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Evaluation of Groundwater Quality for Domestic Use in Federal Capital Territory, Nigeria

Yahaya Ahmed Asawu[1], Prof. Ishaya Kefas Samaila[2]

Department Of Geography, Falculty of Environmental Science, Nasarawa State University, Keffi in for the Award of Master of Science in Environmental Resource Management

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ABSTRACT

This research evaluated the quality of groundwater for domestic uses among the three major lithological units (older granite, migmatite-gneiss complex and metasediment) of the Federal Capital Territory (FCT), Nigeria. The research adopted an experimental research design whereby a total of thirty (30) groundwater samples (from boreholes and wells) were collected using stratified sampling at a rate of five samples per lithological unit for two seasons (wet and dry). Results of analysis for the wet and dry seasons, respectively were as follows: pH (3.51-6.58 & 4.2-6.62), temperature (15-22.80C & 17-21.80C), Electrical conductivity (13.4-1669S/cm & 20.5-1442.9S/cm), Turbidity (0.63-32.6 mg/L & 0.6-30.8 mg/L), Dissolved Oxygen (7.87-11.10 mg/L & 6.41-9.41 mg/L), Nitrate (1.0-71.5 mg/L & 0.8-68 mg/L), Total dissolved solids (24.5-622.9 mg/L & 13.8-592 mg/L), Total Alkalinity (71.1-178 mg/L & 71.8-179.2 mg/L), Total hardness (20.2-668.6 mg/L & 15.9-659.1 mg/L), Calcium (14-298 mg/L & 13-282 mg/L), Magnesium (1.5-8.01 mg/L & 1.0-10.0 mg/L), Copper (0.08-0.42 mg/L & 0.04-0.36 mg/L), Iron (0.1-0.32 mg/L & 0.16-0.36 mg/L), Bicarbonate (7.48-306.2 mg/L & 8.8-300.6 mg/L).

Except for pH, which recorded below the World Health Organization and Nigeria Standards for Drinking Water Quality of 6.5-8.5 in all the samples, all parameters in the study areas fall within acceptable limits for both standards, although two samples (HDW1 and HDW2) recorded high nitrate and iron concentrations in both seasons.

Hypothesis test show no significant difference between the groundwater quality for the two seasons ($p=0.117718>0.05$) and strong positive correlation between the seasons' data sets ($r=0.999632$). The study concludes that the water quality for the two seasons classified using the CCME Water Quality Index (WQI) are marginal (55.45 for wet season and 55.46 for dry season), the FCT ground water remains constantly under the threat of contamination and needs to be treated before use. Further ongoing monitoring and assessment of groundwater in the region are necessary due to changing quality from constant anthropogenic activities.

Keywords: Groundwater quality, physic-chemical parameters, lithology, Federal Capital Territory, Nigeria

INTRODUCTION

Background to the Study

Water is essential for human existence, and it makes up about 71% of the Earth's surface of which only 2.5% is freshwater and only 0.3% of that water is available for human use (United State Geological Survey, 2016). Studies have shown that over one billion people in the world lack access to safe drinking water and 2.5 billion people do not have access to adequate sanitation services (Tar *et al*., 2009). Water-related disease remains one of the major health concerns in the world. Diarrhea diseases, which are largely derived from poor water and sanitation, accounted for 1.8 million deaths in 2002 and contributed around 62 million disability adjusted life years per annum (WHO, 2004).

According to World Health Organization (WHO, 2004), groundwater is the water contained beneath the surface of the Earth in rocks and soil, and is the water that accumulates in underground aquifers. It constitutes 97% of global freshwater and is an important source of drinking-water in many regions of the world. Groundwater plays an important role in supplying water to much of the global population for domestic, agriculture, and industrial purposes. Approximately 40 to 70% of the total global water resources being used for irrigation and domestic purposes are from groundwater, and these values could be increased due to the continuous decline in the quantity and quality of available surface water resources which are largely caused by increase in global pollution threats, industrialization and urbanization, as well as the effects of the climate change (Qiu, 2010). Groundwater is often more reliable, in closer proximity to users, less vulnerable to pollution, and more resilient to climate variability than surface water (MacDonald *et al.* 2011; Lapworth *et al*. 2013).

Within countries the usage of groundwater varies substantially, depending on the terrain and access to alternative water sources. For instance, in the United States of America (USA), it ranges from 25% in Colorado and Kentucky to more than 95% in Hawaii and Idaho. In rural areas of the USA, 96% of domestic water comes from groundwater (WHO, 2006). In Latin America, many of the continent's largest cities – Mexico City, Mexico; Lima, Peru; Buenos Aires, Argentina and Santiago de Chile, Chile – obtain a significant proportion of their municipal water supply from groundwater. In India, China, Bangladesh, Thailand, Indonesia and Vietnam, more than 50% of potable supplies are provided from groundwater (WHO, 2006).

In Africa, groundwater is the largest and most important water resource due to the deteriorating quality and quantity of surface water through increased urbanization and industrialization and high cost of developing new dams (Adelana *et al*, 2008), not forgetting the effect of climate change. In Sub-Saharan Africa, many expanding urban areas are dependent on groundwater for at least some, and many cases the majority, of domestic water supply (Adelana *et al*. 2008). However, the most populous nation in Africa, Nigeria, is not left out of this growing challenge.

In Nigeria, majority of the human population are heavily reliant on well and borehole water as the main source of water supply for drinking and domestic use due to inadequate provision of potable pipe borne water. These groundwater sources can easily be contaminated and thus increase the incidence and outbreaks of preventable water-borne diseases (Alonge et al., 2018). Groundwater is a valuable freshwater source, and its physical, chemical, and biological parameters are of serious concern when being used for consumption purposes. In the Federal Capital Territory (FCT), Nigeria, groundwater has become a very vital source of water due to the ever increasing demand for water supply especially in areas with inadequate pipe borne and surface water supply. The rate of urbanization characterized by high population concentration, increasing industrial and agricultural activities coupled with environmental pollution/degradation are perceived to pose serious pollution threats on groundwater quality (Ajala, 2005; Ocheri, 2006, Adelana et al, 2008; Eni et al, 2011).

Natural water, from surface or ground sources, contains dissolved solids and gases as well as suspended matter. The quality and quantity of these constituents depend on geologic and environmental factors, and they are continuously changing as a result of the reaction of water with the contact media and human activities (Kashef, 1987, Lloyd, 1994). Groundwater is invisible and so its depletion or degradation due to contamination can proceed unnoticed, unlike our surface waters such as: rivers, lakes and reservoirs, where drying up or pollution rapidly becomes obvious and is reported (Morris et al, 2003).

In conclusion, evaluating the groundwater quality in FCT, Nigeria is vital for ensuring a safe and sustainable water supply, protect public health, and support economic development while mitigating environmental impacts.

Statement of Research Problem

Federal Capital Territory (FCT) is located in an environment characterized by moderate precipitation and limited surface water sources. The availability of potable water for domestic use in most of the areas greatly depends on the harnessing of hand-dug wells and the construction of boreholes (CIWAT, 2010). Consequently, public water supply from Lower Usman Dam Water Works, designed to serve the residents of the Federal Capital Territory more than three decades ago has failed to meet the growing demand for water as a result of population increase and urbanization. Within the last decade, therefore, there has been a significant increase in groundwater demand and utilization in the Federal Capital Territory, especially for domestic and institutional purposes (CIWAT, 2010; FCT SDGs, 2010).

The suitability of groundwater for domestic use in the study area therefore has raised concerns about the contamination due to continuous anthropogenic activities like agricultural, mining, infrastructural developments and industrial activities, and natural activities such as geochemical process and the devastating impacts of climate change. This study will focus on the evaluation and spatial seasonal variation in groundwater quality for domestic use in the Federal Capital Territory, Nigeria.

Research Questions

This study provides answers to the following questions;

1. What are the physico-chemical characteristics of groundwater in Federal Capital Territory?
2. Are there seasonal variations in groundwater quality between the wet season and dry season in Federal Capital Territory?
3. How suitable is groundwater in Federal Capital Territory for domestic use?
4. What are the management strategies for improving and protecting groundwater quality in the study area?

Objectives of the Study

The aim of this study is to evaluate groundwater quality in Federal Capital Territory for domestic use. This was achieved through the following specific objectives:

1. conduct physico-chemical analysis of groundwater quality parameters in the study area.
2. assess the seasonal variation in groundwater quality for domestic use in wet and dry seasons in the study area.
3. evaluate the suitability of groundwater for domestic use in the study area using Water Quality Index (WQI).
4. develop strategies for managing, improving, and protecting groundwater quality in the study area.

Hypothesis

$H_{o:}$ There is no significant seasonal variation in groundwater quality for domestic use in Federal Capital Territory (FCT) between the wet and dry seasons.

Significance of the Study

Water quality has become a subject of concern to every nation of the world, as it's an indicator of health and paramount concern to environmentalists, since without water life cannot exists. The consumption of water worldwide increases yearly while most of the world's water resources continue to dwindle due to improper environmental management practices (UNEP, 2000). Globally, more than twenty-five thousand people die daily as a result of water related diseases (WHO, 2002); Diarrhoeal diseases, which are largely derived from poor water and sanitation, accounted for 1.8 million deaths in 2002 and contributed around 62 million Disability Adjusted Life Years per annum (WHO, 2004a). On a global scale, this places diarrhoeal disease as the sixth highest cause of mortality and third in the list of morbidity and it is estimated that 3.7 percent of the global disease burden is derived from poor water, sanitation and hygiene (Prüss-Üstün et al., 2004).

Groundwater has been recognized as playing a very important role in the development of Federal Capital Territory, Nigeria's Capital as many private, government, and households establishments depend solely on hand-dug wells and boreholes for their daily water needs (Akoachere et al, 2019).

In this regard and as a Sustainable Development Goal six (SDG 6), there is dire need to carry out this study to evaluate the groundwater quality for domestic use in the study area which was

significant in providing useful and vital data on the groundwater quality to water managers and policy makers such as Federal Ministry of Water Resources, Federal Capital Territory (FCT) Water Board and other relevant water managers and agencies like Federal Capital Development Authority (FCDA) and Abuja Environmental Protection Board (AEPB) to interpret the groundwater quality conditions for proper actions on groundwater quality management. It will also be beneficial to Federal Capital Territory residents, researchers and the general public since water is used by all.

Scope of the Study

This study was conducted in Federal Capital Territory, Nigeria. Particularly focusing on the evaluation of groundwater quality for domestic use in Federal Capital Territory (FCT), Nigeria. The study assessed the quality of groundwater in the study area through the physico-chemical analysis of groundwater samples collected from different geological regions (lithological units) within the study area. Groundwater quality was examined by various physico-chemical parameters such as pH, electrical conductivity, temperature, turbidity, dissolved oxygen, colour, total dissolved solids, total alkalinity, total hardness, calcium, magnesium, nitrate, iron, copper, and bicarbonate. These parameters were used to determine the suitability of groundwater quality for domestic use in the study area by comparing the values with the World Health Organization (WHO) and Nigerian Standard for Drinking Water Quality (NSDWQ) standards.

LITERATURE REVIEW

Concept of the Hydrologic Cycle

The hydrologic cycle also known as the water cycle describes the continuous process by which water is circulated between the Earth's oceans, atmosphere, and land (Kundzewicz et al., 2007).The water on the Earth's surface occurs as streams, lakes, and wetlands, as well as bays and oceans. Surface water also includes the solid forms of water, snow and ice. The water below the surface of the Earth primarily is groundwater, but it also includes soil water. However, for understanding hydrologic processes and managing groundwater resources, the hydrologic cycle needs to be viewed at a wide range of scales and as having a great deal of variability in time and space. Precipitation, which is the source of virtually all freshwater in the hydrologic cycle, falls nearly everywhere, but its distribution, is highly variable. Similarly, evaporation and transpiration return water to the atmosphere nearly everywhere, but evaporation and transpiration rates vary considerably according to climatic conditions. As a result, much of the precipitation never reaches the oceans as surface and subsurface runoff before the water is returned to the atmosphere. The relative magnitudes of the individual components of the hydrologic cycle, such as evapotranspiration, may differ significantly even at small scales, as between an agricultural field and a nearby woodland (Doughari, *et al.,* 2011).

Components of the Hydrological Cycle

The circulation of water masses seen in all spheres of the earth involves several causative factors and components. The major components (or) elements of the hydrologic cycle are :

1. Precipitation: Precipitation is the process of transforming the water vapour into a liquid or solid form, depending upon the temperature of air near the clouds. The term precipitation is a common term. It includes a variety of forms of precipitation. It includes mist, rain, hail, sleet and snow. The term precipitation and rainfall are always used 4 synonymously. Precipitation mainly depends on the water vapour present in the atmosphere. When the air temperature is well below the freezing point, clouds may form tiny ice crystals (Kundzewicz et al., 2007).

2. Evaporation: Evaporation Evaporation is the process of converting a liquid (or) solid into a gas, through the transfer of heat energy. In hydrologic cycle this conversion is towards water vapour. Heat energy can convert water mass (or) ice into a vapour. Evaporation occurs more rapidly when there is increase in temperature and also flow of wind. It also depends on the boiling point and vapour pressure.Water from the oceans, lakes, rivers, and the ground surface evaporates into the atmosphere (Trenberth et al., 2007).

3. Transpiration: Transpiration is the process of releasing the water absorbed by the plants through their root system after utilizing the nutrients for building their tissues, in a specified time. Vegetation including numerous growing plantsplays a significant role in the hydrologic cycle. The water which is drawn into the plants rootlets from the soil moisture, owing to osmotic pressure moves up through the plants stems and leaves as vapour through the stomata openings (Trenberth et al., 2007).

4. Evapotranspiration: Evapotranspiration is the combined effect of both evaporation of water from the soil, surface water bodies, snow, ice and transpiration from vegetation. The total water loss due to both evaporation and transpiration is called as evapotranspiration.

5. Surface Runoff: Runoff is the quantity of water that is discharged ("runs off") from a drainage basin during a given period of time. It refers to the overland flow of water, after every rainfall or snowmelt. The overland flow starts when the rate of rainfall is greater than the rate of infiltration of the soil and increase in the amount of slope. Precipitation that does not infiltrate the soil flows over the land as runoff (Wohl, 2013).

6. Infiltration: Infiltration is the downward percolation of rainwater (or) snow melt water into the soil horizons. The downward movement of water happens in the top soil layer, especially through the smaller pore spaces seeps into the soil and becomes groundwater (Scanlon et al., 2002).

7. Groundwater base flow: The rainwater that is falling over the ground surface percolates down through the soil and reaches the groundwater zone. Depending upon the slope of the groundwater system, the groundwater moves towards the rivers, lakes or the oceans. This flow of groundwater is known as baseflow. It depends on the hydrologic properties of rocks forming the groundwater systems. This is an invisible flow of water.

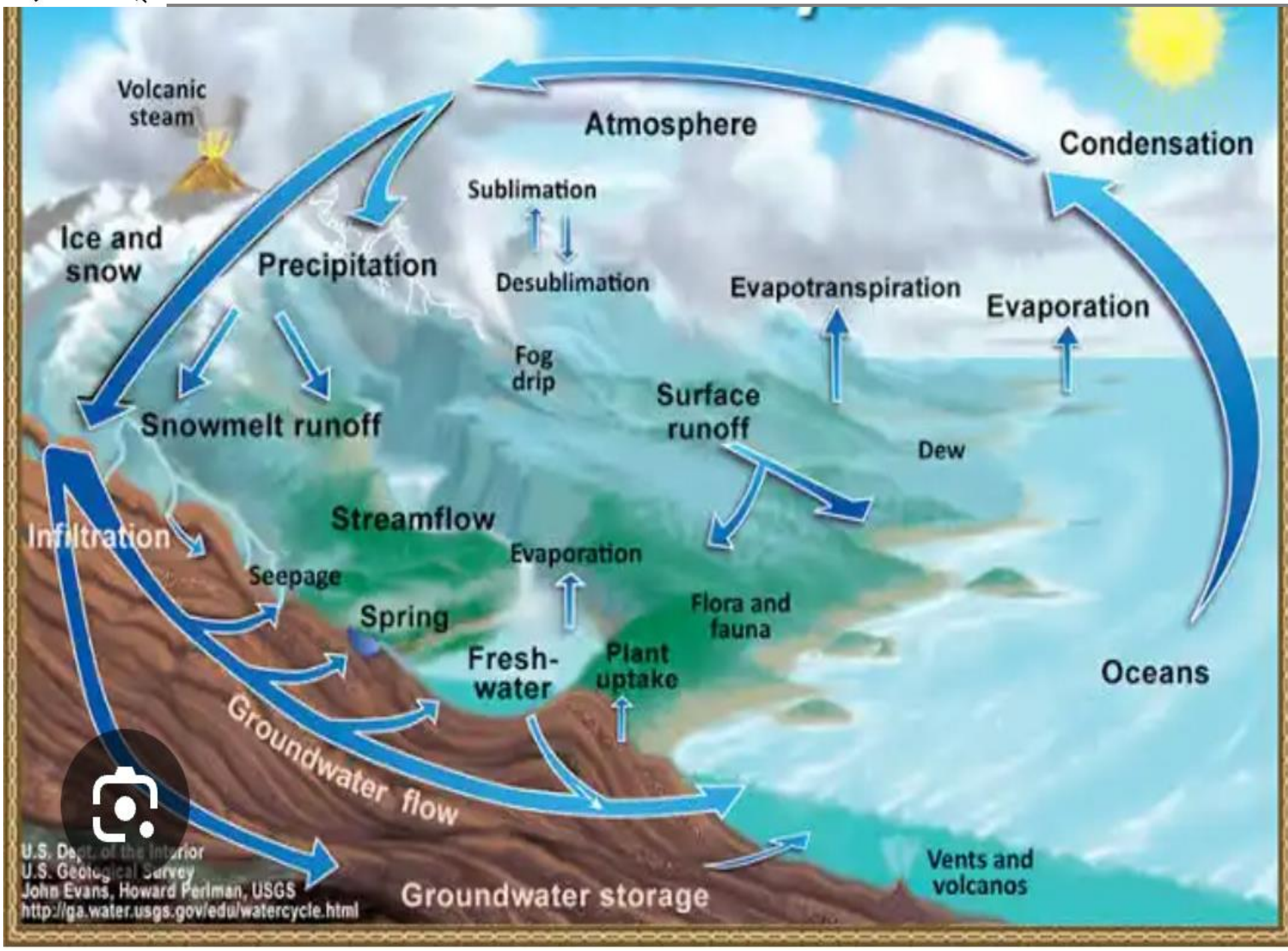

Fig. 2.1: Hydrological Cycle

Source: United States Geological Survey (USGS, 2016)

Impact of Hydrological Cycle on Groundwater Quality

1. Recharge and Discharge: The hydrological cycle influences groundwater recharge and discharge, leading to changes in groundwater quality (Scanlon et al., 2002).
2. Geochemical Processes: The hydrological cycle affects geochemical processes, such as weathering and leaching, which can impact groundwater quality (Appelo&Postma, 2005).
3. Microbial Activity: Changes in temperature, moisture, and nutrient availability due to the hydrological cycle can influence microbial activity, affecting groundwater quality (Griebler&Avramov, 2015).
4. Contaminant Transport: The hydrological cycle can facilitate the transport of contaminants into groundwater systems, particularly during periods of high precipitation or runoff (Wexler, 2013).

Factors Influencing Hydrological Cycle and Groundwater Quality

1. Climate: Climate change and variability can impact the hydrological cycle, leading to changes in groundwater quality (Kundzewicz et al., 2007). During wet season, there’s higher and continuous recharge of aquifers, while tge dry season
2. Land Use: Human activities, such as deforestation, urbanization, and agriculture, can alter the hydrological cycle and affect groundwater quality (Foley et al., 2005).

3. Soil Properties: Soil texture, structure, and composition can influence infiltration, percolation, and groundwater quality (Scanlon et al., 2002).
4. Geology: The underlying geology can affect the movement and quality of groundwater (Freeze & Cherry, 1979).

Conceptual Framework for Groundwater Quality

The word groundwater quality is used universally to denote the state of groundwater that reaches the universal standard set for genuine and vital water usage at any level such as local, regional, and international level (WHO, 2006). The quality of groundwater is the resultant of all the processes and reactions that act on the water from the moment it condensed in the atmosphere to the time it is discharged by a well or spring and varies from place to place and with the depth of the water table (Jain et al., 1995).

Variation in groundwater quality in an area is a function of physical and chemical parameters that are greatly influenced by geological formations and anthropogenic activities (Magesh&Chandrasekar 2011; Krishna Kumar et al. 2011). With sufficient water infiltration, soil contaminants such as heavy metals can leach to underlying groundwater. Unconfined aquifers are especially vulnerable to various contaminants (Nouri et al., 2006)

Groundwater is normally fresh under ordinary conditions, though not essentially of good chemical quality. However, whatever the source of pollution and type of pollutant, understanding the way groundwater occurs and flow is crucial to: (1) setting up groundwater protection policies; (2) establishing water quality monitoring systems; (3) designing pollution control or aquifer remediation measures (WHO, 2006).

The two essential factors that determine the groundwater quality of a place are:

1. Quality of the infiltrated water. This includes recharging water (rain, dry deposition, evapotranspiration, surface water) as well as added substances (manure, fertilizers, and organic contaminants).

2. Post-infiltration reactive processes. These can be divided into several geochemical processes, such as sorption, redox reactions, buffering, degradation, dissolution, etc. Consequently, the chemical properties of groundwater depend upon the chemistry of water in the recharge area as well as the different geochemical processes that are occurring in the subsurface (Kumari et al. 2012; Singh et al. 2011b, c).

