ASSESSMENT OF GROUNDWATER POTENTIAL IN KUJE AREA COUNCIL USING MULTI-CRITERIA DECISION ANALYSIS

A Thesis Submitted to the
Department of Geoinformatics and GIS Applications
INSTITUTE OF SPACE SCIENCE AND ENGINEERING
An Affiliate of AFRICAN UNIVERSITY OF SCIENCE AND TECHNOLOGY
In Partial Fulfilment of the Requirements for the Degree of
Masters of Science
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JANUARY 2023

DEDICATION

I declare this project to God Almighty who granted me abundant grace, wisdom, favour and strength all through the period this research project was conducted and also for inspiration and understanding to start and follow through with this project. This project is also dedicated to my parents, Dr and Mrs. Wategire and siblings for supporting me, showing me love and most importantly, offering financial support all through the period I carried out the research work.

CERTIFICATION

This is to certify that the thesis titled **ASSESSMENT OF GROUNDWATER POTENTIAL IN KUJE AREA COUNCIL USING MULTI-CRITERIA DECISION ANALYSIS**, submitted to the school of postgraduate studies, African University of Science and Technology (AUST), Abuja, Nigeria for the award of a Master's degree, is a record of an original research carried out by WATEGIRE DANIELLA EYIOTORISHE in the GEOINFORMATICS AND GIS APPLICATIONS DEPARTMENT of the Institute of Space Science and Engineering (ISSE), an affiliate of AUST.

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BY

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A THESIS APPROVED BY THE DEPARTMENT OF GEOINFORMATICS AND GIS APPLICATIONS

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ACKNOWLEDGEMENT

I start by appreciating and thanking God Almighty, the all-sufficient God, for seeing me through this project from the beginning to the end. He gave me strength when I most needed it, with this I give him all the glory. Thank you, Jesus. I want to appreciate my project supervisors, Prof. Lazarus Ojigi and Dr Rakiya Babama'aji for your help and support during this research work. I want to sincerely appreciate you for the time you sacrificed in order to help me out when I needed it during the course of the research work and for providing me with the necessary materials to carry out my study effectively. God will continue to bless you and grace you with great things as your heart desires. My sincere gratitude goes to the Head of Department, Dr Godstime James, thank you for your support and encouragement. Also, to all my lecturers a very big thanks for the knowledge impacted in me throughout my stay in ISSE. Additionally, my deepest gratitude goes to my parents Dr and Mrs Wategire for their prayers, kindness, moral and financial support throughout this work. I am most happy to make them proud. A special thanks to my siblings Samuel and Sharon for their love and support.

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ABSTRACT

Over-exploitation of groundwater over the years has imposed immense pressure on the global groundwater resources. As demand of potable water increases across the globe for human consumption, agriculture and industrial uses, the need to evaluate the groundwater potential and productivity of aquifers also increases. The study therefore involves assessment of groundwater potential Zones using Multi-Criteria Decision Analysis technique in Kuje Local Government Area of FCT. The Data used for this study includes remotely sensed data like Landsat 8 (OLI) image of kuje and Shuttle Radar Topographic Mission Digital Elevation Model (SRTM DEM); conventional maps (soil map of the study area), software used include ArcGIS 10.5, Erdas Imagine 2015. Several prepared thematic layers, including geology, elevation, slope, lineament density, land use land cover (LULC), drainage density and soil type, were assigned with a weight, depending on their influence on groundwater potential. Normalization concerned with relative contribution is applied in this study using the AHP method. Vertical electrical sounding has been conducted on different points to locate water-bearing formations/fracture zones. The groundwater potential zone map thus obtained have been categorized into five zones; very high, high, moderate, low and very low. The study reveals that about 34% of the area is covered under moderate groundwater potential zone. The low and high groundwater potential zones are observed in 23% and 20% respectively. Area under very high and very low potential zones are recorded in 8% and 14% respectively. This shows that majority of the study area has moderate groundwater potential.

The results of the study are useful for the information planner and local authorities for the assessment, planning, management and administration of groundwater resources in the Kuje Local Government Area of FCT

CHAPTER ONE

INTRODUCTION

1.1 Background to the Study

Water is one of the most important resources for the existence of man and it can be found either on the Surface (Rivers, Oceans, Streams) or Underground (tap water, borehole, hand pumps, open wells to list a few). However the source, the essentiality of this resource cannot be undermined as it contributes to the Growth and development of mankind. More so, the largest available source of water (fresh water) is found underground and both human and economic activities highly depend on freshwater (Kumar *et al*., n.d.). Interestingly, there are a lot of variations in terms of quantity and quality of natural water whether surface or underground this is due to the rate of increase in population, urbanization and industries as well as regional severity of aridity on water resources, which is further complicated by climate change (Owolabi *et al*., 2020; Ramamoorthy and Rammohan 2015). Yet, people and animals need clean potable water to survive.

One cannot undermine the pivotal role of Groundwater for Human existence due to its natural quality, fairly well distributed and continuous availability while also supporting human health, economic development and ecological diversity (Selvan *et al*., 2015). Explains why Groundwater has become major source of water supply for domestic, industrial and agricultural uses in both rural and urban settlements globally (Todd Dk 2005).

Groundwater level is declining due to excessive groundwater extraction thereby water supply in both rural and urban areas are affected. The amount and distribution of groundwater is a function of the amount of open space and the special extent of these rocks. The behaviour of these rocks in turn is function of their formation and geological processes that shaped their status. Several conventional methods exist for the exploration and development of groundwater potential zone of an area. These methods include; geological, geospatial, geophysical, and hydrogeological. However, geospatial amongst these methods are considered more favourable as it is less expensive and applicable even in inaccessible areas. Integrating advanced geospatial techniques is essential for the continuous assessment and monitoring of groundwater status periodically. Therefore, the possible groundwater zones for successful groundwater exploration need to be evaluated to meet the population's demand (Nagarajan and Singh 2009).

Groundwater potential zone is a zone of saturation where water is being stored and transmitted in large quantities. Groundwater potential zones are areas enclosing the occurrence of a considerable and economically exploitable quantity of groundwater resources (Mandel 2012; Waikar and Nilawar 2014; Thompson 2017). The groundwater potential of a region depends on different facts and it varies from place to place according to its change.

Hydrogeological mapping is among the major methodologies used for groundwater investigation. The result is utilized by drillers, coordinators as well as stakeholders in order to designate, establish and also take care of groundwater among a national water plan. Hydrogeological maps are existing hydrogeological information in a map form. A hydrogeological map reveals circulation of aquifers, as well as their topographical, geological, hydrographical, hydrological and also hydro-chemical attribute. Discussion of these information in the form of maps allows fast analysis of specific location. Appropriately, hydrogeological maps help to identifying locations requiring unique security (Dar *et al*., 2010, Nasir *et al*., 2018).

Groundwater investigation approaches that rely on geophysical technologies are both costly and time-consuming (Gnanachandrasamy *et al*., 2018). Due to these issues, people have been compelled to turn to various technologies that can aid them study big regions in a short space of time while working with little resources. These approaches, comprising GIS and remote sensing, have been used to identify groundwater potential zones. It is a simple and quick approach for exploring the groundwater potential zone in various geological settings (Thapa *et al*., 2017 Ifediegwu *et al*., 2019; Kanagaraj *et al*., 2019, Igwe *et al*., 2020)

Amongst the different methods and tools available for the discovery of groundwater potential zones in a particular area, (Sadeghfam *et al*., 2016; Mogaji & Lim 2018; Termeh *et al*., 2019), remote sensing and geographic Information System is categorized as the most useful tools which require little mechanical and physical work. Recently, the application of Geographic Information System(GIS) is being applied to deciphering the potential areas of groundwater occurrence with cost effective manner. GIS has great role for effectively addressing ground-water exploration and delineating potential areas in a certain region of study. Extensive use of remote sensing satellite images along with ground truth data has made it easier to provide the baseline information for delineating groundwater potential zones. The combination of GIS and remote sensing technologies reduce the ambiguity of hydrogeological data in various aspect.

In the study area, there is little or no existing work done on the use of geospatial techniques for the assessment of groundwater potential zones. The existing work done centred on other conventional methods such as geophysical, hydrogeological, geochemical were employed for groundwater exploration (Sunkari, Kore, and Abioui 2021, Ibrahim *et al*., 1970, Asije and Igwe 2014). Consequently, this research will dwell on deploying geospatial techniques (Remote Sensing and GIS) in assessing groundwater potential zones by identifying the characteristics for the determination of groundwater potential, establishing the spatial pattern of the groundwater potential zones, and the relationship between the results obtained from geospatial and geophysical techniques

In these studies, the commonly used thematic layers are geology, geomorphology, slope, soil type, land use/land cover, drainage density and lineament density.

1.2 Problem Statement

With the rapid urbanization in the Federal Capital Territory, Abuja and Kuje Area Council in particular, one of the major obstacles dealing with the sustainable growth in the study area is the demand for fresh water resources. Severe water scarcity has been one of the problems of the people of Kuje LGA, if not properly handled the scarcity and quality of water may result to severe risk to the people in the nearest future.

Many researchers have conducted studies on groundwater potential mapping using GIS techniques some of which include; (Hussein *et al.,* 2017, Ifediegwu *et al.,* 2019, Abdullahi *et al.,* 2019, Ikegwuonu *et al.,* 2021)

There has been no research done with respects to the assessment of groundwater potential zones using multi-criteria decision analysis in Kuje LGA Abuja which has created a gap and this study intends to fill the gap. Hence this research aims to map, delineate, and access the groundwater potential zones of Kuje LGA of FCT using multi-criteria decision analysis

Water projects constructed in the study area are no longer capable of providing enough water for the ever-growing population. This development has subjected the people of the study area to rely on other sources of water such as; rain water and groundwater which are seasonal. Hand dug wells in the area yield little water which dries up eventually due poor construction and also lack of information on groundwater potential zone before groundwater exploration, likewise the poor yields from boreholes constructed by government agencies and other private organizations in area of interest are few of the water challenges.

1.3 Aim and Objectives

The aim of the study is to assess the potential of groundwater potential in Kuje Area Council using Multi-Criteria Decision Analysis Approach

The specific objectives of the study are to:

i. Identify the sources and types of water supply in the Study Area
ii. Determine the water supply needs of the Study Area
iii. Identify factors for determining Ground Water in the study Area
iv. Determine the major factors that influences Ground Water potentials in the Study Area.
v. Delineate and map the groundwater potential zones in the study using integrated approach of Multi-Criteria Decision Approach.

1.4 Justification of the Study

There has been increased competition for water usage and has resulted in scarcity of water for various uses due to the growth in population and infrastructural development in the Kuje Local Government Area (LGA) of FCT. This has led to more individuals drilling boreholes and artisan wells to access groundwater. The effect of unregulated borehole drilling in most cases has an effect on soil structure leading to distortion of buildings, roads and even minor tremors due to differential settlement of disturbed soil structures. This has led to high depletion of shallow aquifers especially those within the overburden/weathered layer of basement complex. Boreholes are drilled next to dump sites, septic tanks, animal pen, storm water canals and even sewage lines. This affects greatly the quality of groundwater. Hence the importance to thoroughly understand the potential areas where groundwater has a high recharge rate within this LGA to enhance its efficiency and performance in planning, utilization, and management.

The findings from this research will hopefully serve as a guide and assist water policy makers in actions to improve quantity of water supply in the study area. There has been no known study that investigates groundwater potential in the study area, so therefore data on the groundwater potential mapping in the area of interest is important.

This study will therefore, focus on utilizing of Geographic Information System and Remote Sensing in assessing groundwater potentiality in the study area which could serve as a guide when conducting groundwater exploration in the Kuje Local Government Area of FCT.

1.5 Scope of Study

The study area Kuje Local Government is among the largest Local Government Areas of the Federal Capital Territory. It comprises of two major districts, Kuje central and Rubochi. This study focuses on the assessment of groundwater potential zones using multi-criteria decision analysis. The Element to be considered in the study would include the Geology, Digital elevation Model, Drainage density, Lineament Density, Slope and Land use Land Cover. This study is limited to Kuje Local Government area and not the entire Federal Capital Territory.

