INTEGRATED METHODS FOR DELINEATING GROUNDWATER RESOURCE IN ADO-EKITI, SOUTHWESTERN NIGERIA

AKINTUNDE AKINOLA OYEDELE

APRIL, 2017

INTEGRATED METHODS FOR DELINEATING GROUNDWATER RESOURCE IN ADO-EKITI, SOUTHWESTERN NIGERIA

BY

AKINTUNDE AKINOLA OYEDELE

BSc. Physics and Engineering Physics (Ado-Ekiti), MTech. Exploration Geophysics (Akure)

A Thesis in the Department of Geology,

Submitted to the Faculty of Science

in partial fulfillment of the requirements for the award of PhD Degree

University of Ibadan, Ibadan, Nigeria

APRIL, 2017

CHAPTER ONE

INTRODUCTION

1.1 GENERAL BACKGROUND

The growing demand for potable water supply has been a major challenge in Ado-Ekiti, Southwestern Nigeria. Delivery of good quality water by the Ekiti State Water Board to individual consumers in the required quantity and under satisfactory pressure is suspect. Even in areas that are supposedly served by piped water, the supplies to homes are extra-ordinarily intermittent in flow. This inevitably undermines the confidence of consumers, resulting to complaints and possibly the use of water from unhygienic sources. The supplies from the Water Board have proven over the years to be grossly inadequate in meeting the growing potable water demands of this fast developing town.

The responsibility for the supply of potable water to the city assigned to the Ekiti State Water Corporation (EKSWC) is to be met through a supply from Ureje Dam; the only dam in the ancient town. The construction of the dam was completed in 1958 with the primary purpose of storage of water for municipal use in Ado-Ekiti. The dam had a design capacity of 4,950 m^3 per day on commissioning in 1962 (Ebisemiju, 1993).

Olajuyigbe (2010) observed an obvious gap between the water supply from the Ureje Dam and the increasing water needs in the metropolis noting that Ado township barely receiving 750 m^3 daily would require about 16,000 m^3 of water supply per day with an estimated population figure of 209,866 (Ekiti State Department of Population Activities, 2004). The population of Ado - Ekiti rose over the years with National Population Census figures of 158,000 and 308,626 in 1963 and 2006 respectively. With increasing population and urbanization the reservoir has become inadequate to meet the potable water needs of the people. The State Water Corporation has resorted often to rationing of water to the serviced parts of the town (Ebisemiju, 1993, and Ige and Adetunji, 2014).

The study of Olajuyigbe (2010) critically examined some factors responsible for the poor service delivery level of the Ekiti State Water Corporation. The work revealed that adequacy of supply, frequency of pumping of water, response to leakages, adequacy of public standing pipes and appropriate location or distribution of standing pipes among other factors significantly affect the performance level of the Corporation. It was noted, for instance, that the initial pipe network coverage has hardly been extended since commissioning. The paper clamored for an evolvement of sustainable water policy for the state. Bankole (2010) in the Geographical Distribution of Water Supply in Ekiti State affirmed that the central and southern parts of the state are worse off in water supply inadequacies. Ado-Ekiti is located in the central part of the State.

The study area relies mainly on supplies from surface and/or groundwater sources. The Surface water is usually not available all year round owing to the seasonal flow regime of the rivers; and where available and accessible, cannot guarantee the required water quality status required for most domestic activities. Most homes depend on water from hand–dug wells whose overall yield and quality are influenced by the alternating wet and dry seasons among other factors. Some wells turn pretty dry in the prolonged dry season. (Ademola and Afeikhena, 2006, Tinuola and Owolabi, 2007 and Taiwo *et al*., 2011)

Acute shortage of potable water supply is taking an appalling toll on the residents of Ado-Ekiti, causing hardship and untold sufferings to families. Women and children bear the brunt of these sufferings as they commit much time and energy in the daily search for water to meet their domestic consumption demands (Plates 1 and 2).

Plate1: A typical scenario of the daily search for potable water in Ado – Ekiti metropolis (Groundwater Supply Facility provided in honour of Pa Bodunde Adeyanju along Mathew Street, Ijigbo, Ado – Ekiti. November, 2011)

Plate 2: Water-Scarcity-Bites-Harder (March, *2*015)

(**Source:** http://sunnewsonline.com/new/ekiti-water-scarcity-bites-harder/*26 Mar 2015*)

This has detrimental effects on level of environmental sanitation and quality of life of the people. The odd situation is worsening as new areas are opened up in the town. Demand shall be on the increase with increasing population. Water, sanitation and hygiene are also linked to school attendance and performance, safety and security of women and girls, and socio-economic development of communities (UNICEF, 2006 and Ikeji, 2013). The study of Bankole (2010) reported that substantial hours of early part of the day are wasted in search of water as boys, girls and women trek long distances to collect water of varying quality status. Schiffler (2002) lamented that one billion of the world population lack access to safe drinking water.

The dismal performance level of the Water Corporation (indicated by the gross failure of the Corporation to meet the soaring water needs of the populace coupled with economy of scale/ infrastructural decay) has resulted in geometric demand for groundwater in the metropolis. The development of groundwater facilities/schemes in the form of tube wells and boreholes with minimal cost compared to the costlier surface water development stands out as the credible option to the epileptic pipe-borne water supply from reservoirs and dams. Groundwater is said to be a more dynamic renewable natural resource. It is acclaimed as the primary source of potable water supply in many developing and developed countries for domestic, agricultural and industrial applications (Chowdhury *et al*., 2010; Talabi and Tijani, 2011; Magesh *et al*., 2012; Forkuor *et al*., 2013; Fashae *et al*., 2014; Ghosh *et al*., 2016)

Unlike rivers, streams and shallow hand-dug well waters which are highly susceptible to contamination through anthropogenic sources, groundwater is significantly protected from surface pollutants as the earth media (composed of different subsurface layers) act as natural filter to infiltrated water. It very rarely needs to be treated before consumption. It is considerably cheap to develop. Groundwater sources provide a reasonable constant supply that is most unlikely susceptible to drying up under severe drought conditions much as they are less vulnerable to surface contamination (Olayinka and Olorunfemi, 1992, Olorunfemi *et al.*, 1999 and Ojo *et al.*, 2015).

According to Falconer (2003) water is one of the world's most precious resources. However, urbanization presents increasing challenges of how to ensure adequate water supplies and a suitable water environment for future generations worldwide. Such an environment should place premium on the groundwater quality. Mancosu *et al.* (2015) acknowledged water as the most important resource for life. The study noted that provision of water has been a central issue on the international agenda for several decades. Present water shortage remains one of the primary world issues.

Tinuola and Owolabi (2007) observed an increase in environmental pollution with urbanization in Ekiti State. The highest percentage of pollution was reported in Ado-Ekiti, with an alert on possible health hazards to the residents. Ige and Adetunji (2014) examined the relationship of some socio-economic factors and household sanitation in Ado-Ekiti. An indifferent status was observed for the general attitude of the residents towards household sanitation and waste disposal.

Increasing population with the attendant human activities geometrically leads to increasing demand for groundwater since the creation of Ekiti State in October, 1996 and the establishment of the State Capital at Ado-Ekiti. The reliance on groundwater is to ensure availability of significant quantities of water of a high quality. Groundwater is a vital natural resource for the reliable and economic provision of potable water supply in both urban and rural environment (Magesh *et al.*, 2012 and Ige and Adetunji, 2014).

Groundwater is expected to form a significant part of the water resources of Ado-Ekiti and its environs. Efforts by government and individuals to sink boreholes have not been very successful. Geologically, Ado-Ekiti is underlain by hydrogeologically challenging crystalline basement rocks. In a typical hard rock terrain, the geological sequence normally encountered is characterized by the existence of basement rock overlain by variable unconsolidated materials referred to as overburden. The hydraulic properties of the hard rocks are characterized by extreme variations over short distances which often limit water development in the area to low-yielding well (Wright, 1992, Adiat *et al*., 2009 and Ojo *et al*., 2015)

In the early 1990s, Government Agencies, DFRRI (Directorate for Food, Roads and Rural Infrastructure) and WATSAN (The Ekiti State Rural Water Supply and Sanitation Agency) provided a few rural communities in Ado-Ekiti with boreholes. Assessments of these facilities indicate that a good proportion of them are either no longer functioning or plagued by the challenge of the low yield.

Wright (1992) put the frequent failure rate commonly in the range 10-40%, with the higher rate in drier regions or where the weathered overburden is thin. WATSAN reported a 54% failure rate in the previously drilled boreholes in the State. This account was attributed to the poor understanding of the hydrogeological characteristics of the crystalline basement rocks occurring in the area (Bayowa *et al*., 2014). According to Ojo *et al*. (2015) the poor understanding of the hydrogeological characteristics of the Basement Complex environment is significantly responsible for borehole failures in the terrain.

Ogundana *et al*. (2015) conducted a preliminary assessment of primary causes of borehole failure in basement complex terrains using Afe Babalola University, Ado-Ekiti (ABUAD) as a case study. A total of fourteen boreholes were studied. Four boreholes (representing 29%) are productive and in-use, while the remaining ten (representing 71%) are out-of-use and abandoned largely for reasons of low yield. The failed holes were unable to support continuous flow of water beyond 5 minutes.

Notably, major constraints to the development of basement aquifers include the complex and erratic nature of groundwater occurrence and movement in the crystalline basement terrains, the discontinuous nature of the basement aquifer system and attendant high rate of well/borehole failure particularly in the absence of detailed pre-drilling hydrogeological/hydrogeophysical investigations. Fashae *et al*. (2014) noted that the occurrence and movement of groundwater in a crystalline terrain depends on the degree of weathering and extent of fracturing of the bedrock rocks. Olayinka and Olorunfemi (1992), Ariyo and Adeyemi (2009) and Olorunfemi (2009) upheld that most often, the occurrence of groundwater in the Basement Complex terrain is localized and confined to weathered/fractured zones. The aquifers respond to abstraction in discontinuous fashion, due either to discontinuities or barrier boundaries within the fracture system being tapped or to the constraints of the low-permeability regolith. A thorough and definitive evaluation of the overall resource and aquifer occurrence must be done to assist development efficiency and longer-term sustained control.

It is evident that the exploration for groundwater in hard rock terrains is a complex enterprise. To overcome this complexity, the integrated approach based on the use Vertical Electrical Sounding (VES), Remote Sensing (RS) and Geographical Information Systems (GIS) lends itself as an efficient and effective method for mapping potential zones that are relevant to the development of groundwater resources (Rao *et al*., 2003, Venkatewaran *et al*., 2014 and Ojo *et al*., 2015).

Olayinka and Barker (1990), Olorunfemi *et al*. (1999), Afolayan *et al*. (2004), Owen *et al*.(2006) and Ariyo and Adeyemi (2009) among several workers acknowledged that the Electrical

Resistivity Method has the widest adoption in groundwater exploration among the various geophysical methods with its usefulness in bedrock delineation, lithological boundary differentiation and determination of structural trends.

The large dependence on groundwater resources puts premium on its quality status. The method could effectively be used for assessing the potential risk of groundwater contamination, as neither the structure nor the dynamics of the soil is disturbed. Vertical Electrical Resistivity Sounding offers a compact tool for locating promising areas for water boreholes/wells amidst prevailing attitudes/disposition of the site. It has proved very popular with groundwater studies due to the simplicity of the technique, the ruggedness of the instrumentation and the success rate.

Remote sensing (RS) provides an opportunity for detailed observation and more systematic analysis of various geomorphic units, landforms, lineaments and drainages, due to its synoptic and multi-spectral coverage of a terrain. It is increasingly applied in prospecting for groundwater potential zones mainly to identify and outline different ground features that may serve as direct or indirect indicators of the presence of groundwater resources (Ndatuwong and Yadav, 2014). Remote Sensing is considered to be fascinating as it is less expensive and applicable even in inaccessible areas (Rao, 2006, Fadahunsi, 2010 and Fashae *et al*., 2014). The use of remote sensing and GIS techniques is a fast emerging field in groundwater resource identification, mapping and sustainable development. Singh *et al.* (2013) remarked that Geospatial techniques provide rapid and cost - effective tools for producing valuable geo-data (geology, geomorphology, land-use, lineaments/structures and slope, etc.) that can be used in mapping groundwater potential zones in hard-rock terrain. GIS technologies are valuable tools in developing environmental models through their specialized features of data storage, management, analysis, and display.

GIS tools provide unique and powerful means for obtaining spatio-temporal information about earth resources within a short time. Data of relevance can be integrated by weighted index overlay method to produce appropriate models (Hung *et al.*, 2005, Gupta and Srivastava, 2010 and Badamasi *et al.*, 2016).

A reduction of failure rate of over 82% recorded for boreholes in Northern Nigeria to less than 20% failure rate was achieved using geoelectric technique and a combination of geological and photogeological inspection (Hazell *et al.*, 1988, Reynolds, 1997 and Amadi and Olasehinde, 2010.). Prabu and Rajagopalan (2013) discussed mapping of lineaments for groundwater targeting and sustainable water resource management in hard rock hydrogeological environment using RS – GIS. The work focused on developing the remote sensing and GIS methodology for regional groundwater potential evaluation at the Vaigai sub-basin in the Western Ghats, India**.** Fashae *et al*. (2014) employed an integrated GIS and remote sensing approach for the delineation of groundwater potential zones in the crystalline basement terrain of Southwestern Nigeria. The study involved integration of thematic layers of drainage density, drainage proximity landuse, lineament density, geology, geomorphology, rainfall, slope and soil based on weights assignment and normalization with respect to the relative contribution of the different themes to groundwater occurrence. Ojo *et al*. (2015) effectively integrated geomorphological, geological and geoelectrical data in a GIS environment to assess the groundwater potential of the Akure metropolis.

Badamasi *et al.* (2016) utilized the techniques of remote sensing and GIS to delineate the groundwater potential zones in Zaria, North Central Nigeria. Frequent occurrences of well/borehole dry-up were observed in some areas within the study area. The study demarcated good / very good groundwater promising zones within the alluvium deposits along river channels and vegetated areas. The very low groundwater zones were delineated in the region of low lineament density, high drainage density, high slopes, luvisol, built-up and rock outcrops.

According to Magesh *et al*. (2012), the integration of remote sensing with GIS for preparing various thematic layers, such as lithology, drainage density, lineament density, rainfall, slope, soil and land-use with assigned weightage in a spatial domain will support the identification of potential groundwater zones. The methodology will assist in assessing, monitoring, and conserving groundwater resources.

Prospective groundwater zones are poorly defined in the hard rock terrain. The use of satellite data, hydro-geophysical data, conventional maps and rectified ground truth data would permit establishment of the base line information for groundwater potential zonation in the basement complex terrain (Chowdhury *et al*., 2010; Talabi and Tijani, 2011; Fashe *et al*., 2014; Bayowa *et al*., 2014; Ojo *et al*., 2015).

Access to safe drinking water for every individual regardless of the economic and social status is one of the objectives of the World Health Organization (WHO). Inadequacy or absence of good water supply has been found to have a direct bearing on the spread of certain water-borne diseases. Large portions of the populace in developing countries die annually as a result of water borne diseases such as cholera, typhoid, hepatitis, diarrhoea, etc. Water quality is indicated by the constituents dissolved or contained within the water. Physico – chemical Analysis of the groundwater is thus imperative (WHO, 2008, Gbadebo *et al*., 2010 and Ikeji, 2013).

Harnessing groundwater has been compounded by the poor understanding of the hydrogeological characteristics of the hard-rock terrain occurring in Ado-Ekiti. The complex and erratic nature of groundwater occurrences in the crystalline basement terrains suggests the attendant high borehole failure rate in the environment when groundwater development in form of boreholes and deep wells is undertaken without appropriate pre-drilling hydrogeological/hydrogeophysical investigations. The discontinuous nature of the basement aquifer system makes detailed knowledge of the subsurface geology, its weathering depth and structural disposition through geologic and geophysical investigations inevitable (Adiat *et al*., 2009 and Jayeoba and Oladunjoye, 2013). Detailed characterization of basement aquifers and delineation of groundwater potential zones in the study area is thus imperative for optimum results in sustainable groundwater development. Improvements in the understanding of the various groundwater indicators (quantity and quality) and relationships will be fundamental to the planning and management of groundwater resources in crystalline basement terrain and reduction of overall development cost. A rich database needs to be developed for sustainable groundwater development and management for the region and similar terrains.

1.2 DESCRIPTION OF THE PROJECT AREA

The study area, Ado-Ekiti, Southwestern Nigeria, lies within latitudes 7° 32′ and 7° 42′ N and longitudes 5° 9′ and 5° 22′ E (Figure 1.1(a)). It is bounded in the North by Irepodun/Ifelodun Local Government Area, in the West by Ijero and Ekiti West Local Government Areas, in the South by Ekiti Southwest, Ikere, Emure and Ise-Orun Local Government Areas and in the East by Gbonyin Local Government Area (Figure 1.1(b)). The topography of the area is rugged due to the presence of crystalline basement rocks like charnockite and quartzite ridges which rise abruptly above the surrounding country rocks (Figure 1.2).

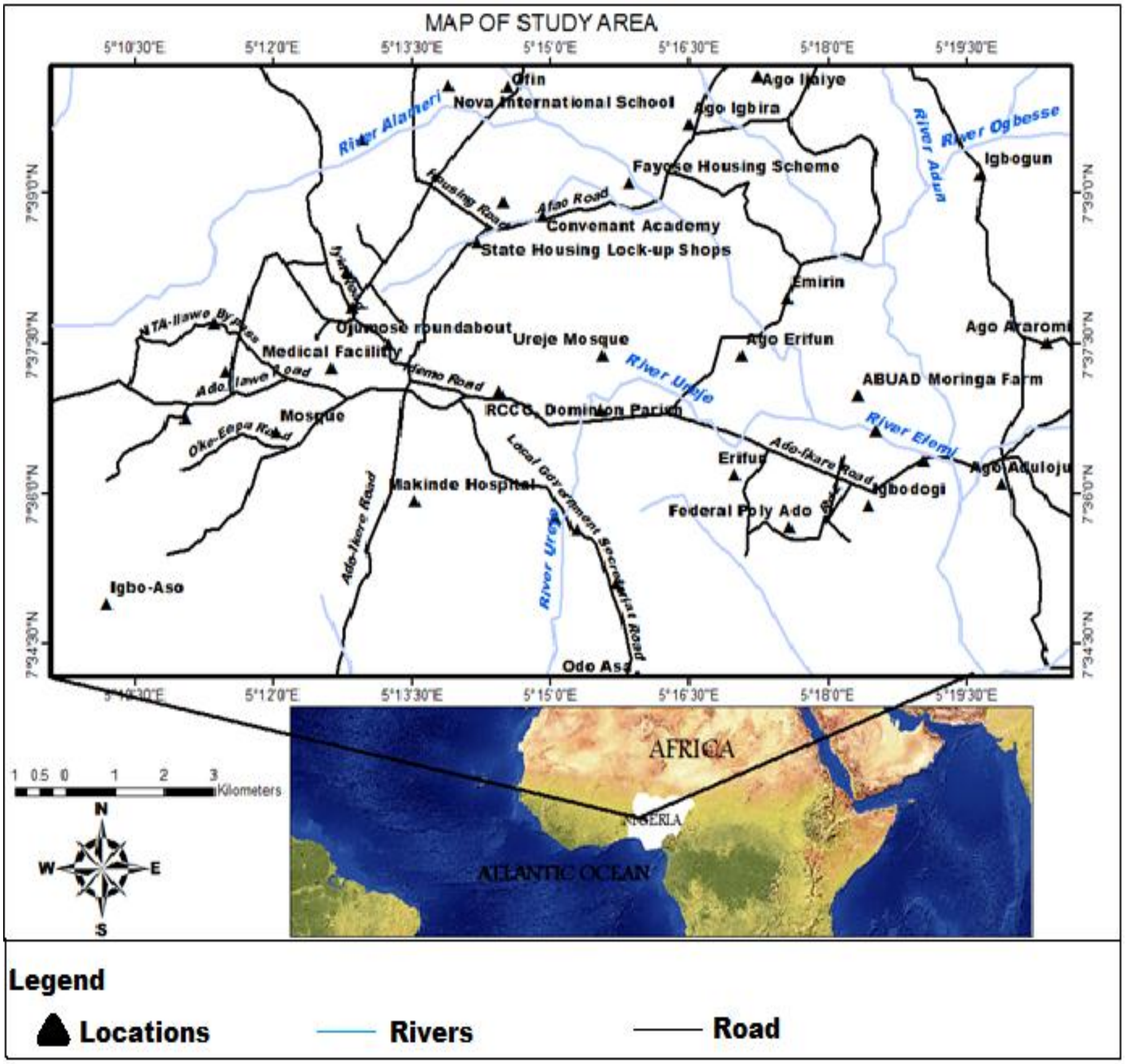


Figure 1.1(a): Location Map of Ado-Ekiti - the Study Area (adapted from google map)

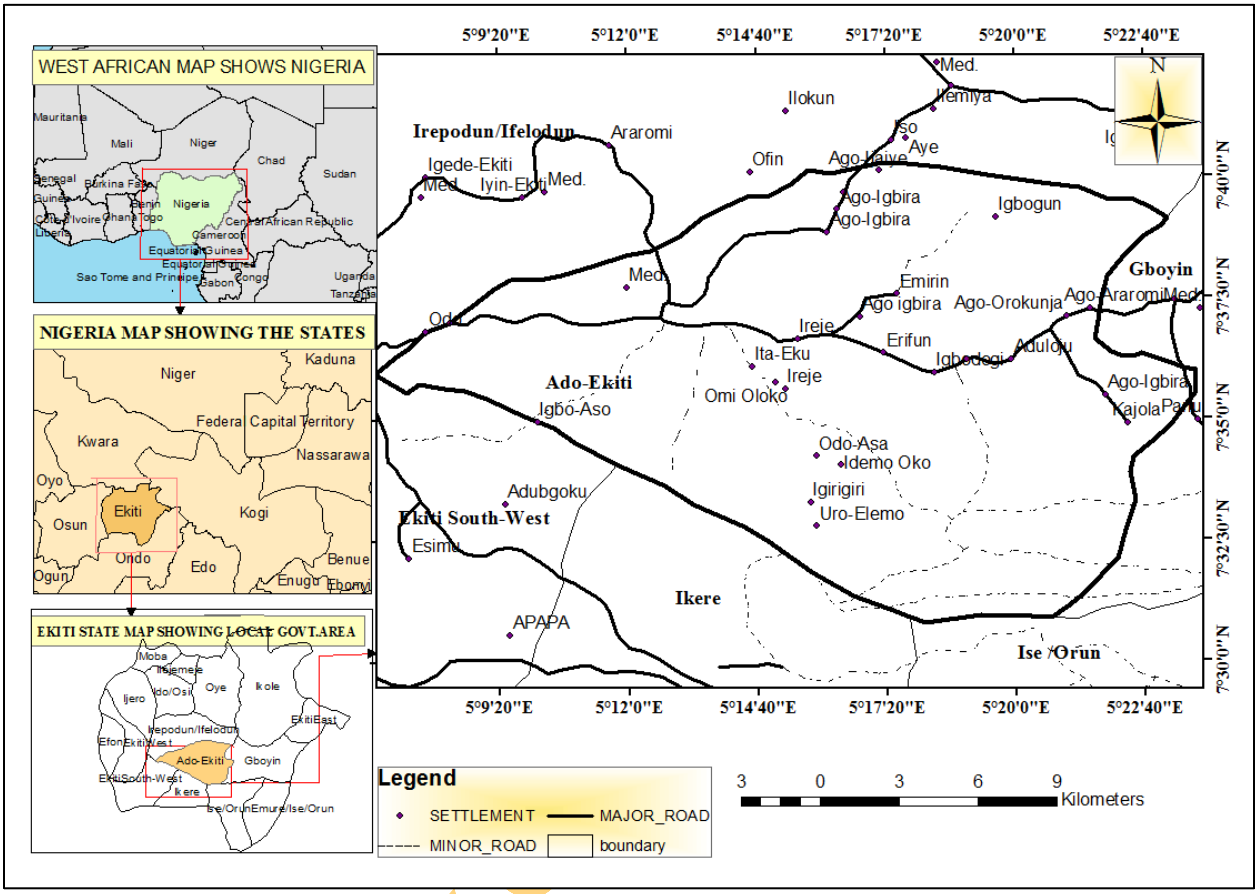


Figure 1.1(b): Location Map showing Ado-Ekiti Area (adapted from google map)

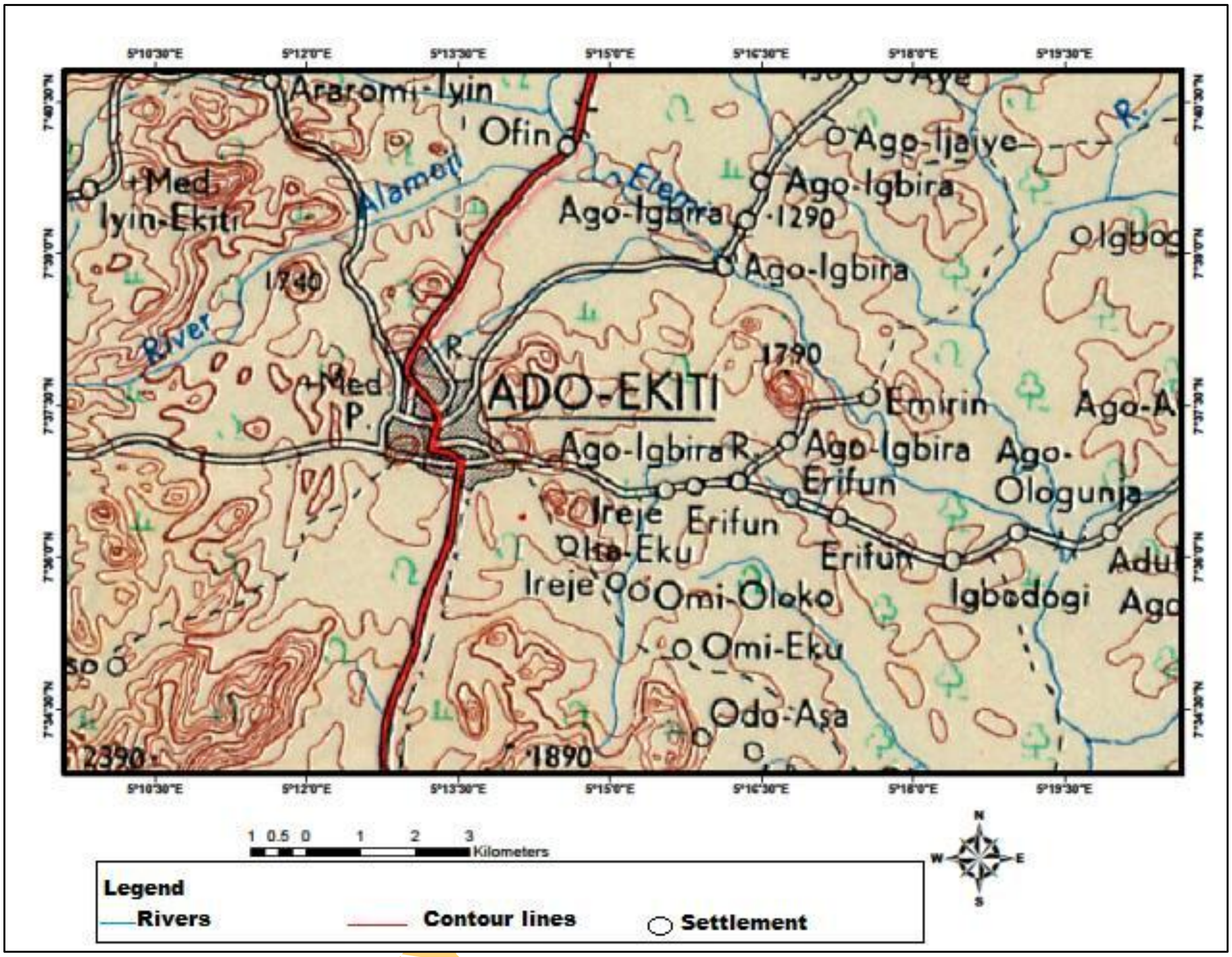


Figure 1.2: Topographical Map of the Ado-Ekiti (Adapted from Federal Surveys, 1966)

Ado-Ekiti experiences a tropical climate with distinct wet and dry seasons. Temperature is almost uniform through the year with a little deviation from the mean annual of 27 °C. Rainfall is highly seasonal with the well-marked wet and dry seasons and double maxima as a result of break in August. The rainy season lasts from March to November with a break in August when rainfall is relatively low. The dry season lasts from November to early March. Most of the rainfall events occur in the form of high intensity showers of short duration. Light showers of less than 10 mm/hr account for only 25% of all rainfall intensities. About 75% of all rainfall events are of moderate to high intensities (Bankole, 2010 and Olajuyigbe, 2010).

The major rivers draining the area include Alamoji and Ireje. Both rivers are major tributaries of River Elemi. The general direction of flow is due east. These rivers are seasonal. River Ireje, Elemi, Omisanjana and Awedele Stream flow into River Ose and River Owena and empty into the Atlantic Ocean (Ebisemiju, 1993).

1.3 AIM AND OBJECTIVES OF THE STUDY

The central goal of this study is to utilize integrated investigations involving Hydro-geophysics, Remote Sensing and Physicochemistry in delineating groundwater resource in Ado-Ekiti.

The objectives of the study are to:

(i) produce regional structural lineament map and other terrain features of the study area from remotely sensed data.

(ii) delineate the geoelectric sequence beneath the VES stations

(iii) delineate subsurface structures favourable to groundwater accumulation

(iv) determine the hydrogeological characteristics favourable to groundwater resources development,

(v) delineate the major groundwater recharge / discharge zones, the groundwater flow direction and the groundwater divides in the metropolis to ensure groundwater resource protection,

(vi) evaluate the Aquifer Protective Capacity of Overburden Units; required for groundwater resource protection,

(vii) demarcate regional groundwater potential areas

(viii) evaluate groundwater quality

(ix) establish geospatial database for the sustainable Development and Management of Groundwater Resources in the study area

1.4 GEOLOGY OF THE STUDY AREA

Ado-Ekiti falls within the basement complex of south-western Nigeria (Rahaman, 1988). The geology is therefore dominated by the crystalline rocks of the basement. The rock sequence in the area includes pegmatite and aplites, granitite rocks, charnockitic rocks, the quartzite series and gneisses and migmatites.

The granitic rocks occupy the western and north central parts, the charnockitics rocks are found in the central and eastern parts while the gneisses and migmatites occur in the eastern part. The quartzite occurrences are located in the western and central portion as elongated bodies within the granitic and coarse grained charnockitic rocks (Figure 1.3).

The Gneisses and Migmatitic Rocks: The gneissic rocks in this area form the country rock into which the granitic and charnockitic rocks intruded. They occur as low-lying exposures. Xenoliths

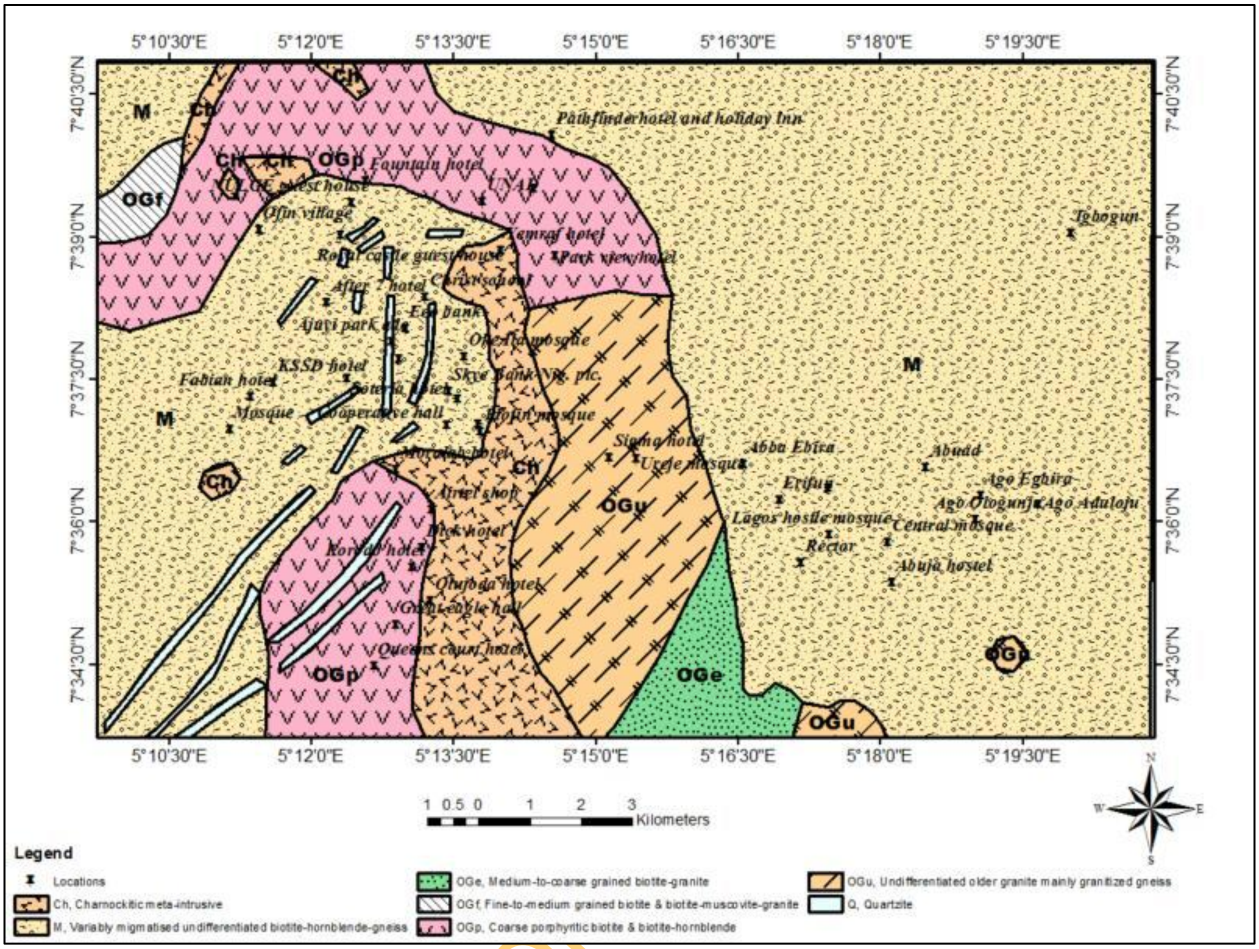


Figure 1.3: Geological Map of Ado Ekiti Area (after NGSA; Geological Map of Akure Sheet 56, 1966)

of these units are frequently found in the granitic and charnockitic bodies. The gneisses includes banded gneiss (43%), granite (35%) and the early gneiss (22%) (Olarewaju, 1987).