When the spatial distribution and variation of groundwater quality is taken into account, a third factor comes into play as, Groundwater flow (Engelen, 1981; Vissers et al. 1999). The aforementioned factors form the conceptual framework for this study, but could be summarize as:

1. The input at infiltration

2. Geochemical processes (post infiltration)

3. Groundwater flow regime which portrays the general independent factors that define the spatial distribution and variation of groundwater quality.

The framework explains the relations between processes and activities at the Earth's surface and groundwater quality using advances in hydro-chemical analysis (Engelen, 1981; Schot, 1990; Alley, 1993; Vissers et al. 1999, Vissers et al. 2006). Another motive for the rolling down of factors to three from the several factors such as geology and groundwater age, soil type and depth is that, it leads to induced and false or unauthentic correlation and violates the scientific principle of parsimony (Brett, 2004). These factors such as land use, urbanization, population density, or soil type are so correlated that they are not truly single factors but represent a complex interaction of these factors (Beka, 2018).

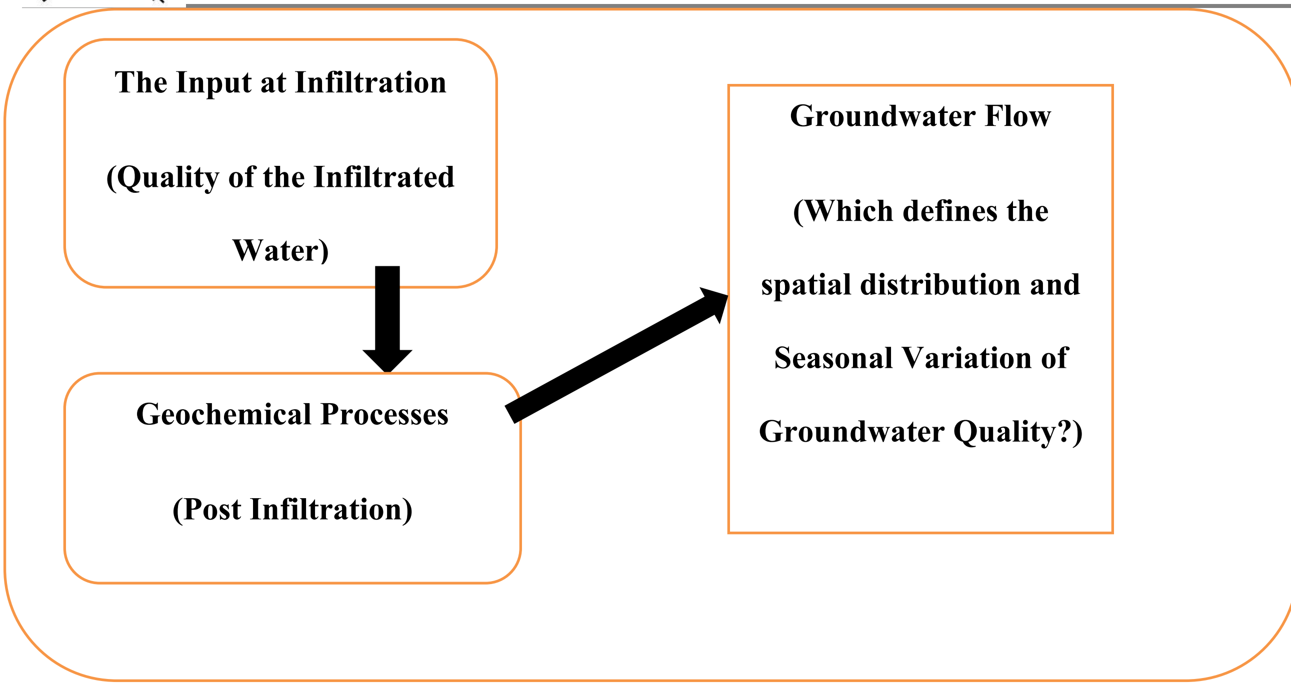

Fig 2.2: Conceptual Framework for Seasonal and Spatial Variation of Groundwater Quality

Source: Modified from Beka (2018)

The Interaction of Input, Geochemical Processes and Groundwater Flow

Input (Anthropogenic):

The input is generally considered as the most vital factor determining groundwater quality, especially from an environmental risk assessment perspective, because the substances likely to be release are enormous (Khatri&Tyagi, 2015). Inputs determines the composition of infiltrated water, meaning water from rain infiltrating the Earth surface meets different sources of input either in a diffuse or point source manner and takes substances from them into the groundwater reservoirs (Vissers, 2006). These inputs are associated with human (anthropogenic) activities on Earth surface such urbanization, modernization, industrialization, and agriculture.

Natural or Geochemical Processes

Geochemical processes occur after infiltration of water into the Earth crust. The age (or residence time) of groundwater in an aquifer system progressively increases along a groundwater flow path from the point of recharge to the point of discharge. The increase in residence time provides greater opportunity for the water-rock and geochemical processes to occur (Daughney, 2007). This idea of groundwater in aquifers (or at depths) can further be expanded because, when the rate of groundwater flow is low, there is greater time for geochemical evolution of groundwater to occur. Conversely, in groundwater systems with high rate of groundwater flow, there was lesser time for these natural processes to occur and, because there is greater flux of water through the aquifer system, there is greater potential for dilution of contaminant inputs into the aquifer system (Kumari et al., 2012; singh et al., 2011).

Geochemical processes can both be beneficial and harmful for groundwater quality. The high reactivity of the sub-surface, both as substrate for bacteria that may breakdown pollutants and as an immobilizing agent for pollutants, bacteria, and viruses, is also referred to as the geo-cleaning capacity or natural attenuation capacity in case of point source pollution. Natural attenuation and its enhancement receive a high amount of scientific interest for its possibilities as a cheap and efficient sanitation strategy. The geo-cleaning characteristic of aquifer has in fact long been recognized, and when actively considered for purification of water, it is called soil aquifer treatment (Pyne, 1995). The Amstardam Water Supply has used infiltration of river water in the coastal dunes since 1957 for Natural cleaning. Harmful effects of geochemical processes also happen, the most well-known example is the high concentration of arsenic found in groundwater wells in Bangladesh where groundwater wells were installed to decrease the occurrence of waterborne diseases (Nickson et al., 1998).

Groundwater – sediment interaction along the flow path includes a wide variety of processes, such as buffering, redox processes, sorption, dissolution, precipitation, and degradation. The resulting evolution of groundwater composition along flow paths was first described by Back (1966), who defined the principle of hydro-chemical facies to describe the formation of distinct water types. For major element of hydrochemistry, buffering and redox processes are considered the most important (Vissers et al. 1999, Van Sambeek et al. 2000).

Groundwater Flow

A groundwater flow system is a discrete, closed three-dimensional system containing flow paths from the point at which recharging water enters an aquifer to the topographically lower point at which it leaves the aquifer (WHO, 2006). It simply describe the movement of groundwater within aquifers from recharge to discharge.

The flow of water through an aquifer is governed by **Darcy's Law**, which states that the rate of flow is directly proportional to the hydraulic gradient:

$$Q = - K\, i\, A$$

Where Q is the rate of flow through unit area A under hydraulic gradient i. The hydraulic gradient dh/dl is the difference between the levels of the potentiometric surface at any two points divided by the horizontal distance between them. The parameter K is known as the hydraulic conductivity, and is a measure of the permeability of the material through which the water is flowing. Darcy's Law provides a valid description of the flow of groundwater in most naturally occurring hydrogeological conditions. The groundwater flow system is a useful concept in describing both the physical occurrence and geochemical evolution of groundwater (WHO, 2006).

There are three different types of groundwater flow systems: local, intermediate and regional. Multiple flow systems can occur within an aquifer. Local flow systems respond quickly to changes in rainfall, extraction or land use; regional flow systems may take decades to respond. Upper aquifers are unconfined and receive recharge directly from rainfall. Middle and lower aquifers are only unconfined near the basin margin and rely mainly on leakage from overlying aquifer for recharge. The rate and direction of groundwater flow is driven mainly by gravity and pressure as well as how easily water can move through the aquifer material (Australian Government Bureau of Meteorology, 2017). In large, deep aquifers, groundwater may be moving slowly, at rates of a few metres per year, from recharge to discharge areas for hundreds or thousands of years. In small, shallow aquifers, recharge and discharge areas may be much closer or even adjacent to each other, and residence times can be restricted to a few months or years. In arid and semi-arid areas, groundwater discharge areas are often characterized by poor quality groundwater, particularly with high salinity. In these areas, groundwater discharge occurs from seepages or salt marshes with distinctive vegetation, known as Salinas or playas, in which evapotranspiration at high rates, over a long time, has led to a build-up of salinity (WHO. 2006).

The flow of groundwater determines where and when groundwater of certain composition is found. Within this framework, it accounts for the spatial component of the factors affecting groundwater quality. Natural chemical constituents or contaminants are transported as dissolved substances or solutes in a groundwater flow system, this capacity of the flow system to transport these substances is the focus of water quality investigations. The transported solutes moved by the bulk movement of the flowing water are controlled by two processes namely:

1. Molecular diffusion in the direction of the concentration gradient due to the thermal kinetic energy of the solute

2. Mechanical dispersion which arises from the convolution of the pore channels in granular aquifer and of the fissures in fractured aquifer, and from the different speeds of groundwater flow in channels or fissures of different widths (Chilton, 1996).

In many aquifer systems, groundwater flow in the horizontal direction predominates over flow in vertical direction. This means groundwater commonly flows more rapidly through the upper parts of an aquifer system with comparatively slow rates of groundwater circulation through deeper levels of the aquifer (Daughney, 2007).

This conceptual framework for the study of input, geochemical processes and groundwater flow measures the spatial variation of groundwater quality in Federal Capital Territory. It also provide a good insight in determining the major factors influencing the spatial variation of groundwater in the study area.

Understanding Groundwater Quality through Input, Geochemical Processes and Groundwater Flow Framework

Engelen (1981) developed this conceptual framework of input, geochemical processes and groundwater flow, but later modified by Schot (1990) and Vissers et al. (1999). It explained how understanding the balance between the input of contaminants and geochemical processes is a measure of the changes that are currently occurring along groundwater flow paths (Ward et al., 2004). Vissers, (2006) explains this to be understanding the quality of groundwater during infiltration into the earth crust and groundwater quality after infiltration during its residence inside the earth crust as it encounters diverse geochemical processes, but since all these two happen in space the idea of groundwater flow comes into play.

This approach is commonly associated with groundwater quality assessment for protection and conservation initiatives which identify the major groups of factors determining groundwater quality in a given area. The framework is one of the major tools used by some countries to understand their groundwater resources and proffer ways to protect these resources (Van der Perk, 2013). This tool shows input, geochemical processes and groundwater flow as framework that simplifies the usually enormous factors influencing groundwater quality studies such as depth, age, soil type, geology, land use, population density which might lead to induce and spurious correlations because these latter factors are not truly single factors but represent a complex interaction between geologic, climatic, socio-economic, and historic-cultural circumstances (Brett, 2004). This framework would be the tool in understanding the groundwater quality pattern and the processes influencing the groundwater quality in Federal Capital Territory (FCT).

The framework provides explanations that shape water resources, urban planningand environmental managers' decision in the formulation and design of policies, plans and programs for effective groundwater resources protection and management. The framework can be used to explain the kind of inputs and their likely causal activities or land uses. In reality, this framework can help the Federal Ministry of Water Resources, Federal Capital Territory (FCT) Water Board and other relevant water managers and institutions in the Federal Capital Territory to develop a simple design to monitor the groundwater quality and establish talking points to synergize with Planning and regulatory Agencies like Federal Capital Development Authority (FCDA) and Abuja Environmental Protection Board (AEPB) for different levels of implementation.

Review of Empirical Studies on the input, geochemical processes and Groundwater flow.

This framework was first mention by Engelen (1981) in his work on a systems approach to groundwater quality where he argued that groundwater quality at a given point is dependent on: (i) the input, (ii) the pathway through the system, (iii) the matter encountered along the pathway, (iv) the residence time or flow velocity variations along the pathway, (v) rates and threshold values of conversion processes. Schot (1990) however, after considering a number of factors broke it down to two main components namely (a) groundwater flow and (b) factors influencing solute concentration due to inputs and geochemical processes. Vissers (2006) also argued that the consideration of many factors such as land use, soil type among others would bring the factors to relate falsely, but went on to outline three factors that would determine groundwater quality namely: input, geochemical processes, and ground water flow.

Rijtema and Elias (2012) defined this framework as structural model which must be capable of giving a valid representation of, first the flow system and second, the physical and geochemical processes acting on the contaminant during its migration along the flow path.

Geospatial Analysis in Groundwater Quality

The Relevance of Seasons and Spatial Variation in Groundwater Quality Study

According to the Encyclopedia Britannica, seasons are defined as “any of the several conceptual divisions of the annual cycle of climate, and plant and animal activity, recognized in a given region”. The concept of seasons is based on changes in temperature, precipitation, and day length that occur as the Earth orbits the sun. Seasons play a significant role in groundwater quality studies as they can influence the movement of contaminants, recharge rates, groundwater flow, and water table levels. The concept of seasons in groundwater quality studies involves understanding how seasonal variations in climate, land use, and hydrological processes can impact groundwater quality. There are two major seasons in the study area which are dry season and wet season.

Spatial is derived from the Latin word “Spatium” meaning space. The term in geography relates to space on the earth's surface, it means each item of data has a geographical reference so it is possible to tell where it occurs on a map (Haining, 2003). Hence, "Spatial Variation" means the changes across a given landscape that is normally associated with a measured quantity such as population, activities, resources (Berglee, 2012). This spatial variability occurs when a quantity that is measured at different spatial locations exhibits values that differ across the locations. This spatial perspective of geography leans to the locational theory where there is great concern for distance as a controlling factor of human activities in space (Dale & Fortin, 2014).

Spatial variation in groundwater quality therefore referred to the differences in groundwater quality in different locations on the Earth’s surface. The concept of spatial variation is indeed the concept of geography as it involves the study of why things vary from place to place on the earth, also known as spatial distributions or spatial patterns or anything that can be mapped.

The Use of Geographic Information System (GIS) in Groundwater Quality

A Geographic Information System (GIS) is a framework or system designed to store, manipulate, analyze, manage, and present all types of geographical data. It analyzes spatial locations and organizes layers of information into visualizations using maps and three-Dimensional (3D) scenes. According to Ramaraju (2006), GIS is now applied to solve past and present water quality issues. It applies an electronic database to accumulate enormous amount of spatial and chronological data. This permits the incorporation of different forms of information into an arrangement that makes it potential to reflect diverse methods to land control and environmental difficulties prior to management resolutions. Spatial data is evidence that defines how a particular feature is positioned or spread in space (Ramaraju, 2006).

This study requires a tool like the GIS to handle and manipulate the data that would be generated from various sampled locations or points through map produced and can pave way for further study. A good application of this tool would display the pattern of various variations of groundwater quality in the study area.

Groundwater Quality Standards/Guidelines

Water quality varies from place to place and therefore the need to bring some form of standard to find a basis in categorizing water to be safe or unsafe. Redmond (2005) considers water quality standards as guidelines that set the concentration levels of chemicals compounds and bacteria that can be safely allowed in our drinking, industrial or agricultural water. Water quality standards are important because they help to protect and restore the quality at any Nation's water resources. Standards help to identify water quality problems caused for instance, by improperly treated wastewater discharges, runoff or discharges from active or abandoned mining sites, sediments, fertilizers, and chemicals from agricultural areas, and erosion of stream banks caused by improper grazing practices. Standards also support efforts to achieve and maintain protective water quality conditions, (Benson, 2005).

According to Gray, (2008) the WHO guidelines for drinking water are the most universally used standards relating to water quality and are the basis for European Council (EC) and United States Environmental Protection Agency (USEPA) legislation. The original guidelines were published in two volumes in 1984 (WHO, 2004; Gray, 2008) This Guideline was superseded by further editions (1993-2002 second edition, third edition 2004-2008, fourth edition 2011) it is also preceded by the International Standards (1963, 1971 & 1976). The Guidelines are recognized as representing the position of the United Nations system on issues of drinking-water quality and health. The Volume 1 is the guidelines while volume 2 contains the scientific evidence on which the recommendations in volume 1 are based. These standards go through a periodic review to assess their efficacy as more information becomes available and are evaluated. Water quality standards are best tailored to suit the region under concern, so every country ought to have a standard for water quality. This is to provide the authoritative guidance on analytical methods used in the monitoring of drinking water.

Standards in the United States of America (USA) arise from the safe drinking water Act 1974 which directed the United States Environmental protection Agency (USEPA) to establish minimum National Drinking Water Standards. The Act was to ensure uniformity and consistency of state drinking water quality regulation (NEHA, 1989). The standards are split into primary and secondary drinking water Standards. The primary National drinking Water standards cover 30 parameters at present which are considered to be potentially harmful to health. The secondary National Drinking water Standards are intended to protect public welfare as opposed to public health. These parameters are not considered to pose a threat to public health but are concerned with aesthetic factors such as taste, odour, appearance and colour.

In Nigeria the water quality standards outlook has improved over the last decade. The only known standard use is the Nigerian Standard for Drinking Water Quality (NSDWQ) developed by the National Council on water Resources (NCWR) in 2005 because they observed that the “Nigerian Industrial Standard for Potable Water" developed by Standards Organisation of Nigeria (SON) and the National Guidelines and Standards for Water Quality in Nigeria" developed by Federal Ministry of Environment did not receive a wide acceptance by all stakeholders in the country (SON, 2007). The creation of the National Environmental Standards and regulations enforcement Agency (NESREA) in 2007 saw the development of several standards and development of several regulations one of which is that on Surface and Groundwater Quality Control, (2010). The Standards Organization of Nigeria (SON) and The National Agency for Food and Drug, Administration and Control (NAFDAC) who by virtue of its monitoring responsibility are also interested in the quality of drinking water, especially packaged or bottled water. Where the former chiefly concerns itself with the setting of standards for the bottled water, the latter enforces it. Both bodies draw their standards from the World Health Organization (WHO) guidelines for drinking water. The National Environmental Standards and Regulations Enforcement Agency (NESREA) is concern about wastewater or additives that is disposed in the environment either through effluent discharge or some human activity that would lead to impact on the environment.

Consequently, it is obvious that Nigeria lacks a nationwide policy on groundwater quality which will encompass private wells, boreholes such that they support a large number of people in the country and in Federal Capital Territory (FCT) as well. Whether groundwater of a given quality is suitable for a particular purpose depends on the criteria or standards of acceptable quality for that use. Quality limits of water supplies for drinking water, industrial purposes, and irrigation apply to groundwater because of its extensive development for these purposes (Beka, 2018).

Todd & Larry (2005) describes groundwater quality standard as a concentration of groundwater compound (mostly a contaminant), or a group of compounds, which should not be exceeded in order to protect the environment and human health. The debate about concentration standards centres around the question: at what concentration or flux thresholds is action required? (Hoehn, 2011). This has not been established in our environment because of the lack of systems in place to check periodically the quality of the groundwater and to plan effective response to the scenarios. This only increase the need for a framework to protect these groundwater resources that would imbibe these concerns (Beka, 2018).

Quality standards are given as constant values. Such values have to be judged in the light of a spatial variation of concentrations, temporal changes of contaminant concentrations; a rising concentration trend of a contaminant compound is alarming, even if within safe limits and in some cases even below today's detection limits. The European Union (EU) states that the effects of human impact on groundwater, the effects of contamination on the groundwater quality and the chemical state (i.e. the composition) of the groundwater must be monitored (EU, 2000).

Water Quality Index (WQI)

Water Quality Index (WQI) is a mathematical tool used to assess and communicate the quality of water in a specific location or watershed. It is a composite measure that integrates multiple water quality parameters into a single index value, providing a comprehensive overview of the water quality (Ramakrishnaiah, 2009).

The Canadian Council of Ministers of the Environment (CCME, 2001) defined Water Quality Index as a numerical expression that reflects the quality of water in a specific location or watershed, based on the measurement of various physical, chemical and biological parameters. The purpose of WQI is to provide a simple and understandable way to communicate water quality information to the public, policymakers, and stakeholders. It also facilitates the comparison of water quality between different locations or over time, and to identify areas where water quality improvement is needed.

Empirical Review of Related Literatures

Studying the seasonal variation in groundwater quality is crucial for understanding when pollution occurs in the groundwater system. It is also an important aspect of hydrology and environmental management, as it can significantly influence the availability and suitability of groundwater for different purposes, including water supply, irrigation, and industrial practices.

Kayode et al. (2024) studied the Seasonal variation of groundwater quality in a basement complex geology of Ado Ekiti Nigeria using water quality index model The research aimed to determine the suitability of groundwater for consumption and domestic use and also provide information about groundwater quality in bedrock lithologies using water quality index. Samples were taken from two major sources, boreholes and wells, covering all of the study area's major lithologies. The groundwater was a little acidic in majority of the water samples in all the rock types. The mean values of EC, TDS, DO, alkalinity, and turbidity were mostly within the WHO acceptable limit except for total hardness (TH) which recorded high mean values in almost all the rock types. The ion concentration revealed that calcium and magnesium ions were dominant in the cationic species while phosphate and chloride ions were dominant in the anionic species.