1.6 Study Area

1.6.1 Location and Accessibility

The study area, Kuje, is located in the North Central part of Federal Capital Territory, Abuja Nigeria. The coordinates of the study area lies between latitudes 080 53’ 24’’ N and 080 53’ 47’’ N and longitudes 070 14’ 24’’ E and 070 14’ 35’’ E. It is located at about 13.2 km from Abuja municipality. It is bounded on the North-Eastern part by Abuja Municipal Area Council (AMAC), to the West by Gwagwalada and Kwali Area Councils and to the South by Abaji Area council. The Kuje Area Council covers a total land of about 1,644sq km about 22.5% of the FCT. The average rainfall is 1200mm and spread from late April to late October, while the dry season starts in late October to March. It has an estimated population of about 270,000 people. It comprises of two major districts, Kuje central and Rubochi. The area comprises of different ethnic groups with varying cultural and social backgrounds namely the Egbirakoto, Gade, Gbari, Gbagyi, Bassa, Hausa-fulani and others. The people are predominantly farmers and traders who specialize in agriculture and livestock breeding. However, other economic activities of the people includes trading in pharmaceuticals, provisions, building materials and other essentials such as fruit, vegetables, fresh meat, household goods, fabric, shoes, clothing, smoked fish etc.

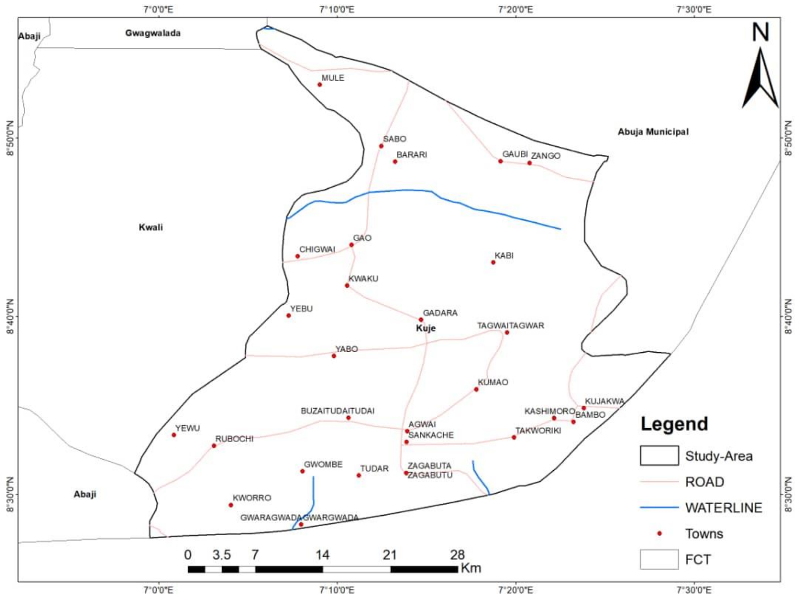

Figure 1.1 Map of the Study Area

1.6.2 Climate and Vegetation

The climatic condition of study Area (kuje) comprises of two seasons which are wet season and dry season. In Kuje, the wet season is oppressive and overcast, the dry season is humid and partly cloudy, and it is hot year round. According to Balogun (2001), the maximum temperature during the dry season ranges between 30.4 and 35.1^{o}C while the temperature ranges between 25.8 and 30.2^{o}C in the raining season. The diurnal temperatures can be as high as 17^{o}C during the dry season and rarely exceed 7^{o}C at the peak (July, August) of the rainy season.

The vegetation zone is savannah mainly dominated by shrubs, grasses, and light vegetation sparsely populated by trees of moderate height and sizes (Ajayi *et al.*, 2020).

1.6.3 Soil, Topography and Geology

Kuje Local Government Area of FCT is predominantly of a thin soil structure therefore its basin hydrology has high runoff potentials. The texture of the soil is generally stony sand to gravelly sand with smaller occurrences of loam. The soil are generally shallow and sandy in November especially on the major plains in Rubochi.

The topography is characterized by flat and elevated terrains, it is drained by seasonal river channels. The agent of weathering and erosion being water as indicated by rivers in the area, and biological weathering resulting from plants penetration in between fracture zones of rocks.

On exposure to the surface, the rocks are subjected to various temperatures and different form of mechanical, chemical and biological surface processes resulting in the present condition of rocks and its environment.

Geologically, the study area is predominantly underlain by the Precambrian basement complex rocks. The lithological units in the study area are migmatite gneiss, granite, and schistose gneiss. The migmatite gneiss is the most wide spread rock unit. The granite occurs in several locations. They are porphyritic and of medium-coarse-grained texture. Granites mostly occur as intrusive, low-lying outcrops around the gneiss. They are severely jointed and fairly intruded by quartz veins (Oyawoye, 1964).

CHAPTER TWO

LITERATURE REVIEW

2.1 Conceptual Framework

Ground water is contained in underground rocks, which contains and transmit water in economical rate generally referred to as aquifers (Mallick *et al.,* 2015). The amount and distribution of groundwater is a function of the amount of open space and the special extent of these rocks. The behaviour of these rocks in turn is function of their formation and geological processes that shaped their status (Mallick *et al.,* 2015). Groundwater is the largest available reservoir of fresh water, it comes from rain, snow sheet and hail that infiltrate the ground and become the groundwater responsible for the spring, wells and bore holes (Oseji *et al.,* 2015).

The complex and changeable nature of groundwater occurrences, as well as the high risk of well/borehole failure in the absence of adequate pre-drilling hydrogeological investigations, is a crucial constraint (Fashae *et al.,* 2014). Geophysical techniques, in combination with other traditional methods such as geology, hydrogeology, and photogeology, can be used to define groundwater potential zones (Abdullahi *et al*., 2019, Arulbalaji, Padmalal, and Sreelash 2019, Dar, Rai, and Bhat 2021, Melese, Belay, and Belay 2021, Srivastava and Bhattacharya 2006;) are of the opinion that combining various traditional methods using multi-criteria decision approach will improve the accuracy of results in the delineation of groundwater potential zones.

The Multi-criteria decision analysis using Analytical Hierarchical Process (AHP) is the most common and well known Remote sensing and Geographic Information System (GIS) based method for delineating groundwater potential zones. Remotely sensed data and GIS are playing increasing role in the field of hydrology, groundwater resource development and management. Remote sensing provides multi-spectral, multi temporal and multi sensor data of the earth’s surface (Choudhury, 1999). These tools are very effective in delineating groundwater potential zones, and recharge zones. Modern tools of GIS, Remote sensing and Multi criteria analysis using AHP and ground trotting can provide efficient method for delineating groundwater prospect zones in an area and can establish relationship between geological characteristics and yield data in an area (Kavidha and Elangovan, 2013).

2.2 Geology of Nigeria

The geological framework of Nigeria is made up of three major litho-petrological components, namely the Basement complex, Younger granite and the Sedimentary Basins (Obaje, 2009). The Precambrian Basement Complex rocks underlie three areas of Nigeria: North-central area including the Jos Plateau; South-west area adjacent to Benin; and south-east area adjacent to Cameroon.

The Basement Complex, which is Precambrian in age, is made up of the Migmatite-Gneiss Complex, the Schist Belts and the Older Granites. The Younger Granites comprise several Jurassic magmatic ring complexes centred around Jos and other parts of north-central Nigeria. They are structurally and petrologically distinct from the Older Granites. The Sedimentary Basins, which is made up of sediments of Cretaceous to Tertiary ages, comprise the Niger Delta, the Anambra Basin, the Lower, Middle and Upper Benue Trough, the Chad Basin, the Sokoto Basin, the Mid-Niger (Bida-Nupe) Basin and the Dahomey Basin.

In general the geological framework of Nigeria consists essentially of the following.

(i) The Basement Complex
(ii) The Sedimentary Basins
(iii) The Younger granite

The basement complex rocks are exposed in about half the surface area of Nigeria. The remaining 50% is covered by sedimentary rocks of cretaceous to recent ages. The Nigerian basement was affected by the 600 Ma Pan-African orogeny and it occupies the reactivated region which resulted from plate collision between the passive continental margin of the West African craton and the active Pharusian continental margin (Burke and Dewey, 1972; Dada, 2006).

Oyawoye (1965) carried out the first review of works done on the rocks in the Precambrian Basement Complex of Nigeria. Oyawoye (1965) succeeded in subdividing the Basement Complex rocks into three major groups which he described as;

(a) The older metasediments, consisting of calc-silicate rocks, arkosic quartzite and high grade schists which are present as lensoid relicts in regional gneisses or as paleosomes of the migmatites. He considered this group as the oldest rocks of the Basement Complex.

(b) The gneisses, migmatites and the older granites. In this group, the author recognized two major types of gneisses which include: the biotite gneiss and the banded gneiss. He also grouped the migmatites into two types, namely; the lit-par-lit gneiss and the migmatitic gneiss. According to the author, the paleosome (a granulite or high grade schist of the ancient meta-sediment) occurs with quartz-feldspar veins and dykes in parallel orientation.

Cooray (1974) in further review added another family of rocks (the intrusives) to the works of Oyawoye (1965). He further effected some changes in the conclusions of Oyawoye (1965) such as (a) The Older granites and related charnockitic rocks are of intrusive rather than metasomatic origin. (b) The Older granites and granodiorites based on the relative time of emplacements and deformation are subdivided into; syn-tectonic microcline-megacrystic, partly foliated granites and late- tectonic, less richly megacrystic, weakly foliated xenolithic granites and granodiorites with cross-cutting contacts and occasional thermal aureoles (McCurry and Wright, 1977; Jones and Hockey, 1964). (c) The author pin- pointed the generally north-south to northeast-southwest structural pattern in the Basement Complex and suggested a poly phase metamorphism to have affected the Basement Complex rocks.

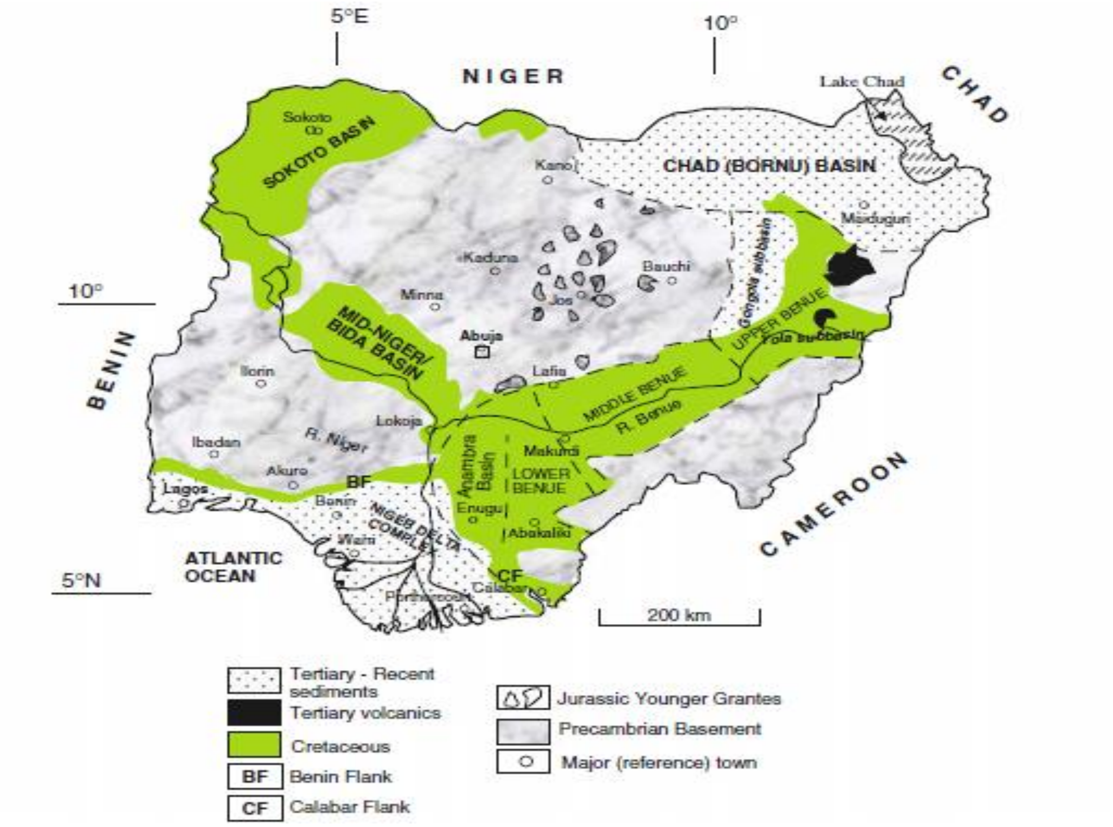

Figure 2.1 Geological Map of Nigeria showing the major geological components (Obaje, 2009)

2.2 Hydrogeology

Groundwater refers to water beneath the surface of the earth which saturates the pores and fractures of sand, gravel and rock formation, it is stored in and moves slowly through geologic formation of soil, sand and rocks called aquifers (Todd, 1980). Groundwater may occur close to the land surface as in a wetland, or it may lie many hundreds of feet below the surface as in some arid regions.