Mineralogically, the dark bands consist of melanocratic minerals like biotite and hornblende while the lighter bands consist of leucocratic minerals like quartz and Plagioclase feldspar.

The Quartzite Series: The quartzite series are the most obvious meta-sedimentary rock in the area. The quartzite occurs as elongated bodies within the charnockitic, granitic, gneissic and migmatitic rocks. They are prominent as narrow ridges. Texturally, they vary from massive crystalline quartzite to highly foliated quartz schist. Muscovites are commonly present as flakes and define schistocity characteristics of the unit. Some schistose quartzites are rich in muscovites. The quartzites have a simple mineralogical composition consisting of predominantly quartz and muscovite with accessory tourmanile, biotite and garnet.

Charnockitic Rock: These are the coarse grained type, massive fine grained varieties. These rocks occur generally as low lying outcrops with smooth rounded boulders and few hills all forming oval to sub-circular and elongated bodies. The coarse grained charckititic rocks occupy the central portion of the study area. The coarse grained type is the most prominent and is found in association with coarse grained porphyritic granites. This unit also houses some xenolithic inclusion of fine grained charnockites. The fine grained type occurs between the coarse grained and gniessic fine grained charnockitic rocks

The gneissic fine grained units re distinguished by staining of potash feldspars which reveals the presence of strong foliation commonly conformable to surrounding rocks. The charnockitic rocks are generally dark greenish grey with bluish quartz and greenish feldspars. Plagioclase feldspars, antiperthite, biotite and hypersthene are the other minerals present. The field relationship of different rock units indicates that the coarse grained variety is the youngest.

The Granitic Rocks: The granitic rocks which are member of the older granite suite occupy 25% of the total area of study. The textural characteristics vary from fine to medium to coarse grained. On the basis of texture, three principal varieties are recognized in the area. These are fine grained biotite granites, medium to coarse grained non-porphyritics biotite-hornblende granite and the coarse porphyritic biotite-hornblende granite. These rocks and especially the medium-coarse non-porphyritic biotite-hornblende granite and coarse porphyritic biotite-hornblende granite form inselberges which are so characteristic of this area such as behind the Specialist Hospital, Ado-Ekiti. The fine grained biotite granites occur as small dykes and venus in the other granitic units. This indicates that unit is later than the two other prominent units. The mineralogical composition of the fine grained biotite consists of feldspars, quartz, amphibolites and biotite. Biotite is the dominant ferromagnesian mineral present. The feldspars are well rounded and pinkish in colour.

The medium-coarse grain non- porphyritic biotite-hornblende granites are characterized by large abundance on feldspars in a ground mass rich in quartz, biotite and hornblende. The color is normally pinkish, white and yellowish-brown in some localities. Massive and gneissic varieties also occur.

The foliation is defined by the alignment of biotite and parallelism of some large phenocrysts of feldspars. This unit is the most prominent in Ado-Ekiti. The coarse porphyritic biotite-hornblende granite is the most typical among the three varieties. The mineralogical composition includes microcline megacryst in a fine to medium grained matrix. It consist of potash feldspar dominantly microcline and microperthites, quartz, sodic plagioclase feldspar, biotite-hornblende. The field relationship between these varieties and with the other rocks units in term of actual contact is very difficult to decipher. This is due mainly to thick vegetation and urbanization. The geological boundaries are therefore inferred.

Pegmatite and Applite: The pegmatite varies from few a centimeters to about 0.5 meters in width and several meters in length and occurs as guilds in the granitic and charnockitic rocks in Ado-Ekiti area. The mineralogy of the pegmatite are generally simple; quartz, microcline and biotite. Magnetite exists as large crystals in some few pegmatite dykes along new Ado-Iyin road. Aplitic dykes of variable width (5 cm - 0.5 m) occur within the granitic and charnockitic rocks. Their mineralogy is commonly alkali feldspar quartz and hornblende.

1.5 HYDROGEOLOGY OF THE BASEMENT COMPLEX TERRAIN

Ado-Ekiti is underlain by the Precambrian Basement Complex rocks of Southwestern Nigeria. The metropolis is drained by River Ireje, Elemi, Omisanjana and Awedele Stream.

According to Malomo *et al.* (1990) the aquifers in the region are formed primarily from the mantle of superficial deposits above weathered rock and secondarily by fractures in the rock itself. The superficial deposits are derived mostly from *in-situ* weathering of the crystalline rocks and form a fairly permeable overburden. Their thicknesses vary widely from place to place and are controlled by local and regional factors such as weathering resistance of rocks, intensity of fracturing (density), fracture pattern, etc. Well yield is a function of the saturated thickness of fracturing. The depth of weathering is usually irregular and may cause variation in well yields from place to place.

Olayinka and Olorunfemi (1992) also held that the crystalline basement rocks are generally of low porosity and permeability, and as such, have no water storage capacity in their fresh (unaltered) form; consequently, their groundwater resources are limited and commonly restricted to features produced by weathering and tectonic processes. Aquiferous units in the basement complex terrain are mainly found in the thick and porous weathered overburden (saprolite zone) and the fractured part of the bedrock.

Most crystalline rock areas of Nigeria are located in areas of high relief; as a result runoff water is high and infiltration rates very low (Ariyo and Adeyemi, 2009). Basement complex area of Nigeria contains vast quantities of groundwater resources in the weathered and fractured zones overlying the fresh basement rocks and in the overlying alluvium which is recoverable as well water, base flow and springs. However, the amount of water depends on the rock type, structure, degree of decomposition and fracturation of bedrock (Ajayi and Adegoke, 1988).

Shemang (1993) gave the factors considered for a good aquifer formation out of the basement complex rocks and their weathered derivatives to include high annual rainfall and temperature which results in the formation of deep weathered zones, high density of fractures and low density of clay minerals in the weathered rocks.

Tropical weathering and erosion affect the basement rocks of the Southwestern Nigeria. The rocks in the basement complex of Southwestern Nigeria, have undergone polycyclic metamorphic deformation leading to folding, foliation, faulting and fracturing. In the basement complex terrain, both the regolith and fractured bedrocks have been described as the aquifers for groundwater. They are structurally controlled (Clark, 1985).

The prolonged *in-situ* weathering under tropical conditions has produced a lithologic sequence of unconsolidated material whose thickness and lateral extent vary extensively. The localization of groundwater within the lithologic zones is controlled by a number of factors such as type of parent rock, depth, extent and pattern of weathering, thickness of the weathered materials, the sand/clay ratio and the degree of fracturing, fissuring and jointing (Olaniyan and Gwary, 2015 and Eduvie and Olaniyan, 2013).

1.6 THE RESEARCH OUTLINE

The outline of the research work is given as follows:

(i) Literature review

(ii) Data acquisition (RS, hydro-geoelectric and Physico – chemical)

(iii) Data processing and Interpretation

(iv) Preparation of thematic layers

(v) Integration of thematic maps

(vi) Creation of spatial database for the groundwater resources development and management of the study area.

(vii) Discussion of Results, Conclusion and Recommendations.

1.7 JUSTIFICATION

It has been recognized that the exploration for groundwater in hard rock terrains such as Ado - Ekiti could be a tasking enterprise. Augmentation of potable water supplies in the metropolis could be accomplished using the integrated approach involving Remote Sensing, Hydro-geoelectrical Investigations and Geographical Information Systems (GIS). Groundwater potential zones, along with zones of water quality suitable for domestic purposes, could be delineated and classified. The DC resistivity method is appropriate as it has a high near surface resolution. The inclusion of remote sensing will permit a wide coverage and overcome the constraint of inaccessibility in some parts of the study area. Physico – chemical Analysis will provide a basis for water quality assessment. With the implementation of GIS, large volume of geospatial data and information are maintained in a standard format, revised and updated with additional features. Sustainable development and management are thus facilitated at real time.

CHAPTER TWO

LITERATURE REVIEW

2.1 Previous Works

Various hydro-geophysical investigations had been carried out in the Basement Complex of Nigeria and other similar hydro-geological terrain. These works mainly utilized conventional geologic/geophysical techniques.

Olorunfemi and Olorunniwo (1985) examined the relevance of the overburden coefficient of electrical anisotropy in lithological differentiation in a typical basement complex area. The authors concluded that irrespective of the overlap in the values for igneous and metamorphic overburden materials, the slight contrast may be used in broad lithological differentiation of the bedrock.

Ogunkoya (1987) investigated the potential groundwater discharges and safe yields of drainage basins in the basement complex of Southwestern Nigeria. From the study, it was observed that occurrence of groundwater and its yield in the basement complex terrain depend on the thickness, lateral extent and lithologic properties of the saprolite, and the degree and extent of fissuring of the fresh-bedrock. The study showed that location of wells by mere intuition brought about the low success ratio of boreholes/wells in the basement terrain; and suggested hydro-geophysical survey as one of the effective means of groundwater prospecting methods.

Palacky (1989) also showed that the resistivity of saprolite (or weathered layer- the layer overlying the fresh bedrock directly) can be used as a means of lithological differentiation in the basement complex area where the weathered layers have not been removed by erosion. The geoelectric parameters enumerated in the Precambrian Terrains in the Republic of Upper Volter were adjudged quite relevant in areas where the basement rocks were concealed.

Olayinka (1992) upheld that the occurrence of the groundwater in the basement complex terrain is highly localized and unpredictable and emphasized the need to employ a scientific approach in siting boreholes. In this regard, the use of geophysical techniques, mainly Vertical Electrical Sounding (VES) has been shown to be cost effective, accounting for only about 10% of the total borehole cost.

Olorunfemi and Fasuyi (1993) identified five aquifer types in their study of the Aquifer types and the geoelectric / hydrogeologic characteristics of part of the central basement terrain of Nigeria (Niger State). These included the weathered aquifer; the weathered/fractured (unconfined) aquifer; the weathered/fractured (confined) aquifer; the weathered/fractured (unconfined)/ fractured (confined) aquifer and the fractured (confined) aquifer. The mean groundwater yield for the aquifer types varies from 0.83 L/s for the weathered layer aquifer to 3.0 L/s for the weathered/fractured (unconfined)/ fractured (confined) aquifer.

Idowu *et al*. (1998) carried out investigation of groundwater occurrence in the Southwestern Nigeria Basement Complex. The study established that most weathered rock materials are clayey, and consequently have poor permeability. It was asserted that the weathered rock materials characterized by lowest quartz content could not provide medium for the quantities of extractable groundwater.

The work of Olorunfemi *et al.* (1999) utilized lineament, static water level analysis and geoelectrical investigation to evaluate the groundwater potential of the Akure Metropolis, Southwestern Nigeria. The study broadly classified the metropolis into low, medium and high groundwater potential zones.

Eduvie and Olabode (2001) evaluated the aquifer potential in the basement complex of southern part of Kaduna State, Nigeria, using geoelectric sounding data. It was observed from the study that the difficulties in exploration and exploitation usually encountered in groundwater development in the basement terrains, where aquifer units are both isolated and compartmentalized, require the use of GIS technique, which could integrate relevant multidisciplinary hydro-information for sustainable groundwater exploitation and development.

Rao *et al.* (2003) adopted the Schlumberger VES of electrical resistivity method to delineate the subsurface lithological configuration, aquifer characteristics and depth to bedrock. Groundwater potential zones and recharge pockets were identified based on hydro-geological data and geoelectrical data in the investigations made for groundwater exploration and artificial recharge for groundwater augmentation in Champavathi River Basin area (CRB), Vizianagaram District of Andhra Pradesh under the Eastern Ghat Mobile Belt (EGMB) consisting of Precambrian formations of high grade metamorphic rocks, charnockites, quartzites, migmatites and calc-granulites. Feasible groundwater pockets like valley fills, weathered zones and fractured zones were delineated in the study area. The study further demonstrated the application of the Dar Zarrouk parameters (transverse resistance (T), longitudinal conductance (S) and coefficient of anisotropy (λ)) in hydrogeophysical investigations.

Oladapo *et al.* (2004) carried out Schlumberger vertical electrical soundings at the Ondo State Housing Corporation Estate, Ijapo, Akure. Corrosivity, isopach, coefficient of anisotropy and total longitudinal unit conductance maps were generated from the combination of first and second order geoelectric parameters. The result reasonably provided a basis for which groundwater potential zones were appraised for safety in case industrial facilities are planned for areas adjoining the estate under study.

Braga *et al.* (2006) conducted Resistivity (DC) measurements using the technique of the vertical electrical sounding (VES) – Schlumberger array applied to environmental studies with the objective of investigating groundwater conditions in the vicinity of Canoas/RS, Brazil. The study showed a geoelectrical identification of the lithology and an estimate of the relationship between the resistivity and Dar Zarrouk parameters (transverse unit resistance and longitudinal unit conductance) with the properties such as aquifer Transmissivity and protection of groundwater resources. It suggested zones for the installation of monitoring wells.

Mallam and Emenike (2008) reported Preliminary Findings of Subsurface Characteristics From DC Resistivity Survey of The Federal Capital Territory (FCT), Nigeria. The survey was aimed at determining the geoelectric parameters of the subsurface layers, mapping the bedrock relief and hence the subsurface structural disposition. The structural trend maps delineated series of bedrock ridges and depressions within the survey area with implications for groundwater development and engineering construction.

Ariyo and Adeyemi (2009) examined the Role of Electrical Resistivity Method for Groundwater Exploration in Hard Rock Areas with a Case Study from Fidiwo/Ajebo Areas of Southwestern Nigeria essentially to determine the geoelectrical and hydrogeological characteristics of the aquifers present in the area. The work underlined the usefulness of the electrical resistivity method as a potential tool in solving the complex geo-hydrological problems associated with groundwater occurrence and its development in a typical hard rock terrain.

Ehirim and Nwankwo (2010**)** observed that groundwater as the main source of potable water supply for domestic, industrial and agricultural uses has been under intense pressure of degradation and contamination due to urbanization, industrial and agricultural related activities stressing that the impact of this trio on soil and groundwater has been alarming with years of devastating effects on humans and the ecosystem. The study characterized the aquifer in the area and assessed its potential risk to contaminant seepage in terms of the aquifer hydraulic properties and protective capacity of the overburden rock materials using the Dar Zarouk parameters.

Ademilua and Olorunfemi (2000) presented a regional view of the groundwater potential zones of the basement complex areas of Ekiti and Ondo States. The authours anticipated local variations owing to the very heterogeneous and discontinuous nature of basement aquifers and suggested additional localities, VES and borehole yield data to improve the accuracy of the map. Ojo *et al*. (2015) commented that the groundwater potential map produced might not be representative as limited VES data points and few numbers of sampled localities accounted for the data base. Ado-Ekiti had data from only 14 VES points. The methodology dwelled on conventional geoelectric/geologic estimation. Inclusion of remotely sensed data and GIS in the work would improve the coverage and offer more robust geospatial information.

Remote sensing and GIS are increasingly applied for groundwater investigation and for successful groundwater potential mapping (Chowdhury *et al*., 2010 and Asiyanbola, 2014). The quest for groundwater can be enhanced by mapping the sub-surface water potential sites using remote sensing and GIS techniques. The methodology is inexpensive, rapid, accurate, and wide area coverage as well as reducing time and cost of field surveys (Badamasi *et al.*, 2016).

Talabi and Tijani (2011) used integrated RS and GIS approach to assess the groundwater potential of the basement terrain of Ekiti State. Thematic maps of geology, geomorphology, lineament, slope and drainage density were prepared and integrated using ArcGIS 9.1 software to produce the groundwater potential map. The groundwater potential zonation did not utilize Ground Geophysics in the methodology. The authours recommended further geophysical investigation to determine the aquifer characteristics and the overburden thickness of various groundwater potential zones highlighted to compliment the study.

Bagyaraj *et al.* (2013) remarked that remote sensing could serve as the preliminary inventory method to understand groundwater potential and help in delineating areas where further explorations need to be taken up through hydrogeological and geophysical methods. The study emphasized the advantage of using remote sensing techniques together with GPS in a single platform and integration of GIS techniques to facilitate improved data analysis and interpretations.

Singh *et al.* (2013) adopted integration of thematic information (geomorphology, lithology, drainage density, slope and lineaments) in a GIS environment in order to identify groundwater potential zones in the Deccan Volcanic Province, Maharashtra, India, using multi-criteria analyses (MCDA). The authours emphasized the usefulness of the methodology in predictive groundwater resource management and as a rapid assessment tool in groundwater exploration.

The study of Prabu and Rajagopalan (2013) delineated areas most promising for groundwater occurrences / sustainable supply and suggested where further geophysical surveys could be concentrated. The authours suggested that the portions of high lineament intersection and density should be combed with detailed geoelectrical surveys for quantitative evaluation of the groundwater potential of the study area.

Forkuor *et al.* (2013) assessed Groundwater development potential in Northern Ghana by combining spatial layers of recharge rate, regolith thickness, transmissivity, borehole success rate and static water level using a multi-criteria analysis approach to rank development potential. The study emphasized the need to base development on knowledge of the suitability of targeted areas for groundwater development in order to achieve sustainable groundwater production and reduce investment losses through failures in well drilling.

Ndatuwong and Yadav (2014) used the technique of remote sensing data and GIS to evaluate the hydrogeomorphological characteristics of the Vindhyan basin in Central India and demarcate the groundwater potential zones for exploration of the resource in shallow aquifer using thematic maps of geomorphologic units, slope, drainage density and lineaments density. The authors submitted that the result obtained from the analysis would help narrow down the targeting area for further geophysical exploration for groundwater development.

The work of Fashae *et al*. (2014) utilized the integration of multi-criteria decision analysis (MCDA), remote sensing (RS) and geographical information system (GIS) techniques to delineate groundwater potential zones in crystalline basement terrain of Southwestern Nigeria. The study demonstrated the efficacy of the integrated MCDA, RS and GIS methods as useful modern approach for proper groundwater resources evaluation; providing quick prospective guides for groundwater exploration and exploitation in crystalline basement settings. The authours remarked that the groundwater potential zonation presented could be applied only for regional studies for the purpose of groundwater development noting that individual site selection for groundwater development should take into consideration other site-specific conventional ground-truthing methods.

Similarly, Bayowa *et al*. (2014) presented a regional view of the groundwater potential zones of the basement complex areas of Ekiti State, Southwestern Nigeria. The study broadly classified Ijesa-Isu, Iludofin, Iyemero, Esure, Otun, Osi, Iropora, Ifaki, Ikun, Ijero, Emure, Ise/Orun and Ado-Ekiti into low groundwater potential zone. The drawbacks of the work include the heterogeneous and discontinuous nature of basement aquifers which makes local variations possible particularly over such distances, limited data points and spatial resolution. The present study shall span Ado-Ekiti. The sampling points will be properly geo-referenced with enhanced spatial distribution. Several thematic maps will be generated, re-classified and synthesized in a GIS environment to define the groundwater potential of the region.

These works underlined the need for an integrated approach involving Remote Sensing and Geoelectrical Investigations in a GIS environment. Delineation of areas suitable for sustainable groundwater development in hard rock terrains demands such complementary approach.

As inferred from the literature survey, only few studies have been conducted in the area of identification and delineation of groundwater resources within the basement complex region of Nigeria with the aid of the modern research tools of RS and GIS. Principal limitations observed include the coarseness of scale, the varying set of factors selected for integration and adopted methodology. These often limit the use of the studies. The works only provided general overviews of the groundwater situation at various scales. Prospective groundwater zones are poorly defined in the hard rock terrain.

Groundwater exploration in the basement complex terrain demands precise determination of the lateral and vertical limits of the diastrophic features like faults, fractures, joints and shears. The extent and thickness of the weathered mantle should be demarcated. It has been widely recommended that geophysical investigation methods should be employed to locate zones of weakness and areas of deep weathering in the rocks. The marked variability and the unpredictability of the nature of basement aquifers suggests that precision is essential as a location error of less than 5 m can make all the difference between a productive borehole and a dry hole (Olayinka, 1992). A pragmatic and scientific planning is required in order to achieve sustainable groundwater production and reduce investment losses through failures in well drilling (Forkuor *et al*., 2013, Jayeoba and Oladunjoye, 2013 and Ndatuwong and Yadav, 2014).

In this study, efforts shall be made to generate and integrate relevant thematic layers of parameters with proven hydrogeological significance from RS and VES in a GIS environment with due attention to details. The integrated approach would improve resolution.

2.2 Groundwater Source / Occurrence

Groundwater is widely acclaimed as an important component of the earth environment and as one of the world's most precious resources. The main source of groundwater is precipitation that penetrates the soil, moves through the zone of aeration, the capillary fringe and finally reaches the water table. Other sources are water infiltrated from surface water, including rivers and lakes, recharge ponds, waste - water treatment systems such a cesspools and septic tank drain fields

Groundwater occurs in aquifers under two conditions; confined and unconfined. A confined aquifer is overlain by a confining bed, such as an impermeable layer of clay or rock. An unconfined aquifer has no confining bed above it and is usually open to infiltration from the surface. Unconfined aquifers are often shallow and frequently overlie one or more confined aquifers. They are recharged through permeable soils and subsurface materials above the aquifer. Unconfined aquifers are also called water table aquifers as they are usually the uppermost aquifer. Confined aquifers usually occur at considerable depth and may overlie other confined aquifers. They are often recharged through cracks or openings in impermeable layers above or below them. Confined aquifers in complex geological formations may be exposed at the land surface and can be directly recharged from infiltrating precipitation. Confined aquifers can also receive recharge from an adjacent highland area such as a mountain range. Water infiltrating fractured rock in the mountains may flow downward and then move laterally into confined aquifers. Groundwater occurs under unconfined conditions in shallow, moderately weathered zones and in semi-confined conditions in joints, fissures, and fractures that extend beyond the weathered zones (Lobo-Ferreira, 1999, Offodile, 2002 and Falconer, 2003)

2.3 Basement Aquifer Occurrence

Basement aquifers occur within the weathered residual overburden (the regolith and the fractured bedrock). Viable aquifers wholly within the fractured bedrock are of rare occurrence because of the typically low storability of fractured system, which according to Clark (1985) is about 1%. According to Wright (1992), the basement aquifers are of particular importance in tropical and sub-tropical regions both because of their widespread extent and accessibility and because there is often no readily available alternative source of water supply particularly for rural population. Even in more humid tropical regions, water quality considerations can favour their use. To be effective, development of the bedrock component requires interaction with storage available in overlying or adjacent saturated regolith, or other suitable formations such as alluvium. Basement aquifers are essentially phreatic in character but may respond to localized abstraction in semi-confined fashion if the rest water level occurs in low-permeability horizon, such as clayey regolith (Offodile, 2002 and Tijani *et al.*, 2014).

2.4 Geoelectric Surveying

2.4.1 The Basic Concept of Electrical Resistivity Method

The traditional purpose of electrical resistivity survey is to determine the subsurface resistivity distribution by taking measurements on the ground surface. The resistivity of the earth is related to the mineral and fluid content, porosity and degree of water saturation in the rock (Mallam, 2004). The method can be used to define aquifer types in a geologic formation based on structural and lithologic characteristics (Aboh and Osazuwa, 2000).

The electrical resistivity of subsurface materials can be determined by the subsurface resistivity distribution to the ground. This can be related to the physical conditions of interest such as lithology, porosity, degree of water saturation and presence or absence of voids in the rocks (Ako, 1996). The resistivity of crystalline rock formations is largely dependent upon the water in the fissures and fractures (Sheriff *et al*., 2002).

Hard rocks are known to be of high resistivity of several thousands of Ohms-metre (Ωm). Zones of crushed and badly fractured rocks may sometimes have resistivities of as low as 1 – 2 Ωm. Water may occur as subsurface groundwater, accumulating in reservoir rocks (sands, gravels, silt, limestone, etc) in the sedimentary rocks, and in weathered overburden, joints, fractures and faults zones in crystalline basement rocks. Some clays as well as water logged soils may possess very low resistivities of the order of 1 – 20 Ωm (Mohammed *et al*., 2008).

The electric conduction in most rocks is essentially electrolytic. This is because most mineral grains (except metallic ores and clay minerals) are insulators. Electric conduction is through interstitial water in pores and fissures. Groundwater filling the pore spaces of a rock is a natural electrolyte with a considerable amount of ions. The more porous or fissured a rock is, the larger is its groundwater content, the higher is the conductivity and the lower is the resistivity. Generally, resistivity increases with depth due to decreasing pores, fractures, faults and shear zones arising from increasing lithostatic or overburden pressure.

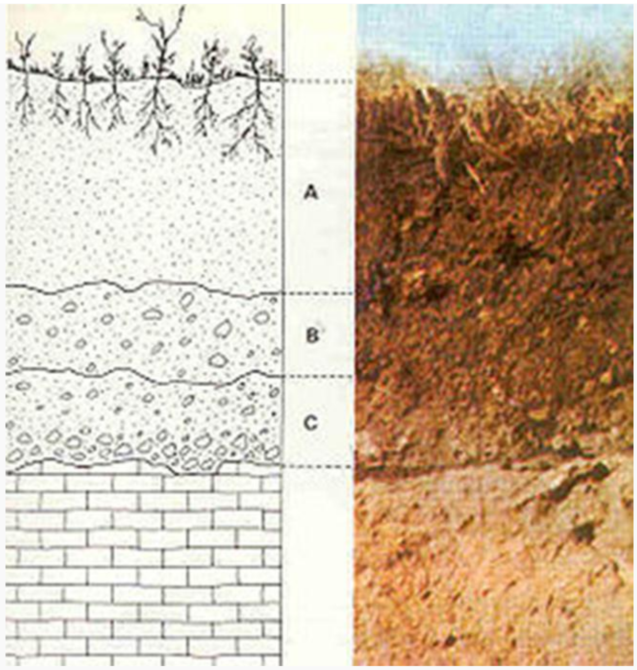
The factors which control the electrical resistivity of rocks include the amount and salinity of the water present, the amount and arrangement of the pore spaces, the matrix conductivity and the resistivity of the rock grains. Expectedly, the resistivity of a water-bearing formation decreases as the amount of water present increases. The development of secondary porosity by jointing and fracturing results in a further reduction of the resistivity (Olayinka, 1992).

Olayinka and Olorunfemi (1992), Ariyo and Adeyemi (2009) and Ojo *et al*. (2015) recognized weathering as an important factor in the hydrogeology of the Nigerian Basement Complex since the weathered mantle is known to provide avenues through which water can percolate. Weathering may thus render the normally impermeable crystalline rocks suitable for ingress and storage of water.

2.4.2 The Weathered Profile In Crystalline Basement Rocks

Figure 2.1 shows a typical soil profile in which **A** represents soil; **B** represents laterite, a regolith; **C** represents saprolite, a less-weathered regolith; and beneath **C** is the bedrock. According to Olayinka (2010), a vertical section through the weathered profile developed above crystalline basement rocks in low-latitude regions comprises, from top to bottom, the soil layer, the saprolite (product of the *in situ* chemical weathering of the bedrock), the saprock (fractured bedrock) and the fresh bedrock. Table 2.1 shows the geo-electrical succession over a tropically-weathered regolith based on Southwestern Nigeria conditions and the hydrogeological significances. When the regolith is rich in clay the resistivity of the saprolite can be as low as 10 Ωm.

Regolith is a layer of loose, heterogeneous superficial material covering solid rock. It includes dust, soil, broken rock, and other related materials. It is everything between fresh rock and fresh air. The regolith includes fractured and weathered basement rocks, saprolites, soils, organic accumulations, volcanic material, alluvium, evaporitic sediments, aeolian deposits and groundwater (Taylor and Eggleton, 2001)



A represents soil **B** represents laterite **C** represents saprolite **beneath** C is bedrock.

Figure 2.1: Typical Soil Profile in Crystalline Basement terrain (Eggleton, 2001)

Table 2.1: Geoelectrical succession over a tropical-weathered regolith base on southwestern Nigerian condition (Olayinka, 2010)

Layer	Thickness (m)	Resistivity Ω-m	Hydrogeological significances
1	<5	<200 (wet)	Residual soil
		Up to 500(dry)	Often forms lateritic capping. Could be associated with deep weathering
2	5-35	10-800	The Saprolite zone. Often have high clay content, good aquifers when permeable.
3	0-20	200-1000	The fractured basement sequence. Has low effective relative thickness, which makes it detection difficult for surface geoelectrics. Often a transitional zone. Good aquifers when not too highly resistive
4		∞	The semi-infinite bedrock. Poor aquifer unless when fracture.

2.4.3 The Vertical Electrical Sounding (VES)

As resistivity is a fundamental electrical property of rock materials closely related to their lithology, the determination of the subsurface distribution of resistivity from measurement on the surface can yield useful information on the structure or composition of buried formations.

The Vertical Electrical Sounding (VES) or geoelectrical sounding is based on the principle that a fraction of electric current injected into the ground, penetrating below a given depth increases with the separation of the current electrodes. Hence, as current electrodes separation is increased, the depth of penetration is increased. It follows that any anomalous body lying between the ground surface and the last depth of penetration will have great influence on the electrical potential field at depth (Mallam and Emenike, 2008).

The layout of the Vertical Electrical Sounding technique is based on the 4 - electrode principle as shown in Figure 2.2; one pair for introducing current into the earth, the other pair for measuring the potential associated with the current. The Electrical Current (I) is applied to A and B electrodes and the Potential (ΔU) is measured between M and N electrodes. The VES array consists of a series of the electrode combinations AMNB with gradually increasing distances among the electrodes for consequent combinations.

The resistivity meter contains both the transmitter unit, through which current enters the ground and the receiver unit, through which the resultant potential difference is recorded. Current is injected into the earth through the terrameter to produce electric field within the subsurface with electric potentials. The potential difference between the two inner electrodes (the Potential Electrodes) is thus measured. In this field procedure, only the current electrodes are moved more often during measurements until the measurable signal becomes very small. The potential electrodes are then expanded along the transverse.

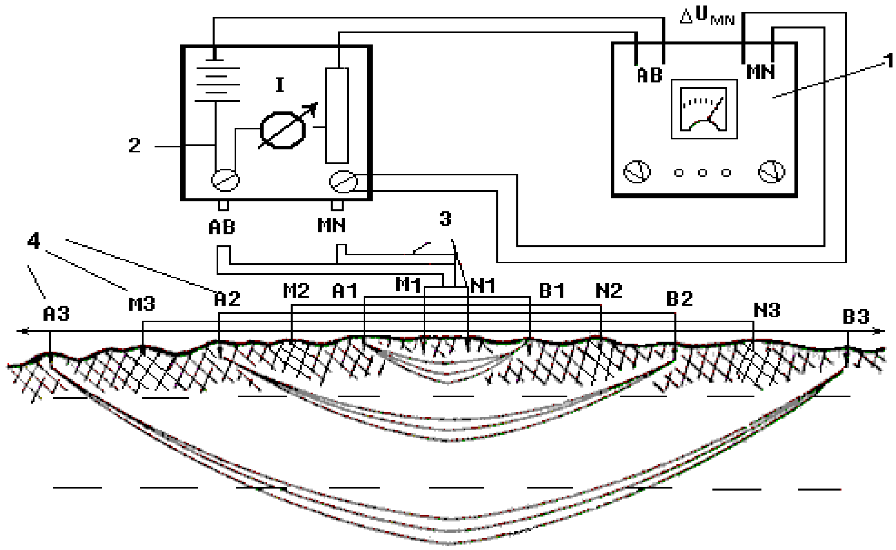


Figure 2.2: Scheme of the Vertical Electrical Sounding (VES) device: (1) auto-canceller, (2) commutator for electrodes AB and MN, (3) netted wires for different distances among electrodes AB and MN, and (4) electrodes (http://larisa_pozd.tripod.com/ves/ves.htm)

The Resistance value, R (Ω), at each VES point is recorded and multiplied by the corresponding geometric factor (k) for each electrode separation to obtain the apparent resistivity ($\rho_a = kR$) in Ohm-meters. The recorded resistivity is called the apparent resistivity and not the exert resistivity since measurement is not made directly on the body particularly where there is inhomogeneity.

In a homogeneous layer the resistivity is constant and independent of electrode spacing and surface location. However, some terrains show inhomogeneous subsurface and anomalies in apparent resistivity values. In such studies the wider the electrode spacing, the deeper the penetration and ultimately the depth of investigation. Current penetration to a depth say Z is achieved with a total current spread L, given by $L = 3Z$ or $Z = L/3$. For very large current electrode separation, the potential electrode separation is increased to maintain measurable potential difference. In this array, the current and potential pairs of electrodes have a common midpoint but the distance between adjacent electrodes differs (Kearey and Brooks, 1991 and Okolie *et al.*, 2005).

