GROUNDWATER POTENTIAL ZONE MAPPING OF LANIBA, AKINYELE LOCAL GOVERNMENT AREA OF IBADAN, OYO STATE USING GEOSPATIAL MULTI-CRITERIA ANALYSIS AND HYDROGEOPHYSICS.

BY

ANIFOWOSHE OLAMIDE ESTHER

140405004

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SUPERVISED BY

DR. E.E. EPUH

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CERTIFICATION

This is to certify that I, **ANIFOWOSHE OLAMIDE E**, of matric number 140405004 of the department of Surveying and Geoinformatics Engineering, University of Lagos, carefully and judiciously carried out this project in partial fulfilment of the requirements for the award of Bachelor of Science (B.Sc.) degree in Surveying and Geoinformatics Engineering, University of Lagos.

ANIFOWOSHE OLAMIDE E. **DATE**

(STUDENT)

DR. E.E. EPUH **DATE**

(PROJECT SUPERSIVOR)

DEDICATION

I dedicate this paper to Almighty God, the entirely merciful, for His abundant grace and guidance bestowed upon me throughout the period of executing this project.

I also dedicate this paper to my ever loving Mother for her relentless and consistent support during the course of this project.

ACKNOWLEDGEMENT

I am grateful to God Almighty for his grace upon my life to have gotten the time, good health and strength for the successful completion of my project.

Firstly, I would like to honor and appreciate the distinguished Prof. P.C Nwilo the amiable head of the department.

I also value the immense support of my Project supervisor Dr. E.E Epuh, for his guidance, wisdom and direction before and during the course of this project. Thank you, Sir.

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ABSTRACT

With the increase in population of Akinyele local government area, the necessity to provide water to the populace has become a disturbing problem. In this study, a systematic approach to delineate the groundwater potential zones of the area was carried out using Remote Sensing, Geographic Information Systems (GIS) and Hydrogeophysics as a tool. Vertical Electrical Sounding (VES) observations were also carried out to validate the results obtained from the integrated remote sensing and GIS observation and also determine the aquifer depth and possible pollution. The various thematic maps such as: soil map, land use/Land, geological map, rainfall map, lineaments map were obtained from enhanced satellite imagery and Slope map was generated from Shuttle Radar Topographic Mission elevation model (SRTM DEM). These maps were overlaid in terms of weighed overlay method using Spatial Analysis tool in Arc GIS. During weighed overlay analysis, different ranks were given to each individual parameter of each thematic map and weights were assigned according to their influence. The groundwater potential map obtained from the study area showed that 27% of the total study area lie within the "very high" potential zone, 23% of the area falls within the "high", 20% lies within the of "moderate" zone, 17% lies within the "low" potential zone while 13% lies within the very low potential zone

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CHAPTER ONE

INTRODUCTION

1.0 BACKGROUND STUDY

Access to safe drinking water is indicated by the number of people using proper sanitary sources, (Wikipedia, 2008). These improved drinking water sources include household connection, public standing pipe, borehole condition, protected dug wells, protected springs, and rain water collection, (Aderogba, 1999 and 2005 and Wikipedia, 2008). However, the success of groundwater development programme is predicated on good understanding of the geomorphological, geological, hydrogeological and geophysical characteristics of the basement complex terrain. These characteristics are required for the assessment of the groundwater potential. Groundwater investigation is therefore often multidisciplinary in approach and could involve terrain analysis, geology/hydrogeology, remote sensing and geophysics.

Groundwater has become immensely important for the different water supply purposes in urban and rural areas of both the developed and developing countries (Al-garni, 2009). However, groundwater exploration in hard rock terrain is a very challenging and difficult task, if the promising groundwater zones are associated with fractured and fissured media (Venkata, et al. 2014). In such an environment, the groundwater potentiality depends mainly on the thickness of the weathered/ fractured layer overlying the basement. Groundwater can be explored using different methods. The four major groundwater exploration methods are the areal method, surface method, subsurface method and esoteric methods. Among these methods, esoteric method is not based on science, mostly based on traditional indicators. Each of the above listed groundwater exploration methods have different sub-methods under them. Geophysical survey is therefore one of the sub-methods under the surface method of groundwater exploration (Al-garni, 2009). This method is very important for both groundwater resource mapping and water quality evaluations (Al-garni, 2009). Its application for groundwater exploration purposes has increased over the last few years due to the rapid advances in computer packages and associated numerical modeling solutions (Venkata, et al. 2014).

Subsurface water is the fraction of total precipitation which infiltrates the ground and fills the voids in the rock or unconsolidated materials. The origin of groundwater was not clearly established until by the later part of the seventeenth century. A French hydrologist, Pierre Perrault, from the result of hydrologic investigations in the basins of Seine river was the first to prove that the water contained within earth was not drawn up from the oceans but rather was provided by rainfall and snowmelt. In his assertion, about 97% of all water is contained within the ocean basins while of the 3% outside the basins; nearly 80% is contained within the glacier and polar ice. About 0.7% is represented by the more visible surface accumulations of water and 20% of all the water outside the ocean basins resides underground. Hydrologists also estimate that more than about 8 million cubic kilometers of water exist below the earth's surface as groundwater (Renton, 1994).

Remote sensing and geographical information system (GIS) has become one of the leading tools in the field of groundwater research, which helps in assessing, monitoring, and conserving groundwater resources. This paper mainly deals with the integrated approach of remote sensing and GIS to delineate groundwater potential zones. Digitized vector maps pertaining to chosen parameters, viz. geomorphology, geology, land use/land cover, lineament, relief, and drainage, were converted to raster data. Moreove3r, curvature of the study area was also considered while manipulating the spatial data. The raster maps of these parameters were assigned to their respective theme weight and class weights. The individual theme weight was multiplied by its respective class weight and then all the raster thematic layers were aggregated in a linear combination equation in Arc Map GIS Raster Calculator module. Moreover, the weighted layers were statistically modelled to get the areal extent of groundwater prospects with respect to each thematic layer. The final result depicts the favourable prospective zones in the study area and can be helpful in better planning and management of groundwater resources especially in hard rock terrains.

The area under study (Laniba) being a developing residential area with good surface sandy and laterite soil and considerable distance to the road needs all the amenities and infrastructures required to make the habitation conducive. Unfortunately there is no public water supply to the inhabitant but they depend on personal effort for domestic use, and can sometimes be inaccessible through digging of wells and sinking of boreholes which could be as a result of inadequate information from the subsurface or lack of technical "know how" among others which this research work stand to address. Since the area is developing and human habitation is springing up, the study therefore seeks to provide good portable water site for human and industrial use, also knowing the best possible location for sinking boreholes in order to access the quality and quantity of underground water.

1.1 PROBLEM STATEMENT

There is always a need to determine the depth at which boreholes can be drilled to obtain portable water used for various functions due to the different lithology of various areas around the world. The need to determine the subsurface lithology which will help delineate depth to which boreholes can be drilled is of great importance. There is therefore the need for detailed assessment of the groundwater potential using integrated hydro geomorphological, geological/hydrogeological (involving recent satellite imageries covering the study area) and geophysical data acquired across the study area.

1.2 AIM OF THE PROJECT

The aim of the project is to determine and delineate groundwater potentials in Oyo State, Laniba Akinyele LGA using the application of remote sensing, GIS, and Hydro geophysical approach.

1.3 OBJECTIVES OF THE PROJECT

- Digitizing the map of Laniba Akinyele LGA, Oyo State showing the various groundwater potentials using the application of GIS.
- To prepare other thematic layers required for ground water delineation, such as Soil, Geology, Slope, Rainfall, Land Cover, and Lineament density layer based on existing datasets.
- Identification of the wells, boreholes and estimating the VES locations within the study area by integrating the thematic layers with the use of GIS techniques
- To know the quality of groundwater (fresh, salty, heavily mineralized, contaminated)
- Application of GIS in the analysis of these hydrogeophysical, geological, characteristics

1.4 DESCRIPTION OF THE STUDY AREA

The study area Laniba is located in the north eastern part of Ibadan, southwestern Nigeria within longitude E3° 52' 24.6" and E3° 52' 59.3" and latitude N7° 28' 44.7" and N7° 28' 59.6". Laniba an area of about 150km square including the catchment area. The elevation ranging from 221m to 241m above sea level and surrounded by quartzite ridge hills towards north.

The area, falls under tropical hinter land climatic zone (about 150 km - 240km northward from the coast) with 1000 to 1500mm annual rainfall, temperature range of 21-25°C and relative humidity range of 50-80%, the dry season range from 4-5 months between November to March, with December to January characterized by NE-SW dry Cold and dusty harmattan wind from the Sahara desert. For the study area Laniba, the hilly quartzite ridges are covered by forest, while the lowland area is dominated by light forest about one kilometer (1 km).

1.5 SIGNIFICANCE OF STUDY

The importance of this study is to map the groundwater potential zones in Lamina Akinyele LGA, Oyo State and assess the contributing factors for exploration of potential groundwater resources. Remote sensing data and geographic information system will be used to locate potential zones for groundwater. Various maps (i.e. base, soil, geological, hydro-geological, geomorphologic map, structural, drainage, slope, land use/land cover and average annual rainfall map) will be prepared based on geospatial techniques. The groundwater availability of the basin will qualitatively classified into different classes based on its hydro-geo-morphological conditions.

1.6 SCOPE OF WORK

The study will focus on the application of VES (Vertical Electrical Sounding) in–order to delineate the geoelectic sequence beneath the VES stations but more importantly the evaluating the ground water potential of the area and also to determine the feasibility of groundwater development in the community. It entails getting a map of the study area, digitizing the locations for potential zones for groundwater using remote sensing and GIS techniques, calculation of groundwater balance and analyzing the hydro geophysical, geological characteristics. The result of the survey will be interpreted and will go a long way to recommend appropriate depth for borehole drillings.

CHAPTER TWO

LITERATURE REVIEW

2.0 THEORETICAL FRAMEWORK OF THE STUDY

Groundwater, water that occurs below the surface of Earth, where it occupies all or part of the void spaces in soils or geologic strata. It is also called subsurface water to distinguish it from surface water, which is found in large bodies like the oceans or lakes or which flows overland in streams. Both surface and subsurface water are related through the hydrologic cycle (the continuous circulation of water in the Earth-atmosphere system).

Most groundwater comes from precipitation. Precipitation infiltrates below the ground surface into the soil zone. When the soil zone becomes saturated, water percolates downward. A zone of saturation occurs where all the interstices are filled with water. There is also a zone of aeration where the interstices are occupied partially by water and partially by air. Groundwater continues to descend until, at some depth, it merges into a zone of dense rock. Water is contained in the pores of such rocks, but the pores are not connected and water will not migrate. The process of precipitation replenishing the groundwater supply is known as recharge. In general, recharge occurs only during the rainy season in tropical climates or during winter in temperate climates. Typically, 10 to 20 percent of the precipitation that falls to the Earth enters water-bearing strata, which are known as aquifers.

Groundwater is constantly in motion. Compared to surface water, it moves very slowly, the actual rate dependent on the transmissivity and storage capacity of the aquifer. Natural outflows of groundwater take place through springs and riverbeds when the groundwater pressure is higher than atmospheric pressure in the vicinity of the ground surface. Internal circulation is not easily determined, but near the water table the average cycling time of water may be a year or less, while in deep aquifers it may be as long as thousands of years.

Groundwater plays a vital role in the development of arid and semiarid zones, sometimes supporting vast agricultural and industrial enterprises that could not otherwise exist. It is particularly fortunate that aquifers antedating the formation of deserts remain unaffected by increases in aridity with the passage of time. Withdrawal, however, will deplete even the largest of groundwater basins so that development based on the existence of aquifers can be only temporary at best.

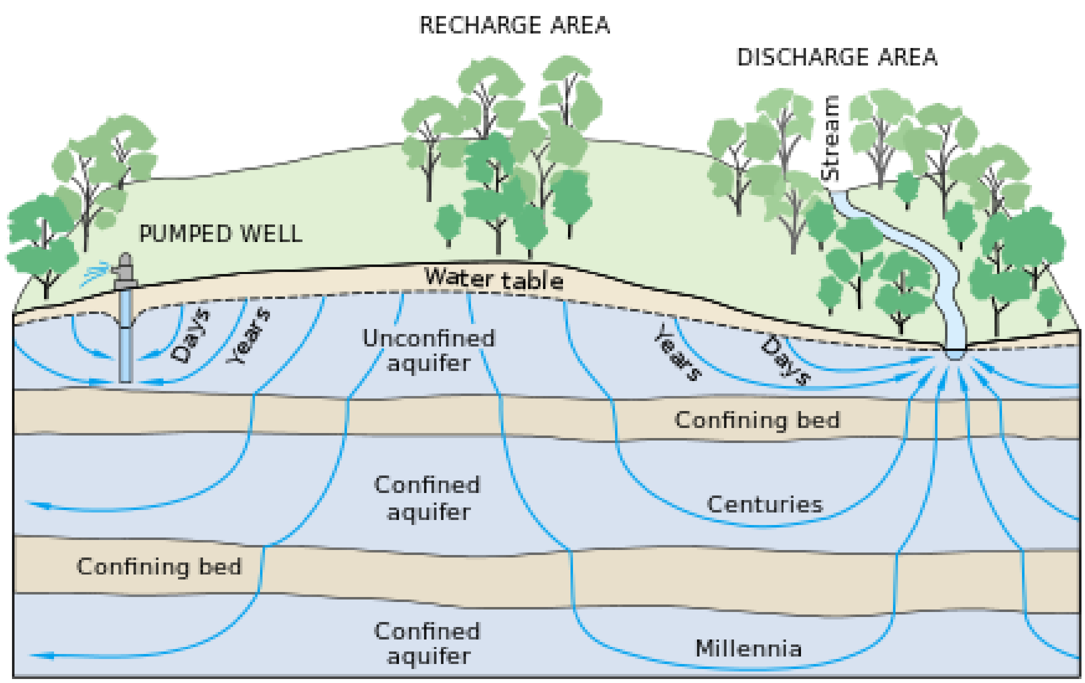

Figure 2.1: Water Cycle (Wikipedia, 2018)

A vast amount of groundwater is distributed throughout the world, and a large number of groundwater reservoirs are still underdeveloped or uninvestigated. Scientists estimate that some 5.97 quintillion gallons (22.6 million cubic km [5.4 million cubic miles]) of groundwater reside in the upper 2 km (1.2 miles) of Earth’s surface. The most frequently investigated or exploited groundwater reservoirs are of the unconsolidated clastic (mainly sand and gravel) or carbonate hard rock type found in alluvial valleys and coastal plains under temperate or arid conditions. Though some groundwater dissolves substances from rocks and may contain traces of old seawater, most groundwater is free of pathogenic organisms, and purification for domestic or industrial use is not necessary. Furthermore, groundwater supplies are not seriously affected by short droughts and are available in many areas that do not have dependable surface water supplies. However, aquifers and other groundwater supplies are at risk of chemical pollution from fracking, agricultural chemicals, leaking or unfit landfills and septic tanks, and other point and nonpoint sources of pollution. Such contamination can render groundwater unfit for use and is expensive and difficult to clean up.

Polluted groundwater is less visible, but more difficult to clean up, than pollution in rivers and lakes (Hassan, 2008). Groundwater pollution most often results from improper disposal of wastes on land. Major sources include industrial and household chemicals and garbage landfills, excessive fertilizers and pesticides used in agriculture, industrial waste lagoons, tailings and process wastewater from mines, industrial fracking, oil field brine pits, leaking underground oil storage tanks and pipelines, sewage sludge and septic systems.

Increasing population and water scarcity have raised the importance of groundwater zones, as they are a major source of freshwater. Integrated remote sensing and GIS are widely used in groundwater mapping. Locating potential groundwater targets is becoming more convenient and cost-effective with the advent of a number of satellite imageries. Remotely sensed based groundwater exploration has made it feasible to explore the areas with limited human access, for the wide visual range, short time cycle, and increasing spatial resolution.

Aquifers

An aquifer is an underground layer of water-bearing permeable rock or unconsolidated materials (gravel, sand, silt or clay) from which groundwater can be usefully extracted using water well. Imagine if all of the water that fell onto the location where you lived in a single year stayed right where it landed. Everyone would be wading through water higher than their waists! Fortunately, the precipitation runs into lakes, rivers, oceans, or into underground storage areas called aquifers.