The general pattern of groundwater occurrence is dependent upon the physical framework of the host rock and the hydrologic balance that results from recharge and discharge mechanisms. The local occurrence of groundwater is the consequences of a finite combination of climatic, hydrologic, geologic, topographic, and soil forming factors, which together form an integrated dynamic system (Sekhar *et al.,* 1994). Groundwater can be said to be meteoric in origin, which means they originate from the surface and atmosphere. Also a small percentage is known to enter the hydrologic cycle (a conceptual model that describes the storage and movement of water between the biosphere, atmosphere, lithosphere and the hydrosphere). Groundwater usually occurs in subsurface reservoirs which are formed by adjacent less permeable or impermeable rock, in a situation where the reservoir is in direct contact with the atmosphere it is said to be unconfined aquifer, which is the most accessible groundwater resource though vulnerable to contamination.

On the other hand, a situation where the reservoir is bounded above and below by impermeable or relatively impermeable strata, thereby making the water pressure high is said to be confined aquifer. An aquifer can thus be defined as a saturated permeable geological bed, formation or any lithological unit which transmit and yield water to wells in sufficient quantities to be economically useful (McFarlane, 1992). Most aquifers are unconsolidated sand and gravels, but permeable sedimentary rocks such as sandstones and lime stones and heavily fractured or weathered volcanic and crystalline rocks can also be classified as aquifers. These fractured or weathered zones in crystalline rocks are usually targets of surface geophysical exploration for groundwater in the basement complex terrain. Invariably porosity and permeability is improved by joint and fractures in the rocks system. The interconnectivities of those joints and the extent of fracturing determine the hydrological potential of these rocks as potential aquifers.

2.3 Groundwater Exploration

Groundwater exploration is the investigation of underground formations to understand the hydrologic cycle, know the groundwater quality, and identify the nature, number and type of aquifers. Groundwater exploration in the past years has reached a place of importance to the world because of the rising need for portable source of fresh water and the pursuit to reduce failed boreholes. Prospecting for water is essentially a geological problem and the geophysical approach is dependent on the mode of the geological occurrence of water. It needs a lot of information on various aspects such as geology, stratigraphy, geomorphology, geophysical techniques, etc.

The knowledge of stratigraphy is essential to know the position and thickness of water-bearing horizons and the continuity of confining beds are of particular importance in groundwater exploration. Structural geology in conjunction with stratigraphy is used to locate water-bearing horizons which have been displaced by earth movements, to locate weathered, fractured, faulted and joined patterns in rock formations.

Remote sensing data are found particularly useful in identifying the various geologic, geomorphic units, structures such as faults, lineaments, joints, fractures, folds and drainage which are important as they control the movement and occurrence of groundwater. In order to access the groundwater potential, a field check is very essential to identify the geomorphological features after an in-depth study of the satellite imagery and geomorphology map.

In any groundwater exploration programme well inventory study is very essential.

2.3.1 Groundwater Exploration methods

Groundwater can be explored using different methods. Groundwater exploration can be done in two ways: directly or indirectly. A range of geological, hydrogeological, and geophysical approaches are employed to identify groundwater potential zones. This technique is further facilitated by the interpretation of satellite and aerial imagery. Over the last two centuries, new methods of researching groundwater have emerged. They are classified into two (surface and subsurface methods) (Balasubramanian, 2007).

Subsurface groundwater exploration techniques involves both test drilling and borehole geophysical logging. They are significantly more expensive than surface methods. Subsurface approaches are extremely accurate since they allow for direct observations of features in the form of bore-hole lithology as core samples, as well as geophysical measurements of formation parameters.

The surface methods are easy to operate and implement, they require minimum materials like maps, remote sensing data, topo-sheets, field measurement, interpretation of data and reports.

2.3.2 Geological Methods

Geologic investigation begins with the collection, analysis, and the hydro-geologic interpretation of existing topographic maps, aerial photographs, geologic maps and logs, and other pertinent records. This could be supplemented, by geologic field reconnaissance and by the evaluation of available hydrologic data on stream flow and springs, well yields, ground water recharge, discharge, and levels and water quality. In some places, the drainages may be fully controlled by the presence of minor and major structures like joints, faults and lineaments. Such zones are good and potential zones for groundwater exploration. These are the channels for the groundwater flow.

2.3.3 Geophysical Method

Geophysical method is one of the most suitable methods in exploration of groundwater. This method has been widely applied in geotechnical and geo-environment investigation. Geophysics has played a useful part in such investigations for many years in improving the instruments and development for better result in widening its applications. The application of geophysical method offers a better way than most conventional method in groundwater exploration. Well drilling is one of the conventional method which applies a direct way in exploring subsurface groundwater system, sufficient number of boreholes are required to be drilled to describe the depth and constituency of various geological formation. Geophysical method was originally developed for oil and mineral exploration, this technique is now being applied in groundwater exploration and has improved the understanding of groundwater resources. This technique is extremely useful in analysing the groundwater potentiality of geologic formations, estimated weathered zone thickness and bedrock topography, fractures in hard rock terrain, and paleo-channels.

The primary geophysical methods that can be used to solve hydrogeological problems are the electrical, seismic, gravity, and magnetic methods.

2.3.3.1 Electrical Resistivity Method

The Electrical resistivity method is the most extensively used geophysical approach for groundwater studies (Todd 1959). Electrical Resistivity Method has been applied for many years to determine the thickness of layered media as well to map geological environment of existing aquifer. It has been effectively used for groundwater due to simplicity of the technique, efficient and non-destructive implementation in producing the subsurface imaging compared to conventional method.

The purpose of electrical surveys is to determine the subsurface resistivity distribution by making measurements on the ground surface. From these measurements, the true resistivity of the subsurface can be estimated. The ground resistivity is related to various geological parameters such as the mineral and fluid content, porosity and degree of water saturation in the rock. Electrical resistivity surveys have been used for many decades in hydrogeological, mining and geotechnical investigations. More recently, it has been used for environmental surveys. Each electrical property is the basis for a geophysical method. The resistivity measurements are normally made by injecting current into the ground through two current electrodes (C_1 and C_2), and measuring the resulting voltage difference at two potential electrodes (P_1 and P_2).

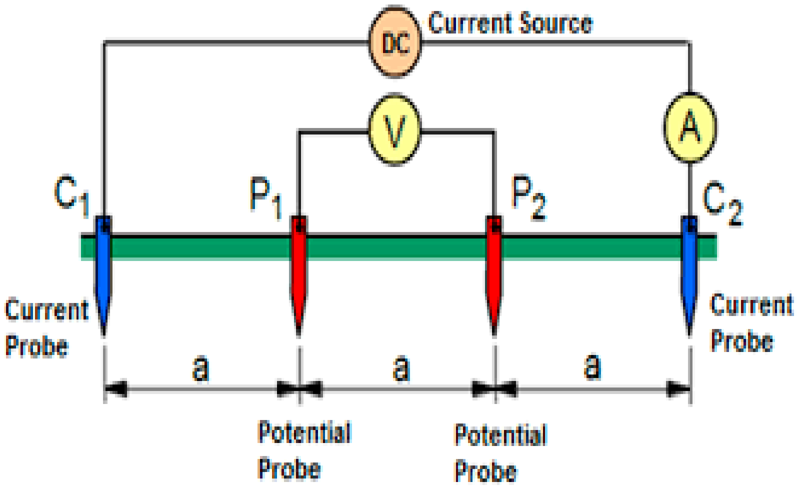

Figure 2.2 Basic Concept of Resistivity Measurement

From the current (I) and voltage (V) values, an apparent resistivity (pa) value is calculated, using pa = k $\frac{V}{I}$, where k is the geometric factor which depends on the arrangement of the four electrodes. The electrode arrangement in these investigations are called as arrays. Some of the most common electrode arrays are Wenner, Schlumberger, pole-pole, Pole-dipole and dipole-dipole array.

The resistivity approach has two primary techniques for conducting research. The first is the **Electrical Profiling (EP)** approach, and the second is the **Vertical Electrical Sounding technique (VES).**

Electrical profiling investigations are carried out in order to trace the lateral boundaries of lithological units with varying electrical characteristics. For the Electrical Profiling survey the spacing between the electrodes remains fixed, but the entire array is moved along a straight line. This gives some information about lateral changes in the subsurface resistivity, but it cannot detect vertical changes in the resistivity. Interpretation of data from profiling surveys is mainly qualitative. The most severe limitation of the resistivity sounding method is that horizontal (or lateral) changes in the subsurface resistivity are commonly found. In many engineering and environmental studies, the subsurface geology is very complex where the resistivity can change rapidly over short distances. The resistivity sounding method might not be sufficiently accurate for such situations. Resistivity surveys give a picture of the subsurface resistivity distribution. To convert the resistivity picture into a geological picture, some knowledge of typical resistivity values for different types of subsurface materials and the geology of the area surveyed, is important.

On the other hand the Vertical electrical sounding is used to determine the resistivity variation with depth. Single Vertical Electrical Sounding should only be applied in areas, where the ground is assumed to be layered horizontally with very little lateral variation, since the sounding curves only can be interpreted using a horizontally layered earth (1D) model. To measure the apparent resistivity values a resistivity meter is used. Resistivity meters normally give a resistance value, R = $\frac{V}{I}$, so in practice the apparent resistivity value is calculated by

Pa = k R. The calculated resistivity value is not the true resistivity of the subsurface, but an “apparent” value which is the resistivity of a homogeneous ground which will give the same resistance value for the same electrode arrangement. The relationship between the “apparent” resistivity and the “true” resistivity is a complex relationship. To determine the true subsurface resistivity, an inversion of the measured apparent resistivity values using a computer program must be carried out. The measured apparent resistivity values are normally plotted on a log-log graph paper. To interpret the data from such a survey, it is normally assumed that the subsurface consists of horizontal layers.

2.4 Groundwater Potential Zones

The groundwater potential of an area mainly depends on the hydrogeological setup, for a well detailed and systematic hydrogeological survey is a prerequisite. Areas or zones of abundant groundwater available for use are referred to as areas of good groundwater potential (Mathew, 2006). Productive water bearing zones referred to as excellent groundwater potential aquifers. The search for groundwater has become quite extreme in human history. This can be achieved through groundwater potential studies. For example, Matthew (2006) pointed out that the groundwater potential of United States is divided into principal aquifers of over 300,000km^2, principal aquifers of over 20,000km^2, principal aquifers of less than 20,000km^2 and non-principal aquifers. Classification of areas into groundwater potential zones or classes is not a new issue in the field of hydrology.

2.5 Remote Sensing Method

Remote sensing can provide a quick and inexpensive summary of the principal indicators indicating the presence of groundwater across a vast area.

Remote sensing and Geographic Information Systems method provide important data and tools for groundwater exploration. These methods permit rapid and cost-effective natural resource survey and management. The remote sensing data helps in identification and delineation of land features (Kumar and Srivastava, 1991). With sufficient ground data, hydrological characteristics of geomorphological features can be deciphered. Groundwater occurrence being subsurface phenomenon, its identification and location is based on indirect analysis of some directly observed terrain features like geological and geomorphic features and their hydrologic characters. Remote sensing provides an opportunity for better observation and more systematic analysis of various geomorphic units, lineament features, following the integration with the help of Geographical Information System to demarcate the groundwater potential zones. Therefore, an integrated approach, including studies of lithology, hydro geomorphology and lineament, has been taken up, using remote sensing and GIS techniques, for a proper assessment of groundwater potential zones.

2.6 Review of Related Works

With the advancements in GIS technology over the years, an integrated approach to assessing groundwater potential has grown in popularity. Many researchers all over the world have used this technique, or variations on it, in routine groundwater research;

(Qazi et al., 2015) assessed groundwater potentiality areas in Allahabad region in India, utilizing RS & GIS techniques. The study was conducted to investigate potential ground water zone in Allahabad district utilizing RS data and GIS techniques. In the study, remotely sensed land use and DEM data were used to assess ground water potential zones. DEM (Digital Elevation Model) data used was also obtained from USGS. The presence of ground water in a given area depend on many hydro geological factors such as land use pattern and slope. The assessment of ground water potential zone was done by taking into account an impact of land use and slope on ground water after assigning ranks and weightage to these factors. Similarly slope of the study area were weighted and ranked according to its impact on ground water potential for example areas with steep slopes were weighted and ranked least because the surface water would stand long enough to get infiltrated and subsurface water in these areas will tend to less slope or to the level areas. It was found that the ground water potential zones information analysed for Allahabad district can be used for effective utility of ground water for domestic and other purposes. It is also important to get suitable wells location for extraction of water and it‘s a convenient and time saving method as compared to field methods. The ground water potentiality areas map of interest was classified in 4 groups; excellent, good, moderate and poor zones which gave a more realistic view to understand potential ground water areas and can be utilized for groundwater growth & monitoring.