2.4.4 Geoelectric Succession and Curve Types

Geoelectric succession varied greatly in the basement complex terrain. This gives rise to different geoelectric curve types. A 2-layer case is defined when the topsoil is directly underlain by a resistive bedrock. For three layers, there are four possible types of VES curves depending on the nature of the successive resistivity contrasts (Figure 2.3). The classification of these curves is found in the literature with the notations H, K, A, and Q. These symbols correspond respectively to bowl-type curves, which occur with an intermediate layer of lower resistivity than

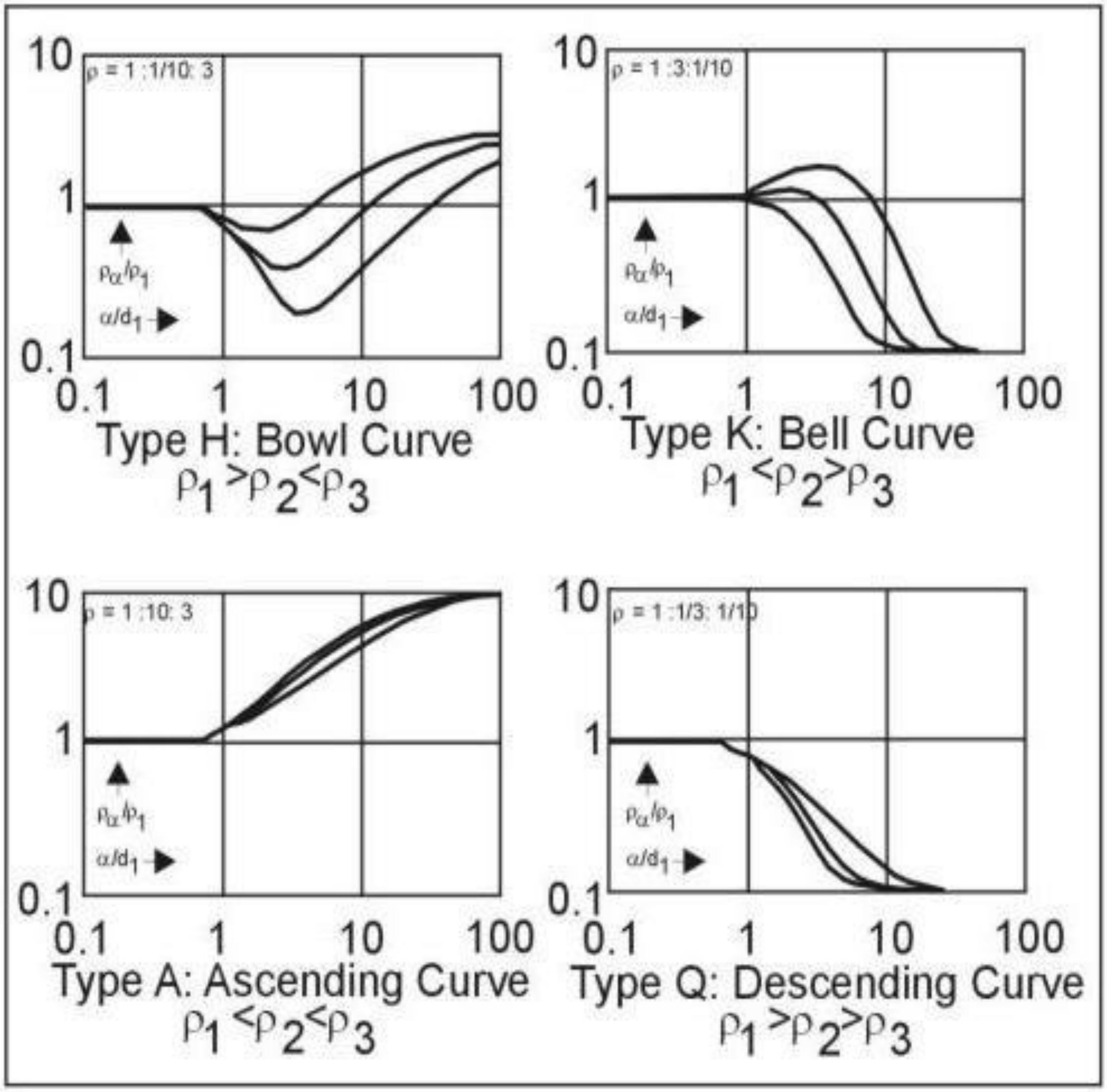


Figure 2.3: Four types of three-layer VES curves (Adapted from Resistivity Methods: Environmental Geophysics US EPA.htm)

layers 1 or 3; bell-type curves, where the intermediate layer is of higher resistivity; ascending curves, where resistivities successively increase; and descending curves, where resistivities successively decrease. The presence of another curve segment gives 4-layer type curves in which case 16 curve types can be identified. These include HK for a bowl-bell curve, AA for a monotonically ascending curve, and so on.

The basic geoelectrical succession commonly encountered in tropical and subtropical areas underlain by crystalline basements complex rocks has been shown to comprise, from top to bottom, the topsoil, the conductive regolith and the highly resistive bedrock (Olayinka and Olorunfemi, 1992). A typical 3 - layer sequence having the topsoil composition of variable alluvium, sand, lateritic clay or clay followed by clay or sandy clay and the bedrock defines the H-type curve ($\boldsymbol{\rho_1 > \rho_2 < \rho_3}$).

In basement complex area, the H-type curve is often characterized by sandy/lateritic topsoil, underlain by clayey/sandy clay weathered layer that overlies the fresh bedrock in a typical stratigraphic section. The intermediate layer is characterized by low resistivity, high porosity, low specific yield and low permeability. It is commonly water-saturated. It may constitute an aquifer if sandy and significantly thick. A semi-confined aquifer condition may be created if the clay content is very high. More often, the main aquifer zone is found at the base of the weathered profile where mineral decomposition resulting from *in-situ* chemical weathering has produced a gravel-like material of moderate to high permeability (Olayinka and Olorunfemi, 1992, Olorunfemi and Okhue, 1992 and Olorunfemi and Fasuyi, 1993).

The HA-type curve is characterized by the third layer that has a resistivity which is intermediate between that of deeply weathered material above and the highly resistive bedrock below; a stratigraphic sequence, whereby the weathered section could be underlain by a partially weathered or partially fractured bedrock, which are overlying the fresh basement rock. Olorunfemi and Idornigie (1992) asserted that the sandy/sandy clay layer and /or the weathered bedrock could be exploited for groundwater. The third horizon then constitutes the main aquifer unit if it is significantly weathered and appreciably thick. Olorunfemi and Olorunniwo (1985) suggested that a resistivity low of less than 1500 Ohm-m might be diagnostic of a weathered layer. The authours remarked that in the QH-type curve, two horizons of clay could be differentiated: sandy clay and clay, otherwise, the sequence is as of the H-type curve.

2.5 The Dar Zarrouk (DZ) Parameters and Aquifer Characteristics

For a sequence of n horizontal, homogeneous and isotropic layers of resistivity ρ_i and thickness h_i, a columnar prism gives geoelectric parameters of a section (Figure 2.4), as:

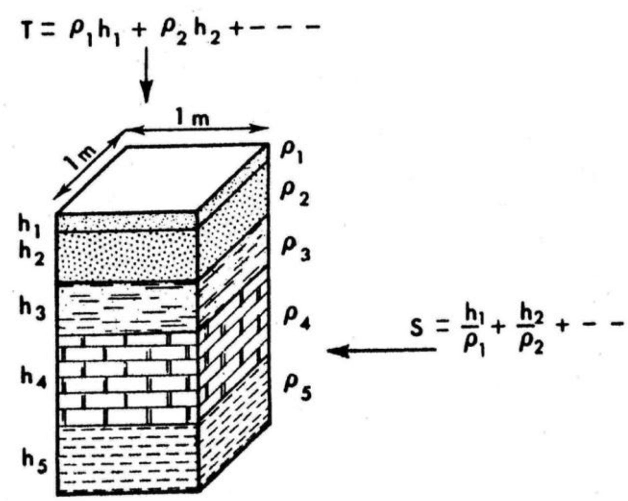


Figure 2.4: Geoelectric Section of vertical prism

Where

i = Summation index (i = 1 – (n-1))

n = Number of geo-electric layers delineated

h = Layer thickness

H = Overburden thickness = Summation of the Layer thickness

(i) Transverse Resistance (T)

$$T = \sum_{i=1}^{n-1} (h_i * \rho_i) \qquad \text{(Ohm-m}^2\text{)} \qquad (2.1)$$

This is the sum of the resistance contributed by all beds in the geoelectric section.

(ii) Transverse Resistivity (ρ_T)

$$\rho_T = \sum_{i=1}^{n-1} (h_i * \rho_i) / \sum h_i = {}^{T}/_{H} \qquad \text{(Ohm-m)} \qquad (2.2)$$

(iii) Total Conductance (S)

This is the current flowing horizontally through the overburden thickness

$$S = \sum_{i=1}^{n-1} \frac{h_i}{\rho_i} \qquad \text{(Siemens)} \qquad (2.3)$$

(iv) Longitudinal Resistivity (ρ_L)

This is the reciprocal of the average conductivity.

$$\rho_L = \sum_{i=1}^{n-1} h_i \Big/ \sum_{i=1}^{n-1} \left({}^{h_i}/_{\rho_i} \right) \qquad \text{(Ohm-m)} \qquad (2.4)$$

(v) Coefficient of Anisotropy (λ)

This is obtained from combination of the overburden thickness and resistivity.

$$\lambda = {}^{\sqrt{(TS)}}/_{H} \qquad (2.5)$$

$$\text{i.e., } \lambda = \sqrt{\frac{\rho_T}{\rho_L}} = \sqrt{\frac{\sum_{i=1}^{n-1} (h_i * \rho_i) * / \sum h_i / \rho_i}{(\sum h_i)^2}} \qquad (2.6)$$

The parameters T and S are the primary Dar – Zarrouk parameters while ρ_T, ρ_i and λ are the secondary Dar Zarrouk parameters (Zohdy, 1974, Oladapo *et al*., 2004 and Dewashish *et al*., 2014)

For an anisotropic section such as the basement complex environment,

$\rho_T > \rho_L$, implies that $\lambda > 1$

For an isotropic section, $\rho_T = \rho_L$, which implies that $\lambda = 1$

The Dar Zarrouk parameters can be used as a basis for the evaluation of properties such as aquifer transmissivity and protection of groundwater resources (Henriet, 1975 and Braga *et al*., 2006). Transmissivity is a major property of an aquifer and aids in the characterization of rocks as water conducting media (Rao *et al*., 2003 and Ehirim and Nwankwo, 2010). The ability of the overburden to retard and filter percolating fluid is a measure of its protective capacity (Oladapo *et al*., 2004). Estimating these properties from the traditional methods of pumping tests can be very expensive and time consuming. Ehirim and Nwankwo (2010) applied surface geoelectrical methods as an alternative, rapid and cost effective approach for aquifer evaluation and groundwater quality assessment using empirical relations between hydraulic and geoelectric parameters.

The combination of the thickness and resistivity of the geoelectric layers into single variables; the Dar-Zarouk parameters of Transverse resistance (T) and Longitudinal conductance (S) can be used as a basis for the evaluation of aquifer properties such as transmissivity and protective capacity of the overburden rock materials.

The longitudinal conductance (S) gives a measure of impermeability of geologic medium. It could then be used as an index of the clay content in a geologic medium. Heavily weathered layer often have low hydraulic conductivity (K) and low resistivity (ρ). Protective capacity (P_c) of overburden materials is proportional to its longitudinal conductance (Oladapo *et al*., 2004).

Ehirim and Nwankwo (2010) used geoelectric studies to delineate aquiferous zones and characterized the conditions of the underground flow in terms of the transmissivities and porosities of the aquifers and the protective capacities of the overburden rock materials. Low values were obtained for the protective capacities of the overburden rock materials in the study area which was indicative of aquifer system of high vulnerability to contamination. A high transmissivity value of the aquifer materials implied highly permeable aquifers which enhanced the migration of contaminants within the groundwater system over large areas. The study revealed that the groundwater quality might have been impaired.

2.6 Groundwater and Pollution Impact

The quantity and quality of the drinking water is directly linked to health. The protection of groundwater reservoirs is given by the covering layers; the protective layers. Surface water percolates through the protective layers leading to groundwater recharge. During this process contaminant degradation can occur by mechanical, physicochemical, and microbiological processes. The near surface geology often shows large variations. An effective groundwater protection is given by protective layers with sufficient thickness and low hydraulic conductivity leading to high residence time of percolating water (Lobo-Ferreira, 1999). The vulnerability of aquifers is to a large degree determined by the content of clay minerals in the near surface geology. Clay minerals have a large cation exchange capacity (CEC) and clayey sediments reduce the infiltration speed thus reducing the aquifer vulnerability. Covering layers dominated by sand serve both as fast infiltration zones and as vulnerable zones where possible contaminants can infiltrate and pollute the underlying aquifers while clay dominated areas restrict the infiltration rates due to the significantly lower permeability. This can be deduced from VES. Hence, a physical delineation of sandy and clayish zones of aquifer covering layers plays an important role in the total estimation of vulnerability. Sandy formations are characterized by high resistivities with low resistivities across clay-dominated horizons. The delineation of the resistivity structure thus provides essential information on the composition of the near surface layers covering the aquifers. As a non-invasive geophysical method, VES measurements are useful in groundwater vulnerability studies as neither the structure nor the dynamics of the soil is disturbed.

2.7 Groundwater Contamination and Quality Indicators

Naturally occurring contaminants present in the rocks and sediments may be dissolved as groundwater flows through and may later be found in high concentrations in the water. Industrial discharges, urban activities, agriculture, groundwater pumpage and disposal of waste all can affect groundwater quality. Movement of water and dispersion within the aquifer spreads the pollutant over a wider area, its advancing boundary often called a plume edge, which can then intersect with groundwater wells making the water supplies unsafe for humans and wildlife (Olayinka and Olayiwola, 2001, Gbadebo *et al.*, 2010 and Tijani *et al*., 2014).

Water quality is indicated by the constituents dissolved or contained within the water due to natural processes and human activities. It is normally characterized by different physicochemical characteristics. A variety of common groundwater constituents, their effects on humans, and remediation are summarized in Tables 2.2 and 2.3

Table 2.2: Summary of Physical characteristics of Groundwater (Waller, 1982, and WHO, 2008)

Turbidity	Caused by the presence of suspended matter such as clay, silt, and fine particles of organic and inorganic matter, plankton, and other microscopic organisms. A measure how much light can filter through the water sample	Objectionable for aesthetic reasons. Indicative of clay or other inert suspended particles in drinking water. May not adversely affect health but may cause need for additional treatment. Following rainfall, variations in ground-water turbidity may be an indicator of surface contamination.
Colour	Can be caused by decaying leaves, plants, organic matter, copper, iron, and manganese, which may be objectionable. Indicative of large amounts of organic chemicals, inadequate treatment, and high disinfection demand. Potential for production of excess amounts of disinfection by-products.	Suggests that treatment is needed. No health concerns. Aesthetically unpleasing.
pH	Indicates, by numerical expression, the degree to which water is alkaline or acidic. Represented on a scale of 0-14 where 0 is the most acidic, 14 is the most alkaline and 7 is neutral.	High pH causes a bitter taste; water pipes and water-using appliances become encrusted; depresses the effectiveness of the disinfection of chlorine, thereby causing the need for additional chlorine when pH is high. Low-pH water will corrode or dissolve metals and other substances.
Odour	Certain odours may be indicative of organic or non-organic contaminants that originate from municipal or industrial waste discharges or from natural sources.	
Taste	Some substances such as certain organic salts produce a taste without an odour and can be evaluated by a taste test. Many other sensations ascribed to the sense of taste actually are odours, though the sensation is not noticed until the material is taken into the mouth.	

Table 2.3: Safe Levels in Drinking Water (Waller, 1982, and WHO, 2008)

Coliform bacteria	**No coliform bacteria is acceptable**
pH	6.5 - 8.5
Nitrates	< 10 mg/l as NO3 -N < 45 mg/l as NO3
Total dissolved solids (TDS)	< 500 mg/l
Chloride	< 250 mg/l
Fluoride	0.7 - 1.2 mg/l
Calcium and magnesium	Calcium - limits not set by EPA Magnesium > 125 mg/l may show laxative effects
Iron and manganese	Iron < 0.3 mg/l Manganese < 0.05 mg/l
Sodium	< 100 mg/l
Sulphates	< 250 mg/l
Arsenic	< 10 ppb
Conductivity	0.4-0.85 micromoles per centimetre
Total hardness	< 270 mg/l
Turbidity	1 turbidity unit (TU). Note: > 5 TUs are detectable easily in a glass of water and usually objectionable for aesthetic reasons.
Potassium	No maximum limit has been set
Colour	< 10 colour units

2.8 Remote sensing

Groundwater availability in any terrain is largely controlled by the prevalence and orientation of primary and secondary porosity. Only secondary porosity predominates in the hard rock terrain. Groundwater exploration entails delineation and mapping of different lithological, structural and geomorphological units. Satellite based remote sensing data facilitate the preparation of lithological, structural, and geomorphological maps particularly at a regional scale. These data reveal structural features such as faults, fractures, and different landforms, due to their synoptic coverage and multispectral capability (Hungs *et al*., 2005 and Bayowa *et al*., 2014).

Remote Sensing entails the science and technology by which the characteristics of objects of interest can be identified, measured or analysed without direct contact. It is the process of acquiring data/information about objects/substances not in direct contact with the sensor, by gathering its inputs using electromagnetic radiation or acoustical waves that emanate from the targets of interest (Shaw and Burke, 2003 and Teewu *et al.*, 2005)

The first Landsat flew with a multispectral scanner, multispectral (MSS) imager and a TV-like sensor (the return-beam Vidicon, or RBV). Beginning with Landsat 4, the primary instrument became the Thematic Mapper (TM), though the MSS was also carried to maintain continuity in archival, synoptic datasets. The TM sensor has provided seven bands of spectral information at 30-m resolution since 1982. On the most recent vehicle, Landsat 7, the instrument was revised as the Enhanced Thematic Mapper plus, or ETM+. The instrument features improved spatial resolution in the LWIR channel (60 m) and a new panchromatic band with higher spatial resolution (15 m). Landsat Earth-observation satellites, operative since 1972, produce digital images in the visible and infra-red parts of the spectrum: each covers thousands of kilometres square, with sufficient detail to map many geo-ecological features. Other recent developments, such as millimeter-precision Global Positioning System (GPS) receivers, improved digital data compression software and internet transfers of remotely sensed data, have facilitated the use of remotely sensed data (Sander, 2006 and Prasad *et al*., 2008).

Hobbs (1904, 1912) defined lineaments as significant lines of landscape caused by joints and faults, revealing the architecture of the rock basement. O' Leary *et al*. (1976) defined Lineaments as extended mappable linear or curvilinear features of a surface whose parts align in straight or nearly straight relationships that may be the expression of folds, fractures or faults in the subsurface.

Satellite images, aerial photographs and digital elevation models (DEM) will give lineament information. Recent advances in digital image processing allow such lineament extraction to be accomplished in semi-automatic to fully automatic approaches. The identified line features may represent natural morphological alignments or those of anthropogenic nature (roads, aqueducts, crops, etc.). Structural discontinuities of rocks and other features related to tectonic activity often results in morphological lineaments (fault scarps, joints, fold axis, etc.). The accuracy of extracting lineaments depends strongly on the spatial resolution of the imagery, higher resolution imagery result in a higher quality of lineament map (Hung *et al.*, 2005 and Asiyanbola, 2014).

Lineaments are known to be underlain by zones of localized weathering and increased permeability and porosity; which are closely related to groundwater occurrence and yield.

Mapping of lineaments (or the number of lineaments within specifically designated areas - lineament density) is essential to groundwater surveys, development and management as it provides useful information for geological mapping and understanding of groundwater flow and occurrence in fractured rocks (Hung *et al.*, 2005 and Prabu and Rajagopalan, 2013)

Analysis of lineaments from satellite imagery thus offer an attractive approach in groundwater and environmental studies since areas of high groundwater potential in hard-rock aquifers are generally associated with conductive fracture zones.

Satellite-based remote sensing (RS) technology has been used to provide organized, synoptic, repetitive and multi-resolution coverage of the Earth's features (Singh *et al*., 2013). Remote sensing has been widely used in hydro-geological studies. Prasad *et al.* (2008), Talabi and Tijani (2011), Magesh *et al*. (2012), Singh *et al*. (2013), Fashae *et al.* (2014), Bayowa *et al*. (2014), Ndatuwong and Yadav (2014), Ojo *et al*. (2015), Badamasi *et al.* (2016) and Ghosh *et al.* (2016) are among recent studies.

2.9 Geographic Information System (GIS)

Geospatial techniques provide a rapid and cost-effective tool for generating valuable geo-data (geology, geomorphology, land-use, lineaments/structures and slope, etc.) that can be used to delineate groundwater potential zones in hard-rock terrain (Talabi and Tijani, 2011 and Singh *et al*., 2013). These tools provide unique and powerful means for obtaining spatio-temporal information about earth resources within a short time (Gupta and Srivastava, 2010). A large amount of geo-data related to various groundwater parameters enables geospatial techniques to be used to make significant conclusions about the groundwater potential of any area (Chowdhury *et al*., 2010).

GIS techniques facilitate integration and analysis of large volumes of data which in turn can aid a better understanding of groundwater controlling features in hard rock aquifers. Integration of the two or more technologies has proven to be an efficient tool in groundwater studies. 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 enhance reliability of decisions (Sander, 2006.). 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. Remote sensing and GIS are useful tools for groundwater investigation and for successful groundwater potential mapping (Chowdhury *et al*., 2009 and Al Saud, 2010).

Fabiyi (2004) defined GIS as a unique integration of computer hardware, software, peripherals, procedural techniques, organizational structure, people and institution for capturing, manipulating, storing, analysing, modulating, modeling and displaying geographically referenced data for solving complex human related problems.

A GIS is designed to accept geographic data from a variety of sources, including maps, satellite imageries, photographs, and printed text and statistics. Geographic information systems are capable of managing large amounts of spatially related information, providing the ability to integrate multiple layers of information and to derive additional information. (Dai *et al*., 2001)

According to Srivastava and Singh (2008) the use of conventional techniques/tools (such as geophysical, statistical or geostatistical techniques, numerical modelling, etc.) for groundwater management is often severely limited by the lack of adequate data in developing nations. Geospatial techniques have become one of the leading tools in the field of natural sciences for assessment, monitoring and management of natural resources, particularly in groundwater research (Singh *et al.,* 2013). GIS enables manipulation and integration of large data base.

2.10 Basis of Groundwater Potential Evaluation

Any realistic Groundwater Potential Evaluation must incorporate a number of attributes/ parameters relevant to groundwater occurrence and accumulation. Olorunfemi *et al.* (1999) acknowledged that the groundwater potential of a basement complex area is determined by a complex inter-relationship between the geology, post emplacement tectonic history, weathering processes and depth, nature of the weathered layer, groundwater flow pattern, recharge and discharge processes.

On the basis of Weathered Basement/Aquifer resistivity, Weathered Basement /aquifer thickness and bedrock relief maps, a composite map could be generated. The map would offer information on the groundwater potential of the area of study.

An evaluation of the groundwater potential could be based on the delineated groundwater converging and radiating zones evolved from the groundwater head map and characteristic aquifer geoelectrical parameters obtained from correlated VES interpretation results.

Attempts have been made to assess groundwater potential on the basis of the DZ Parameters. These include the works of Rao *et al*. (2003), Bayowa *et al*. (2014) and Ojo *et al*. (2015).

Olayinka (2009) evolved a groundwater–prospect ranking, which incorporated aquifer potential as a function of the depth to bedrock, saprolite resistivity and the fractured bedrock resistivity (Table 2.1(a) – (c)). The ranking served as the basis of the preliminary estimate of the aquifers potentials in a low latitude terrain underlain by precambrian basement complex rocks. Olayinka *et al*. (1997) demonstrated the application of the scheme for the ranking of VES data from around Shaki, Oyo State, Nigeria. Ado – Ekiti falls within similar hard rock terrain.

Table 2.4(a): Aquifer Potential as a Function of the Depth to Bedrock

Depth To Bedrock (m)	Weighting
<10	2.5
10-20	5.0
20-30	7.5
>30	10.0

(Source: Olayinka *et al*. 1997)

Table 2.4(b)**:** Aquifer Potential as a Function of Saprolite Resistivity

Saprolite resistivity (Ω-m)	Aquifer characteristics	Weighting
<20	Clayey; limited aquifer potential	7.5
20-100	Optimum weathering and groundwater potential	10.5
100-150	Medium aquifer conditions and potential	7.5
150-300	Limited weathering and poor potential	5.0
>300	Negligible	2.5

(Source: Olayinka, 2009; Modified after Wright, 1992)

Table 2.4(c): Aquifer Potential as a Function of the Fractured Bedrock

Saprolite resistivity (Ω-m)	Aquifer characteristics	Weighting
<750	High fractured permeability as a result of weathering; high aquifer potential.	10.0
750 - 1500	Reduced influence of weathering; medium aquifer potential.	7.5
1500 - 3000	Fairly low effect of weathering; low aquifer potential	5.0
>3000	Little or no weathering of the bedrock; negligible aquifer potential.	2.5

(Source: Olayinka *et al*., 1997)

2.11 Groundwater Potential Zonation In GIS Environment

The use of remote sensing and GIS techniques is a fast emerging field in groundwater resource identification, mapping and development. Groundwater Potential Zonation could utilize RS – GIS Approach / VES – GIS. In both cases, applications of GIS permit preparation of thematic layers which are integrated to produce desired results. A stand-alone study dwelling on either approach might be deficient owing to the draw-backs of each technique. Groundwater Potential Zonation using the Integrated Approach (RS-GIS/VES-GIS) would improve reliability.

Magesh *et al*. (2012) observed that different sets of factors were selected in RS – GIS Approach by a number of researchers around the world in determining the groundwater potential zones and hence the results varied accordingly. Remote sensing data can be used as reconnaissance tool for identifying groundwater potential zone. Result obtained from RS – GIS analysis would help narrow down the targeting area for further geophysical exploration (Forkuor *et al*., 2013, Ndatuwong and Yadav, 2014 and Fashae *et al*., 2014)

2.12 Groundwater Quality Evaluation

The quality of water is a vital concern for mankind since it is directly linked with human welfare. In developing countries around 80% of all diseases are directly related to poor drinking water quality and unhygienic conditions (Olajire and Imeokparia, 2001, Tinuola and Owolabi, 2007 and Olajuyigbe, 2010). In recent times, GIS has been used in the map classification of groundwater quality. Some studies have used GIS as a database system in order to prepare maps of water quality according to concentration values. Nas and Berktay (2010) have mapped urban groundwater quality in Koyna, Turkey, using GIS. Yammani (2007) utilized GIS to locate groundwater quality zones suitable for different usages such as irrigation and domestic. Some studies have been conducted on groundwater quality of surface water and groundwater from boreholes and hand-dug wells in Ado-Ekiti. Adefemi *et al*. (2007) reported an Assessment of Physico-Chemical Status of Water Samples from Major Dams in Ekiti State, including the Ureje dam. Oyedele (2009) examined the Physico-Chemical Status of Water Samples from Hand-Dug Wells in Ajebamidele Area of Ado-Ekiti. Such studies considered physico-chemical parameters and/or the bacteriological status of these waters and at discrete instance. There have been no reports on groundwater quality mapping on Ado-Ekiti at a regional level. Spatial variation of the groundwater quality has not been reported. It would be useful to visualize the spatial variation of certain physico-chemical parameters through GIS, hence provide an overview of present groundwater quality, integrate relevant thematic layers and generate groundwater quality map for Ado-Ekiti metropolis.

2.13 Critical Issues In RS - GIS Research Works

Critical issues in research works utilizing RS and GIS for demarcation of groundwater potential zones include the coarseness of scale and the set of factors selected for integration. MacDonald *et al.* (2001) considered only rainfall and geology. Bayowa *et al*. (2014) relied on Hydrogeomorphological, lineament density, lineament intersection density and overburden coefficient of anisotropy. Forkuor *et al*. (2013) noted that various studies have been conducted to map groundwater potential zones for groundwater development at varying scales. Prominent works include a global assessment of the World-wide Hydrogeological Mapping and Assessment Programme at 1:25000000 scale (WHYMAP, 2008), a regional assessment at 1:40000000 scale (MacDonald and Davies, 2000), country-level analyses in Ghana and South Africa (Woodford *et al.*, 2006 and Gumma and Pavelic, 2012). The coarseness of a scale of 1:40 000 000 used for a study, for instance, might jeopardize application of the results at sub-national level.

Groundwater investigations in hard rock areas often require precision as tube-wells must be located exactly to be successful. Tube-wells drilled without proper geophysical and hydrogeological study often fail to produce groundwater (Venkateswaran *et al*., 2014). The present study would offer high resolution to justify the precision required in groundwater exploration in a typical basement complex terrain of Ado-Ekiti.

CHAPTER THREE

MATERIALS AND METHODS

3.1 MATERIALS

The materials used for the study included the following:

- Street Guide of Ado Ekiti
- Hand-held GPS Receiver
- Compass Clinometer
- Water sampling accessories
- Measuring tapes
- Resistivity Metre and accessories
- Personal computers and accessories
- Recording Sheets

Data Used

- Landsat Enhanced Thematic Mapper ETM+ (8 bands)
- Aster Digital Elevation Model (GDEM)
- Geological Map from Nigeria Geological Survey Agency (NGSA)
- Soil Map surveyed and drawn by the soil survey section, Ministry of Agriculture and Natural Resources
- Toposheet compiled and drawn by Federal Survey

Softwares Employed

Softwares used for carrying out this research work are:

- ArcHydro module for drainage network extraction
- Google map for preparing base map.
- Google Earth for Lineament correction
- AutoCAD for digitizing pre-existing Geological map
- ArcGIS 10.2.2 for georeferencing and derivation of thematic layers
- PCI Geomatica 2013 for Automatic Lineament Extraction
- Rock ware 15 for generating lineament statistics and plotting diagram
- ArcGIS 10.2.2 for Weighted Index Overlay Analysis
- Surfer v9
- Ecognition Developer for image classification(Landuse/Land cover)
- RESIST Version 1.0

3.2 METHODOLOGY

3.2.1 Reconnaissance Survey

The study commenced with a Reconnaissance Survey. Existing base maps (topographical and geological maps) of the study area were examined. It also entailed studying the drainage pattern and groundwater utility distributions within the area. In the course of obtaining permit, interviews were conducted with residents to secure copious and first - hand information on the exploration targets. The information gathered was subsequently used to prepare fieldwork layout map, which was used as a guide for fieldwork logistic planning. Detailed investigation involving Hydro-geophysical Surveying, Remote Sensing and GIS application was then put on course.

The processing flow charts of methodology are shown in Figure 3.1(a and b)

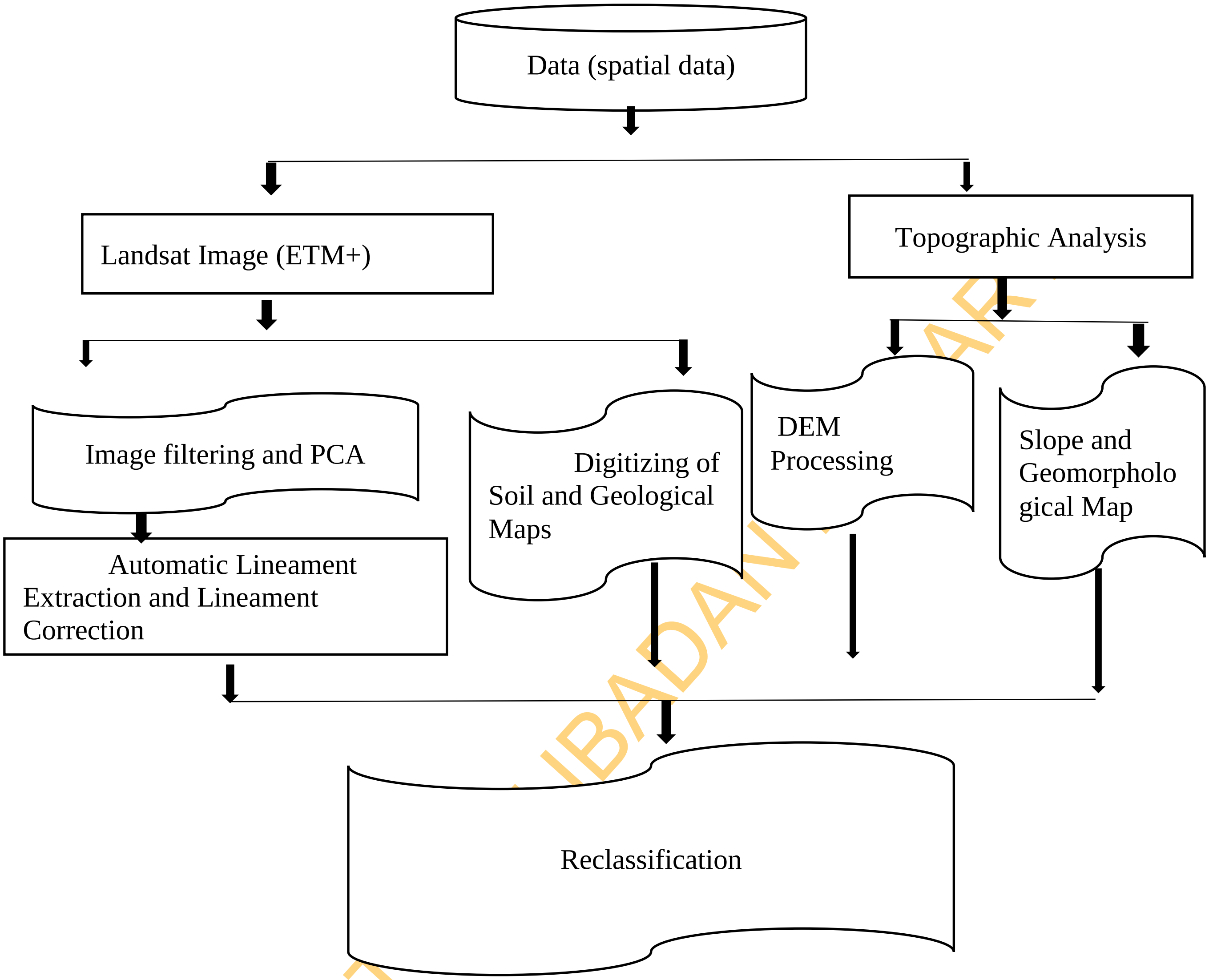


Figure 3.1(a): Flow chart of methodology used in the study.

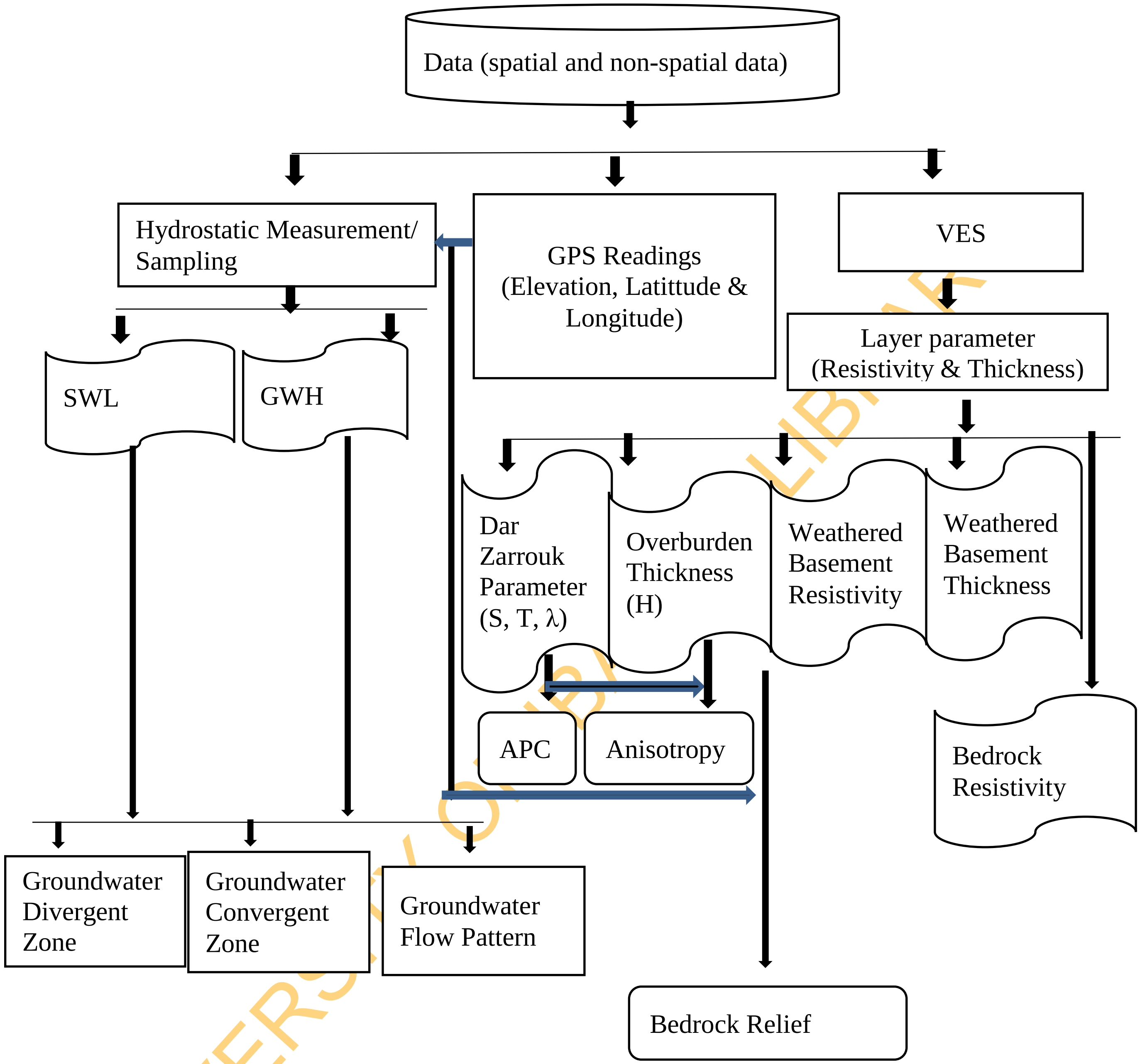


Figure 3.1(b): Flow chart of methodology used in the study.