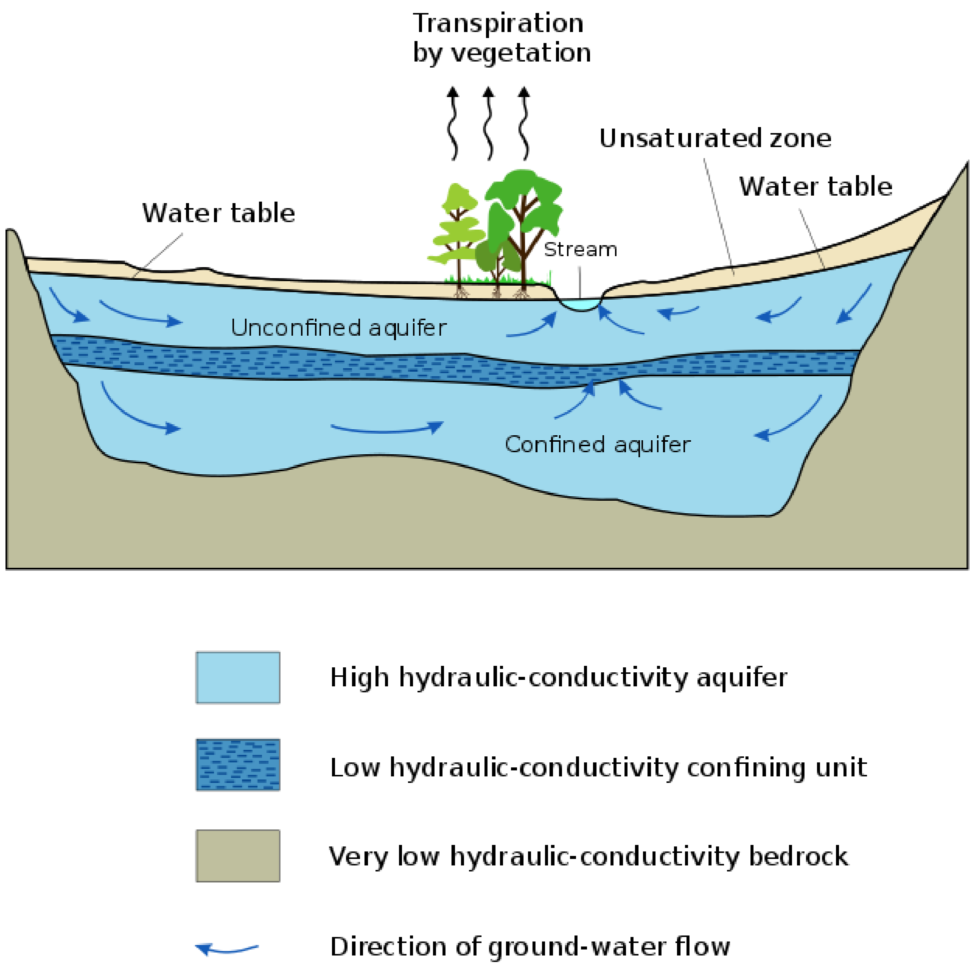

Figure 1.2: Aquifer (Wikipedia, 2018)

Water movement in aquifers is highly dependent of the pearmeablility of the aquifer material. Permeable material contains interconnected cracks or spaces that are both numerous enough and large enough to allow water to move freely. In some permeable materials groundwater may move several meters in a day; in other places, it moves only a few centimetres in a century. Groundwater moves very slowly through relatively impermeable materials such as clay and shale

Aquifer can be broadly categorized into two; confined and unconfined aquifers. Confined aquifer is one which is completely filled with water under confining pressure and which is overlain by a relatively impermeable layer called aquitard. Water rises up a well drilled into confined aquifer owing to the fact that the water is under pressure. The level at which the water stands in the well defines an imaginary surface called the potentiometric surface whose height above the aquifer depends on the confining pressure in the aquifer. An artesan well develops when the potentiometric surface rises above the ground level (Ugwuanyi, 2010).

An unconfined aquifer is one in which water table condition prevails owing to the absence of layer of relatively impermeable material on top. The conditions for the formation of unconfined aquifer are specific. First, there is no impermeable confining bed. Secondly, the water in the aquifer is not under pressure. Thirdly, an unconfined aquifer is rapidly recharged by precipitation hence, it has rising and falling water table according to the seasons. Hanging or perched aquifer also exists. This occurs when a relatively impermeable layer occurs above the water table and holds up infiltrating water to form a saturated lens of limited extent above the saturated zone of the aquifer (Ugwuanyi, Johnson C, & Obiora, 2015)

The volume of groundwater in an aquifer can be estimated by measuring water levels in local wells and by examining geologic records from well-drilling to determine the extent, depth and thickness of water-bearing sediments and rocks. Before an investment is made in production wells, test wells may be drilled to measure the depths at which water is encountered and collect samples of soils, rock and water for laboratory analyses. Pumping tests can be performed in test wells to determine flow characteristics of the aquifer.

Subsidence

Subsidence occurs when too much water is pumped out from underground, deflating the space below the above-surface, and thus causing the ground to collapse. The result can look like craters on plots of land. This occurs because, in its natural equilibrium state, the hydraulic pressure of groundwater in the pore spaces of the aquifer and the aquitard supports some of the weight of the overlying sediments (Ludwig et al., 1993). When groundwater is removed from aquifers by excessive pumping, pore pressures in the aquifer drop and compression of the aquifer may occur. This compression may be partially recoverable if pressures rebound, but much of it is not. When the aquifer gets compressed, it may cause land subsidence, a drop in the ground surface. The city of New Orleans, Louisiana is actually below sea level today, and its subsidence is partly caused by removal of groundwater from the various aquifer/aquitard systems beneath it.

2.1 GEOLOGY OF IBADAN, OYO STATE

Geology plays vital importance in groundwater occurrence in any given location. The type of rock in an area is an important factor governing the characteristics of its groundwater. Basement complex rocks, composed mainly of metamorphic and igneous rock types are relatively low in groundwater production in comparison with sedimentary rock areas to the south. The basement complex nature of the rocks in Ibadan does not however completely rule out the possibility of the presence of isolated good and productive aquifers, if proper searching is carried out. The factors which account for the presence of good aquifers in particular locations over the basement complex rocks are the thickness of the regolith (weathered layer), the size and density of fractures, fissures and other cracks, and the permeability and porosity of the rocks. Ibadan is located near the forest grass-land boundary of South-western Nigeria (Amanambu, Ojo Kolawole 2013).

The latitudinal location (07° 26’N) of Ibadan means it enjoys the characteristic West African monsoon climate, marked by a distinct seasonal shift in the wind pattern. It therefore means that the climate of Ibadan is tropical with distinct wet and dry seasons and a mean annual temperature of 27.1°C (Egbinola, Amanambu 2013) but in consonance with seasonal variations in radiation, sunshine and cloud cover, the mean annual temperature could change. Between March and October, the city is under the influence of the moist maritime. South-west monsoon winds, which blow inland from the Atlantic Ocean. This is the rainy season. The dry season occurs from November to February, when the dry dust-laden winds blow from the Sahara desert.

Below is the Geological Map of Nigeria and Oyo state are shown on Figures 2.1a and 2.1b respectively

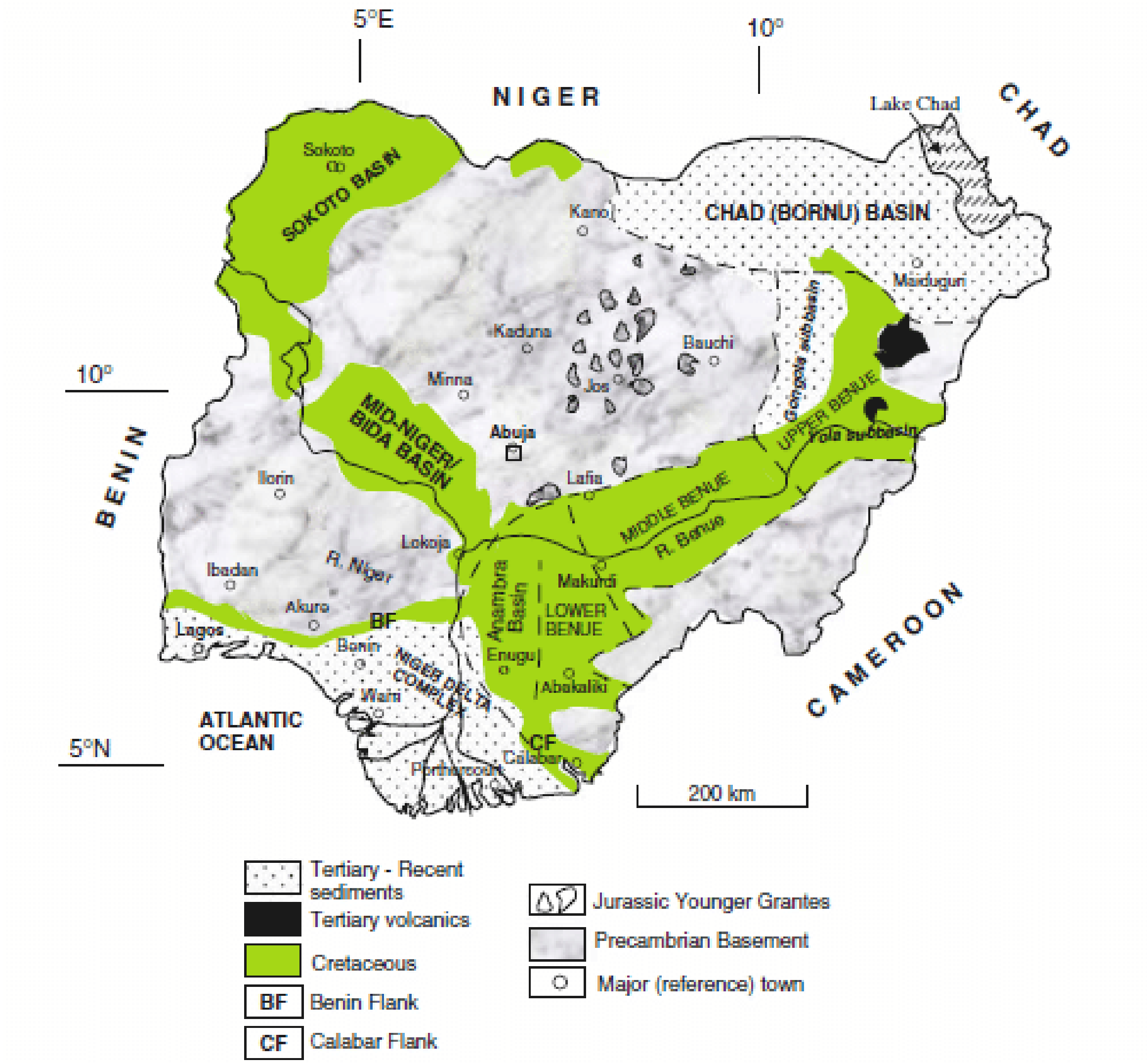

Figure 2.2: Geological Map of Nigeria (Obaje, 2009)

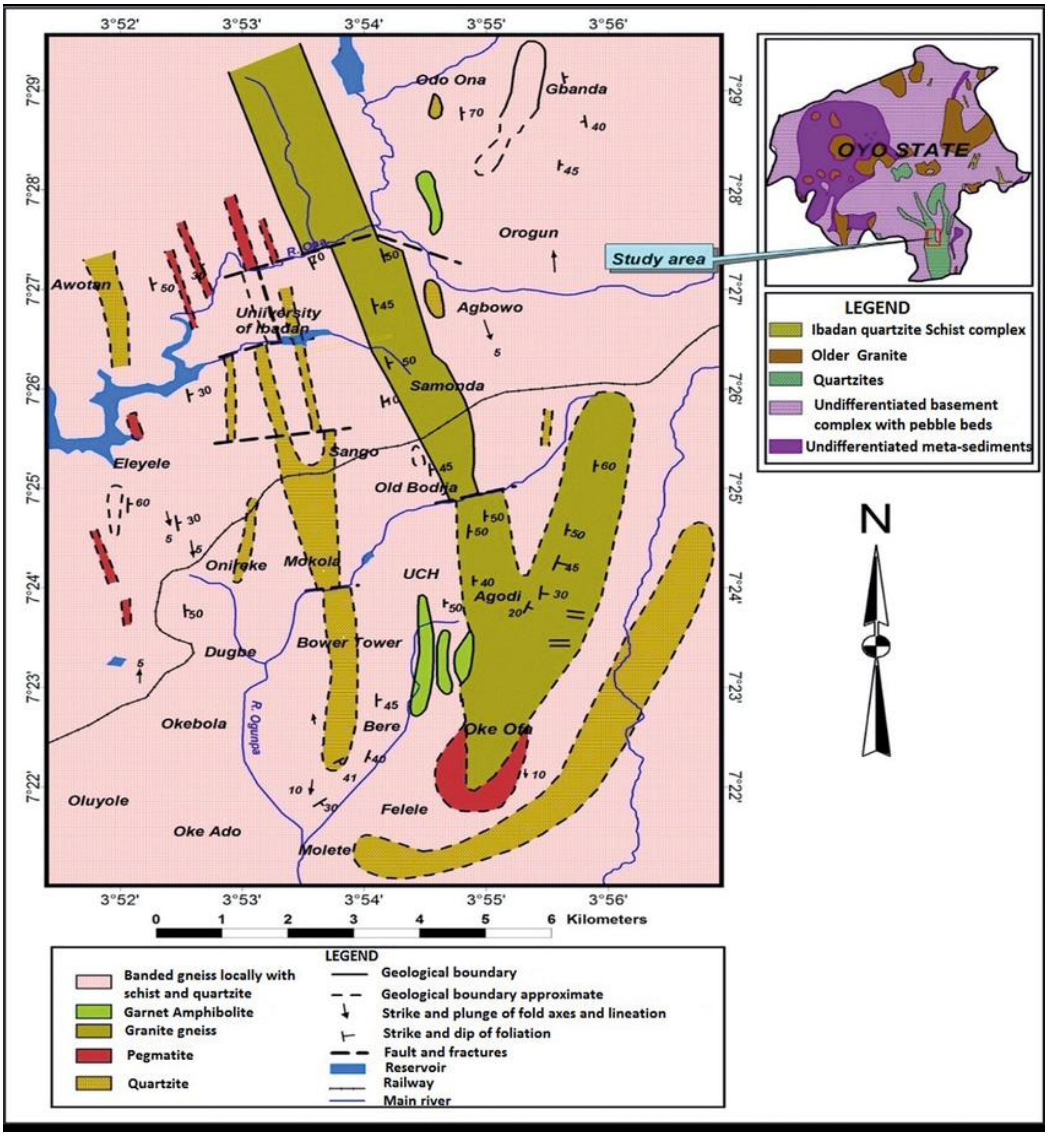

Figure 2.3: Geology Map of Oyo State showing the geology of Ibadan (Amanambu 2013)

2.2 HYDRO-GEOPHYSICAL METHODS FOR GROUNDWATER EXPLORATION

Groundwater exploration is a typical task of a hydrogeologist or an engineer. Identifying the location of its availability is a challenging task. Exploration of groundwater requires a basic understanding of its position in the subsurface geological setup. Groundwater Exploration is attempted through either by direct or indirect methods. Test drilling is the direct approach to find out the resource. This is an expensive affair. Every individual cannot go for test drilling. During the last two centuries, more and more techniques have been developed to explore the groundwater. They are classified into surface and sub-surface methods.

2.2.1 SURFACE METHODS

The surface methods are easy to operate and implement. These require minimum facilities like topo-sheets, maps, reports, some field measurements and interpretations of data in the laboratories. The surface methods of groundwater exploration include

- Esoteric Methods
- Geomorphologic methods
- Geological and structural methods
- Soil and micro-biological methods
- Remote Sensing techniques
- Surface geophysical methods

2.2.2 SUBSURFACE METHODS

The subsurface methods of groundwater exploration includes both Test Drilling and Borehole Geophysical Logging techniques. When compared to the surface methods, the subsurface methods are very expensive. These are done for government level projects where large scale investigations are carried out to ascertain the results of surface surveys. The subsurface methods are very accurate methods as the help in direct observations of features in the form of bore-hole lithology as core samples and also geophysical measurements of formation properties**.**

2.2.3 ESOTERIC METHODS

The Esoteric methods are the ancient methods. These are the oldest water divining methods practiced by ancient people for several centuries. They are also called as water-dowsing. People believed that the flow of groundwater can induce some vital currents above the surface. When a wet plant twig is moved above such zones, it tends to rotate the twig as well. Wet twigs of trees, husk-removed coconuts, watches and other materials have been used as dowsing materials. The person handling the twig has some role of induction and hence it is not applicable to everybody attempting to divine water. All these methods have been practiced since 17th century. There is no scientific explanation available with reference to these approaches. Probability of success is a mere coin-tossing experiment. These methods are called as water divining.

2.2.4 WATER WITCHING

Water witching is a traditional method adopted by people to detect bore-well locations. Using a forked stick to locate water source is known as water witching. Although this method is lacking any scientific justification for the method, water witches diligently practice the art wherever people can be persuaded of its potential value. Commonly, the method consists of holding a forked stick in both hands and walking over the local area until the butt end is attracted downward-ostensibly by subsurface water. It is amazing that the idea of supernatural powers has such a continued fascination for people to use despite its limitations.

2.2.5 GEOMORPHOLOGIC METHODS

Surface drainage is the subdued replica of topography. It is controlled by the basement rocks. Mostly, groundwater flow coincides with the surface drainages. The streams and water courses may also be controlled by some underlying structures. Junctions of streams at the down slopes are promising zones for groundwater. Landforms originate due to several geological processes. Some of them are likely to contain relatively permeable strata. River-borne modern alluvial terraces, floodplains, stratified valley-fill deposits in abandoned channels, glacial outwash and moraine deposits are good landforms for groundwater. Alluvial fans, beach ridges, partly drift-filled valleys, sand dunes, moist depressions, and marshy environments are good localities.

2.2.6 STUDY OF LAND FORMS

Landforms are the likely indicators to show the relatively permeable strata. The locations of modern alluvial terraces and floodplains, stratified valley-fill deposits, glacial outwash plains, glacial deltas, kames, moraine complexes, eskers, alluvial fans and beach ridges are good locations for groundwater occurrence. Partly drift-filled valleys marked by a chain of elongate closed depressions, largely masked bedrock valleys cutting across modern valleys that are indicated by local non-slumping of weak shale strata in valley sides, sand dunes assumed to overlie sandy glacio-fluvial sediments, nearby locations of lakes and streams are very good indicators for groundwater prospecting.

2.2.7 GEOLOGICAL METHODS

A geologic investigation begins with the collection, analysis, and hydrogeologic interpretation of existing topographic maps, aerial photographs, geologic maps and logs, and other pertinent records. This should be supplemented, when possible, by geologic field reconnaissance and by evaluation of available hydrologic data on stream flow and springs, well yields, groundwater 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 potential exploration. These are the conduits for groundwater flow

2.2.7 STRUCTURAL METHODS

Contact points between permeable water-bearing strata overlying relatively impermeable strata-usually along the sides of valleys that cut across the interface between different strata are suitable locations for groundwater. Springs occurring on or near the base of hillsides, valley slopes, and local scarps are indicators of groundwater occurrence over hilly terrain. Dykes are good barriers for arresting the flow of groundwater. Location of dykes and analyzing their dip and strike help in selecting the groundwater potential zones in the upstream side.