(Obimba *et al.*, 2017) evaluated the use of Remote Sensing and GIS techniques for ground water potential of Ilesha region, Osun State. The study area is in the Basement Complex terrain, southwest Nigeria. Thematic maps of geology, lineament, drainage and topography was analysed and incorporated utilizing ARCGIS 9.3 to generate a map of ground water potential research areas. Multi-criteria and weighted classification were adopted which revealed that the topography of the study area. Areas with high elevation or hilly areas (1450m - 1700m) were observed to have lower ground water potential, this could be attributed to the fact that at high altitude water runs off and has little or no residence time to percolate into groundwater. This is because one of the driving forces for ground water flow is gravity. Water go from higher altitude to lower altitude and from higher force to lower force. Areas with topography range of 1150m - 1400m are regarded as moderate altitude and moderate groundwater potential. Lastly areas with range of 850m - 1100m are regarded as low altitude and high groundwater potential.

Based upon water retaining capacity of the rocks in the study area (schists, gneisses and undifferentiated migmatite) the geology was grouped into excellent, good and fair groundwater potential depend on their ability to let water pass through them. Result of the study reveals that Ilesha (urban area) is seated on a moderate groundwater potential area. While other settlements like Eyinta, Ibede and Itagunmodi were situated on high groundwater potential zones. The groundwater potentiality in areas of interest is grouped in excellent, good and fair water potential region. A big side of the interest falls in the good-excellent groundwater potentiality region; in Ilesha city.

2.7 Multi-Criteria Decision Analysis

Multi-Criteria Decision Analysis, or MCDA, is a valuable tool that can be useful in making many complex decisions. It is most applicable to solving problems that are characterized as a choice among alternatives from which the best decision is to be made. It has all the characteristics of a useful decision support tool: It helps focus on what is important, is logical and consistent, and is easy to use.

The MCDA technique was developed worldwide for quantitative analysis by Saaty (1980) as an effective way for solving problems associated with multifaceted decision making and is also suitable at assisting in setting priorities in order to reach the best unbiased decision. The decision making incorporates AHP (Analytical Hierarchy Process) as a functional method for evaluating the degree of consistency in decision maker's appraisals.

AHP has recently found application in several fields of geology and more importantly in groundwater-related studies and has performed satisfactorily, especially in delineating groundwater potential zones (Adiat 2013; Fashae and Tijani 2014; Mogaji et al., 2014; Adiat et al., 2018). Spatial problems like groundwater exploration is a multiple attribute decision-making challenge as it involves a group of factors that are appraised on the core of competitive and disproportionate criteria (Malczewski 1999). The integration of these various factors helps in developing a reliable and valid prediction map for future planning of groundwater exploitation within the area. This integration can be achieved through the use of multi-criteria decision analysis (MCDA). Multi-criteria decision analysis is a knowledge-driven, mathematical-based system that allows decision making between two or more contradictory alternatives. It also helps decision maker(s) to opt for the best option from a list of available substitutes and among competing criteria (Adiat, 2013).

2.8 Inferences from Reviewed Literature

Groundwater sources is one of the sustainable sources in the world. Remote sensing and Geographic Information system method based on multi-criteria decision analysis technique are most effective and accurate tool for the assessment of groundwater potentiality. Both these techniques are widely used in recent age for more reliability. The integration of various factors such as geology, elevation, slope, lineament density, etc. was considered for each study for developing a reliable groundwater potential map. The number of factors considered varied depending on the author. The rate of each assigned factor decides the contribution of each factor on groundwater storage and potentiality.

Individual features in all thematic layers were assigned certain weights based on their relative importance in groundwater occurrences by considering its role in a particular area. The groundwater potentiality map derived are grouped into different classes ranging from high to low to give a more realistic view and to understand potential ground water areas. This can be utilized for groundwater growth & monitoring.

CHAPTER 3: RESEARCH METHODOLOGY

3.1 Data and Tools

This research work used both primary and secondary Sourced data.

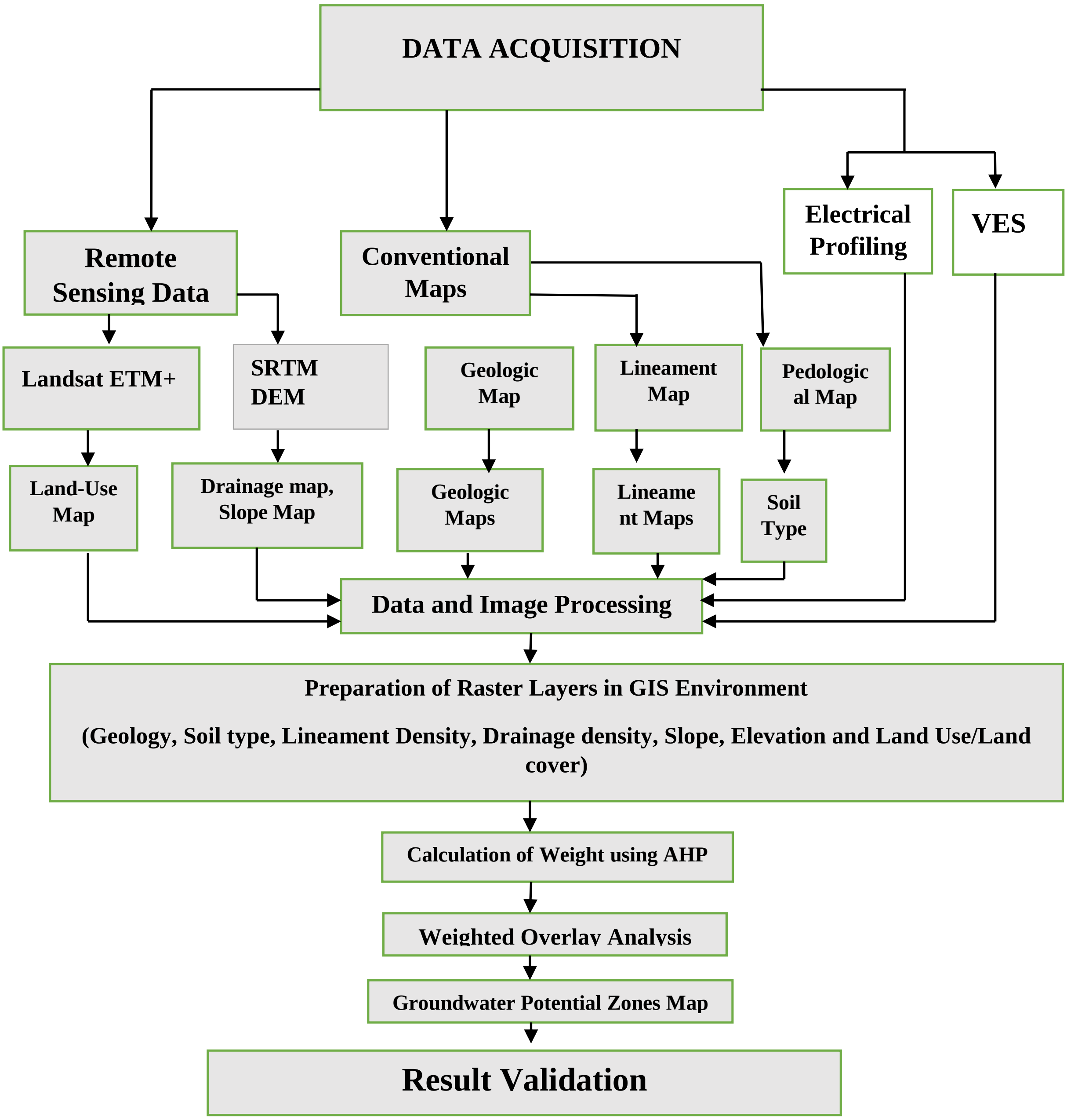

Figure 3.1 Flow Diagram of the methodology used for groundwater potential zone mapping of the study Area

3.3 Data Acquisition

3.3.1 Geophysical Survey

The geophysical survey was carried out using the Campus Ohmega Terameter to determine the thickness of the regolith and depth to bedrock within the study area. Four-electrode array was used at the surface, one pair for introducing current into the earth and the potential difference established in the earth by the current is measured in the vicinity of current flow with the second pair.

3.3.1.2 Equipment Used

i. **Ohmega Resistivity meter:** Resistivity meters are electronic meters used to measure resistivity of fluids or semi solids. The OHMEGA Ω resistivity meter is a high-quality portable earth resistance meter that can measure accurately in a variety of settings. It includes a maximum power output of 36watts, manual current selection in stages up to 200mA, a sampling time / signal length averaged selection, and three frequency options. The receiver has automated gain stages that provide measurements ranging from 0.001Ω to 360kΩ. In ordinary terrain conditions, the instrument is powered by a large capacity internal rechargeable battery, which allows for several days of usage without recharging. External power can be supplied by any 12 VDC source, the most common of which being a vehicle battery.

ii. **Reels of Cables**: It is commonly referred to as the Ohmega cables. They are ordinary single conductor insulated cables that are typically wound on four steel cable drums to form four reels. Two of the reels are used to link current electrodes, while the other two are used to connect potential electrodes. To connect to the four cable reels, four cables of varying lengths are permanently linked to the Terameter.

iii. **Stainless steel Electrode pegs**: The electrode pegs are constructed of steel and have a pointed end. They are used to peg the soil. A sledge hammer is used to drive the pointed end a few cm into the ground.

iv. **Measuring Tapes**: The tape is used to determine the distance between electrodes. They are also used to grade the space between electrodes. This causes the transverse lines to move faster.

v. **Hammers**: Used to drive the electrodes properly into the ground.

vi. **Clamps:** They are used for cable wire connections to the electrodes

3.2 Data Analysis

The Data used include remotely sensed data like Landsat 8 (OLI) image of kuje and Shuttle Radar Topographic Mission Digital Elevation Model (SRTM DEM); conventional maps (soil map of the study area), software used include ArcGIS 10.5, Erdas Imagine 2015.

Table 3.1 Data type and sources for the Study

S/N	**Name**	**Data Type**	**Format**	**Sources**	**Resolution**	
					Spatial	Temporal
1	Elevation	SRTM DEM	Raster	https://earthexplorer.usgs.gov	30m	2015
2	Soil map	Soil Data	Raster	FAO soil map		2020
3	Drainage Map	Drainage Density	Raster	Extracted from DEM	30m	2015
4	Slope Map	Slope	Raster	Extracted from DEM	30m	2015
5	Geologic Map	Geologic Map	Raster	Geologic Survey Agency		2020
6	Land Use Land Cover	Landsat 8 OLI	Raster	https://earthexplorer.usgs.gov	30m	2020
7	Lineament Map	Lineament Density	Raster	Extracted from DEM	30m	2015

3.3 Map groundwater potential zones in the study area

A total of thirty (30) wells were identified with their coordinates for the groundwater potentiality mapping in area of interest.

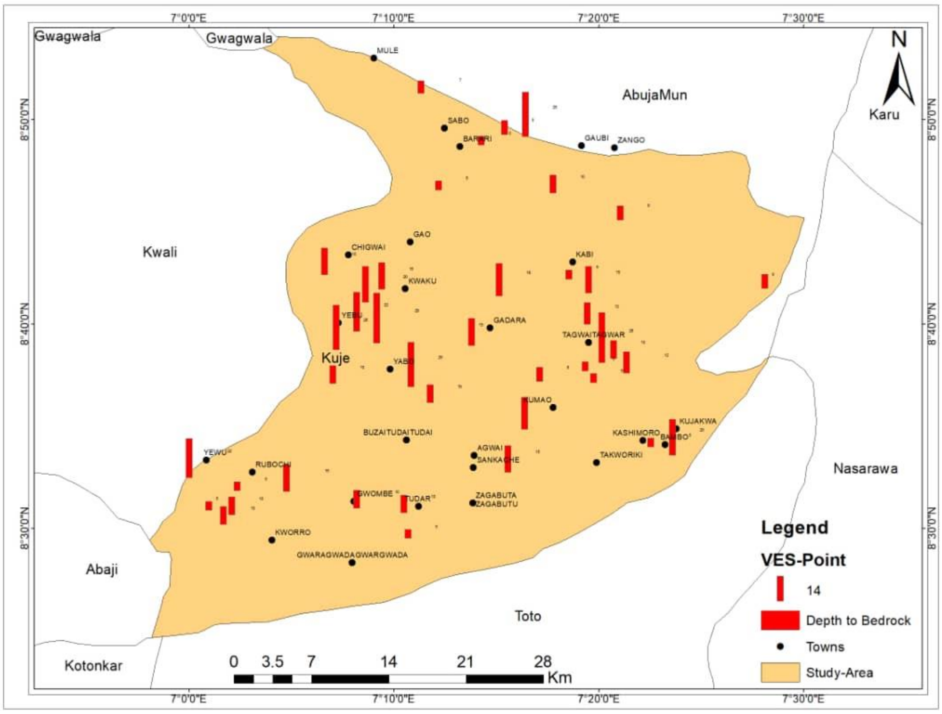

Figure 3.2 Map of Study Area Showing the Location of each borehole identified and their depth to bedrock

To generate groundwater potential zone map, following methods were adopted:

i. Field visits was carried out.

ii. Thematic maps was prepared using Arc GIS Software.

iii. Multi-Criterion Evaluation technique was used for assigning weightages, ranks and scores to different themes and features class by assessing the relevance of it in ground water occurrence. After which ranks and scores to the themes and element were converted to raster format using _Spatial Analysis‘, extension of ArcGIS software.

