**0.03**
Na^{+}	(mg/l)	63.51 ± 5.23	63.51 ± 5.23	-1.30	29	0.20
K^{+}	(mg/l)	57.27 ± 6.54	57.27 ± 6.54	-2.06	29	0.05
Fe^{2+}	(mg/l)	0.19 ± 0.05	0.19 ± 0.05	-2.42	29	**0.02**
F^{-}	(mg/l)	1.03 ± 0.07	0.95 ± 0.07	-8.70	29	1.41
Cl^{-}	(mg/l)	12.17 ± 1.99	12.15 ± 1.99	-6.44	29	4.86
NO_3^{2-}	(mg/l)	0.90 ± 0.07	0.88 ± 0.07	-6.44	29	4.85
SO_4^{2-}	(mg/l)	51.14 ± 4.85	51.13 ± 4.85	-4.33	29	4.18

The supply aquifer, Nairobi Aquifer, whose central aquifer unit is the Upper Athi Series found mainly between 120 and 300 mbgl and thins eastwards (WRMA 2010); hence most boreholes are not drilled to the same depth. The variation in borehole depths within Kamiti-Marengeta could also contribute to seasonal variation in the water quality. Lastly, construction blasting and induced vibrations during the rapid development of road and housing infrastructure within the study area could have easily generated seismic disturbances causing micro-fractures (Hiscock, 2009).

4.3.3.2 Seasonal mean differences for physicochemical parameters for SHWs

The student's t-test analysis performed for the 17 shallow well samples at a 95% confidence interval showed that there was a remarkable statistical variation ($P < 0.05$) between the two seasons for all 16 tested parameters ($p = 0.000$) except for Magnesium ($p = 0.052$) as shown in Table 4-9. The null hypothesis that the mean concentration of physical and chemical parameters in shallow wells during the dry and wet seasons are not significantly different was rejected at 95% CL for all 16 tested parameters and accepted at 95% CL for Magnesium.

Table 4-9: Seasonal mean differences for physicochemical parameters for SHWs

Parameter	**Quality Units**	**Wet Season**	**Dry Season**			
		Mean ± S.E	Mean ± S.E	**t**	**Df**	**p Value**
Temp	(^{0}C)	21.875 ± 0.325	22.373 ± 0.321	-8.491	16	0.000
pH	(mg/l)	7.456 ± 0.102	6.949 ± 0.153	5.514	16	0.000
EC	(µS/cm)	474.059 ± 0.236	403.588 ± 31.266	7.491	16	0.000
Turbidity	(NTU)	4.296 ± 0.236	2.785 ± 0.218	9.618	16	0.000
TDS	(mg/l)	505.049 ± 31.395	359.888 ± 20.872	6.252	16	0.000
DO	(mg/l)	3.715 ± 0.302	2.655 ± 0.290	6.942	16	0.000
TH	(mg/l)	211.471 ± 19.063	151.824 ± 12.960	6.810	16	0.000
TA	(mg/l)	171.453 ± 20.694	146.018 ± 18.017	3.847	16	0.001
Mg^{2+}	(mg/l)	6.798 ± 1.322	9.390 ± 2.355	-2.101	16	**0.052**
Ca^{2+}	(mg/l)	62.738 ± 11.551	53.070 ± 10.787	7.341	16	0.000
Na^{+}	(mg/l)	85.547 ± 12.492	59.958 ± 7.693	3.896	16	0.001
K^{+}	(mg/l)	86.170 ± 8.712	60.334 ± 7.294	7.499	16	0.000
Fe^{2+}	(mg/l)	0.180 ± 0.025	0.122 ± 0.020	6.395	16	0.000
F^{-}	(mg/l)	0.907 ± 0.085	0.842 ± 0.083	12.222	16	0.000
Cl^{-}	(mg/l)	27.294 ± 2.124	14.529 ± 1.670	10.259	16	0.000
NO_3^{2-}	(mg/l)	3.316 ± 0.263	1.594 ± 0.197	9.483	16	0.000
SO_4^{2-}	(mg/l)	49.653 ± 3.671	37.728 ± 4.021	10.103	16	0.000

Most tested parameters showed an upward trend in concentration levels during the wet period except for Temperature. Water from shallow wells is sensitive to land uses and anthropogenic activities such as the construction of sewer systems, septic tanks, and crop and livestock farming, among others. According to Mechenich and Shaw (2011), the water that soaks into the ground in areas under heavy human activities is pulled down by gravity to the water table. The contaminants dissolved in the water are carried along.

They might not be fully filtered by the soil, compromising the quality of shallow wells as they mainly get their waters from the highest water table. 76% of sampled shallow wells (13 out of 17) within Kamiti-Marengeta sub-catchment lacked proper infrastructure, including good drainage channels, concrete cover, and well aprons that increased their vulnerability to contamination by storm runoff, leachates from farms as well as dirty water from the washing of domestic wear. The wooden planks and iron sheets used to cover the wells do not protect them from storm runoff and dust particles blown by the wind into the water. This is supported by a study by Munyebvu (2014), who attributed contamination of shallow well waters to a lack of well aprons and proper head cover.

4.4 Water quality perception by users

Water quality can be defined by microbial, chemical, and aesthetic (physical) characteristics. Engaging water consumers in solving complex water quality issues are significantly influenced by their perceptions, beliefs of issues related to water resources, and value derived from the resources. Several scholars and environment management practitioners recommend that environmental challenges such as water quality issues can be addressed effectively when scientific knowledge and findings are integrated with local knowledge in public deliberations (Dupont, 2005, Dietrich et al., 2014). This section assessed drinking water quality through the perceived impression of water quality, not the technical quality.

4.4.1 Places or sources of water

The primarily used source of water was reported to be borehole by 37% (142) of the respondents, followed by a mixture of borehole and Water Service Provider's (WSP) water at 32% (124), and water supply by the WSP alone at 21% (81) and shallow wells at 10% (38) as shown in Figure 4-37. It was noted that despite the area being endowed by rivers/streams and experiencing both short and long rains each year, none of the residents practiced rainwater harvesting or collected water directly from the streams.

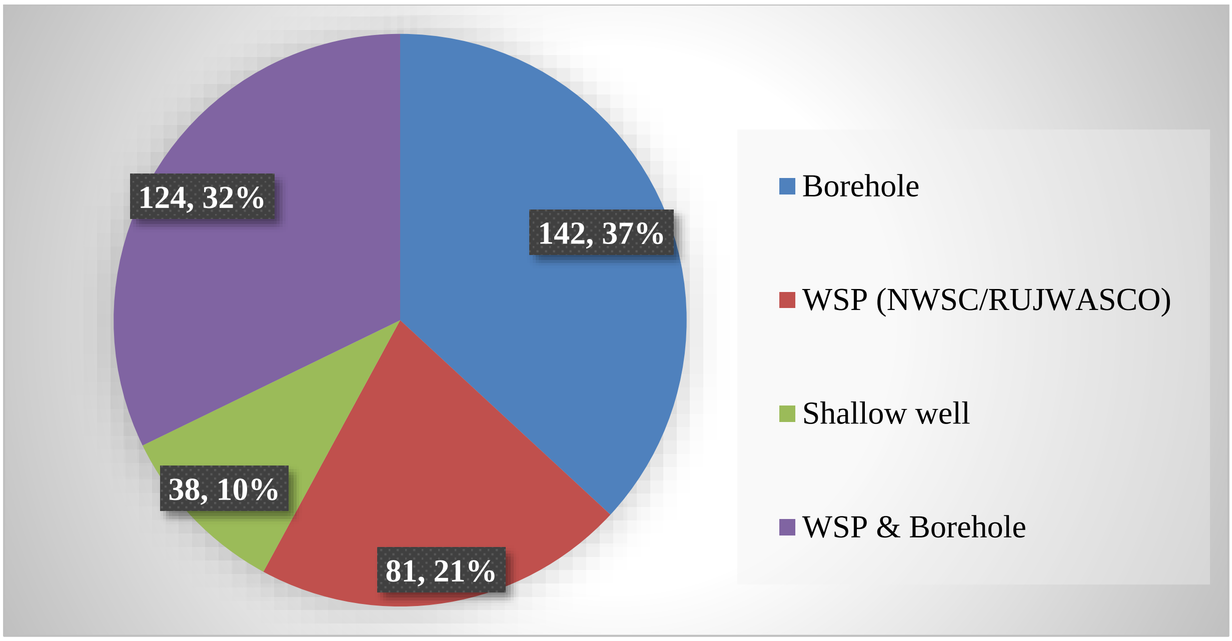


Figure 4-37: Sources of water for domestic use

4.4.2 Main problem of water supply

Poor water quality and broken water supply were reported as the significant problems with water supply by 169 (44%) and 150 (39%) of the respondents, and the cost of water was recorded by 39 (10%) of respondents as a minor problem with water supply. It is also important to note that 27 (7%) of the respondents did not find any problem with the water supply in the area as highlighted in Figure 4-38.

Bad quality as a water supply problem was reported mainly by 81, 31, and 30 respondents who depended on boreholes, a combination of borehole and WSP, and shallow wells, respectively, for water supply. Additionally, broken water supply was reported as the second major problem by 57, 53, and 37 respondents who relied on a combination of WSP and boreholes, solely on WSP and boreholes, respectively, as shown in figure 4-39. The respondents expressed concerns about prolonged water supply interruptions, especially during the dry season, and at times water being released in the wee hours of the night when most of them were asleep.

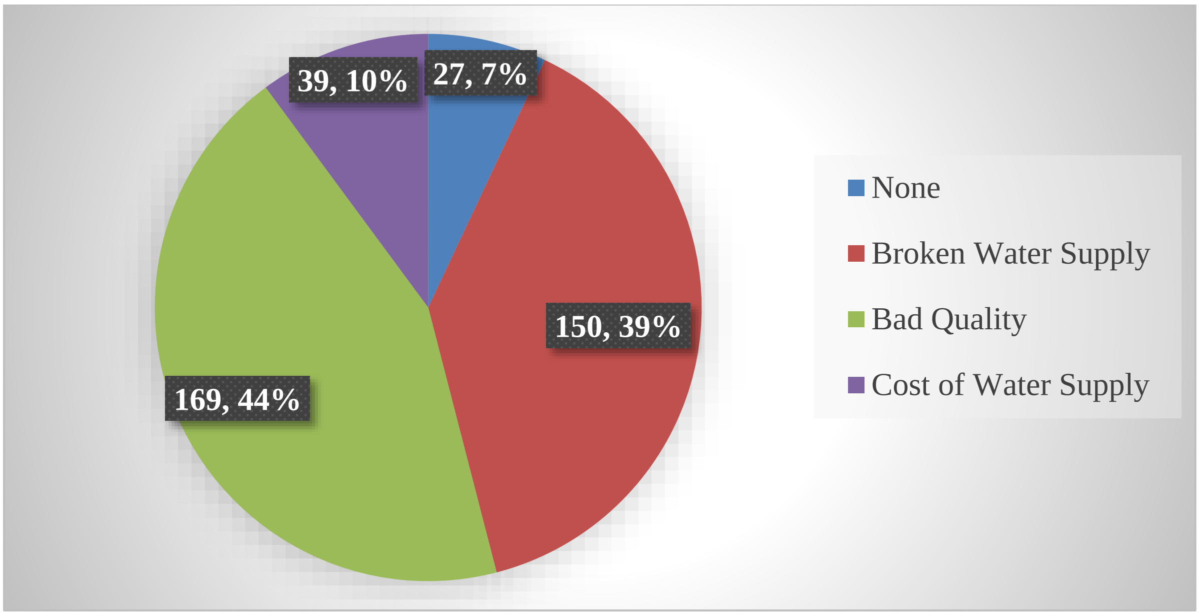


Figure 4-38: Main water supply problems

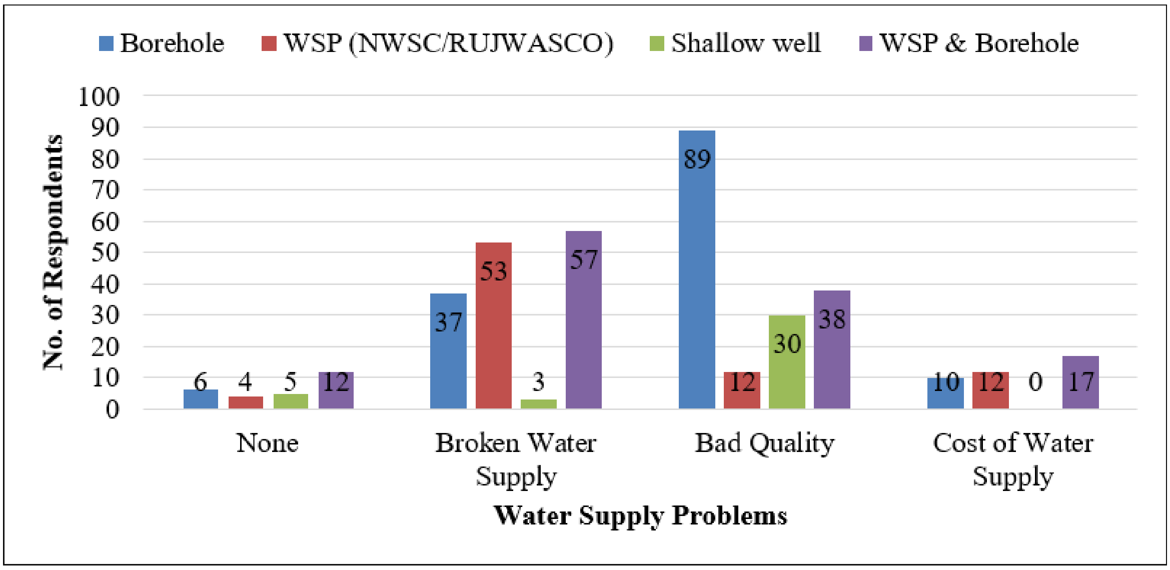


Figure 4-39: Problems of water supply by source

Cost of water supply was the least problem for the majority; however, from the 39 respondents, 17 depended on supply from a combination of WSP and borehole, which could also mean that they had to pay the WSP as well as the borehole owner different water bills thereby finding the arrangement costly.

4.4.3 Perception on safety of water for drinking

The findings on residents' perception on the quality of the water they use for drinking are highlighted in Figures 4-40 and 4-41. 56% (217) considered the water safe for drinking). These comprised 81 respondents sourcing water solely from boreholes, 47 relying on water from the WSP, 16 getting water from shallow wells, and 17 who had both borehole and WSP connections. The water was considered unsafe by 39% (149) of respondents, 48 of whom relied on boreholes, 38 on WSP, 16 on shallow wells, and 47 from a combination of WSP and borehole connection. 5% (19) respondents, 13 relying on boreholes and six on shallow wells were not sure of water's safety for drinking.