2.2.8 SOIL AND MICRO BIOLOGICAL METHODS

Geo-botanical indicators are valuable tools in groundwater exploration. The anomalous growth of vegetation and alignment of big trees on a straight line, growth of termite mounds and location of age old, deep rooted heritage trees can indicate the occurrence of groundwater at shallow depths. Presence of Halophytes, plants with a high tolerance for soluble salts, and white efflorescence of salt at ground surface, indicate the presence of shallow brackish or saline groundwater. Xerophytes, the well-known desert plants, subsisting on minimal water, suggest a considerable depth to the water table. All these are supplementary tools in detecting the locations of groundwater zones.

2.3 REMOTE SENSING TECHNIQUES

Remote sensing is the science (and to some extent, art) of acquiring information about the Earth's surface without actually being in contact with it. This is done by sensing and recording reflected or emitted energy and processing, analyzing, and applying that information. In much of remote sensing, the process involves an interaction between incident radiation and the targets of interest. Remote sensing shows an increasing role in the field of hydrology and water resources development. Remote sensing provides multi-spectral, multi-temporal and multi-sensor data of the earth’s surface which are suitable for mineral explorations, water resources evaluation, environmental monitoring and groundwater targeting. Remote sensing helps in the demarcation of groundwater potential zones, identification of groundwater recharge sites and, to analysis the future artificial recharge sites.

2.3.1 APPLICATIONS OF REMOTE SENSING

Satellite data products are much varied depending upon the spectra considered. The high resolution satellite images are interpreted (visually or digitally) to identify the groundwater potential zones. Thematic layers are prepared based on hydrogeomorphic units, land-use/ land-cover/ lineaments, rock types, structures and many other features. The methodology involves the delineation of hydrogeomorphic units which are influenced by the hydro geological conditions of the area. The hydrogeological conditions are controlled by the lithology, geomorphology, and structures like lineaments, faults and fractures. The visual interpretation of satellite data in conjunction with limited field verification of these features will focus on the priority zones. Most of them are reflected as hydrogeomorphic units. Remote sensing provides the distribution of these units.

2.4 GEOGRAPHIC INFORMATION SYSTEM

The full potential of remote sensing and GIS can be utilized when an integrated approach is adopted. Integration of the two technologies has proven to be an efficient tool in groundwater studies (Krishnamurthy et. al 1996, Sander 1996, Kamaraju et. al 1996, Saraf and Choudhury 1998). For effective groundwater exploration and exploitation it is important to study the different parameters in an integrated approach. The integration of multiple data sets, with various indications of groundwater availability, can decrease the uncertainty and lead to 'safer' decisions (Sander 1996). The Geographic information system offers spatial data management and analysis tools that can assist users in organizing, storing, editing, analyzing, and displaying positional and attribute information about geographical data (Burrough 1986). Remote sensing data provide accurate spatial information and can be economically utilized over conventional methods of hydrogeological surveys. Digital enhancement of satellite data results in extraction of maximum information and an increased interpretability. GIS techniques facilitate integration and analysis of large volumes of data. Whereas field studies help to validate results further. Integrating all these approaches can offer a better understanding of groundwater controlling features in hard rock aquifers.

2.5 INTEGRATED METHOD FOR GROUNDWATER MAPPING

A variety of geophysical techniques exist with the capability of locating and mapping sub-surface phenomena. Each method has limitations in depth of exploration and resolution depending on the geological settings, target size and orientation. These techniques include the following:

- Electrical Method (Resistivity and Conductivity)
- Ground Penetrating Radar
- Magnetic Method
- Seismic Method
- Gravity Method

2.5.1 ELECTRICAL RESISTIVITY 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 and measuring the resulting voltage difference at two potential electrodes (P1 and P2). From the current (I) and voltage (V) values, an apparent resistivity (pa) value is calculated, using

pa = kV/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.

2.5.2 GRAVITY METHOD

The gravity method is a widely used geophysical method for finding out mineral resources and groundwater in sedimentary terrain. Gravimeters are used in this method to measure the differences in density on the earth's surface that may indicate the underlying geologic structures. Because the method is expensive and because differences in water content in subsurface strata seldom involve measurable differences in specific gravity at the surface, the gravity method has little application to groundwater prospecting. Under special geologic conditions, such as a large buried valley, the gross configuration of an aquifer can be detected from gravity variations.

2.5.3 MAGNETIC METHOD

The magnetic method enables detecting the magnetic fields of the earth which can be measured and mapped. Magnetometers are the equipment used to measure the magnetic fields and variations. Because magnetic contrasts are seldom associated with groundwater occurrence, the method has little relevance for exploring groundwater. Indirect information pertinent to the groundwater studies, such as the presence of dikes that form aquifer boundaries or limits of a basaltic flow, could be obtained with this method.

2.5.4 SEISMIC METHOD

Seismic methods are of two kinds as seismic refraction and reflection methods. The seismic refraction method involves the creation of a small shock at the earth's surface either by the impact of a heavy instrument or by a small explosive charge and measuring the time required for the resulting sound, or shock, wave to travel known distances. Seismic waves follow the same laws of propagation as light rays and may be reflected or refracted at any interface where a velocity change occurs. Seismic reflection methods provide information on geologic structure thousands of meters below the surface, whereas seismic refraction methods-of interest in groundwater studies-go only about 100 meters deep. The travel time of a seismic wave depends on the media through which it is passing through. The velocities are greatest in solid igneous rocks and least in unconsolidated materials. Based on these indications, it is possible to delineate the subsurface zones of fractures, fissures, faults and lineaments.

2.6 ELECTRICAL SURVEYING

In resistivity method, artificially generated electric currents of D.C or low frequency alternating currents are introduced into the ground; the resulting potential differences are measured at the surface.

Deviation from homogeneous ground provides information on the form and electrical properties of subsurface in homogeneities

The theory is developed by making the following assumptions.

a. The subsurface consists of a finite number of layers separated by horizontal boundaries.

b. Each layer is electrically homogeneous and isotropic

c. The current source which approximate to a point source is at the surface of the earth.

There are two main types of field procedures involved in Electrical resistivity. These are;

1. Vertical Electrical Sounding (VES)
2. Constant Separation Traversing (CST)

2.6.1 VERTICAL ELECTRICAL SOUNDING

Vertical electrical sounding, VES, is used to determine the resistivity variation with depth. Single VES should only be applied in areas, where the ground is assumed to be horizontal layered 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 = V/I, so in practice the apparent resistivity value is calculated by pa = kR. 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.

2.6.2 CONSTANT SEPARATION TRAVERSING (CST)

Constant separation traverse is known as lateral electrical profiling. In this case, 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. Results from a series of CST with fixed electrode spacing can be employed in the production of resistivity contour maps.

2.7 GEOINFORMATICS AND HYDROGEOPHYSICS IN THE INTEGRATION OF GROUNDWATER POTENTIALS

Several geological, hydrogeological and geophysical methods are employed to target the groundwater potential zones. The interpretation of satellite images and aerial photographs also help more in this process. Groundwater exploration is a very unique exercise. As it is a hidden resource, various indirect methods are attempted to identify the points. The success in the groundwater targeting lies in experience of understanding the geological conditions, structural conditions and hydro geological conditions which favor the occurrence of groundwater. The modern tools like remote sensing and aerial photography also provide a lot of spatial data for a quick understanding of the domain for a better decision-making.

CHAPTER THREE

RESEARCH METHODOLOGY

3.0 GENERAL

This entails the various activities embarked upon in the process of generating the desired product that is, Ground water potential map of the study area. These activities ranges from the acquisition and pre-processing of Satellite Imagery of the study area, Image classification for Land cover determination. It also involves the preparation of other thematic layers required such as Geomorphology map, Lineament density map from lineaments map extracted through principal component analysis of the satellite image, slope map obtained from the Digital Elevation Model (DEM) of the study area, Rainfall Map based on rainfall data of the study area averaged over time etc.

This also includes the integration of these thematic layers through overlay analysis based on ranking of individual thematic layers by weights.

Furthermore, the research methodology also explains the detailed procedures adopted in the integration and development of spatial database for the Vertical Electronic Sounding (VES) data.

The stages involved in generating the desired deliverables and fundamental elements of survey operations are outlined below.

- **a)** Reconnaissance
- **b)** Data Acquisition
- **c)** Data Storage
- **d)** Data Processing and Analysis
- **e)** Data Presentation

3.1 RECONNAISSANCE

Reconnaissance is the preparatory stage for carrying out the project. It involves the overall examination and collection or visualization of the project site or the study area and logistics for the successful execution, i.e. a successful project depends on a reconnaissance. Its value before the actual survey work cannot be under estimated and it allows you to get a picture of the entire area in your mind so that you can work economically in terms of time, workforce, energy and funds.

For the purposes of this work, the study area was precisely recognized using existing processed images, SRTM (Shuttle radar topographical mission) Image and Google Earth to visualize the study area so as to have an idea of what it looks like and also understand the its terrain.

3.2 SYSTEM PROPERTIES

This includes all hardware and software employed in the execution of this project, ranging from data acquisition, data management and information presentations.

3.2.1 Hardware:

This includes all the devices used to acquire, store, process data and display the information obtained in the course of the study.

- HP 17-g121 laptop computer,1TB hard drive
- Logitech Wireless mouse
- 2G RAM
- 1.40Ghz processor

3.2.2 Software used

The following software's were used in the processing and analysis of data:

- ArcGIS 10.4
- Global Mapper 17
- PCI Geomatica 2018
- ENVI Classic 5.0
- 3.3.1 Software
- Window 7 ultimate (O/S) 64bits
- Rockworks 17
- Microsoft office 2013

3.3 DATA ACQUISITION

Data could be referred to as a set of information defining a particular form of entity or defining various forms of entities. Acquisition is gathering this particular information on an entity or various forms of entity. Data acquired for this project are as follows;

S/N	***DATA TYPE***	***SOURCE***
1	Digitized Administrative map of Nigeria	DIVA-GIS
2	Landsat 8 Imagery - Operational Land Imager (OLI)	NASA/USGS
	30m x 30m resolution	https://earthexplorer.usgs.gov/
3	Shuttle Radar Topography Mission –	NASA/USGS
	SRTM DEM (1 Arc-second Global)	https://earthexplorer.usgs.gov/
4	Rainfall data	UCI CHRS's DataPortal
	0.25° x 0.25°	https://chrsdata.eng.uci.edu/
5	Soil Map	Federal Department of Agricultural Resources of Nigeria
6	Geological Map	Nigerian Geological Survey Agency (NGSA)

3.3.1 SATALLITE IMAGERY

The Landsat Imagery covering the study area was downloaded from the USGS Landsat download website (http://earthexplorer.usgs.gov/) using the Firefox web browser.

The Landsat program is the longest running enterprise to acquire Earth's satellite imagery. The Earth Resources Technology Satellite was launched on 23 July 1972. Eventually this was renamed

Landsat. The most recent one, Landsat 8, opened on 11 February 2013. Millions of images were acquired by the Landsat satellite instruments. Archived in the United States and at Landsat receiving stations worldwide, these images are a unique resource for global change research and applications in agriculture, cartography, geology, forestry, regional planning, surveillance and education, and can be viewed throughout the United States Geological Survey(USGS)website' EarthExplorer.'

The Landsat 8 satellite images the entire Earth every 16 days in an 8-day offset from Landsat 7. Data collected by the instruments onboard the satellite are available to download at no charge from EarthExplorer, GloVis, or the LandsatLook Viewer within 24 hours of acquisition.

Landsat 8 is equipped with two push- broom instruments: The Operational Land Imager (OLI) and the TIRS. The spectral bands of the OLI sensor provides enhancement from prior Landsat instruments, with the addition of two additional spectral bands: a deep blue visible channel (band 1) specifically designed for water resources and coastal zone investigation, and a new shortwave infrared channel (band 9) for the detection of cirrus clouds. The tirs instrument collects two spectral bands for the wavelength covered by a single band on the previous tm and etm+ sensors. There are also descriptions of the band names for all Landsat sensors and information on comparisons between Landsat 8 and previous bands. Both of these sensors offer improved radiometric performance from signal to noise (SNR) over a dynamic range of 12 bits.

The procedures are as follows:

• The URL of the USGS Landsat download website was entered into the address bar of the web browser (http://earthexplorer.usgs.gov/),

• The appropriate search criteria was entered into Search Criteria tab of the webpage using the Address/Place tab,

• The appropriate Data Sets for the search were also entered into the Data Sets tab of the webpage and additional search criteria were set;

- Landsat Archive: Landsat 8 OLI

• The appropriate additional search criteria were set;

- Cloud Cover: less than 10%

• The result of the search was viewed in the Result tab and the best imagery (cloud free) for the study area for the year was downloaded in the .tar.gz compressed file format.

These images were obtained from the United States Geological Survey (USGS) website as standard products i.e. geometrically and radiometrically corrected. In order to avoid the impact of seasonal variation, all images are selected from the same season in such a way that the cloud cover will not exceed 10%. The images are also of the same level of spatial resolution of 30m. All dataset used in this study are geometrically references to the WGS 1984.

Figure 3.1: Earth Explorer (USGS) Download Interface

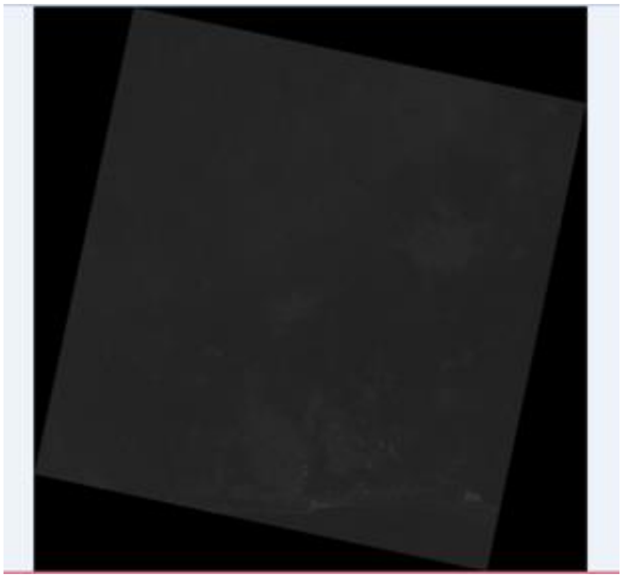

Figure 3.2: Landsat 8 OLI Image (Path/Row = 191/55)

The imagery has eleven (11) bands (as shown in Table 3.1) with similar and different properties (wavelength range, resolution, description and significance) and each band is meant for different purposes. In Image Data Processing the combination of two or more are require to have colour image otherwise gray colour image.

Band	Wavelength	Useful for mapping
Band 1 – coastal aerosol	0.43-0.45	coastal and aerosol studies
Band 2 – blue	0.45-0.51	Bathymetric mapping, distinguishing soil from vegetation and deciduous from coniferous vegetation
Band 3 – green	0.53-0.59	Emphasizes peak vegetation, which is useful for assessing plant vigor
Band 4 - red	0.64-0.67	Discriminates vegetation slopes
Band 5 - Near Infrared (NIR)	085.-0.88	Emphasizes biomass content and shorelines
Band 6 - Short-wave Infrared (SWIR) 1	1.57-1.65	Discriminates moisture content of soil and vegetation; penetrates thin clouds
Band 7 - Short-wave Infrared (SWIR) 2	2.11-2.29	Improved moisture content of soil and vegetation and thin cloud penetration
Band 8 - Panchromatic	.50-.68	15 meter resolution, sharper image definition
Band 9 – Cirrus	1.36 -1.38	Improved detection of cirrus cloud contamination
Band 10 – TIRS 1	10.60 – 11.19	100 meter resolution, thermal mapping and estimated soil moisture
Band 11 – TIRS 2	11.5-12.51	100 meter resolution, Improved thermal mapping and estimated soil moisture

Table 1: Landsat 8 Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS)

The coordinate systems of the imagery acquired are listed below:

- Projection: Transverse Mercator
- False Easting: 500000.000000

- False Northing: 0.000000
- Central Meridian: 3.000000
- Scale Factor: 0.999600
- Latitude Of Origin: 0.000000
- Linear Unit: Meter
- Datum: WGS 1984

3.3.2 SHUTTLE RADAR TOPOGRAPHIC MISSION (SRTM) IMAGERY

The Landsat SRTM Imagery covering the study area was downloaded from the USGS Landsat download website (http://earthexplorer.usgs.gov/) using the Firefox web browser.

The Shuttle Radar Topography Mission (SRTM) is an international research effort that obtained digital elevation models on a near-global scale from 56°S to 60°N, (Nikolakopoulos, 2006) to generate the most complete high-resolution digital topographic database of Earth prior to the release of the ASTER GDEM in 2009. SRTM consisted of a specially modified radar system that flew on board the Space Shuttle Endeavour during the 11-day STS-99 mission in February 2000, based on the older Spaceborne Imaging Radar-C/X-band Synthetic Aperture Radar (SIR-C/X-SAR), previously used on the Shuttle in 1994. To acquire topographic data, the SRTM payload was outfitted with two radar antennas. (Nikolakopoulos, 2006) One antenna was located in the Shuttle's payload bay, the other – a critical change from the SIR-C/X-SAR, allowing single-pass interferometry – on the end of a 60-meter (200-foot) mast that extended from the payload bay once the Shuttle was in space. (Nikolakopoulos, 2006) The technique employed is known as interferometric synthetic aperture radar. Intermap Technologies was the prime contractor for processing the interferometric synthetic aperture radar data.