Ganiyu et al. (2018) assessed the seasonal variations of groundwater samples from hand-dug wells near Ajakanga dumpsite, Ibadan, South-western Nigeria, using analysis of physicochemical parameters, principal component analysis (PCA), and cluster analysis (CA) to identify probable sources of groundwater contamination. The groundwater in the study area was found to be fresh, hard, and basic in nature, with strong relations between EC and TDS, HCO_3^- and CO_3^{2-}in dry and wet seasons. The study's results showed the identification of major factors accounting for the total variation in water quality for both dry and wet seasons using PCA, and CA revealed groups based on similar water quality characteristics and proximity to the dumpsite.

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Bolarinwa (2018) conducted "a hydro-chemical study of forty boreholes drilled on the basement and sedimentary rocks in lbadan and Lagos metropolis South-western Nigeria". The study recorded higher concentrations for samples obtained during the dry season, while concentrations were observed to be low at the peak of the wet season.

Dan-Hassan et al (2012) also carried out a study on the Spatial and temporal distribution of nitrate pollution in groundwater of Abuja. The study revealed that, some areas have nitrate concentration above the World Health Organization (WHO) and Nigeria Standard for Drinking Water Quality (NSDWQ) guide limit of 50mg/l and it is dominant in the rainy season than dry season. The sources of nitrate in the groundwater were attributed to bedrock dissolution in the course of groundwater migration and more importantly anthropogenic activities such as on-site sanitation, waste dumpsites and agricultural chemicals.

Ige and Korede (2014) studied "seasonal variations on groundwater facies classification in Otte, South-western Nigeria", to determine the dominant ions and sources of pollutants. The study established that as a result of seasonal change, no significant variation in the chemical budget and mobilization of ions was observed. Understanding seasonal variations is crucial for effective monitoring programs.

SUMMARY OF LITERATURE REVIEW

This chapter sought to critically review relevant and related literature concerning groundwater quality. The literature on the Conceptual framework and clarifications yielded that there are three (3) major factors that determine groundwater quality in any given area: (i) Inputs or quality of the infiltrated water (ii) Geochemical processes or post-infiltration reactive processes and (iii) Groundwater flow which is due to the spatial attribute of the study. The three factors above formed the conceptual framework of the study.

The concept of geospatial analysis in groundwater quality was also spotted, viewing the use of Geographic Information System (GIS) in groundwater quality studies.

Despite the abundant studies on groundwater quality, non to the best of the researchers' knowledge studied the evaluation of groundwater quality for domestic use in Federal Capital Territory (FCT) based on seasonal variations. This therefore, necessitated the need to undertake the study on a sub-regional scale that cuts across the lithological units of the territory in order to have a fair representation of the study area.

STUDY AREA AND METHODOLOGY

Location, Position and Size

Federal Capital Territory is located in the North-Central geopolitical zone of Nigeria known as middle belt region, between latitudes 7° 40' to 9° 25' North and longitudes 6° 47' to 7° 40' East. It is bounded in the North by Kaduna State, in the West by Niger State, in the East by Nasarawa State and Kogi State in the South-West. It has a land area of about 8,000 Kilometre square and is situated at elevation 476 metres above sea level and was conceived with adequate allocation of resources to be a model city of urbanization in sub-Saharan Africa (FCT Handbook, 1994). The Federal Capital Territory is made up of six Area Councils which include: Municipal (AMAC), Kuje, Gwagwalada, Abaji, Kwali and Bwari Area Councils, as shown in Figure 3.1.

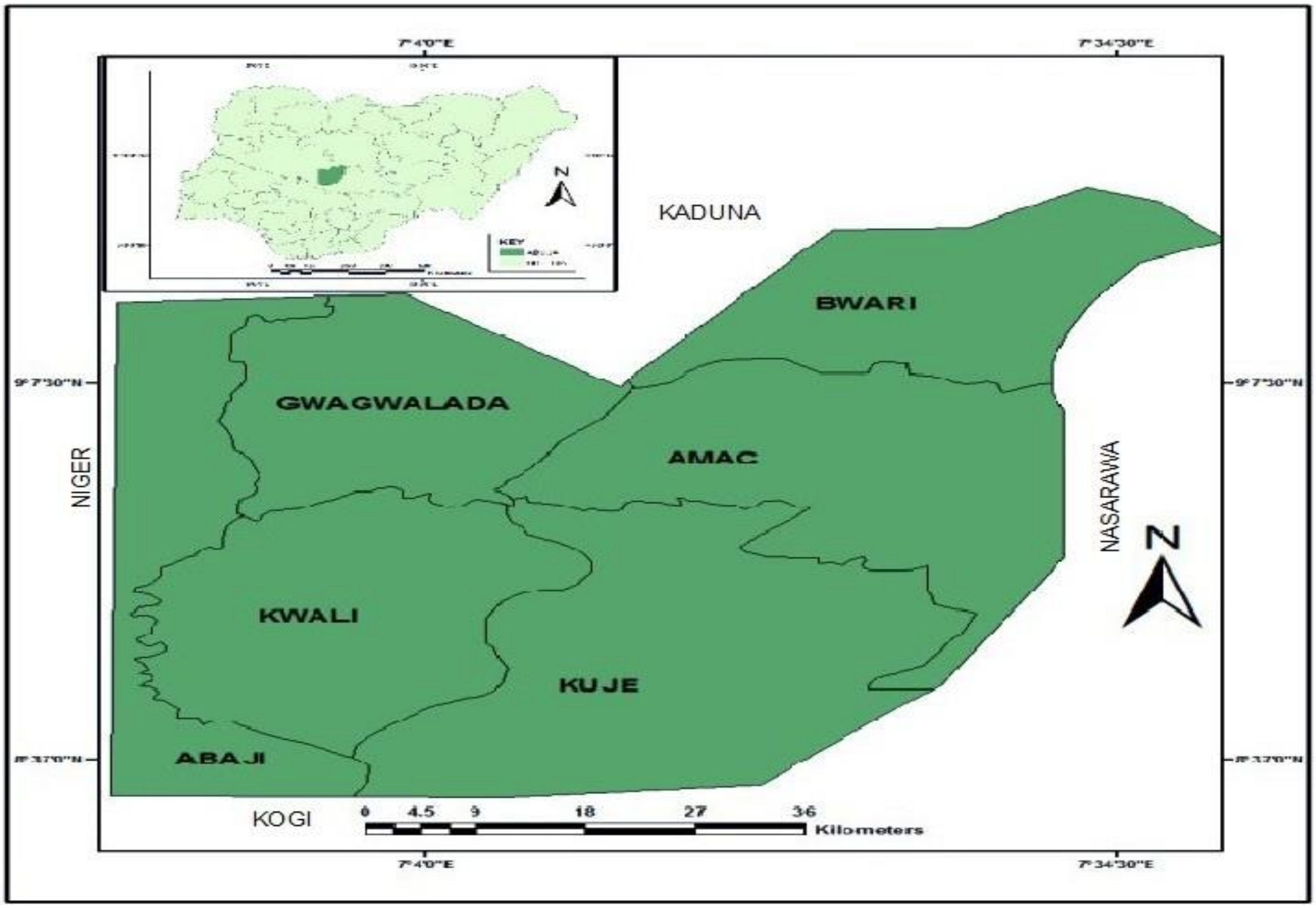

Fig 3.1: Federal Capital Territory Showing the Six Area Councils

Source: Modified from National Space Research Development Agency (NASRDA), Abuja, 2015

Geology and Hydrogeology

Federal Capital Territory (FCT) is predominantly underlain by the Basement Complex rock of the Precambrian age, which cover about 85 percent of the land surface and sedimentary rocks which cover about 15 percent of the territory in the south-western part (Mamman&Oyebanji, 2000). According to Dan-Hassan (2016), the major lithological units in Federal Capital Territory include:

The Older Granite

The Older granites include Biotite Granite (coarse porphyritic), large intrusive masses commonly elliptical in shape forming dissected zones of the Zuma/Bwari – Aso hills and outcrops of the Gwagwa Plains, Biotite Granite (fine to medium grained) forms ridge line trending Northeast-Southwest through the territory; Ryolite, forming small round intrusive surrounded by porphyritic gneiss in the Usuma Valley in the north-eastern part of the study area.The Older granite suite is noted for its lack of associated mineralization, although the thermal effects may play a role in the remobilization of mineralizing fluids. The older Granites are the most obvious manifestation of the Pan-African Orogeny and represent significant additions of materials (up to 70% in some places) to the crust (Rahaman, 1988). The Older Granites include rocks of a wide range of compositions, granites, granodiorites, adamellites, quartz monzonite, syenites, pegmatites (Rahaman, 1988).

The Metasediments

The Metasedimentary/Metavolcanic series consist of phyllites, schists, amphibolites, quartzites and serpentinites. These are found in various places within the study area. The series comprises low grade, metasediment-dominated belts trending north- south and considered to be Upper Proterozoic super crustal rocks that have been infolded into the migmatite-gneiss complex. The lithological differences include fine to coarse grained clastics, politic schists, phyllites, carbonate rocks (marble and dolomitic marbles) and mafic metavolcanics. Metasediments have been mapped along a general NNE-SSW direction through the West of Kusaki (in the south) and East of Takushara (in the North) (USGS 1977).

The Migmatite – Gneiss Complex

The Migmatite-Gneiss complex comprises the most widespread group of rocks and is considered as the Basement Complex sensostricto (Dada, 2006). It comprises migmatites, orthogneisses, paragneisses, quartzites, calc-silicate rocks, biotite-hornblende schist and amphibolites. The Migmatite-Gneiss Complex displays ages varying from Pan African to Eburnean with three main geological phenomena recorded (Rahaman& Lancelot, 1984); the first at (2,500 Ma), involved in initiation of crust forming process and of crustal growth by sedimentation and orogeny; the second event was the Eburnean (2,000 Ma), marked by the granite gneisses, which structurally obliterated the older rocks and re-set the geo-chronological clock to give rise to granite gneisses, migmatites and other similar lithological units.

The Nupe Sandstones

This Basin has not undergone intense tectonic activities and is described as a "down warped basin" (Adeleye, 1973). It comprises Upper Cretaceous (Maastrichtian) sediments with a thickness range of 915 – 2000m (Udensi&Osazuwa, 2005). The Bida Sandstone Formation in the study area is well exposed on a road section along Gwagwalada – Abaji highway, about 10km before Abaji town. It consists of arkoses, feldspathic sandstone and quartz sandstone. Minor amounts of lithic – feldspathic sandstone, subgreywackes, sandy siltstone and intra-formational breccias occur (Adeleye, 1973).

Hydrogeology

Hydrogeologically, two types of aquifers are recognized namely, the regolith or weathered basement aquifers and the fractured zone aquifers. However, five different combinations of the two aquiferous zones described by Olorunfemi&Fasuyi (1993) were encountered in the study area (Dan-Hassan, 2016). The aquifer types include: (i) Weathered layer aquifer (ii) Weathered/fractured (unconfined) aquifer (iii) Weathered/fractured (confined) aquifer (iv) Weathered/fractured (unconfined)/fractured (confined) aquifer (v) Fractured (confined) aquifer. Fortunately, there exists in the territory a thick loose and discontinuous blanket of decayed and decaying rock debris (regolith). A combination of thick regolith and high rainfall and favourable temperature pattern in the Federal Capital Territory offers a conducive condition for occurrence of groundwater. The decayed/decaying and fresh rock fragments lie on top of, below and adjacent one another in an irregular manner creating inter-granular spaces between rock fragments lying together. Precipitation introduces water into the regolith through the usually numerous pore spaces. The regolith therefore acts as a storage medium for water from rainfall and can also transmit water vertically and horizontally to underlying rocks. If the underlying bed rock has high fracture density, regolith can serve to transmit water to underlying bedrock storage sites. The occurrence of the groundwater is a function of the overburden thickness, the type, composition and texture of rock fragments that constitute the overburden and the degree density and interconnections of the fractures. The overburden aquifers occur extensively and receive recharge directly from rainfall. Some measure of artificial recharge comes from the Lower Usman and Jabi dams. The direction of groundwater flow is generally downhill converging in the valleys and river channels. Depths to water table vary from place to place with the water level rising during the rainy season and falling during the dry season resulting in seasonal fluctuation in the actual volume of water in storage (Abam et al, 2013).

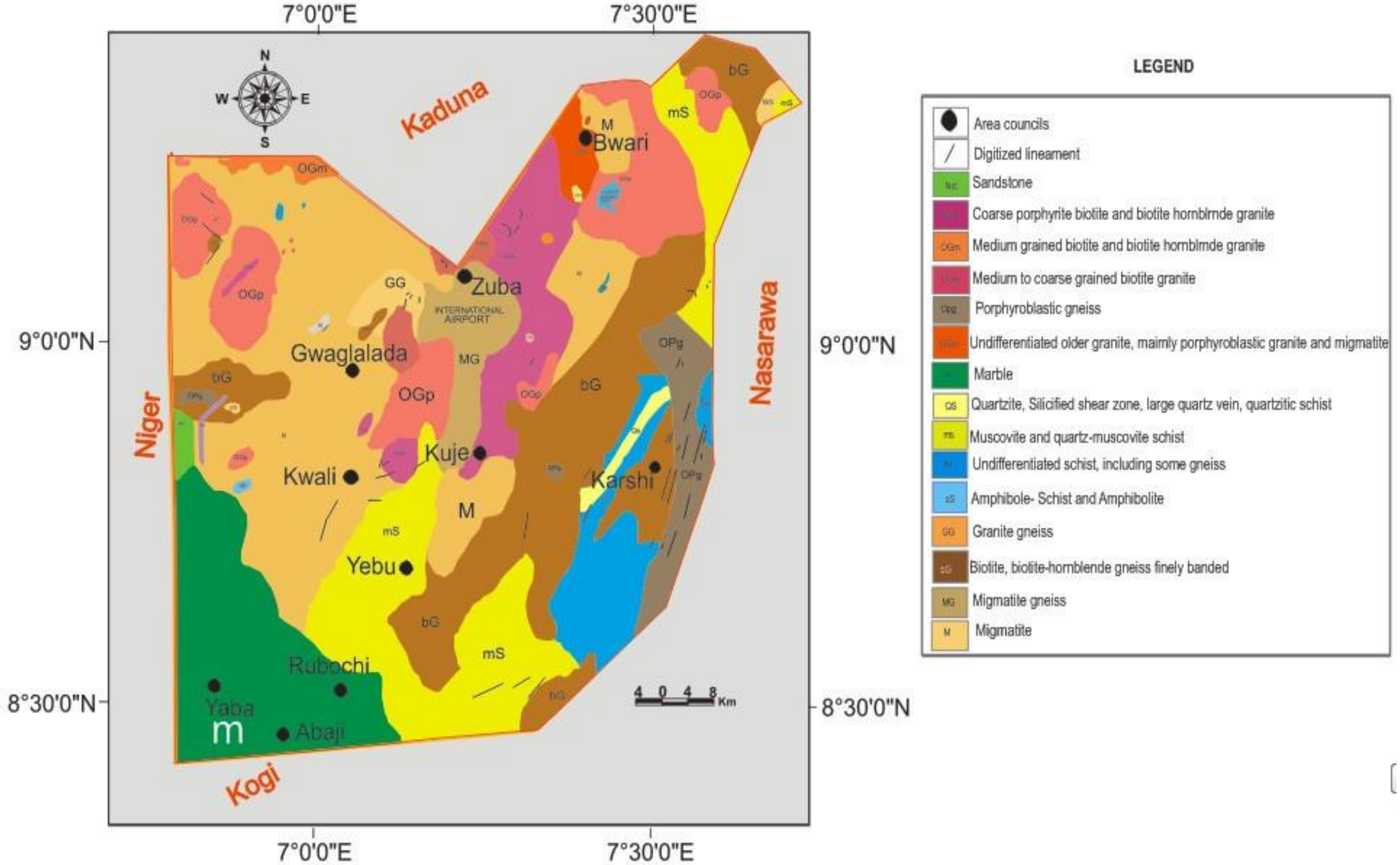

Fig 3.2: Geology of Federal Capital Territory, Nigeria

Source: Modified from Nigerian Geological Survey Agency (NGSA, 2006)

Relief and Drainage

The relief of Abuja is undulating with hills and inselbergs that rise North-Westwards to a maximum of 1060m above sea level. There are extensive plains found between hills in the study area. The Zuma rock stands out clearly on its own as the most conspicuous inselberg at the boundary of the Abuja with Niger State. The lowest elevations are in the South-Western flood plains of the River Gurara, (about 76m above sea level). From there, the land rises irregularly Eastwards, Northwards and North-Westwards. The highest part of the territory is in the North-East where there are many peaks over 760m above sea level.

Hills occur as clusters and long ranges all over the Territory. The most prominent of these include the Gawu range in the North-West, the Bwari-Aso range in the North-East, Idon-Kasa to the North-West of Kuje, Wuna range in the north of Gwagwalada and the Wasa-Sukuku range running across the centre of the Territory from Wasa in the East to Kwali in the West. In-between the major hills are extensive plains, the most important of which are the Gwagwa plains, the lku-Gurara plains, the Robo plains and the Rubochi plains. Indeed, about fifty two percent (52%) of the Federal Capital Territory consists of plains. Out of these plains, the Gwagwa plains occurring at the west of the Federal Capital Territory (FCT) underlain by migmatites and gneisses stand about 305m in the south-west and 516m in the East above mean sea level which form part of River Usuman that originates in the Bwari-Aso hills was selected for the building of the Federal Capital City (FCC) (Audu, 2016).

The rivers rise from the hills in the North-East and flow to the South-West. The area is drained by many rivers in and around Abuja including River Gurara and River Usman while River Wupa, Wosika and other smaller seasonal southerly-flowing streams form the tributaries and drain the study area. The drainage pattern generally varies from trellis to dendritic. The two major rivers (River Gurara and River Usman) join at Nyimbo village to form a tributary of River Niger in the south. These rivers depend on rainfall for their recharge. As such, their volumes are high in rainy season and decrease drastically during the dry season. (Audu, 2016).

Climate of Federal Capital Territory

The Federal Capital Territory records its highest temperature during the dry season months (November - March), which are generally cloudless. Extreme maximum temperatures occur everywhere in the vicinity of the Territory in these months and vary from 37^0C in the South-West to about 30^0C in the North-East. In the dry season, daytime temperatures can soar as high as 40°C and night-time temperatures can dip to 12°C. Even the chilliest nights can be followed by daytime temperatures well above 30°C (see table 3.1). The high altitudes and undulating terrain of the FCT act as a moderating influence on the weather of the territory. The city's inland location causes the diurnal temperature variation to be much larger than coastal cities with similar climates such as Lagos (Nimet, 2018)

The rainy season starts from March on the Southern boundary of the Territory and around April in the Northern limits. The rains taper off around October in the North and November in the South (see table 3.2). Thus, the duration of the rainy season is between 190 days in the North and 240 days in the Southern parts of the Territory. The annual total rainfall is in the range of 1100mm to 1600mm (CIWAT, 2010).In between the two seasons, there is a brief interlude of harmattan occasioned by the North-East trade wind, with the main feature of dust, haze and dryness. Table 3.1 and Table 3.2 display the Temperature and Rainfall data for FCT(Nimet, 2018)

Table 3.1 Temperature Data for Federal Capital Territory, Nigeria.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average high °C	34.7	36.8	36.9	35.6	32.7	30.6	29.1	28.9	30.0	32.0	34.4	34.6
Average low °C	20.4	25.5	24.3	24.7	19.5	18.3	21.9	17.7	17.5	21.4	15.7	15.5

Source: (Nimet, 2018)

Table 3.2 Rainfall Data for Federal Capital Territory, Nigeria.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average rainfall (mm)	1.7	5.4	11.3	62.8	134.1	164.2	217.5	262.7	253.4	103.2	3.7	1.2
Average Rainy days	0.1	0.2	1.3	4.2	9.4	12.3	14.0	16.2	15.9	8.0	0.3	0.1

Source: (Nimet, 2018)

Vegetation

Two major types of vegetation, namely, forest and savannah, are found within the FCT. The forest is predominantly of woody plants, from which grasses are virtually absent. Two types of forest have been identified on the basis of both topographical locations and differences in characteristics including physiognomy and floristic composition.

They are rainforest and riparian vegetation complex (FCT Handbook, 1994). The patches of rainforest occur in the Gwagwa plains, especially in the rugged terrain to the South-Eastern parts of the territory, where a landscape of gullies and rough terrain is found. These areas of the Federal Capital Territory (FCT) form one of the few surviving occurrences of the mature forest vegetation in Nigeria (Audu, 2016).

Population and Human Activities

The population of Federal Capital Territory has been steadily growing since its movement from Lagos. It has grown phenomenally from 113,000 in 1976 and 378,671 in 1991 to 1.4 million in 2006 (National Population Commission, 2006); and the population is now estimated at 3,277,740 in 2020 (UN, 2020). United Nations figures showed that Federal Capital Territory grew by 139.7% between the year 2000 and 2010, making it the fastest-growing city in the African continent and one of the fastest growing city in the world. The indigenous inhabitants of Federal Capital Territory includes: Gwandara, Gbagyi, Gade, Bassa, Koro, Egburah and Ganagana language. The city has a large and growing immigrant community consisting of nationals from the ECOWAS sub-region and beyond.

The Federal Capital Territory (FCT), Nigeria is a hub of various human activities. Some of the notable ones include: Agriculture, Administration and Governance, Business and Commerce, Mining, Tourism, Education, Healthcare, Infrastructure Development, Cultural Events, Recreation and Entertainment. These human activities showcase the FCT's dynamic nature and its role as a hub for politics, economy, culture, and social life in Nigeria.