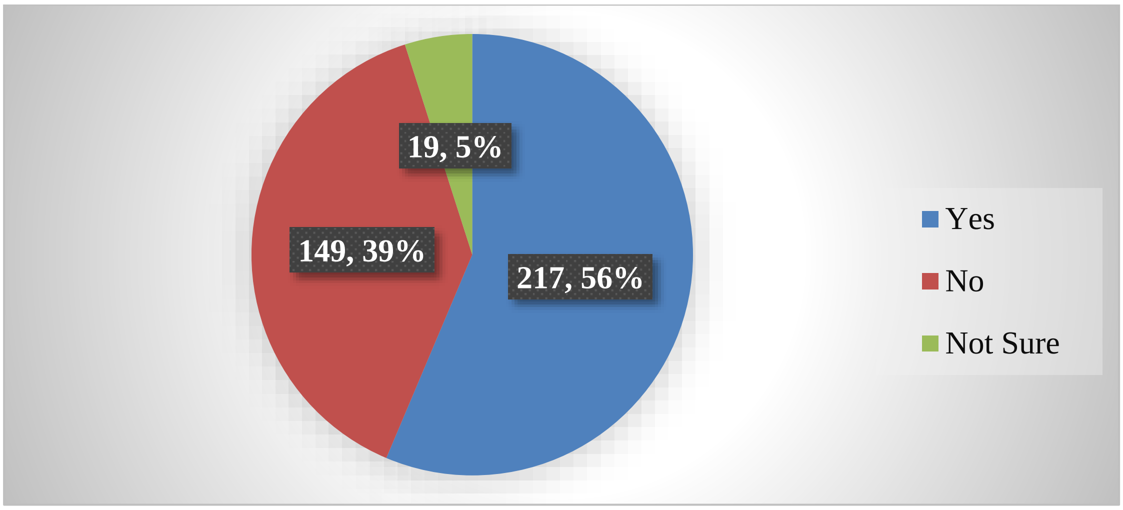


Figure 4-40: Safety of water for drinking purposes

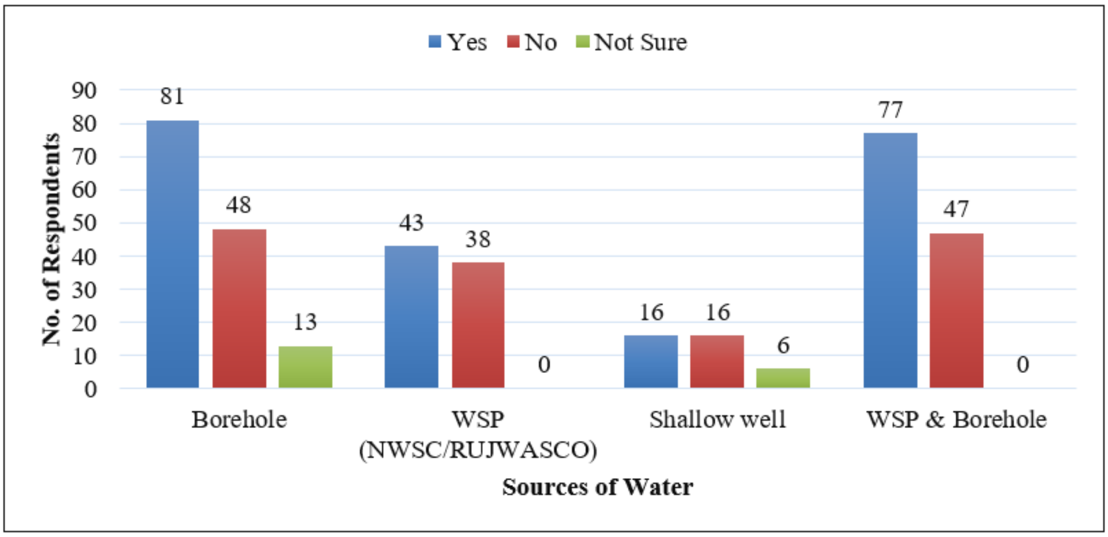


Figure 4-41: Safety of water safe for drinking

4.4.4 Important water quality attribute as perceived by residents

Even though it is assumed that water's colour, taste, and smell are just aesthetic issues, water users commonly use them to gauge the quality and safety of water from their taps (Jardine *et al.*, 1999). Figures 4-42 and 4-43 depict the summary findings of the important water quality attributes from the survey. 50% (193) of respondents, 78 with borehole water supply, 61 with a combination of WSP and borehole water supply, 47 solely relying on WSP, and 7 with shallow well supply; perceived taste as the most critical water quality attribute. The odour was perceived to be important by 36% (137), with the majority at 56 having borehole supply, followed by 49 with a combination of WSP and borehole supply, 21 with WSP, and 11 with shallow well supplies. The appearance of water was perceived to be the least significant, with the response from only 14% (55) of participants, the majority of which depended on shallow wells as their primary source of water supply. As pointed out by World Health Organization (WHO), changes in the typical colour, taste or smell of drinking water supply may indicate changes in quality of water because of pollution of the source, insufficient treatment, or pollution along the distribution line (World Health Organization, 2011).

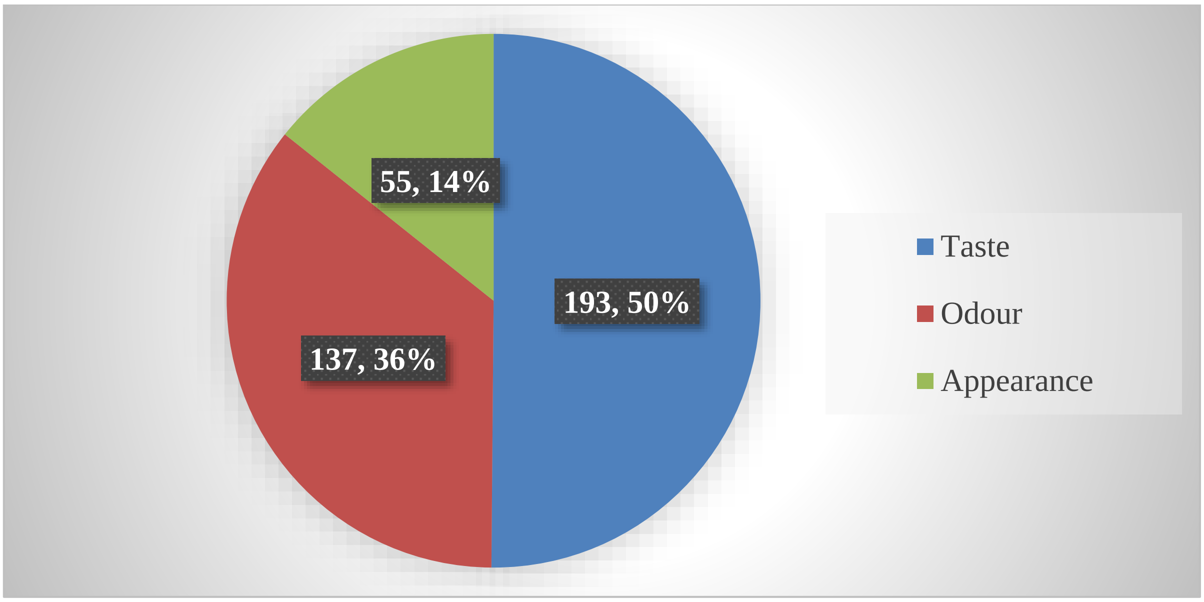


Figure 4-42: Important water quality attributes as perceived by residents

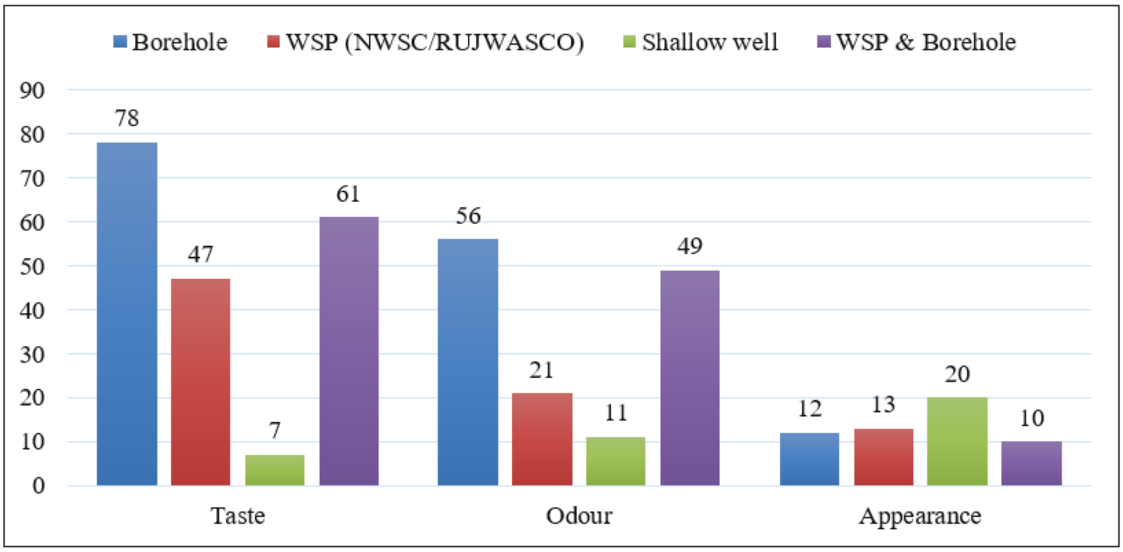


Figure 4-43: Important water quality attributes

The findings on sources of water, challenges of the supply, and general perception of the residents of the quality of water point to the fact that the drinking water quality in the study area is not assured. The lack of water treatment systems also backs up this argument where borehole and shallow well water samples were collected. This, therefore, meant that most households within Kamiti-Marengeta sub-catchment were at risk of drinking unsafe water that must be treated and safely stored.

CHAPTER 5 : SUMMARY, CONCLUSION, AND RECOMMENDATIONS

5.1 Introduction

The overall objective of this study is to determine the physical and chemical characteristics of boreholes and shallow wells in Kamiti-Marengeta sub-catchment, the effects of seasonal variation on the water quality attribute along with water quality through the perceived impression of the consumers.

5.2 Summary of findings

The significance of groundwater in meeting demand in Nairobi and the surrounding towns such as Kiambu has drastically increased over the past years because of the ever-increasing risks to surface water sources such as pollution and drying up of streams due to climate change. With the growing demand for exploitation and use of groundwater, its quality has remained the limiting factor. Assessing groundwater quality in different sections of the aquifer has become crucial to ensure the safety and availability of the resources for utilization by humans and ecosystem support.

5.2.1 Physical and chemical characteristics of boreholes and shallow wells

From the study findings and comparison with the WHO (2010) and KEBS standards values in this study, it is apparent that the quality of borehole water in the study area is high in turbidity, calcium, potassium, iron, and fluoride. Turbidity had high values above WHO and KEBS limits of 5 NTU in BH17, BH19, BH16, and BH 20 in Membley and BH02 in Bypass. Calcium recorded concentrations high above WHO standards of 100mg/L and KEBS standards of 150mg/L in BH07 in Kiwanja. Potassium exhibited a high concentration above the KEBS standards of 50mg/L in 16 out of the 30 sampled boreholes but within WHO limits of 100mg/l in all the sampled boreholes. Iron concentration was high above the KEBS standards of 0.3mg/l in BH 24 in Kahawa Sukari, BH12 and BH15 in Kenyatta University, BH5 and BH4 and high above both WHO and KEBS standards of 0.3mg/l and 0.5mg/l BH23 in Kahawa Sukari. Fluoride was high above WHO and KEBS limit of 1.5mg/l BH20 in Membley and BH08 in Kiwanja.

Shallow well water was slightly acidic with pH units lower than the WHO and KEBS standards of 6.5 units and 8.5 units in SHW7 recorded in Kiwanja and SHW 9 and SHW 10 in Membley during the dry season. Additionally, the quality of shallow well waters was found to be high in calcium, sodium, and iron. Calcium recorded high concentration above WHO and KEBS standards of 100 mg/L and 150mg/L in SHW04 in Kiwanja during the wet season; Sodium concentration above WHO and KEBS standards of 100 mg/L was recorded in SHW02 in Bypass during the wet season; and Iron concentration above the KEBS standards of 0.3mg/l during the wet season recorded in SHW03 and SHW02 in bypass and SHW08 in Kiwanja. However, all the sampled groundwater from both borehole and shallow wells within the catchment were within permissible limits for use in agriculture, domestic, and livestock watering.

5.2.1.1 Correlation analysis of water quality tested parameters

The correlation matrix of water quality parameters of sampled boreholes in the study area confirmed that EC in boreholes during the dry season was mainly contributed to by TDS (0.57), total alkalinity (0.59), and sodium (0.6). In the dry season, potassium (0.51) was found to be the significant element contributing to total alkalinity; however, during the wet season, the major minerals contributing to alkalinity were identified as potassium (0.51) and sodium (0.64). Total hardness also exhibited a positive correlation with calcium (0.54) during the dry season and with calcium (0.54) and fluoride (0.64) during the wet season. The correlation matrix of water quality parameters of sampled shallow wells in the study area confirmed a positive correlation in temperature with sodium; TDS with potassium (0.82), total hardness (0.67), fluoride (0.50), and nitrate (0.68); EC with potassium (0.67), fluoride (0.66), chloride (0.64), and nitrate (0.57); magnesium with chloride (0.80); hardness with fluoride (0.81); and negative correlation in pH with hardness (-0.63) and fluoride (-0.56) during the dry season. During the wet season, moderate positive correlations were recorded in total hardness with calcium (0.54) and fluoride (0.53); total alkalinity with sodium (0.64) and potassium (0.51); and EC with TDS (0.57), total alkalinity (0.59) and sodium (0.61).

5.2.1.2 Variations in physicochemical parameters in BHs across the six zones

The study through the contour maps indicated a higher concentration of the tested parameters in some parts of the study area, which can be attributed to a couple of reasons such as natural mass circulation, pollution from various sources, human activities, aquifer properties, and groundwater recharge. Statistical analysis of the spatial variation of these parameters revealed a statistically significant difference between Kiwanja and Kenyatta University and Kenyatta University and Kahawa Wendani for Dissolved Oxygen; between Bypass and Membley and Bypass and Kahawa Wendani for Total at Hardness; and between Kiwanja and Membley and between Membley and Kahawa Sukari for Turbidity during both dry and wet seasons.

5.2.2 Seasonal variation in physicochemical properties of BHs and SHWs

Seasonal box and whisker plots for parameters assessed in boreholes were nearly symmetrical indicating minor seasonal influence on their concentration, whereas the box and whisker plots for parameters in shallow wells showed relatively individual patterns indicating seasonal influence on their concentrations and values. Statistical analysis through Student t test confirmed that there was no substantial statistical variation ($P > 0.05$) between the two seasons for temperature and pH units and concentration of TDS, DO, Mg^{2+}, Na^{+}, K^{+}, F^{-}, $Cl^{-,}$ NO_3^{2-}, and SO_4^{2-} in sampled boreholes and Mg^{2+} in shallow wells. However, substantial statistical variation ($p < 0.05$) was registered between the two seasons for concentrations levels of EC, Turbidity, TH, Ca^{2+}, and Fe^{2+} in sampled boreholes and between dry and wet season and for pH, EC, Turbidity, TDS, DO, TH, TA, Mg^{2+}, Ca^{2+} Na^{+}, K^{+}, Fe^{2+}, F^{-}, $Cl^{-,}$ NO_3^{2-}, and SO_4^{2-} in shallow wells.

5.2.3 Water quality perception by users

Boreholes were found to be the significant sources of water, followed by a mixture of borehole and Water Service providers, water supply by the WSP alone, and shallow wells. In ranking order, poor water quality was perceived to be the major problem with water supply, followed by broken water supply and cost of water supply as the least problem.

Most respondents who perceived the water as safe for drinking purposes were individuals who had water connections solely from the WSP and the private boreholes within their compounds. In contrast, those who received the water from boreholes not located in their compounds and from a combination of WSP and borehole connection considered the water unsafe for drinking. A small percentage was not sure of the water quality. Half of the respondents perceived the taste of water as the most critical water quality attribute followed by odour and appearance.

5.3 Conclusion

The findings of this study present the water quality attributes of the Kamiti-Marengeta sub-catchment from six different regions (Kahawa Wendani, Kenyatta University, Kahawa Sukari, Membley, Bypass, and Kiwanja). The study revealed that groundwater in some parts of the study area is chemically unfit for drinking purposes. The quality of borehole water in the Kamiti-Marengeta is high in turbidity, calcium, potassium, iron, and fluoride, and shallow well waters high in calcium, sodium, and iron above WHO-2010 and KEBS-2007 standard values for drinking water quality. Shallow wells waters were slightly acidic during the dry season, while borehole waters were alkaline during the day and during the wet seasons.

The significant statistical variation in turbidity, dissolved oxygen, and total hardness and spatial variation in concentration and units of the tested parameters across the study area result from a function of chemical, physical and biological characteristics that highly influenced human activities and geological properties.

Contrary to the belief that confined aquifers have impermeable strata and are not recharged by percolating rainwater, the study findings highlight seasonal variation in electrical conductivity, turbidity, total hardness, calcium, and iron in boreholes found within the Nairobi Aquifer in this region. Significant seasonal variation in all parameters tested in shallow wells confirmed seasonal influence on shallow well water quality.

The scientific findings on the physical and chemical characteristics of the groundwater and findings of the social survey point to the fact that the drinking water quality in the study area is not assured. The individual’s water sources greatly influence the divide in residents’ perception of water safety. This calls for awareness creation on water quality issues among residents, monitoring groundwater abstractions, and regular monitoring of water quality to ensure residents are not exposed to health risks associated with poor state of the water.