The procedures are as follows:

- The URL of the USGS Landsat download website was entered into the address bar of the web browser (http://earthexplorer.usgs.gov/),

- The appropriate search criteria was entered into Search Criteria tab of the webpage using the Address/Place tab,

- The appropriate Data Sets for the search were also entered into the Data Sets tab of the webpage and additional search criteria were set;

- Digital Elevation > SRTM > 1 Arc-second Global

- The result of the search was viewed in the Result tab and the best imagery for the study area for the year was downloaded in the .tar.gz compressed file format,

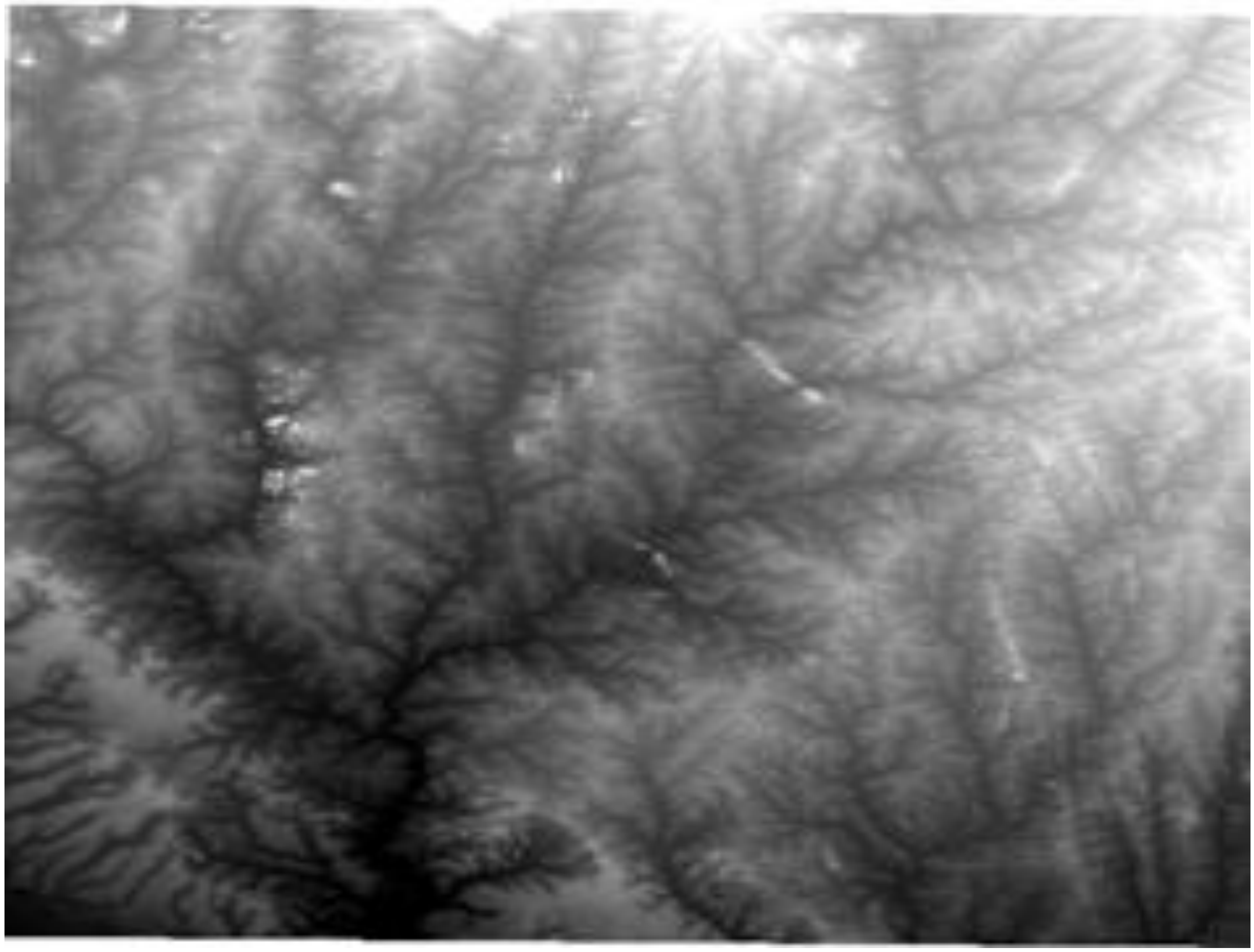

Figure 3.3: SRTM DEM covering the study area

3.3.3 TROPICAL RAINFALL MEASURING MISSION (TRMM)

The Tropical Rainfall Measuring Mission (TRMM), a joint mission of NASA and the Japan Aerospace Exploration Agency, was launched in 1997 to study rainfall for weather and climate research. After over 17 years of productive data gathering, the instruments on TRMM were turned off on April 8. The spacecraft re-entered the Earth's atmosphere on June 15, 2015, at 11:55 p.m. EDT, over the South Indian Ocean, according to the U.S. Strategic Command's Joint Functional Component Command for Space through the Joint Space Operations Center (JSpOC), and most of the spacecraft was expected to burn up in the atmosphere during its uncontrolled re-entry.

The TRMM rainfall precipitation data that covers the study area was downloaded via https://mirador.gsfc.nasa.gov in NetCDF format. The boundary shapefile of the study area was then used to clip the required portion of the precipitation raster after which it was reclassified.

KEY STRENGTHS:

- Consistent, long-term data set with more than 30 years of data, updated quarterly
- Uses many different data sources which makes the product more reliable
- High resolution (0.25) monthly precipitation consistent with GPCP monthly estimates.

KEY LIMITATIONS:

- CDR version has daily temporal resolution, does not resolve the diurnal cycle, may not record some short-lived, intense events
- Relies heavily on infrared data - conversion from IR to precipitation rate requires complex algorithm, not quite global (60◦S - 60◦N)
- Is not independent of other precipitation estimates such as GPCP-1DD.

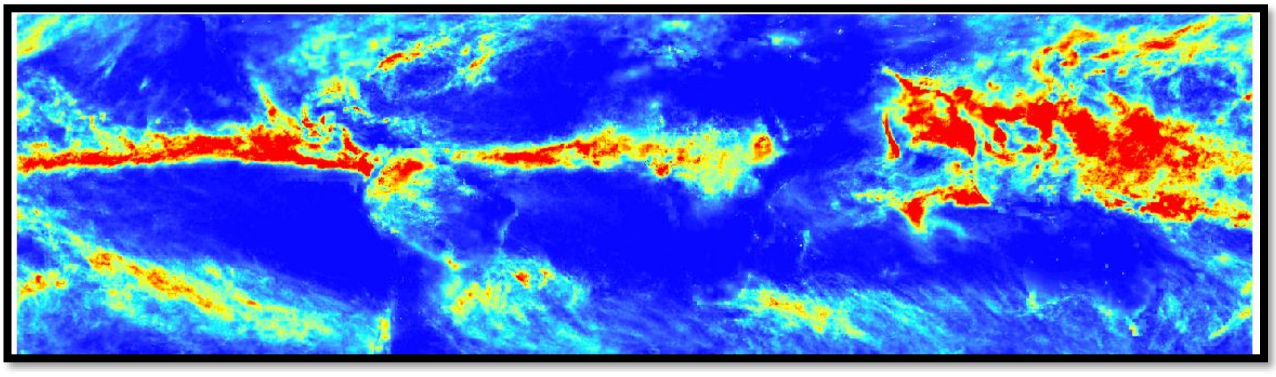

Figure 3.4: Precipitation Raster of Tropical and Subtropical regions of the earth in NetCDF format

3.3.4 GEOLOGICAL MAP OF OYO

Geologic maps represent the distribution of different types of rock and surficial deposits, as well as locations of geologic structures such as faults and folds. Geologic maps are the primary source of information for various aspects of land-use planning, including the siting of buildings and transportation systems. And perhaps most importantly, such maps help identify ground-water aquifers, aid in locating water-supply wells, and assist in locating potential polluting operations, such as landfills, safely away from the aquifers. The Geological Map of the study area was extracted from the Geological Map of Oyo shown below.

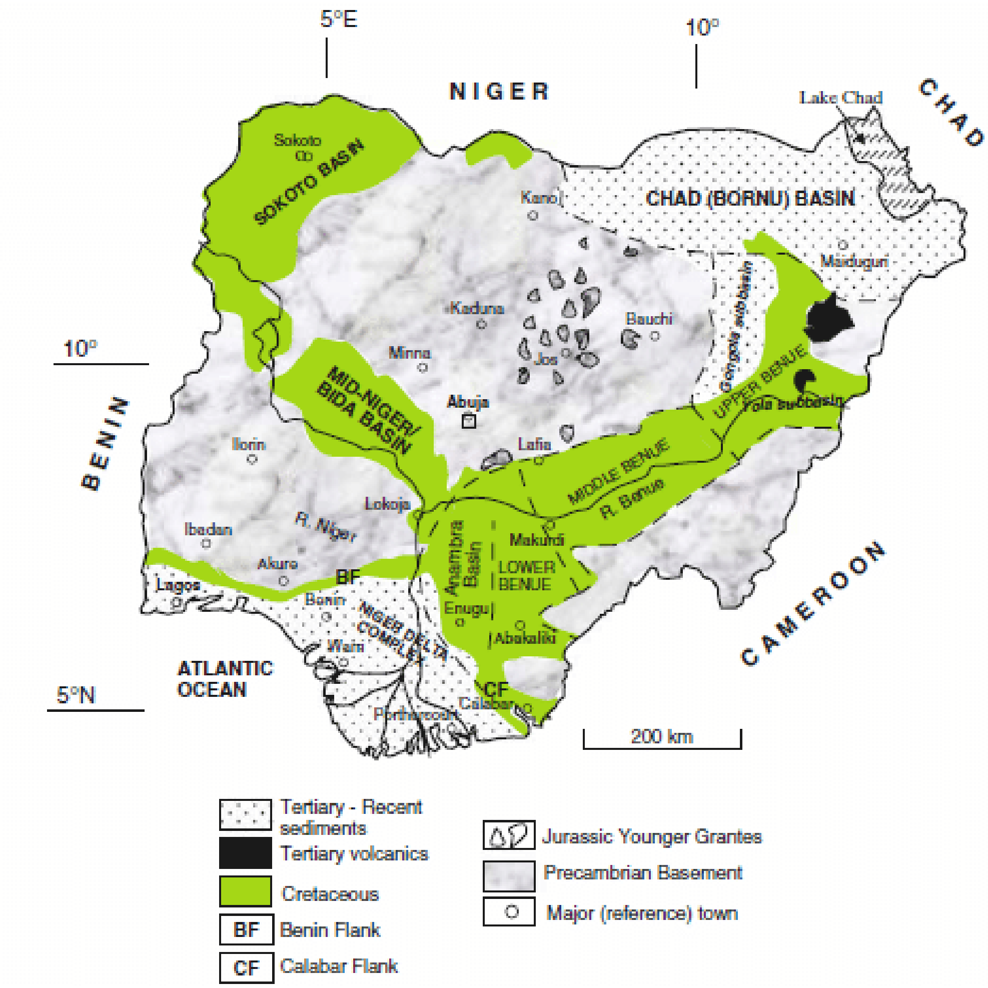

Figure 3.5: Geological Map of Oyo

3.3.5 SOIL MAP

Soil map is a map showing the diversity of soil types and/or soil properties (pH of soil, textures, organic matter, horizon depths, etc.) in the area of interest. Soil maps are most often used for land assessment, spatial planning, extension of agriculture, environmental protection and similar projects. Traditional soil maps typically only show general soil distribution, along with the soil survey report. Many new maps of soil are based on digital soil mapping techniques. Such maps typically have a higher context and spatial detail than traditional maps.

The soil map of the study area was extracted from the soil map of Nigeria which was acquired via the European Digital Archive of Soil Maps (EuDASM).

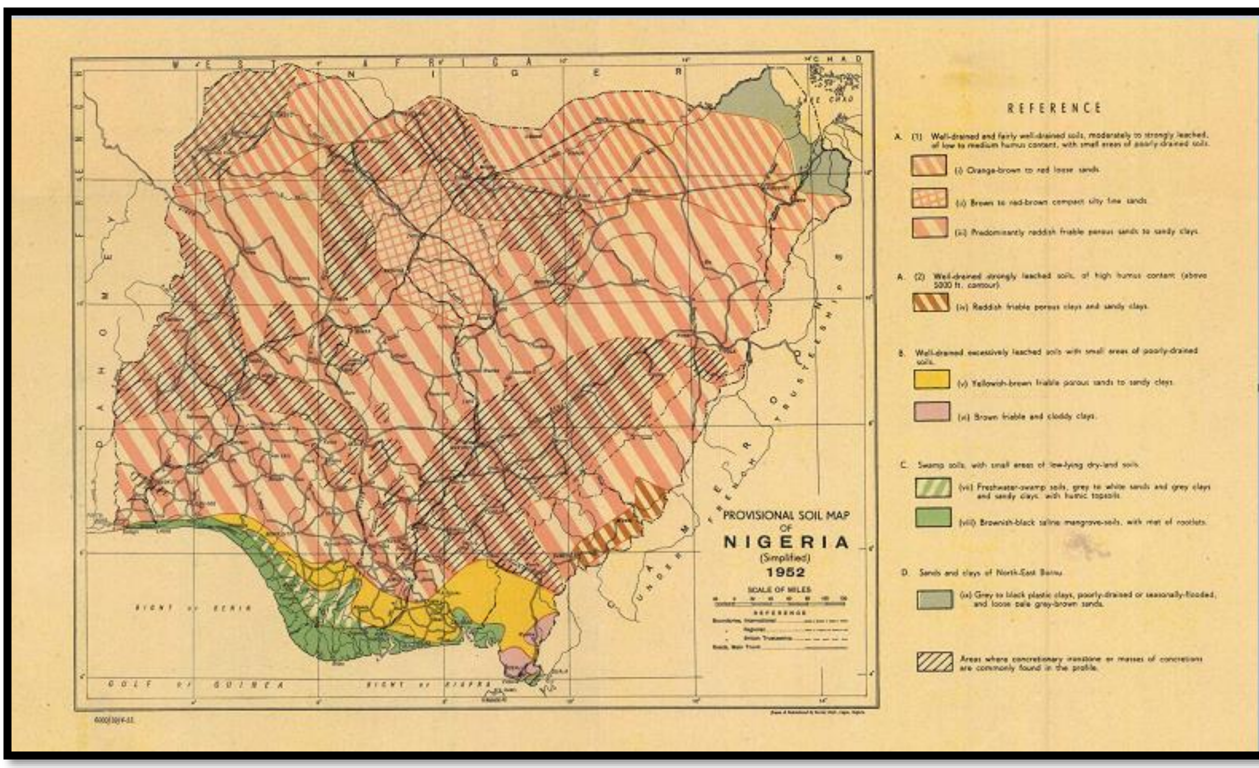

Figure 3.6: Provisional Soil Map of Nigeria (Survey Department, 1952)

3.4 IMAGE PRE-PROCESSING

Pre-processing operations, sometimes referred to as image restoration and rectification, are intended to correct for sensor- and platform-specific radiometric and geometric distortions of data.

Radiometric corrections may be necessary due to variations in scene illumination and viewing geometry, atmospheric conditions, and sensor noise and response. Each of these will vary depending on the specific sensor and platform used to acquire the data and the conditions during data acquisition. Also, it may be desirable to convert and/or calibrate the data to known (absolute) radiation or reflectance units to facilitate comparison between data.

The image pre-processing operations performed on the acquired Landsat 8 Image include atmospheric correction, Noise reduction, and conversion of data into a geophysical unit such as surface reflectance. The image pre-processing steps are explained below.

3.4.1 NOISE REDUCTION

The Minimum Noise Fraction Transform (MNF) tool was used to determine the inherent dimensionality of the image data, to segregate noise in the data, and to reduce the computational requirements for subsequent processing.

The MNF transform was used to remove noise from the data by performing a forward transform, determining which bands contain the coherent images (by examining the images and eigenvalues), and running an inverse transform using a spectral subset to include only the good bands.

3.4.2 IMAGE ENHANCEMENT

The Landsat 8 OLI image comprises of 8 multispectral bands with spatial resolution of 30m and 1 Panchromatic band of spatial resolution of 15m. The panchromatic band of higher resolution 15m was used to pan sharpen the multispectral band of lower resolution 30m. The Gram-Schmidt Pan Sharpening Algorithm was used to achieve this.

From the Toolbox, the Gram-Schmidt Pan Sharpening tool was launched.

In the Select Low Spatial Resolution Multi Band Input file dialog box displayed, the metadata was selected, the panchromatic bands were entered in the Select High Spatial Resolution Pan Input Band dialog box, the resampling method used was Nearest Neighbour as it is most suitable for discrete data, Landsat 8 OLI was also chosen as a Sensor and the output filename, the output file format were also set. The OK button was clicked to run the pan-sharpening process.

3.5 DATUM HARMONISATION

All the datasets used were projected onto a Universal Transverse Mercator (UTM) coordinate system (Zone 31N) on WGS84 datum. This projection helped to overcome linear measurement difficulties and preserve geometric properties of the layers.

3.6 PROCESSING AND PREPARATION OF THEMATIC LAYERS

Producing a groundwater map involves the overlay analysis of several thematic layers. The following sections discuss the processing and preparation of these layers used in this study.

3.6.1 LAND COVER MAP

Land cover maps represent spatial information on different types (classes) of physical coverage of the Earth's surface, e.g. forests, grasslands, croplands, lakes, wetlands. Dynamic land cover maps include transitions of land cover classes over time and hence captures land cover changes. Land use maps contain spatial information on the arrangements, activities and inputs people undertake in a certain land cover type to produce, change or maintain it.

For the purpose of land cover extraction, a False Colour Composite (FCC) was created comprising Bands 6, 5 and 4 in that order. The preliminary interpretation of the composite involved categorizing the study area land cover into four classes namely;

- Bare Land,
- Built-Up Areas,
- Vegetation, and
- Water Bodies.