3.2.2 Remote Sensing

In this study, Enhanced Thematic Mapper (ETM+) Sensor of path 190 and row 055 acquired in 2005 was used for lineament extraction. PCI Geomatica 2013 was used for Automatic Lineament Extraction with ArcGIS 10.2.2. The Landsat ETM+ image used has 8 spectral bands with a resolution of 30 m and the panchromatic band 8 with a resolution of 15 m. Rockware 15 was used for generating lineament statistics and plotting Rose diagram which discerned the orientation and frequency of occurrence of the extracted lineaments.

Shuttle Radar Topographic Mission (SRTM) Digital Elevation Model (DEM) was used for drainage network extraction, slope and geomorphological analysis. ArcHydro module was employed for drainage network extraction. Geomorphological and slope maps were prepared.

Several topographic analyses were carried out on the DEM including Sink Fill, Flow Direction, Flow accumulation, Stream Order and Stream to Feature. The fill tool in the spatial analyst of Arcmap was used to fill the sink and remove peaks within the data. With Stream to Feature, the stream order function in Arcmap Spatial Analyst converts the stream raster into a polyline feature class (Hung *et al*., 2005, Sander, 2006 and Prasad *et al*., 2008).

Landuse/Land Cover (LULC) Map of the study area was produced using Landsat 8 imagery of path 190 and row 055 acquired in 2015. Ecognition Developer was used for image classification.

Other data inputs are Soil map 3000/853/9-65 drawn by Ministry of Agriculture and Natural Resources on 1:500,000 scale, Geological map 3300/6/66/3289/OS prepared by the British Government Ministry of Overseas Development on 1:250,000 scale and Topographical sheet 1000/404/6.68 compiled and drawn by Federal Survey from photo reduction 244(Ado-Ekiti), 245(Ikole), 264(Akure) and 265(Owo).

3.2.2.1 Land-use/land-cover (LULC)

Land-use/land-cover (LULC) information is an important factor in groundwater storage and recharge. It reveals the type of soil, water/wet bodies, outcrops, the distribution of residential areas and vegetation cover in the study area. Spatial variation in the amount of groundwater storage occurs due to changes in land use and vegetation cover. Man-made construction, such as concrete embankments, buildings, hangers, roads etc. and thick accumulations of soil deposits with clay content reduce the rate of water percolation while the vegetation cover has effective role in the enhancement of recharge rate. Remote sensing and GIS techniques provide reliable basic information about land use/land cover (Fashae *et al*., 2014, Selvam *et al*., 2014 and Ghosh *et al*., 2016).

3.2.2.2 Geomorphology

Hydrogeomorphological map of the study area was prepared to show important geomorphic units and landforms in the area. Geomorphology reflects various landform and topographical features. The landform and structural features are useful in categorizing groundwater occurrence as well as groundwater prospects /potentiality. Hydrogeomorphological studies are considered essential in the planning and execution of groundwater exploration (Singh *et al*., 2013).

3.2.2.3 Slope

Slope is a significant factor for the detection of groundwater prospective zones as it has a dominant influence on the contribution of rainfall to the stream flow and recharge to the groundwater reservoir. Slope controls the duration of overland flow, infiltration and subsurface flow (Ghosh *et al*., 2016). Steeper slopes induce less recharge as a result of rapid runoff during rainfall, and hence insufficient time to infiltrate the surface and recharge the saturated zone. Groundwater potential Evaluation with respect to the slope characteristics of the study area has been considered. Topographic slopes within the study area were classified from a slope percent analysis. The nature of slope alongside other geomorphic features reflect groundwater prospect of an area (Prasad *et al*., 2008 and Talabi and Tijani, 2011).

3.2.2.4 Lineaments Analysis

Lineaments and their intersections play a significant role in the occurrence and movement of groundwater resources in crystalline rocks (Prasad *et al.*, 2008 and Fasae *et al.*, 2014). The presence of lineaments may act as a conduit for groundwater movement. The connectivity of lineaments is indicative of the groundwater transport since the connected lineaments create an underground route for groundwater flow. Groundwater potential could be inferred from Lineament density of an area since the presence of lineaments usually denotes a permeable zone (Ghosh *et al.*, 2016). Areas with high lineament density are good for groundwater potential zones. In this study, the lineament distributions were analysed using rose diagram, lineament density and lineament intersection density maps.

3.2.2.5 Drainage and Drainage density

The drainage network analysis is germane to evaluate the recharge property. The drainage network in the area of study is determined fundamentally by the underlying lithology. It is thus indicative of water percolation rate (Shaban *et al.*, 2006 and Singh *et al.*, 2013). Inherently, the denser the drainage network, the less recharge rate and vice versa. Drainage density is a measure of the total length of the stream segment of all orders per unit area. It is measured in km/km^2.

The drainage density is an inverse function of permeability. The less permeable a rock is, the less the infiltration of rainfall, which conversely tends to be concentrated in surface runoff. A higher drainage density tends to indicate lower groundwater potential (Selvam *et al.*, 2014 and Ghosh *et al.*, 2016). The drainage density of the study area was grouped into classes wherein more weightage was assigned to very low drainage density regions and low weightage assigned to very high drainage density regions.

3.2.2.6 Soil

Soil characteristics in the study area were considered. The rates of infiltration and permeability are directly interrelated to Soil characteristics. They control the infiltration of surface water into an aquifer system. Coarse textured soils are generally permeable while fine textured soils indicate less permeability. The major soil associations found in the study area was evaluated on the account of the type of soil and the associated water-holding capacity (Ojo *et al*., 2015 and Ghosh *et al*., 2016)

3.2.3 Geoelectric Survey

3.2.3.1 Geoelectric Data Acquisition

The geoelectric data acquisition was carried out using the prolific method of Vertical Electrical Sounding (VES) to delineate the subsurface lithological configuration, aquifer characteristics and depth to bedrock. One hundred and thirty three (133) VES points (Figure 3.2) were fully occupied for data acquisition based on well inventory data. The instrument used for the resistance measurement was the ABEM Terrameter SAS 300 B with ABEM 2000 Booster. A Garmin 12-Channel Global Positioning System (GPS) was used to obtain the Eastings

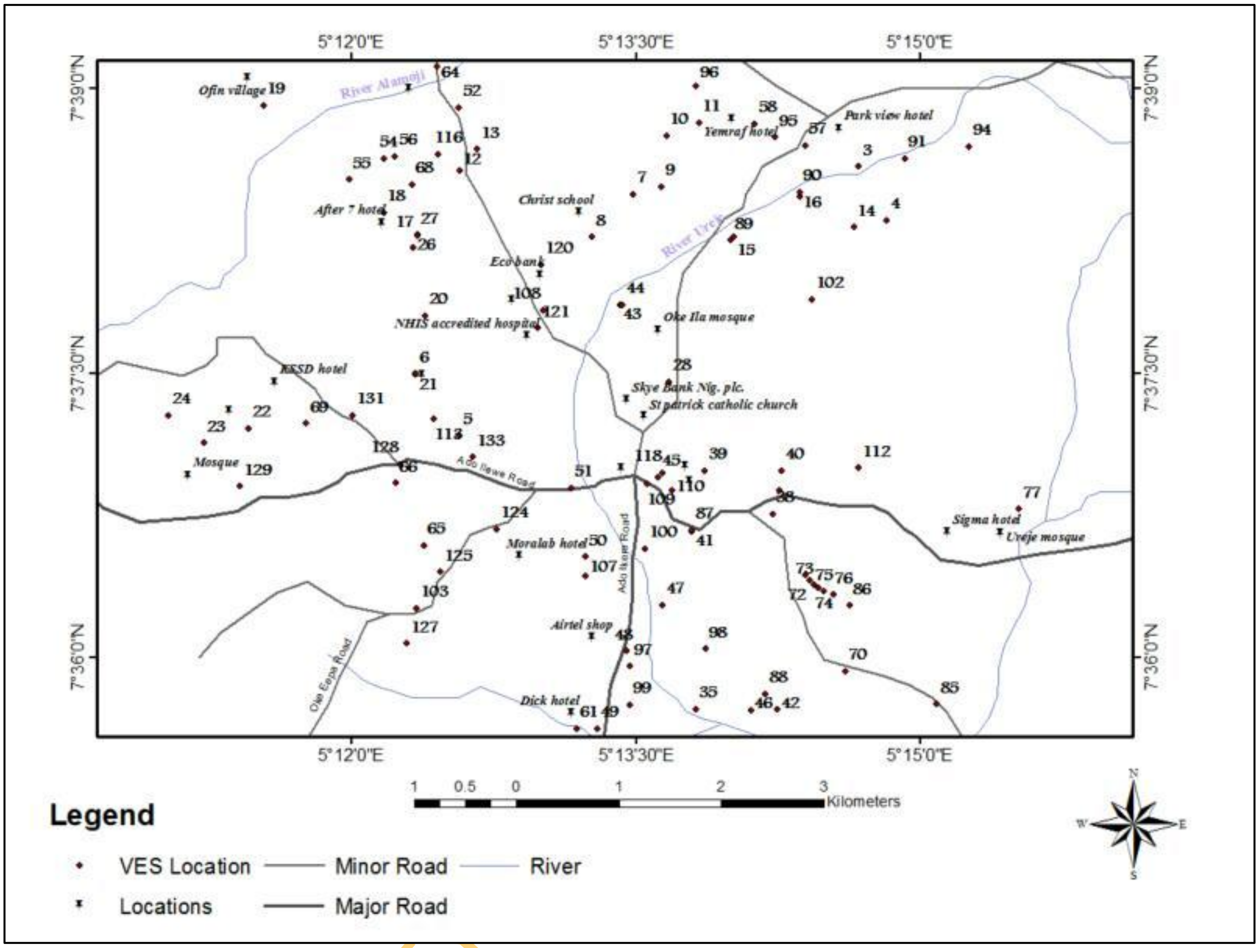


Figure 3.2: Location Map of the Study Area showing the VES Stations

(Longitude), Northings (Latitude) and Elevation above mean sea level of each point of interest during the fieldwork thus permitting application of the Geographical Information System (GIS).

It has been noted that among the various geophysical methods often applied in groundwater exploration, the Electrical Resistivity Method enjoys the widest adoption. The field operation is easy, the equipment is portable, it has greater depth of penetration and it is accessible to modern communication systems of the computer (Afolayan *et al*., 2004, Ariyo and Adeyemi, 2009 and Jayeoba and Oladunjoye, 2013).

3.2.3.2 Geophysical Data Analysis

Plotting the apparent resistivity values against half the current electrode separation (AB/2 or half the spread length) at each station on a bi-logarithmic (log – log) paper readily yielded the depth sounding curves. The curves were inspected to determine the number and nature of the layering. Partial curve matching of field curves with relevant Schlumberger developed master and auxiliary curves was carried out to obtain the layer resistivity values and corresponding thicknesses for the quantitative analyses of the curves. Geoelectric parameters from this manual interpretation were improved upon using computer iteration technique using the computer algorithm RESIST Version 1.0 (Vander Velpen, 1988). In the iterative forward modelling application the manually obtained results were used as starting model. Computer-generated curves were compared with corresponding field curves. Computer iteration of between 1 - 30 were carried out to reduce errors to a desired limit and to improve the goodness of fit (Olorunfemi *et al*., 1999, Omosuyi *et al*., 2003 and Adelusi *et al*., 2004).

3.2.3.3 Resistivity Sounding Curves

The visual inspection of the resistivity sounding curves permitted qualitative interpretation of the subsurface resistivity variations. The geoelectric curves obtained were inspected and classified. The curve types observed has implication on the degree of weathering and fracturing in the area and probable aquifer types. The bedrock could indicate distinct mineralogy and structural disposition. It could be weathered or possibly fractured basement or fresh basement. While the weathered / fractured basement could be too thin to be identified as a geoelectric unit it could be possible in some instances to detect a sufficiently thick transitional zone between the intensely weathered regolith atop and fresh bedrock below (Olayinka and Olorunfemi, 1992).

3.2.3.4 Computation of Dar Zarrouk Parameters

The Dar – Zarrouk parameters for the VES points were computed with the layer parameters as inputs. They are relevant in lithological differentiation and delineation of aquifer geometry (Rao *et al*., 2003 and Ehirim and Nwankwo, 2010). Oladapo, *et al* (2004) generated coefficient of anisotropy and total longitudinal unit conductance (s) maps from the combination of first and second order geolectric parameters (DZ) while conducting geoelectrical investigation of the Ondo State Housing Corporation Estate, Ijapo Akure, Southwestern Nigeria.

3.2.3.5 Determination of Overburden Protective Capacity

Contamination of the hydrogeologic system in metropolitan areas is fast becoming a critical issue in groundwater quality considerations. Installation of facilities, though essential but capable of provoking permanent damage of the underlying aquifers particularly in areas where residents rely mostly on groundwater mandates an understanding of the aquifer protective capacity of the overburden units of the host soil medium. Urbanization and industrialization remain the predominant contributors of contaminants to the hydrological systems. The potability of groundwater can be compromised by leachate from dumpsites, mining activities, buried petroleum pipes/tanks, latrines and septic tanks. All life depends on the environment. However, the attitudes of humans toward the wholesome environment are on the overall negative and are often contrary to the concept of sustainable development, which admits that economic growth and environmental protection are inextricably linked. The quality of life (present and future) rests on meeting the basic human needs without destroying the environment (Goni, 2006, Momoh and Oladebeye, 2010 and Ige and Olatunji, 2014).

Indiscriminate disposal of domestic and industrial solid wastes and the widespread use of chemical products such as pesticides, herbicides, and solvents portend risks to the hydrogeological settings of the area. Ige and Olatunji (2014) remarked that the rapid pace of urbanisation and the enormous scale of unmet needs are taking a heavy toll on the nation's cities and urban populations, especially the urban poor who live and work in appalling conditions that threaten their health and undermine their productivity.

The ability of the overburden to retard and filter percolating fluid is a measure of its protective capacity and a function of transmissivity. Estimating these properties from the traditional methods of pumping tests can be very expensive and time consuming. Surface geoelectrical method offers a rapid and cost effective approach. Oladapo *et al*. (2004), Braga *et al*. (2006) and Ehirim and Nwankwo, (2010) demonstrated the applications of the Dar Zarrouk Parameters as one of the most effective ways of evaluating impacts on the environment without interfering with the hydrogeologic system. The DZ parameters exhibit the combination of the thickness and resistivity of the geoelectric layers into single variables.

The total longitudinal unit conductance, S, values would be utilized in evaluating overburden protective capacity in the study area. The earth is applauded as a medium which acts as a natural filter to percolating fluid. Its ability to retard and filter percolating fluid is a measure of its protective capacity (Olorunfemi *et al*., 1999). Henriet (1975) described the protective capacity of an overburden overlying an aquifer as being proportional to its hydraulic conductivity. High clay content which impedes fluid movement is generally characterized by low resistivity values and low hydraulic conductivities and thus low longitudinal unit conductance.

The classification of Henriet (1975) as modified by Oladapo *et al.* (2004) has been shown to suit a crystalline Precambrian basement complex environment. The modification involves the increase of protective capacity ratings owing to the geologic and geoelectric complexity characterizing the basement complex rocks and their associated sediments. The classification has been adopted in evaluating the protective capacity in this study. The total longitudinal unit conductance map is prepared to show the protective capacity distribution of the study area.

3.2.4 Hydrostatic Level Sampling

Static Water Level (SWL) measurements were made from 108 hand – dug wells evenly distributed within the study area (Figure 3.3). The choice of a well was guided by its distance from a previously chosen well in the locality, availability of space to conduct VES and the permission of the owner to make the well available for study. With the GPS the topographical elevations of the well locations were recorded. The depths to the static water level were measured using steel band tape while information about water level of existing boreholes was obtained from the Government agencies (WATSAN).

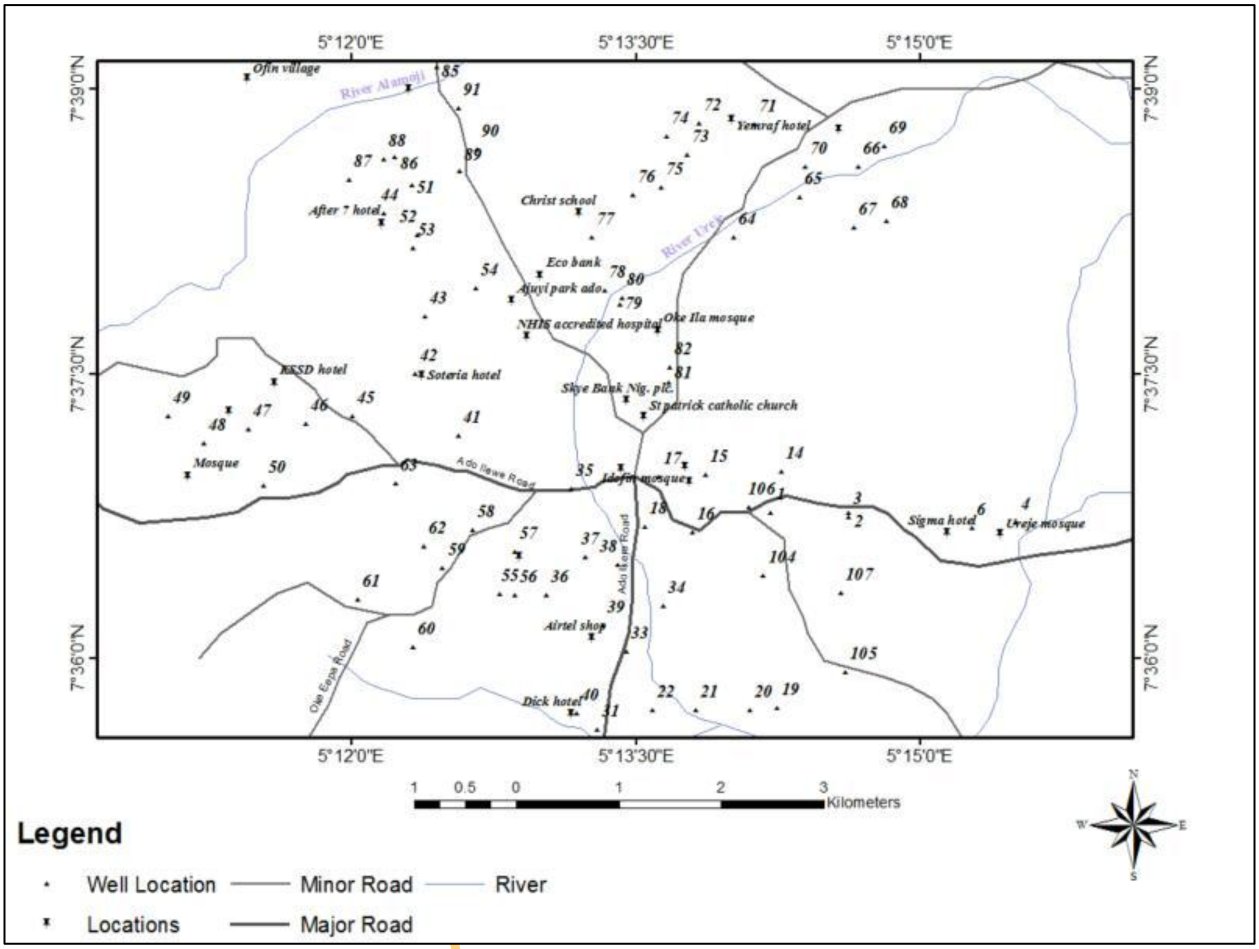


Figure 3.3: Location Map of the Study Area showing the Well Points

Deep wells drilled by government agency fitted with hand pumps were encountered. A good number were no longer functioning properly. They could only support a little column of water. On the spot examination at Erifun, Ikowe, Opposite Golf Club, Federal Poly Road and Ago Corner, Ijan Ekiti Road indicated that well drilling was terminated in clayey formations with varying significant clay contents. Shemang Jnr (1993) classified areas characterized by the presence of substantial amount of clay as zones diagnostic of low groundwater potentials and less appeal for groundwater development.

The value of the elevation of the water table – unconfined aquifer, was determined for each well point. The processed hydrostatic level data would offer adequate information about the groundwater head and the distribution pattern from which the groundwater divergent/convergent zones and direction of groundwater flow would be delineated.

3.2.5 Hydro – Chemical Analysis

Groundwater samples were taken from the existing wells using the Grab water sampling technique. The samples were collected in the pre-cleaned polythene bottles with necessary precautions. The samples were stored in well-drained, clean polyethylene bottles already rinsed out with the same water samples in each case. The samples were collected early in the morning. The temperature of each sample and a couple of other parameters were determined immediately at the point of collection while other analyses were carried out in the laboratory.

The Physico - chemical analysis of the water samples were carried out with a view to determining the potability of the well water. A total of 20 physico-chemical parameters were identified and measured against the provisions of the World Health Organization (WHO) standards for potable water. The samples were analysed at the Public Health Laboratory in the

Department of Civil Engineering of the Federal Polytechnics, Ado – Ekiti. Standard sampling and laboratory procedures were followed throughout the process (Adeyeye and Abulude, 2004, Adefemi *et al*., 2007 and Ishaku *et al.*, 2015).

The results of the tests were recorded alongside the co-ordinates and elevation of the well - points using a Garmin 12-Channel GPS unit. The depths of the wells and the static water levels in the wells were measured. The data were fed into an electronic database. The electronic database was subjected to thorough data-checking exercises. Mapping and Statistical Software were utilized to provide detailed analysis (Tijani *et al*., 2014)

3.2.6 Geographic Information System (GIS) Application

Data Preparation (mainly digitizing), Data Pre-processing (Georeferencing and resampling.), Data Processing (Edge Detection and Principal components analysis (PCA)), Data Analysis and Integration (Lineament Extraction and Statistics, Geostatistical Analysis, IDW) formed the basic methodology of this study. The elements of image interpretation include colour, tone, texture, shape, size, drainage pattern and associated landforms.

Inverse Distance Weighted was used for this study to interpolate Geographic point data. Inverse distance weighted (IDW) interpolation explicitly implements the assumption that things that are close to one another are more alike than those that are farther apart. To predict a value for any unmeasured location, IDW uses the measured values surrounding the prediction location. The measured values closest to the prediction location have more influence on the predicted value than those farther away. IDW assumes that each measured point has a local influence that diminishes with distance. It gives greater weights to points closest to the prediction location, and the weights diminish as a function of distance (Balakrishnan *et al.*, 2011, Srinivas *et al.*, 2013 and Badamasi *et al.*, 2016)

ArcGIS 10.2.2 was used to perform all operations including the Weighted Index Overlay Analysis.

3.2.7 Groundwater Potential Evaluation

Groundwater potential zones were demarcated by the integration of thematic layers generated from remote sensing and geoelectrical investigations using Geographic Information System (GIS) techniques. Thematic layers of relevant parameters including lithology, geomorphology, drainage density, slope, lineaments and geoelectric factors/attributes were considered. Multi-criteria evaluation techniques were used to integrate the thematic layers. Weightage factors were assigned to themes and their corresponding categories based on the groundwater prospects. The resultant layers were reclassified. The reclassified layers were integrated in a GIS environment to produce a composite groundwater potential map of the study area. The generated groundwater potential zones were validated with field checks and borehole / hand-dug well yield data (Singh *et al.*, 2013, Bagyaraj *et al.*, 2013 and Ojo *et al.*, 2015)

3.2.8 Evaluation of Groundwater Quality

The spatial distribution maps of concentrations of selected parameters were prepared to show the variation in concentrations of the chemical parameters in water samples across the study area using inverse distance weighted (IDW) raster interpolation technique of the spatial analyst module in ArcGIS software. GIS has emerged as a powerful tool for creating the spatial distribution maps.

The work of Balakrishnan *et al*. (2011) demonstrated the effectiveness of geographic information system (GIS) in Groundwater quality mapping. The study utilized data from physico-chemical analysis of 76 water samples collected from bore wells and open wells representing the entire area. Thematic layers of TDS, TH, Cl^- and NO^-_3 were overlaid in a GIS platform. In this study, Groundwater quality assessment using GIS, based on the physico-chemical data from 108 locations in Ado-Ekiti has been conducted to provide an overview of present groundwater quality and generate groundwater quality map for the metropolis. GIS application for storing, displaying, and analyzing spatial data enabled creation of the data base (Srinivas *et al*., 2013).

CHAPTER FOUR

RESULTS

4.1 Remote Sensing

Geologic features identified in respect of the study area are shown in Figure 4.1. The prominent rock suits include quartzites, gneisses, granites and charnockites.

The results of the lineament analysis are presented as the lineament map and lineament density map. The lineament map (Figure 4.2) shows that the lineaments/fracture distribution is not homogeneous. The lineament density variation map (Figure 4.3) shows the lineament numbers to be in the range of 0.00 and 0.24 km/sq km.

The hydrogeomorphological map of the study area is shown in Figure 4.4. The landforms identified in the area include hills, ridges, pediments, pediplains, pediplain with alluvium and valley fills. The various slope classes and their spatial distribution is presented in Figure 4.5. The slope map shows slope varying from 0º to 49º across the study area (*Ojo et al.*, 2015).

The drainage pattern, in general, is dendritic, typical of granitic terrain (Figure 4.6). It reflects the surface characteristics as well as subsurface formation (Prasad *et al.*, 2008). Drainage pattern is an important indicator of hydrogeological features as drainage pattern and density are controlled fundamentally by the underlying lithology. Drainage density is the length of streams per unit area (Bagyaraj *et al.*, 2013 and Chuma *et al*., 2013).

The Iwo, Ondo and Itagunmodi Associations are the three major soil units found in the study area (Figure 4.7). Soils in the study area are of the residual type derived from the weathering of the basement crystalline rocks; granites, gneisses and schists.

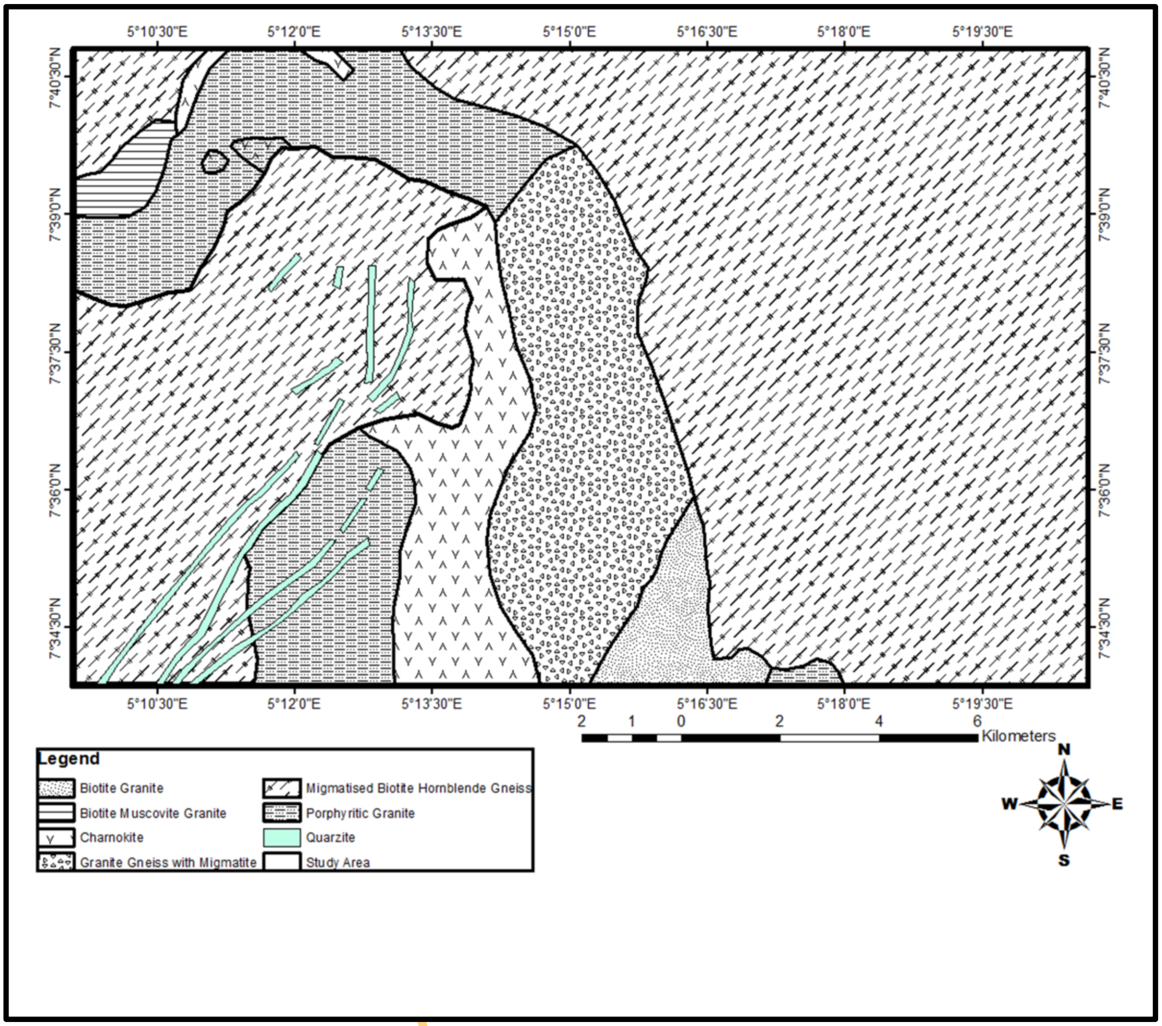


Figure 4.1: Geological Map (The Federal Geological Survey)