5.4 Recommendations

Based on the study findings, some of the recommendations arrived at included:

i. The residents or investors planning to drill boreholes or dig shallow wells within the study areas to be on the lookout for turbidity and fluoride in boreholes and pH in shallow wells in Membley; calcium, potassium, and fluoride in boreholes and pH, calcium, and iron in shallow wells in Kiwanja; turbidity in boreholes and sodium and iron in shallow wells in Bypass; potassium and iron in boreholes in Kenyatta University and Kahawa Sukari; and potassium in boreholes in Kahawa Wendani.

ii. Some boreholes and shallow wells exhibited high concentration levels of some physical and chemical parameters above WHO and KEBS permissible limits for drinking. This study recommends that borehole and shallow well owners to invest in water treatment systems before the water is pumped into residents' taps to prevent any health effect that the consumption of the water might cause.

iii. Groundwater exploitation and utilization status in the study area warrant continuous monitoring and implementation of groundwater quality improvement technologies. Water Resource Authority should therefore carry out regular groundwater monitoring to ensure the water supplied to consumers complies with the recommended water quality standards.

iv. Water Resources Authority should also ensure that Water Resource Users Associations responsible for the sub-catchment is active and can create awareness on groundwater status and monitor abstraction rates to ensure the sustainability of the resource for both human and ecosystem uses.

5.4.1 Recommendation for further research

Further research in the following areas in Kamiti-Marengeta sub-catchment is required:

i. Comprehensive hydrogeological study to determine the effects of the intensive infrastructure development on the aquifer rocks since 2010.

ii. Assessment of the microbiological characteristic of the boreholes and shallow wells of Kamiti-Marengeta sub-catchment.

iii. Impacts of land use on groundwater quality in Kamiti-Marengeta sub-catchment.

iv. Health effect of groundwater contamination on residents of Kamiti-Marengeta sub-catchment

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APPENDICES

Appendix I: Descriptive statistics of physicochemical parameters

Parameter	Quality Units	BOREHOLE						SHALLOW WELLS						WHO Standards	KEBS KS 459-1:2007
		Maximum		Minimum		Mean		Maximum		Minimum		Mean			
		Dry S.	Wet S.	Dry S.	Wet S.	Dry S.	Wet S.	Dry S.	Wet S.	Dry S.	Wet S.	Dry S.	Wet S.		
Temp	(^{0}C)	28.8	29	21.2	21.3	22.99	23.03	24.70	24.30	20.18	19.70	22.37	21.88	20 - 35	20 - 35
pH	(mg/l)	8.22	8.17	7.02	7.01	7.25	7.24	8.20	8.30	6.18	7.00	6.95	7.46	6.5-8.5	6.5-8.5
EC	**(**µS/cm**)**	796.93	797	64.22	64.21	431.97	432.29	587.00	641.00	219.00	269.00	403.59	474.06	1500	NS
Turbidity	(NTU)	6.34	6.36	0.17	0.21	2.77	2.79	4.83	5.81	1.20	2.50	2.79	4.30	5.0	5.0
TDS	(mg/l)	576.77	576.8	205.97	206	323.93	323.93	465.30	875.00	206.40	305.20	359.89	505.05	1000	1000
DO	(mg/l)	7.8	7.77	1.02	1.03	4.66	4.66	4.73	6.18	0.52	1.69	2.65	3.72	NS	NS
TH	(mg/l)	194.98	195	41.96	42	108.73	108.75	241.00	340.00	48.00	63.00	151.82	211.47	500	300
TA	(mg/l)	301.05	300	19.97	20	201.90	202.03	296.30	327.00	49.30	60.00	146.02	171.45	500	NS
Mg^{2+}	(mg/l)	35.99	35.96	0.25	0.26	6.40	6.44	31.60	17.80	0.65	0.71	9.39	6.80	100	100
Ca^{2+}	(mg/l)	151.52	151.51	0.6	0.61	29.08	29.08	141.20	151.51	2.39	3.61	53.07	62.74	100	150
Na^{+}	(mg/l)	113	113.01	0.89	0.9	66.44	63.52	127.02	244.63	10.90	34.89	59.96	85.55	200	200
K^{+}	(mg/l)	178.94	178.96	10.62	10.61	57.27	57.30	99.80	132.73	15.46	32.70	60.33	86.17	200	50
Fe^{2+}	(mg/l)	1.29	1.31	0.02	0.01	0.19	0.20	0.25	0.34	0.01	0.02	0.12	0.18	0.3	0.5
F^{-}	(mg/l)	1.87	1.98	0.21	0.32	0.95	1.03	1.37	1.42	0.28	0.32	0.84	0.91	1.5	1.5
Cl^{-}	(mg/l)	49.98	50	4.97	5	12.15	12.17	31.00	47.00	6.00	15.00	14.53	27.29	250	250
NO_3^{2-}	(mg/l)	1.98	2	0.13	0.15	0.88	0.90	3.40	5.83	0.56	1.43	1.59	3.32	10	50
SO_4^{2-}	(mg/l)	132.92	132.93	30.15	30.16	51.13	51.14	68.80	79.31	10.20	29.73	37.73	49.65	450	400

Appendix II: Statistical output of box and whiskers for BHs

	Temperature	
	Dry	Wet
Min	21.2	21.3
Q1	21.8325	21.825
Median (Q2)	22.305	22.3
Q3	23.6	23.8
Max	28.8	29
Box 1 -hidden	0.6325	0.525
50th percentile	0.4725	0.475
75th percentile	1.295	1.5
Whisker Top	5.2	5.2
Whisker Bottom	0.6325	0.525

	TDS	
	Dry	Wet
Min	205.97	206
Q1	247.91	247.93
Median (Q2)	318.79	318.75
Q3	349.81	349.83
Max	576.77	576.8
Box 1 -hidden	41.94	41.93
50th percentile	70.88	70.83
75th percentile	31.02	31.08
Whisker Top	226.96	226.98
Whisker Bottom	41.94	41.93

	pH	
	Dry	Wet
Min	7.02	7.01
Q1	7.04	7.06
Median (Q2)	7.13	7.11
Q3	7.39	7.33
Max	8.22	8.17
Box 1 -hidden	0.02	0.05
50th percentile	0.08	0.04
75th percentile	0.26	0.23
Whisker Top	0.83	0.84
Whisker Bottom	0.02	0.05

	DO	
	Dry	Wet
Min	1.02	1.03
Q1	3.58	3.6
Median (Q2)	4.63	4.62
Q3	6.03	6.01
Max	7.8	7.77
Box 1 -hidden	2.56	2.57
50th percentile	1.05	1.02
75th percentile	1.4	1.39
Whisker Top	1.77	1.76
Whisker Bottom	2.56	2.57

	Turbidity	
	Dry	Wet
Min	0.17	0.21
Q1	1.19	1.21
Median (Q2)	2.86	2.89
Q3	4.11	4.13
Max	6.34	6.36
Box 1 -hidden	1.02	1
50th percentile	1.68	1.68
75th percentile	1.25	1.24
Whisker Top	2.23	2.23
Whisker Bottom	1.02	1

	Hardness	
	Dry	Wet
Min	41.96	42
Q1	86.97	87
Median (Q2)	107.67	107.7
Q3	141.73	141.75
Max	194.98	195
Box 1 -hidden	45.01	45
50th percentile	20.71	20.7
75th percentile	34.06	34.05
Whisker Top	53.25	53.25
Whisker Bottom	45.01	45

	EC	
	Dry	Wet
Min	64.22	64.21
Q1	322.13	322.15
Median (Q2)	434.482	434.5
Q3	532.3	533.3
Max	796.93	797
Box 1 -hidden	257.91	257.94
50th percentile	112.352	112.35
75th percentile	97.818	98.8
Whisker Top	264.63	263.7
Whisker Bottom	257.91	257.94

	Alkalinity	
	Dry	Wet
Min	19.97	20
Q1	170.3425	170.25
Median (Q2)	196.48	197
Q3	282.285	281.75
Max	301.05	300
Box 1 -hidden	150.3725	150.25
50th percentile	26.1375	26.75
75th percentile	85.805	84.75
Whisker Top	18.765	18.25
Whisker Bottom	150.3725	150.25

	Magnesium	
	Dry	Wet
Min	0.25	0.26
Q1	1.2	1.21

	Sodium	
	Dry	Wet
Min	13.09	13.1
Q1	52.83	52.84

Median (Q2)	2.37	2.38
Q3	6.22	6.2
Max	35.99	35.96
Box 1 -hidden	0.95	0.95
50th percentile	1.17	1.17
75th percentile	3.85	3.82
Whisker Top	29.78	29.76
Whisker Bottom	0.95	0.95

	Calcium	
	Dry	Wet
Min	0.6	0.61
Q1	3.1	3.11
Median (Q2)	17.04	17.03
Q3	41.22	41.21
Max	151.52	151.51
Box 1 -hidden	2.5	2.5
50th percentile	13.94	13.92
75th percentile	24.18	24.18
Whisker Top	110.31	110.3
Whisker Bottom	2.5	2.5

	Iron	
	Dry	Wet
Min	0.02	0.01
Q1	0.0325	0.0625
Median (Q2)	0.105	0.125
Q3	0.27	0.2925
Max	1.29	1.31
Box 1 -hidden	0.0125	0.0525
50th percentile	0.0725	0.0625
75th percentile	0.165	0.1675
Whisker Top	1.02	1.0175
Whisker Bottom	0.0125	0.0525

	Fluoride	
	Dry	Wet
Min	0.21	0.32
Q1	0.655	0.765
Median (Q2)	0.945	1.055
Q3	1.26	1.285
Max	1.87	1.98
Box 1 -hidden	0.445	0.445
50th percentile	0.29	0.29
75th percentile	0.315	0.23
Whisker Top	0.61	0.695
Whisker Bottom	0.445	0.445

	Chloride	
	Dry	Wet
Min	4.97	5
Q1	6.2475	6.25
Median (Q2)	9.98	10
Q3	11.98	12
Max	49.98	50
Box 1 -hidden	1.2775	1.25
50th percentile	3.7325	3.75

Median (Q2)	65.63	65.64
Q3	86.07	86.08
Max	113	113.01
Box 1 -hidden	39.74	39.74
50th percentile	12.81	12.81
75th percentile	20.44	20.44
Whisker Top	26.93	26.93
Whisker Bottom	39.74	39.74

	Potassium	
	Dry	Wet
Min	10.62	10.61
Q1	35.1	35.12
Median (Q2)	52.5	52.51
Q3	63.49	63.49
Max	178.94	178.96
Box 1 -hidden	24.48	24.51
50th percentile	17.39	17.4
75th percentile	11	10.98
Whisker Top	115.45	115.47
Whisker Bottom	24.48	24.51

	Nitrate	
	Dry	Wet
Min	0.13	0.15
Q1	0.6725	0.7025
Median (Q2)	0.795	0.82
Q3	0.97	1
Max	1.98	2
Box 1 -hidden	0.5425	0.5525
50th percentile	0.1225	0.1175
75th percentile	0.175	0.18
Whisker Top	1.01	1
Whisker Bottom	0.5425	0.5525

	Sulphate	
	Dry	Wet
Min	30.15	30.16
Q1	33.91	33.92
Median (Q2)	39.17	39.18
Q3	54.405	54.415
Max	132.92	132.93
Box 1 -hidden	3.76	3.76
50th percentile	5.26	5.26
75th percentile	15.235	15.235
Whisker Top	78.515	78.515
Whisker Bottom	3.76	3.76

75th percentile	2	2
Whisker Top	38	38
Whisker Bottom	1.2775	1.25

Appendix III: Statistical output of box and whiskers for SHWs

	Magnesium	
	Dry	Wet
min	0.65	0.71
Q1	2.6	2.9
Median (Q2)	6	5.4
Q3	8.09	9.94
Max (Q4)	31.6	17.8
hidden box	1.95	2.19
50th %tile	3.4	2.5
75th %tile	2.09	4.54
top whisker	23.51	7.86
bottom Whisker	1.95	2.19

	Potassium	
	Dry	Wet
min	0.65	32.7
Q1	2.6	50.73
Median	6	89.71
Q3	8.09	120.74
Max	31.6	132.73
hidden box	1.95	18.03
50th %tile	3.4	38.98
75th %tile	2.09	31.03
top whisker	23.51	11.99
bottom whisker	1.95	18.03

		Sodium
	Dry	Wet
min	10.9	34.89
Q1	39.2	57.92
Median (Q2)	61.13	74.21
Q3	77.98	97.9
Max (Q4)	127.02	244.63
hidden box	28.3	23.03
50th %tile	21.93	16.29
75th %tile	16.85	23.69
top whisker	49.04	146.73
bottom whiskers	28.3	23.03

	SO	
	Dry	Wet
min	10.2	29.73
Q1	27.32	39
Median (Q2)	37.3	47.8
Q3	42.98	53.54
Max (Q4)	68.8	79.31
hidden box	17.12	9.27
50th %tile	9.98	8.8
75th %tile	5.68	5.74
Top Whisker	25.82	25.77
Bottom Whisker	17.12	9.27

	Calcium	
	Dry	Wet
min	2.39	3.61
Q1	17.1	23
Median	43.3	54.78
Q3	91.27	101.96
Max	141.2	151.51
hidden box	14.71	19.39
50th %tile	26.2	31.78
75th %tile	47.97	47.18
Top Whisker	49.93	49.55
Bottom Whisker	14.71	19.39

	T Alkalinity	
	Dry	Wet
min	49.3	60
Q1	96.9	117.4
Median (Q2)	136.8	157.3
Q3	174.1	219
Max (Q4)	296.3	327
hidden box	47.6	57.4
50th %tile	39.9	39.9
75th %tile	37.3	61.7
Top Whisker	122.2	108
Bottom Whisker	47.6	57.4

	Fluoride	
	Dry	Wet
min	0.28	0.32
Q1	0.59	0.67
Median (Q2)	0.8	0.86
Q3	1.19	1.26
Max (Q4)	1.37	1.42
hidden box	0.31	0.35
50th %tile	0.21	0.19
75th %tile	0.39	0.4

	EC	
	Dry	Wet
min	219	269
Q1	273	329
Median (Q2)	413	516
Q3	515	607
Max (Q4)	587	641
hidden box	54	60
50th %tile	140	187
75th %tile	102	91

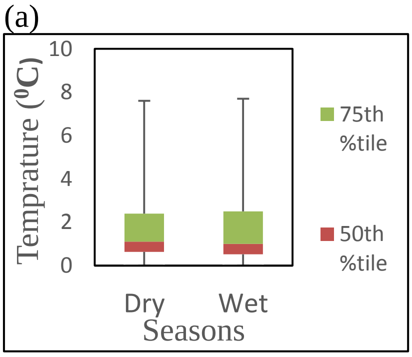
Top Whisker	0.18	0.16
Bottom Whisker	0.31	0.35
	TEMP	
	Dry	Wet
min	20.18	19.7
Q1	21.7	21.1
Median	22.3	21.7
Q3	23.17	23.08
Max	24.7	24.3
hidden box	1.52	1.4
50th %tile	0.6	0.6
75th %tile	0.87	1.38
Top Whisker	1.53	1.22
Bottom Whisker	1.52	1.4
	PH	
	Dry	Wet
min	6.18	7
Q1	6.54	7.15
Median (Q2)	6.73	7.36
Q3	7.11	7.88
Max (Q4)	8.2	8.3
hidden box	0.36	0.15
50th %tile	0.19	0.21
75th %tile	0.38	0.52
Top Whisker	1.09	0.42
Bottom Whisker	0.36	0.15
	Turbidity	
	Dry	Wet
min	1.2	2.5
Q1	2.34	4.2
Median (Q2)	2.75	4.3
Q3	3.09	4.91
Max (Q4)	4.83	5.81
hidden box	1.14	1.7
50th %tile	0.41	0.1
75th %tile	0.34	0.61
Top Whisker	1.74	0.9
Bottom Whisker	1.14	1.7
	Chloride	
	Dry	Wet
min	6	15
Q1	9	21
Median (Q2)	12	27
Q3	17	32
Max (Q4)	31	47
hidden box	3	6
50th %tile	3	6
75th %tile	5	5
Top Whisker	14	15
Bottom Whisker	3	6
	Iron	