This map was reclassified into GIS home utilizing Arc GIS to demarcate different ground water potentiality areas. The generated outcome consists different classes of ground water potentiality zones namely Very high, High, Moderate, Low and Very Low Zones from ground water potential point of view. Score of feature class for weightages and rank. Raster Calculator of Arc Info Arc GIS software was utilized to prepare incorporated groundwater potential zones map by adopting appropriate map algebra.

3.3.1 Data processing Procedure for Deriving Thematic Maps

The thematic layers of drainage density, slope, lineament density, land use and land cover, soil type, Geology and Elevation map were prepared and integrated for the delineation of groundwater potential zones. Prior to weighting of the thematic layers and delineation of groundwater potential, the groundwater influencing thematic layers was analysed with series of GIS techniques such as raster calculator, multi-dimension analysis, inverse distance weight interpolation, line density, Maximum likelihood supervised classification, cell statistics, hydrology, and surface function of spatial analyst tool of ArcGIS 10.5.

The Topographic elevation and slope thematic maps were created using the Digital Elevation Model (DEM) data with a 30 m spatial resolution. SRTM-DEM was adopted to prepare the drainage map, which was then processed to create the drainage density map. The study area's drainage density layer was made utilizing the line density tool and the stream network. The stream network was established from DEM by following the procedures in the hydrology toolbox for "fill DEM, flow direction, flow accumulation, stream order, and stream to feature. The resulting drainage density data were categorized in order to create a drainage density map of the research region. LULC map of the study was generated from a mosaicked Landsat 8 OLI data via supervised classification of the chromaticity composite of the band 4, 3 and 2 to derive the land use classification in GIS software package. Following the preparation of all the various thematic maps with distinct features (such as; slope, drainage density, soil, land use land cover, slope, geology, and lineament thematic maps), the maps were transformed to raster format and appropriate weights were given in sequence of their hierarchy in groundwater potentiality adopting the analytic hierarchy process (AHP).

3.3.2 Procedure for weighting the derived maps using the analytical hierarchical process (AHP)

Weighting of individual thematic layer class weight and scores was carried out using the Analytical Hierarchical Process based on Satty’s and Vargas (1991) Analytic Hierarchy Process (AHP); in this method the relative importance of each individual class within the same thematic map will be compared to each other by pair-wise comparison matrix and seven important matrices will be prepared for assigning weight to each class. The AHP was used to differentiate the zones into very good, good, moderate, low and very low and these zones was characterized based on the individual thematic layers properties. The delineation of groundwater potential zones for the study area was made by groups the interpreted layers through weighed multi-influencing factor and finally assigned different potential zones were categorized.

3.3.3 Procedure for Delineation of the Groundwater Potential Zones

The multi-criteria decision analysis using Analytical Hierarchical Process (AHP) is the most common and well known GIS based method for delineating groundwater potential zones. This method helps integrating all thematic layers. A total of 7 different thematic layers was considered for this study. These 7 thematic layers are supposed to control factor of flow and storage of water in the study area. The association of these influencing factors was weighted according to their reaction for groundwater occurrence. A parameter with a high weight illustrates a layer with high impact and a parameter with a low weight illustrates a small impact on groundwater potential. To generate groundwater potential zone map of study area, all seven thematic layers were integrated with weighted overlay analysis function of spatial tool in ArcGIS platform using the following equation;

$$GWPI = [(LDw * LDwi) + (SLw * SLwi) + (DDw * DDwi) + (LUw * LUwi) + (STw * STwi) + (TEw * TEwi) + (Gw * Gwi)] \quad (1)$$

where;

GWPI refers to groundwater potential index,

LD stands for lineament density,

SL for slope,

DD for drainage density,

LU for land use land cover,

ST for soil type,

TE for topographic elevation,

G for Geology,

The subscripts *w* and *wi* refers to the normalized weight of a *theme* and *individual features* respectively. The final groundwater potential zone map will be classified into low, moderate, high and very high zones.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Factors Mapped for Groundwater Potential Zones in Kuje, Abuja

4.1.1 Geology and Lithology

The study area's lithology is considered as one of the controlling factors influencing the groundwater flow and its existence. The serial arrangement of different rocks or lithological units and their interaction determines the area's total infiltration capacity. Porous and permeability of the litho units refer to the storage and transmitting capacity, which supports the groundwater occurrence and occurrence of an area. An extensive field check with literature review and satellite data analysis by visual interpretation found that the study area comprises Precambrian basement complex rocks and Cretaceous rocks as shown in Figure 4.1

The Delineated rock units in the study area were further classified into migmatite gneiss, granite, and schistose gneiss.

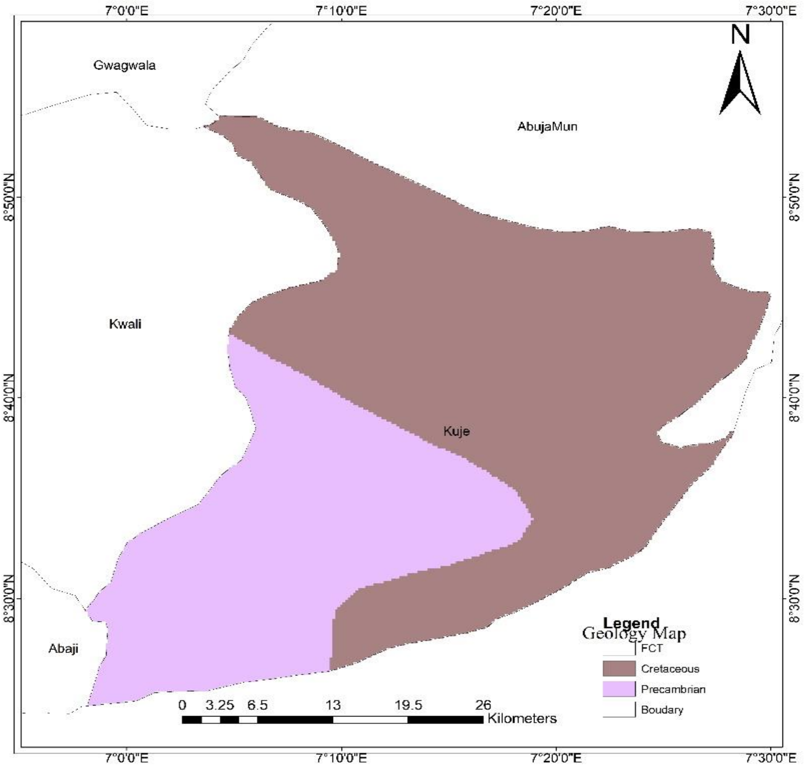

Figure 4.1 Extracted Geology Map of Study Area

Groundwater is typically found in structural units known as aquifers; in crystalline rock terrain, such as the one underlying the Kuje area, groundwater occurs in the weathered section over laying the fresh rock, as well as in fractures within the rocks. Because the weathering profile in the area is fairly shallow, groundwater occurs largely within the fractures in the rock, and hand bored wells are mostly dry at the start of the dry season. The studied area has a high level of fracture.

4.1.2 Drainage and Drainage Density

The length of the stream to a unit area of the region is defined as the drainage density (Horton 1945; Strahler 1952). It is a suitable tool for analysis of the landform in terms of groundwater potential. The ordering of the tributary streams has been done according to Strahler's stream ordering method (Strahler 1957). The drainage network development within an area is controlled by the rock formation, which it drains, and gives some indirect information about the percolation rate. The drainage density is determined using the equation;

$Dd = Li/A$

where Dd denotes Drainage density and Li is the total length of drainage. Dd is drainage density that is significantly correlated with the groundwater recharge. It is a fact that a high Drainage density zone indicates a probable recharge zone of groundwater.

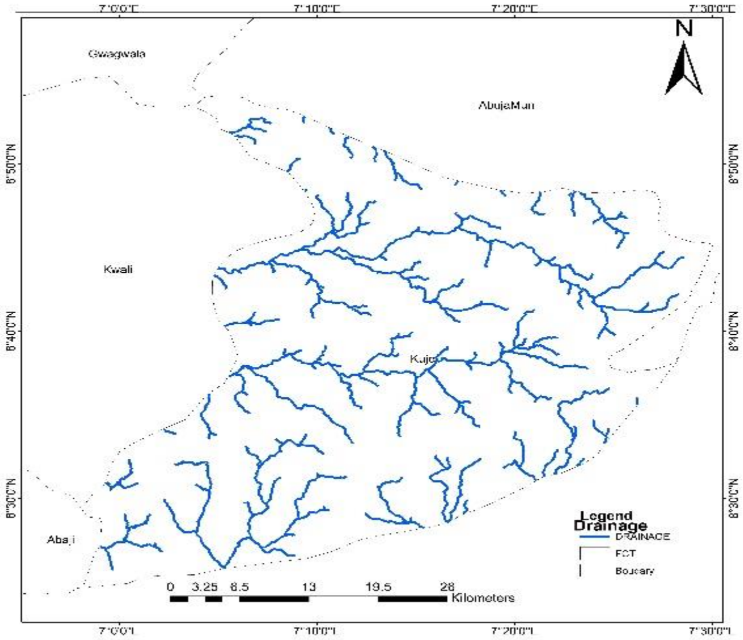

Figure 4.2 Drainage Map of the Study Area

The Drainage density has been divided into five classes, ranging from very-low to very-high as shown below in Fig 4.2.1

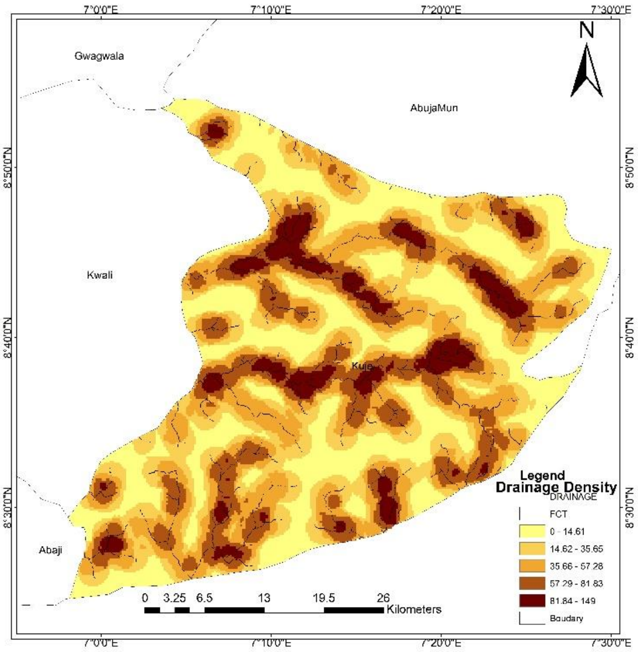

Figure 4.2.1 Drainage Density Map of the Study Area

Consequently, drainage density is one the important factors that determines groundwater potential zones as it give ideas on the amount of rainfall percolation relative to runoff, slope, presence of morphological features and the subsurface formations within an area. However, it has also been observed that a low drainage density is more likely to occur in area of highly permeable subsurface, while high drainage density is the resultant of impermeable subsurface materials, inselberg relief, low lineaments and high slope.

The drainage density is inversely related to permeability which influences runoff and quantity of infiltration (Ibrahim-Bathis and Ahmed 2016). When the drainage density is very high, the runoff is very high, and the rate of infiltration is quite low. Conversely, as drainage density decreases, runoff decreases and infiltration increases. The digital elevation model with 30m resolution was used to derive the drainage density map. By determining the flow direction and flow accumulation of the region using ArcGIS 10.5 software, the drainage density was obtained and was grouped into five classes. The drainage density of the study area varies between 0-14.6km (very- low) to >81km (very-high).