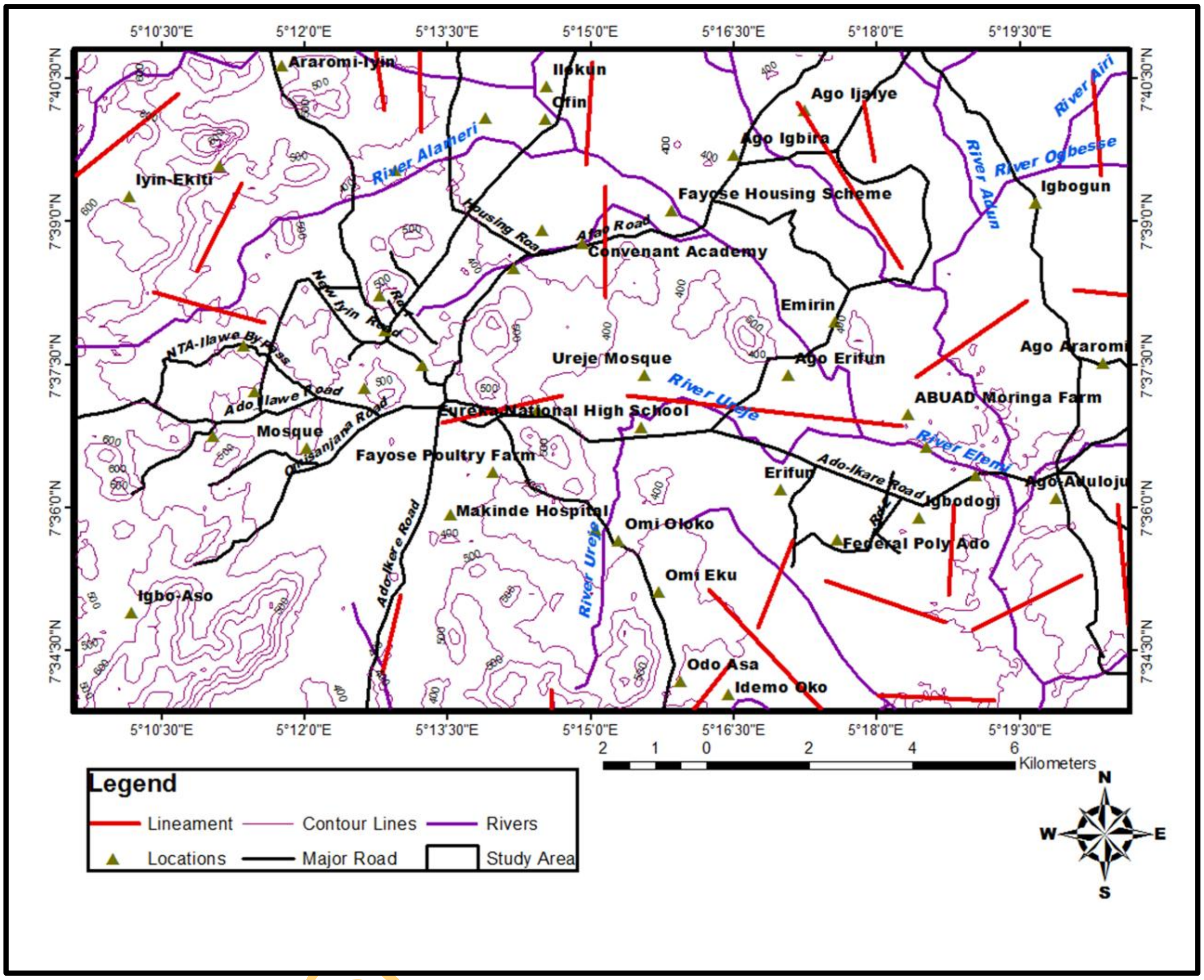


Figure 4.2: Lineament Map

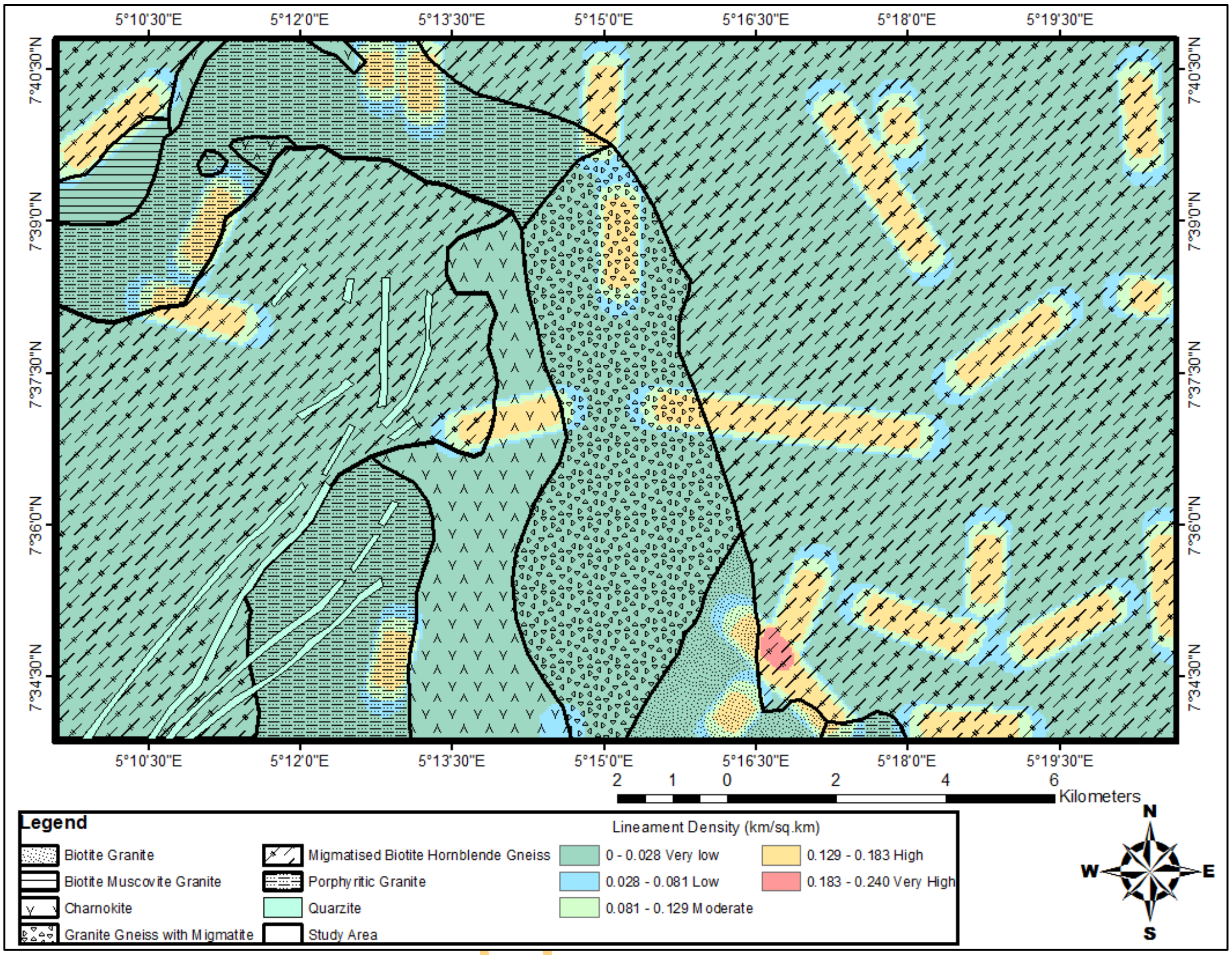


Figure 4.3: Lineament Density Map

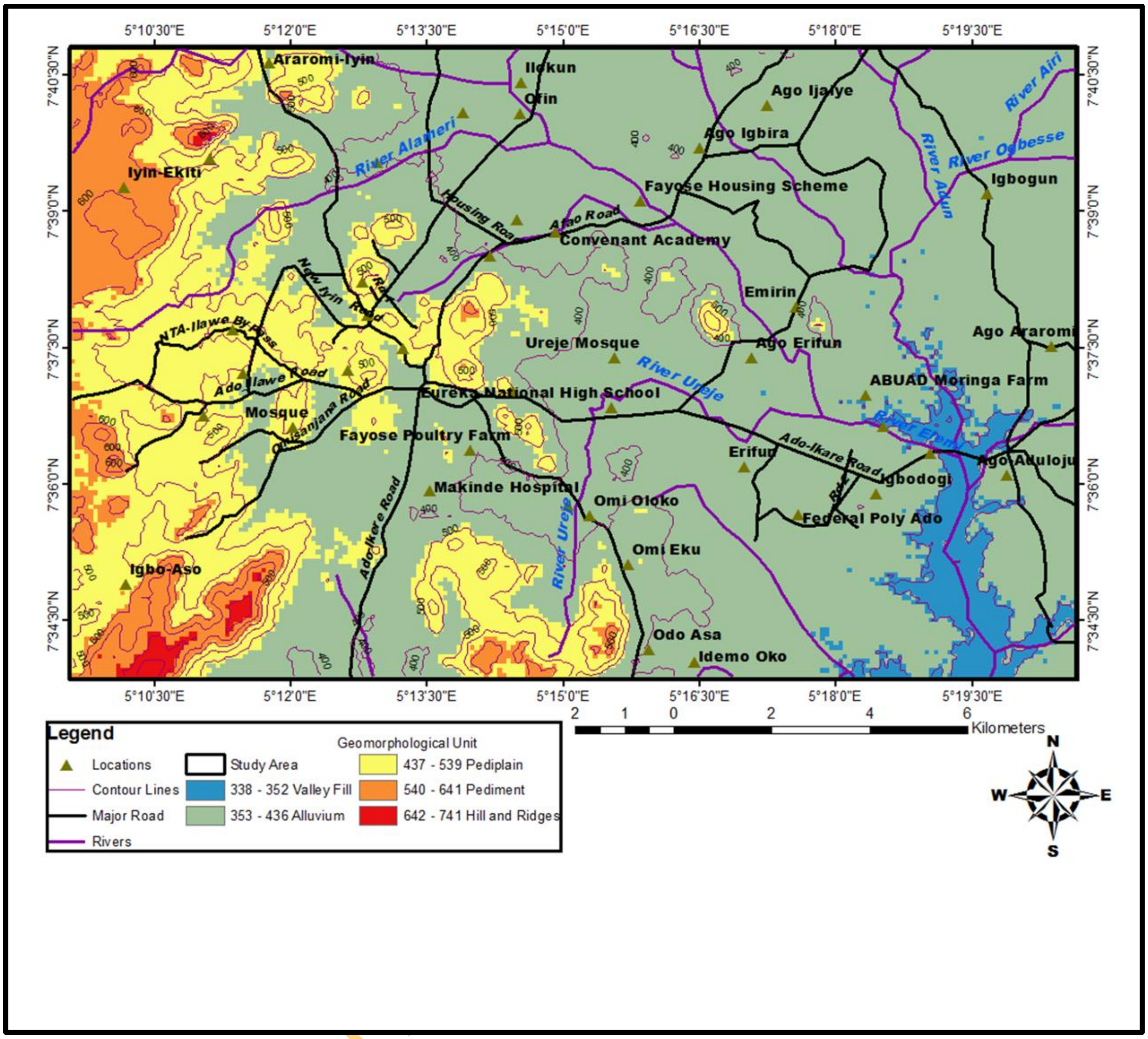


Figure 4.4: Geomorphological map

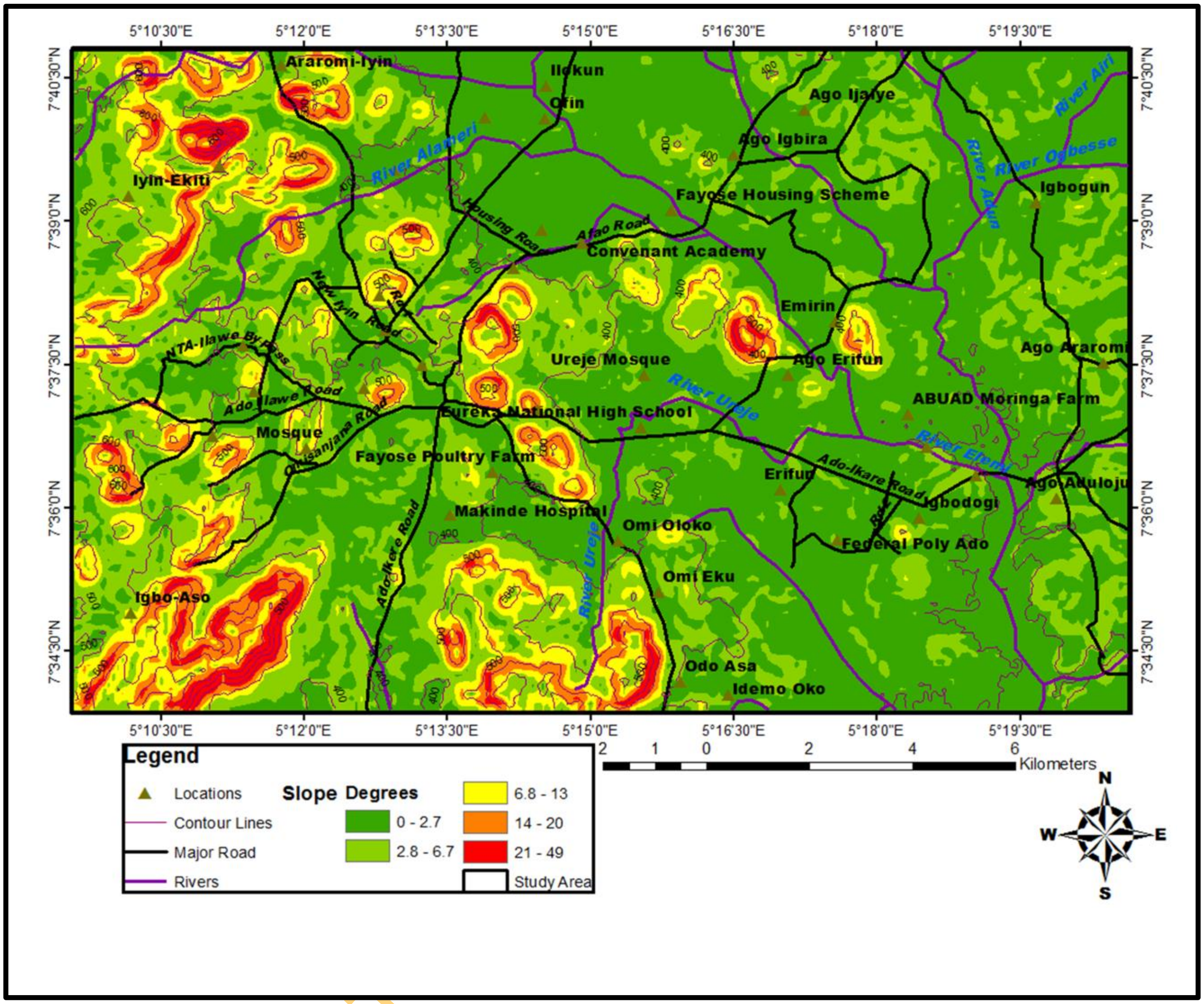


Figure 4.5: Slope Map

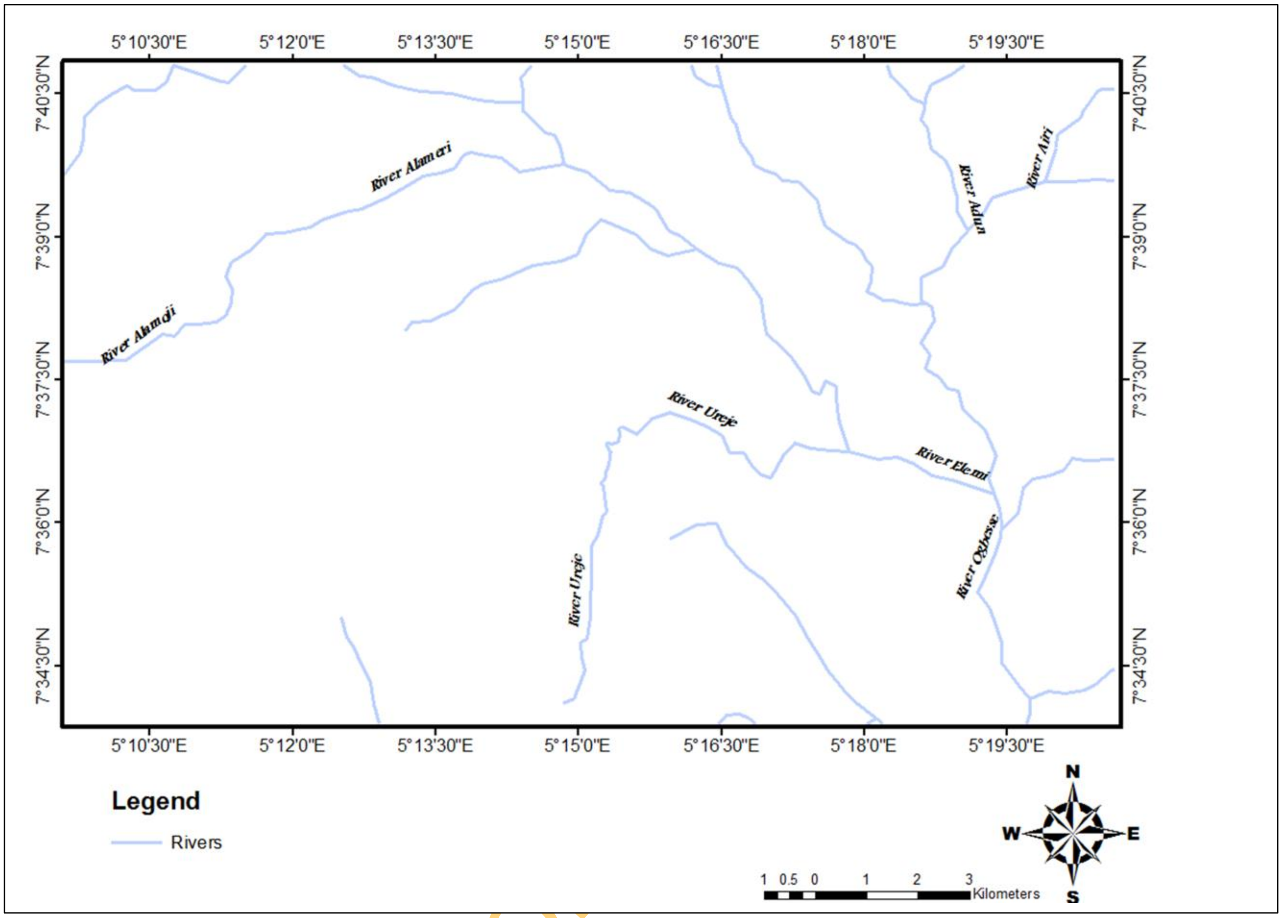


Figure 4.6: Drainage Map

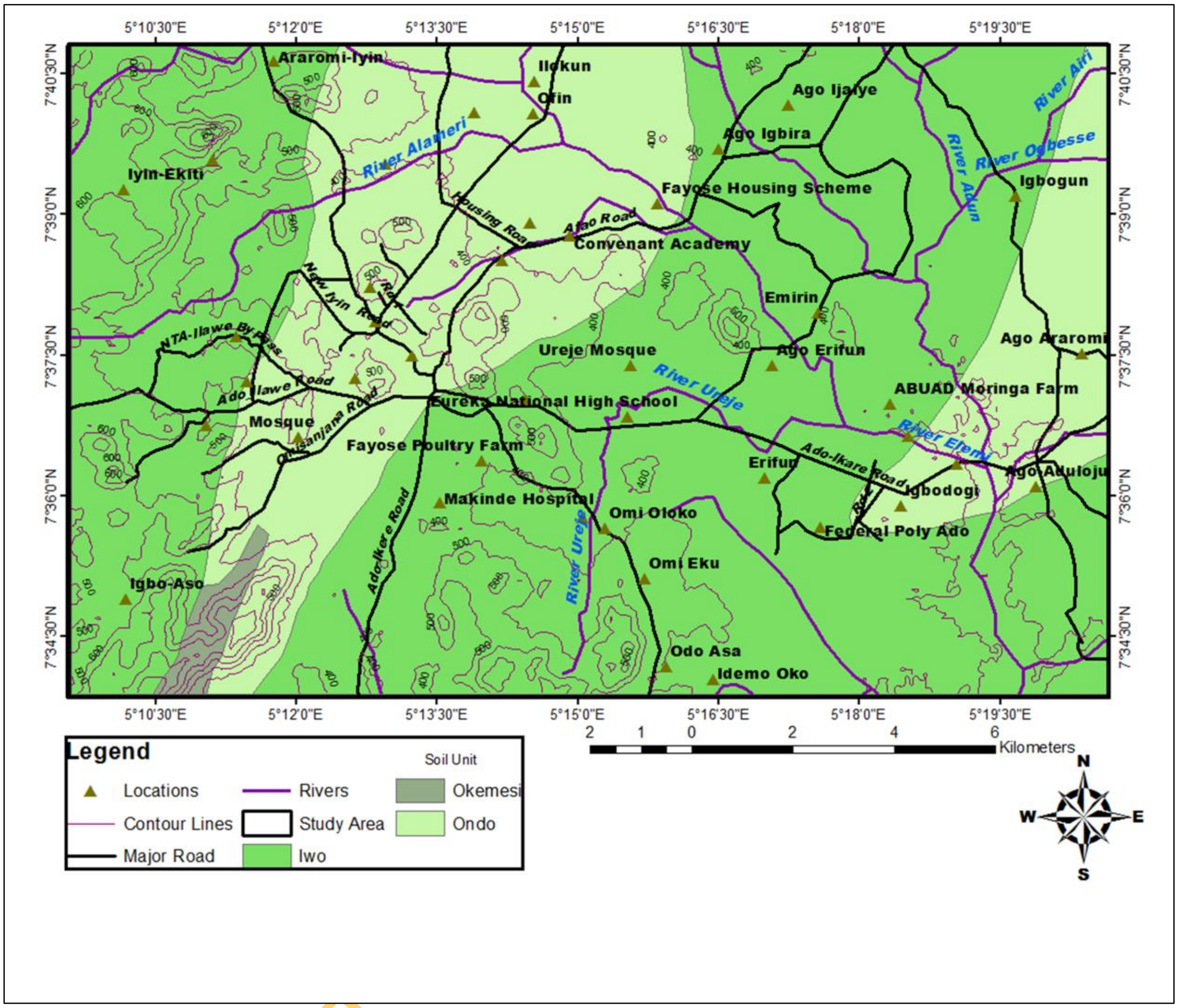


Figure 4.7: Soil Map (The Soil Survey Section, Ministry of Agriculture and Natural Resources)

Landuse/Landcover Classes in the study area are vegetation, water body, built-up and outcrops as shown in Figure 4.8. Built - up land (dense, medium and sparse residential areas) comprises of 68.6 km^2 of the total study area. Coverage of 52.4 km^2, 13.5 km^2 and 2.7 km^2 is recorded for dense, medium and sparse residential areas respectively (Table 4.1). The Light vegetation/Bare soil has an area extent of 110.9 km^2 with the Outcrops located in the northwestern and southwestern parts covering a total area of 14.9 km^2. Chart of the values are shown in Figure 4.9.

4.2 Geo-Electric Investigation

4.2.1 Resistivity Depth Sounding Type Curves

Generally in the study area, there are different curve types presenting varying number of layers (between two and six layers) as shown in Table 4.2. They include A, AA, H, HA, HK, K, KH, Q, QH and combinations as typical of the basement complex terrain (Olorunfemi and Okhue, 1992, Olayinka and Olorunfemi, 1992 and Ojo *et al*., 2015). The H-type, KH-type and HA-type curves account for 50.37% of the geoelectric curves with frequencies of 21.80%, 15.04% and 13.53% respectively. The layer parameters (layer resistivity and thickness) vary from one sounding curve type to another. This is a reflection of the geoelectric complexity often associated with basement complex terrain. It is also an indication of the degree of weathering and fracturing in the study area (Adelusi *et al*., 2004 and Oladapo *et al*., 2004).

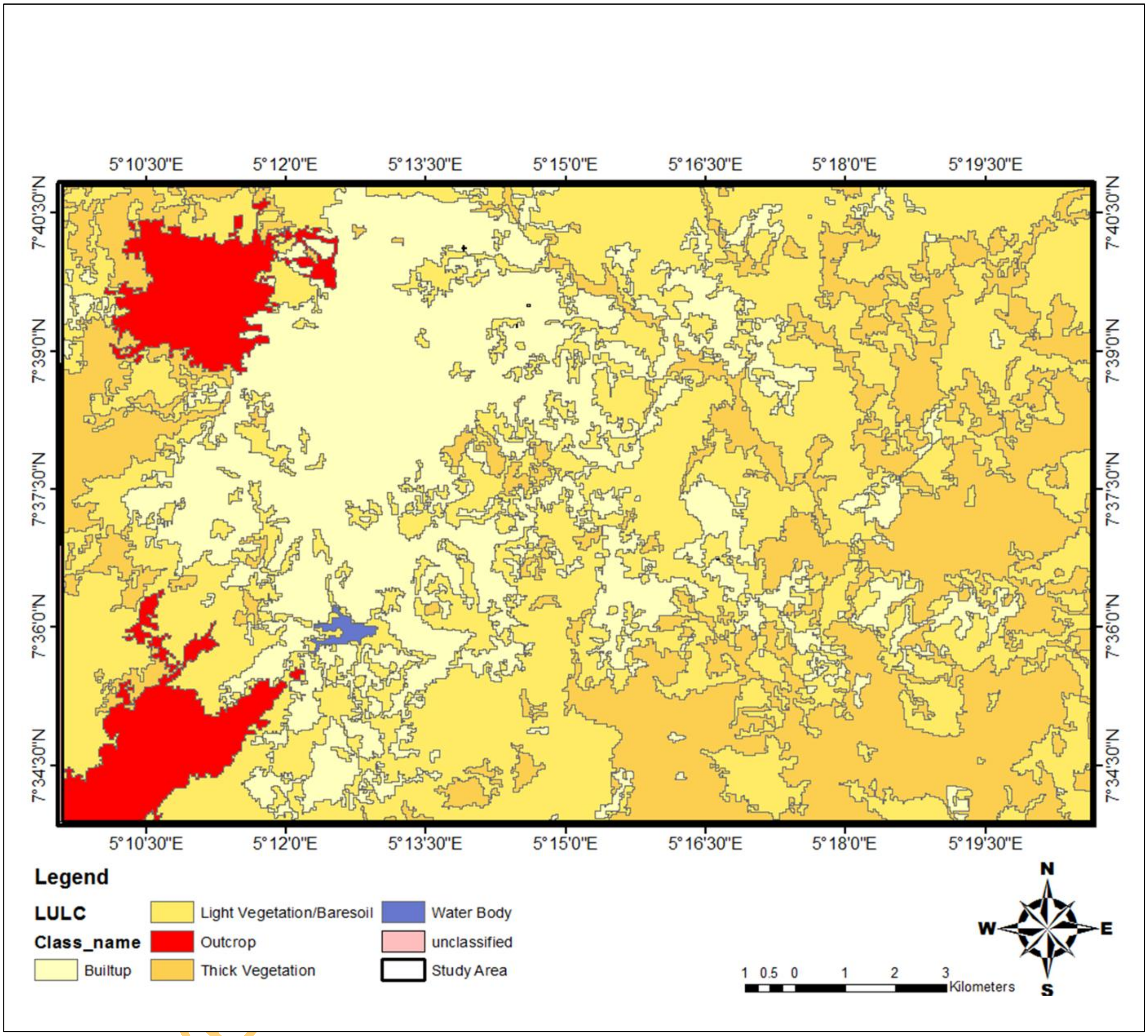


Figure 4.8: Landuse/Landcover Map

Table 4.1: Landuse/Landcover Area Extent

OBJECT ID	Class name	Shape Length	Shape Area(sqm)	Area(sqKm)
1	Built-up	687420	68658300	68.6583
2	Light Vegetation/Baresoil	1287780	110983500	110.9835
3	Outcrop	96180	14925600	14.9256
4	Thick Vegetation	681840	63722700	63.7227
5	Unclassified	124980	3847500	3.8475
6	Water Body	7020	410400	0.4104

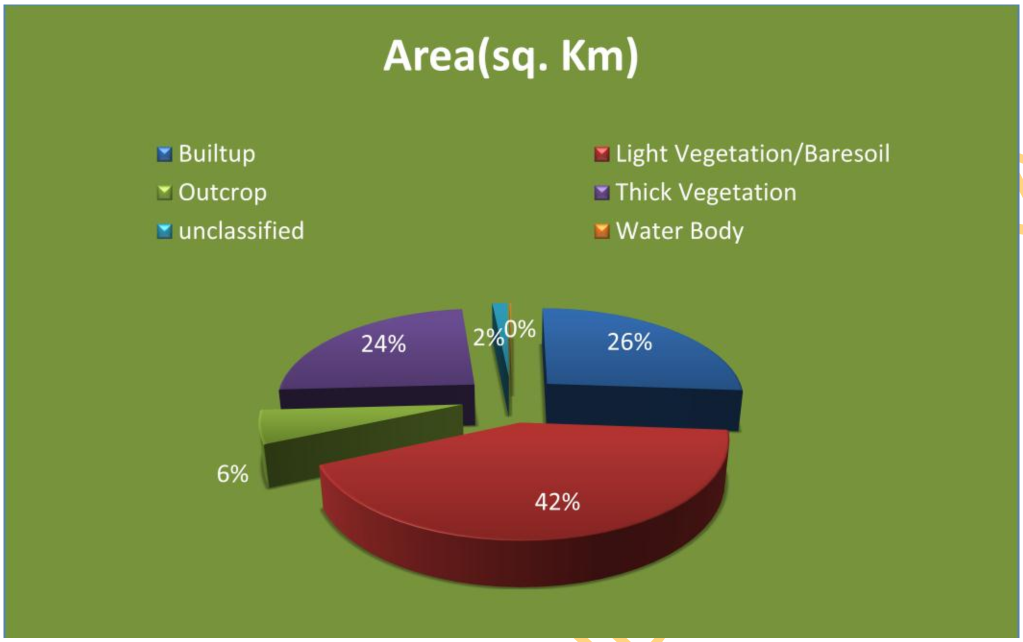


Figure 4.9: Pie chart of Landuse/Landcover

Table 4.2: Resistivity Depth Sounding Curves in the study area

CHARACTERISTICS	CURVE TYPES	NO. OF LAYERS	NO. OF OCCURRENCE	% OCCURRENCE
$\rho_1<\rho_2$	2 Layers	2	2	1.50
$\rho_1<\rho_2<\rho_3$	A	3	4	3.01
$\ell1<\ell2<\ell3<\ell4$	AA	4	2	1.50
$\rho_1>\rho_2<\rho_3$	H	3	29	21.80
$\rho_1>\rho_2<\rho_3<\rho_4$	HA	4	18	13.53
$\rho_1>\rho_2>\rho_3<\rho_4$	QH	4	6	4.51
$\ell1>\ell2>\ell3<\ell4<\ell5$	QHA	5	2	1.50
$\rho_1<\rho_2>\rho_3$	K	3	6	4.51
$\rho_1<\rho_2>\rho_3<\rho_4$	KH	4	20	15.04
$\rho_1>\rho_2<\rho_3>\rho_4$	HK	4	9	6.77
$\rho_1>\rho_2<\rho_3>\rho_4<\rho_5$	HKH	5	11	8.27
$\ell1>\ell2>\ell3$	Q	3	2	1.50
$\ell1<\ell2<\ell3>\ell4$	AK	4	2	1.50
$\ell1<\ell2>\ell3>\ell4$	KQ	4	1	0.75
$\ell1>\ell2<\ell3<\ell4>\ell5$	HAK	5	1	0.75
$\rho_1>\rho_2<\rho_3>\rho_4>\rho_5$	HKQ	5	2	1.50
$\rho_1<\rho_2>\rho_3>\rho_4<\rho_5$	KQH	5	3	2.26
$\ell_1<\ell_2>\ell_3<\ell_4<\ell_5$	KHA	5	4	3.01
$\rho_1<\rho_2>\rho_3<\rho_4>\rho_5$	KHK	5	4	3.01
$\ell_1<\ell_2<\ell_3>\ell_4<\ell_5$	AKH	5	1	0.75
$\ell1>\ell2<\ell3<\ell4<\ell5$	HAA	5	1	0.75
$\rho_1<\rho_2>\rho_3<\rho_4>\rho_5<\rho_6$	KHKH	6	1	0.75
$\ell_1<\ell_2>\ell_3<\ell_4<\ell_5<\ell_6$	KHAA	6	1	0.75
$\ell1>\ell2<\ell3>\ell4<\ell5<\ell6$	HKHA	6	1	0.75
	Total		133	100%

4.2.2 Geo-Electric and Dar Zarrouk Parameters

The Geoelectric and Dar Zarrouk Parameters are presented in Table 4.3. The topsoil is characterized by resistivity values ranging from 18 to 6409.9 Ωm with a mean of 339.4 Ωm and an average thickness of 1.3 m. The second layer is characterized by resistivity values ranging from 4.8 to 5200 Ω-m giving the mean value of 319.7 Ωm. The thickness of the layer varies from 0.2 m to 46.7 m with a mean value of 8.1 m.

A mean value of 383.9 Ωm has been obtained for the weathered basement / fractured basement layer in the study area. The fractured basement layer resistivities were generally less than 1600 Ωm. The thickness of the layer varies from 0.2 m to 53.2 m, with a mean of 17.6 m.

The bedrock is infinitely resistive at some points and the resistivity values remain generally very high at several other points. Localized variations may be attributed to differences in the bedrock mineralogy and structures. The overburden thickness varies from 1.0 to 79.9 m with a mean of 25.24 m.

The results are consistent with Okhue and Olorunfemi (1992), Olorunfemi *et al*. (1999), Mallam and Emenike (2008), Adiat *et al* (2009), Ariyo and Adeyemi (2009), Jayeoba and Oladunjoye (2013) and Ojo *et al*., (2015)

The Longitudinal Unit Conductance varies widely with a mean value of 0.30 mhos and a maximum of 4.40 mhos. This follows the trends observed by Obiora, *et al*., 2015, Adeniji *et al.*, (2014), Oladapo *et al.*, (2004) and Rao *et al*., (2003). The transverse resistance indicates a general value of T with a mean value of 11272 Ωm^2. Much higher values recorded at a few points might be due to localized variations.

Table 4.3**:** Descriptive Statistics of Geoelectric and Dar Zarrouk Parameters

Parameters	Minimum	Maximum	Mean	Standard Deviation
Overburden thickness(m)	1.0	79.9	25.4	17.2
Longitudinal Conductance (Ω^{-1})	0.01	4.4	0.3	0.5
Transverse Resistance (Ωm^2)	102.8	191390	11272	24308
Coefficient of Anisotropy	1.0	3	1.4	0.4
Bedrock Resistivity(ohms-m)	35.9	999999	101230	297180
Weathered Basement Resistivity(ohms-m)	6.0	5717	383.9	791.7
Weathered Basement Thickness(m)	0.2	57.5	17.6	12.9
Elevation(m)	367.0	522	420.6	22.3
Bedrock Relief (m)	321.6	518.7	395.2	27.2
TopSoil Resistivity (ohms-m)	18.0	1634.4	339.4	655.7
TopSoil Thickness(m)	0.3	7.8	1.3	1.5
Second layer Resistivity (ohms-m)	4.8	5200	319.7	633.9
Second layer Thickness(m)	0.2	46.7	8.1	19.4

The coefficient of anisotropy varies from 1.00 to 3.00 with a mean of 1.40. The result agrees with Olorunfemi and Olorunniwo (1985), Rao *et al*. (2003) and Oladapo *et al.* (2004).

4.3 Hydro –Static Measurements

The results of hydrostatic measurements are presented in Table 4.4. The static water level in the study area varies from 1.55 to 13.12 m with a mean of 5.89 m and standard deviation of 2.35 m. The total depth of well varies from 2.4 to 14.10 m with a mean of 6.65 m and standard deviation 2.47 m.

The Elevation of the wells varies from 362 to 464 m and averaging 418.84 ± 21.18 m. The groundwater head varies between 292.2 and 460.4 m with a mean of 412.08 m and standard deviation of 23.54 m. Groundwater is abstracted from the metropolis mainly via hand-dug wells and deep wells.

4.4 Hydrochemical Analysis

The summary of the results of the physicho-chemical analysis are presented in Table 4.5 in order to provide a statement on groundwater quality in the area of investigation.

The colour rating of the water samples ranges between 5 and 60 with an average of 15.58 ± 12.35 HU. Particularly high colour ratings of 60 HU were observed in two Wells. 67% of the samples are odourless with similar patterns displayed in taste and appearance. Taste and odour are of prime importance in assessing the palatability of water.

Turbidity of water samples ranges from 0.65 to 105.5 NTU with a mean value of 12.48 ± 14.81 NTU. This is a reflection of the values of the suspended solids in the water samples, which vary from 0.00 to 455; the mean value being 16.95 ± 52.67 mg/l. The prevalent turbidity lies in the range of 0.00 to 10.00 NTU.

Table 4.4: The results of Hydro –Static Measurements

Parameters	Minimum	Maximum	Mean	Std. Deviation
Well Elevation (m)	362	464	418.67	21.21
Static water level (m)	1.55	13.12	5.89	2.29
Total depth (m)	2.4	14.1	6.65	2.47
Groundwater Head (m)	292.2	460.4	412.08	23.54
Water Column (m)	0.01	8.9	0.76	1.07

Table 4.5: Summary of Descriptive Statistics of Physico-chemical Parameters

Parameters	Minimum	Maximum	Mean	Std. Deviation
COLOUR(H.U)	5.00	60.00	15.5825	12.3531
TURBIDITY(N.T.U)	.65	105.50	12.4804	14.8121
SITETEMP	4.25	33.00	30.9150	2.6968
TEMP(Deg C)	1.05	39.00	29.0888	3.7766
ELECTRICAL CONDUCTIVITY	.79	77.00	13.1999	13.6197
TOTAL SOLID(mg/l)	.50	420.00	42.1605	72.5723
SUSPENDED SOLID(mg/l)	.00	455.00	16.9549	52.6683
DISSOLVED OXYGEN(ppm)	3.37	68.00	6.3650	6.4150
DISSOLVED SOLIDS(mg/l)	.00	405.00	33.5700	64.0992
PH	3.50	8.20	6.5019	.8798
CALCIUM(mg/l)	3.20	346.00	51.7618	51.5006
MAGNISIUM(mg/)	6.30	220.00	51.2927	39.2176
CHLORIDE(mg/l)	.51	480.00	53.3831	71.9412
AMMONIA	.00	2.00	.5075	.6309
TOTAL HARDNESS(mg/l)	20.00	420.00	112.2330	67.4018
ACIDITY	.10	10.40	.8068	1.7433
CARBONATE ALKALINITY	.00	60.00	7.1922	14.4996
NITRATE	.00	50.00	3.8022	11.2884
BI-CARBONATE ALKALINITY	2.05	304.00	87.7027	65.1391
Valid N (listwise)				

The mean values for total solids and suspended solids are 42.16 ± 72.52 mg/l and 16.95 ± 52.67 mg/l respectively. High values are however recorded in a number of wells. These wells also exhibit correspondingly high values of turbidity. The wells are characterized by low values of total dissolved solids with an average of 33.57 mg/l and standard deviation of 64.10 mg/l.