Top Whisker	72	34
Bottom Whisker	54	60
	DO	
	Dry	Wet
min	0.52	1.69
Q1	1.75	3.05
Median (Q2)	2.63	3.61
Q3	3.64	4.84
Max (Q4)	4.73	6.18
hidden box	1.23	1.36
50th %tile	0.88	0.56
75th %tile	1.01	1.23
Top Whisker	1.09	1.34
Bottom Whisker	1.23	1.36
	TDS	
	Dry	Wet
min	206.4	305.2
Q1	303.4	438
Median (Q2)	387.8	510.4
Q3	423.5	537.6
Max (Q4)	465.3	875
hidden box	97	132.8
50th %tile	84.4	72.4
75th %tile	35.7	27.2
Top Whisker	41.8	337.4
Bottom Whisker	97	132.8
	Hardness	
	Dry	Wet
min	48	63
Q1	144	201
Median (Q2)	163	227
Q3	179	248
Max (Q4)	241	340
hidden box	96	138
50th %tile	19	26
75th %tile	16	21
Top Whisker	62	92
Bottom Whisker	96	138
	Nitrate	
	Dry	Wet
min	0.56	1.43
Q1	0.76	2.7
Median (Q2)	1.5	3.43
Q3	2.1	3.98
Max (Q4)	3.4	5.83
hidden box	0.2	1.27
50th %tile	0.74	0.73
75th %tile	0.6	0.55
Top Whisker	1.3	1.85
Bottom Whisker	0.2	1.27

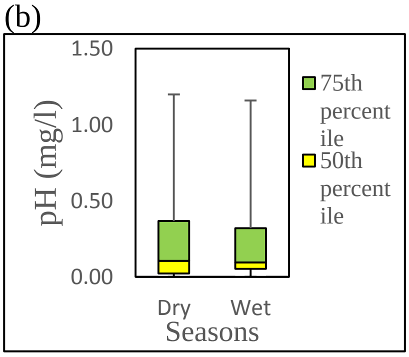
	Dry	Wet
min	0.01	0.02
Q1	0.05	0.08
Median (Q2)	0.13	0.18
Q3	0.2	0.27
Max (Q4)	0.25	0.34
hidden box	0.04	0.06
50th %tile	0.08	0.1
75th %tile	0.07	0.09
Top Whisker	0.05	0.07
Bottom Whisker	0.04	0.06

Appendix IV: Plots of temp, pH, EC, turbidity, and TDS for BHs

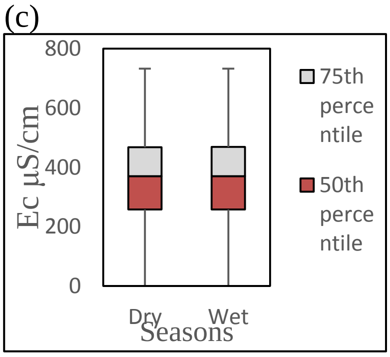
(a)



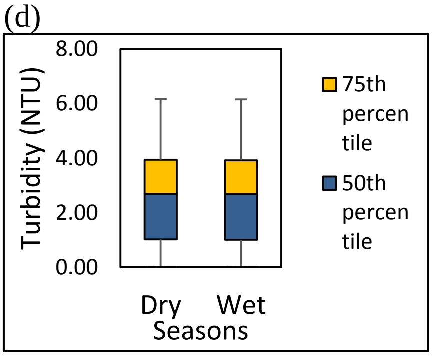
(b)



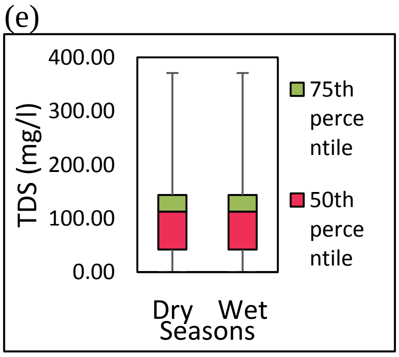
(c)



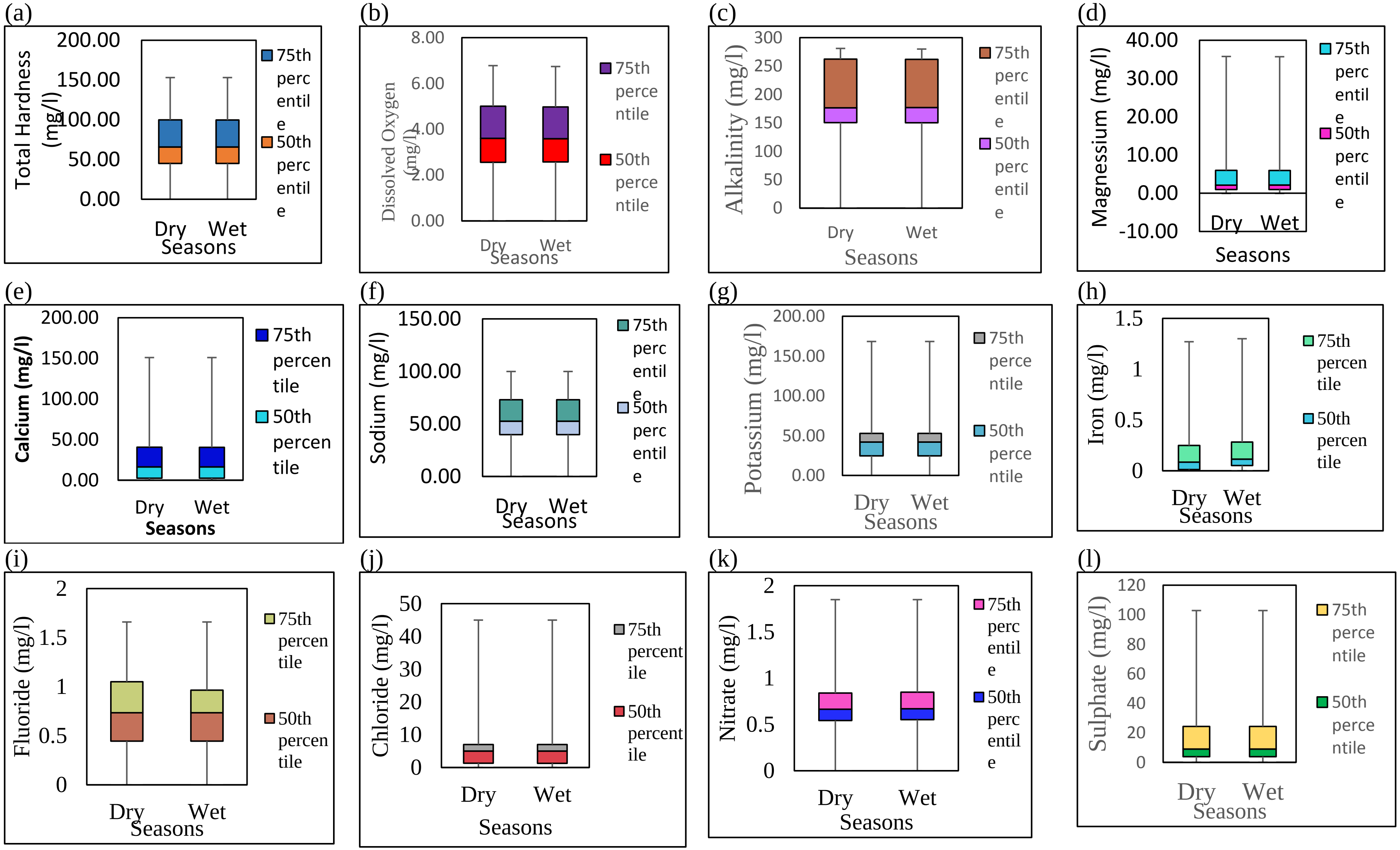
(d)



(e)



Appendix V: Plots of TH, DO, TA, Mg, Ca, Na, K, Fe, F, Cl, NO and SO for BHs



Appendix VI: Statistical output of ANOVA for BHs in dry season

TEMPRATURE DRY SEASON

	ByPass	Kiwanja	KU	Membley	Sukari	Wendani
SMPL 1	24.5	23.27	24.1	21.81	24.3	21.2
SMPL 2	22.1	22.3	22.2	21.57	28.8	22.85
SMPL 3	22.11	24.8	22.5	21.27	21.6	21.5
SMPL 4	22.1	21.4	28.2	22.2	23.01	22.31
SMPL 5	23.6	23.6	24.21	21.9	22.8	21.57

Anova: Single Factor Temperature Dry Season

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Bypass	5	114.41	22.882	1.23812
Kiwanja	5	115.37	23.074	1.67388
KU	5	121.21	24.242	5.72282
Membley	5	108.75	21.75	0.12285
Sukari	5	120.51	24.102	7.81452
Wendani	5	109.43	21.886	0.45713

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	27.896	5.000	5.579	1.966	0.120	2.621
Within Groups	68.117	24.000	2.838			
Total	96.013	29				

pH (Dry season)

	ByPass	Kiwanja	KU	Membley	Sukari	Wendani
SMPL 1	7.62	7.57	7.16	7.4	7.13	7.5
SMPL 2	7.02	7.03	7.04	7.19	7.2	7.12
SMPL 3	7.04	7.44	7.11	7.11	7.04	7.03
SMPL 4	7.35	7.05	7.17	8.22	7.04	7.4
SMPL 5	8	7.1	7.03	7.16	7.1	7.05

Anova: Single Factor pH Dry Season

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Bypass	5	37.03	7.406	0.17118
Kiwanja	5	36.19	7.238	0.06217
KU	5	35.51	7.102	0.00427
Membley	5	37.08	7.416	0.21423
Sukari	5	35.51	7.102	0.00452
Wendani	5	36.1	7.22	0.04645

ANOVA

Source of Variation	*SS*	*Df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.484	5.000	0.097	1.154	0.360	2.621
Within Groups	2.011	24.000	0.084			
Total	2.495	29				

EC (Dry season)

	Bypass	Kiwanja	KU	Membley	Sukari	Wendani
SMPL 1	313	460.01	357.4	320.98	315.98	458.01
SMPL 2	68.45	515.98	64.22	270	796.93	410.954
SMPL 3	577.18	464	466.41	366.91	716.98	576.13
SMPL 4	325.58	277.954	661.01	493.954	534.3	640.93
SMPL 5	355	280.954	526.3	399	350.75	593.9

Anova: Single Factor EC Dry Season

Turbidity (Dry season)

	Bypass	Kiwanja	KU	Membley	Sukari	Wendani
SMPL 1	1.16	0.6	3.63	6.34	0.31	0.5
SMPL 2	5.25	4.18	3.26	5.14	1.42	1.77
SMPL 3	3.76	0.17	2.15	3.36	3.9	4.3
SMPL 4	1.28	0.53	0.23	5.87	3.36	2.46
SMPL 5	1.26	2.14	3.87	6.07	0.29	4.48

Anova: Single Factor Turbidity Dry Season

SUMMARY

Groups	Count	Sum	Average	Variance
Bypass	5	1639.21	327.842	32604.15
Kiwanja	5	1998.9	399.78	12553.87
KU	5	2075.34	415.068	50478.99
Membley	5	1850.84	370.169	7154.49
Sukari	5	2714.94	542.989	45830.44
Wendani	5	2679.92	535.985	9423.018

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	195640.90	5.00000	39128.18	1.485	0.231	2.621
Within Groups	632179.86	#######	26340.83			
Total	827820.8	29				

TDS (Dry season)

	Bypass	Kiwanja	KU	Membley	Sukari	Wendani
SMPL 1	231.39	344.23	205.97	240.67	237.06	345.97
SMPL 2	230.97	383.74	361.88	206.36	576.77	300.39
SMPL 3	329.74	336.06	269.63	307.84	345.16	331.96
SMPL 4	510.03	213.29	380.64	436.83	307.84	465.27
SMPL 5	305.57	209.33	304.14	351.09	305.96	342.04

Anova: Single Factor TDS Dry Season

SUMMARY

Groups	Count	Sum	Average	Variance
Bypass	5	1607.7	321.54	13045.18
Kiwanja	5	1486.65	297.33	6493.258
KU	5	1522.26	304.452	5003.49
Membley	5	1542.79	308.558	8329.101
Sukari	5	1772.79	354.558	16954.15
Wendani	5	1785.63	357.126	3974.867

SUMMARY

Groups	Count	Sum	Average	Variance
Bypass	5	12.71	2.542	3.49072
Kiwanja	5	7.62	1.524	2.77723
KU	5	13.14	2.628	2.23122
Membley	5	26.78	5.356	1.44323
Sukari	5	9.28	1.856	2.86813
Wendani	5	13.51	2.702	2.87272

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	45.76028	5.00000	9.15206	3.50134	######	2.62065
Within Groups	62.73300	24.00000	2.61388			
Total	108.493	29				

DO (Dry season)

	Bypass	Kiwanja	KU	Membley	Sukari	Wendani
SMPL 1	5.31	6.49	2.01	6.26	7.65	7.75
SMPL 2	3.68	4.91	3.74	3.6	5.82	6.82
SMPL 3	7.8	5.99	2.05	3.94	3.45	5.99
SMPL 4	4.34	5.2	1.02	3.74	3.98	6.16
SMPL 5	1.66	5.78	2.73	2.17	3.57	6.04

Anova: Single Factor DO Dry Season

SUMMARY

Groups	Count	Sum	Average	Variance
Bypass	5	22.79	4.558	5.07322
Kiwanja	5	28.37	5.674	0.39633
KU	5	11.55	2.31	1.01075
Membley	5	19.71	3.942	2.16772
Sukari	5	24.47	4.894	3.28163
Wendani	5	32.76	6.552	0.55967

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	16845.06	5.00	3369.01	0.38	0.86	2.62
Within Groups	215200.19	24.00	8966.67			
Total	232045.2	29				

Hardness (Dry season)

	Bypass	Kiwanja	KU	Membley	Sukari	Wendani
SMPL 1	47.97	119.98	98.97	150.01	104.98	149.97
SMPL 2	41.96	167.97	68.98	143.97	107.98	120.01
SMPL 3	108.01	74.98	134.96	86.98	48.01	89.96
SMPL 4	44.98	86.96	104.98	149.96	107.96	194.98
SMPL 5	51.96	135.01	107.38	155.01	166.98	90.01

Anova: Single Factor Hardness Dry Season

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Bypass	5	294.88	58.976	765.0304
Kiwanja	5	584.9	116.98	1399.815
KU	5	515.27	103.054	554.5333
Membley	5	685.93	137.186	802.9975
Sukari	5	535.91	107.182	1770.804
Wendani	5	644.93	128.986	1979.566

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	18990.929	5.000	3798.186	3.133	0.026	2.621
Within Groups	29090.986	24.000	1212.124			
Total	48081.91	29				

Magnesium (Dry season)

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	53.554	5.000	10.711	5.146	0.002	2.621
Within Groups	49.957	24.000	2.082			
Total	103.512	29				

Alkalinity (Dry season)

	Bypass	Kiwanja	KU	Membley	Sukari	Wendani
SMPL 1	187.99	279.99	176.92	198.97	184.99	299.93
SMPL 2	20.92	60.05	19.97	135.05	300.05	226.97
SMPL 3	283.05	300.15	246.05	168.15	27.92	300.05
SMPL 4	178.99	160.05	299.93	179.97	275.97	299.92
SMPL 5	193.99	93.97	267.99	199.92	187.98	301.05

Anova: Single Factor Alkalinity Dry Season

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Bypass	5	864.94	172.988	8985.12
Kiwanja	5	894.21	178.842	11653.6
KU	5	1010.86	202.172	12412.3
Membley	5	882.06	176.412	713.306
Sukari	5	976.91	195.382	11414
Wendani	5	1427.92	285.584	1073.85

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	45313.9	5.00	9062.78	1.176	0.350	2.621
Within Groups	185008.9	24.00	7708.70			
Total	230323	29				

Calcium (Dry season)

	Bypass	Kiwanja	KU	Membley	Sukari	Wendani
SMPL 1	2.89	29.8	3.485	0.48	3.47	6.23
SMPL 2	1.75	7.437	1.2	6.17	20.3	3.77
SMPL 3	3.37	0.33	31.3	1.55	1.36	35.99
SMPL 4	8.94	1.2	0.86	0.251	2.95	9.95
SMPL 5	0.785	0.47	1.77	1.84	0.35	1.69