Research Design

The research design most suitable for this study is the "Experimental Research Design''. This involves the collection of groundwater samples from the field and analysing them in the labouratory.

The result of the physico-chemical analysis conducted in the labouratorywas compared with the World Health Organization (WHO) and Nigerian Standards for Drinking Water Quality (NSDWQ) guidelines for drinking water. This is to ascertain the seasonal spatial variation of groundwater quality parameters and its suitability for domestic use in the study area.

METHODOLOGY

Types and Sources of Data

Both primary and secondary data was used in this study. Primary data was generated through direct observation, coordinates of sampled stations, water samples collected and analysed in the laboratory. While secondary data was gotten through the review of relevant literatures, from documents and materials such as journals, proceeding of seminars, textbooks and other research findings.

Sample Size, Sample Location and Sampling Technique

A total of thirty (30) groundwater samples (borehole and well-water), fifteen (15) samples from each season (i.e. dry season and wet season) was collected from ten (10) locations across the three major lithological regions within Federal Capital territory (FCT), Nigeria. The water samples was collected with clean plastic bottles properly washed, sterilized and labelled for easy identification using acronyms such as: HDW (Hand Dug Well) and B (Borehole). Water from the boreholes was allowed to rush for at least Ten (10) minutes before sampling, while well water was agitated for few minutes using the sampler before sampling. This is to ensure that no particle is left out of the water sample. Parameters such as temperature, pH, conductivity, turbidity and Dissolved Oxygen were conducted in-situ. Preservation of the samples was carried out as prescribed by American Public Health Association (APHA, 2012) methods and was kept in ice box and transported to the laboratory for analyses within twenty-four hours (24hrs).

A stratified sampling technique was applied in selecting the sampling locations, as the study area was divided into the three (3) major lithological regions and sampling locations was randomly selected from each lithological unit. A portable Global Positioning System (GPS) was used to take the coordinates of the sampled stations which was used to construct the spatial distribution of sampling points.

Table 3.3: Location of Sampling Points

S/N	Geological Unit	Sample ID	Sample Location	GPS Coordinates Lat.	Long.	Elevation (m)
1.	Older Granite	HDW-1	IDU	09^0 04’ 09”N	07^0 21’ 08”E	442.3
2.	Older Granite	HDW-2	Dakwa	09^0 06’ 54”N	07^0 13’ 58”E	413.5
3.	Migmatite-Gneiss	HDW-3	Zuba	09^0 05’ 44”N	07^0 13’ 02”E	397.0
4.	Migmatite-Gneiss	HDW-4	Anagada	09^0 02’ 23”N	07^0 10’ 26”E	306.1
5.	Metasediments	HDW-5	Kwaita	08^0 39’ 55”N	06^0 55’ 30”E	136.0
6.	Metasediments	HDW-6	Kwaita	08^0 39’ 51”N	06^0 55’ 46”E	140.6
7.	Migmatite-Gneiss	B-1	Anagada	09^0 02’ 22”N	07^0 10’ 17”E	313.6
8.	Older Granite	B-2	Kuje	08^0 53’ 04”N	07^0 13’ 07”E	306.5
9.	Migmatite-Gneiss	B-3	Gwagwalada	08^0 55’ 55”N	07^0 05’ 45”E	198.5
10.	Migmatite-Gneiss	B-4	Gwagwalada	08^0 55’ 48”N	07^0 05’ 40”E	196.8
11.	Older Granite	B-5	Lugbe	08^0 58’ 33”N	07^0 22’ 22”E	411.6
12.	Metasediments	B-6	Abaji	08^0 28’ 41”N	06^0 56’ 31”E	135.0
13.	Metasediments	B-7	Abaji	08^0 28’ 30”N	06^0 56’ 36”E	135.5
14.	Metasediments	B-8	Abaji	08^0 28’ 46”N	06^0 56’ 38”E	144.3
15.	Old Granite	B-9	Bwari	09^0 16’ 23”N	07^0 22’ 55”E	596.7

Source: Author’s Field Work (20204

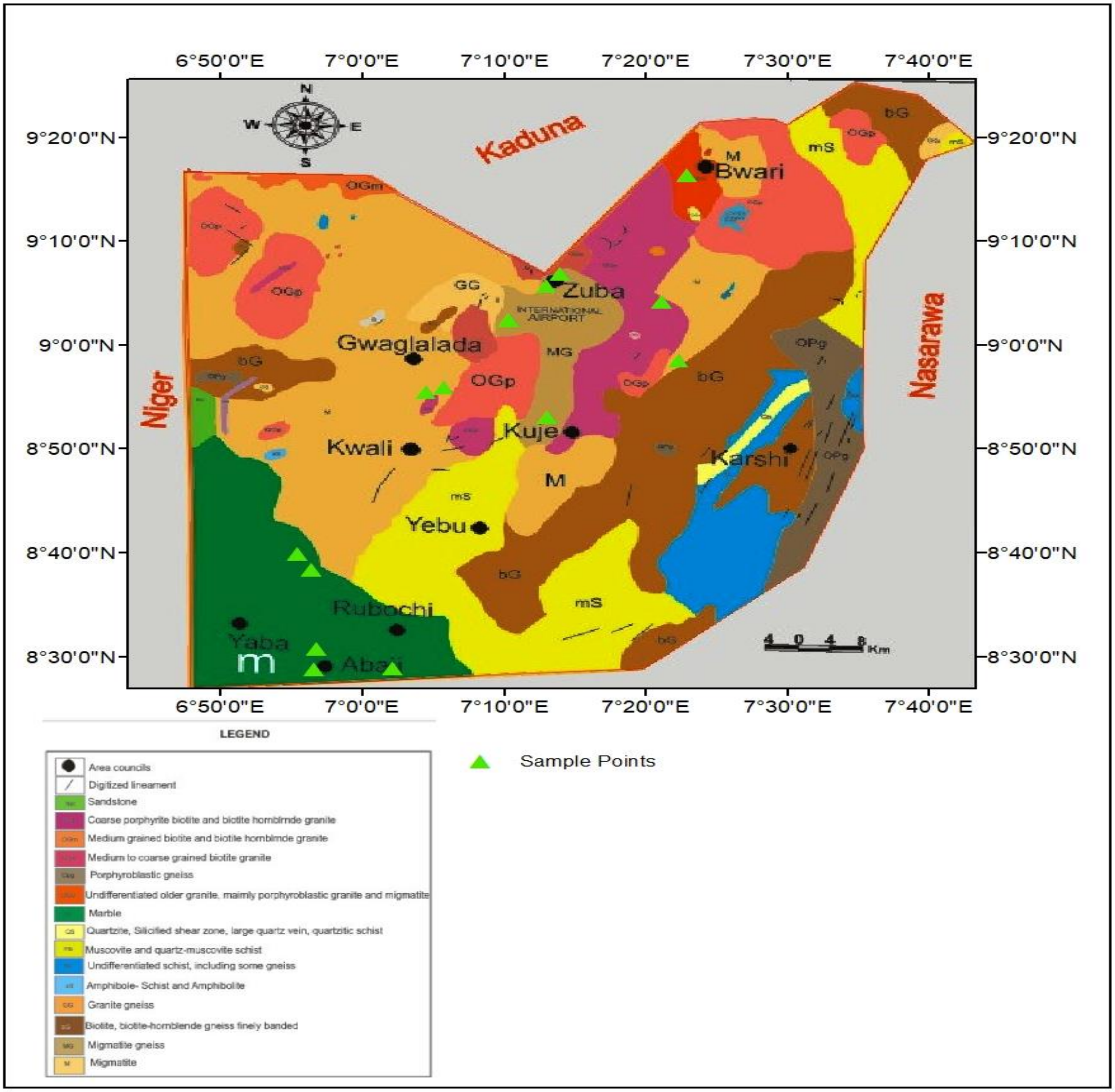

Fig. 3.3: Geological Map of FCT Showing the Spatial Distribution of Sampling Points

Laboratory Equipments And Reagents

The equipment and reagents used in carrying out both the field and laboratory operations include: Global Positioning System (GPS) device (GPS 72H), Cooler, Spectrophotometer (Spectroquant NOVA 60), Burette, Beakers, Conical flask, Micro Pipettes (eppendorf Research 1000), Pipette (eppendorf Research 5000), cuvette, Auto Selector, Filter paper (Whatman 110 mm Cat No 1001110), Measuring bottle, Electrically heated temperature controlled oven (Binder), Evaporating dish, Timer, Measuring cylinder (100mL and 250ml), , Plastic bottle for collection of sample, EMB Plates, Neogloves (Surgical gloves), Pressure pump (Model No DOA-P730-NB), Beakers, Funnel, Magnetic stirrer (Heidolph instrument MR 1000), Autoclave (Certoclav sterilizer GmbH, A-4050 Traun/Australia), Incubator, Desiccator, Digital weighing balance (Model EP114C SNR1126372109 OHAUS), Distilling flask, 125mL, Water bath, pH meter (pH 330i), Test tubes, Reaction cell, Litmus paper, Mercuric sulphate, Starch indicator (Solution)

Magnesium (O2-1), Ammonia reagent (NH_4^--1, NH_4^+& NH_4^+), Nitrate reagent (NO_3^--1), Nitrate pellet (NO_3^--2), Chloride reagent (Cl^--1, &Cl^--2), Potassium dichromate, Sulfuric acid (H_2SO_4), Ferrous ammonium sulphate Silver Sulphate, Standard sodium thiosulphate, Mackonkey agar, 15 tubes of double strength lactose broth, Sodium hydroxide, Distilled water, Sodium hydroxide pellet, EDTA reagent, Standard ammonium solution, Hydrochloric acid solution, Aluminium hydroxide suspension, Standards silver nitrate solution Potassium chromate indicator solution, Colorimeter.

Labouratory Techniques

The following labouratory techniques was employed in the physico-chemical analysis of the groundwater samples. These include: Photometric, Gravimetric, Colorimetric, Electrometric and Titrimetric (Volumetric techniques). The physico-chemical parameters includes: Temperature, pH, Electrical Conductivity (EC), Turbidity, Appearance, Odour, Dissolved Oxygen (DO), Total Dissolved Solids (TDS), Colour, Nitrate, Calcium, Total Alkalinity, Total Hardness (TH), Magnesium, Bicarbonate, Copper (Cu), Iron (Fe). The analysed labouratory data was presented on tables and content analysis was done by explanation.

Physical Analysis

pH

(Electrometric method)

The Power or potential of Hydrogen (PH) generally is a measure of hydrogen ion concentration in a given sample; the pH scale usually ranges from 0 to 14. Aqueous solutions at 25°C with a pH of less than seven are acidic, while those with a pH greater than seven are basic or alkaline. A pH level of 7.0 at 25°C is defined as 'neutral' because the concentration of hydronium ion (H_3O^+) equals the concentration of hydroxyl ion(OH^-) in pure water. World Health Organization (WHO) and Nigerian Standard for Drinking Water Quality (NSDWQ) recommended pH values of 6.5 - 8.5 as standard.

Apparatus: pHmeter, Beaker, Distilled water, groundwater sample

Procedure:10ml of the sample was poured into a beaker that has been rinsed with distilled water. The pH meter's electrode was also rinsed with distilled water, then with the sample to be analysed. The electrode was then dipped into the sample and the Automatic Reader (AR) button was clicked and the values recorded when stable.

Turbidity

(Electrometric method)

Turbidity is the degree of cloudiness or haziness of a substance caused by large numbers of individual particles that are usually invisible to the naked eyes. It also refers to the measure of the degree to which water loses its transparency due to the presence of suspended particulates. The unit of turbidity is Nephelometric Turbidity Unit (NTU). The World Health Organization (WHO) and Nigerian Standard for Drinking Water Quality (NSDWQ) recommends 0-5 NTU as standard.

Apparatus: Turbidimeter, wash bottle, Groundwater sample

Procedure: The turbidimeterwas placed on a flat surface and switched "ON".The turbidimeter sample cell was rinsed with distilled water, then with the sample to be analysed respectively. Then the turbidimeter sample cell was filled with the water sample and inserted back to the sample well of the turbidimeter. The "Run" button was then clicked and readings taken when stable.

Electrical Conductivity

(Electrometric method)

Electrical conductivity generally is the ability of an aqueous solution to carry an electric current. This ability depends wholly on the presence of ions, their total concentration, mobility, and the temperature. The unit of measuring conductivity is Micro-Siemen per centimetre (µS/cm). World Health Organization (WHO) and Nigerian Standard for Drinking Water Quality (NSDWQ) recommend 0 - 1000µS/cm as standard for drinking water.

Apparatus: Conductivity meter, Beaker, Groundwater sample

Procedure: The beaker was rinsed with distilled water and a portion of the water sample respectively. The beaker was then filled with the sample before inserting the electrode from the conductivity meter into the sample and allowed for 1-2 minutes for a stable reading to be obtained and recorded.

Temperature

(Electrometric method)

Temperature is simply the degree of coldness or hotness of a substance. Temperature is also defined as a measurement of the average thermal energy of a substance. Thermal energy in turn is the kinetic energy of atoms and molecules. It is measured in degree Celsius (^{0}C) using Thermometer or Multipurpose Electrical Conductivity Meter.

Procedure: The conductivity meter's electrode was rinsed with distilled water and with the sample to be analysed respectively. The electrode was then inserted into the beaker containing the water sample and reading recorded when it's stable.

Dissolved Oxygen (DO)

(Electrometric method)

Dissolved oxygen level of the samples was measured with the D.O meter.

The electrode of the DO meter was rinsed with distilled water and with the water sample respectively. The electrode was then dipped into the water sample, and reading recorded when stable.

Colour

(Colorimetric Method)

Colour in water is primarily a concern of water quality for aesthetic reason. Coloured water give the appearance of being unfit to drink, even though the water may be safe for public use. Colour of the water body can indicate the presence of organic substances, such as algae or humic compounds. In recent times, colour has been used as a quantitative assessment of the presence of potentially hazardous or toxic organic materials in water.

Apparatus used includes: Colorimeter or lovibond comparator and Wash bottles.

Procedure: Rinse the cell with distilled water, fill it to the mark with distilled water and place it in the left sample position of the comparator. Rinse another cell with distilled water and the sample respectively, fill it also to the mark with the sample and place it in the right side of the sample position. Place the colour disc and rotate so as to match the colour. Record the number on the disc as colour of the sample.

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Chemical Analysis

Total Alkalinity

(Volumetric Method)

Total Alkalinity is a measure of the capacity of water to neutralize acids or hydrogen ions. Alkalinity can sometimes be referred as "Carbonate hardness". Alkalinity acts as a buffer if any changes are made to the water's pH value. Alkalinity in water will help keep the water's pH stabilized. Alkaline water helps balance the body's pH, which tends to be acidic because of our high acid food diet, stress and exposure to environmental toxins such as smog. Nigerian Standard for Drinking Water Quality recommends 0 - 500mg/L as standard for Alkalinity. Total alkalinity of water sample is determined quantitatively using titration

Apparatus: burette, pipette, conical flask, beakers and droppers.

Reagents: Methyl Orange Indicator, 0.2N H_2SO_4

Procedure: The apparatus to be used were rinsed with distilled water, then with the water sample (rinse the measuring cylinder and the conical flask) and with the reagent – H_2SO_4 (rinse the burette and the funnel). Then 100ml of the water sample was measured using measuring cylinder and was transferred into 250ml conical flask. Two (2) drops of methyl orange indicator was added and Titrated against 0.02N H_2SO_4 to the first colour change (faint yellow) and the titre value recorded.

Calculation

$$Total\ Alkalinity(mg/l) = \frac{Titre}{Volume\ of\ sample\ used} \times 1000$$

Total Dissolved Solids (TDS)

(Gravimetric method)

Total Dissolved Solids (TDS) are solids in water that can pass through a filter (usually with a pore size of 0.45 micro-metre). TDS is the measure of the amount of materials dissolved in water. This material can include carbonate, bicarbonate, chloride, sulphate, phosphate, nitrate, calcium, magnesium, sodium, organic ions, and other ions. A certain level of these ions in water is necessary for aquatic life. Similar to Total Suspended Solids (TSS), high concentrations of TDS may also reduce water clarity, contribute to a decrease in photosynthesis, combine with toxic compounds and heavy metals, and lead to an increase in water temperature. TDS is used to estimate the quality of drinking water, because it represents the amount of ions in the water. Water with high TDS often has bad taste and/or high water hardness, and could result in a laxative effect. TDS is measured in milligram per litre (mg/l).

Principle: The difference in the weights of Total Solids (A) and Total Suspended Solids (B) expressed in the same units gives Total Dissolved Solids (TDS).

Apparatus: glass-fibre filter paper, filtration unit, suction pump, oven, beakers and evaporating dishes.

Procedure: The apparatus were washed and rinsed with distilled water. The evaporating dishes were placed in an oven to dry at 105ºC and then transferred to the desiccator to cool before weighing the initial weight (B). A Glass fibre filter paper was then placed on a funnel placed over a measuring cylinder. The sample was stirred with magnetic stirrer and poured through the filter into the funnel and allowed to drain. 30ml of the filtrate (sample volume) was poured into the already treated dish and steam heated to dryness over the water bath. The dish was then placed in the oven and heated to 105ºC then transferred to desiccators to cool before measuring the final weight (A) using a weighing balance.

The weight of the dissolved solids was determined using the formula below:

Total Dissolved Solids (TDS) $= \frac{A - B}{Sample\ Volume} = \times 10^6$ **(mg/l)**

Where:

A = weight of content + dish (g) B = weight of dish

Total Hardness (TH)

(Volumetric Method)

Total hardness is the amount of dissolved Calcium and Magnesium in water. Hardness is defined as the sum of all polyvalent cations (in consistent units). The common unit of expression is milligram per litre (mg/l). Hardness in natural water comes from the dissolution of minerals from geologic formations that contain Calcium and Magnesium, two common minerals are Calcite ($CaCO_3$) and Dolomite [CaMg (CO_3)2]. Because Calcium and Magnesium predominate, the convention in performing softening calculations is to define the total hardness of water as the sum of these elements TH = Ca^{+2} + Mg^{+2}.

Nigerian Standard for Drinking Water Quality (NSDWQ) recommends 0 - 150mg/L as standard in the case of Total Hardness. Total hardness of water sample is ascertained quantitatively using titrimetric also known as volumetric method.

Apparatus: Burette, Pipette, Conical Flask, Beaker.

Reagents: Buffer solution, Eriochrome black-T indicator, Ethylene Diamine Tetra Acetic Acid (EDTA) solution

Procedure: The Measuring cylinder and the conical flask were rinsed with distilled water, then with the water sample respectively. The burette and the funnel were then rinsed with the reagent –EDTA.100ml of the water sample was measured using measuring cylinder and poured into 250ml conical flask.A pinch of Eriochrome Black T indicator and 1ml of Ammonia buffer was added and titrated with the EDTA solution to the end point (finite blue). The titre value from the burette was then recorded.

Calculation

$$\boldsymbol{Total\ Hardness\ (TH) = \frac{titrant}{Volume\ of\ \ sample\ used} \times \frac{1000mg}{l}}$$

Nitrate (NO_3)

(Photometric)

Nitrate is a common water pollutant made up of nitrogen and oxygen. Nitrate may arise from the excessive application of fertilizers or from leaching of wastewater or other organic wastes into surface water and groundwater (WHO, 2006). The nitrite ion contains nitrogen in a relatively unstable oxidation state, chemical and biological processes can further reduce nitrite to various compounds or oxidize it to nitrate. Because of its solubility and its anionic form, nitrate is very mobile in groundwater. Nitrate and Nitrite in water has been associated with methaemoglobinaemia (Blue baby Syndrome), especially in bottle-fed infants, with a methaemoglobin level of 3-15%, skin can turn to a pale grey or blue. This prevents the blood from delivering oxygen effectively in the body. If severe, the condition can affect breathing and may lead to death (WHO, 2020).

Nigerian Standard for Drinking Water Quality (NSDWQ) and World Health Organization (WHO) recommend 0-50mg/l as standard.

Apparatus: Spectrophotometer, Testube, Auto-selector, Micro-pipette, Cuvette

Reagent: Sulphanilic acid.

Procedure: 5ml of the water sample was measured into a testube and one loopful of the reagent (Sulfanilic acid) was added and shakes. The solution was allowed to stand for 10mins (reaction time), and then it was poured into the auto-selector and inserted into the Spectrophotometer and the result was recorded.

Iron (Fe)

(Photometric)

Iron is a metallic element that makes up about 5% of the Earth's crust. It occurs mainly in Fe^{2+} (ferrous iron) and Fe^{3+} (ferric iron). Usually, iron occurring in groundwater is in the form of ferric hydroxide, in concentrations less than 500µg/l. In its pure form, iron is a dark-grey metal, but it is exclusively found in combination with other elements called ores. Most common iron-containing ores are hematite, magnetite, and taconite. When in the presence of oxygen, iron is a reactive element that oxidizes (rusts) very easily. The shortage of iron causes disease called "anemia''. Although iron is an essential mineral, prolonged consumption of drinking water with high concentration of iron can lead to liver disease called Haermosiderosis (Rajappa et al., 2010; Nagendrappa et al., 2010), gastrointestinal problems Llike nausea, vomiting, and diarhea (WHO, 2020). Diseases of aging such as Alzheimer's disease, other neurodegenerative diseases, arteriosclerosis, diabetes mellitus, and others have been linked to excess iron intake (Brewer, 2009). High concentrations of dissolved iron can result in poor tasting, unattractive water that stains both plumbing fixtures and clothing (Hem, 1985).