Electrical conductivity varies from 0.79 to 77 µS/cm with a mean of 13.20 µS/cm and standard deviation of 13.62 µS/cm. The most frequently occurring value is 5.00 µS/cm. Conductivity is a measure of the conductance of an electric current in water. The Temperature of the samples lies within 29.08 ± 3.78 ^{o}C. Temperature is basically important for the chemical and biological reactions of organisms in water. The pH values vary from 3.50 to 8.20 with a mean of 6.50 ± 0.88 for the study area. Most of the sampled wells are within the WHO limit for pH values.

The concentrations of calcium in the wells ranged between 3.20 and 346 mg/l with mean value of 51.76 ± 51.50 mg/l while values obtained for magnesium ranged between 6.30 and 220 mg/l with an average of 51.29 ± 39.22 mg/l. Calcium and magnesium are the prime constituents concerned with hardness. Total Hardness in the samples varies from 20 – 420 mg/l with a mean of 112.23 ± 67.40 mg/l. These values are within the tolerable limit of the WHO standards except for a couple of wells.

Chlorides concentrations in the wells ranged between 0.51 and 480 mg/l with mean value of 53.38 ± 71.94 mg/l. The concentrations of nitrates in the water samples are quite minimal; the mean value being 3.80 ± 11.29. Natural nitrate levels in groundwater are generally very low (typically less than 10 mg/l NO_3). The Ammonia values of the water samples are generally low (0.01 – 2.00) with an average of 0.51 ± 0.63.

Bicarbonate and carbonate cause alkalinity of groundwater. In Carbonate and Bi-carbonate alkalinity considerations, nearly all the samples have low values with mean values of 7.19 ± 14.50 and 87.70 ± 65.14 respectively.

4.5 Evaluation of Groundwater Quality

Figures 4.10 to 4.15 show the re-classified thematic layers of pH, Total Hardness, Total Dissolved Solids (TDS), Nitrate, Chloride and Calcium ions concentrations in water samples.

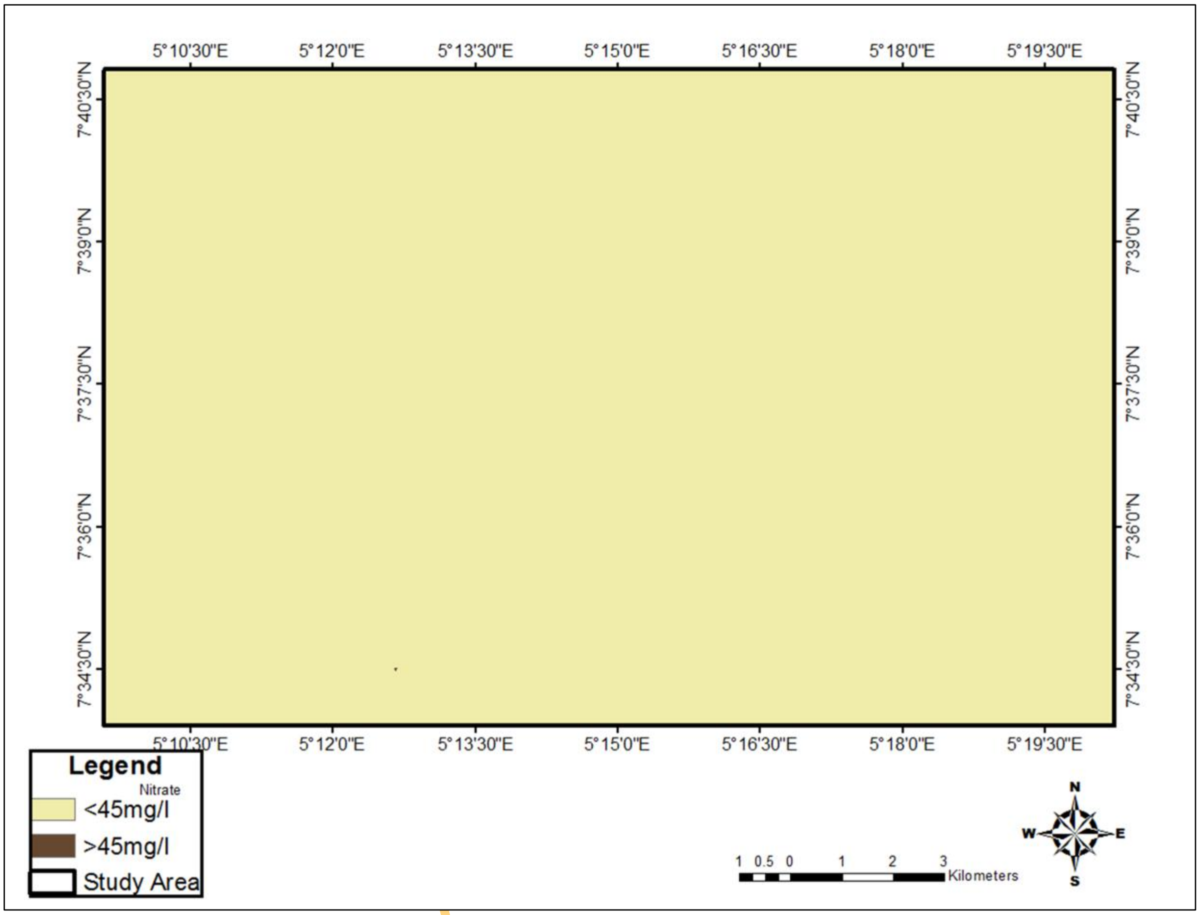


Figure 4.10: Nitrate Map

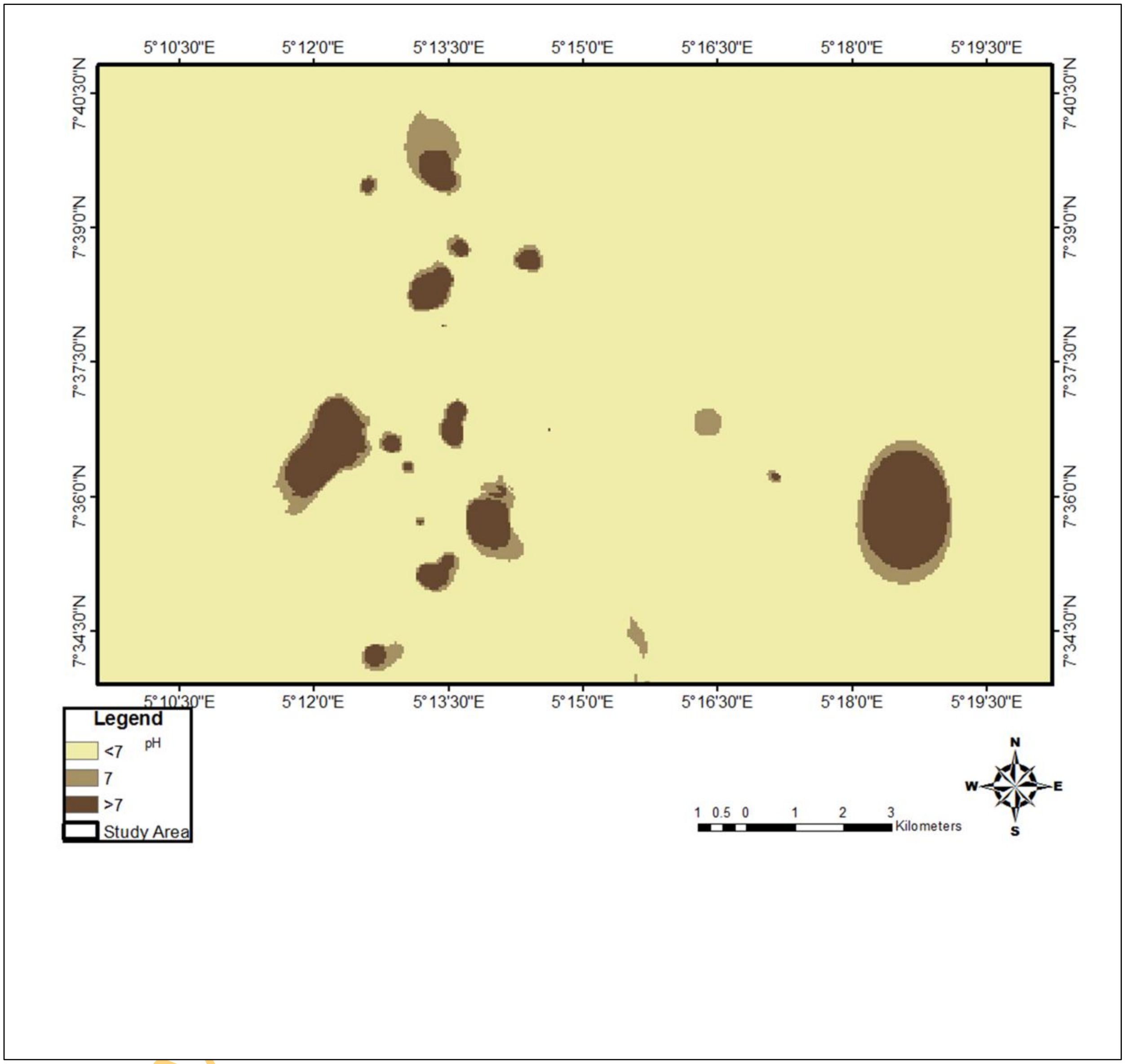


Figure 4.11: pH Map

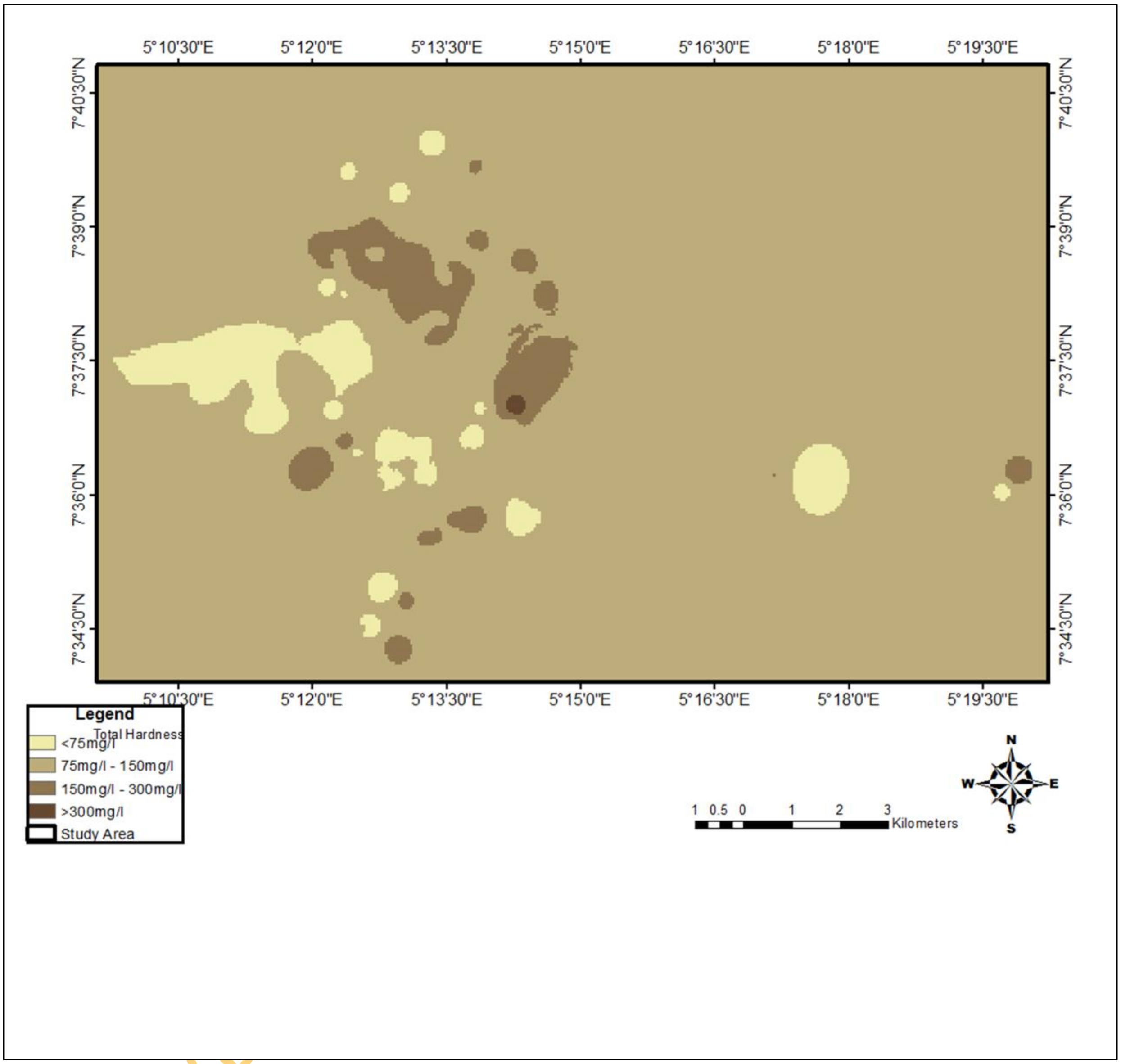


Figure 4.12: Total Hardness Map

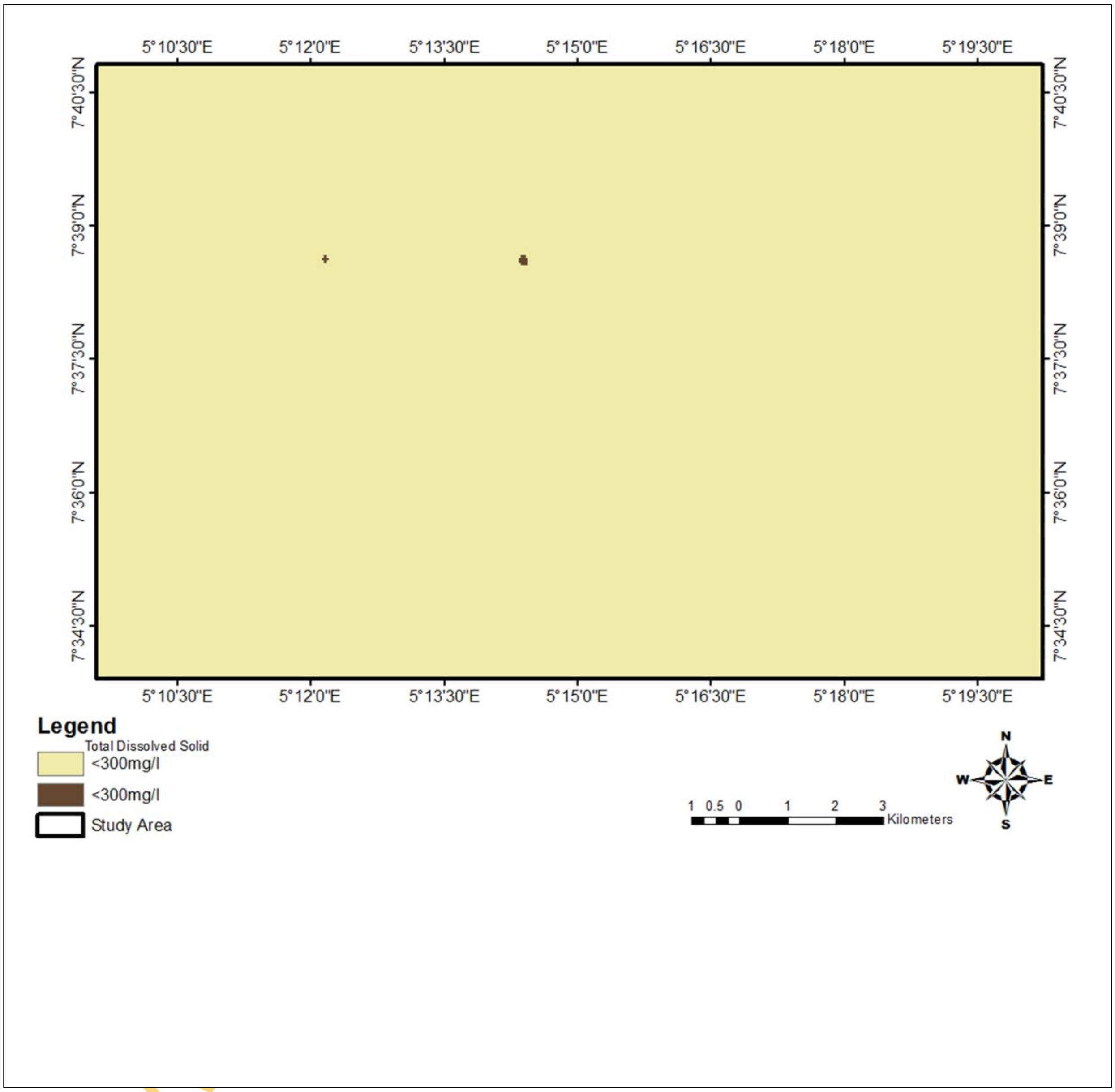


Figure 4.13: Total Dissolved Solid Map

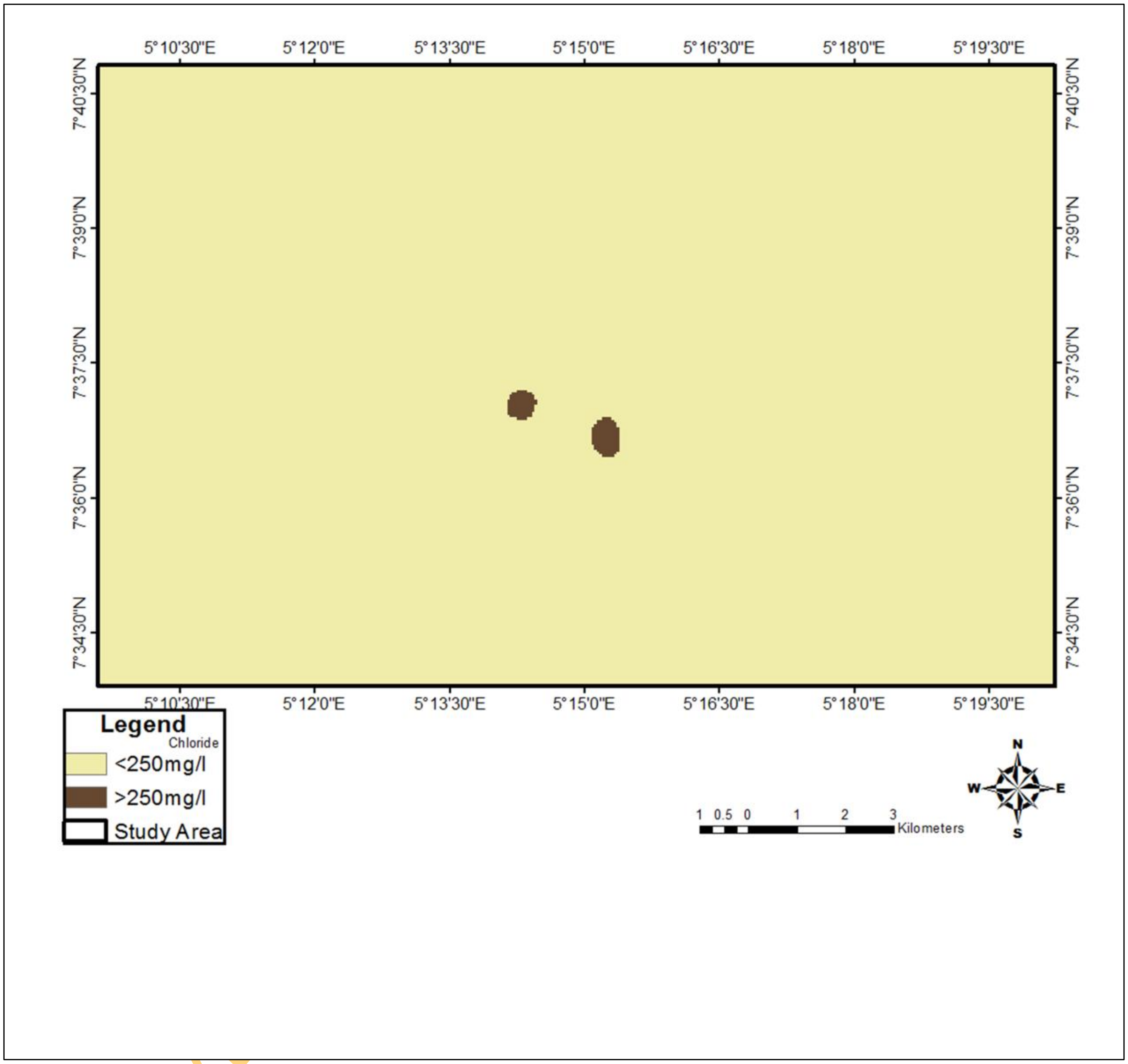


Figure 4.14: Chloride Map

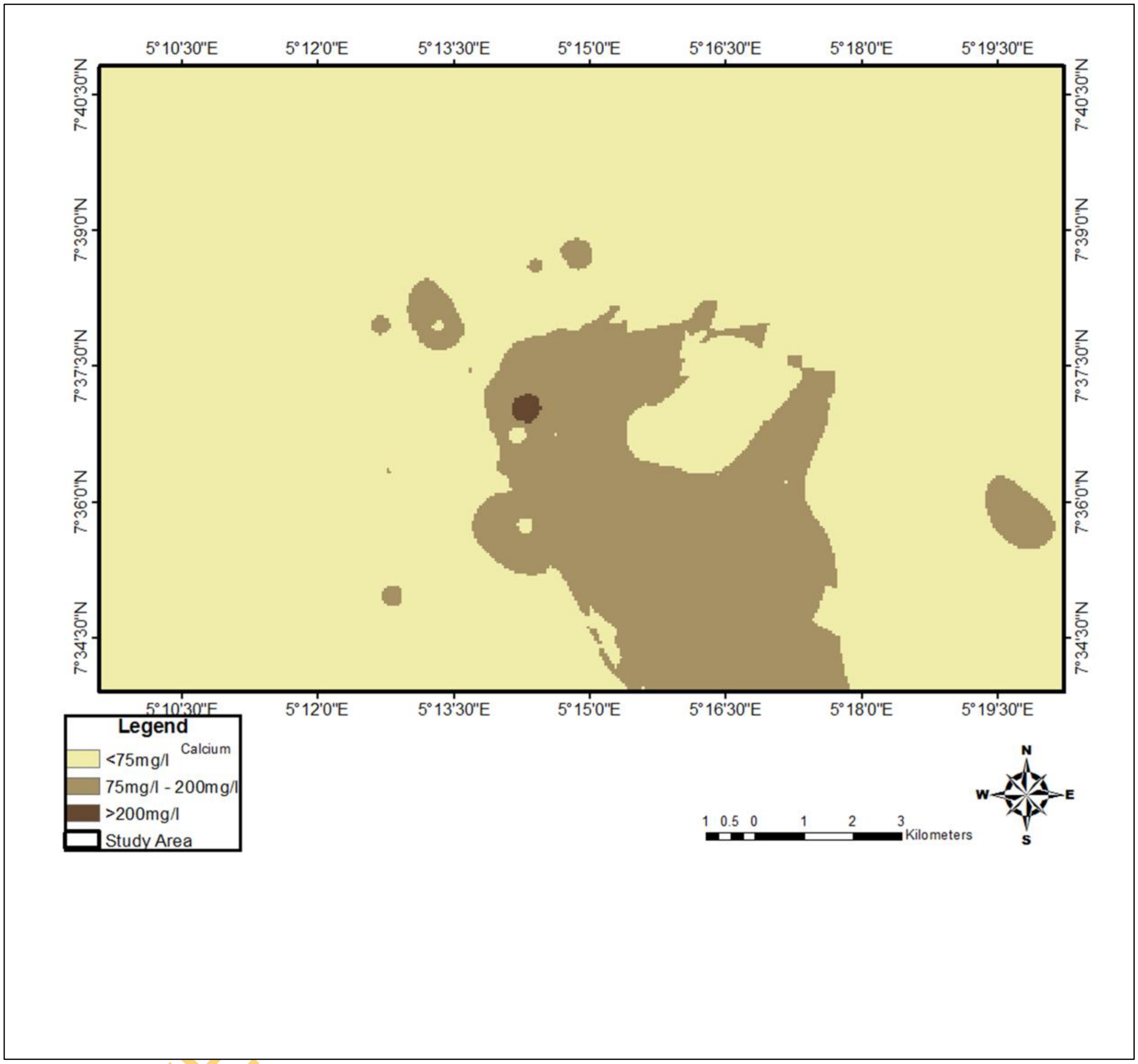


Figure 4.15: Calcium Map

CHAPTER FIVE

DISCUSSION

5.1 Remote Sensing

5.1.1 Lineament Analysis

Lineament analysis of the study area gave important information on subsurface features that control the movement and/or storage of groundwater. The lineaments show predominantly NNW-SSE, ENE-WSW and NNE-SSW orientations and subsidiary NW-SE and W-E trends that are typical of the Basement Complex region of Nigeria. Lineaments represent surface manifestation of structurally controlled features such as faults, fractures and rock contacts. In most cases the orientation of the fractures is identical to the orientation of the preferential flow path (Ojo *et al*., 2015)

The majority of the lineaments/fractures are located on the migmatised biotite hornblende gneiss with the minorities on the charnokites (Figure 5.1). The distribution of lineaments suggests geologic control. The granites and gneisses are more responsive to stress by fracturing than charnockites. Lineaments like joints, fractures etc., develop generally due to tectonic stress and strain. They are responsible for the infiltration of surface runoff into the subsurface as well as the movement and storage of groundwater. Higher groundwater potentials are thus envisaged from areas underlain by gneisses and granites (Olorunfemi *et al.*, 1999 and Chuma *et al.*, 2013).

The lineaments density map, Figure 5.2, gives an indication of the degree of hydraulic interconnection within the lithologic units as surface water circulates through these discontinuities. It is a measure of quantitative length of linear feature per unit area which can indirectly reveal the groundwater potentials as the presence of lineaments usually denotes a permeable zone (Fashae *et al*., 2014).

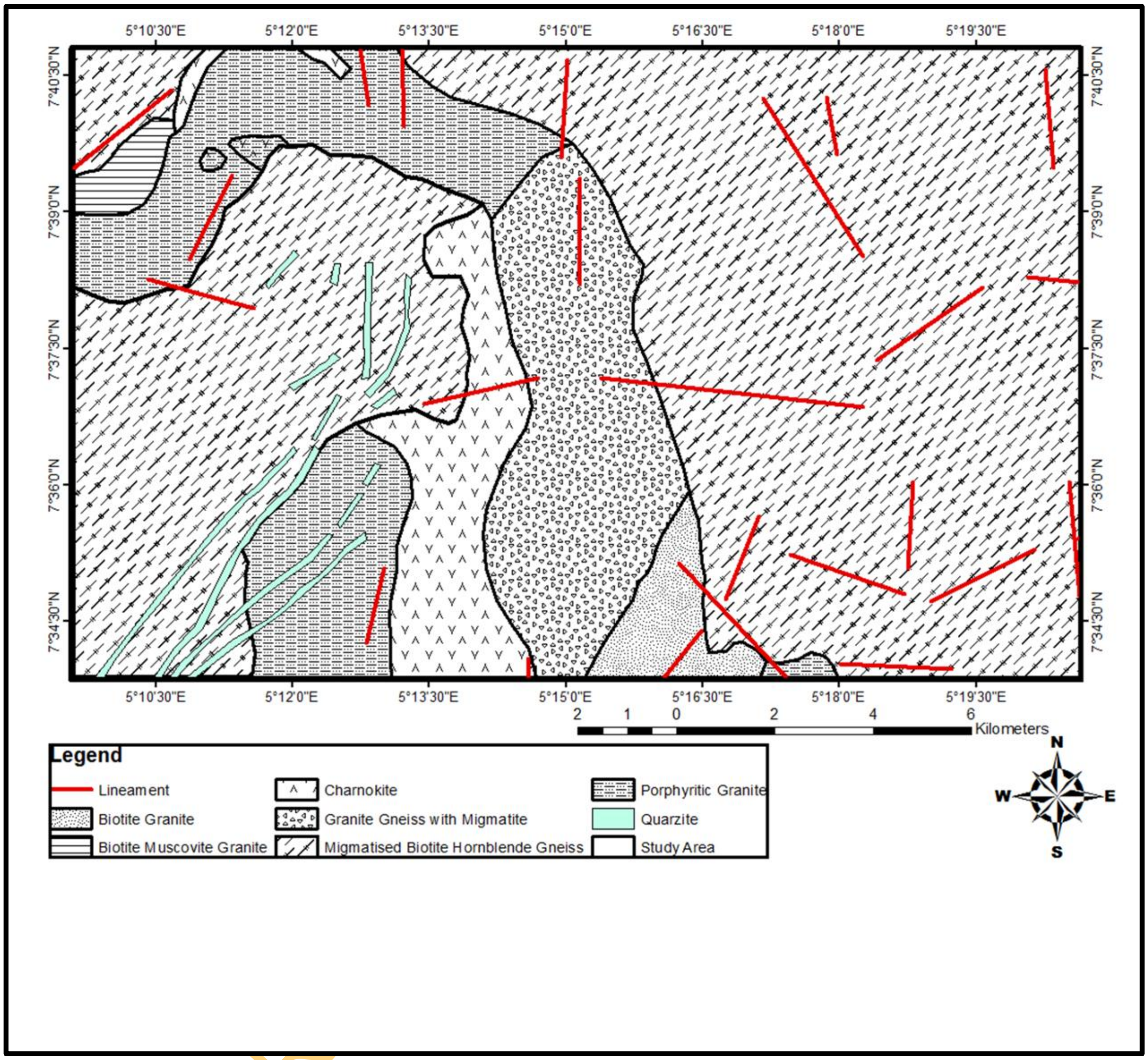


Figure 5.1: Lineament Map

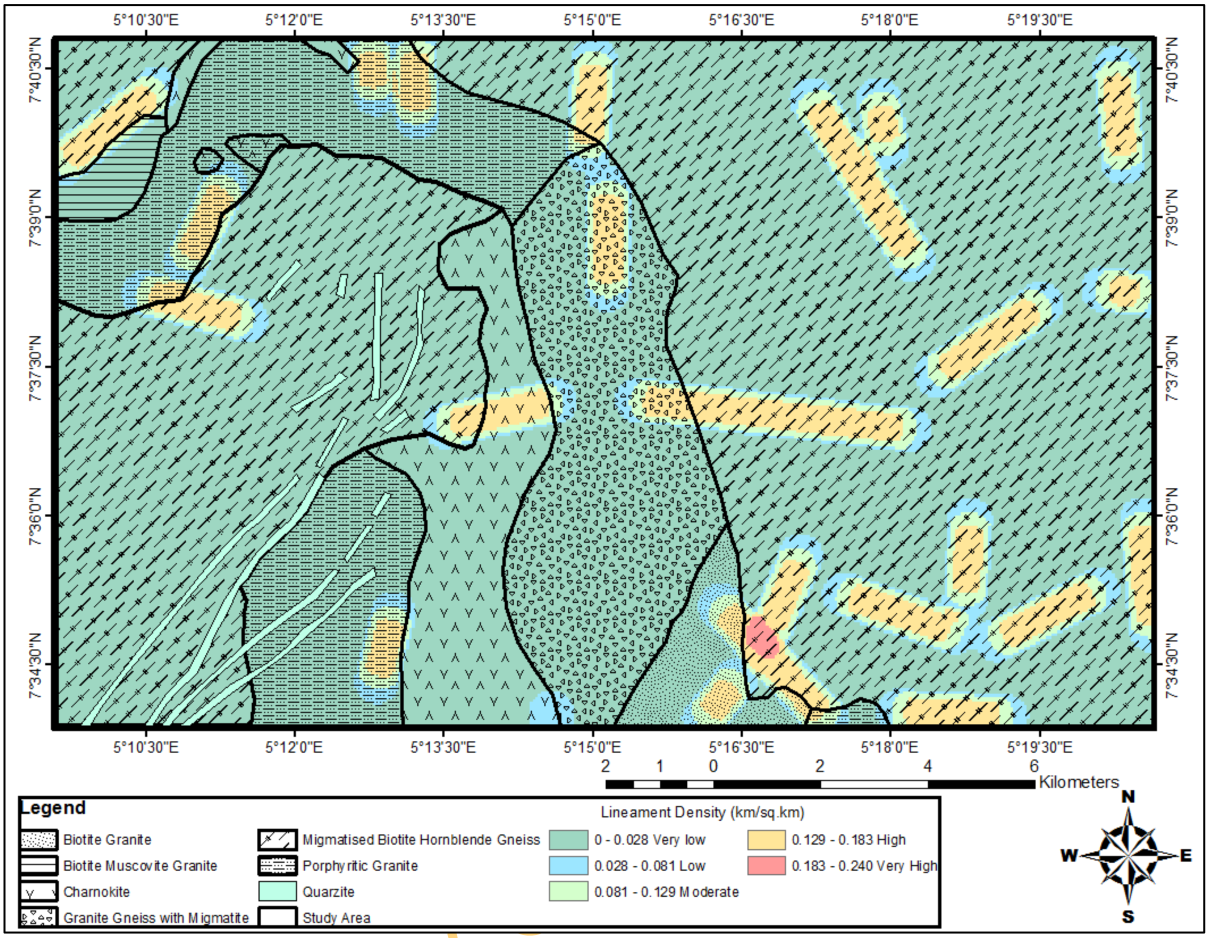


Figure 5.2: Lineament Density Map

High Lineaments density may present incipient highly connected fractures that are favorable for the accumulation of groundwater (Chuma *et al.*, 2013, Prabu and Rajagopalan, 2013 and Ojo *et al.*, 2015)

5.1.2 The Hydrogeomorphological Map

Hydrogeomorphologically, the study area has been classified as Hills, ridges, pediments, pediplains, pediplain with alluvium and valley fills (Figure 5.3). Their characteristics and groundwater prospects are given in Table 5.1. The hills in the area are mainly made up of quartzites, gneisses, granites and charnockites.