4.1.3 Land Use and Land Cover

Water infiltration into the earth is influenced by land use/land cover features. LULC of the study area was captured and monitored by satellite image (Landsat 8 OLI) using visual interpolation techniques in ERDAS IMAGINE software.

The current LULC is evaluated for its suitability for groundwater potential. It comprises the distribution of developed land, forest land, and agricultural land. Many hydrogeological processes, such as evapotranspiration, runoff, and groundwater recharge, are controlled by LULC. The LULC was categorized into five extensive classes, namely, outcrop, water-body, built-up areas, vegetation and bare surface, that has been identified and demarcated, as shown in Figure 4.3. Despite its continuous decline over the years, owing largely to human activities in the study area, vegetation still maintains its lead with large area coverage. The dominance of vegetation cover could be attributed to widespread of agricultural practice in the study area.

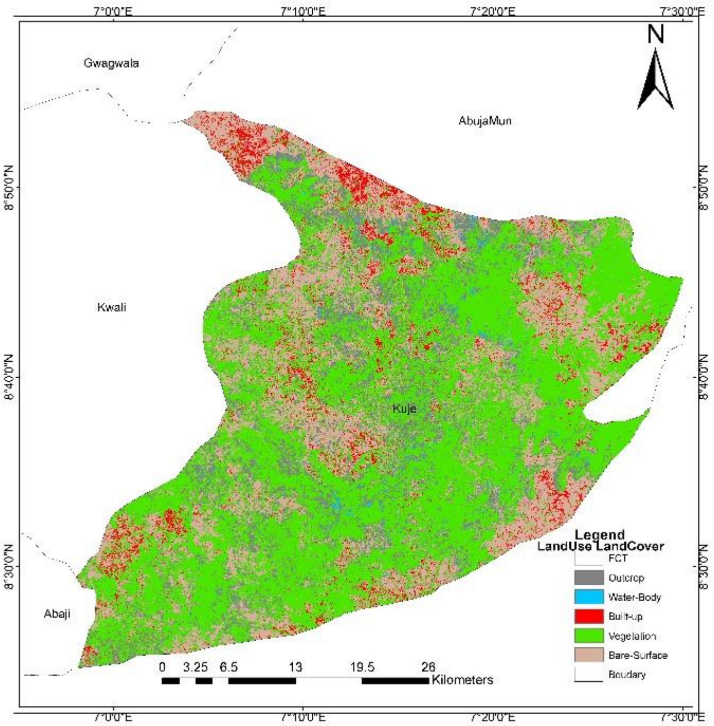

Figure 4.3 Land Use Land Cover Map of the Study Area

4.1.4 Soil Type

The increase in water entry into the soil is affected by soil type, which is determined by the activities of pore saturation or desaturation (Gbosh *et al*., 2020). Water transport into the ground is controlled by the porosity of the soil categories. Soil is a significant parameter for the identity zone of potential groundwater occurrence. The soil texture of an area is one of the major factors that control the surface runoff and infiltration of rainwater. The study area consists of three types of soil, i.e; Clay, Silt Loam and Silt Clay. The soil type of the study area is one of the major factors that control the surface runoff and infiltration of rainwater. Clay soil makes up the larger percentage of the soil type in the study area.

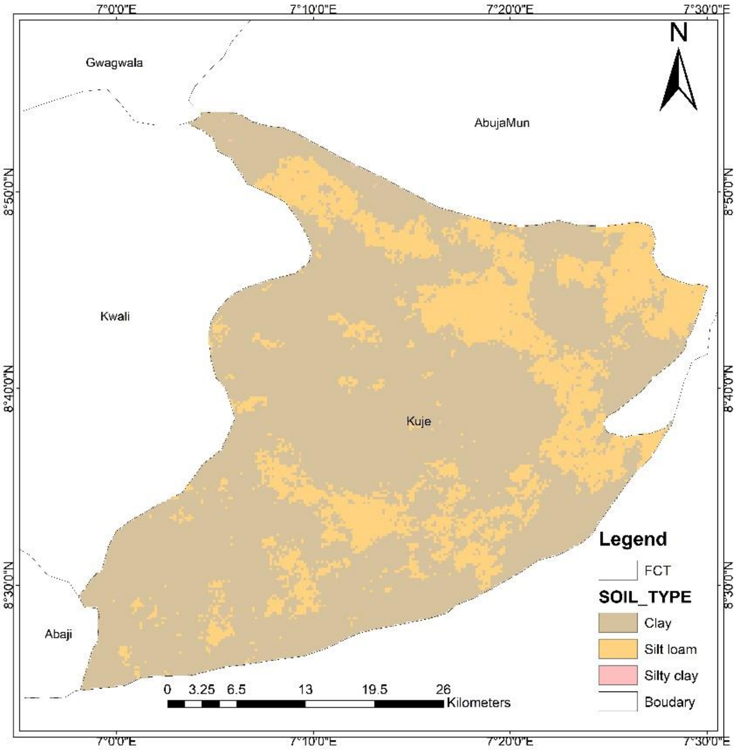

Figure 4.4 Soil Type Map of the Study Area

4.1.5 Lineament Density

Lineament is the surface expression of structurally regulated subsurface structures like fractures (faults and or Joints). Lineament density is an important Hydro-geomorphic parameter in groundwater studies. Like primary porosity, secondary porosity is also essential for the determination of hydrogeological conditions. Lineaments represent secondary porosity and are linear features of tectonic origin. Due to their linear, direct, curvilinear form, they can easily be demarcated in satellite imagery which are typically portrayed as linear features. Some other indications like tone, texture, relief, drainage, and vegetation soil tone's linearity also give valuable information for lineament differentiation. Correlation of structural features like faults, fractures, joints, and bedding planes with these lineaments is an excellent practice to determine the potential areas of groundwater occurrence (Pandian *et al*., 2013).

The thematic layers of lineament density map of the study area revealed five main lineament density classes ranging from very-low to very-high. 0-5.67km(very-low), 5.67-15.72km(Low), 15.73-26.29km(Moderate), 26.3-39.17km(High), 39.18-65.72(Very-high). It is apparent from Fig 4.5.2 that the majority of the study Area is dominated with low lineament density.

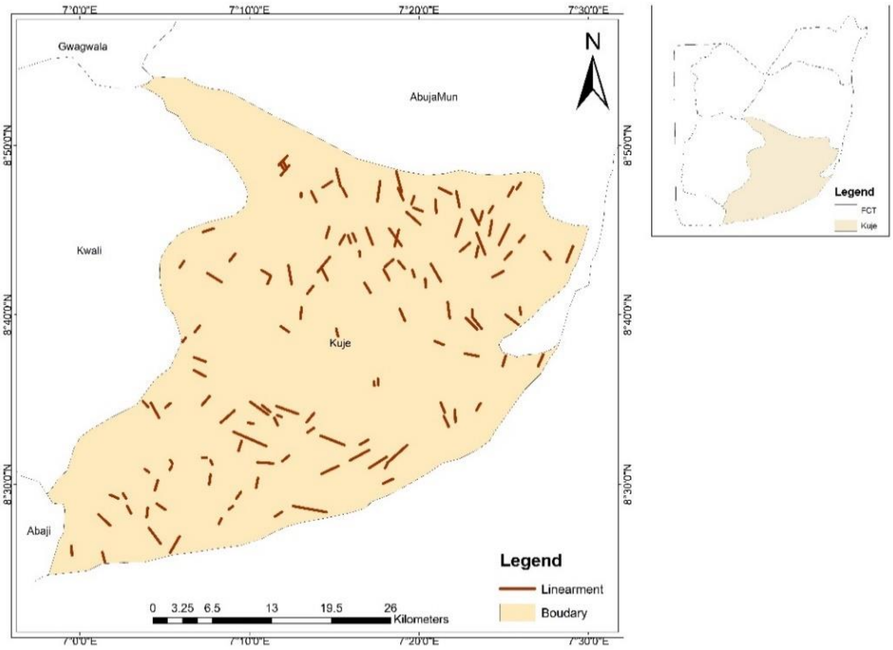

Figure 4.5.1 Lineament Map of the Study Area

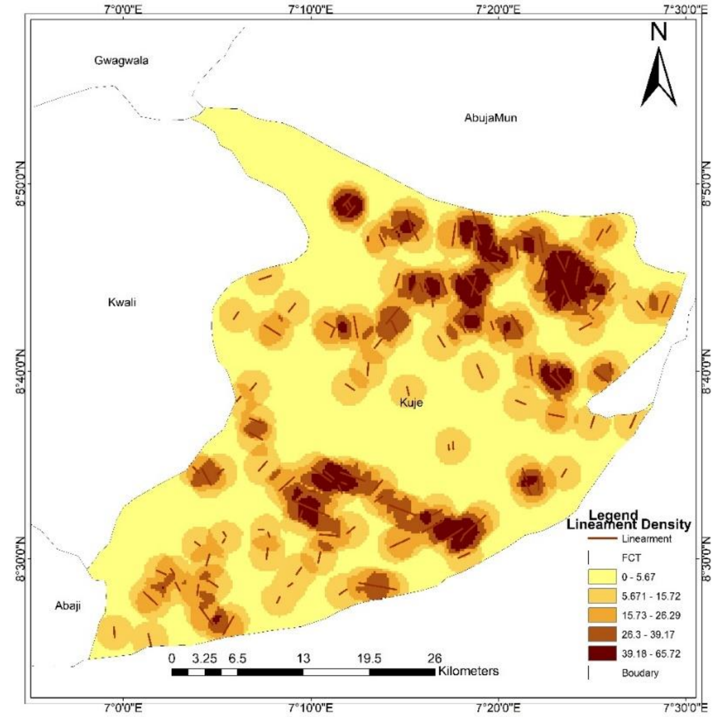

Figure 4.5.2 Lineament Density Map of the Study Area

4.1.6 Elevation

The rate of groundwater recharge and the nature of precipitation are influenced by altitude. SRTM Digital Elevation Model was used to obtain the elevation of the area in the ArcGIS environment; five classes were obtained. The elevation of the study area ranges from 117m – 906m from sea level.

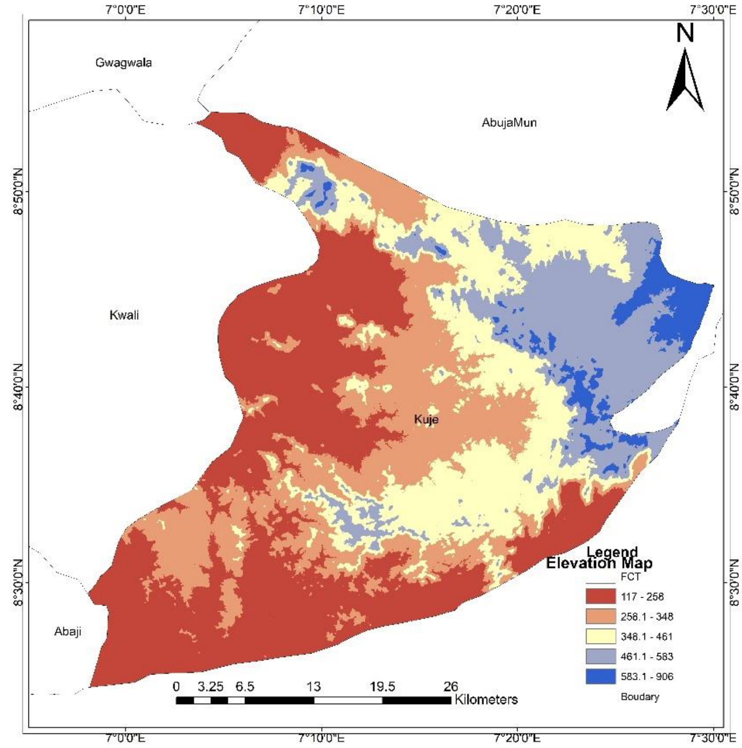

Figure 4.6 Elevation Map of the Study Area

4.1.7 Slope

Slope is among the mechanisms that govern groundwater recharge and percolation based on geomorphologic features; however, the nature of slope of an area alongside with other geomorphic features determines the occurrence of groundwater. Similarly, slope map of an area plays a vital role in determination of groundwater recharge as it is influenced by rate of surface water infiltration.