Anova: Single Factor Magnesium Dry Season

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Bypass	5	17.735	3.547	10.10132
Kiwanja	5	39.237	7.8474	159.3026
KU	5	38.615	7.723	174.731
Membley	5	10.291	2.0582	5.742366
Sukari	5	28.43	5.686	68.28813
Wendani	5	57.63	11.526	196.4803

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	288.109	5.000	57.622	0.562	0.728	2.621
Within Groups	2458.583	24.000	102.441			
Total	2746.692	29				

Sodium (Dry season)

	Bypass	Kiwanja	KU	Membley	Sukari	Wendani
SMPL 1	88.08	97.28	105.65	66.49	58.53	84.31
SMPL 2	89	60.17	13.09	34.88	113	60.91
SMPL 3	85.95	27.18	66.41	52.37	54.19	83.73
SMPL 4	30.86	61.81	79.05	24.62	86.11	98.67
SMPL 5	44.62	26.75	94.98	64.85	80.37	59.35

Anova: Single Factor Sodium Dry Season

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*

	Bypass	Kiwanja	KU	Membley	Sukari	Wendani
SMPL 1	0.6	14.68	5.25	35.89	0.6	4.22
SMPL 2	0.6	151.52	42.99	54.77	2.41	2.86
SMPL 3	57.13	3.84	28.84	2.01	3.82	52.41
SMPL 4	4.22	2.23	19.4	33.54	80.72	101.95
SMPL 5	35.89	54.79	12.3	24.1	35.89	2.86

Anova: Single Factor Calcium Dry Season

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Bypass	5	98.44	19.688	658.093
Kiwanja	5	227.06	45.412	3971.06
KU	5	108.78	21.756	217.12
Membley	5	150.31	30.062	369.752
Sukari	5	123.44	24.688	1194.27
Wendani	5	164.3	32.86	1943.97

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	2215.636	5.000	443.13	0.318	0.897	2.621
Within Groups	33417.05	24.000	1392.38			
Total	35632.7	29				

Potassium (Dry season)

	Bypass	Kiwanja	KU	Membley	Sukari	Wendani
SMPL 1	32.5	64.62	33.4	35.5	52.49	80.73
SMPL 2	10.62	120.75	11.6	52.74	118.25	54.21
SMPL 3	80.01	178.94	47.04	39.2	15.83	76.5
SMPL 4	34.4	32.69	54.8	37.43	56.45	107.15
SMPL 5	50.7	60.11	56.05	35.8	34.97	52.5

Anova: Single Factor Potassium Dry Season

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*

Bypass	5	338.51	67.702	772.9922
Kiwanja	5	273.19	54.638	858.0158
KU	5	359.18	71.836	1302.902
Membley	5	243.21	48.642	340.3994
Sukari	5	392.2	78.44	560.3545
Wendani	5	386.97	77.394	284.4881

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	3753.778	5.000	750.756	1.094	0.389	2.621
Within Groups	16476.607	24.000	686.525			
Total	20230.38	29				

Iron (Dry season)

	Bypass	Kiwanja	KU	Membley	Sukari	Wendani
SMPL 1	0.05	0.11	0.14	0.27	0.04	0.1
SMPL 2	0.09	0.14	0.37	0.27	0.08	0.02
SMPL 3	0.03	0.02	0.15	0.06	1.29	0.25
SMPL 4	0.33	0.03	0.22	0.03	0.44	0.03
SMPL 5	0.36	0.02	0.36	0.07	0.03	0.27

Anova: Single Factor Iron Dry Season

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Bypass	5	0.86	0.172	0.02552
Kiwanja	5	0.32	0.064	0.00323
KU	5	1.24	0.248	0.01237
Membley	5	0.7	0.14	0.0143
Sukari	5	1.88	0.376	0.28993
Wendani	5	0.67	0.134	0.01423

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*

Bypass	5	208.23	41.646	663.134
Kiwanja	5	457.11	91.422	3416.94
KU	5	202.89	40.578	343.663
Membley	5	200.67	40.134	51.8382
Sukari	5	277.99	55.598	1485.67
Wendani	5	371.09	74.218	501.03

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	11363.82	5.00	2272.76	2.110	0.099	2.621
Within Groups	25849.10	24.00	1077.05			
Total	37212.92	29				

Fluoride (Dry season)

	Bypass	Kiwanja	KU	Membley	Sukari	Wendani
SMPL 1	0.45	1.26	1.37	1.28	1.11	1.26
SMPL 2	0.67	0.7	0.3	0.84	1.28	0.65
SMPL 3	0.62	1.56	0.94	0.78	0.51	0.75
SMPL 4	0.6	1	1.04	1.18	0.85	1.25
SMPL 5	0.21	0.5	1.31	1.87	1.26	0.95

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Bypass	5	2.55	0.51	0.03485
Kiwanja	5	5.02	1.004	0.18028
KU	5	4.96	0.992	0.18197
Membley	5	5.95	1.19	0.1903
Sukari	5	5.01	1.002	0.10517
Wendani	5	4.86	0.972	0.07842

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*

Between Groups	0.299	5.000	0.060	0.998	0.440	2.621
Within Groups	1.438	24.000	0.060			
Total	1.737	29				

Chloride (Dry season)

	Bypass	Kiwanja	KU	Membley	Sukari	Wendani
SMPL 1	5.96	5.01	11.98	9.98	4.97	5.01
SMPL 2	10.01	14.96	6.96	8.98	9.98	9.96
SMPL 3	12.97	49.98	10.01	19.96	7.96	9.98
SMPL 4	9.98	49.97	6.98	4.98	10.01	14.98
SMPL 5	11.98	4.98	14.97	6.01	9.97	4.97

Anova: Single Factor Chloride Dry Season

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Bypass	5	50.9	10.18	7.22535
Kiwanja	5	124.9	24.98	537.1754
KU	5	50.9	10.18	11.70535
Membley	5	49.91	9.982	35.34032
Sukari	5	42.89	8.578	4.83837
Wendani	5	44.9	8.98	17.45035

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	999.395	5.000	199.879	1.954	0.122	2.621
Within Groups	2454.940	24.000	102.289			
Total	3454.335	29				

Sulphate (Dry season)

	Bypass	Kiwanja	KU	Membley	Sukari	Wendani
SMPL 1	33.91	33.42	56.72	53.82	33.91	34
SMPL 2	55.64	86.98	80.6	42.56	132.92	36.52

Between Groups	1.295	5.000	0.259	2.015	0.113	2.621
Within Groups	3.084	24.000	0.128			
Total	4.379	29				

Nitrate (Dry season)

	Bypass	Kiwanja	KU	Membley	Sukari	Wendani
SMPL 1	0.77	0.72	0.69	0.64	0.9	0.83
SMPL 2	1.17	1.08	0.74	0.54	0.67	0.82
SMPL 3	1.98	0.97	0.97	0.63	0.94	0.54
SMPL 4	0.77	1.51	1.01	0.68	0.96	1.51
SMPL 5	0.73	0.13	1.48	0.66	0.89	0.44

Anova: Single Factor Nitrate Dry Season

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Bypass	5	5.42	1.084	0.28318
Kiwanja	5	4.41	0.882	0.25827
KU	5	4.89	0.978	0.09817
Membley	5	3.15	0.63	0.0029
Sukari	5	4.36	0.872	0.01357
Wendani	5	4.14	0.828	0.17467

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.582	5.000	0.116	0.841	0.534	2.621
Within Groups	3.323	24.000	0.138			
Total	3.905	29				

SMPL 3	33.95	119.67	33.04	34.78	33.66	30.15
SMPL 4	33.91	40.95	54.53	54.03	30.35	40.99
SMPL 5	53.53	37.05	37.39	54.03	33.91	97.12

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Bypass	5	210.94	42.188	128.6281
Kiwanja	5	318.07	63.614	1454.806
KU	5	262.28	52.456	354.6333
Membley	5	239.22	47.844	77.70863
Sukari	5	264.75	52.95	2000.777
Wendani	5	238.78	47.756	777.0074

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1315.309	5.000	263.062	0.329	0.890	2.621
Within Groups	19174.244	24.000	798.927			
Total	20489.553	29				

Appendix VII: Statistical output of ANOVA for BHs in wet Season

Temperature (Wet season)

	Bypass	Kiwanja	KU	Membley	Sukari	Wendani
SMPL 1	24.7	23.5	24.2	21.6	24.2	21.4
SMPL 2	22	22.2	22.1	21.8	29	22.8
SMPL 3	21.9	24.7	22.7	21.5	21.8	21.7
SMPL 4	22	21.3	28.1	22.4	22.8	22.1
SMPL 5	23.8	23.8	24	22.1	23	21.8

Anova: Single Factor for Temperature Wet Season

SUMMARY

Ph Wet season

	Bypass	Kiwanja	KU	Membley	Sukari	Wendani
SMPL 1	7.61	7.61	7.06	7.41	7.16	7.4
SMPL 2	7.06	7.06	7.07	7.23	7.1	7.15
SMPL 3	7.07	7.34	7.06	7.01	7.05	7.04
SMPL 4	7.3	7.09	7.07	8.17	7.08	7.41
SMPL 5	8.01	7.11	7.06	7.2	7.13	7.08

Anova: Single Factor for pH Wet Season

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Bypass	5	114.4	22.88	1.667
Kiwanja	5	115.5	23.1	1.815
KU	5	121.1	24.22	5.477
Membley	5	109.4	21.88	0.137
Sukari	5	120.8	24.16	8.048
Wendani	5	109.8	21.96	0.283

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	25.94	5	5.19	1.79	0.15	2.62
Within Groups	69.708	24	2.9045			
Total	95.6467	29				

Turbidity (wet season)

	Bypass	Kiwanja	KU	Membley	Sukari	Wendani
SMPL 1	1.2	0.63	3.66	6.36	0.3	0.52
SMPL 2	5.27	4.2	3.28	5.18	1.44	1.79
SMPL 3	3.79	0.21	2.17	3.38	3.91	4.29
SMPL 4	1.3	0.55	0.27	5.9	3.38	2.5
SMPL 5	1.25	2.13	3.9	6.1	0.32	4.51

Anova: Single Factor for Turbidity Wet Season

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Bypass	5	12.81	2.562	3.50257
Kiwanja	5	7.72	1.544	2.75018
KU	5	13.28	2.656	2.21853
Membley	5	26.92	5.384	1.44728
Sukari	5	9.35	1.87	2.8735
Wendani	5	13.61	2.722	2.85557

ANOVA

Groups	*Count*	*Sum*	*Average*	*Variance*
Bypass	5	37.05	7.41	0.1626
Kiwanja	5	36.21	7.242	0.0547
KU	5	35.32	7.064	3.00E-05
Membley	5	37.02	7.404	0.2035
Sukari	5	35.52	7.104	0.0018
Wendani	5	36.08	7.216	0.0313

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.53	5	0.11	1.4	0.26	2.62
Within Groups	1.81556	24	0.07565			
Total	2.3448	29				

EC (Wet season)

	Bypass	Kiwanja	KU	Membley	Sukari	Wendani
SMPL 1	314	460	358.4	321	316	458
SMPL 2	68.52	516	64.21	271	797	411
SMPL 3	577.2	465	466.4	366.9	717	576.2
SMPL 4	325.6	278	661	494	535.3	641
SMPL 5	356	281	527.3	400	350.8	594.9

Anova: Single Factor for Electrical Conductivity Wet Season

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Bypass	5	1641.3	328.264	32604
Kiwanja	5	2000	400	12582
KU	5	2077.3	415.462	50506
Membley	5	1852.9	370.58	7121.5
Sukari	5	2716.1	543.22	45830
Wendani	5	2681.1	536.22	9454.8

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	46.01	5.00	9.20	3.53	0.02	2.62
Within Groups	62.591	24.000	2.608			
Total	108.602	29				

DO Wet season

	Bypass	Kiwanja	KU	Membley	Sukari	Wendani
SMPL 1	5.34	6.5	1.94	6.28	7.71	7.72
SMPL 2	3.61	4.84	3.71	3.61	5.83	6.88
SMPL 3	7.77	5.96	2.11	3.91	3.42	6.02
SMPL 4	4.4	5.13	1.03	3.8	4.04	6.18
SMPL 5	1.69	5.81	2.76	2.2	3.6	5.97

Anova: Single Factor for Dissolved Oxygen Wet Season

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Bypass	5	22.81	4.562	5.01937
Kiwanja	5	28.24	5.648	0.44267
KU	5	11.55	2.31	0.99445
Membley	5	19.8	3.96	2.15765
Sukari	5	24.6	4.92	3.34475
Wendani	5	32.77	6.554	0.55798

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	53.27	5.00	10.65	5.11	0.00	2.62
Within Groups	50.0675	24	2.08615			
Total	103.333	29				

Hardness (Wet season)

	Bypass	Kiwanja	KU	Membley	Sukari	Wendani

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	195311	5	39062.3	1.48	0.23	2.62
Within Groups	632393	24	26349.7			
Total	827704	29				

TDS (Wet Season)

	Bypass	Kiwanja	KU	Membley	Sukari	Wendani
SMPL 1	231.4	344.2	206	240.7	237.1	346
SMPL 2	231	383.7	361.87	206.4	576.8	300.4
SMPL 3	329.7	336.1	269.6	307.8	345.13	332
SMPL 4	510	213.3	380.6	436.8	307.8	465.3
SMPL 5	305.6	209.3	304.1	351.1	306	342

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Bypass	5	1607.7	321.54	13040
Kiwanja	5	1486.6	297.32	6492.5
KU	5	1522.2	304.434	5000.7
Membley	5	1542.8	308.56	8324.3
Sukari	5	1772.8	354.566	16955
Wendani	5	1785.7	357.14	3975.8

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	16858	5	3371.6	0.38	0.86	2.62
Within Groups	215155	24	8964.8			
Total	232013	29				

Alkalinity (Wet season)

	Bypass	Kiwanja	KU	Membley	Sukari	Wendani

SMPL 1	48	120	99	150	105	150
SMPL 2	42	168	69	144	108	120
SMPL 3	108	75	135	87	48	90
SMPL 4	45	87	105	150	108	195
SMPL 5	52	135	107.4	155	167	90

Anova: Single Factor for Hardness Wet Season

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Bypass	5	295	59	764
Kiwanja	5	585	117	1399.5
KU	5	515.4	103.08	554.832
Membley	5	686	137.2	802.7
Sukari	5	536	107.2	1771.7
Wendani	5	645	129	1980

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	18985.71	5.00	3797.14	3.13	0.03	2.62
Within Groups	29090.9	24	1212.12			
Total	48076.6	29				

Magnesium Wet season

	Bypass	Kiwanja	KU	Membley	Sukari	Wendani
SMPL 1	2.9	30.9	3.49	0.48	3.49	6.21
SMPL 2	1.76	7.49	1.21	6.16	20.33	3.76
SMPL 3	3.38	0.32	31.34	1.54	1.37	35.96
SMPL 4	8.94	1.21	0.87	0.26	2.99	9.94
SMPL 5	0.78	0.48	1.76	1.86	0.37	1.71

Anova: Single Factor for Magnesium Wet Season

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Bypass	5	17.76	3.552	10.09512

SMPL 1	189	281	177	199	186	300
SMPL 2	21	60	20	135	300	227
SMPL 3	282	300	246	168	28	300
SMPL 4	180	160	300	180	276	300
SMPL 5	195	94	269	200	188	300

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Bypass	5	867	173.4	8943.3
Kiwanja	5	895	179	11698
KU	5	1012	202.4	12444.3
Membley	5	882	176.4	716.3
Sukari	5	978	195.6	11400.8
Wendani	5	1427	285.4	1065.8

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	44994.97	5.00	8998.99	1.17	0.35	2.62
Within Groups	185074	24	7711.42			
Total	230069	29				

Calcium (Wet season)

	Bypass	Kiwanja	KU	Membley	Sukari	Wendani
SMPL 1	0.61	14.67	5.24	35.9	0.61	4.23
SMPL 2	0.61	151.51	42.98	54.78	2.42	2.87
SMPL 3	57.14	3.83	28.83	2.02	3.83	52.42
SMPL 4	4.23	2.22	19.39	33.55	80.73	101.96
SMPL 5	35.9	54.78	12.31	24.11	35.9	2.87

Anova: Single Factor for Calcium Wet Season

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Bypass	5	98.49	19.698	658.093