Groundwater occurs under unconfined conditions in shallow, moderately weathered zones of the pediplain and in semi-confined conditions in joints, fissures, and fractures that extend beyond the weathered zones. The crystalline granites and gneisses of the region lack primary porosity. As such, secondary porosity (joints, lineaments and the weathered zone) is the main source for groundwater occurrence, movement and transmission (Rao and Jugran, 2003). The groundwater in a typical Basement Complex environment is usually contained in the weathered and/or fractured basement rocks or alluvial deposits within flood plains (Jayeoba and Oladunjoye, 2013). Areas within the valley fills, the pediplain with alluvium, pediplains, pediment and hills and ridges could be classified as having tendency for very high, high, moderate, low and very low groundwater prospect respectively (Bayowa *et al.*, 2014 and Ojo *et al.*, 2015).

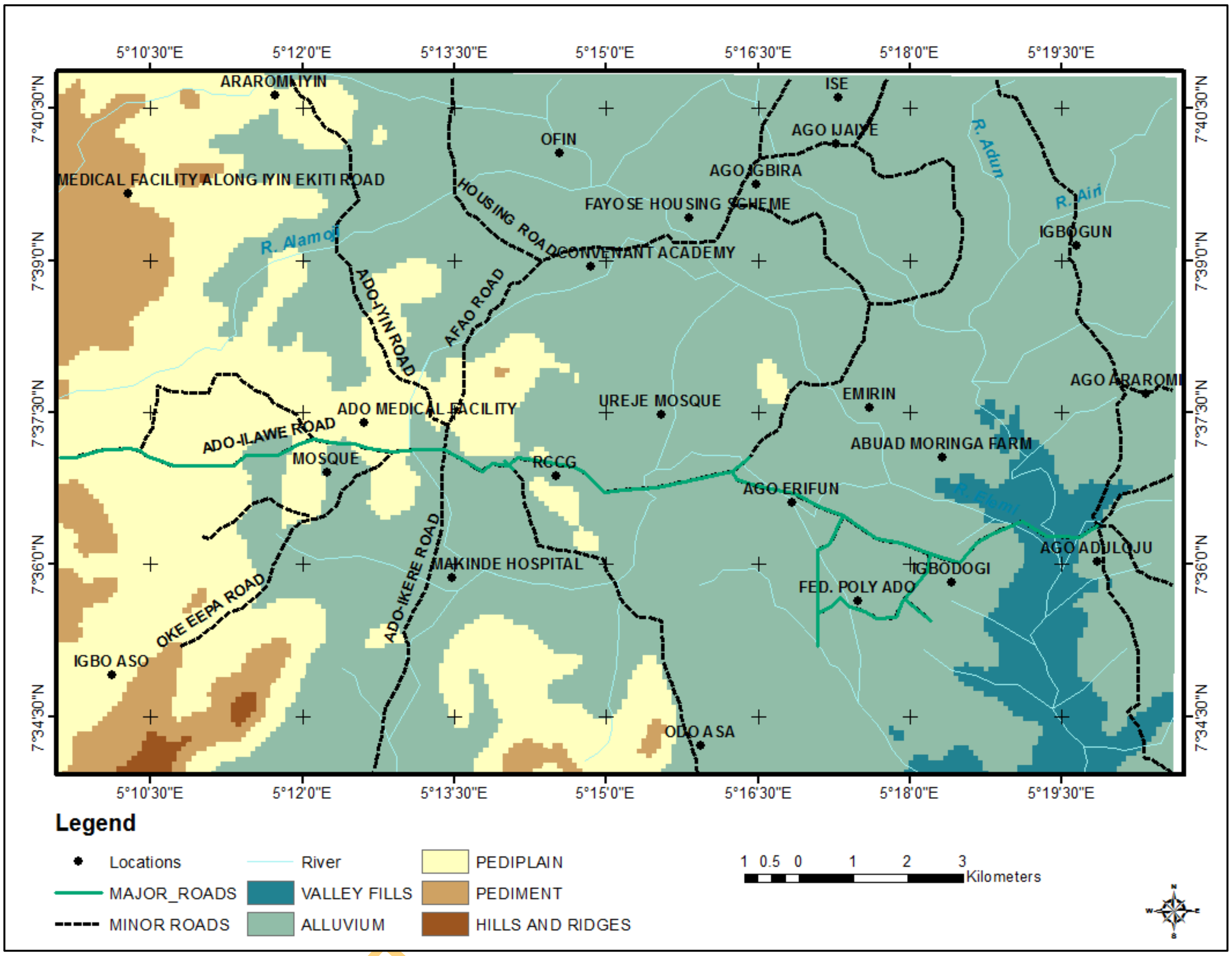


Figure 5.3: The Hydrogeomorphological Map of the Ado-Ekiti area, SW, Nigeria

Table 5.1: Hydrogeomorphological Characteristics in Ado –Ekiti (Rao and Jugran, 2003 and Bayowa *et al.*, 2014)

Units	Characteristics	Groundwater prospects
Alluvium	Nearly level surface along the river courses with gravel, coarse-fine sand, clay etc.,	Very good to excellent
Moderately weathered pediplain	Occurring away from hills with gentle slopes and more vegetation. The potentials are increased when underlain by fractures with increased weathered zone thickness	Good to very good.
Shallow weathered pediplain	Gentle to medium slope with sparse vegetation; possess only medium groundwater prospect unless when underlain by fractures	Medium to good
Inselberg, Residual hill and Denudational hill	characterized by medium to high relief / Steep slopes with varying area extent or dimensions	Nil
The valley fills	are developed due to deposition of transported and or weathered materials in valley areas and are normally controlled by lineaments. They are low linear areas	Very Good

5.1.3 Slope

The slope map (Figure 5.4) displays surface gradients that range from 0 - 49^0. Slope is a crucial parameter for occurrence and recharging conditions of groundwater in a particular area. The topographic slope of the area affects the runoff, recharge and movement of surface water. From a slope degree analysis, topographic slopes within the study area were classified as nearly level, very gentle, gentle, moderate, strong, moderately steep to steep, and very steep. The relationship with groundwater potential is presented in Table 5.2.

Gentle slopes are indicative of slow runoff thereby allowing more time for rainwater infiltration. Steep slope areas are characterized by high runoff, with less residence time for rainwater and less infiltration. The steeper the slope, the greater is the runoff and thus, lesser is the groundwater recharge (Talabi and Tijani, 2011 and Bagyaraj *et al*., 2013).

5.1.4 Soil

The three major soil units distributed across the study area include the Iwo, Ondo and Okemesi Associations (Figure 5.5). The nature of residual soils in the study area is determined by the underlying geology (Bayowa *et al*., 2014 and Ghosh *et al*., 2016). The Iwo soil type is underlain by coarse grained granite, gneiss and charnokites. The soil is composed of coarse textured, grayish brown to brown sandy to fairly clayey soils. The soil type is widespread in the study area. The sandy nature of this soil promotes infiltration. The Ondo association is found on medium grained granite and gneiss underlain areas. The soil comprise fine to medium textured, orange brown to brownish red fairly clayey soils overlying orange, brown to red mottled clay. The Okemesi Association is located on quartz schist and gneisses. The soil is composed of very coarse textured, Gravelly, pale greyey brown to brown, usually Sandy soil.

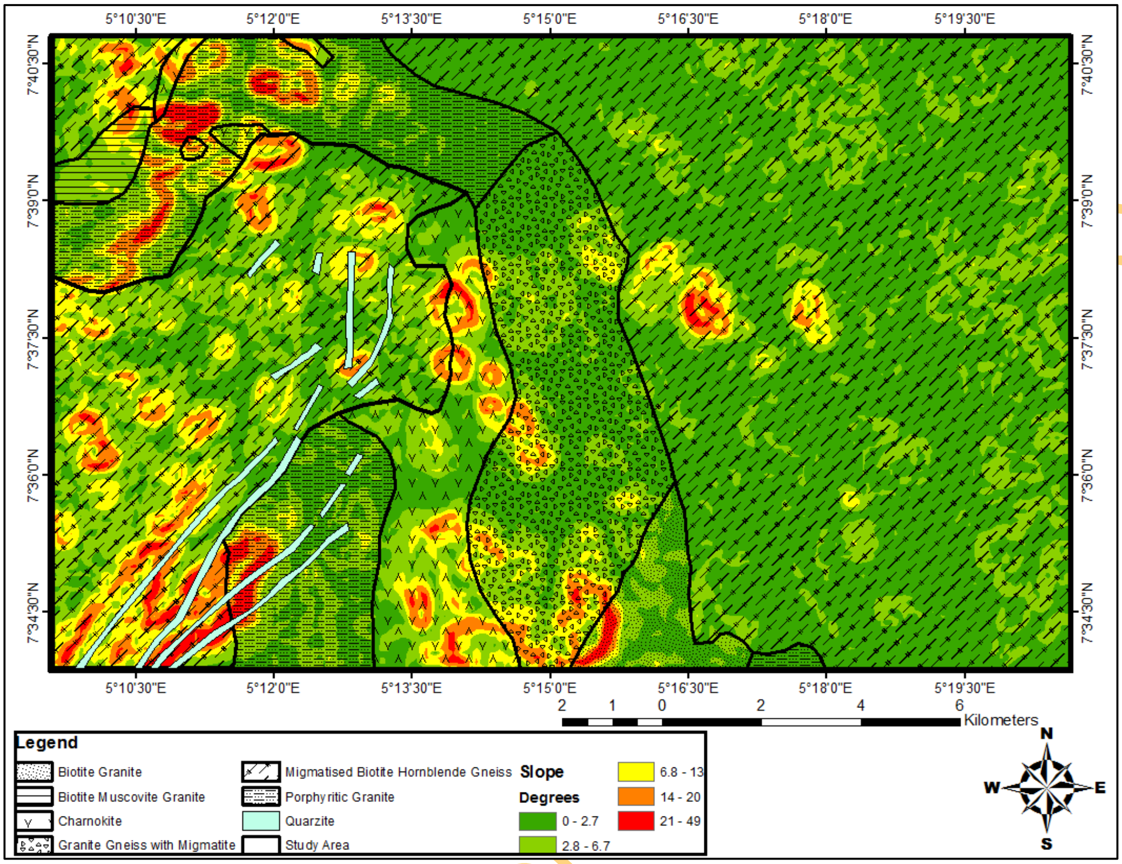


Figure 5.4: Slope Map of the Ado-Ekiti area, SW, Nigeria

Table 5.2**:** Classification of Slope in the study area

Classes	Attributes	Groundwater Prospect
0° – 2.7°	Gently sloping	Very High
2.8° – 6.7°	Moderately sloping	High
6.8 °– 13°	Moderate steep sloping	Medium
14° – 20°	Steep sloping	Low
>21°	Very steeply sloping	Very Low

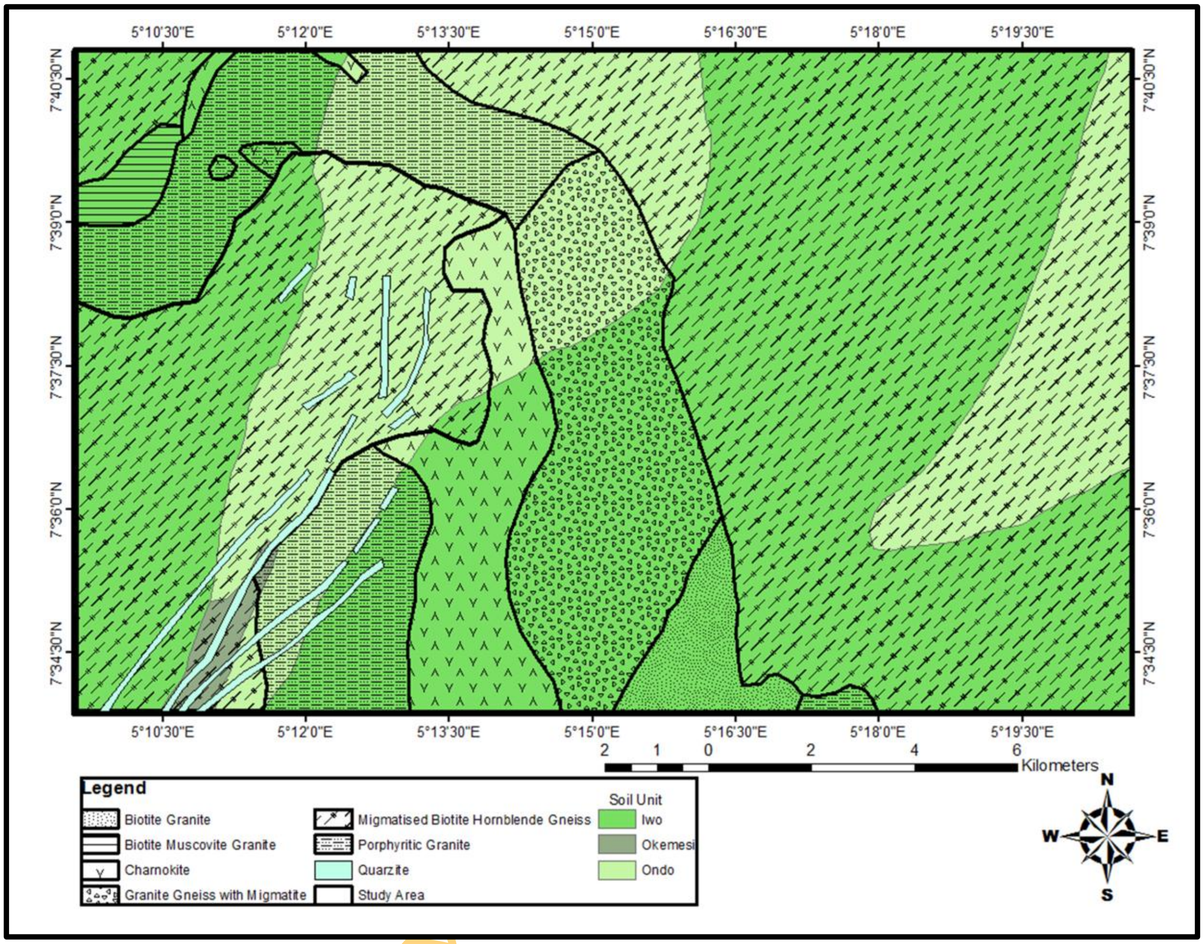


Figure 5.5: Soil Map of the Ado-Ekiti area, SW, Nigeria

5.1.5 Landuse/Landcover

Land use/land cover is a significant factor affecting the recharge process. Presence of water bodies, vegetation, soil deposits and human settlements are important elements of this factor. Only four zones of landcover/landuse were defined; vegetation, water body, built-up, and outcrops. The barren/fallow lands and settlements would have poor water - holding capacity unlike the wet/water bodies and cultivated lands (Selvam *et al*., 2014 and Badamasi *et al.*, 2016).

5.1.6 Drainage density

Drainage density is proportional to surface run-off, the higher the drainage density, the higher the runoff. The drainage density reflects the runoff in an area as the volume of relative water unable to penetrate into the subsurface (Parasad *et al.*, 2008 and Singh *et al.*, 2013). Low drainage density enhances recharge and groundwater availability if other groundwater occurrence conditions are favourable.

The drainage density map reflects the infiltration characteristics with high drainage density indicating low-infiltration and the low drainage density high infiltration respectively. The drainage density of the study area has been grouped into five classes (very low, low, moderate, high and very high). On the stand point of recharge/groundwater prospect, more weightage has been assigned to regions characterized by very low drainage density while low weightage was assigned to regions of very high drainage density.

5.2 Geoelectric Characteristics

5.2.1 Characteristics of the Resistivity Sounding Curves / VES Curves

Type curves having striking similar features have been classified to give groups of curves (Olorunfemi and Olorunniwo, 1985, Olayinka and Olorunfemi,, 1992 and Adelusi *et al*., 2009). The Class 1 comprises of the 2 - layers, A and AA - type curves. The 2-layers, A and AA - type curves present subsurface conditions in which there is a persistent increase in the layer resistivity values from the topsoil to the basement rock **($\rho_1 < \rho_2$, $\rho_1 < \rho_2 < \rho_3$** and **$\rho_1 < \rho_2 < \rho_3 < \rho_4$** respectively**)**. In the 2-layer curves, the topsoil overlies the highly resistive bedrock. Points of occurrence of such curve types hold no promise for groundwater development particularly when the bedrock is at a shallow depth (Olorunfemi and Idornigie, 1992). This class represents 6.01% of the sounding curves.

The Class 2 of the type curves consists of H, HA, QH and QHA-type curves. The H-type curve accounts for 21.8% of the total and hence the most predominant (Figure 5.6). In the HA-type curves the succession consists of the topsoil, the clay/sand regolith; the slightly weathered/ fractured basement, and the fresh bedrock. The third layer has a resistivity value that is intermediate between those for the overlying deeply weathered material and the underlying highly resistive bedrock. It is thick enough to be differentiated. The horizon may be clayey sand or sand as prescribed by the layer resistivity ranging between 181 and 561 Ωm. This agrees with Olorunfemi and Olorunniwo (1985). The authors had observed that the layer resistivity would often be less than 600 ohm-m. Any location exhibiting this curve type (HA) and having thick partly weathered layer, holds a good promise for groundwater development.

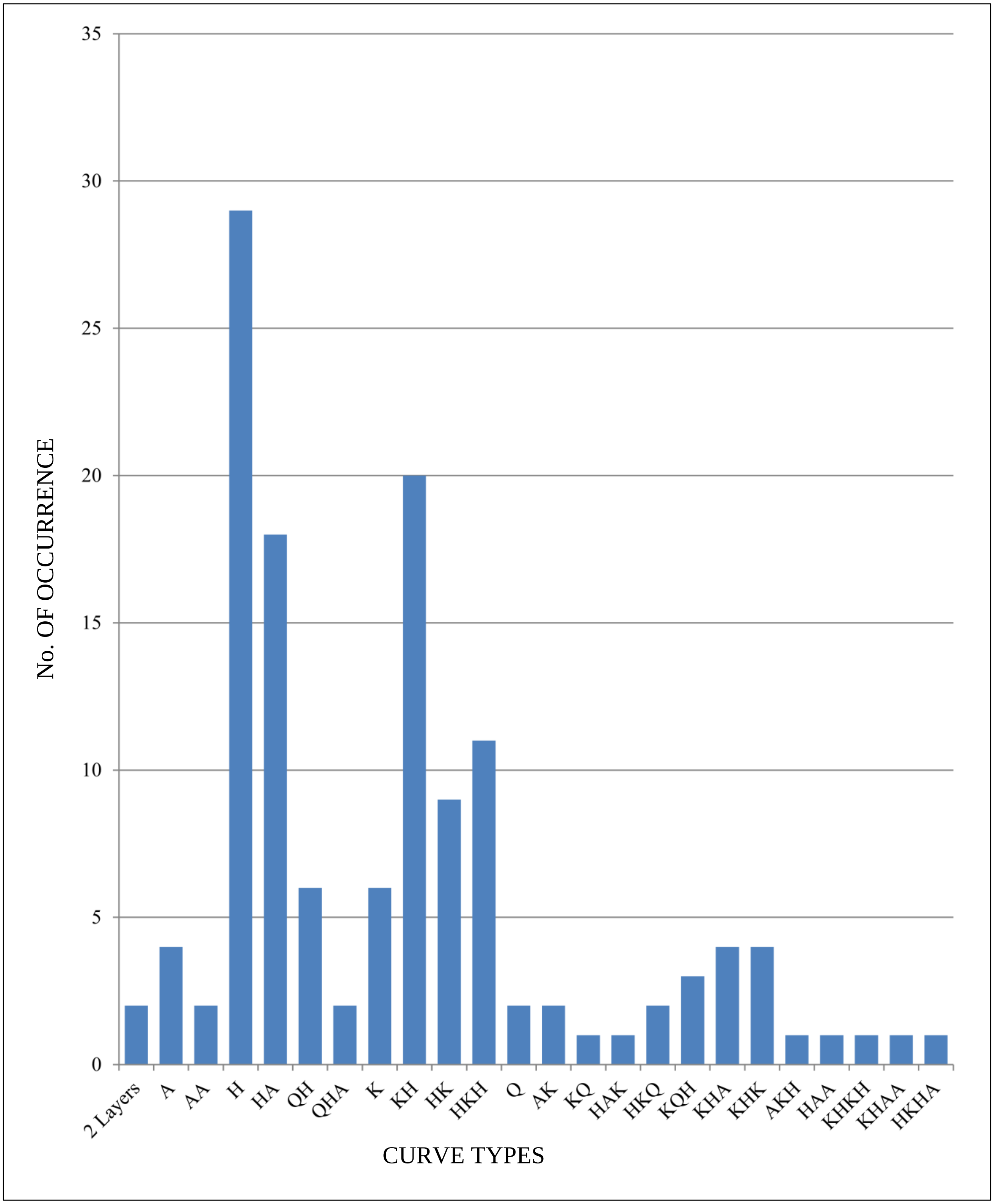


Figure 5.6: The VES Type Curves

The underlying geoelectrical units in QH- and QHA-type curves consist of clay and clayey sand/sand, respectively, while the latter is underlain directly by the bedrock. The clayey sand and the weathered or fractured basement herein constitute the main aquifer. The yield from such an aquifer is often significant (Olayinka and Olorunfemi, 1992).

The third Group comprises of the K, KH, HKH and HK – type curves**.** The K-curve type is characterized by low – high - low layer resistivities horizons. The KH-curve type has a succession of sand/sandy clay top soil, lateritic clay, weathered basement and the fresh bedrock. The third layer may constitute the aquifer if sandy and significantly thick. In the HKH-type, a highly resistive third layer typical of laterite or hardpan is sandwiched between two relatively low resistive second and fourth layers; the fifth layer being the bedrock. The relatively low resistive layers are aquifers when significantly thick and sandy. The weathered/fractured basement of the HK-curve is usually explored for groundwater abstraction (Olorunfemi and Olorunniwo, 1985 and Oladapo *et al.*, 2004).

5.2.2 The Aquifer Types and Geoelectric Characteristics

The analysis of the observed type curves indicated that the area under study has both weathered layer aquifers and fractured layer aquifers occurring in distinguishable combinations. The H-type curves are diagnostic of weathered layer aquifers if the second horizon is sandy and significantly thick. The resistivity depth sounding curves which ends with H-type (e.g. QH) also fall in the weathered aquifer group. The groundwater yield from this aquifer type could be low particularly when the layer resistivity is low (<<150 ohm-m) due to high clay content (Olayinka, 1992 and Ademilua and Olorunfemi, 2000).

The HA-type curve or those ending with HA attributes such as KHA and QHA are typical of the weathered/fractured (unconfined) aquifer type wherein a fractured zone underlies the weathered zone directly. The weathered/fractured (confined) aquifer type occurs when there is a combination of an upper weathered layer and an enclosed (within the fresh basement) fractured zone. The depth sounding curve is the HKH-type or those curves ending with appendage of KH- or HK such as HKHK, HKHKH. The yield could be expected to be high, given a high density of fractures (Olorunfemi and Fasuyi, 1993 and Shemang-Jnr, 1993).

Occurrence of two fracture systems complementing the weathered aquifer indicates the weathered/fractured (unconfined) / fractured (confined) aquifer type. The first (unconfined) aquifer underlies the weathered layer aquifer directly while the other (confined) is sandwiched within the fresh bedrock. The fractured (confined) aquifer type was obtained where there was a very thin weathered layer. The confined fractured zone can be obtained only when it is relatively shallow or when deep but densely fractured and significant thickness. The characteristic VES curves are the KH-type and other varieties of type curves ending with KH such as AKH (Olorunfemi and Olorunniwo, 1985, Olayinka, 1992 and Ademilua and Olorunfemi, 2000).

5.2.3 Subsurface Geoelectric Sequence

5.2.3.1 The Topsoil

The topsoil in the metropolis varied in composition from clay, sandy clay, clayey sand to sand and laterite with the topsoil resistivity values ranging from 18 to 6409.9 Ωm. The highest % frequency occurs in the resistivity values of between 100 and 200 Ωm (Figure 5.7). The low resistivity end (< 1000 Ωm) is diagnostic of alluvium-sand horizon while the high resistivity end (>1000 Ω-m) typifies laterites and compact sand (Figure 5.8).

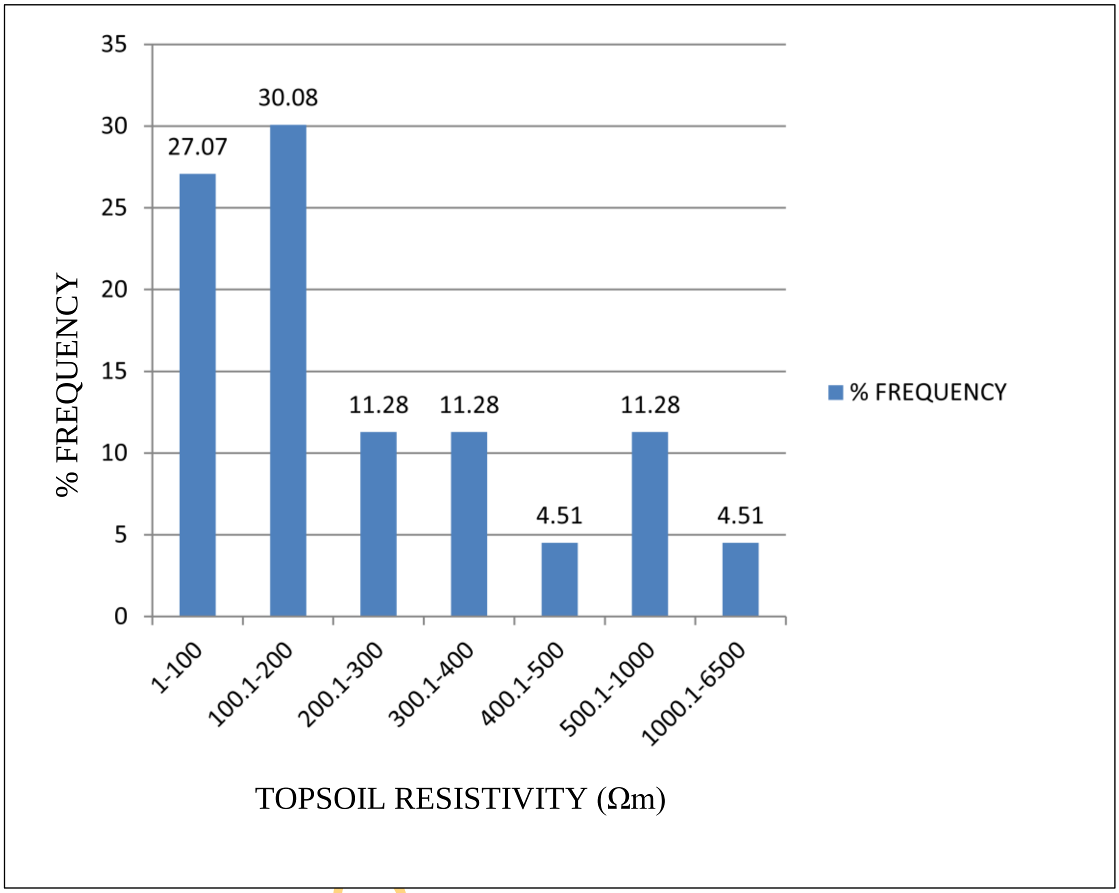


Figure 5.7: Frequency Distribution of Topsoil Resistivity

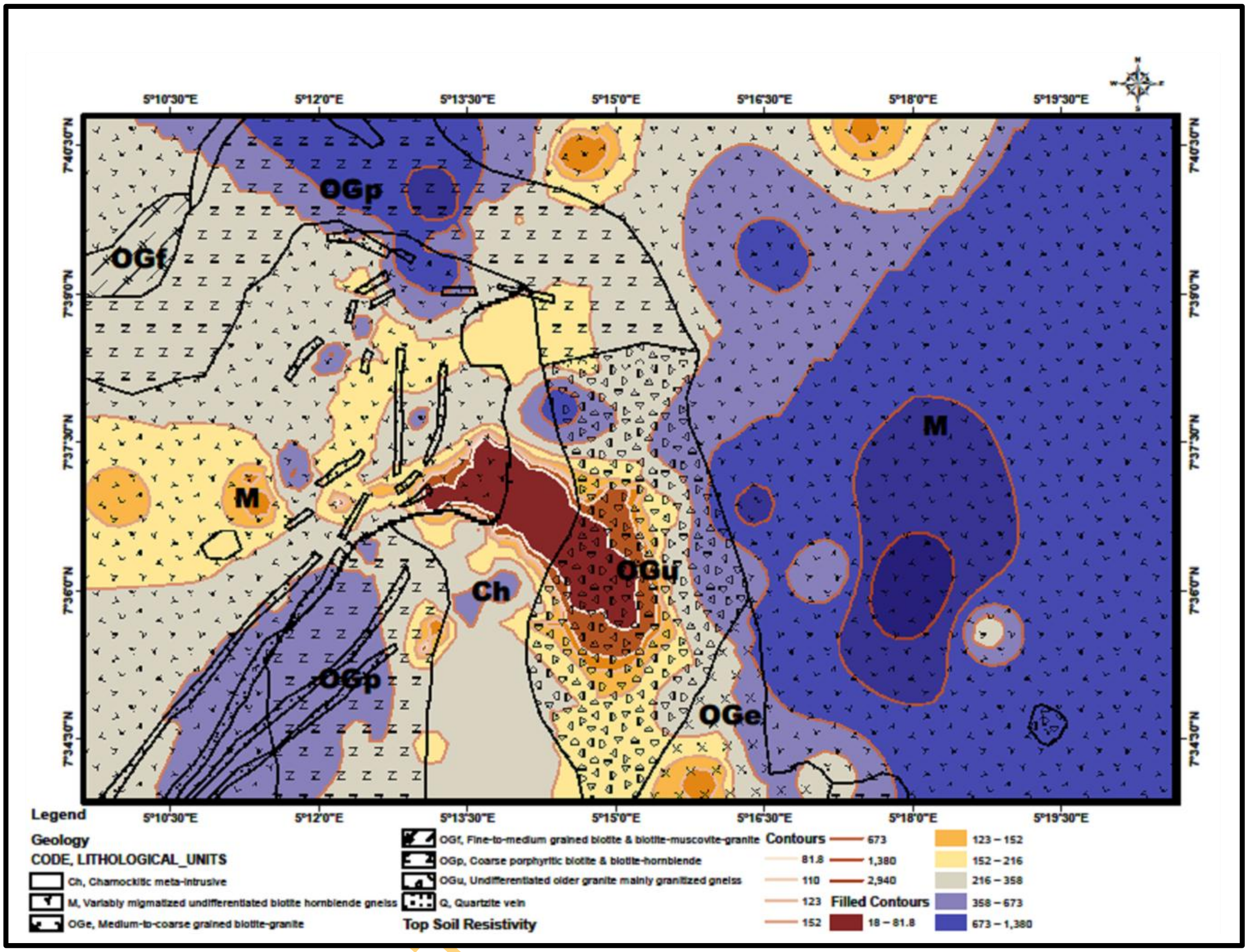


Figure 5.8: Topsoil Resistivity map

The wide resistivity range is a consequence of the variable composition of this layer, degree of fluid saturation (or moisture content) and degree of compaction (Olorunfemi and Olorunniwo, 1985 Adiat *et al*., 2009 and Ojo *et al*., 2015). The lateritic cappings could be associated with deep weathering (Olayinka, 2010). The frequency distribution of the thickness of the topsoil across the study area is presented in Figure 5.9. The thickness of the topsoil varies widely. It is commonly around 1.2 m (Figure 5.10). Olorunfemi *et al.*(1999) reported that the topsoil in the Akure metropolis varied in composition from clay, sandy clay, clayey sand to sand and laterite and characterized by layer resistivity values ranging from 14 to 7920 Ωm with thickness generally less than 2 m.

5.2.3.2 The Second Layer

The second layer resistivity values range between 5 ohm-m and 5200 ohm-m with the highest frequency in the 1-50 Ωm range (Figure 11). The spatial distribution of the layer resistivity is presented in Figure 5.12. The low resistivity end (resistivity, $\rho < 60$ Ohm-m) is typical of silt or clay horizon with little or no sand content. Such horizon plays an important role in the hydrogeology of the area by sealing off the surface contaminated water from the subsurface groundwater.

When the clay is sandy ($\rho > 60$ ohm-m), it may possess appreciable permeability and porosity to constitute a probable aquifer. This follows the trend observed by Olorunfemi and Olorunniwo (1985), Adiat *et al.* (2009) and *Ojo et al.* (2015). Formation resistivity values ranging between 5 and 150 Ohm-m with the most frequent resistivity values occurring between 10 and 50 ohm-m were observed for the sandy clay-clay unit.