Preliminary investigations have revealed that the low slope regions have a good potential for groundwater storage due to the extended residence time for rainwater to infiltrate the subsurface. Steep slope regions, on the other hand, possess poor groundwater potential due to rapid water runoff from the landscape (Igwe *et al.*, 2020). In the study area, slope is classified between 0- 3.995(Very-High) to 21.26- 46.31(Very-Low) designed as very high potential, high potential, moderate potential, low potential and very low potential (Fig 4.7)

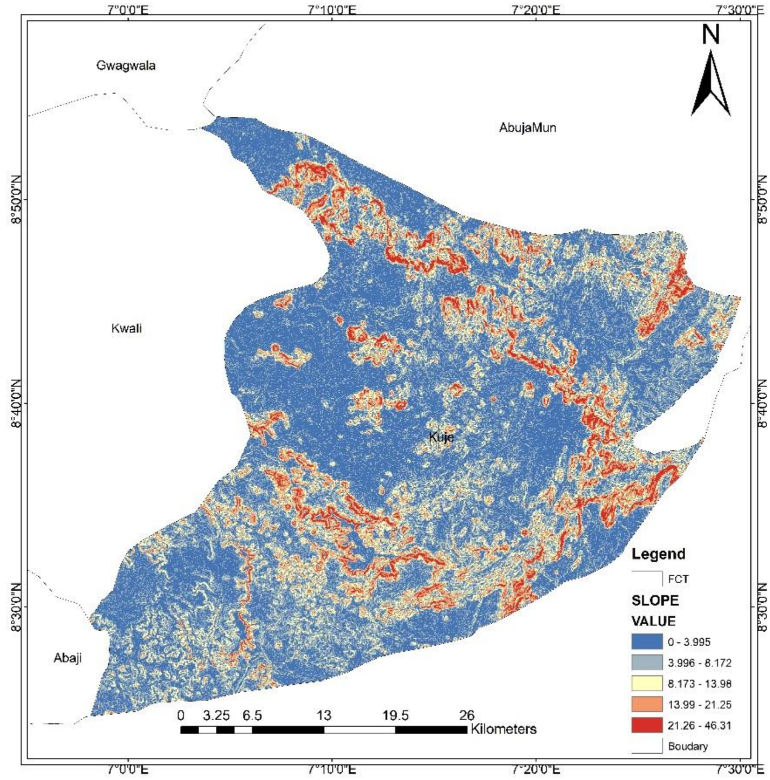

Figure 4.7 Slope Map of the Study Area

4.1.8 Depth to Bedrock

The Depth to Bedrock map shows that areas with the thickest overburden are sparsely distributed in the area. In the Study Area the overburden thickness ranges from 5m to 28 m. The average thickness of overburden in the area is 15 m. Areas with heavy overburden and a low percentage of clay, with noticeable inter-granular flow, are known to have high groundwater potential, particularly in basement complex terrain (Okhue and Olorunfemi, 1991). Deeper overburden shows high weathering and high fractures which means high groundwater potential zones.

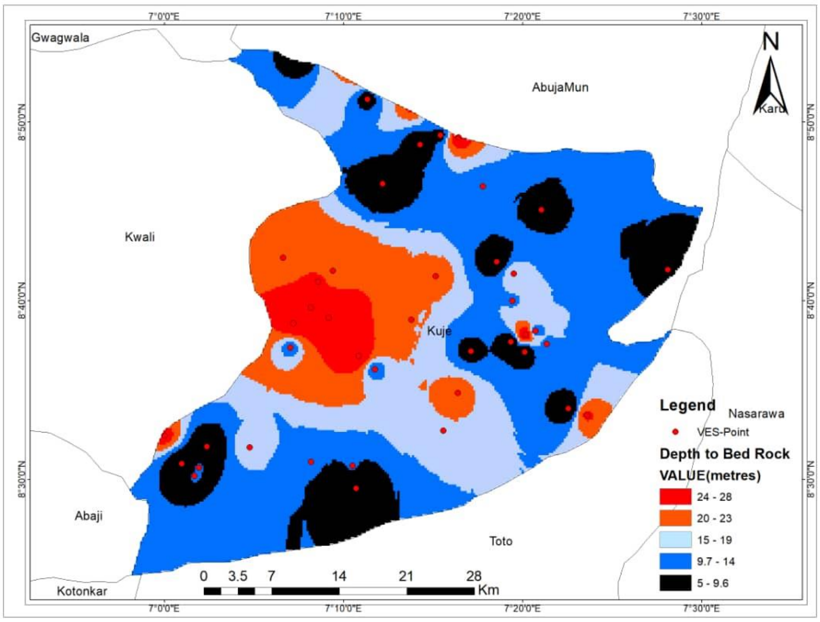

Figure 4.8 Depth to Bedrock Map of the Study Area

4.1.9 Aquifer's Resistivity

The aquifer's resistivity plays a significant role in determining a location's groundwater potential. Groundwater potential zones are characterized by low resistivity. Aquifer is defined as a rock formation which can yield sufficient quantities of water for use (Anwar *et al*., 2003). The weathered layer is the principal aquifer unit in the research area, and areas with fractured basements are an added advantage and are categorized as secondary aquifers in the area. Aquifers in basement complexes are characterized qualitatively as weathered fractured basement aquifers or partly weathered or fractured basement aquifers, and these classes are related to the subsurface layer's resistivity. The aquifers in the research area are partly weathered, weathered/fractured basement, and fresh fractured basement.

4.2 Geophysical Data Presentation and Interpretation

Electrical Survey are among the most difficult of all the geophysical methods to interpret quantitatively because of the complex theoretical basis of the technique. In resistivity interpretation, mathematical analysis is most highly developed for Vertical Electrical Sounding(VES), less well for ERP (Electrical resistivity profiling) over two dimensional structures and least well for ERP over three dimension bodies (Kerary, 1984). It is generally appreciated that sounding interpretation is influenced by electrical equivalence with several contrasting earth models fitting the same set of field data. Unlike in sedimentary formation the major source of ambiguity in basement terrains is not necessarily the total number of layers identifiable from the sounding data, instead it consist of different resistivity and thickness for the low resistivity, typically clay-rich weathered layer within the overburden (Olayinka, 1992). The VES data are presented as sounding curve plots of apparent resistivity (ρa) against electrode spacing. AB/2 on a log-log graph sheet.

4.2.1Vertical Electrical Sounding (VES) Interpretation

The VES data are presented as sounding curve plots of apparent resistivity (ρa) against electrode spacing. AB/2 on a log-log graph sheet. For this research Computer aided Interpretation was used for interpreting the VES data. Computer aided interpretation is usually based on the algorithm which employ digital linear filters for the fast computation of resistivity function for a given set of layer parameters. The electrical resistivity curves generated using computer aided interpretation of the field data is displayed in the form of Graphs and Numerals. Ten curve types exist in the study area, namely: H, HA, HKH, KH, A, AA, HKHKH, KHA, KHKH and QH. The KH, H and HKH VES curves are the predominant curve types as they account for 32%, 21% and 10%, respectively. The high degree of variation in curve types confirms the heterogeneity of the geology of a typical basement complex as shown in the Appendix.

4.2.2 Computer Aided Interpretation

Computer aided interpretation is usually based on the algorithm which employ digital linear filters for the fast computation of resistivity function for a given set of layer parameters. This technique involves seeking a solution to the inverse problem, namely the determination of the subsurface resistivity distribution from surface measurements. An important parameter in seeking a solution to the inverse problem is the Kernel function which is useful in interpreting apparent resistivity measurement in terms of lithological variation with depth. The function assumes the earth to be locally stratified in homogenous and isotropic layer and unlike apparent resistivity function, it is independent of electrode configuration it cannot be measured in the field but has to be obtained from transformation of measured electrical potential or apparent resistivity. The electrical resistivity curves generated using computer aided interpretation of the field data is displayed in the appendix.

4.3 Multi-Criteria Decision Analysis (MCDA)

The AHP is a multi-criteria decision making method for complex decision making by assessing multiple factors, which was first introduced by (Saaty, 1990). The GIS-based multi-criteria assessment applies to define the rates of various classes in each layer. Weights of each thematic layer are allocated according to its influence on groundwater potential and by considering Saaty's AHP method (Saaty 1980). In MCDA, weightage assignment for each influencing factor is applied by considering its practical role in a particular area (Chow & Sadler 2010; Agarwal & Garg 2016; Jhariya *et al.*, 2017; Murmu *et al.*, 2019). AHP is a subjective approach in which sub-unit selection and its weightage allocation are based on the comparison between various criteria derived from the appropriate strategy of decision-making proposed by Saaty (1980). The AHP method is applied according to the calculation of weightage from a preference matrix representing map layers. The weightage is generated by the comparison of relevant criteria based on preference factors.

4.3.1 Weight assignment using AHP and normalization

In AHP, decision-making functions through different processes such as division of different parameters, hierarchical arrangement, judgments based on the relative significance of a set of elements, and derivation of its results (Saaty 1999; Agarwal *et al.*, 2013). The AHP was first introduced by Saaty for solving a complex problem by splitting it into different categories and integrating each subsection to find out the big picture that has to be solved. In this study, seven thematic layers have been developed and their relationships are defined with the aid of the AHP. The steps involved in the derivation of weights of major thematic layers and their subclasses are shown below (Saaty 2001; Agarwal *et al.*, 2013; Kumar *et al.*, 2014; Jhariya *et al.*, 2016; Khan & Jhariya 2019; Murmu *et al.*, 2019). The first step involves the determination of the relative importance values. Saaty's 1–9 scale is the standard reference used for the finalization of relative important values (Table 2), in which the score of 1 represents two themes of equal importance, whereas 9 is an indicator of a highly important theme (Saaty 1980). In Saaty's AHP, a comparison of considered criteria of 'n' numbers to be done (in this case; Land Use Land Cover, Elevation, Geology, Slope, Lineament density, Drainage density, and Soil) were the criteria used and a square matrix of A = (aij) as developed.

Table 4.1 Saaty's 1-9 scale of relative importance (Saaty 1980)

Scale	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Importance	Equal Importance	Weak	Moderate	Strong	Strong	Strong	Very Strong	Very Very Strong	Extreme Imp

The obtained square matrix normalized through the pairwise comparison matrix is as follows;

A = a_{ij}

$$A = \begin{vmatrix} a11 & a21 \ldots.. & a1n \\ a12 & a22 \ldots.. & a2n \\ a13 & a23 \ldots.. & a3n \end{vmatrix} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.(1)$$

$A_{ij} = \sum a_{ij}$

I,j= 1,2,……..n

The calculation of eigenvalue and the eigenvector are as follows Eqns (2) and (3)

$$W = \begin{bmatrix} w1 \\ w2 \\ . \\ . \\ wn \end{bmatrix} \quad \text{and } w1 = \frac{\sum_1^n aij}{n} \quad \text{for I = 1, 2,……n}$$

$$Aw = \begin{bmatrix} w1 \\ w2 \\ . \\ . \\ wn \end{bmatrix} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

$$\lambda\text{max} = \frac{1}{n}\left(\frac{W1}{W1} + \frac{W2}{W2} + \cdots + \frac{Wn}{Wn}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(3)$$

where, W = eigenvector, w_i = eigenvalue of criterion i, and, λmax = eigenvalue of the pairwise comparison matrix.

Table 4.2 Pairwise Comparison Matrix between all criteria for AHP model

Criteria	Geology	LULC	Drainage Density	Lineament Density	Soil	Slope	Elevation
Geology	1	6	3	4	5	3	2
LULC	1/6	1	1	1/4	3	1/3	3
Drainage Density	1/3	1/3	1	2	3	1	5
Lineament Density	1/4	4	1/2	1	1	1/3	5
Soil	1/5	1/3	1/3	1	1	1/5	2
Slope	1/5	3	1	3	5	1	1
Elevation	1/2	1/3	1/5	1/5	1/2	1	1

The normalized pairwise comparison matrix is prepared by the division of each cell by the total of each column, and normalized weights are obtained for each factor by the average of each row shown in Table 4.3

Table 1.3 Normalized Pairwise Comparison matrix and weights of each criterion

Criteria	Geology	LULC	Drainage Density	Lineament Density	Soil	Slope	Elevation	Criteria Weight	Weighted Sum
Geology	0.38	0.40	0.43	0.35	0.27	0.44	0.11	0.340	2.587
LULC	0.06	0.07	0.14	0.02	0.16	0.05	0.16	0.094	0.667
Drainage Density	0.13	0.02	0.14	0.17	0.16	0.15	0.26	0.147	1.076
Lineament Density	0.09	0.27	0.07	0.09	0.05	0.05	0.26	0.126	0.902
Soil	0.08	0.02	0.05	0.09	0.05	0.03	0.11	0.061	0.441
Slope	0.08	0.20	0.14	0.26	0.27	0.15	0.05	0.164	1.219
Elevation	0.19	0.02	0.03	0.02	0.03	0.15	0.05	0.070	0.491

The judgment of uncertainty is based on Saaty's Consistency Index (CI),

$$\text{CI} = \frac{\lambda\text{max} - \text{n}}{n-1} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

where n represents the number of criteria or classes,

CI is the consistency index

λmax is the eigenvalue of the pairwise comparison matrix

Once the weights are assigned, it is required to calculate the consistency of the matrix; the consistency ratio judges it by the following equation developed by (Saaty, 1990).

$$CR = \frac{CI}{RI} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5)$$

Where; CR is the consistency ratio,

CI is the consistency index, and

RI is the random index taken from a table prepared by (Saaty, 1990).