The Classification type used was "Supervised Classification - Parallelpiped". The step-by-step procedure for the classification of the imagery was done with ENVI Classic 5.0 software as follow;

- Launched the application, on the menu-bar go-to File > Open Image File, locate your Landsat Imagery (Scene) and select the bands you would like to use to form your image composite (Bands 6-5-4, in this case),
- "Available Band List" pop-up menu, select your preferred bands into RGB color option and load click Load RGB,
- Save the composite by selecting on the Image Composite Screen, File > Save Image As > Image File, with resolution set as "24bit Color (BSQ)" and output file in "GeoTIFF/TIFF format",
- On the Image Composite Screen go-to Overlay > Region of Interest
- Load the area of interest, File > Open Vector File, locate/select your saved area/boundary shapefile, select/name the output file (which would be saved in .evf) and pick the appropriate co-ordinate system and overlay it on your image composite.
- Start taking "training samples" on the image using the region of interest screen. When satisfied training samples have been created its advised to save your regions of interest by, on its menu bar File > Save ROIs
- Classify the image, from ENVI Classic menu bar Classification > Supervised > Parallelpiped

- The "classification input file" pop-up comes on, select your image composite and define your spatial subset to your area boundary which is now a vector (.evf),
- Define parameters on the "parallelpiped parameter" pop-up and save, load/display the classified image,
- Vectorize the classes from the classified image, from ENVI Classic menu bar Classification > Post-Classification > Classification to Vector, a pop-up screen "Raster to Vector input band" appears
- Select your classified image, select the classes you want to convert to vector and save,
- Load your vector on the vector display,
- Convert to shapefile, on the vector display select File > Export Layer to Shapefile, select the output location and name the file.

Figure 3.7: Landsat Imagery covering the study area

CLASS NUMBER	***CLASS NAME***
1	Built up

2	Water Bodies
3	Vegetation
4	Bare land

3.6.2 LINEAMENTS MAP

This will be done with the help of PCI Geomatica 2017 software using automated extraction techniques. It involves turning each point in the shape into a straight line in the space parameter. The main advantages of automated linear extraction over manual linear extraction are its ability to approach different images in a uniform manner; processing operations are carried out in a short time and its ability to extract lineaments that are not recognized by human eyes. The automated lineage extraction in this study would be performed by the Geomatica software line module. The procedure for this is as follows in PCI Geomatica:

PCI Geomatica > Tools > Algorithm librarian > Find (line) > Find next > Line – lineament extraction > Files > Browse > ".tif"

Check "Content not specified" > then Input the necessary parameters > RUN

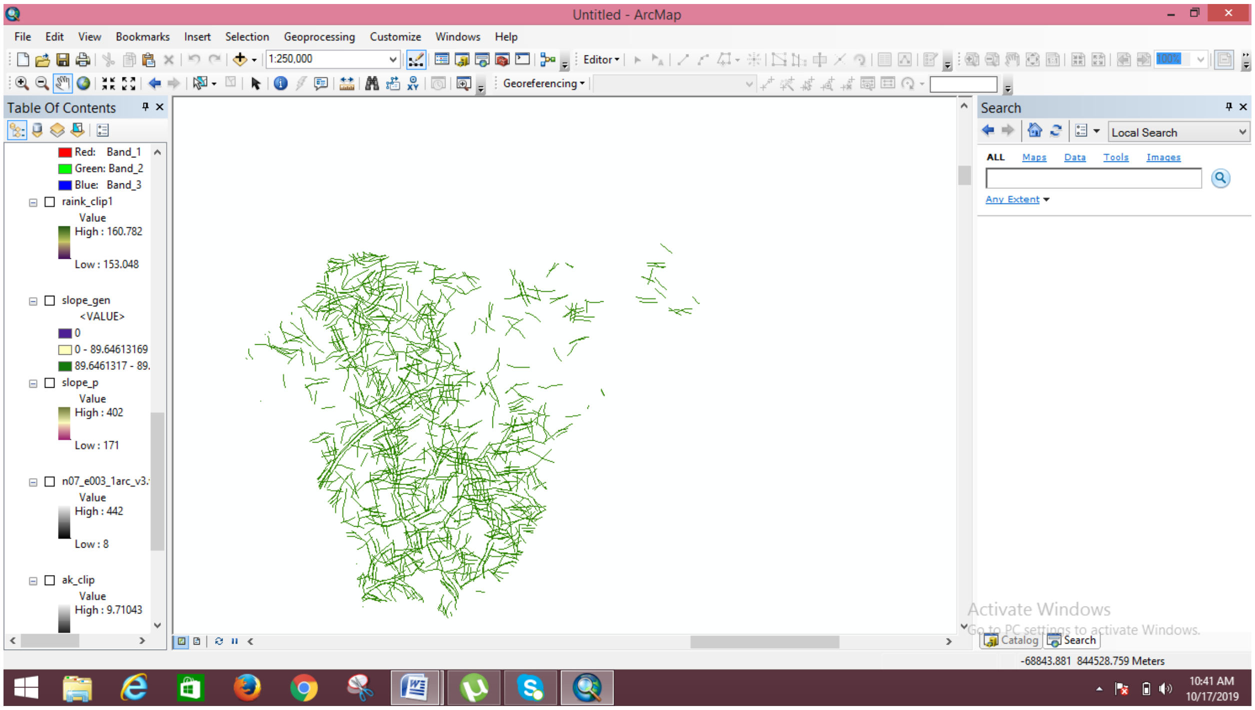

Figure 3.8: Lineaments clipped to study area boundary

3.6.3 GENERATING THE LINEAMENT DENSITY RASTER

Another method for analyzing the extracted lineaments is a linear density map. It shows the lines distribution in two - dimensional maps. The map is created by adding the available line length to a defined grid size. To achieve this, ArcMap 10.4 was used with the help of the line density tool as shown in figure 3.7 below under the tools of the Space Analyst.

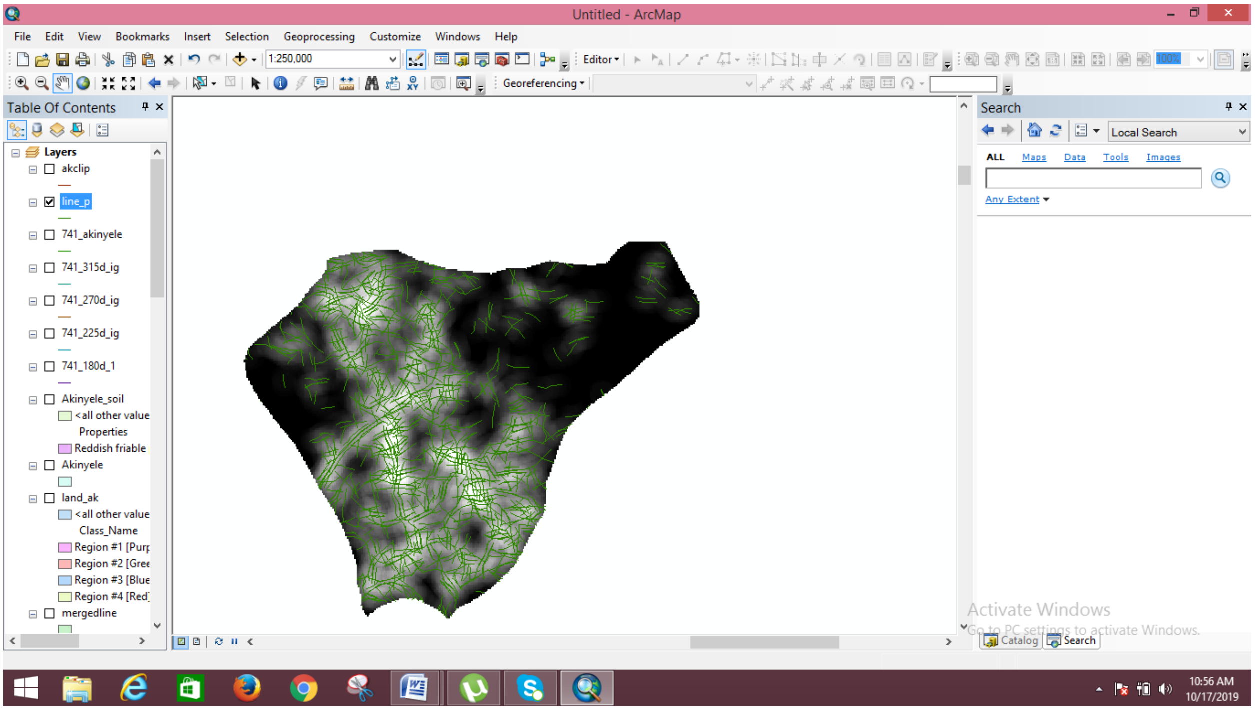

Figure 3.9: Lineament Density

3.6.4 GENEATION OF GEOLOGICAL MAP

Geologic maps represent the distribution of different types of rock and surficial deposits, as well as locations of geologic structures such as faults and folds. Geologic maps are the primary source of information for various aspects of land-use planning, including the siting of buildings and transportation systems. And perhaps most importantly, such maps help identify ground-water aquifers, aid in locating water-supply wells, and assist in locating potential polluting operations, such as landfills, safely away from the aquifers.

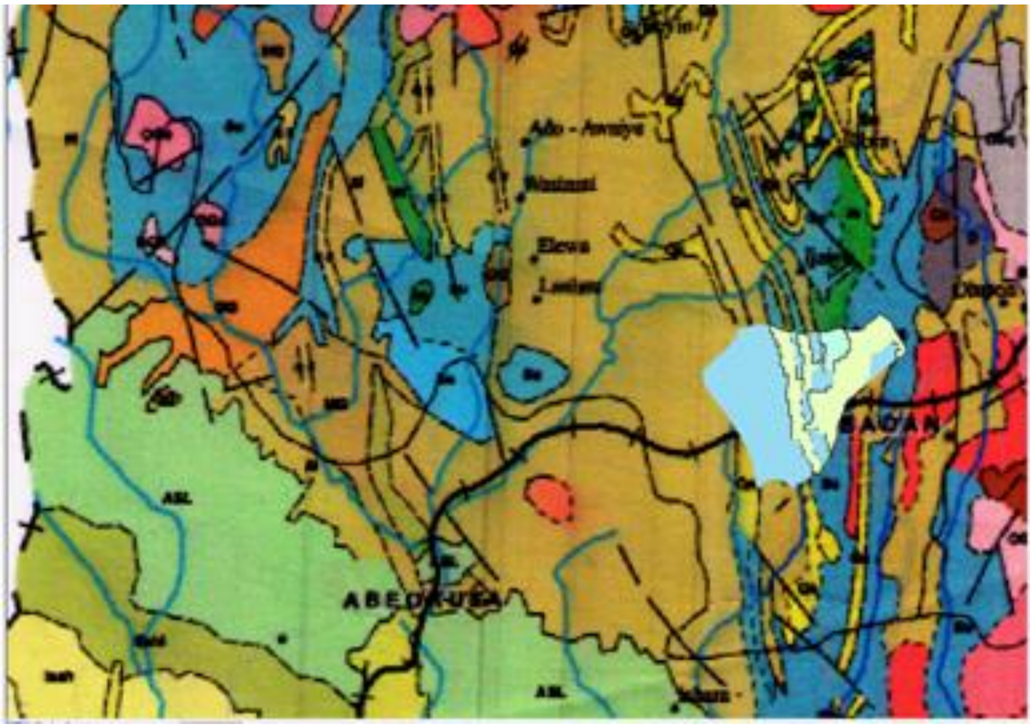

Figure 3.10: Geological Map of Oyo state

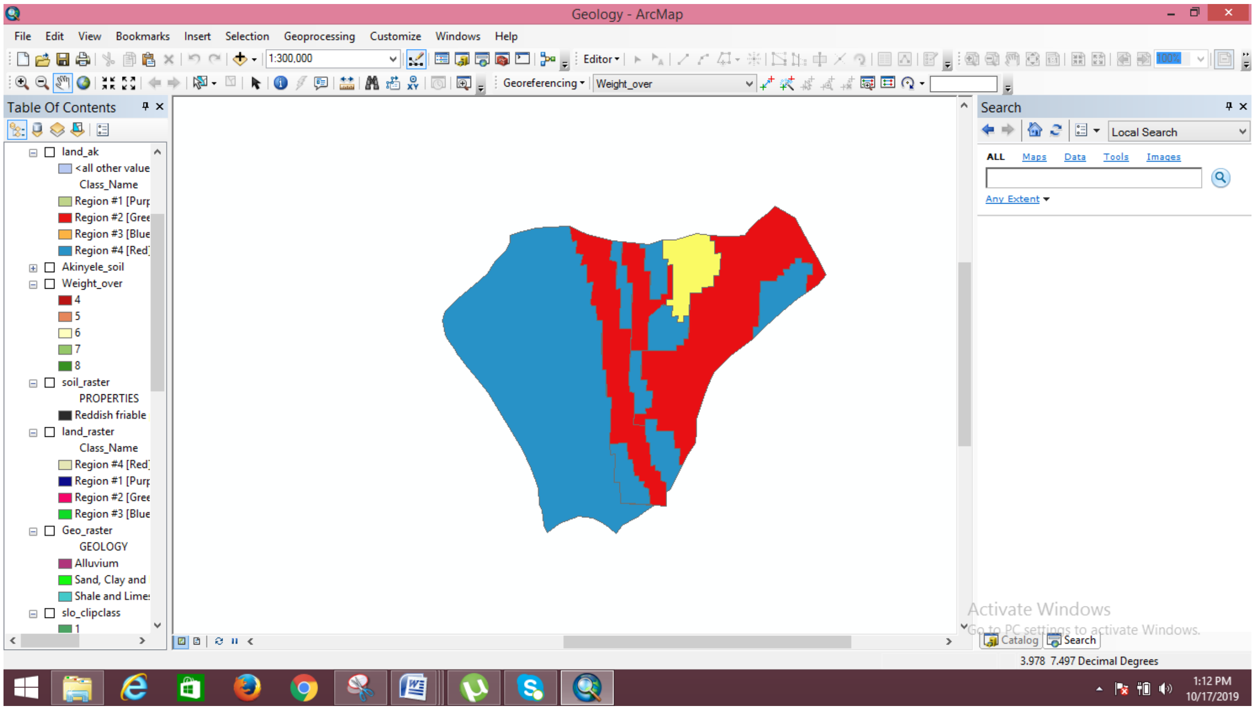

Figure 3.11: Geological Map of Study area

3.6.5 GENERATION OF SOIL MAP

Soil map is a map showing the diversity of soil types and/or soil properties (pH of soil, textures, organic matter, horizon depths, etc.) in the area of interest. Soil maps are most often used for land assessment, spatial planning, and extension of agriculture, environmental protection and similar projects. Traditional soil maps typically only show general soil distribution, along with the soil survey report. Many new maps of soil are based on digital soil mapping techniques. Such maps typically have a higher context and spatial detail than traditional maps.

The soil map of the study area was extracted from the soil map of Nigeria which was acquired via the European Digital Archive of Soil Maps (EuDASM)