Kiwanja	5	40.4	8.08	171.5688
KU	5	38.67	7.734	175.1551
Membley	5	10.3	2.06	5.7142
Sukari	5	28.55	5.71	68.3556
Wendani	5	57.58	11.516	196.1149

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	290.94	5.00	58.19	0.56	0.73	2.62
Within Groups	2508.01	24	104.501			
Total	2798.95	29				

Sodium (wet season)

	Bypass	Kiwanja	KU	Membley	Sukari	Wendani
SMPL 1	88.09	97.29	105.66	66.5	58.54	84.32
SMPL 2	0.9	60.18	13.1	34.89	113.01	60.92
SMPL 3	85.96	27.19	66.42	52.38	54.2	83.74
SMPL 4	30.87	61.82	79.06	24.63	86.12	98.68
SMPL 5	44.63	26.76	94.99	64.86	80.38	59.36

Anova: Single Factor for Sodium Wet Season

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Bypass	5	250.45	50.09	1387.383
Kiwanja	5	273.24	54.648	858.0158
KU	5	359.23	71.846	1302.902
Membley	5	243.26	48.652	340.3994
Sukari	5	392.25	78.45	560.3545
Wendani	5	387.02	77.404	284.4881

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	4825.6	5.0	965.1	1.2	0.3	2.6

Kiwanja	5	227.01	45.402	3971.06
KU	5	108.75	21.75	217.026
Membley	5	150.36	30.072	369.752
Sukari	5	123.49	24.698	1194.27
Wendani	5	164.35	32.87	1943.97

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	2213.54	5	442.71	0.32	0.9	2.62
Within Groups	33416.7	24	1392.36			
Total	35630.2	29				

Potassium (Wet season)

	Bypass	Kiwanja	KU	Membley	Sukari	Wendani
SMPL 1	32.7	64.61	33.8	35.49	52.51	80.7
SMPL 2	10.61	120.74	11.62	52.76	118.3	54.2
SMPL 3	80.02	178.96	47.09	39.22	15.85	76.46
SMPL 4	34.39	32.7	54.79	37.44	56.49	107.19
SMPL 5	50.73	60.13	56.06	35.83	34.99	52.51

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Bypass	5	208.45	41.69	662.747
Kiwanja	5	457.14	91.428	3417.2
KU	5	203.36	40.672	342.136
Membley	5	200.74	40.148	51.8998
Sukari	5	278.14	55.628	1486.62
Wendani	5	371.06	74.212	501.538

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	11339.43	5.00	2267.89	2.11	0.10	2.62

Within Groups	18934.2	24.0	788.9			
Total	23759.8	29				

Iron (Wet season)

	Bypass	Kiwanja	KU	Membley	Sukari	Wendani
SMPL 1	0.07	0.13	0.13	0.3	0.07	0.08
SMPL 2	0.12	0.17	0.39	0.26	0.1	0.01
SMPL 3	0.02	0.04	0.14	0.08	1.31	0.27
SMPL 4	0.35	0.02	0.21	0.07	0.48	0.02
SMPL 5	0.31	0.01	0.38	0.06	0.05	0.31

Anova: Single Factor for Iron Wet Season

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Bypass	5	0.87	0.174	0.022
Kiwanja	5	0.37	0.074	0.005
KU	5	1.25	0.25	0.016
Membley	5	0.77	0.154	0.013
Sukari	5	2.01	0.402	0.289
Wendani	5	0.69	0.138	0.02

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.33	5	0.07	1.08	0.4	2.62
Within Groups	1.463	24	0.061			
Total	1.79155	29				

Chloride (Wet season)

	Bypass	Kiwanja	KU	Membley	Sukari	Wendani
SMPL 1	6	5	12	10	5	5
SMPL 2	10	15	7	9	10	10
SMPL 3	13	50	10	20	8	10
SMPL 4	10	50	7	5	10	15

Within Groups	25848.5	24	1077.02			
Total	37188	29				

Fluoride (wet season)

	Bypass	Kiwanja	KU	Membley	Sukari	Wendani
SMPL 1	0.44	1.37	1.48	1.27	1.22	1.37
SMPL 2	0.78	0.81	0.41	0.95	1.27	0.76
SMPL 3	0.73	1.67	1.05	0.89	0.5	0.86
SMPL 4	0.71	1.11	1.15	1.29	0.84	1.36
SMPL 5	0.32	0.61	1.3	1.98	1.25	1.06

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Bypass	5	2.98	0.596	0.04133
Kiwanja	5	5.57	1.114	0.18028
KU	5	5.39	1.078	0.16577
Membley	5	6.38	1.276	0.18778
Sukari	5	5.08	1.016	0.11453
Wendani	5	5.41	1.082	0.07842

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1.31	5.00	0.26	2.04	0.11	2.62
Within Groups	3.07244	24	0.12802			
Total	4.37783	29				

Nitrate (Wet season)

	Bypass	Kiwanja	KU	Membley	Sukari	Wendani
SMPL 1	0.76	0.76	0.71	0.68	0.92	0.85
SMPL 2	1.2	1.1	0.78	0.56	0.71	0.84
SMPL 3	2	1	1	0.65	0.97	0.58
SMPL 4	0.8	1.5	1	0.7	0.95	1.5

SMPL 5	12	5	15	6	10	5

Anova: Single Factor for Chloride Wet Season

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Bypass	5	51	10.2	7.2
Kiwanja	5	125	25	537.5
KU	5	51	10.2	11.7
Membley	5	50	10	35.5
Sukari	5	43	8.6	4.8
Wendani	5	45	9	17.5

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	999.37	5.00	199.87	1.95	0.12	2.62
Within Groups	2456.8	24	102.37			
Total	3456.17	29				

Sulphate (wet season)

	Bypass	Kiwanja	KU	Membley	Sukari	Wendani
SMPL 1	33.92	33.43	56.73	53.83	33.92	34.01
SMPL 2	55.65	86.99	80.61	42.57	132.93	36.53
SMPL 3	33.96	119.68	33.05	34.79	33.67	30.16
SMPL 4	33.92	40.96	54.54	54.04	30.36	41
SMPL 5	53.54	37.06	37.4	54.04	33.92	97.13

Anova: Single Factor for Sulphate Wet Season

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Bypass	5	210.99	42.198	128.6281
Kiwanja	5	318.12	63.624	1454.806
KU	5	262.33	52.466	354.6333
Membley	5	239.27	47.854	77.70863
Sukari	5	264.8	52.96	2000.777

SMPL 5	0.75	0.15	1.5	0.65	0.92	0.48

Anova: Single Factor for Nitrate Wet Season

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Bypass	5	5.51	1.102	0.28702
Kiwanja	5	4.51	0.902	0.24802
KU	5	4.99	0.998	0.09562
Membley	5	3.24	0.648	0.00287
Sukari	5	4.47	0.894	0.01103
Wendani	5	4.25	0.85	0.1581

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.580	5.000	0.120	0.87	0.52	2.62
Within Groups	3.211	24.000	0.134			
Total	3.79287	29				

Wendani	5	238.83	47.766	777.0074

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1315.31	5.00	263.06	0.33	0.89	2.62
Within Groups	19174.2	24	798.927			
Total	20489.6	29				

Appendix VIII: Post hoc test results for DO, TH, and turbidity in dry season

Univariate Tests

Dependent Variable: DO Dry Season

	Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Contrast	53.554	5	10.711	5.146	.002	.517
Error	49.957	24	2.082			

The F tests the effect of zones. This test is based on the linearly independent pairwise comparisons among the estimated marginal means.

Tukey's Post Hoc Test for Dissolved Oxygen across sampling zones during dry season

Multiple Comparisons

Dependent Variable: DO Dry Season

Tukey HSD

(I) Zones	(J) Zones	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Bypass	Kiwanja	-1.1160	.91248	.821	-3.9373	1.7053
	KU	2.2480	.91248	.175	-.5733	5.0693
	Membley	.6160	.91248	.983	-2.2053	3.4373
	Sukari	-.3360	.91248	.999	-3.1573	2.4853
	Wendani	-1.9940	.91248	.281	-4.8153	.8273
Kiwanja	Bypass	1.1160	.91248	.821	-1.7053	3.9373
	KU	3.3640*	.91248	.013	.5427	6.1853
	Membley	1.7320	.91248	.427	-1.0893	4.5533
	Sukari	.7800	.91248	.954	-2.0413	3.6013
	Wendani	-.8780	.91248	.925	-3.6993	1.9433
KU	Bypass	-2.2480	.91248	.175	-5.0693	.5733
	Kiwanja	-3.3640*	.91248	.013	-6.1853	-.5427
	Membley	-1.6320	.91248	.491	-4.4533	1.1893
	Sukari	-2.5840	.91248	.086	-5.4053	.2373
	Wendani	-4.2420*	.91248	.001	-7.0633	-1.4207
Membley	Bypass	-.6160	.91248	.983	-3.4373	2.2053
	Kiwanja	-1.7320	.91248	.427	-4.5533	1.0893
	KU	1.6320	.91248	.491	-1.1893	4.4533
	Sukari	-.9520	.91248	.898	-3.7733	1.8693
	Wendani	-2.6100	.91248	.081	-5.4313	.2113
Sukari	Bypass	.3360	.91248	.999	-2.4853	3.1573
	Kiwanja	-.7800	.91248	.954	-3.6013	2.0413
	KU	2.5840	.91248	.086	-.2373	5.4053
	Membley	.9520	.91248	.898	-1.8693	3.7733
	Wendani	-1.6580	.91248	.474	-4.4793	1.1633

Wendani	Bypass	1.9940	.91248	.281	-.8273	4.8153
	Kiwanja	.8780	.91248	.925	-1.9433	3.6993
	KU	4.2420*	.91248	.001	1.4207	7.0633
	Membley	2.6100	.91248	.081	-.2113	5.4313
	Sukari	1.6580	.91248	.474	-1.1633	4.4793

Based on observed means.

The error term is Mean Square (Error) = 2.082.

*. The mean difference is significant at the.05 level.

Univariate Tests

Dependent Variable: Hardness Dry Season

	Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Contrast	18990.929	5	3798.186	3.133	.026	.395
Error	29090.986	24	1212.124			

The F tests the effect of Zones. This test is based on the linearly independent pairwise comparisons among the estimated marginal means.

Tukey's Post Hoc Test for Hardness across sampling zones during dry season

Multiple Comparisons

Dependent Variable: Hardness Dry Season

Tukey HSD

(I) Zones	(J) Zones	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Bypass	Kiwanja	-58.0040	22.01930	.127	-126.0862	10.0782
	KU	-44.0780	22.01930	.370	-112.1602	24.0042
	Membley	-78.2100*	22.01930	.018	-146.2922	-10.1278
	Sukari	-48.2060	22.01930	.279	-116.2882	19.8762
	Wendani	-70.0100*	22.01930	.041	-138.0922	-1.9278
Kiwanja	Bypass	58.0040	22.01930	.127	-10.0782	126.0862
	KU	13.9260	22.01930	.987	-54.1562	82.0082
	Membley	-20.2060	22.01930	.938	-88.2882	47.8762
	Sukari	9.7980	22.01930	.998	-58.2842	77.8802
	Wendani	-12.0060	22.01930	.994	-80.0882	56.0762
KU	Bypass	44.0780	22.01930	.370	-24.0042	112.1602
	Kiwanja	-13.9260	22.01930	.987	-82.0082	54.1562
	Membley	-34.1320	22.01930	.637	-102.2142	33.9502
	Sukari	-4.1280	22.01930	1.000	-72.2102	63.9542
	Wendani	-25.9320	22.01930	.843	-94.0142	42.1502
Membley	Bypass	78.2100*	22.01930	.018	10.1278	146.2922

	Kiwanja	20.2060	22.01930	.938	-47.8762	88.2882
	KU	34.1320	22.01930	.637	-33.9502	102.2142
	Sukari	30.0040	22.01930	.748	-38.0782	98.0862
	Wendani	8.2000	22.01930	.999	-59.8822	76.2822
Sukari	Bypass	48.2060	22.01930	.279	-19.8762	116.2882
	Kiwanja	-9.7980	22.01930	.998	-77.8802	58.2842
	KU	4.1280	22.01930	1.000	-63.9542	72.2102
	Membley	-30.0040	22.01930	.748	-98.0862	38.0782
	Wendani	-21.8040	22.01930	.917	-89.8862	46.2782
Wendani	Bypass	70.0100*	22.01930	.041	1.9278	138.0922
	Kiwanja	12.0060	22.01930	.994	-56.0762	80.0882
	KU	25.9320	22.01930	.843	-42.1502	94.0142
	Membley	-8.2000	22.01930	.999	-76.2822	59.8822
	Sukari	21.8040	22.01930	.917	-46.2782	89.8862

Based on observed means.

The error term is Mean Square (Error) = 1212.124.

*. The mean difference is significant at the.05 level.

Univariate Tests

Dependent Variable: Turbidity Dry Season

	Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Contrast	45.760	5	9.152	3.501	.016	.422
Error	62.733	24	2.614			

The F tests the effect of Zones. This test is based on the linearly independent pairwise comparisons among the estimated marginal means.

Tukey's Post Hoc Test for Turbidity across sampling zones during dry season

Multiple Comparisons

Dependent Variable: Turbidity Dry Season

Tukey HSD

(I) Zones	(J) Zones	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Bypass	Kiwanja	1.0180	1.02252	.915	-2.1436	4.1796
	KU	-.0860	1.02252	1.000	-3.2476	3.0756
	Membley	-2.8140	1.02252	.101	-5.9756	.3476
	Sukari	.6860	1.02252	.984	-2.4756	3.8476
	Wendani	-.1600	1.02252	1.000	-3.3216	3.0016
Kiwanja	Bypass	-1.0180	1.02252	.915	-4.1796	2.1436

	KU	-1.1040	1.02252	.885	-4.2656	2.0576
	Membley	-3.8320*	1.02252	.011	-6.9936	-.6704
	Sukari	-.3320	1.02252	.999	-3.4936	2.8296
	Wendani	-1.1780	1.02252	.854	-4.3396	1.9836
KU	Bypass	.0860	1.02252	1.000	-3.0756	3.2476
	Kiwanja	1.1040	1.02252	.885	-2.0576	4.2656
	Membley	-2.7280	1.02252	.119	-5.8896	.4336
	Sukari	.7720	1.02252	.972	-2.3896	3.9336
	Wendani	-.0740	1.02252	1.000	-3.2356	3.0876
Membley	Bypass	2.8140	1.02252	.101	-.3476	5.9756
	Kiwanja	3.8320*	1.02252	.011	.6704	6.9936
	KU	2.7280	1.02252	.119	-.4336	5.8896
	Sukari	3.5000*	1.02252	.024	.3384	6.6616
	Wendani	2.6540	1.02252	.137	-.5076	5.8156
Sukari	Bypass	-.6860	1.02252	.984	-3.8476	2.4756
	Kiwanja	.3320	1.02252	.999	-2.8296	3.4936
	KU	-.7720	1.02252	.972	-3.9336	2.3896
	Membley	-3.5000*	1.02252	.024	-6.6616	-.3384
	Wendani	-.8460	1.02252	.959	-4.0076	2.3156
Wendani	Bypass	.1600	1.02252	1.000	-3.0016	3.3216
	Kiwanja	1.1780	1.02252	.854	-1.9836	4.3396
	KU	.0740	1.02252	1.000	-3.0876	3.2356
	Membley	-2.6540	1.02252	.137	-5.8156	.5076
	Sukari	.8460	1.02252	.959	-2.3156	4.0076

Based on observed means.

The error term is Mean Square (Error) = 2.614.

*. The mean difference is significant at the.05 level.

Profile Plots of Estimated Marginal Means of Turbidity in Boreholes During Dry Season

Appendix IX: Post hoc test results for DO, TH, and turbidity in wet season

Univariate Tests

Dependent Variable: DO Wet Season

	Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Contrast	53.265	5	10.653	5.107	.002	.515
Error	50.067	24	2.086			

The F tests the effect of Zones. This test is based on the linearly independent pairwise comparisons among the estimated marginal means.