The calculation based on the AHP method in this study has been conducted by considering different factors, such as n = number of factors involved (i.e., 7) and λ = average value of the consistency vector

$$\lambda max = \frac{7.61+7.10+7.32+7.16+7.23+7.43+7.02}{7}$$

$$\lambda max = \frac{50.87}{7} = 7.267$$

$$CI = \frac{\lambda max - n}{n-1}$$

$$CI = \frac{7.276-7}{7-1} = 0.046$$

$$CR = \frac{CI}{RI}$$

Where RI is the Ratio Index, the value of RI for selected ‘n’ value is given as 1.32 from Saaty’s ratio index for different values of ‘n’ (Saaty 1980)

$$CR = \frac{0.046}{1.32} = 0.03$$

According to (Saaty, 1990; Malczewski, 1999), the CR obtained must be less than 0.1. If it comes to greater than 0.1, then the pairwise comparison matrix should be readjusted by assigning different values to factors (Saaty, 1977). The CR of this study was found to be 0.03<0.1 which justifies the consistency of the matrix.

The weights of the different criteria are shown in Table 4.3. Finalized weights for Geology, LULC, Drainage Density, Lineament Density, Soil, Slope, and Elevation are 0.34, 0.094, 0.147, 0.126, 0.061, 0.164 and 0.070 respectively.

All the criteria were classified into sub-classes and were ranked based on their impact on groundwater activities as shown in Table 4.4.

Table 4.4 Assigned normalized weights and ranks for all criteria

Criteria	Class	Rank (Very-High=5, Low=1)	Weightage (%)
Geology	Cretaceous	4	**34%**
	Precambrian	5	
Lulc	Outcrop	1	**9.4&**
	Water Body	2	
	Built-Up	3	
	Vegetation	5	
	Bare-Surface	4	
Drainage Density	Very-High	5	**14.7%**
	High	4	
	Moderate	3	
	Low	2	
	Very-Low	1	
Lineament Density	Very-High	5	**12.6%**
	High	4	
	Moderate	3	
	Low	2	
	Very-Low	1	
Soil	Clay	5	**6.1%**
	Silt	4	
	Silt-Clay	2	
Slope	Very-High	5	**16.4%**
	High	4	
	Moderate	3	
	Low	2	
	Very-Low	1	
Elevation	Very-High	5	**7%**
	High	4	
	Moderate	3	
	Low	2	
	Very-Low	1	

4.3.2 Groundwater potential map

The seven thematic layers were created in ArcGIS 10.5 environment, and the appropriated ranks and weights determined by the AHP technique were assigned to them for the weighted overlay analysis process. The result obtained were categorized into five classes from very low potential zone to very high potential zone based on index value calculated using the equation below.

$$GWPZ = [(LDw * LDwi) + (SLw * SLwi) + (DDw * DDwi) + (LUw * LUwi) + (STw * STwi) + (TEw * TEwi) + (Gw * Gwi)] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(6)$$

where;

LD= Lineament Density, SL=Slope, DD= Drainage Density, LU= Landuse land cover, ST= Soil Type, TE= Topographic Elevation, G= Geology

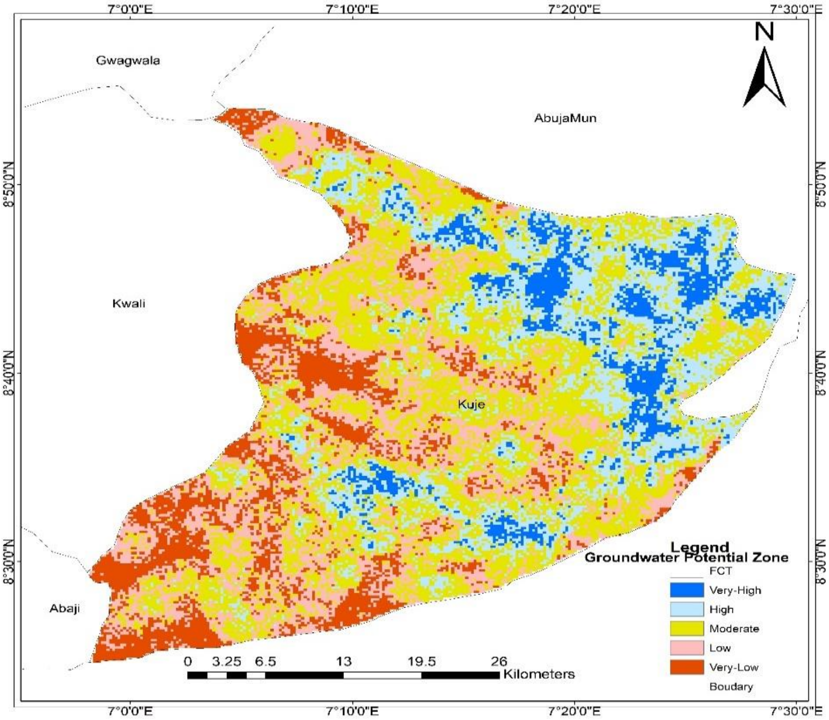

Figure 4.9 Groundwater Potential Map of the Study Area

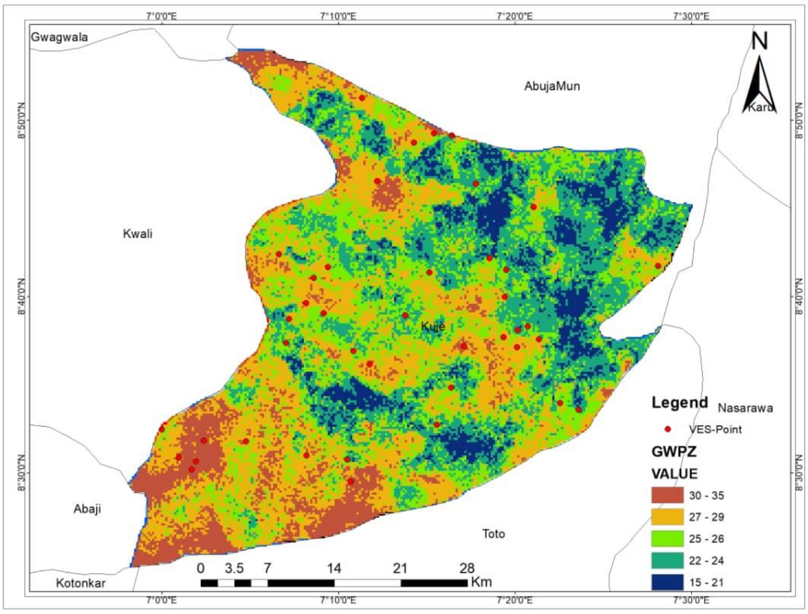

Figure 4.9.1 Groundwater Potential Zone Map overlaid with the Depth to Bedrock of the Study Area

4.3.3 Statistical Analysis

The results obtained were grouped into five classes. Very high potential category covering about 8% of the total area, high potential for groundwater covers about 20%. The moderate zones were about 34%, low and very low category of the potential zone with an area covering 23% and 14% of the total area respectively. The result indicates that the larger chunk of the study area has moderate groundwater potential.

Table 4.5 Groundwater Potential Zones and their area coverage

Zones	AREA(Sqkm)	AREA (%)
Very-High	134.4489	8%
High	344.7669	20%
Moderate	577.9296	34%
Low	392.6755	23%
Very-Low	236.1437	14%
TOTAL	1685.965	100%

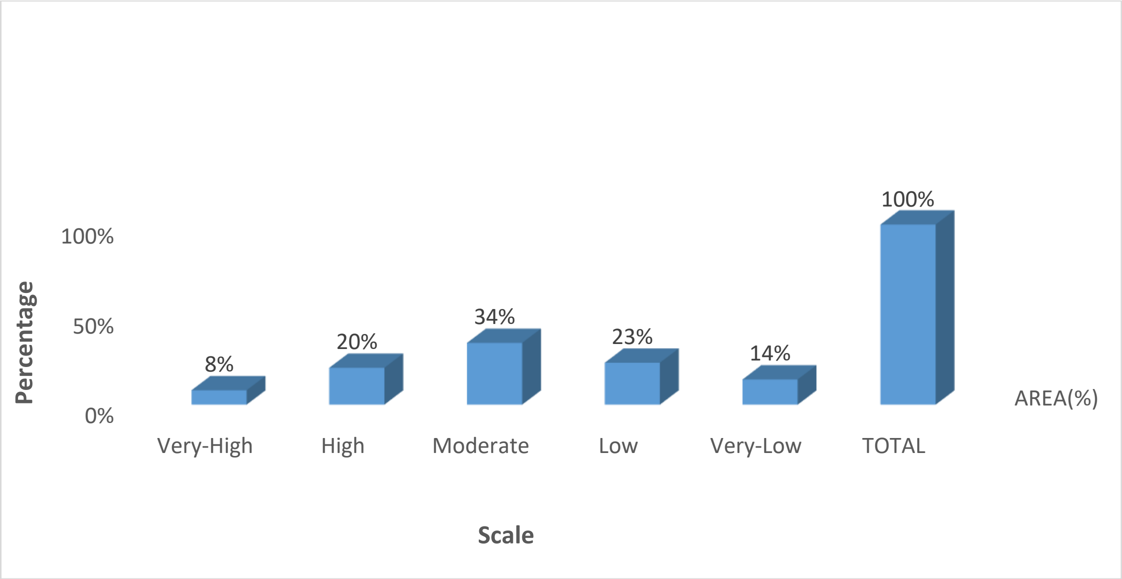

Figure 4.10 Graphical Representation of Groundwater Potential Zone in Kuje, Abuja, Nigeria

4.4 Summary of Findings

A summary of the findings of the study consist the following;

1) The findings from the multi-criteria decision analysis approach shows that based on the different weightage criteria's used for the determination of groundwater potential zones of the study area Geology (34%) is considered to be the major influencing factor that plays a practical role in the groundwater potentiality in the study area. The rocks or lithological units of the study area and their interaction determines the area's total infiltration capacity.
2) The depth to bedrock in Figure 4.8 shows areas with heavy overburden have very high to moderate groundwater potential as shown in Figure 4.9.1, particularly in basement complex terrain which the study area falls in. Deeper overburden shows high weathering and high fractures which means high groundwater potential zones.
3) The overall map has been classified into five major classes very low (14%), low (23%), moderate (34%), high (20%) and very high (8%) groundwater potential zones in Figure 4.9.
4) Result shows that the moderate groundwater potential zones covers the largest percentage (34%) 577.9296km^2 of the study area.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This study has demonstrated the effectiveness of the use Multi-Criteria Decision analysis (MCDA) technique to evaluate and identify probable groundwater potential zones. Different steps chosen for the study include the development of the thematic layer such as (Geology, LULC, Slope, Lineament, Drainage Density, Elevation and Soil) followed by the appointment of weight for each influencing factor with the help of the AHP method and, lastly, overlay analysis for the demarcation of groundwater potential zone.

The results obtained were grouped into five classes. Very high groundwater potential category covers about 8% of the total study area, High groundwater potential area covers about 20%. The moderate groundwater potential zones covers the largest part of the study area which is about 34%; Low and Very low category of the potential zone covers 23% and 14% of the total area respectively. In relation to field geology and geophysical investigation, areas of low potential and medium potential are characterized by clayey sand overburden and weathered/fractured while zones of high groundwater potential are characterized by basement aquifers.

Derived groundwater potential results from the integrated operation of various factors such as slope, lineament, drainage density, LULC and soil patterns, including the elevation and geological control revealed that the Geology plays a major role in the groundwater potential of the area.

The results verification clearly shows the efficiency of the MCDA approach incorporated in this research as a useful tool for identification of suitable locations for groundwater extraction, proper management and sustainable development. However, it is perceived that the current methodology can be used as a prospective guideline for groundwater exploration and exploitation in both hard and soft rock terrains

5.2 Recommendation

It is recommended that groundwater prospects mapping using MCDA approach should be adapted in helping the field geologists to quickly identify the prospective groundwater zones for conducting site specific investigations and reasonably thus, significantly scaling down scope of search. The need for borehole drillers including government agencies to preserve information such as pumping test data cannot be overemphasized, because it will aid groundwater exploration by giving empirical evidence of the groundwater potential of an area.

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