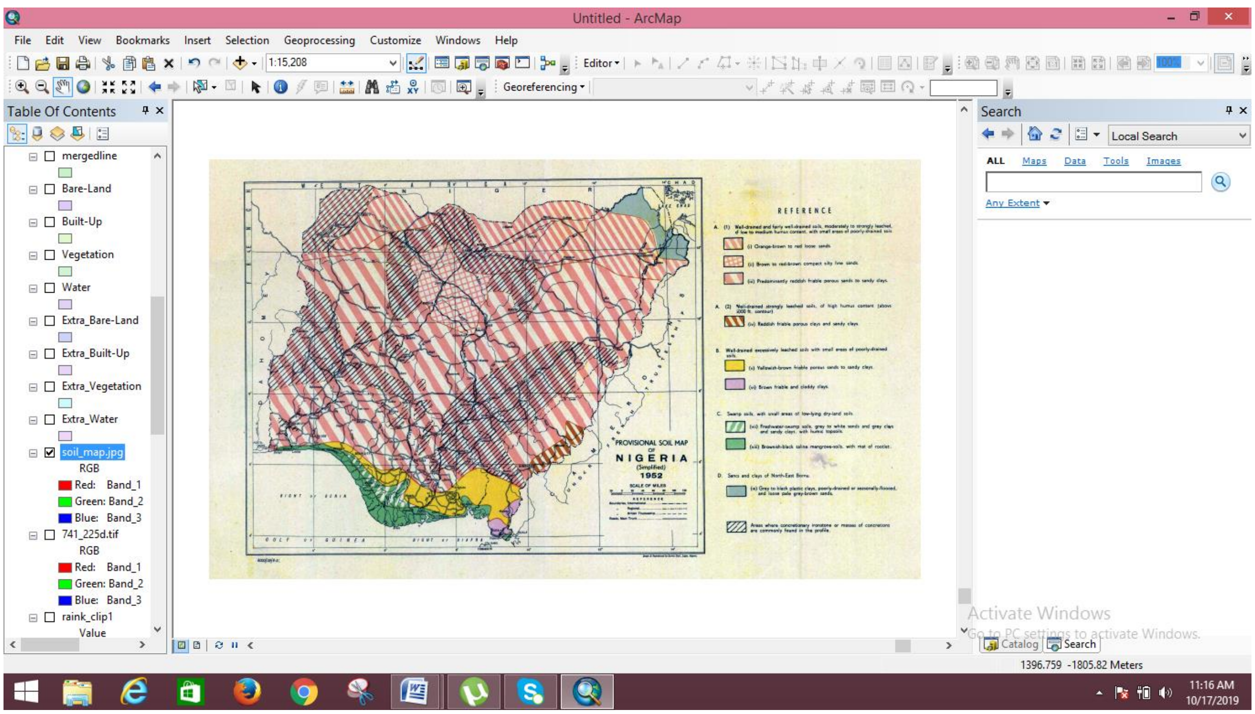

Figure 3.12: Soil Map of Nigeria

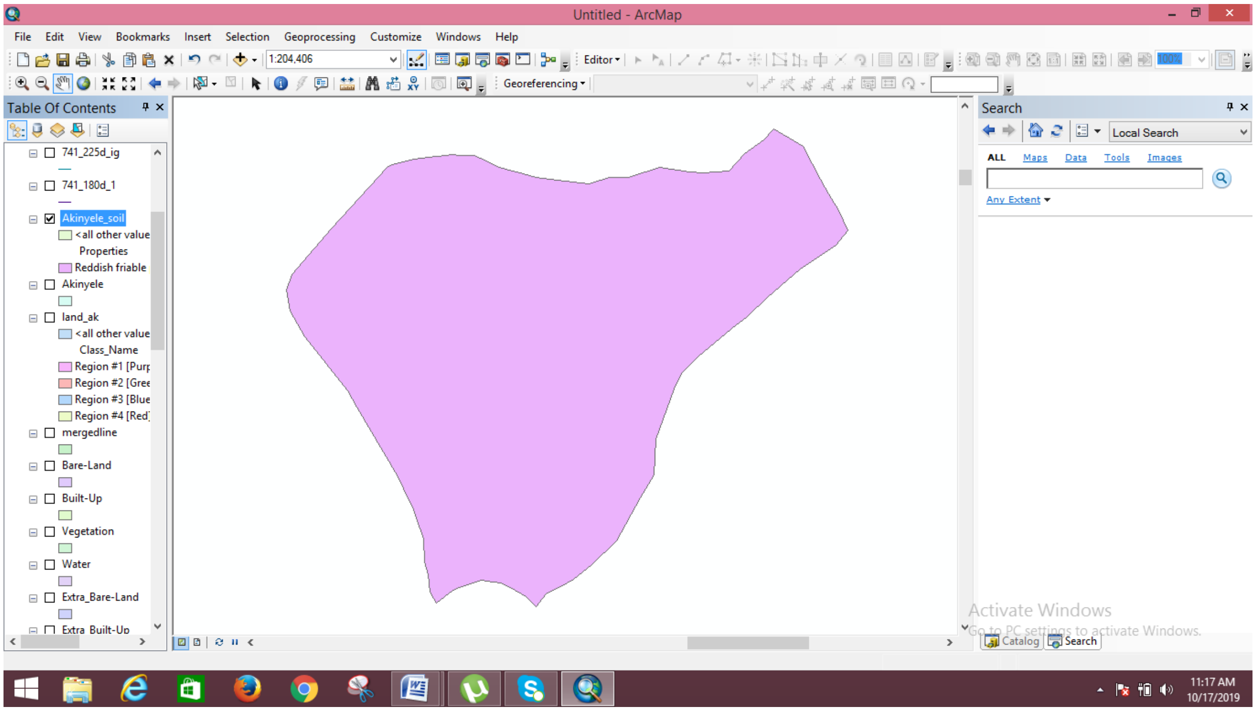

Figure 3.13: Generated Soil Thematic Layer

3.6.6 GENERATION OF RAINFALL MAP

Precipitation is one of the main sources for the availability of ground water through the water cycle. The rainfall is not the same everywhere. Rainfall varies depending on the environment. The groundwater potential is high when the rainfall is high and low when the rainfall is low. The rainfall not only spatially but also temporally. Thus, to determine its influence in any region, the rainfall data is required. The rainfall map was prepared by kriging interpolation of rainfall data points covering Nigeria.

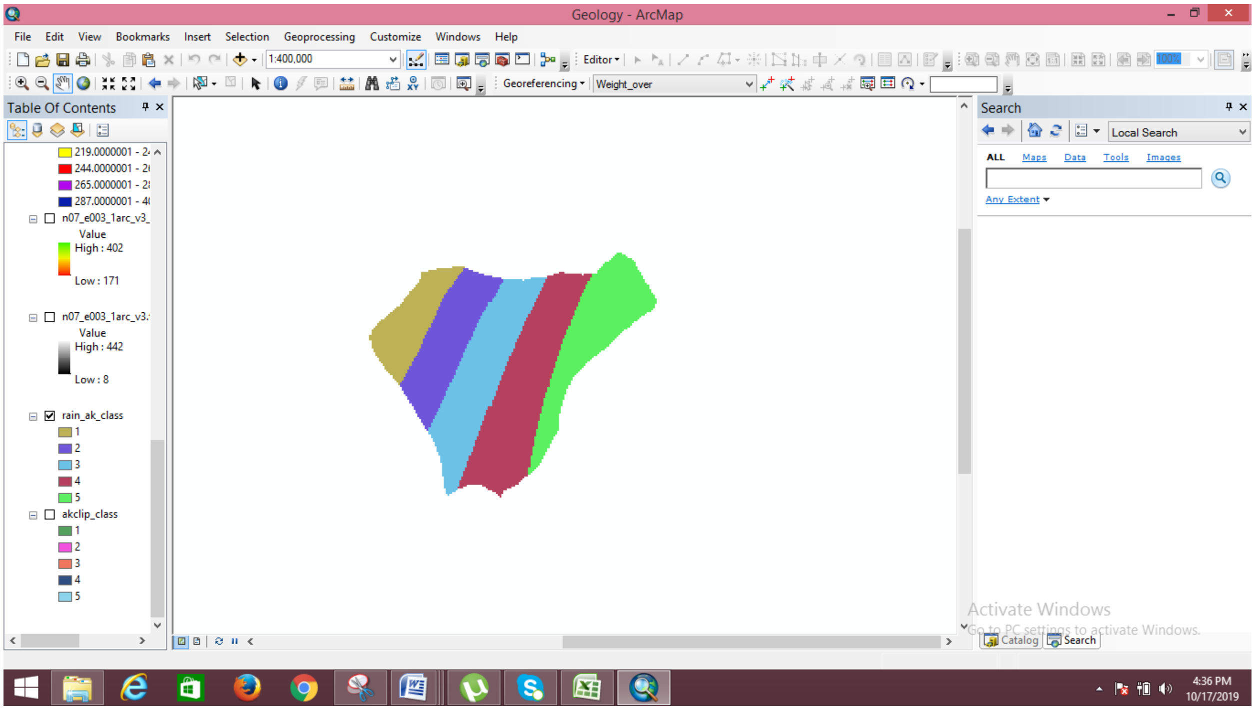

Figure 3.14: Rainfall clipped to study area

3.6.7 WEIGHTED OVERLAY ANALYSIS

The zoning of groundwater potential was done overlaying various cumulative weights assigned to all the five thematic layers that is Land Cover, Lineament Density, Soil, Geology, and Rainfall using the weighted overlay tool, the resulting composite coverage would be classified into five groundwater potential zones viz Very High Potential, High Potential, Moderately Potential, Low Potential, and Very Low Potential.

The various sub-classes of the thematic surfaces were ranked according to the order of relevance and contribution to ground water naturally. The weighted overlay tool in Arcmap Spatial Analyst Toolbox was used for the overlay of all thematic layers.

3.6.8 VERTICAL ELECTRONIC SOUNDING (VES)

To verify the potential of the groundwater map obtained, the VES data of some selected station points would be obtained using Schlumberger array method.

Using the Schlumberger array method, the potential electrode (P1P2) are placed at a fixed spacing ‘b’ which is no more than one-fifth of the current electrode half-spacing ‘a’. The current electrodes are placed at progressively larger distance when the measured voltage between P1 and P2 falls to very low values (owing to the progressively decreasing potential gradient with increasing current electrode separation). The potential electrodes are spaced more widely apart (spacing b2). The measurement is continued and the potential electrode separating increased again as necessary until the VES is completed. A VES using the Schlumberger array take up less space than either of the two Wenner array unless multi core cables are used.

3.7 VES DATA

The VES data of the 20 points selected within the study area are shown in the table below. It contains coordinates of each VES location, Resistivity inferred, Thickness, Depth, Description of each layer.

VES STATION	CURVE TYPES	APPARENT RESISTIVITY (Ωm)	THICKNESS (m)	DEPTH (m)	RMS ERROR (%)	LAYER DESCRIPTION
1	K	44.4 1054.4 435.8	0.5 4.9 ------	0.5 5.4 ----	2.4	Topsoil Weathered layer Fresh basement

2	AK	171.6 283.9 1178.6 211.4	0.6 5.2 9.7 ------	0.6 5.8 15.6 ------	4.3	Topsoil Weathered layer Fractured layer Fresh basement
3	AK	159.7 180.4 822.8 178.9	0.6 2.2 8.2 ------	0.6 2.8 11.3 -------	4.2	Topsoil Weathered layer Fractured layer Fresh basement.
4	AK	88.4 97.6 272.8 182.5	0.8 2.4 8.1 ---------	0.8 3.2 11.3 ----------	2.5	Topsoil Weathered layer Fractured layer Fresh basement
5	AK	36.1 611.1 766.5 172.2	0.7 1.6 4.8 -----	0.7 2.3 7.1 -----	2.3	Topsoil Weathered layer Fractured layer Fresh basement
6	K	57.5 311.5 208.5	1.0 2.1 -----	1.0 3.1 ----	2.5	Topsoil Weathered layer Fresh basement
7	AK	152.1 377.0 985.7 159.5	1.4 1.0 5.2 -----	1.4 2.5 7.7 ----	2.5	Topsoil Weathered layer Fractured basement Fresh basement

8	AK	72.9 100.7 308.3 155.4	0.2 2.9 4.2 -------	0.2 3.1 7.2 ----	4.0	Topsoil Weathered layer Fractured layer Fresh basement
9	AK	137.7 424.2 1403.9 214.0	0.5 1.7 3.5 ----	0.5 2.1 5.6 -----	2.6	Topsoil Weathered layer Fractured layer Fresh basement
10	KQH	148.8 979.1 739.2 39.1 460.9	0.1 1.7 25.6 8.1 ------	0.1 1.8 27.4 35.5 -----	2.5	Topsoil Weathered layer Fractured layer Fresh basement Fresh basement
11	AK	74.2 161.2 440.1 164.7	0.5 2.2 7.8 ------	0.5 2.7 10.5 -----	2.8	Topsoil Weathered layer Fractured layer Fresh basement
12	KH	39.4 1098.8 88.4 1010.2	0.5 2.1 21.2 -----	0.5 2.6 23.8 -----	3.3	Topsoil Fractured layer Clayed Fresh basement
13	AK	95.5 96.9 394.0 116.9	0.4 1.7 3.7 -----	0.4 2.0 5.4 ------	3.5	Topsoil Weathered layer Fractured basement Fresh basement
14	AK	89.6 150.1 204.1 153.9	0.4 2.1 9.0 ------	0.4 2.5 11.4 -------	2.5	Topsoil Weathered layer Fractured layer Fresh basement

15	AK	162.7 119.4 447.2 253.9	0.4 1.8 8.0 ------	0.4 2.1 10.2 ------	2.3	Topsoil Weathered layer Fractured basement Fresh basement
16	KH	45.6 203.9 55.9 146.9	1.2 6.5 12.3 ------	1.2 7.7 20.0 --------	2.5	Topsoil Fractured layer Clayed Fresh basement
17	AK	64.0 333.2 688.1 108.9	0.6 0.8 1.4 ------	0.6 1.4 2.8 ------	3.6	Topsoil Weathered layer Fractured layer Fresh basement
18	KH	143.4 277.6 51.5 218.3	0.4 4.8 9.7 -----	0.4 5.2 14.9 -------	1.7	Topsoil Fractured layer Clayed Fresh basement
19	K	96.0 300.6 226.7	0.9 3.9 ------	0.9 4.7 -----	2.6	Topsoil Fractured layer Fresh basement
20	AK	36.2 251.0 1014.3 157.0	0.6 1.0 2.7 -------	0.6 1.6 4.3 -------	4.4	Topsoil Weathered layer Fractured layer Fresh basement
21	HKH	185.0 98.0 272.0 86.7	0.6 1.9 5.2 20.8	0.6 2.5 7.7 28.5	1.7	Topsoil Weathered layer Fractured layer Clayed layer

		557.0	-----	------		Fresh basement
22	K	60.6 1129.6 285	0.7 5.6 ----	0.7 6.3 -----	2.5	Topsoil Fractured layer Fresh basement

Table 2: VES data

The VES points were overlaid on the Groundwater Potential Raster obtained as shown in the figure below.

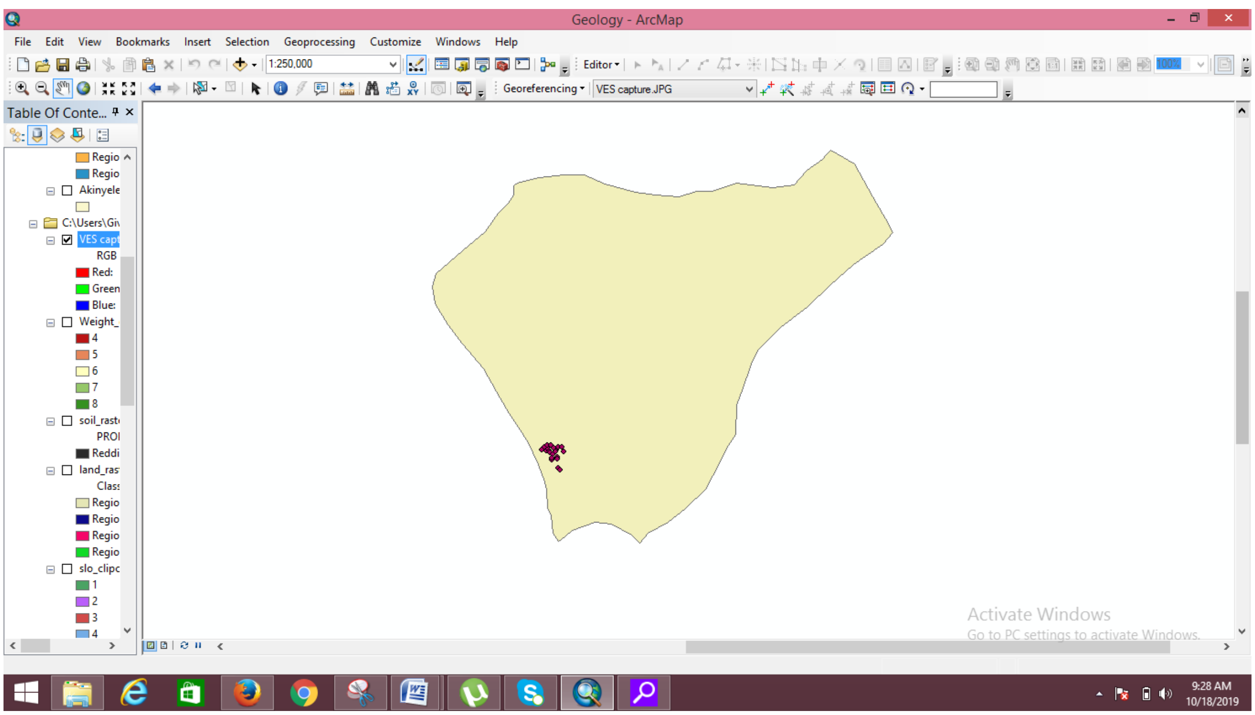

Figure 3.15: Overlay of VES points in the study area

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 SOIL MAP

Soil is an essential factor for delineating ground water potential zones. Geology, climate, and physiography characterizes soil and play an essential role in groundwater discharge and run-off. Soil types and their permeability determines the water holding capacity of an area. The analysis of the soil types shows that the study area is predominantly covered by two main soil types namely; Brownish-black saline mangrove soils and Reddish Friable Porous Sands to Sandy Clays. Based on the influence of groundwater occurrence, areas with Brownish-black saline mangrove soils have high ground water potentials than areas with Reddish Friable Porous Sands to Sandy Clays. The soil map of the area drawn in a scale of 1: 100,000 is shown below.

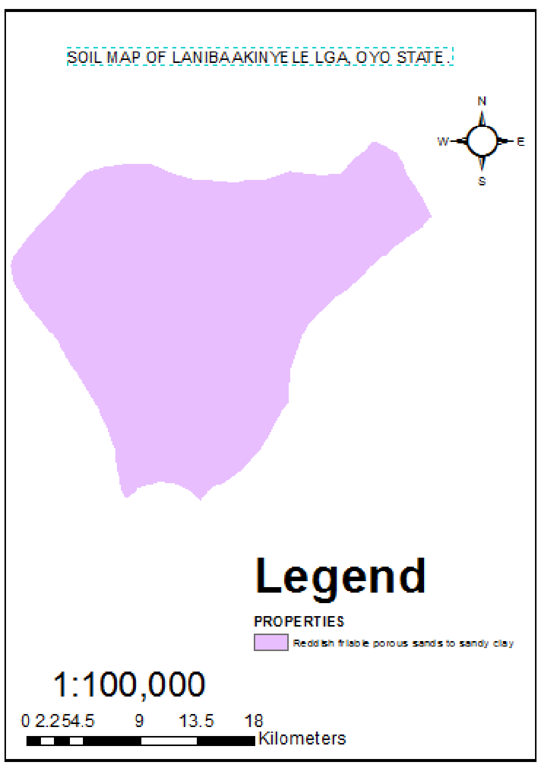

Figure 4.1: Soil Map

4.2 RAINFALL MAP

Precipitation is one of the main sources for the availability of ground water through the water cycle. The rainfall is not the same everywhere. Rainfall varies depending on the environment. The groundwater potential is high when the rainfall is high and low when the rainfall is low. The rainfall of the study area has been calculated in mm based on the annual rainfall. The rainfall raster was classified into three classes viz low, moderate and high. The rainfall map drawn in a scale of 1:100,000 is shown in figure 4.2 below.