Apparatus: Beaker, Spectrophotometer.

Reagent: Fe-1k

Procedure: 1ml of water sample was pipetted into a reaction cell, close the cell and 1 dose of reagent (Fe-1k) was added, and shake vigorously until the reagent was completely dissolved. It was allowed to stand for 5mins (reaction time), then the sample was measured in the photometer.

Copper (Cu^{2+})

(Volumetric and Photometric)

Copper is an essential trace element with an optimal daily oral intake of 1-2 mg per person. Naturally occurring copper concentrations in groundwater are without any health significance and scatter mostly around 20 µg/l. If drinking-water drawn from groundwater contains elevated levels, in most situations corrosion of copper pipes is the primary source. Mean concentrations of more than 2 mg/l could lead to liver cirrhosis in babies if their formula is repeatedly prepared using such water (Zietz et al., 2003). The prevalent endpoint of acute copper toxicity by time, concentration and dose is nausea (Araya et al., 2003). The health based guideline value for copper in drinking-water is 2 mg/l (WHO, 2004a; 2004c).

Apparatus: test tube, pipette, burette, retort stand, photometer.

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Reagent: Cu-1 and Cu-2 for volumetric technique, and NaoH or H_2SO_4 for Photometric technique.

Procedures: 5ml of the groundwater sample was measured into a test tube, and one spoonful of reagent Cu-1 was added and shake vigorously until the reagent was completely dissolved (Sample pH must be within 7 to 9.5)

Add five drops of reagents Cu-2 and mix. Allow to stand for five minute. Sample PH must be within 4 to 10. **If not,** then adjust with either NaOH or H_2SO_4. Fill to the cell and measure in photometer.

Methods of Data Analysis and Presentation

The data obtained from the physico-chemical labouratory analysis was displayed on tables and graphs using excel and compared to World Health Organization (WHO) and Nigerian Standards for Drinking Water Quality (NSDWQ) guidelines to check if they fall within acceptable limits. Water Quality Index (WQI) was computed using the labouratory data obtained to know the level of contamination of the groundwater. The coordinates of the sampling points and locations taken was used to generate spatial distribution map of the study area.

Statistical Technique

The student t-test was used to statistically test the seasonal variation in groundwater quality between the dry season and wet season. This student t-test is used in hypothesis testing to determine if there's a significant difference between the means of two groups.There are two types of student's t-tests: Independent Samples t-test (which compares the means of two independent groups) and Paired Samples t-test(which compares the means of two related groups e.g., before and after a treatment). The paired samples t-test was applied in this study to determine the significant difference between the means of the wet season and the dry season.

Data Presentation And Analysis

Physico-chemical Groundwater Quality Parameters in Federal Capital Territory (FCT), Nigeria.

The results of the aesthetic groundwater quality parameters (Appearance, Colour, and Odour) conducted on all the groundwater samples for both wet and dry seasons in the study area complied with the World Health Organization (WHO) and Nigerian Standard for Drinking Water Quality (NSDWQ) guidelines(table 4.1&2).

pH

The concentration of pH for wet season ranges from 3.51 to 6.58 with mean value of 5.43, while in the dry season, the pH ranges from 4.2 to 6.62 with mean value of 5.81 (see table 4.1 & 4.2). During the wet season, only pH of B3 (6.52) and HDW3 (6.58) were found to be within the WHO and NSDWQ permissible limits. In the dry season, pH of B2 (6.56), B3 (6.58), and HDW3 (6.52) were found to be within the permissible limits, while the remaining samples all fell below the permissible limit of 6.5 to 8.5 (see figure 4.2), indicating the groundwater of FCT to be slightly acidic, which is unsuitable for domestic purpose. This can be attributed to the underlying geology, soil type and land-use such as agricultural and industrial activities which can release ions such as H^+, leading to acidification of the groundwater. Long time consumption of acidic water can lead to gastrointestinal issues like heartburn, Diarrhea, and increased risk of diseases like cancer, liver and kidney damage (WHO, 2020)

The dry season had higher pH values than the wet season in all samples (seen in fig. 4.1). This corresponds to the study on the Aspects of Hydrology of the FCT conducted by Dan-Hassan (2016) and Seasonal Variation in Physico-chemical Characteristics of Rural Groundwater of Benue State, Nigeria by Ocheri et al (2012).

Table 4.1: RESULT OF GROUNDWATER PHYSICO-CHEMICAL ANALYSIS FOR DRY SEASON

parameters	units	B1	B2	B3	B4	B5	B6	B7	B8	B9	W1	W2	W3	W4	W5	W6
		Anagada	Kuje	Gwagwalada	Gwagwalada	Lugbe	Abaji	Abaji	Abaji	Bwari	Idu	Dakwa	Zuba	Anagada	Kwaita	Kwaita
App		clear	clear	clear	clear	clear	clear	clear	clear	clear	clear	clear	clear	clear	clear	clear
color		colorless	colorless	colorless	colorless	colorless	colorless	colorless	colorless	colorless	colorless	colorless	colorless	colorless	colorless	colorless
Odour		odorless	odorless	odorless	odorless	odorless	odorless	odorless	odorless	odorless	odorless	odorless	odorless	odorless	odorless	odorless
TEMP	0c	20.90	17.00	20.00	19.90	22.08	20.00	21.80	22.00	19.90	20.20	19.00	20.00	22.00	21.00	19.00
PH		6.2	6.56	6.58	6.4	6	5.4	5.2	5.4	5.96	5.84	5.85	6.62	6.4	4.2	4.6
E.C	uS/cm	560	470.0	238.9	315.8	238.9	20.5	86.6	30.2	110.4	1442.9	765.0	750.0	690.0	710.9	842.6
Turb.	NTU	0.61	0.6	0.75	0.6	2.9	1.33	1.01	1.55	0.79	9.8	14.2	2.80	3.35	30.8	10.5
TDS	mg/L	231.0	70.2	90.6	78.9	13.8	175.9	135.8	42.6	20.4	592.0	299.0	272.2	388.2	298.0	310.0
T.H	mg/L	172.8	159.9	172.8	181.7	140.2	32.9	32.7	15.9	33.6	659.1	210.0	185.6	249.7	251.4	251.9
D.O	mg/L	8.82	8.49	9.00	8.90	8.48	9.20	9.41	9.10	8.08	6.41	7.20	7.60	8.10	7.90	7.80
Ca^{2+}	mg/L	57.8	50.0	100.0	58.0	49.2	13.0	13.0	6.4	13.0	268.4	80.6	70.0	102.0	102.0	102.0
Mg^{2+}	mg/L	6.7	5.8	7.0	5.8	4.0	1.3	1.3	1.0	0.7	10.0	8.0	6.0	7.0	4.9	7.0
Alkalinity	mg/L	123.00	106.80	179.60	93.40	89.80	88.90	89.20	89.00	71.80	78.80	110.00	179.20	106.80	90.00	90.02
Nitrate	mg/L	12.60	7.60	6.00	10.20	11.00	0.80	0.82	0.80	2.40	68.00	59.80	9.40	16.80	26.00	25.20
Cu2+	mg/L	0.08	0.06	0.22	0.34	0.3	0.16	0.3	0.32	0.36	0.04	0.16	0.30	0.10	0.20	0.18
Fe2+	mg/L	0.2	0.22	0.2	0.24	0.18	0.21	0.28	0.22	0.24	0.16	0.36	0.18	0.28	0.30	0.34
HCO3	mg/L	90.8	74.98	114.6	92.2	64.6	16.68	17.1	8.8	16.2	300.6	94.4	78.8	107	112.2	106.8

Table 4.2: RESULT OF GROUNDWATER PHYSICO-CHEMICAL ANALYSIS FOR RAINING SEASON

parameters	**units**	**B1**	**B2**	**B3**	**B4**	**B5**	**B6**	**B7**	**B8**	**B9**	**W1**	**W2**	**W3**	**W4**	**W5**	**W6**
		Anagada	**Kuje**	**Gwagwalada**	**Gwagwalada**	**Lugbe**	**Abaji**	**Abaji**	**Abaji**	**Bwari**	**Idu**	**Dakwa**	**Zuba**	**Anagada**	**Kwaita**	**Kwaita**
App		clear	clear	clear	clear	clear	clear	clear	clear	clear	clear	clear	clear	clear	clear	clear
color		colorless	colorless	colorless	colorless	colorless	colorless	colorless	colorless	colorless	colorless	colorless	colorless	colorless	colorless	colorless
Odour		odorless	odorless	odorless	odorless	odorless	odorless	odorless	odorless	odorless	odorless	odorless	odorless	odorless	odorless	odorless
TEMP	0c	19.90	15.00	18.00	17.90	20.70	19.60	20.80	20.90	17.90	19.20	18.90	19.00	21.80	20.00	18.80
PH		5.81	6.13	6.52	6.07	5.95	4.58	4.72	4.87	5.81	5.44	5.73	6.58	6.05	3.64	3.51
E.C	uS/cm	553	463.0	670.0	231.0	424.0	13.4	82.9	21.8	113.1	1669.0	761.0	690.0	792.0	709.0	842.0
Turb.	NTU	0.63	0.64	0.76	0.66	2.92	1.32	1.03	1.75	0.83	10.2	14.6	2.10	3.63	32.6	10.6
TDS	mg/L	252.0	80.9	100.8	85.9	25.7	198.6	143.3	49.8	24.5	622.9	321.8	305.1	402.9	309.0	376.8
T.H	mg/L	192.8	176.2	272.8	195.4	142.4	38.6	38.0	20.2	40.0	668.6	217.8	200.2	271.9	266.9	266.8
D.O	mg/L	10.20	10.35	10.79	11.10	10.50	9.90	9.99	9.50	10.20	8.35	7.90	7.87	8.80	8.35	8.70
Ca^{2+}	mg/L	57.8	52.2	102.2	58.6	50.2	14.8	16.0	14.0	14.8	298.6	80.2	75.1	101.8	103.9	105.0
Mg^{2+}	mg/L	6.9	6.2	7.8	6.5	4.8	2.2	2.0	1.8	1.5	12.6	9.0	6.8	7.0	5.5	7.2
Alkalinity	mg/L	124.60	106.80	178.00	89.00	89.00	89.00	87.00	89.00	71.20	71.20	106.80	178.00	106.20	89.00	89.00
Nitrate	mg/L	13.00	7.90	6.10	12.40	11.20	1.00	1.00	1.10	2.80	71.50	68.40	9.80	20.00	26.50	26.00
Cu2+	mg/L	0.2	0.1	0.28	0.41	0.35	0.2	0.4	0.38	0.42	0.08	0.16	0.36	0.18	0.42	0.36
Fe2+	mg/L	0.14	0.14	0.16	0.16	0.12	0.16	0.2	0.14	0.16	0.1	0.32	0.14	0.22	0.30	0.30
HCO3	mg/L	88.11	74.76	113.92	82.24	64.08	15.66	15.31	7.48	15.31	306.16	91.85	78.32	106.8	112.14	106.8

Temperature (^{0}C)

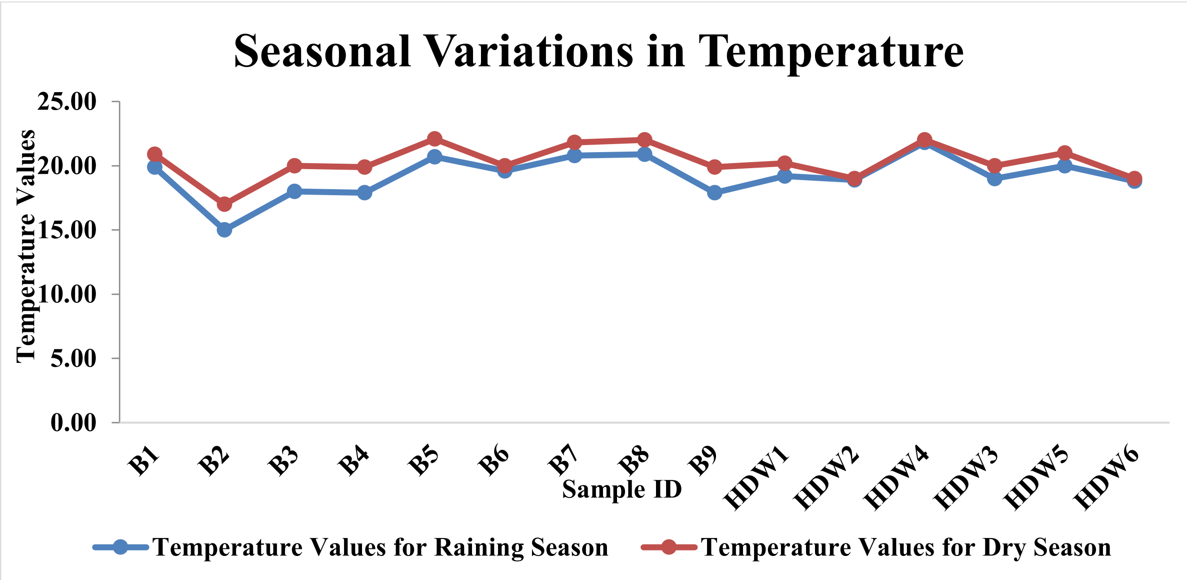

Fig 4.2: Variations in Temperature Values and Comparison with NSDWQ Standard

The temperature values for wet season ranges from 15^{0}C to 22.8^{0}C with a mean value of 19.23^{0}C, while in the dry season, it ranges from 17^{0}C to 21.8^{0}C with a mean value of 20.32^{0}C. There was a seasonal variation in temperature values, as the dry season has a higher temperature values than the dry season across all the samples collected. These results when compared to the meteorological data reports of the study area, indicates an influence of local weather conditions and could be inferred as ambient.

Electrical Conductivity (EC)

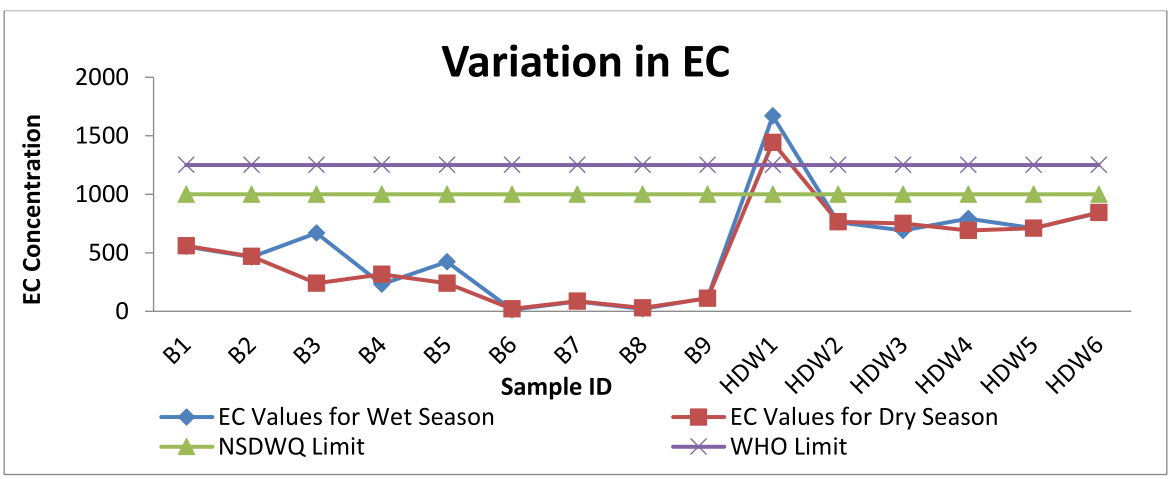

Fig 4.3: Seasonal Variations in Electrical Conductivity Values and Comparison with WHO and

NSDWQ

The concentration of EC for wet season ranges from13.4µS/cm to 1669µS/cm with mean value of 535.68µS/cm, while in the dry season, it ranges from 20.5µS/cm to 1442.9µS/cm with mean value of 484.85µS/cm. Apart from HDW1 (1669µS/cm) for wet season and HDW1 (1442.9µS/cm) for dry season that exceeded the WHO and NSDWQ of 1250 and 1000 respectively, all other samples fell within the acceptable limit of both WHO and NSDWQ.

The wet season experiences higher concentration of EC in most of the samples than the dry season, this might be due to rainwater diluting and infiltrating ionized solutes such as chloride, sulphate, potassium and magnesium into groundwater during rainfall (Al-Tamim et al, 2023).However, samples with low EC such as B6, B7, B8, and B9 for both wet and dry season were also observed to have low pH values, reflecting low mineral solubility, short groundwater residence time, shallow aquifer nature, and its acidic characteristics (Wirmvem et al, 2013).

According to WHO (2006), Electrical Conductivity can be classified as type I, if the enrichments of salts are low (EC < 1,500); type II, if the enrichment of salts are medium (EC = 1,500 to 3,000); and type III, if the enrichments of salts are high (EC > 3,000). Based on the above classification, all of the groundwater samples for both seasons fall in the type I (low enrichment of salts), except for HDW1which fall within the type II (medium enrichment of salts) as seen in figure 4.3.

Turbidity

The turbidity values for wet season ranges from 0.63NTU to 32.6NTU with mean value of 5.62NTU, while for dry season it ranges from 0.6NTU to 30.8NTU with mean value of 5.44NTU. Turbidity values for wet season were slightly higher than the dry season values; this could be due to increased infiltration of suspended particles and sediments into groundwater from the surface during wet season. This corresponds to studies conducted by Ocheri et al (2006) and Dan Hassan (2026), where they both observed higher turbidity concentration during the wet season than the dry season. High turbidity in drinking water can lead to waterborne diseases outbreak, as suspended particles can provide shelter for microorganisms, and it can also lead to gastrointestinal illnesses such diarrhea, nausea, and cramps (WHO, 2017).

However, apart from HDW1 (10.2), HDW2 (14.6), HDW5 (32.6) and HDW6 (10.6) for wet season and HDW1 (9.8), HDW2 (14.2), HDW5 (30.8), and HDW6 (10.5) for dry season which are above the WHO and NSDWQ limit of 5NTU, all other samples for both seasons falls within the permissible limit (see fig. 4.4).

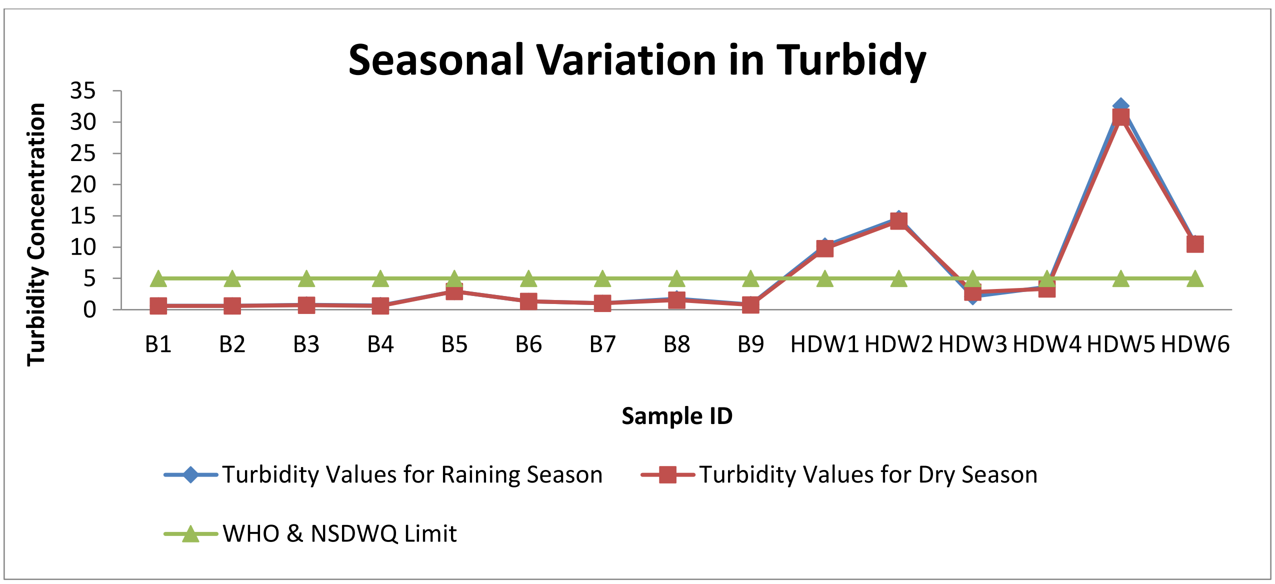

Fig. 4.4: Seasonal Variations in Turbidity Values and Comparison with NSDWQ

Total Dissolved Solids (TDS)

Total Dissolved Solids (TDS) in groundwater refers to the concentration of dissolved minerals, salts, and other inorganic compounds. TDS concentration for wet season ranges from 24.5mg/L to 622.9mg/L with mean value of 220mg/L, while the concentration for dry season ranges from 13.8mg/L to 592.0mg/L with mean value of

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201.20mg/L. The wet season had a slightly higher values of TDS concentration than the dry season, and this can be attributed to natural/geochemical and biological phenomena like geology, hydrology, and increased infiltration and leaching of dissolved minerals and salts from the surface during the wet season, and heavy impact of anthropogenic activities such as agricultural and industrial activities leading to increased fertilizer and pesticides application, contributing to higher TDS in groundwater. This is in line with the study conducted by Sulaiman et al (2019) on the Assessment of Seasonal Variation of Groundwater Quality in Bauchi Town, North-Eastern Nigeria, and Ocheri et al (2006) on Seasonal Variation in Physico-chemical Characteristics of Rural Groundwater of Benue State, Nigeria. High TDS in drinking water do not typically pose direct health risks, but cause aesthetic and technical issues like taste and odor, and corrosion (WHO, 2020).