Tukey's Post Hoc Test for Dissolved Oxygen across sampling zones during wet season

Multiple Comparisons

Dependent Variable: DO Wet Season

Tukey HSD

(I) Zones	(J) Zones	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Bypass	Kiwanja	-1.0860	.91349	.838	-3.9104	1.7384
	KU	2.2520	.91349	.174	-.5724	5.0764
	Membley	.6020	.91349	.985	-2.2224	3.4264
	Sukari	-.3580	.91349	.999	-3.1824	2.4664
	Wendani	-1.9920	.91349	.283	-4.8164	.8324
Kiwanja	Bypass	1.0860	.91349	.838	-1.7384	3.9104
	KU	3.3380*	.91349	.014	.5136	6.1624
	Membley	1.6880	.91349	.456	-1.1364	4.5124
	Sukari	.7280	.91349	.965	-2.0964	3.5524
	Wendani	-.9060	.91349	.916	-3.7304	1.9184
KU	Bypass	-2.2520	.91349	.174	-5.0764	.5724
	Kiwanja	-3.3380*	.91349	.014	-6.1624	-.5136
	Membley	-1.6500	.91349	.481	-4.4744	1.1744
	Sukari	-2.6100	.91349	.082	-5.4344	.2144
	Wendani	-4.2440*	.91349	.001	-7.0684	-1.4196
Membley	Bypass	-.6020	.91349	.985	-3.4264	2.2224
	Kiwanja	-1.6880	.91349	.456	-4.5124	1.1364
	KU	1.6500	.91349	.481	-1.1744	4.4744
	Sukari	-.9600	.91349	.896	-3.7844	1.8644
	Wendani	-2.5940	.91349	.085	-5.4184	.2304
Sukari	Bypass	.3580	.91349	.999	-2.4664	3.1824
	Kiwanja	-.7280	.91349	.965	-3.5524	2.0964
	KU	2.6100	.91349	.082	-.2144	5.4344
	Membley	.9600	.91349	.896	-1.8644	3.7844
	Wendani	-1.6340	.91349	.491	-4.4584	1.1904
Wendani	Bypass	1.9920	.91349	.283	-.8324	4.8164

	Kiwanja	.9060	.91349	.916	-1.9184	3.7304
	KU	4.2440*	.91349	.001	1.4196	7.0684
	Membley	2.5940	.91349	.085	-.2304	5.4184
	Sukari	1.6340	.91349	.491	-1.1904	4.4584

Based on observed means.

The error term is Mean Square(Error) = 2.086.

*. The mean difference is significant at the.05 level.

Univariate Tests

Dependent Variable: Turbidity wet season

	Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Contrast	46.012	5	9.202	3.529	.016	.424
Error	62.591	24	2.608			

The F tests the effect of Zones. This test is based on the linearly independent pairwise comparisons among the estimated marginal means.

Tukey's Post Hoc Test for Turbidity across sampling zones during wet season

Multiple Comparisons

Dependent Variable: Turbidity wet season

Tukey HSD

(I) Zones	(J) Zones	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Bypass	Kiwanja	1.0180	1.02136	.914	-2.1400	4.1760
	KU	-.0940	1.02136	1.000	-3.2520	3.0640
	Membley	-2.8220	1.02136	.099	-5.9800	.3360
	Sukari	.6920	1.02136	.983	-2.4660	3.8500
	Wendani	-.1600	1.02136	1.000	-3.3180	2.9980
Kiwanja	Bypass	-1.0180	1.02136	.914	-4.1760	2.1400
	KU	-1.1120	1.02136	.881	-4.2700	2.0460
	Membley	-3.8400*	1.02136	.011	-6.9980	-.6820
	Sukari	-.3260	1.02136	.999	-3.4840	2.8320
	Wendani	-1.1780	1.02136	.854	-4.3360	1.9800
KU	Bypass	.0940	1.02136	1.000	-3.0640	3.2520
	Kiwanja	1.1120	1.02136	.881	-2.0460	4.2700
	Membley	-2.7280	1.02136	.119	-5.8860	.4300
	Sukari	.7860	1.02136	.970	-2.3720	3.9440
	Wendani	-.0660	1.02136	1.000	-3.2240	3.0920
Membley	Bypass	2.8220	1.02136	.099	-.3360	5.9800

	Kiwanja	3.8400*	1.02136	.011	.6820	6.9980
	KU	2.7280	1.02136	.119	-.4300	5.8860
	Sukari	3.5140*	1.02136	.023	.3560	6.6720
	Wendani	2.6620	1.02136	.134	-.4960	5.8200
Sukari	Bypass	-.6920	1.02136	.983	-3.8500	2.4660
	Kiwanja	.3260	1.02136	.999	-2.8320	3.4840
	KU	-.7860	1.02136	.970	-3.9440	2.3720
	Membley	-3.5140*	1.02136	.023	-6.6720	-.3560
	Wendani	-.8520	1.02136	.958	-4.0100	2.3060
Wendani	Bypass	.1600	1.02136	1.000	-2.9980	3.3180
	Kiwanja	1.1780	1.02136	.854	-1.9800	4.3360
	KU	.0660	1.02136	1.000	-3.0920	3.2240
	Membley	-2.6620	1.02136	.134	-5.8200	.4960
	Sukari	.8520	1.02136	.958	-2.3060	4.0100

Based on observed means.

The error term is Mean Square (Error) = 2.608.

*. The mean difference is significant at the.05 level.

Univariate Tests

Dependent Variable: Hardness Wet Season

	Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Contrast	18985.707	5	3797.141	3.133	.026	.395
Error	29090.928	24	1212.122			

The F tests the effect of Zones. This test is based on the linearly independent pairwise comparisons among the estimated marginal means.

Tukey's Post Hoc Test for Hardness across sampling zones during wet season

Multiple Comparisons

Dependent Variable: Hardness Wet Season

Tukey HSD

(I) Zones	(J) Zones	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Bypass	Kiwanja	-58.0000	22.01928	.127	-126.0821	10.0821
	KU	-44.0800	22.01928	.370	-112.1621	24.0021
	Membley	-78.2000*	22.01928	.018	-146.2821	-10.1179
	Sukari	-48.2000	22.01928	.279	-116.2821	19.8821
	Wendani	-70.0000*	22.01928	.041	-138.0821	-1.9179
Kiwanja	Bypass	58.0000	22.01928	.127	-10.0821	126.0821

	KU	13.9200	22.01928	.987	-54.1621	82.0021
	Membley	-20.2000	22.01928	.938	-88.2821	47.8821
	Sukari	9.8000	22.01928	.998	-58.2821	77.8821
	Wendani	-12.0000	22.01928	.994	-80.0821	56.0821
KU	Bypass	44.0800	22.01928	.370	-24.0021	112.1621
	Kiwanja	-13.9200	22.01928	.987	-82.0021	54.1621
	Membley	-34.1200	22.01928	.637	-102.2021	33.9621
	Sukari	-4.1200	22.01928	1.000	-72.2021	63.9621
	Wendani	-25.9200	22.01928	.843	-94.0021	42.1621
Membley	Bypass	78.2000*	22.01928	.018	10.1179	146.2821
	Kiwanja	20.2000	22.01928	.938	-47.8821	88.2821
	KU	34.1200	22.01928	.637	-33.9621	102.2021
	Sukari	30.0000	22.01928	.748	-38.0821	98.0821
	Wendani	8.2000	22.01928	.999	-59.8821	76.2821
Sukari	Bypass	48.2000	22.01928	.279	-19.8821	116.2821
	Kiwanja	-9.8000	22.01928	.998	-77.8821	58.2821
	KU	4.1200	22.01928	1.000	-63.9621	72.2021
	Membley	-30.0000	22.01928	.748	-98.0821	38.0821
	Wendani	-21.8000	22.01928	.917	-89.8821	46.2821
Wendani	Bypass	70.0000*	22.01928	.041	1.9179	138.0821
	Kiwanja	12.0000	22.01928	.994	-56.0821	80.0821
	KU	25.9200	22.01928	.843	-42.1621	94.0021
	Membley	-8.2000	22.01928	.999	-76.2821	59.8821
	Sukari	21.8000	22.01928	.917	-46.2821	89.8821

Based on observed means.

The error term is Mean Square (Error) = 1212.122.

*. The mean difference is significant at the.05 level.

Appendix X: Statistical output of paired student-t test for BHs

t-Test: Paired Two Sample for Means

	Temp (Dry)	*Temp (Wet)*
Mean	22.989	23.033
Variance	3.311	3.298
Observations	30	30.000
Pearson Correlation	1	
Hypothesized Mean Difference	0	
df	29.000	
t Stat	-1.363	
P(T<=t) one-tail	0.092	
t Critical one-tail	1.699	
P(T<=t) two-tail	0.183	
t Critical two-tail	2.045	

t-Test: Paired Two Sample for Means

	pH (Dry Season)	*pH (Wet Season)*
Mean	7.247	7.240
Variance	0.086	0.081
Observations	30	30.000
Pearson Correlation	1	
Hypothesized Mean Difference	0	
df	29	
t Stat	0.749	
P(T<=t) one-tail	0.230	
t Critical one-tail	1.699	
P(T<=t) two-tail	0.460	
t Critical two-tail	2.045	

t-Test: Paired Two Sample for Means

	EC (Dry Season)	*EC (Wet Season)*
Mean	431.972	432.291
Variance	28545.543	28541.5329

t-Test: Paired Two Sample for Means

	TDS (Dry Season)	*TDS (Wet Season)*
Mean	323.927	323.927
Variance	8001.560	8000.455
Observations	30	30
Pearson Correlation	1.000	
Hypothesized Mean Difference	0	
df	29	
t Stat	0.111	
P(T<=t) one-tail	0.456	
t Critical one-tail	1.699	
P(T<=t) two-tail	0.912	
t Critical two-tail	2.045	

t-Test: Paired Two Sample for Means

	DO (Dry season)	*DO (Wet Season)*
Mean	4.655	4.659
Variance	3.569	3.563
Observations	30	30
Pearson Correlation	1	
Hypothesized Mean Difference	0	
df	29	
t Stat	-0.488	
P(T<=t) one-tail	0.315	
t Critical one-tail	1.699	
P(T<=t) two-tail	0.629	
t Critical two-tail	2.045	

t-Test: Paired Two Sample for Means

	Hardness (Dry Season)	*Hardness (Wet Season)*
Mean	108.727	108.747
Variance	1657.997	1657.815

Observations	30.000	30
Pearson Correlation	1.000	
Hypothesized Mean Difference	0.000	
df	29.000	
t Stat	-3.848	
P(T<=t) one-tail	0.000	
t Critical one-tail	1.699	
P(T<=t) two-tail	0.001	
t Critical two-tail	2.045	

t-Test: Paired Two Sample for Means

	Turbidity (dry season)	*Turbidity (wet season)*
Mean	2.768	2.790
Variance	3.741	3.745
Observations	30.000	30
Pearson Correlation	1.000	
Hypothesized Mean Difference	0.000	
df	29.000	
t Stat	-7.978	
P(T<=t) one-tail	0.000	
t Critical one-tail	1.699	
P(T<=t) two-tail	0.000	
t Critical two-tail	2.045	

t-Test: Paired Two Sample for Means

	Magnesium (Dry)	*Magnesium (Wet)*
Mean	6.398	6.442
Variance	94.714	96.516
Observations	30	30
Pearson Correlation	1.000	
Hypothesized Mean Difference	0	
df	29	
t Stat	-1.205	

Observations	30	30
Pearson Correlation	1.000	
Hypothesized Mean Difference	0	
df	29	
t Stat	-5.824	
P(T<=t) one-tail	0.000	
t Critical one-tail	1.699	
P(T<=t) two-tail	0.000	
t Critical two-tail	2.045	

t-Test: Paired Two Sample for Means

	Alkalinity (Dry Season)	*Alkalinity (Wet Season)*
Mean	201.897	202.033
Variance	7942.165	7933.413
Observations	30	30
Pearson Correlation	1.000	
Hypothesized Mean Difference	0	
df	29	
t Stat	-1.437	
P(T<=t) one-tail	0.081	
t Critical one-tail	1.699	
P(T<=t) two-tail	0.162	
t Critical two-tail	2.045	

t-Test: Paired Two Sample for Means

	Calcium (Dry Season)	*Calcium (Wet Season)*
Mean	29.078	29.082
Variance	1228.713	1228.628
Observations	30	30
Pearson Correlation	1.000	
Hypothesized Mean Difference	0	
df	29	
t Stat	-2.350	

P(T<=t) one-tail	0.119
t Critical one-tail	1.699
P(T<=t) two-tail	0.238
t Critical two-tail	2.045

t-Test: Paired Two Sample for Means

	Potassium (dry season)	*Potassium (wet season)*
Mean	57.266	57.296
Variance	1283.204	1282.343
Observations	30	30
Pearson Correlation	1.000	
Hypothesized Mean Difference	0	
df	29	
t Stat	-2.056	
P(T<=t) one-tail	0.024	
t Critical one-tail	1.699	
P(T<=t) two-tail	0.049	
t Critical two-tail	2.045	

t-Test: Paired Two Sample for Means

	Iron (Dry Season)	*Iron (wet season)*
Mean	0.189	0.199
Variance	0.060	0.062
Observations	30	30
Pearson Correlation	1.00	
Hypothesized Mean Difference	0	
df	29	
t Stat	-2.419	
P(T<=t) one-tail	0.011	
t Critical one-tail	1.699	
P(T<=t) two-tail	0.022	
t Critical two-tail	2.045	

t-Test: Paired Two Sample for Means

P(T<=t) one-tail	0.013
t Critical one-tail	1.699
P(T<=t) two-tail	0.026
t Critical two-tail	2.045

t-Test: Paired Two Sample for Means

	Fluoride (Dry Season)	*Fluoride (Wet Season)*
Mean	0.945	1.027
Variance	0.151	0.150959655
Observations	30	30
Pearson Correlation	0.991	
Hypothesized Mean Difference	0	
df	29	
t Stat	-8.700	
P(T<=t) one-tail	7.029E-10	
t Critical one-tail	1.699E+00	
P(T<=t) two-tail	1.406E-09	
t Critical two-tail	2.045E+00	

t-Test: Paired Two Sample for Means

	Chloride (Dry Season)	*chloride (wet season)*
Mean	12.147	12.16666667
Variance	119.115	119.1781609
Observations	30	30
Pearson Correlation	1.000	
Hypothesized Mean Difference	0	
df	29	
t Stat	-6.437	
P(T<=t) one-tail	2.423E-07	
t Critical one-tail	1.699	
P(T<=t) two-tail	4.845E-07	
t Critical two-tail	2.045	

t-Test: Paired Two Sample for Means

	Sodium (Dry Season)	*Sodium (Wet Season)*
Mean	66.442	66.485
Variance	697.599	699.1723086
Observations	30	30
Pearson Correlation	1.000	
Hypothesized Mean Difference	0	
Df	29	
t Stat	-1.303	
P(T<=t) one-tail	0.101	
t Critical one-tail	1.699	
P(T<=t) two-tail	0.203	
t Critical two-tail	2.045	

	Nitrates (Dry Season)	*Nitrates (Wet Season)*
Mean	0.879	0.899
Variance	0.135	0.130788621
Observations	30	30
Pearson Correlation	0.999	
Hypothesized Mean Difference	0	
df	29	
t Stat	-6.437	
P(T<=t) one-tail	2.423E-07	
t Critical one-tail	1.699	
P(T<=t) two-tail	4.845E-07	
t Critical two-tail	2.045	

t-Test: Paired Two Sample for Means

	Sulphate (dry Season)	*Sulphate Dry Season*
Mean	51.72862069	51.73862069
Variance	720.8083337	720.8083337
Observations	29	29
Pearson Correlation	1	
Hypothesized Mean Difference	0	
df	28	
t Stat	-432705965.2	
P(T<=t) one-tail	2.0906E-223	
t Critical one-tail	1.701130934	
P(T<=t) two-tail	4.1812E-223	
t Critical two-tail	2.048407142	