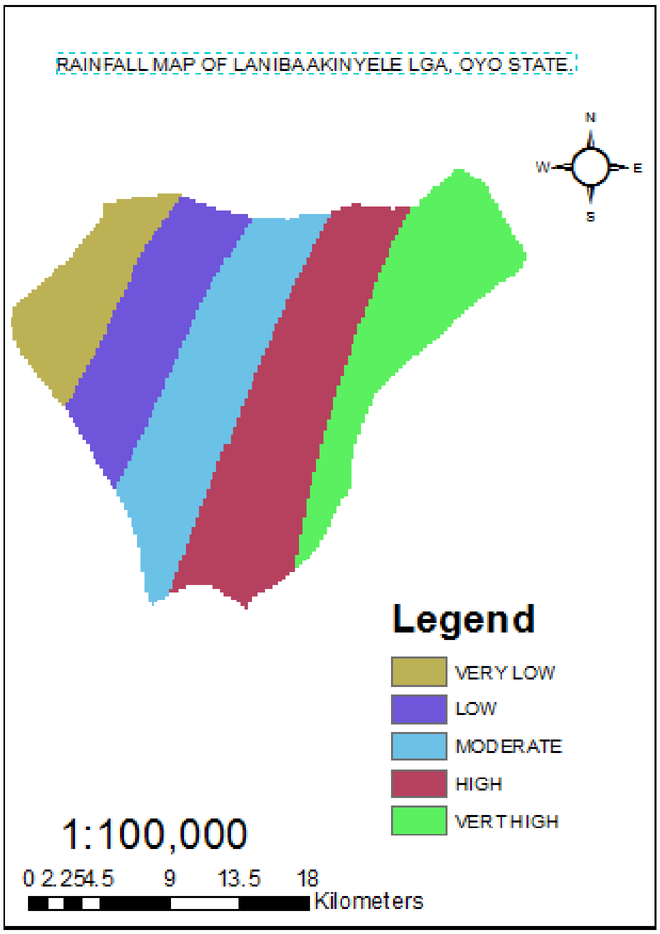

Figure 4.2: Rainfall Map

4.3 GEOLOGICAL MAP

Two main geology types were found in the study area. They are the Alluvial and Coastal plain sand. Alluvial is the depositional structure formed by running water hence highly good for ground water prospect. Although the area is highly dominated by coastal plains, coastal plain sands have been found to be highly permeable for ground water flow.

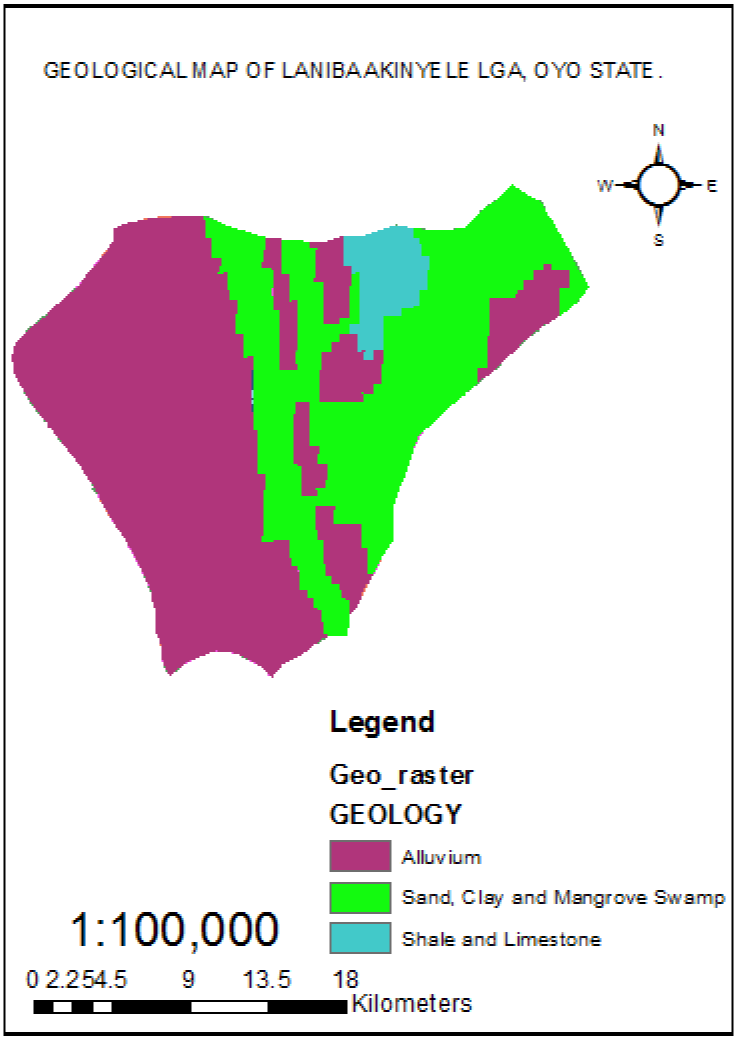

Figure 4.3: Geological Map of Akinyele

4.4 LINEAMENT AND LINEAMENT DENSITY

Lineaments are the irregular earth features which can be easily found on the ground. They reveal the underlying surface features. Lineaments are indicators of sub-surface faults and fractures that influence the occurrence of ground water actin as reservoirs and canals. Lineament density of an area greatly exposes the ground water potential of the area, since the presence of lineaments mostly indicate permeable zones. Areas with high lineament density are have high ground water potentials. The lineaments were extracted from the principal component of the satellite imagery and the lineament density raster was obtained using the line density tool of ArcMap.

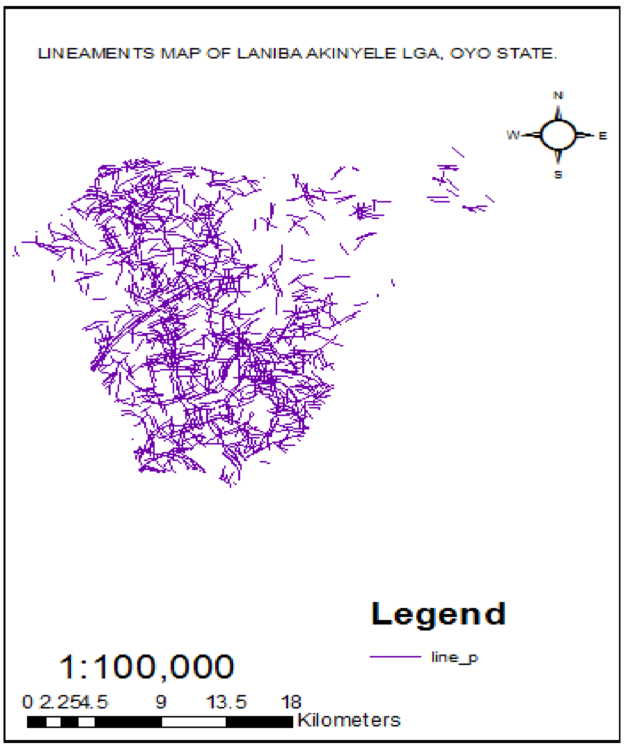

Figure 4.4: Lineament Map

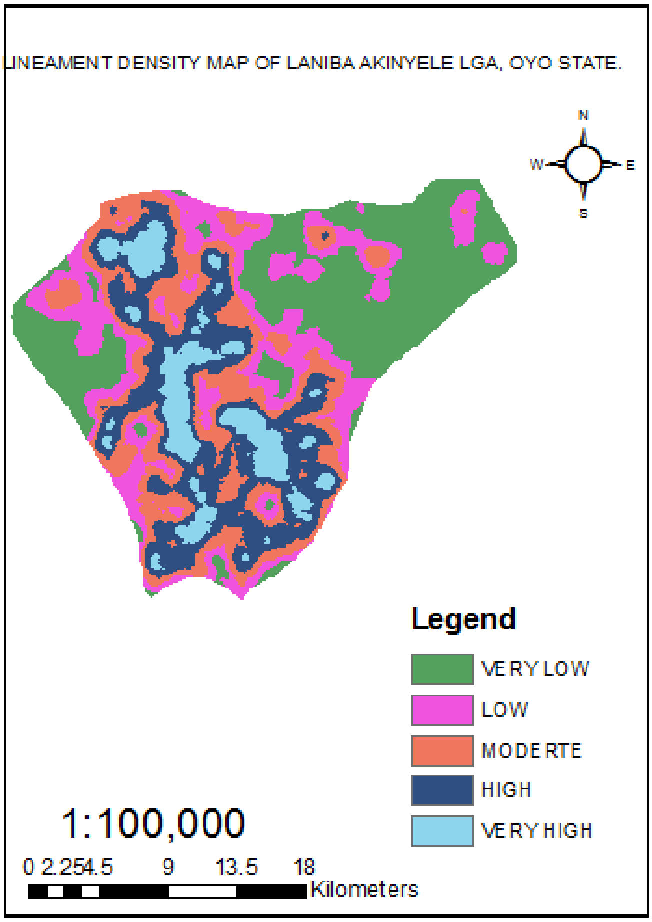

Figure 4.5: Lineament density map

4.5 LAND COVER MAP

The Land cover map was generated by classifying the acquired Landsat 8 OLI Imagery into four Landcover classes using ENVI 5.3 software. The supervised classification methods and Maximum likelihood classification algorithm were applied.

The surface covered by vegetation like forests and agriculture traps and holds the water in root of plants whereas the built-up and rocky land cover affects the recharge of groundwater by increasing runoff during the drain, so land cover classification is necessary for studying the king of features dominant in the study area.

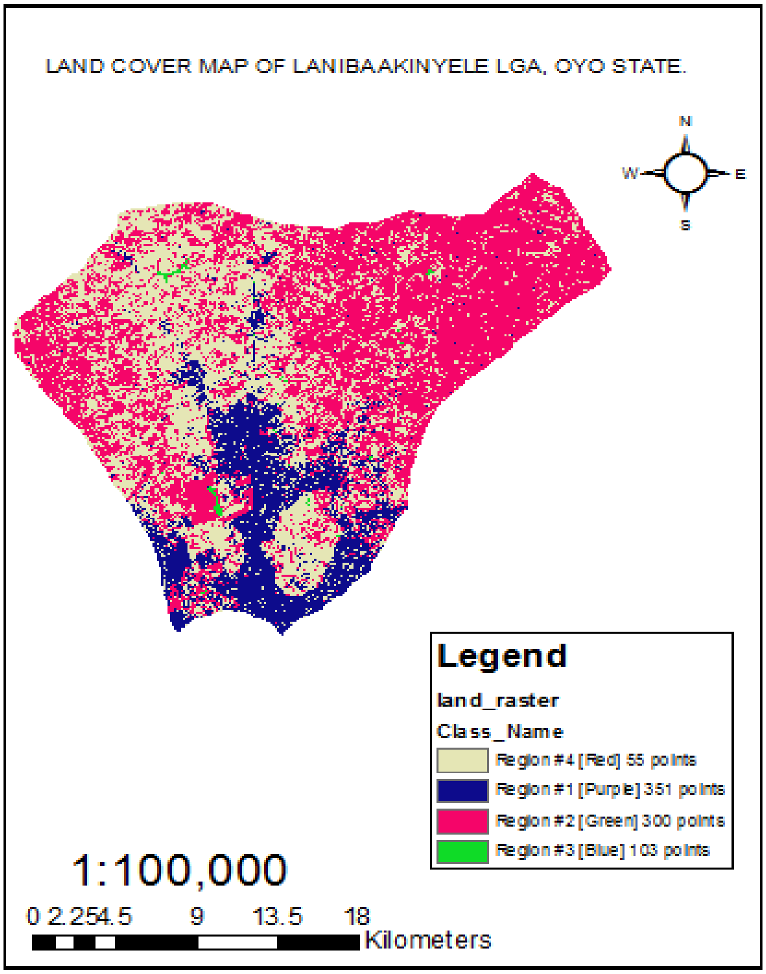

Figure 4.6: Land cover map

4.6 GROUNDWATER POTENTIAL MAP

The ground water potential map of the study area was prepared by the integration of required thematic layers and modeling through GIS. It was classified into five classes of Very High Potential, High Potential, Moderately Potential, Low Potential, and Very Low Potential. The final output was plotted to a scale of 1:100,000 as shown in figure 4.6

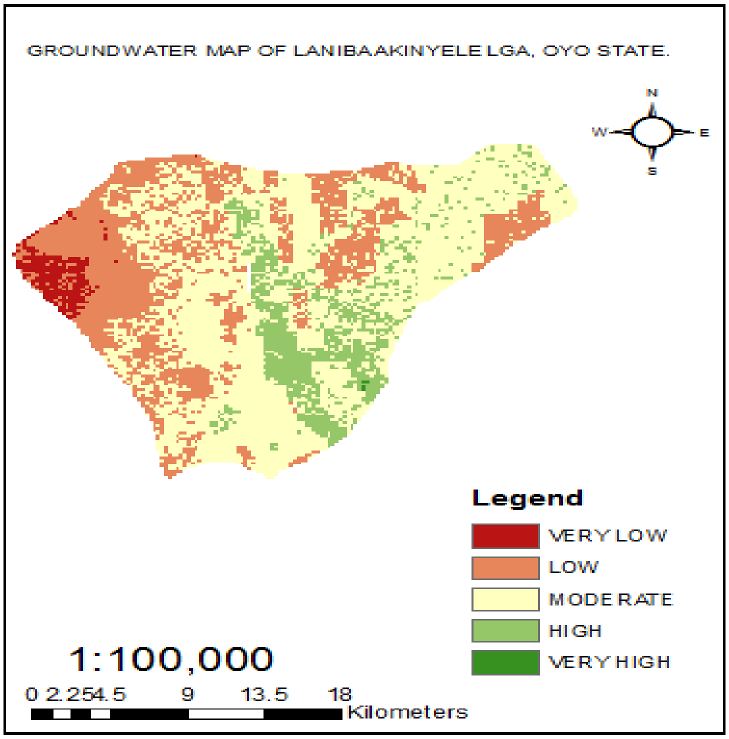

Figure 4.7: Groundwater Potential Map

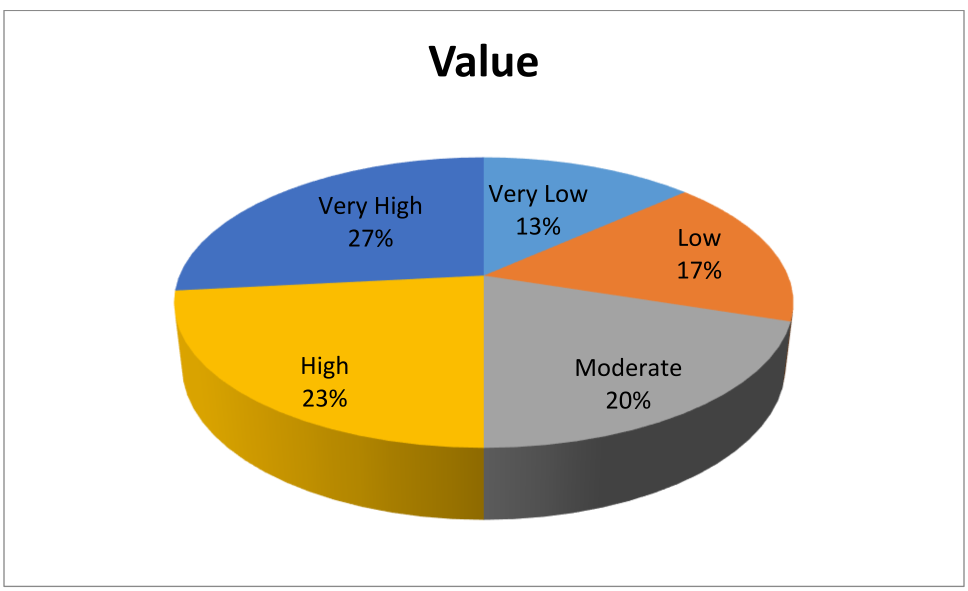

Figure 4.8: Pie Chart depicting the Groundwater Potential distribution of the study area

Figure 4.9: Bar Chart depicting the Groundwater Potential distribution of the study area

4.7 VES STATIONS RESULTS AND ANALYSIS

The VES points were first plotted in ArcMap and it was discovered that all these points concentrate in a low groundwater potential region. Also, the depths at individual layers of each VES point were used to generate a chart depicting the vertical depths at all layer levels.

4.7.1 DATABASE QUERY

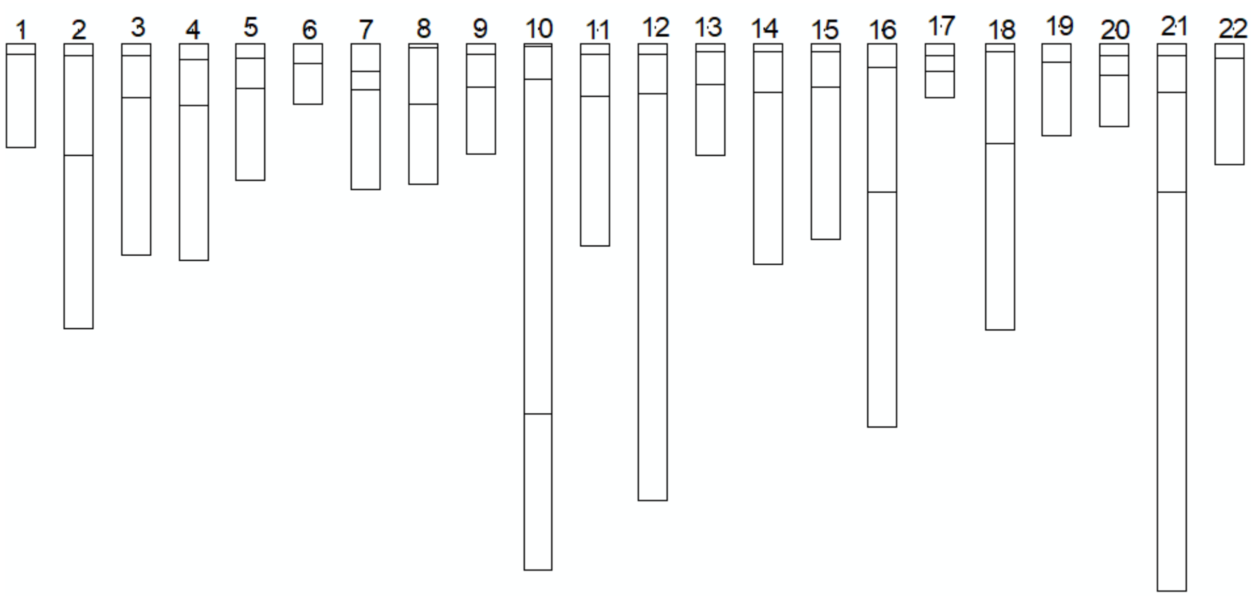

Figure 4.10: VES polygon

- Query 1: "Depth" <=15 AND "Depth" >=5

This query was issued so as to check VES geoelectric layers whose depths falls between 5m and 15m respectively. Thus, if the water is confirmed drinkable, one may decide to drill a well in that location. VES point 1, 2, 3, 4, 5, 7, 8, 9, 11, 13, 14, 15, 16, 18, 21 and 22 have layers that falls in this category.