Water is classified into fresh (TDS 1,000mg/L), saline (TDS > 10,000mg/L), and brine (TDS > 100,000mg/L) categories based on TDS concentrations (Freeze et al, 1979). Based on the above classification, the groundwater of the study area is classified as freshwater.

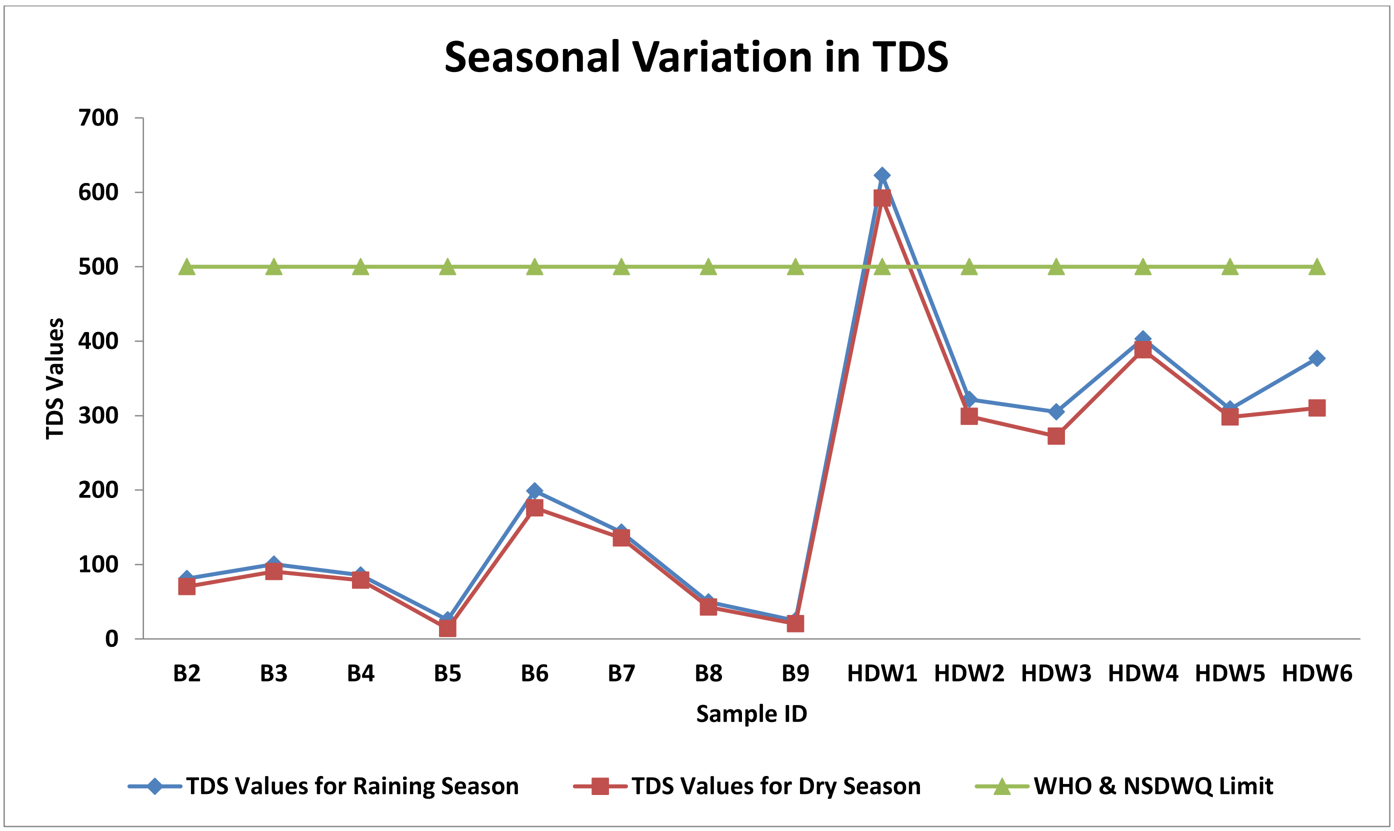

Fig 4.5: Seasonal Variation in Total Dissolved Solids (TDS) Values and Comparison with WHO and NSDWQ

Total Hardness (TH)

Total Harness (TH) in groundwater refers to the concentration of dissolved calcium and magnesium ions in the groundwater. These ions are responsible for the "hardness" of the groundwater. The concentration of total hardness during the wet season ranges from 20.2mg/L to 668.6mg/L with a mean value of 200.6mg/L., while the concentration of total hardness for dry season ranges from 15.9mg/L to 659.1mg/L with a mean value of 190mg/L.

The concentration of total hardness in all wet season samples were slightly higher dry season samples and this can be attributed to the increased infiltration and leaching of dissolved minerals, particularly calcium and magnesium from the soil and rocks leading to higher concentration of total hardness. This is in compliance with the study conducted by Kayode et al (2024) on Seasonal Variation of Groundwater Quality in Basement Complex Geology of Ado Ekiti, Nigeria, and Adekunle et al (2021) on the Multivariate Analysis of seasonal variation in groundwater quality within federal university of Agriculture, Abeokuta, Southwestern Nigeria. Exposure to hard water is considered a risk factor for atopic dermatitis (eczema) in children due to its high mineral content such as calcium and magnesium. Hardness in water also prevent forming when washing (WHO, 2020).

However, apart from B5, B6, B7, B8, and B9 for both seasons that were within NSDWQ permissible limit of 150mg/L, all other samples for both seasons were above the NSDWQ limit, but within the WHO limit of 500mg/L, except for HDW1 for both seasons that was above both WHO and NSDWQ limit (see fig 4.6).

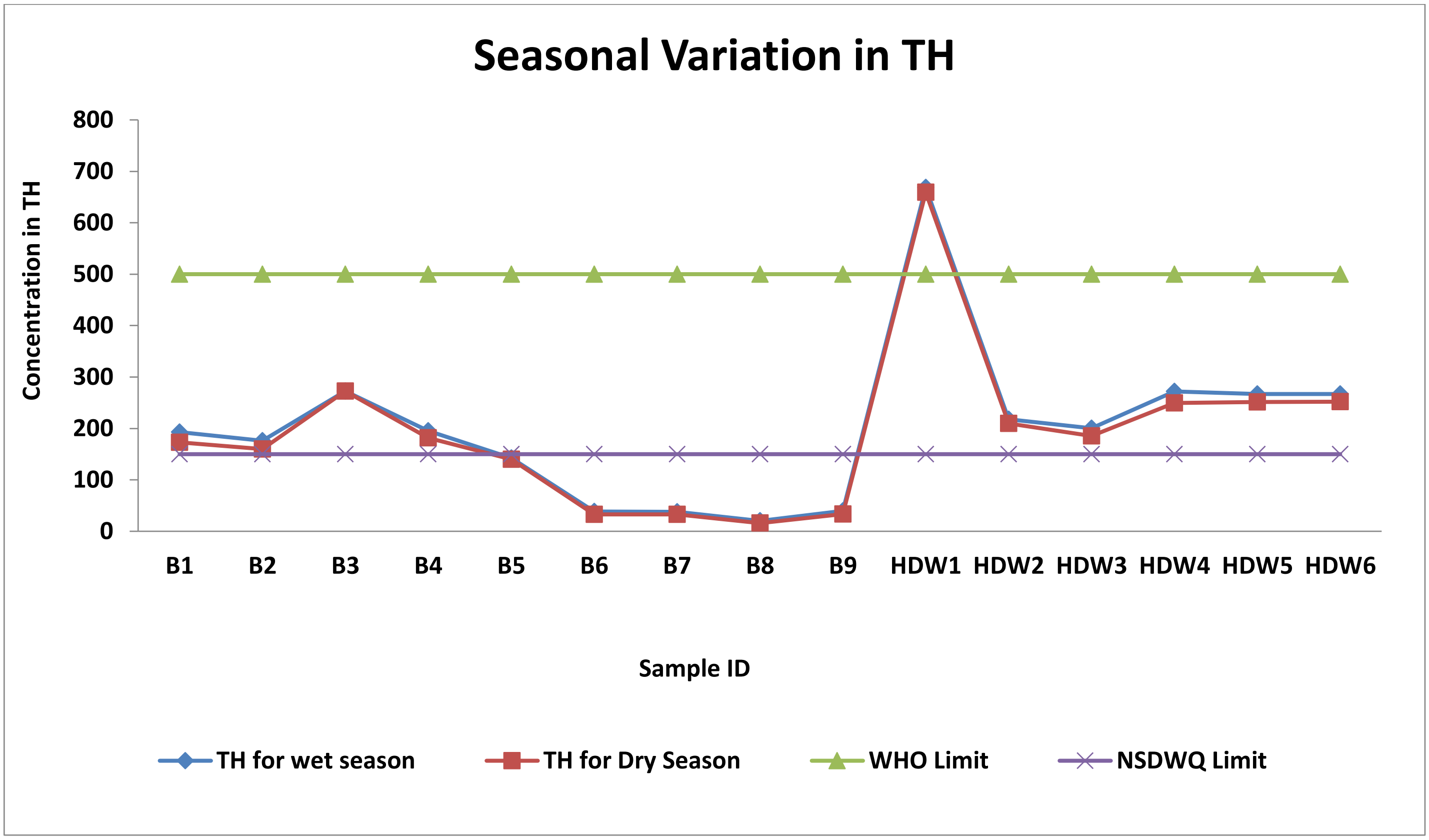

Fig 4.6: Seasonal Variation in Total Hardness and Comparison with WHO and NSDWQ

Dissolved Oxygen (DO)

Dissolved oxygen (DO) refers to the amount of oxygen gas (O_2) dissolved in groundwater, typically measured in milligrams per litre (mg/L). The dissolved oxygen concentration for wet season ranges from 7.87mg/L to 11.10mg/L with mean a value of 9.50mg/L, and from 6.41mg/L to 9.41mg/L with a mean value of 8.30mg/L for dry season. The concentrations of dissolved oxygen for wet season's samples were all higher than dry season samples (see fig 4.7). This might be due to the increased recharge and infiltration of oxygen-rich water by rainfall, thereby replenishing the groundwater with oxygen making the dissolved oxygen higher during the wet season than the dry season.This corresponds to the study on the Aspects of Hydrology of the FCT conducted by Dan-Hassan (2016), and Kayode et al (2024) on Seasonal Variation of Groundwater Quality in Basement Complex Geology of Ado Ekiti, Nigeria.

The result of Dissolved Oxygen (DO) for all the groundwater samples for both seasons were within the NSDWQ permissible limit of 14mg/L (see fig. 4.7).

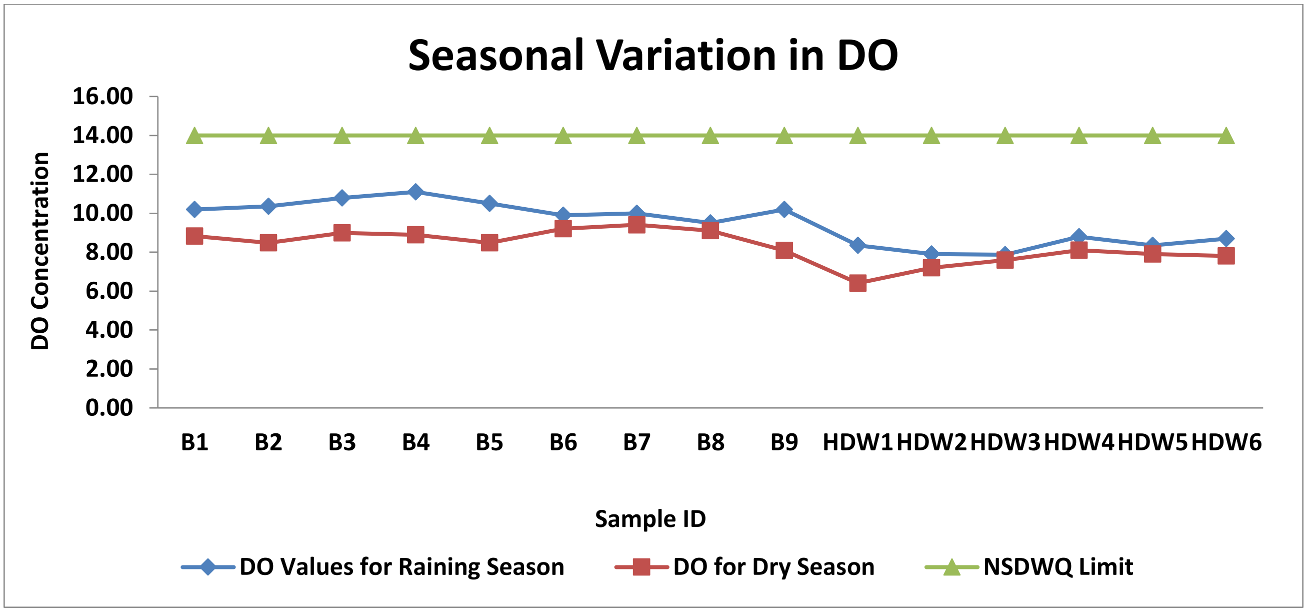

Fig. 4.7: Seasonal Variation in Dissolved Oxygen and Comparison with NSDWQ

Magnesium (Mg^{2+})

Magnesium concentration for wet season ranges from 1.5mg/L to 8.012.6mg/L with a mean value of 5.9mg/L, while for dry season, it ranges from 1.0mg/L to 10.0mg/L with a mean value of 5.1mg/L (see table 4.1&2). The concentrations of magnesium during the wet season were slightly higher in all samples than during the dry season (see fig 4.8). This corresponds to the study conducted by Adekunle et al (2021) on the Multivariate Analysis of seasonal variation in groundwater quality within federal university of Agriculture, Abeokuta, Southwestern Nigeria, and Aspects of Hydrology of the FCT conducted by Dan-Hassan (2016).

The concentration of magnesium in all the water samples collected for both wet and dry seasons were within the NSDWQ permissible limit of 20mg/L (see fig 4.8).

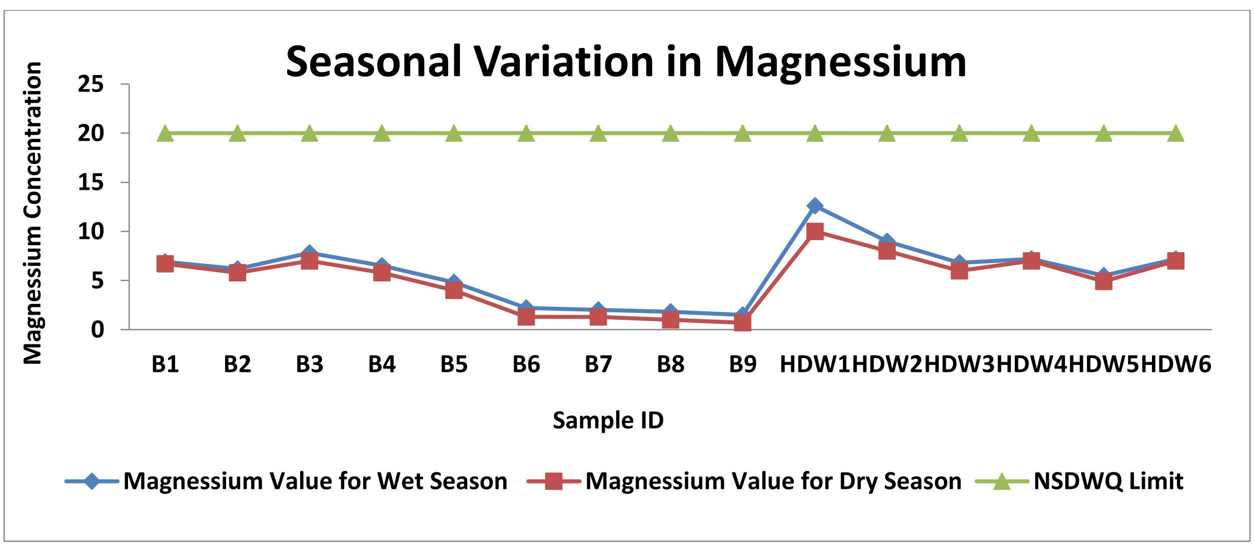

Fig. 4.8: Seasonal Variation in Magnesium Values and Comparison with WHO and NSDWQ

Calcium (Ca^{2+})

Calcium is one of the abundant elements in nature, and occurs from the dissolution of residues of granites, gypsum, dolomite, limestone and any calcium yielding geology (WHO, 2011). The values of calcium for wet season ranges from 14.0mg/L to 298mg/L with a mean value of 76.3mg/L, while for dry season, the values ranges from 13mg/L to 282mg/L with a mean value of 72.4mg/L. The concentration of calcium for wet season was slightly higher that the dry season, this might be due to the increased surface run-off, which carries calcium-rich sediments and solutes into the groundwater system. This is in line with the study conducted by Dan-Hassan (2016), Adekunle et al (2021) and Kayode et al (2024) where they all observed higher calcium values in the wet season than the dry season.

However, apart from the concentration of HDW1 for both wet and dry season that were above the WHO Permissible limit of 200mg/L, all other samples for both seasons were within the permissible limit (see fig. 4.9).

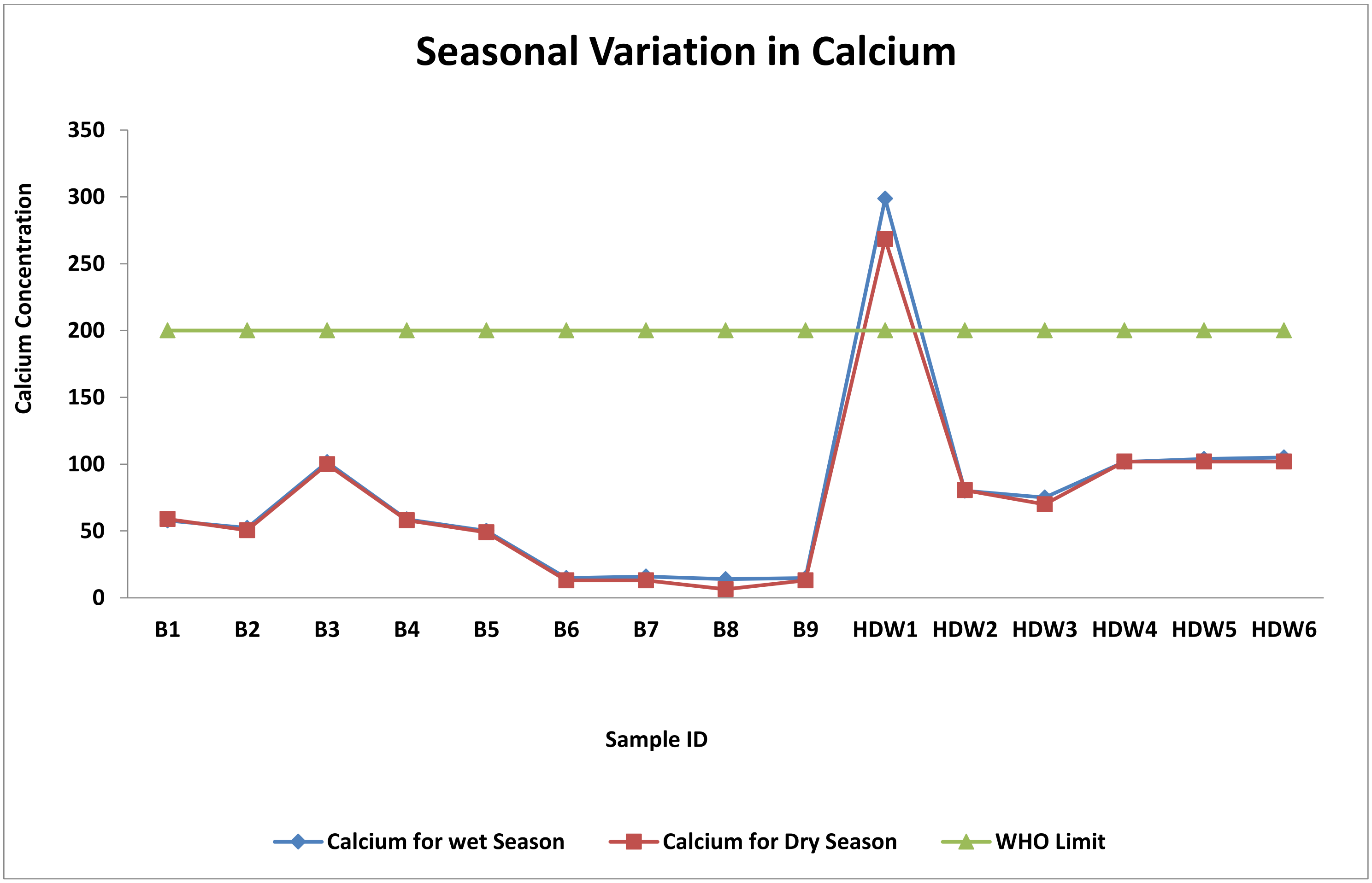

Fig. 4.9: Seasonal Variations in Calcium Values and Comparison with WHO

Total Alkalinity (mg/L)

Total Alkalinity refers to the measure of the capacity of water to neutralize acids, primarily due to the presence of bicarbonates, carbonates, and hydroxides that can help stabilize the pH. The wet season concentration of alkalinity ranges from 71.1mg/L to 178mg/L with a mean value of 104.3mg/L, while the values for dry season ranges from 71.8mg/L to 179.2mg/L with mean a value of 105.8mg/L. The alkalinity concentration for dry season was slightly higher than the concentration for wet season. This can be attributed to the reduced recharge of freshwater by rainfall and increased residence time and dissolution of minerals such as limestone and dolostone, which releases alkalinity-increasing ions.