Appendix XI: Statistical output of paired student-t test for SHWs

Results of the Paired STUDENT t Test for 17 sampled shallow wells in Kamiti Marengeta Sub catchment

t-Test: Paired Two Sample for Electrical Conductivity Means

Summary Statistics	*EC (Wet)*	*EC (Dry)*
Mean	474.059	403.588
Variance	19621.934	16618.132
Observations	17.000	17.000
Pearson Correlation	0.962	
Hypothesized Mean Difference	0.000	
Df	16.000	
t Stat	7.491	
P(T<=t) one-tail	0.000	
t Critical one-tail	1.746	
P(T<=t) two-tail	0.000	
t Critical two-tail	2.120	

t-Test: Paired Two Sample for Magnesium Means

Summary Statistics	*Mg (Wet)*	*Mg (Dry)*
Mean	6.798	9.390
Variance	29.726	94.318
Observations	17.000	17.000
Pearson Correlation	0.927	
Hypothesized Mean Difference	0.000	
Df	16.000	
t Stat	-2.101	
P(T<=t) one-tail	0.026	
t Critical one-tail	1.746	
P(T<=t) two-tail	0.052	
t Critical two-tail	2.120	

t-Test: Paired Two Sample for Sulphate Means

Summary Statistics	*SO (Wet)*	*SO (Dry)*
Mean	49.653	37.728

t-Test: Paired Two Sample for Potassium Means

Summary Statistics	*K (Wet)*	*K (Dry)*
Mean	86.170	60.334
Variance	1290.201	904.463
Observations	17.000	17
Pearson Correlation	0.922	
Hypothesized Mean Difference	0.000	
df	16.000	
t Stat	7.499	
P(T<=t) one-tail	0.000	
t Critical one-tail	1.746	
P(T<=t) two-tail	0.000	
t Critical two-tail	2.120	

t-Test: Paired Two Sample for Sodium Means

Summary Statistics	*Na (Wet)*	*Na (Dry)*
Mean	85.547	59.958
Variance	2653.018	1006.209
Observations	17.000	17.000
Pearson Correlation	0.895	
Hypothesized Mean Difference	0.000	
df	16.000	
t Stat	3.896	
P(T<=t) one-tail	0.001	
t Critical one-tail	1.746	
P(T<=t) two-tail	0.001	
t Critical two-tail	2.120	

t-Test: Paired Two Sample for Calcium Means

Summary Statistics	*Ca (Wet)*	*Ca (Dry)*
Mean	62.738	53.070

Variance	229.041	274.910
Observations	17.000	17.000
Pearson Correlation	0.957	
Hypothesized Mean Difference	0.000	
Df	16.000	
t Stat	10.103	
P(T<=t) one-tail	0.000	
t Critical one-tail	1.746	
P(T<=t) two-tail	0.000	
t Critical two-tail	2.120	

t-Test: Paired Two Sample for Total Alkalinity Means

Summary Statistics	*T.Alk (Wet)*	*T.Alk (Dry)*
Mean	171.453	146.018
Variance	7280.260	5518.547
Observations	17.000	17.000
Pearson Correlation	0.951	
Hypothesized Mean Difference	0.000	
Df	16.000	
t Stat	3.847	
P(T<=t) one-tail	0.001	
t Critical one-tail	1.746	
P(T<=t) two-tail	0.001	
t Critical two-tail	2.120	

t-Test: Paired Two Sample for Temperature Means

Summary Statistics	*Temp (Wet)*	*Temp (Dry)*
Mean	21.875	22.373
Variance	1.797	1.748
Observations	17.000	17.000
Pearson Correlation	0.984	
Hypothesized Mean Difference	0.000	
Df	16.000	
t Stat	-8.491	
P(T<=t) one-tail	0.000	
t Critical one-tail	1.746	
P(T<=t) two-tail	0.000	
t Critical two-tail	2.120	

Variance	2268.404	1978.215
Observations	17.000	17.000
Pearson Correlation	0.995	
Hypothesized Mean Difference	0.000	
df	16.000	
t Stat	7.341	
P(T<=t) one-tail	0.000	
t Critical one-tail	1.746	
P(T<=t) two-tail	0.000	
t Critical two-tail	2.120	

t-Test: Paired Two Sample for Fluoride Means

Summary Statistics	*F (Wet)*	*F (Dry)*
Mean	0.907	0.842
Variance	0.123	0.119
Observations	17.000	17.000
Pearson Correlation	0.998	
Hypothesized Mean Difference	0.000	
df	16.000	
t Stat	12.222	
P(T<=t) one-tail	0.000	
t Critical one-tail	1.746	
P(T<=t) two-tail	0.000	
t Critical two-tail	2.120	

t-Test: Paired Two Sample for pH Means

Summary Statistics	*pH (Wet)*	*pH (Dry)*
Mean	7.456	6.949
Variance	0.178	0.397
Observations	17.000	17.000
Pearson Correlation	0.811	
Hypothesized Mean Difference	0.000	
df	16.000	
t Stat	5.514	
P(T<=t) one-tail	0.000	
t Critical one-tail	1.746	
P(T<=t) two-tail	0.000	
t Critical two-tail	2.120	

t-Test: Paired Two Sample for Total Dissolved Solids

Summary Statistics	*TDS (Wet)*	*TDS (Dry)*
Mean	505.049	359.888
Variance	16755.570	7405.919
Observations	17.000	17.000
Pearson Correlation	0.673	
Hypothesized Mean Difference	0.000	
Df	16.000	
t Stat	6.252	
P(T<=t) one-tail	0.000	
t Critical one-tail	1.746	
P(T<=t) two-tail	0.000	
t Critical two-tail	2.120	

t-Test: Paired Two Sample for Total Hardness Means

Summary Statistics	*TH (Wet)*	*TH (Dry)*
Mean	211.471	151.824
Variance	6177.515	2855.154
Observations	17.000	17.000
Pearson Correlation	0.920	
Hypothesized Mean Difference	0.000	
Df	16.000	
t Stat	6.810	
P(T<=t) one-tail	0.000	
t Critical one-tail	1.746	
P(T<=t) two-tail	0.000	
t Critical two-tail	2.120	

t-Test: Paired Two Sample for Nitrate Means

Summary Statistics	*NO (Wet)*	*NO (Dry)*
Mean	3.316	1.594
Variance	1.173	0.661
Observations	17.000	17.000
Pearson Correlation	0.723	
Hypothesized Mean Difference	0.000	
Df	16.000	

t-Test: Paired Two Sample for Turbidity Means

Summary Statistics	*Turbidity (Wet)*	*Turbidity (Dry)*
Mean	4.296	2.785
Variance	0.944	0.805
Observations	17.000	17.000
Pearson Correlation	0.762	
Hypothesized Mean Difference	0.000	
df	16.000	
t Stat	9.618	
P(T<=t) one-tail	0.000	
t Critical one-tail	1.746	
P(T<=t) two-tail	0.000	
t Critical two-tail	2.120	

t-Test: Paired Two Sample for Chloride Means

Summary Statistics	*Cl (Wet)*	*Cl (Dry)*
Mean	27.294	14.529
Variance	76.721	47.390
Observations	17.000	17.000
Pearson Correlation	0.811	
Hypothesized Mean Difference	0.000	
df	16.000	
t Stat	10.259	
P(T<=t) one-tail	0.000	
t Critical one-tail	1.746	
P(T<=t) two-tail	0.000	
t Critical two-tail	2.120	

t-Test: Paired Two Sample for Means

Summary Statistics	*DO (Wet)*	*DO (Dry)*
Mean	3.715	2.655
Variance	1.548	1.430
Observations	17.000	17.000
Pearson Correlation	0.867	
Hypothesized Mean Difference	0.000	
df	16.000	

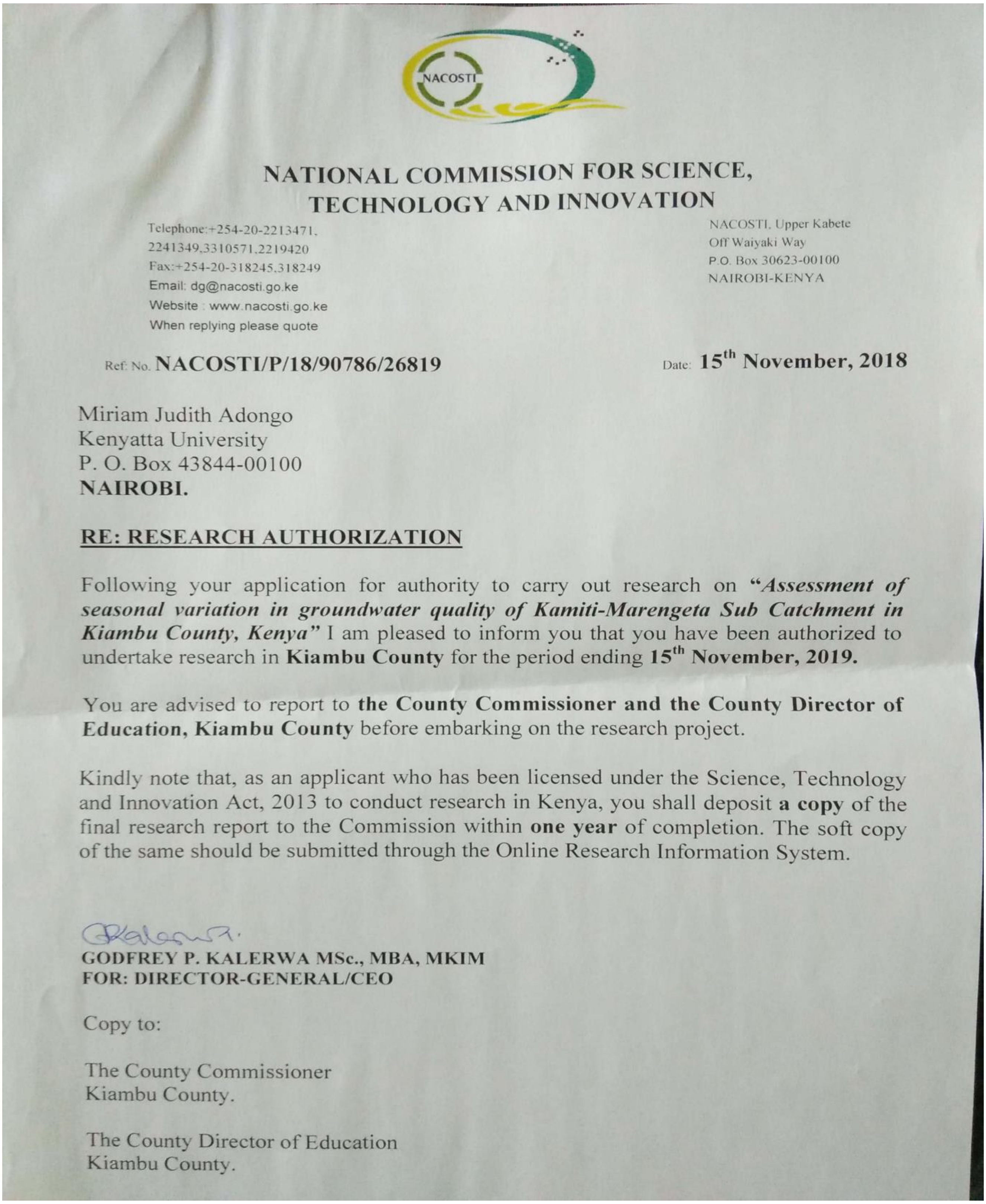
t Stat	9.483	
P(T<=t) one-tail	0.000	
t Critical one-tail	1.746	
P(T<=t) two-tail	0.000	
t Critical two-tail	2.120	

t-Test: Paired Two Sample for Iron Means

Summary Statistics	*Fe (Wet)*	*Fe (Dry)*
Mean	0.180	0.122
Variance	0.011	0.007
Observations	17.000	17.000
Pearson Correlation	0.943	
Hypothesized Mean Difference	0.000	
Df	16.000	
t Stat	6.395	
P(T<=t) one-tail	0.000	
t Critical one-tail	1.746	
P(T<=t) two-tail	0.000	
t Critical two-tail	2.120	

t Stat	6.942
P(T<=t) one-tail	0.000
t Critical one-tail	1.746
P(T<=t) two-tail	0.000
t Critical two-tail	2.120

Appendix XII: NACOSTI research authorization



NACOSTI

NATIONAL COMMISSION FOR SCIENCE, TECHNOLOGY AND INNOVATION

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NAIROBI-KENYA

Ref: No. **NACOSTI/P/18/90786/26819**

Date: **15th November, 2018**

Miriam Judith Adongo
Kenyatta University
P. O. Box 43844-00100
NAIROBI.

RE: RESEARCH AUTHORIZATION

Following your application for authority to carry out research on ***"Assessment of seasonal variation in groundwater quality of Kamiti-Marengeta Sub Catchment in Kiambu County, Kenya"*** I am pleased to inform you that you have been authorized to undertake research in **Kiambu County** for the period ending **15th November, 2019.**

You are advised to report to **the County Commissioner and the County Director of Education, Kiambu County** before embarking on the research project.

Kindly note that, as an applicant who has been licensed under the Science, Technology and Innovation Act, 2013 to conduct research in Kenya, you shall deposit **a copy** of the final research report to the Commission within **one year** of completion. The soft copy of the same should be submitted through the Online Research Information System.

GODFREY P. KALERWA MSc., MBA, MKIM
FOR: DIRECTOR-GENERAL/CEO

Copy to:

The County Commissioner
Kiambu County.

The County Director of Education
Kiambu County.

Appendix XIII: Informed consent

TITLE OF STUDY

Evaluating Seasonal Variations in Chemical Composition of Groundwater in Kamiti-Marengeta Sub-Catchment, Kiambu County, Kenya.

DESCRIPTION OF THE RESEARCH AND YOUR PARTICIPATION

You are invited to participate in a research study being carried out by Miriam Judith Adongo. Before giving your consent, you are required to have a good understanding of what the research is all about, your risks level and the benefits you might draw from the research activity. Kindly take a few minutes to read through the information provided in this form and do not hesitate to seek for clarification on any issue.

The overall objective of this study is:

> To determine the hydro chemical composition of groundwater systems in Kamiti-Marengeta sub-catchment as well as to evaluate the effects of seasonal variations on groundwater levels and chemical composition of groundwater systems of Kamiti-Marengeta sub-catchment

I will be taking borehole water level measurement, collecting water samples, and interviewing residents on issues on water demand, supply, and general quality of the water they use. The data mentioned above will be collected during the months of May and September 2016; your participation will significantly contribute to achievement of the above mentioned objective.

RISKS AND DISCOMFORTS

The research is strictly, for academic purpose, thus there are no known risks associated with this research.

POTENTIAL BENEFITS

Upon request make available to you the water quality results of your borehole/shallow for the two seasons. You will also be invited for the study results dissemination to stakeholders where you will be able to get the information of the status of groundwater off the area and the necessary steps you need to undertake should your borehole/shallow well have high concentration levels.

VOLUNTARY PARTICIPATION

You have no obligation to take part in this study unless you are participating out of your free will and you are free to withdraw your participation at any given time should you wish to do so, and this decision will not be penalized.

YOUR RIGHTS

The researcher is aware of the need to protect the privacy of the study participants. By signing this consent form, you only permit me to:

- Access your borehole to take water level measurements during the months of May 2016 and Sep 2017
- Collect at least 1 litre of water from your borehole/shallow well

Your personal contacts will remain secure and under no circumstance will the researcher share this information with anyone without your permission. If you agree to participate in the study, you will be given a signed copy to keep for your reference. Should you have any doubt or concerns with the information provided you may contact Research Supervisors Prof. Joy Obando (0722966134) or Dr. Mary Makokha (0711554207) of the Department of Geography, Kenyatta University.

CONSENT

I have gone through the document and have a clear understanding of what the study is all about. I have also had an opportunity to seek clarification form the researcher on issues that were not straight forward. I sign this with good knowledge that my participation is voluntary and withdrawing at any time will not result into any penalties and that I will retain a copy of the consent. I volunteer to participate in this research study.

____________________	____________________	____________________
Name of Participant	Date	Signature
____________________	____________________	____________________
Name of Researcher	Date	Signature

Appendix XV: Questionnaire on water supply and demand

1. Do you have piped water?

   In the house............................

   Common pipe stand................

   No.......................................

2. What are your sources of water?

   i. Boreholes,

   ii. Rainwater,

   iii. Shallow Wells

   iv. Water Service Provider

   v. Others specify……………..

3. If more than one what is your main source of water and why?

   ....

   ....

   ....

   ....

4. What are the main uses of the water?

   1. Domestic,

   2. Other (specify)...

5. Do you consider the water you use safe for drinking?

   Yes ___

   No____

   Don’t know _____

   Explain...

   ....

   ....

   ....

6. What do you consider the most important water quality attribute?

   Appearance ☐ Taste ☐ Odour ☐