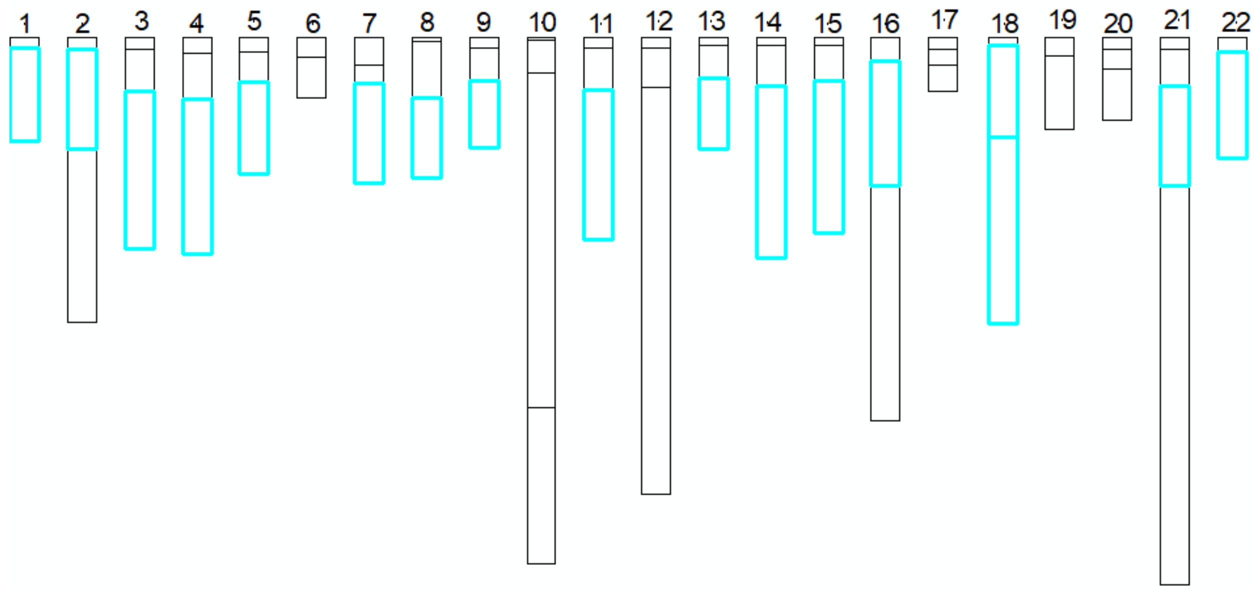

Figure 4.11: Query 1

- Query 2: "Depth_" >=20 AND "Thickness" >=20

This query was issued so as to check VES geoelectric layers whose depth and thickness is greater or equal to 20m. This attributes lead to Salty or saline water. VES points 10, 12 and 21have geoelectric layers that possess high salt or salinity water.

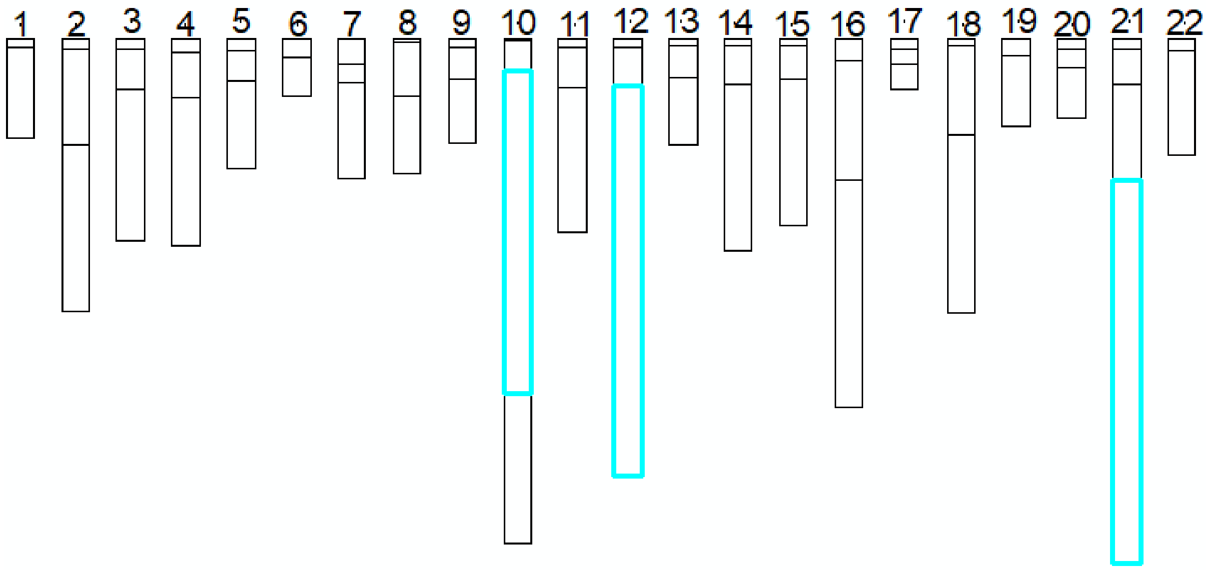

Figure 4.12: Query 2

- Query 3: "Layer_Desc" = Clayed'

This query was issued so as to check VES geoelectric layers whose Layer Description is Topsoil. Upon selecting by attributes, VES points 12, 18, 21 and 22 have some geoelectric layers that possess Clayed.

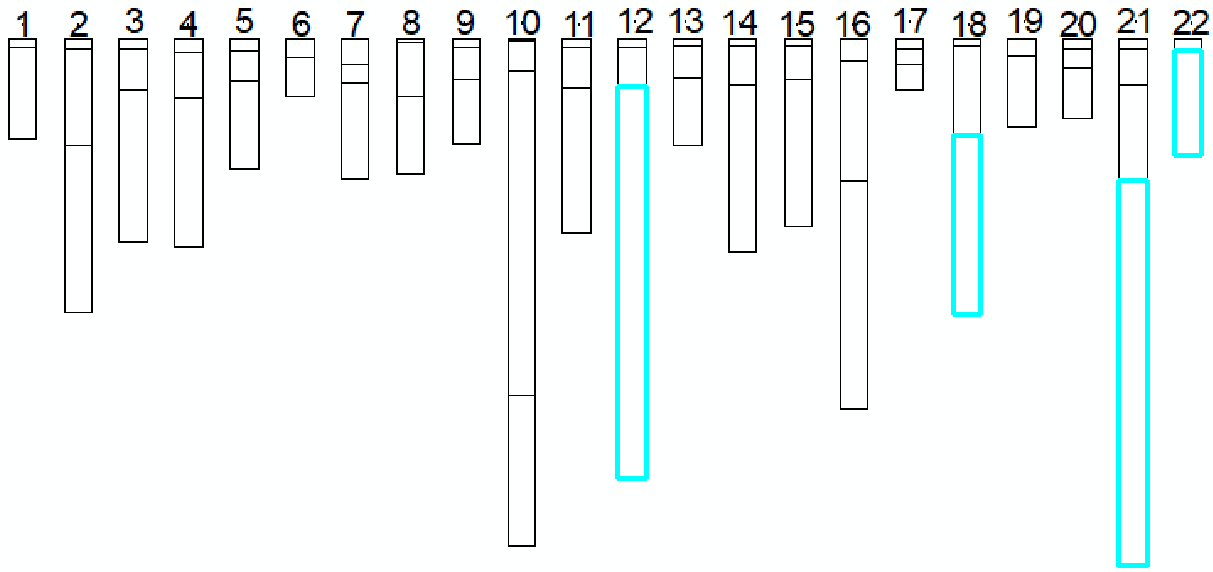

Figure 4.13: Query 3

- Query 4: "LAYER_DESC" = 'Fresh Basement'

This query was issued so as to check VES geoelectric layers whose Layer Description is Fresh Basement. Upon selecting by attributes, VES points 10 has some geoelectric layer that possess Fresh basement.

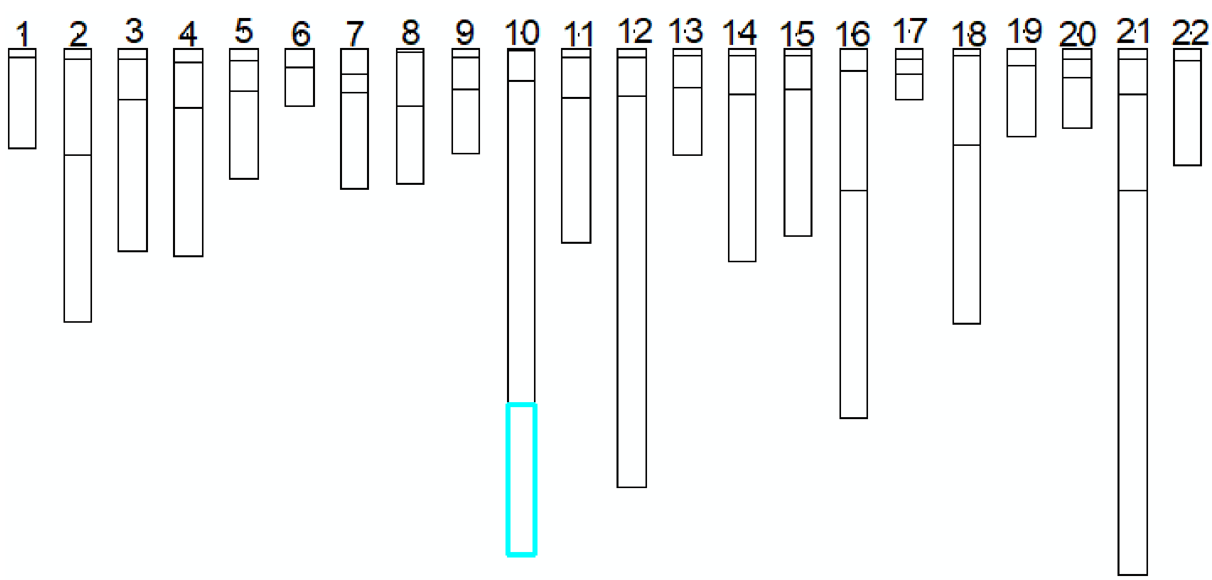

Figure 4.14: Query 4

4.7.2 ISOTHICKNESS OF WEATHERED LAYER

The weathered layer in relation to this study is the thickness of the materials between topsoil and fresh or fractured bedrock. The thickness of this layer varies from 0.1 to 25.6m. The essence of generating the weathered layer Isothickness map is to examine the contribution of weathered basement to aquifer's prospect. VESs 10 and 18 are the two pronounced peaks on the map and this could result in high groundwater potential. VESs 15 and 22 have thicker (medium) weathered layers and could result in medium groundwater potential. The region with thin weathered layer thickness might result in medium to low groundwater potential. VESs 1, 2, 3, 4, 6, 8, 9, 13, and 21points fall in this category.

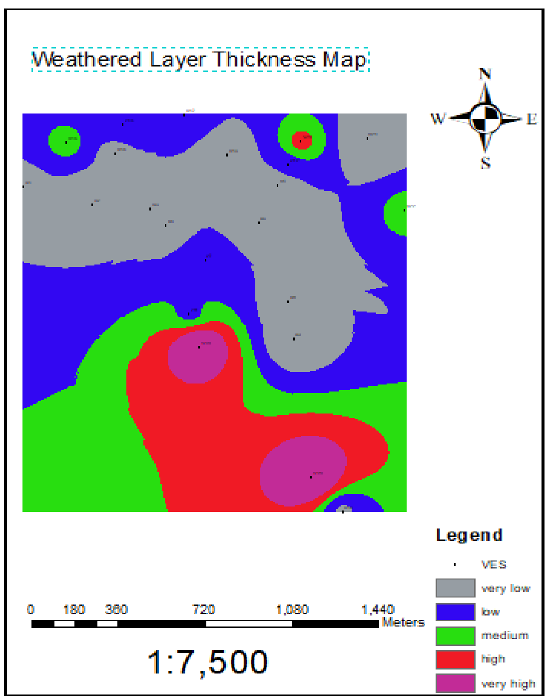

Figure 4.15: Isothickness of Weathered Layer

4.7.3 WEATHERED LAYER ISORESISTIVITY

The weathered layer resistivity as defined in this work is the resistivity of the rock layer between the topsoil and fractured or fresh bedrock. The peak of the aquifer's resistivity (1403.9Ωm) is recorded at VES 9, the high resistivity value associated with these parts is possibly due to the sandy nature of the aquifers which suggests a negligible potential. VESs 1, 12 and 16 have aquifer resistivity range from 21 to 100Ωm which suggests sandy clay aquifer of medium to good groundwater potential. This is probably due to high weathered nature of the weathered basement layer.

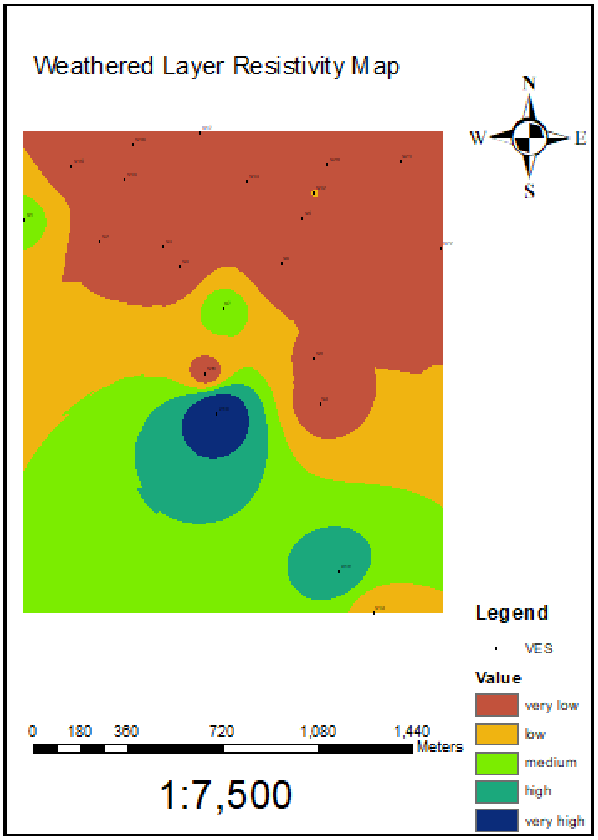

Figure 4.16: Weathered Layer Isoresistivity

4.7.3 OVERALL GROUNDWATER POTENTIAL MAP

The ground water potential map of the study area was prepared by the integration of the layers. It was classified into five classes of Very High Potential, High Potential, Moderate Potential, Low Potential, and Very Low Potential. VESs 15, 20 and 22 regions are associated with high yield of groundwater. VESs 2,3,4,5,6,8,9,10,13,14, and 21 regions are associated with optimum groundwater yield. VES point 1 zone depict very low groundwater.

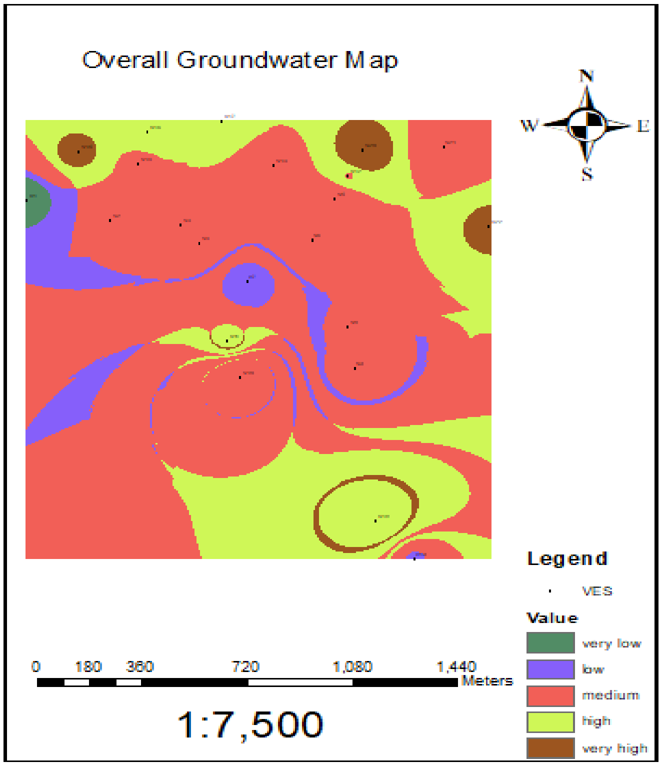

Figure 4.17: Overall groundwater potential map

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.0 CONCLUSION

The best groundwater potential zone can be found in the southwestern region of the study area due to the presence of fractures, swamp soils with a high infiltration capacity and the presence of water bodies primarily responsible for recharging groundwater in any area. The study therefore reveals that; the integration of the thematic maps provides local authorities and planners with direct information about the areas suitable for groundwater exploration. Integration of Remote Sensing, GIS and Hydrogeophysics for ground water potential zones delineation has been proven very efficient, cost effective, time saving, requires less labor. During the weighted overlay analysis, the rankings have been assigned to individual parameter of each thematic map and weights were assigned based on influences. After Overlaying all these layers, the Ground water potential map which is the end product of these research has been duly created.

5.1 RECOMMENDATION

1. The results of this study can serve as guidelines for planning future artificial recharge projects in the study area to ensure sustainable ground water utilization.

2. The result of this study can serve as guidelines to determine depth for drilling wells.

3. Integration of different data layers such as remote sensing, geomorphology and field data in a GIS environment provide means unknot the nature of hardrock aquifers. Spatial and statistical analysis allows us to understand the correlation between different paramaters. Hence this integrated approach of ground water potential assessment in a GIS is highly recommended.

4. The output of this study can also be used to discover regions with low or no ground water or polluted aquifers.

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