Apart from sample B1, B2, B3, HDW2, HDW3, and HDW4 for both wet and dry season that were above WHO and NSDWQ limit of 100mg/L, all other samples for both seasons were within the permissible limit.

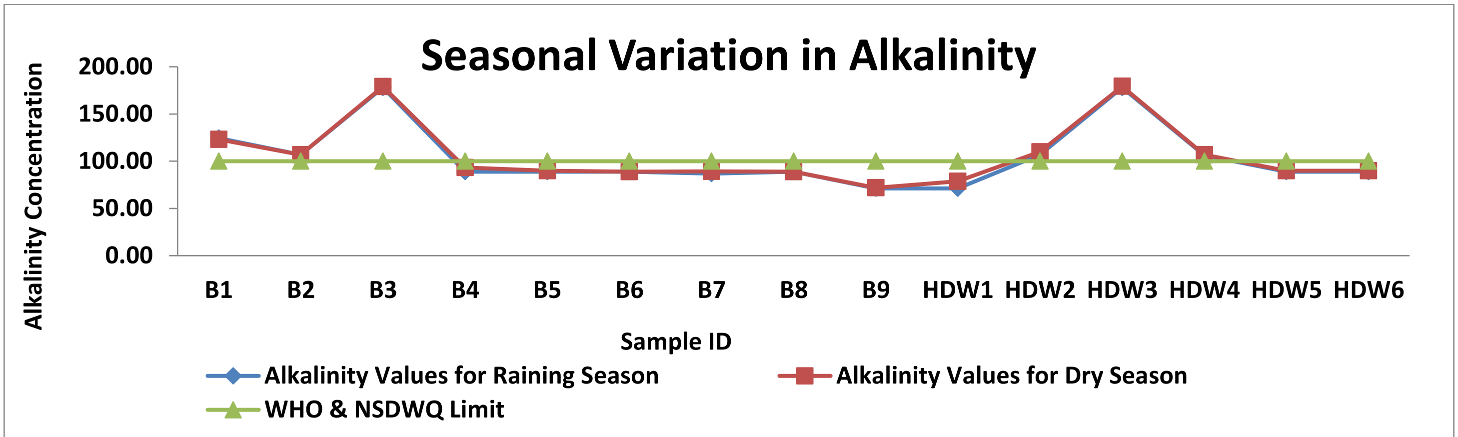

Fig. 4.10: Seasonal Variation in Total Alkalinity Values and Comparison with WHO and NSDWQ

Nitrate (NO_3)

Nitrate is a naturally occurring nitrogen-oxygen compound found in groundwater, but high levels can pose health risks and environmental concerns. Nitrate concentration in the wet season ranges from 1.0mg/L to 71.5mg/L with a mean value of 18.58mg/L, while the concentration for dry season ranges from 0.80mg/L to 68.0mg/L with a mean value of 17.16mg/L.The wet season concentrations of nitrate were slightly higher than the concentration of dry season, and might be due to the increased surface runoff, leaching and infiltration of nitrate-rich water from fertilizers, manures, and other nitrate-rich chemicals into the aquifer, which eventually recharge groundwater. This is in conformity with the study conducted by Imane El Adnani et al (2020), Dan-Hassan (2016), and Adekunle et al (2021).

Apart from HDW1 and HDW2 for both wet and dry seasons that were above the WHO and NSDWQ permissible limit of 50mg/L, all values of other samples for both seasons fell within the permissible limit of WHO and NSDWQ (see fig. 4.11).

High nitrate level in water can lead to blue baby syndrome (methemoglobinemia), kidney disease, and cancer risk such as colorectal cancer, stomach and esophageal cancer, and (WHO, 2020).

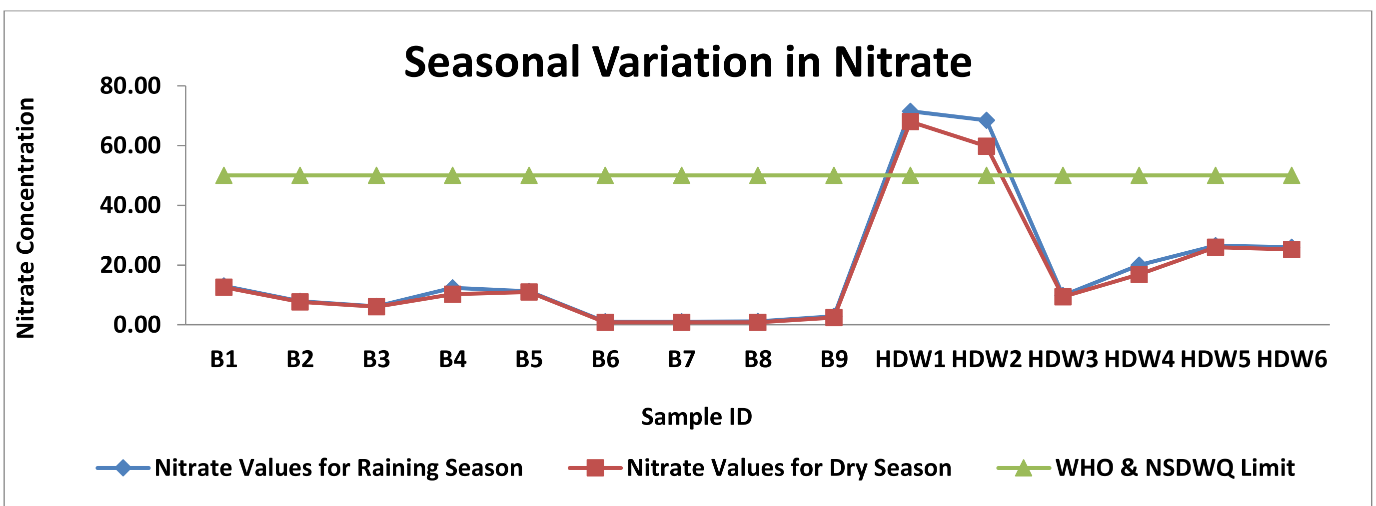

Fig.4.11: Seasonal Variation in Nitrate Values and Comparison with WHO and NSDWQ

Copper (Cu)

Copper is a natural occurring element that can dissolve in water, making it a common groundwater constituent. Concentration of copper for wet season ranges from 0.08mg/L to 0.42mg/L with a mean value of 0.29mg/L, while the concentration for dry season ranges from 0.04mg/L to 0.36mg/L with a mean value of 0.21mg/L. The values of copper for wet season in all samples were slightly higher than the values for dry season, and this is in line with the study conducted by Dan-Hassan (2016), where the autho observed slightly higher copper values in wet season than dry season.

However, all the groundwater samples for both wet and dry seasons were all within WHO and NSDWQ permissible limit of 2.0mg/L and 1.0mg/L respectively (see fig. 4.12). high copper levels in drinking water can lead to gastrointestinal issues (like vomiting, diarrhea, and nausea), liver and kidney damage (EPA, 2022; WHO, 2020).

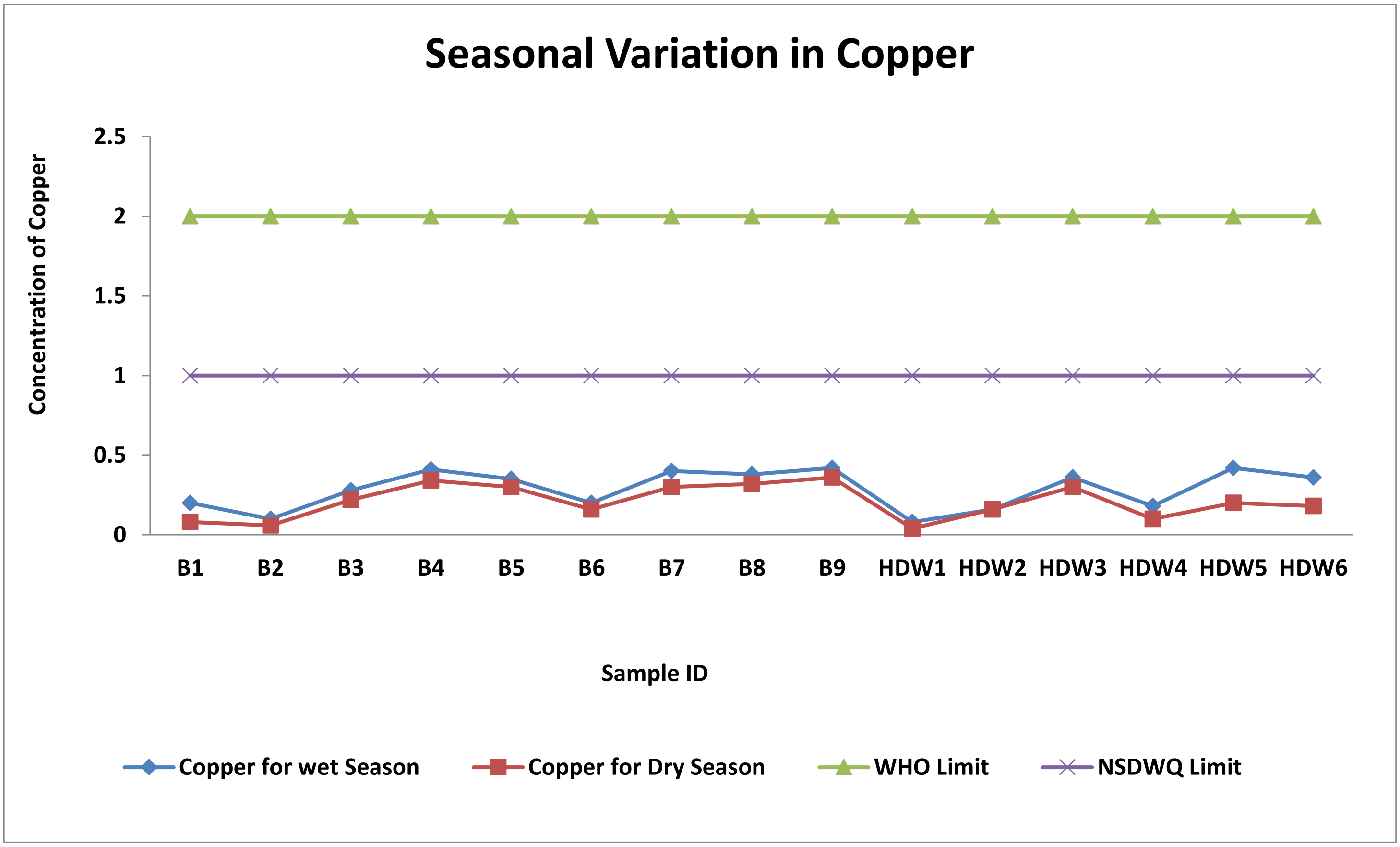

Fig 4.12: Variation in Copper Values and Comparison with WHO and NSDWQ

Iron (Fe)

Iron (Fe) is a naturally occurring metal element that can dissolve in water, making it a common groundwater constituent. High consumption of iron can lead to gastrointestinal problems like nausea, vomiting, and diarrhea (WHO, 2011), and has been linked to increased risk of certain cancers such as liver and colon cancer (ATSDR, 2020).

The concentration of iron for wet season ranges from 0.1mg/L to 0.32mg/L with a mean value of 0.184mg/L, while the concentration for dry season ranges from 0.16mg/L to 0.36mg/L with a mean value of 0.24mg/L. The values for dry season were higher than wet season, and it can be attributed to the reduced dilution of iron-rich groundwater, and increased residence time which allows more time for iron-rich minerals to dissolve and release iron into the groundwater. This is in conformity with the study conducted by Oki et al (2017) and Dan-Hassan (2016).

However, apart from HDW2 for both wet and dry seasonthat were above the WHO and NSDWQ permissible limit of 0.3mg/L, all other samples for both seasons fell within the permissible limit (see fig. 4.13).

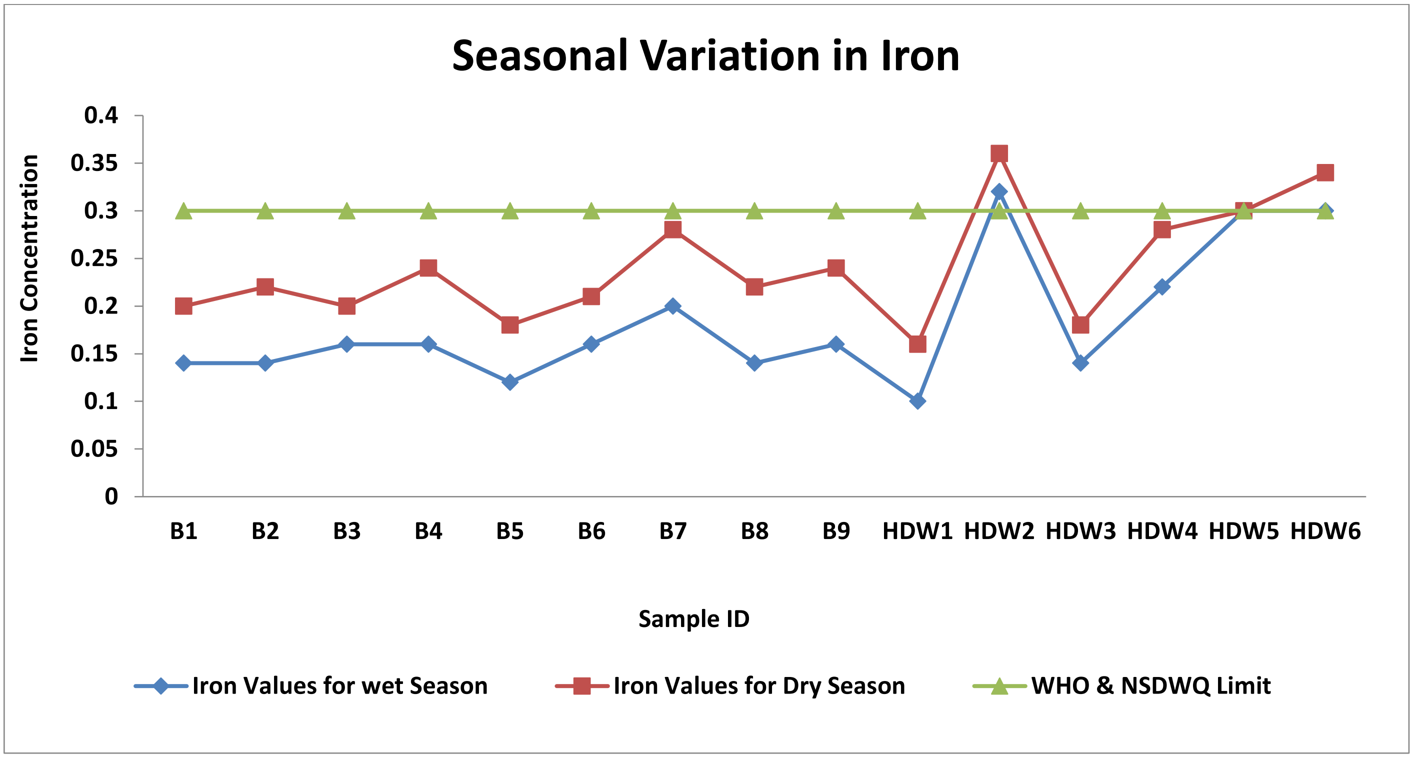

Fig.4.13: Variations in Iron (Fe) Values and Comparison with WHO and NSDWQ

Bicarbonate (HCO_3^-)

Bicarbonate is a naturally occurring ion in groundwater that plays a vital role in maintaining the water pH and alkalinity. It is a negatively charged ion (HCO_3^-) composed of hydrogen, carbon, and oxygen. It is the most common form of alkalinity in groundwater (Hem, 1985). Consuming water with extremely high bicarbonate levels (>600mg/L) can lead to alkalosis, a condition characterized by elevated blood pH (Medline Plus, 2020).

The concentration of bicarbonate for wet season ranges from 7.48mg/L to 306.16mg/L with a mean value of 85.26mg/L, while the concentration for dry season ranges from 8.8mg/L to 300.6mg/L with a mean value of 86.38mg/L. Apart from HDW1 for wet season which is slightly higher than dry season sample, all other samples for dry season were slightly higher than wet season. This might be due to the reduced groundwater recharge and dilution, increased residence time which allows concentration of ions, and dissolution of carbonate minerals which releases bicarbonate into the groundwater and increased pH during the dry season. This deviate from the study conducted by Oki et al (2017), where they observed slightly higher bicarbonate during the wet season than the dry season in in Yenagoa, Niger Delta, Nigeria.

Generally, high concentration of bicarbonate in the groundwater points to the dominance of mineral dissolution (Stumm and Morgan 1996).

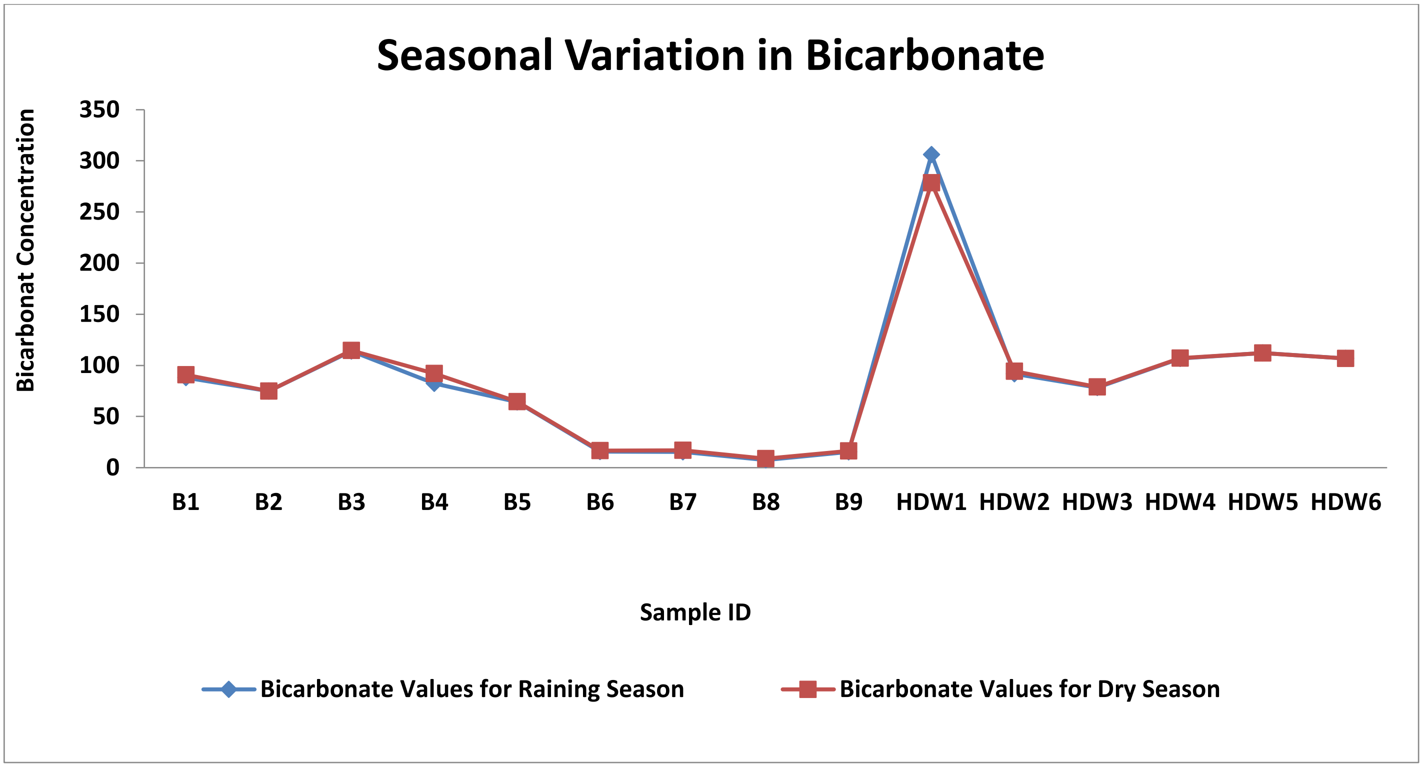

Fig 4.14: Seasonal Variation in Bicarbonate Values (HCO_3)

Table 4.4: Descriptive Statistics for Wet Season's Physico-Chemical Data

Table. Descriptive Statistics of Water Quality Parameters

Parameters	Range	Mean	Variance	Standard Deviation
pH	3.51–6.58	5.43	0.92	0.96
Temperature (°C)	15.0–22.8	19.23	2.80	1.67
Electrical Conductivity (EC, µS/cm)	13.4–1669.0	535.68	185,566.35	430.77
Turbidity (NTU)	0.63–32.6	5.62	75.24	8.67
Total Dissolved Solids (TDS, mg/L)	24.5–622.9	220.00	29,267.09	171.08
Dissolved Oxygen (DO, mg/L)	7.87–11.10	9.50	1.17	1.08
Total Hardness (TH, mg/L)	20.2–668.6	200.60	25,248.89	158.90
Magnesium (Mg^{2+}, mg/L)	1.50–8.01	5.90	9.2627	3.04
Calcium (Ca^{2+}, mg/L)	14.0–298.0	76.30	4,952.85	70.38
Alkalinity (mg/L)	71.1–178.0	104.30	1,084.76	32.94
Nitrate (NO_3^-, mg/L)	1.0–71.5	18.58	503.27	22.43
Copper (Cu, mg/L)	0.08–0.42	0.29	0.02	0.14
Iron (Fe, mg/L)	0.10–0.32	0.18	0.005	0.071
Bicarbonate (HCO_3^-, mg/L)	7.48–306.2	85.26	5,186.88	72.02

Table 4.5: Descriptive Statistics for Dry Season Physico-Chemical Data

Parameters	Range	Mean	Variance	Standard Deviation
pH	4.20–6.62	5.81	0.54	0.73
Temperature (°C)	17.0–21.8	20.32	1.92	1.39

Electrical Conductivity (EC, µS/cm)	20.5–1442.9	484.85	154,599.34	393.19
Turbidity (NTU)	0.60–30.8	5.44	67.69	8.23
Total Dissolved Solids (TDS, mg/L)	13.8–592.0	201.10	26,187.46	161.83
Dissolved Oxygen (DO, mg/L)	6.41–9.41	8.30	0.69	0.83
Total Hardness (TH, mg/L)	15.9–659.1	190.00	24,229.85	155.66
Magnesium (Mg^{2+}, mg/L)	1.0–10.0	5.10	8.14	2.85
Calcium (Ca^{2+}, mg/L)	13.0–282.0	72.40	4,162.92	64.52
Alkalinity (mg/L)	71.8–179.2	105.80	1,056.16	32.50
Nitrate (NO_3^-, mg/L)	0.80–68.0	17.16	424.95	20.61
Copper (Cu, mg/L)	0.04–0.36	0.21	0.012	0.11
Iron (Fe, mg/L)	0.16–0.36	0.24	0.004	0.06
Bicarbonate (HCO_3^-, mg/L)	8.8–300.6	86.38	4,969.76	70.50

Correlation Matrix

The correlation matrixes of groundwater quality parameters for both wet and dry season are tabulated in Table 8 and 9 which was analysed using Microsoft Excel 2010. Correlation values can fall between zero (0) signifying no correlation and one (1) which signifies perfect correlation. There is a strong correlation when the value of r is greater than 0.7 revealing a strong interaction among the physic-chemical parameters. More so, there is a moderate relationship when r is between 0.5 to 0.7, while there is a weak correlation when r is less than 0.5 (Kayode et al, 2024).

Table 4.6: Correlation Matrix for Wet Season Data

	TEMP	PH	E.C	Turb.	TDS	T.H	D.O	Ca2+	Mg2+	Alk	NO3-	Cu2+	Fe2+	HCO3
TEMP	1													
PH	-0.19509	1												
E.C	-0.23337	-0.04352	1											
Turb.	-0.01052	-0.67701	0.497524	1										
TDS	-0.01032	-0.17832	0.89308	0.478313	1									
T.H	-0.13871	0.015424	0.924868	0.401602	0.835507	1								
D.O	0.264307	0.038697	-0.88389	-0.51329	-0.74613	-0.79324	1							
Ca2+	-0.10807	0.004316	0.892167	0.402268	0.827771	0.986538	-0.76681	1						
Mg2+	-0.32218	0.268814	0.85052	0.28368	0.690475	0.826238	-0.65676	0.815388	1					
Alk	-0.13798	0.53116	0.054476	-0.19348	-0.01263	-0.028	0.052751	0.037216	0.342252	1				
NO3-	-0.20142	-0.13685	0.843366	0.557238	0.776246	0.823068	-0.85608	0.802154	0.73083	-0.15272	1			
Cu2+	0.334879	-0.05924	-0.61003	-0.19853	-0.64382	-0.58942	0.375216	-0.56931	-0.63414	-0.01615	-0.51414	1		
Fe2+	-0.14526	-0.51967	0.084122	0.503994	0.139213	-0.12067	-0.11961	-0.12237	0.047077	-0.24889	0.24364	-0.00535	1	
HCO3	-0.1455	0.073182	0.882034	0.355827	0.78704	0.988839	-0.73239	0.989117	0.843545	0.044422	0.792404	-0.58578	-0.17353	1

Table 4.7: Correlation Matrix for Dry Season Data

	TEMP	PH	E.C	Turb.	TDS	T.H	D.O	Ca2+	Mg2+	Alk	NO3-	Cu2+	Fe2+	HCO3
TEMP	1													
PH	-0.19509	1												
E.C	-0.23337	-0.04352	1											
Turb.	-0.01052	-0.67701	0.497524	1										
TDS	-0.01032	-0.17832	0.89308	0.478313	1									
T.H	-0.13871	0.015424	0.924868	0.401602	0.835507	1								
D.O	0.264307	0.038697	-0.88389	-0.51329	-0.74613	-0.79324	1							
Ca2+	-0.10807	0.004316	0.892167	0.402268	0.827771	0.986538	-0.76681	1						
Mg2+	-0.32218	0.268814	0.85052	0.28368	0.690475	0.826238	-0.65676	0.815388	1					
Alk	-0.13798	0.53116	0.054476	-0.19348	-0.01263	-0.028	0.052751	0.037216	0.342252	1				
NO3-	-0.20142	-0.13685	0.843366	0.557238	0.776246	0.823068	-0.85608	0.802154	0.73083	-0.15272	1			
Cu2+	0.334879	-0.05924	-0.61003	-0.19853	-0.64382	-0.58942	0.375216	-0.56931	-0.63414	-0.01615	-0.51414	1		
Fe2+	-0.14526	-0.51967	0.084122	0.503994	0.139213	-0.12067	-0.11961	-0.12237	0.047077	-0.24889	0.24364	-0.00535	1	
HCO3	-0.1455	0.073182	0.882034	0.355827	0.78704	0.988839	-0.73239	0.989117	0.843545	0.044422	0.792404	-0.58578	-0.17353	1

Note:

Bold Blue = Signifies strong positive correlation

Light Blue = signifies moderate positive correlation

Very light Blue = signifies weak positive correlation

Bold Red = signifies strong negative correlation

Light Red = signifies moderate negative correlation

Very light Red = signifies weak negative correlation

White = Signifies "No correlation"

During the wet season, a strong positive correlation was observed between the following parameters (as shown in table 4.6): EC vs TDS, EC vs TH, TDS vs TH (), EC vs Ca^{2+}, TDS vs Ca^{2+}, TH vs Ca^{2+}, EC vs Mg, TH vs Mg, Ca^{2+} vs Mg, EC vs No_3, TDS vs No_3, TH vs No_3, Ca^{2+} vs No_3, Mg vs No_3, EC vs HCO_3, TDS vs HCO_3, TH vs HCO_3, Ca^{2+} vs HCO_3, Mg vs HCO_3, and No_3 vs HCO_3; moderate positive correlation between the following parameters: TDS vs Mg, pH vs Alk, and Turbidity vs Fe; weak positive correlation between EC vs Turbidity, Turbidity vs TDS, Turbidity vs TH, Temperature vs DO, Turbidity vs Ca^{2+}, pH vs Mg, Turbidity vs Mg, Mg vs Alk, Temp vs Cu, DO vs Cu, No_3 vs Fe, TDS vs Fe, EC vs Fe, pH vs HCO_3, Turbidity vs HCO_3. There was a strong negative correlation between EC vs DO, TDS vs DO, TH vs do, DO vs Ca^{2+} , DO vs NO_3, DO vs HCO_3; moderate negative relation between pH vs Turbidity, DO vs Mg, EC vs Cu, TDS vs Cu, TH vs Cu, Ca^{2+} vs Cu, Mg vs Cu, NO_3 vs Cu, pH vs Fe, Cu vs HCO_3; weak negative correlation between Temp vs pH, Temp vs EC, Temp vs Turbidity, Temp vs TDS, pH vs TDS, Temp vs TH, Temp vs Ca^{2+} , Temp vs Mg, Temp vs Alk, Turbidity vs Alk, TH vs Alk, Temp vs NO_3, Alk vs NO_3, pH vs Cu, Turbidity vs Cu, Alk vs Cu, Cu vs Fe, Temp vs HCO_3, and Fe vs HCO_3.

During the dry season, a strong positive correlation was observed between EC vs TDS, EC vs TH, TDS vs TH, EC vs Ca^{2+}, TDS vs Ca^{2+}, TH vs Ca^{2+}, EC vs Mg, TH vs Mg, Ca^{2+} vs Mg, EC vs NO_3, TDS vs NO_3, TH vs NO_3, Ca^{2+} vs NO_3, Mg vs NO_3, EC vs HCO_3, TDS vs HCO_3, TH vs HCO_3, Ca^{2+} vs HCO_3, Mg vs HCO_3, NO_3 vs HCO_3; moderate positive correlation between TDS vs Mg, pH vs Alk, Turbidity vs NO_3, Turbidity vs Fe; weak positive correlation between EC vs Turbidity, Turbidity vs TDS, Turbidity vs TH, Temp vs DO, Turbidity vs Ca^{2+}, pH vs Mg, Turbidity vs Mg, Mg vs Alk, Temp vs Cu, DO vs Cu, No_3 vs Fe, TDS vs Fe, pH vs HCO_3, Turbidity vs HCO_3; strong negative correlation between EC vs DO, TDS vs DO, TH vs DO, DO vs Ca^{2+}, DO vs NO_3, DO vs HCO_3; moderate negative correlation between pH vs Turbidity, Turbidity vs DO, EC vs Cu, TDS vs Cu, TH vs Cu, Ca^{2+} vs Cu, Mg vs Cu, NO_3 vs Cu, pH vs Fe, Cu vs HCO_3; and weak negative correlation between Temp vs pH, Temp vs EC, pH vs TDS, Temp vs TH, Temp vs Ca^{2+}, Temp vs Mg, Temp vs Alk, Turb vs Alk, Temp vs NO_3, pH vs NO_3, Alk vs NO_3, Alk vs Cu, Temp vs Fe, TH vs Fe, DO vs Fe, Ca^{2+} vs Fe, Alk vs Fe, Temp vs HCO_3, Cu vs Fe (see table 4.7).

A strong correlation between TDS and EC in groundwater indicates a significant concentration of dissolved ions. Also a highly significant correlation between total hardness and the concentrations of calcium and magnesium ions indicates that these ions are the primary contributors to water hardness. A very strong correlation between salinity and EC, TDS and EC in groundwater indicates a significant concentration of dissolved ions. Also a highly significant correlation between total hardness and the concentrations of calcium and magnesium ions indicates that these ions are the primary contributors to water hardness (Kayode et al, 2024). The strongly correlated parameters have more impact on the overall evaluation of the groundwater quality. This shows that the input of anthropogenic activities as well as mineral depositions from local geology influences the quality of groundwater in the study area.

Water Quality Index (WQI)

The Canadian Council of Ministers of the Environment Water Quality Index (CCME WQI) was used in this study to calculate the WQI. It is widely used and well established method for calculating a Water Quality Index (WQI). It is a dimensionless index that ranges from 0 to 100, with higher values indicating better quality (CCME, 2001). The CCME WQI was developed from British Colombia WQI Model (BCWQI) in 2001 (Lumb et al, 2011)

Table 4.8: CCME WQI Categorization

S/N	WQI VALUES	CATEGORIZATION / RANKING	CHARACTERISTICS
1	95-100	Excellent	• All measurements within objectives virtually all of the time; condition, very close to pristine water quality level.
2	80-94	Good	• Water quality is protected with only a minor degree of threat or impairment; conditions rarely depart from natural or desirable levels.
3	65-79	Fair	• Water quality is usually protected but occasionally threatened or impaired; conditions sometimes depart from natural or desirable levels.
4	45-64	Marginal	• Water quality is frequently threatened or impaired; conditions often depart from natural or desirable levels.
5	0-44	Poor	• Water quality is almost always threatened or impaired; conditions usually depart from natural or desirable levels.

Source: (CCME, 2001)

The CCME-WQI consists of three main elements:

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- F1 (Scope) represents the percentage of parameters that do not meet their guidelines at least once during the time period under consideration ("failed parameters"), relative to the total number of variables(parameters) measured:

$$\boldsymbol{F1\ (Scope) = \frac{No.\ of\ failed\ variables}{Total\ no.\ of\ variables} \times 100}$$

- F2 (Frequency) represents the percentage of individual tests that do not meet guidelines ("failed tests"):

$$\boldsymbol{F2\ (Frequency) = \frac{No.\ of\ failed\ test}{Total\ no.\ of\ test} \times 100}$$

- F3 (Amplitude) represents the amount by which failed test values do not meet their guidelines. F3 is calculated in three steps

$$\boldsymbol{F3\ (Amplitude) = \frac{\sum Excursion}{0.01NSE + 0.01}}$$

$$CCME\ WQI = 100 - \frac{\sqrt{\boldsymbol{F1}} + \boldsymbol{F2} + \boldsymbol{F3}}{\boldsymbol{1.732}}$$

Table 4.9: Computed Values of CCME WQI

Table. Canadian Council of Ministers of the Environment Water Quality Index (CCME WQI) by Season

S/N	Season	F1	F2	F3	CCME WQI
1	Wet Season	72.73	22.42	12.66	55.45
2	Dry Season	72.73	23.03	11.50	55.46

According to the category ranges of CCME WQI in table 4.8, both the wet season (55.45) and dry season (55.46) of the computed CCME WQI in the study area fell within the marginal category (see table 4.4). This indicates that groundwater quality in the study area is compromised and often deviate from desirable limits, and is occasionally threatened by contaminants, but not severely impaired. This can be attributed to both anthropogenic factors such as agricultural activities (like fertilizer and pesticides application), industrial activities (like chemical spills, leaks and mining) poor waste management, construction activities etc, and natural factors such as geological formation and mineral dissolution.

Statistical Technique

The paired samples t-test was conducted in this study to compare the groundwater quality data between the wet and dry seasons in the study area. The result yielded a p-value of 0.117718 (see table 4.6).

Table 4.10: Paired Samples t-test for Means of Wet and Dry Season Samples

	Wet Season	*Dry Season*	
Mean	91.87274	85.46141	
Variance	21695.79	17819.82	
Observations	14	14	
Pearson Correlation	0.999632		
Hypothesized Mean Difference	0		
Df	13		
t Stat	1.675446		
P(T<=t) one-tail	0.058859		
t Critical one-tail	1.770933		

P(T<=t) two-tail	**0.117718**		
t Critical two-tail	2.160369		

Since the p-value (0.117718) is greater than the significant level (0.05), we accept the null hypothesis (H_0). This suggests that there is no statistical significant difference in the groundwater quality between the wet and dry seasons in FCT. Also, the Pearson Correlation (0.999632) shows that there is a strong correlation between the wet and dry season data.

Strategies for Management, Improvement, and Protection of Groundwater quality

Based on the results of this study the following management, improvement and protection measures are recommended for managing groundwater quality in the study area:

1. Groundwater Monitoring and Assessment Monitoring a network for groundwater is set up, monitoring water levels and flow patterns, water quality and water trends through time. Performing periodic ground water quality analysis tests, both routinely and periodically in order to detect contamination at an early stage and determine long term water quality trend, with a special focus on risk zones. Water quality and vulnerability of the area towards contamination can be assessed to guide decisions, particularly close to the main anthropogenic activities areas with the highest population density.
2. Strengthen Institutions and Regulations A separate groundwater management institution responsible for management of withdrawal, utilization and protection for groundwater within the study area. Clear legislation regulations related to ground water exploitation including permits and the determination of the quality criteria must be prepared.
3. Preventing and Reducing Pollution BMP is prepared, disseminated, and adopted in the agriculture, industrial, and urbanization sectors to reduce the contamination. Sustainable agriculture methods such asforestation and conservationtillage are to be introduced in order to minimize runoff and infiltraton of polluted substances.
4. Raising public Awareness and Participation Raise awareness of the general public concerning the importance of groundwater quality and related public health issues such as the impact of pollution on drinking water safety. Involve the local communities directly in activities concerning the protection of groundwater resources to achieve a collective responsibility in maintaining water resources quality.
5. Infrastructure Facilities Developing and upgrading water supply infrastructure including pipelines, pumping stations and treatment plants, in various points throughout the area, where needed. Promoting rain water harvesting, to minimize pressure on the existing groundwater resources. Identifying and rehabilitating contaminated sites and preventing further spreading of contaminants.
6. Research and Development Encourage studies on the natural behavior of the local groundwater system, and improve existing treatment technology for water resources. Cooperate with international organizations such as the World Health Organization (WHO) and the World Bank, in order to have access to the most modern techniques and adopt best practices from international experiences in the field of groundwater management.

SUMMARY, CONCLUSION AND RECOMMENDATIONS

Summary of Major Findings

This study aimed at evaluating the quality of groundwater for domestic use within the Federal Capital Territory (FCT), Nigeria with consideration of seasonal variations in the wet and dry seasons. Physico-chemical properties of groundwater samples obtained from the major lithological zones in the FCT were analyzed and the findings are presented below.

1. The physico-chemical parameters analysed in the laboratory include Temperature, pH, EC, Turbidity, TDS, TH, DO, Ca, Mg, Alkalinity, NO_3, Cu, Fe and HCO_3.

2. There exist variation in groundwater quality between the wet and dry seasons in the FCT when considered with WHO and NSDWQ for domestic consumption. The mean values for Turbidity (5.62), TDS (220),TH (200.6), DO(9.50),Ca(76.0), Nitrate(18.58) and Cu(0.29) were slightly high in wet season whereas, Temperature (20.32), pH(5.81), EC(484.85),Alkalinity(105.75), Fe (0.24),and HCO3(86.38) were slightly high in dry season.
3. No statistically significant difference exists in the groundwater quality between wet and dry seasons at $p = 0.117718 > 0.05$ in which case, the null hypothesis (H0) cannot be rejected, also the relation between the wet and dry datasets have positive correlation of $r = 0.999632$.
4. Canadian Council of Ministers for the Environment Water Quality Index(CCME WQI) indicate that the groundwater quality falls within marginal class (45-64) for both wet season(55.45)and dry season(55.46) suggesting that groundwaters in the FCT are constantly under threat and therefore should be treated before it can be used for domestic purposes.
5. Various management approaches were suggested to maintain, manage and protect the quality of groundwater in the study area. These include establishing ground water monitoring system and assessment, adequate institution and legislative measures, preventing and controlling pollutants, creating more awareness and education amongst the FCT populace, develop more infrastructures and carrying out further researches on groundwater resources.

CONCLUSION

In this study, groundwater for domestic use was evaluated in the Federal Capital Territory (FCT), Nigeria. Physico-chemical analysis for pH, Temperature, Turbidity, EC, Total hardness, DO, Calcium, Magnesium, Alkalinity, Nitrate, Copper, Iron and Bicarbonate has revealed variation in groundwater quality between wet and dry season in FCT, Nigeria with consideration of the World Health Organization (WHO) and the Nigeria standards for drinking water quality (NSDWQ).

However, calculation of the CCME WQI showed that the computed groundwater samples falls within marginal range in both wet and dry seasons, indicating that the groundwater resources within FCT are constantly under threat and needs further treatment before usage for domestic purpose. It is concluded that no statistically significant variation exists in the groundwater quality between the wet and dry seasons in FCT, Nigeria ($p=0.117718 > 0.05$), therefore the null hypothesis that states no difference cannot be rejected.

RECOMMENDATIONS

Based on the result and conclusion of the research, the following recommendations are made:

1. It is advisable to continuously monitor groundwater in the FCT with participation of government agencies, private organizations, individuals, so that changes in quality over time, especially as a result of direct impacts from sustained human activities can be detected.
2. Public education and awareness campaign should be reinforced to make people in FCT aware about sanitation and waste disposal practices, the importance of groundwater, the impacts of groundwater contamination and the health effects of drinking contaminated groundwater.
3. Investment on infrastructures like providing adequate and accessible piped water to FCT citizens should be promoted and enhanced, so that the consumption of groundwater in domestic activities will be reduced.
4. Strengthening the collaboration and coordination among government, various stakeholders, and communities in the management of groundwater, and disseminating the research result is essential. There is also a need for collaboration between the government, private organizations and professional in geology, hydrology, and public health experts to build more comprehensive knowledge about ground water quality management in the FCT.
5. More research in the FCT with a larger numbers of sampling location and sampling frequency is needed to provide more in-depth analysis on the quality of groundwater resource in the study area over time.

Declaration

I hereby declare that this dissertation has been written by me and it is a report of my research work. It has not been presented in any previous application for academic credit. All quotations are indicated and sources of information specifically acknowledged by means of references.

Dedication

I dedicate this work to my dad, Alhaji Yahaya Asawu Gani for his support and encouragement, without whom I wouldn't have come this far.

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CERTIFICATION

This dissertation titled Evaluation of Groundwater Quality for Domestic Use in Federal Capital Territory, Nigeria meets the regulations governing the award of Master of Science in Environmental Resource Management, Faculty of Environmental Sciences of Nasarawa State University, Keffi, and is approved for its contribution to knowledge.

____________________ ________________

Prof. I.K Samaila Date

(Chairman Supervisory Committee)

____________________ ________________

(Member Supervisory Committee) Date

____________________ ________________

Prof. D.U Sangari Date
(Head of Department)

____________________ ________________

Dr. J.I Magaji Date
(Internal Examiner)

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Prof. N.D Marcus Date
(Dean, Faculty of Environmental Science)

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External Examiner Date

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Prof. M.M Ari Date
(Dean, School of Post Graduate Studies)