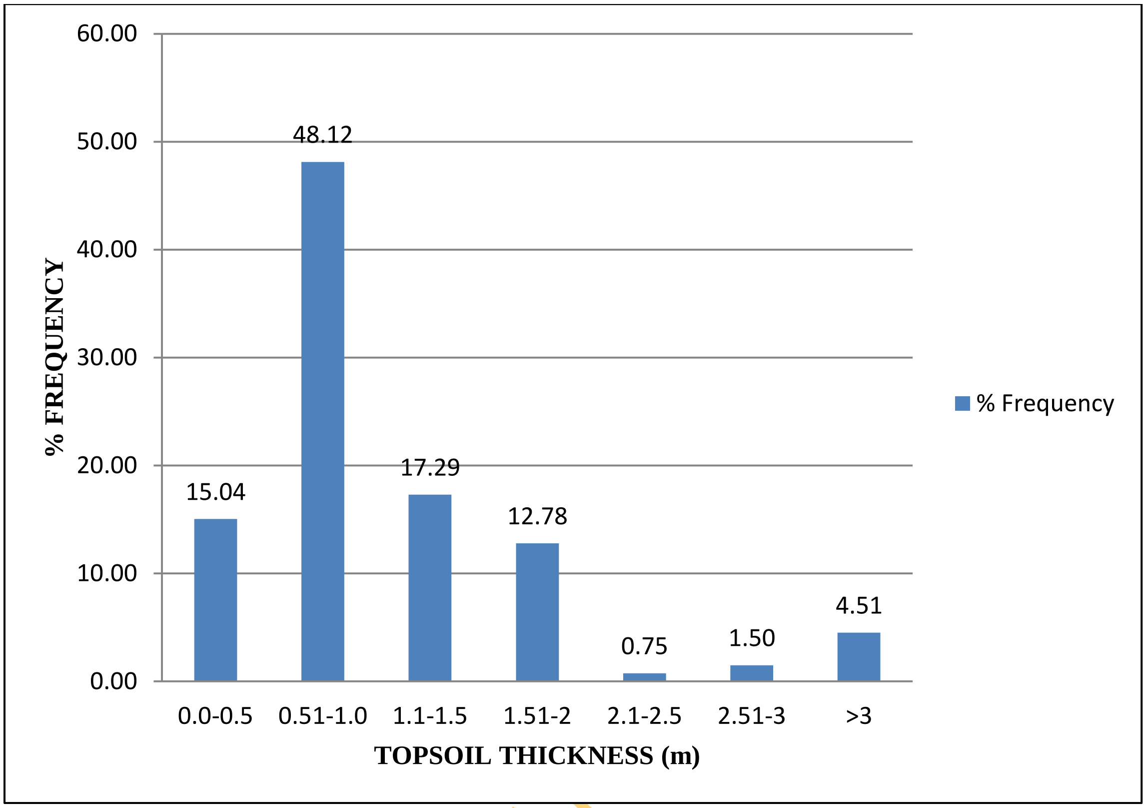


Figure 5.9**:** Frequency Distribution of Topsoil Thickness

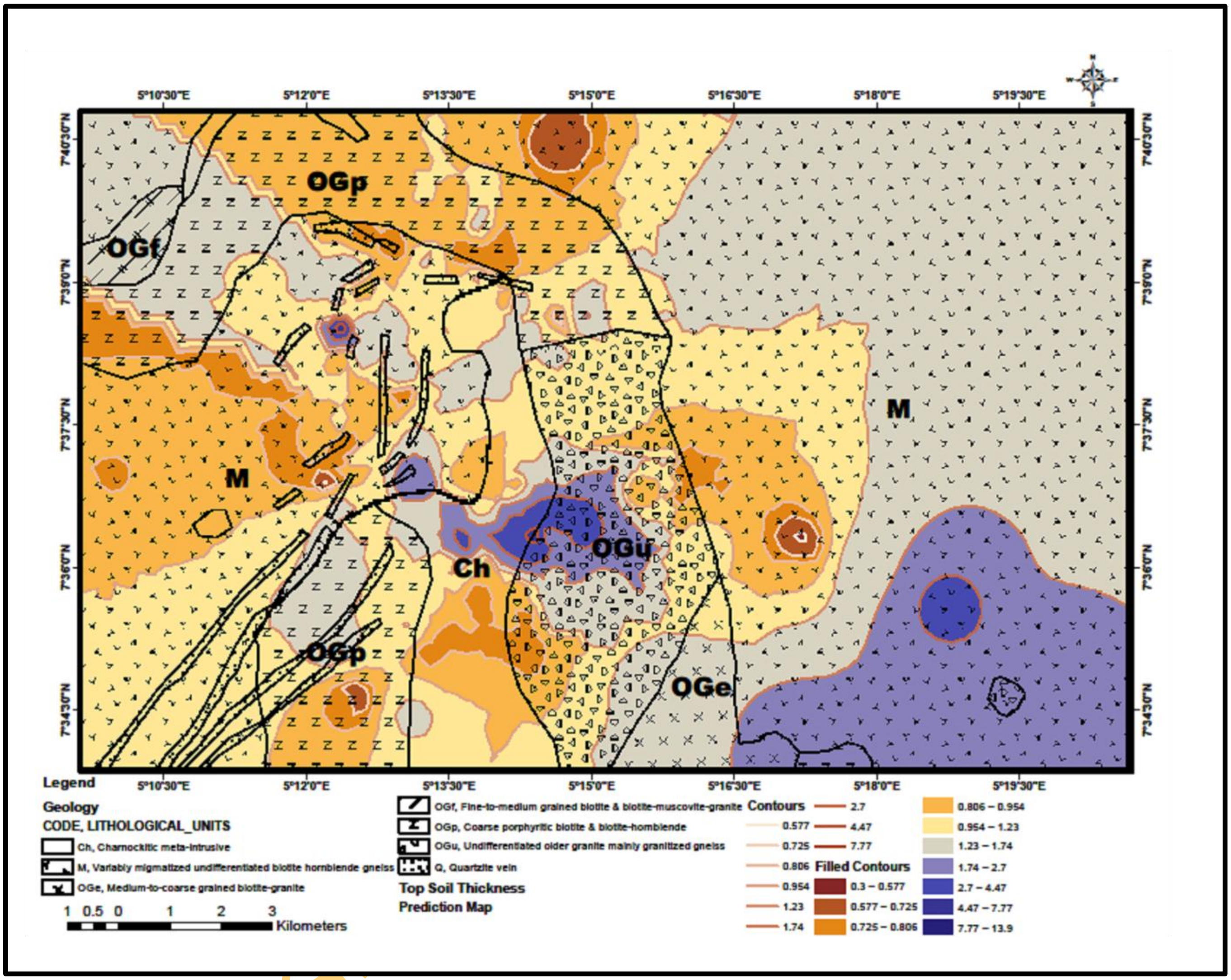


Figure 5.10: Topsoil Thickness map

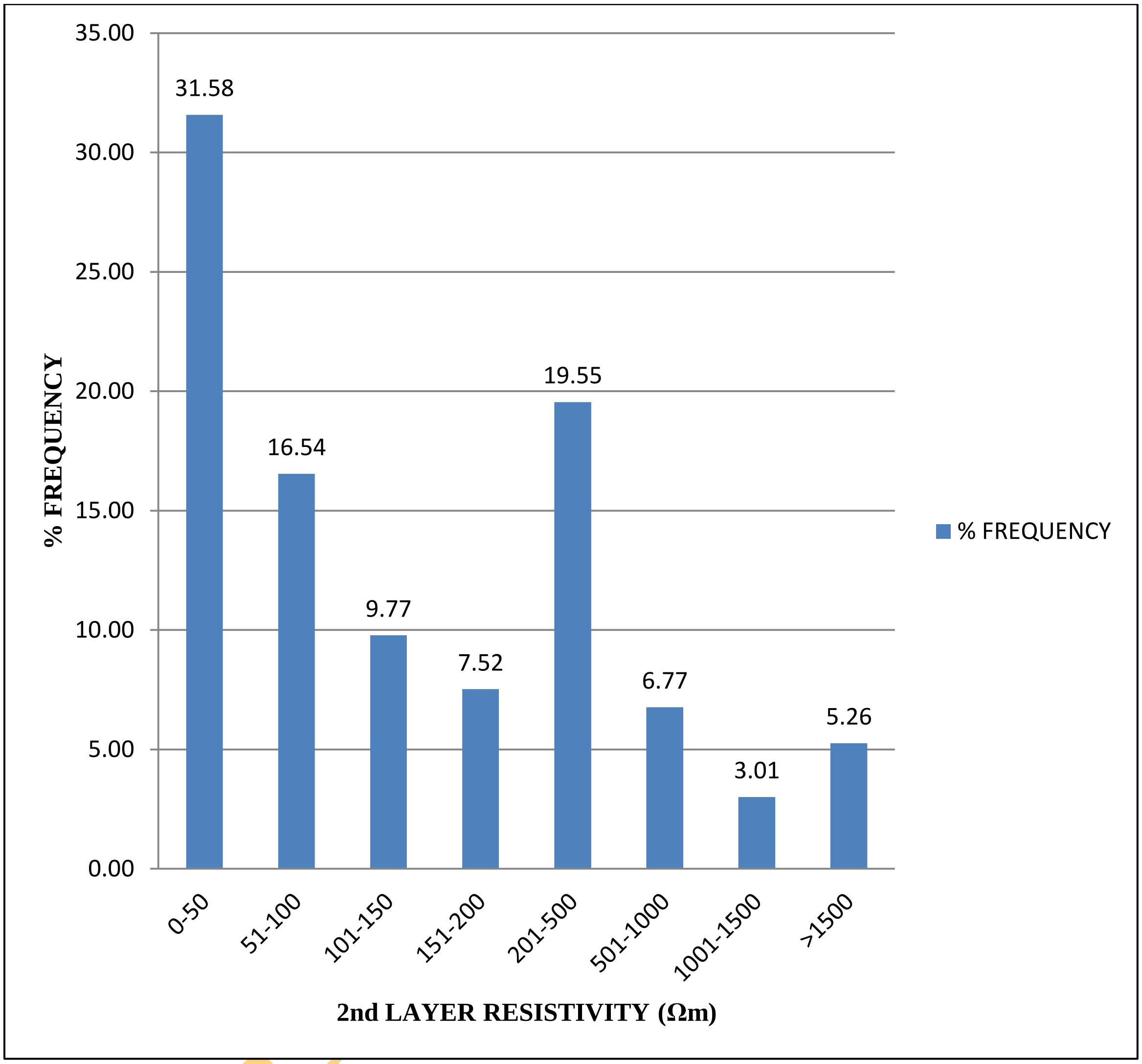


Figure 5.11: Frequency Distribution of the 2nd Layer Resistivity

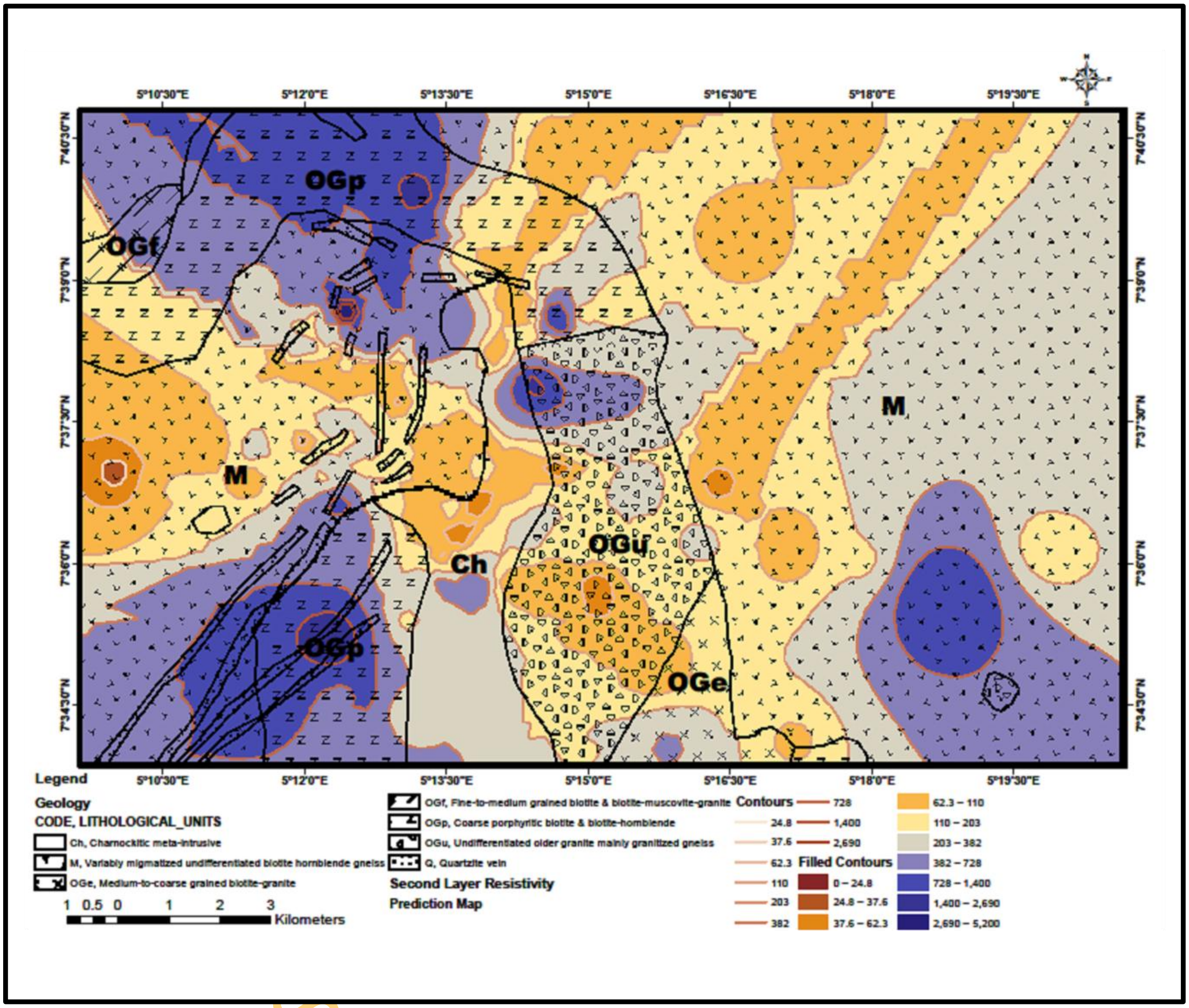


Figure 5.12: The 2nd Layer resistivity map

The layer varies in resistivity and composition depending on the parent rock. It is typically clayey with low layer resistivity values (resistivity, $\rho < 100$ ohm-m) over basic charnockite and sandy/clayey sand (resistivity, $\rho > 100$ ohm-m) on fine-coarse grained granitic/gneissic rocks. Layer resistivity range of between 1 and 100 Ωm accounted for 48.12% frequency of occurrence.

Figure 5.13 shows that the second layer thickness is generally less than 10 m with 81.21% of occurrence. The range of thickness values between 1 m and 5 m has the highest % frequency of 54.89% while thickness values of between 5 m and 10 m has 26.32% occurrence. The spatial distribution map is presented in Figure 5.14.

The second layer coincides with the regolith of the H and HA-type curves. The regolith typically consists of clay, sandy clay and sand. The dispersion observed in the resistivity values could be due to varying degree of weathering. Intense chemical weathering of the parent rocks might result in the formation of a clayey regolith with large local variation especially with respect to the bedrock structure and mineralogy (Olayinka and Olorunfemi, 1992). The thickness of the layer varies from 0.2 m to 46.7 m with a mean of 8.1 m.

5.2.3.3 The Partly Weathered Basement / Fractured Basement Layer of the study area

This horizon is the layer overlying the fresh bedrock directly (Olorunfemi and Okhue, 1992). It could be partly weathered and /or fractured basement. The layer is essentially characterized by resistivity values ranging from 6 to 1316 Ωm. About 4.5% of the data spread had values between 2000 - 5717 Ωm; indicating that the whole of the study area has undergone an appreciable amount of weathering.

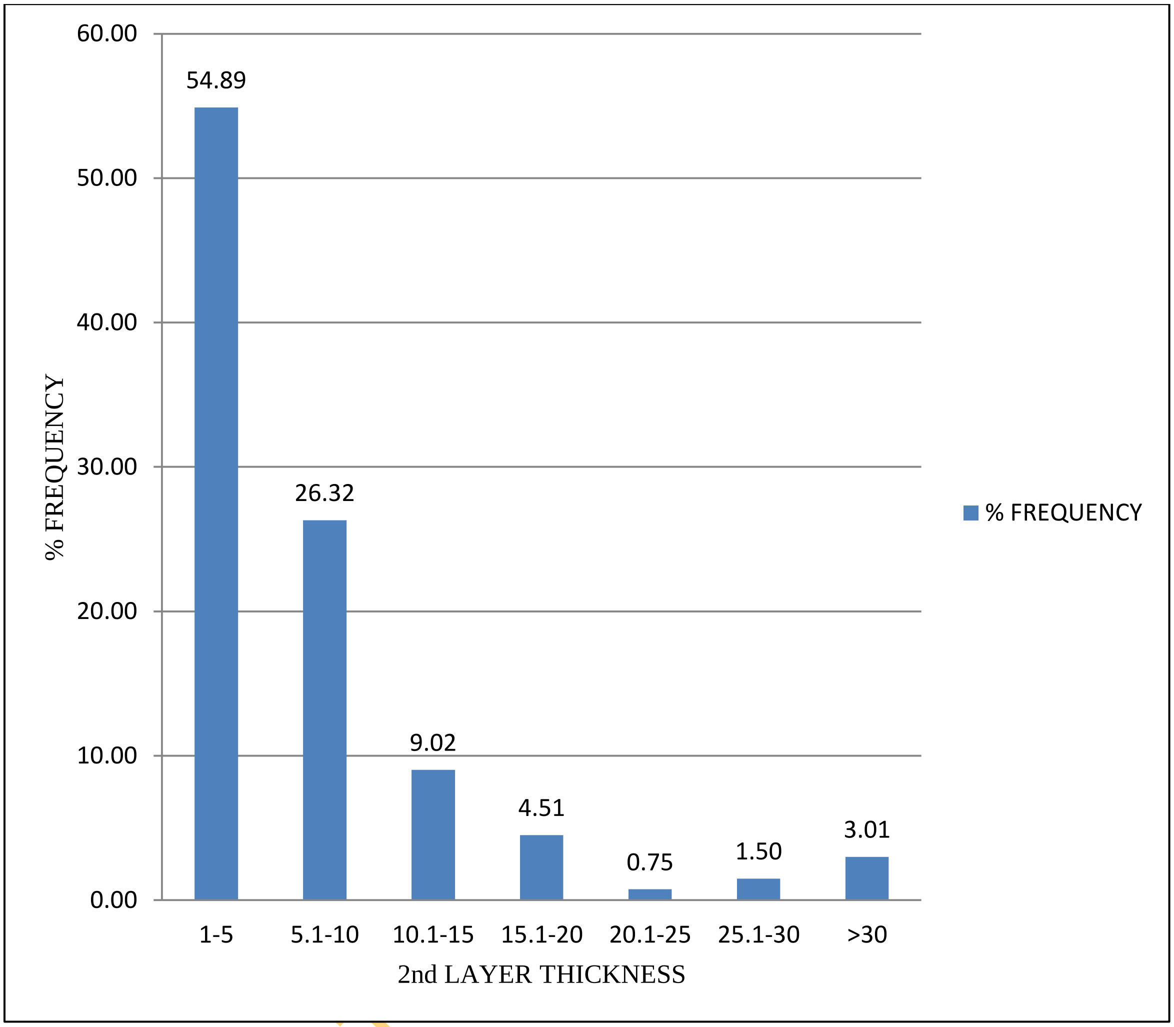


Figure 5.13: Frequency Distribution of 2nd layer Thickness

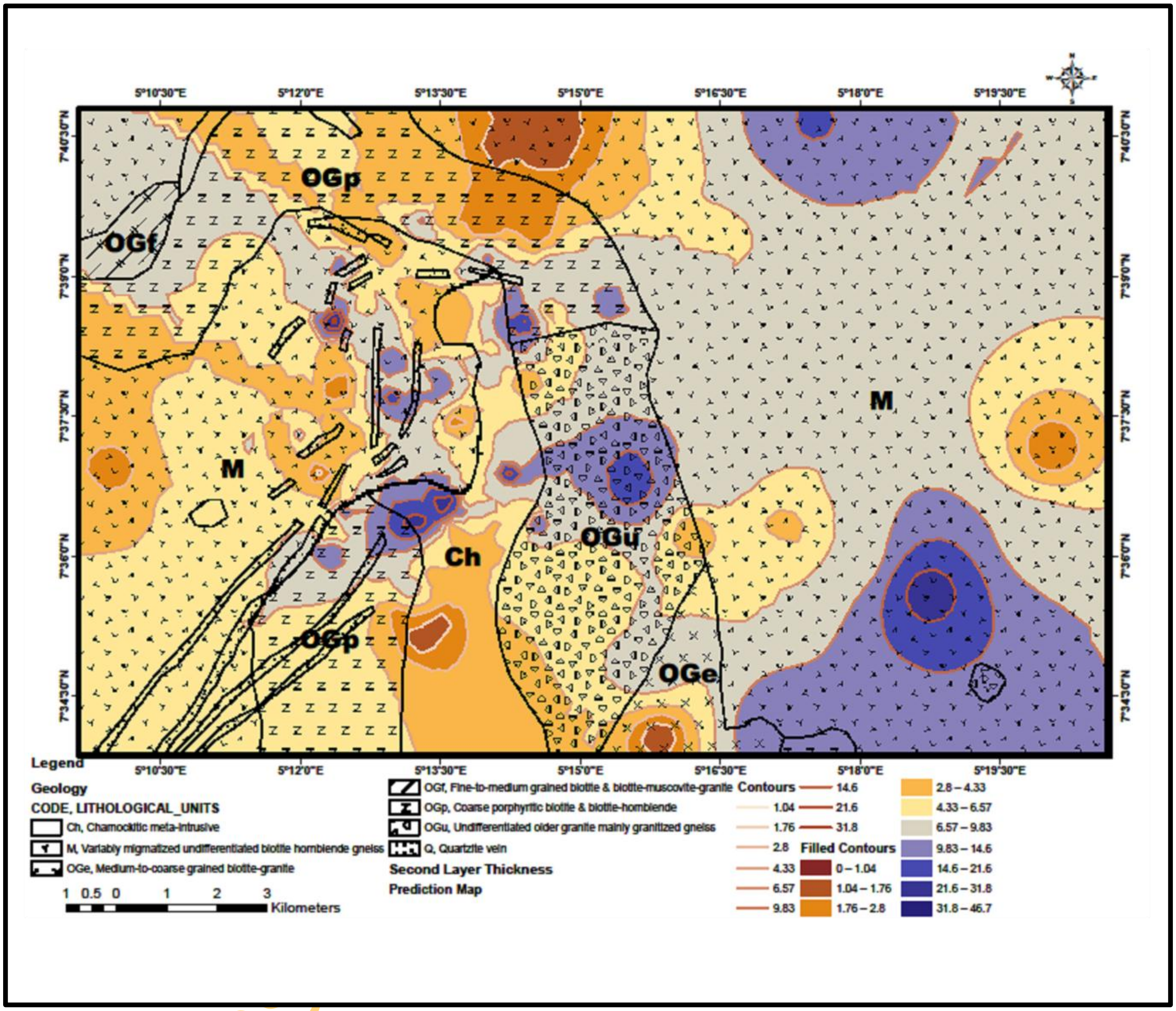


Figure 5.14: The 2nd Layer Thickness map

The material composition is largely clay/sandy clay/clayey sand. Low resistivity values indicate substantial clay content. High resistivity values imply lower clay proportions and increased permeability. Layer resistivity less than 600 Ωm indicates clayey sand-sand while resistivity above 600 Ωm is typical of weathered and or fractured basement (Olorunfemi *et al.*, 1999 and Mallam and Emenike, 2008). The resistivity of the layer varies from 8 – 1267, 6 - 1316 and 7 - 1197 Ωm with mean of 259, 251 and 223 Ωm for the areas underlain by variably migmatized, undifferentiated biotite hornblende gneiss with intercalatted amphibolites, charnockitic meta-intrusive and coarse porphyritic biotite and biotite-hornblende gneiss, respectively while the layer resistivity varies from 9 - 195 and 28 - 450 Ωm with mean of 195 and 202 Ωm for the areas underlain by undifferentiated older granite mainly granitized gneiss and quartzite vein, respectively. Olorunfemi *et al.* (1999) observed the mean of 107, 168 and 176 Ωm for charnockite-derived weathered layer, granites and gneisses respectively. The fractured basement layer resistivities were generally less than 1600 Ωm.

The weathered basement resistivity is controlled by the degree of water saturation. The map, Figure 5.15, discriminated between high water bearing weathered basement zones and the low water bearing ones. It also indicated the variations in the degree of weathering / saturation across the study area. Low weathered basement resistivity values are indicative of the highly weathered nature of the layer, tending towards clay and the fact that the layer is saturated with water at such points. Charnockites weather into low permeability clayey materials with low groundwater discharge capacity while gneisses and granites weather into higher permeability sandy clay and clayey sand and sand with higher groundwater discharge capacity. The zones underlain by thick overburden cover and less percentage of clay with appreciable degree of saturation hold high potentials for groundwater exploitation (Okhue and Olorunfemi, 1991 and Adiat *et al*., 2009).

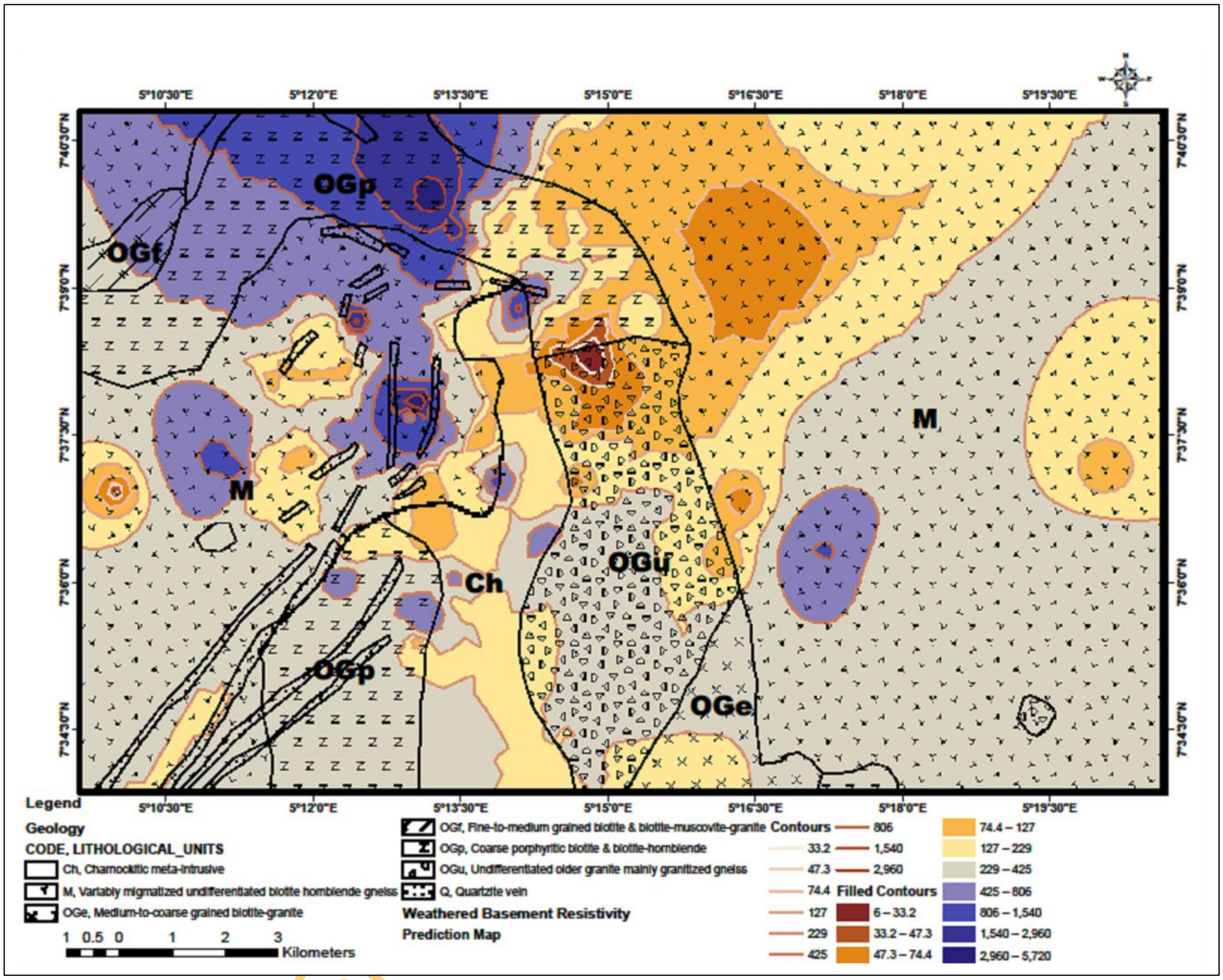


Figure 5.15: Weathered Basement Resistivity Map

The weathered basement resistivity classification with respect to groundwater-prospect is shown in Figure 5.16. Resistivity values of **ρ** < 20 Ωm are indicative of clayey aquifers. The resistivity range of 20 – 100 Ωm shows varying degrees of clay contents. Clayey formations only offer poor / limited aquifer potential. Enhanced groundwater potential and aquifer conditions are associated with resistivity range of 100 - 150 Ωm and the weathered basement resistivity within the range of 150 – 300 Ωm.

Figure 5.17 shows that 13.4% and 37% of the study area is characterized by resistivity values of **ρ** < 20 Ωm and resistivity range of 20 – 100 Ωm, respectively. Areas with resistivity range of 100 - 150 Ωm and 150 – 300 Ωm account for 4.7% and 19.7% of the study area, respectively. Regions with saprolite resistivity values above 300 Ωm offer no strong appeal for groundwater development. About 25.2%, of the study area falls in this bracket. Clayey formations of the study area cannot be expected to support sustainable groundwater development. Ogundana *et al.* (2015) reported high borehole failure of ten (representing 71%) out of fourteen boreholes studied at ABUAD. These boreholes exhibit low groundwater yield as the holes could not support continuous flow of water beyond 5 minutes.

5.2.3 The Weathered Basement Thickness Distribution Map of the study area

The weathered basement thickness map, Figure 5.18, shows that the thickness of the layer ranges from 0.2 – 53.2 m with a mean of 17.78 ± 12.40 m. It is dependent on the degree of weathering and fracturing of the bedrock. Olorunfemi *et al.* (1999) reported weathered layer thicknesses of generally less than 20m though higher values of up to 64.6 m were obtained at some very few locations in Akure. Oloruntoba and Adeyemi (2014) obtained regolith thickness varying from 2.1 - 35.9 m in Abeokuta.

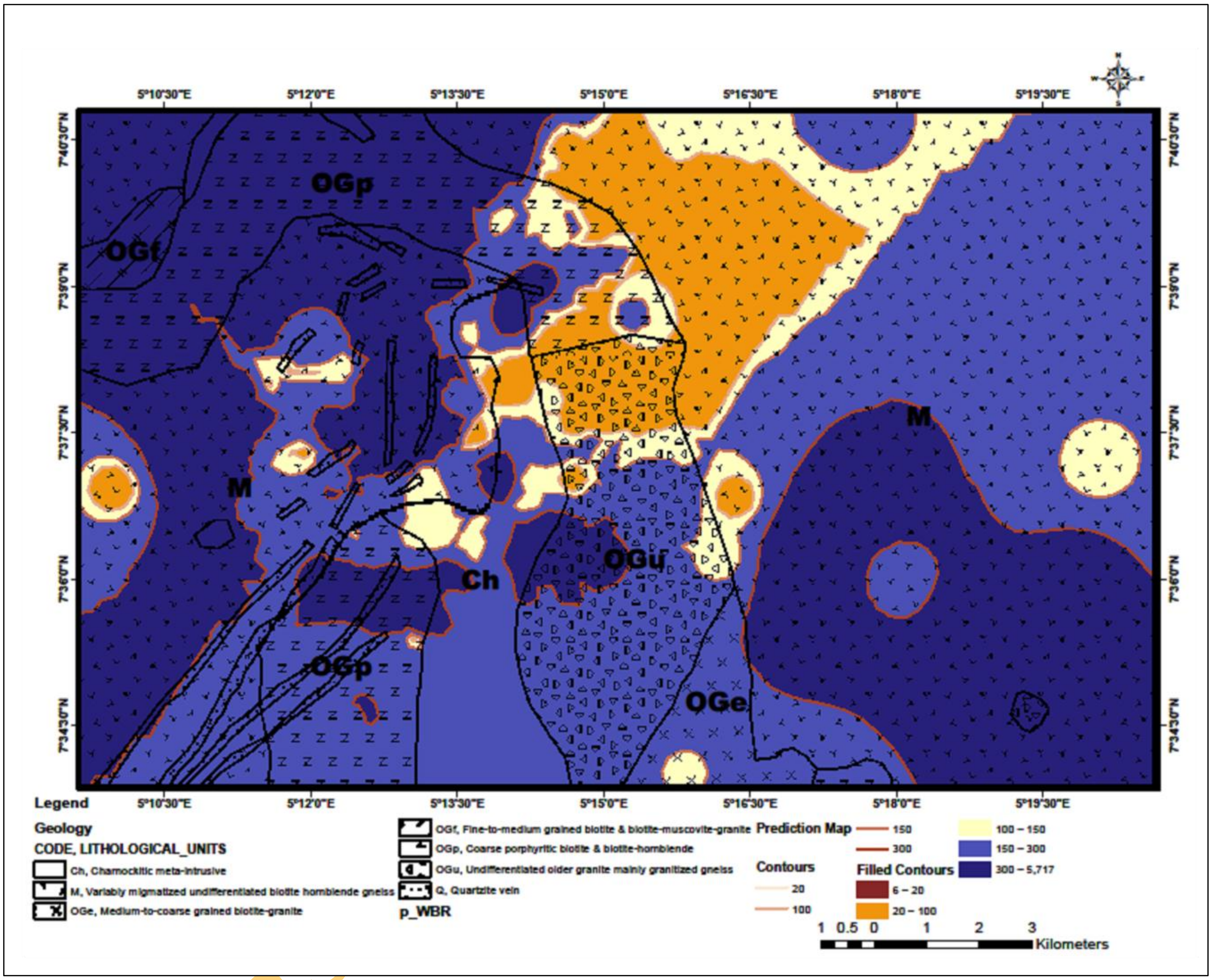


Figure 5.16: Weathered Basement Resistivity Classification Map

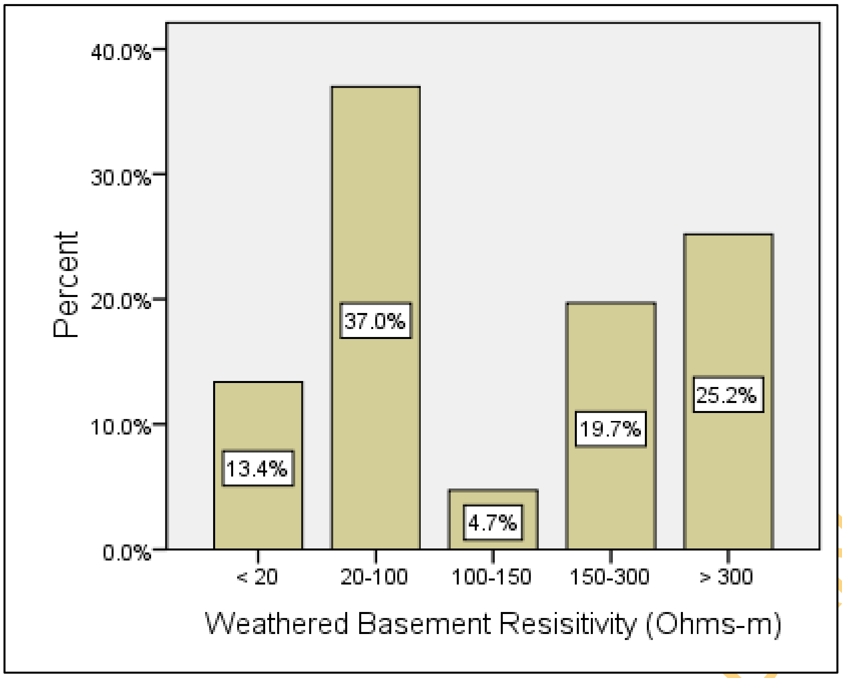


Figure 5.17: Weathered Basement Resistivity Classification of Ado-Ekiti

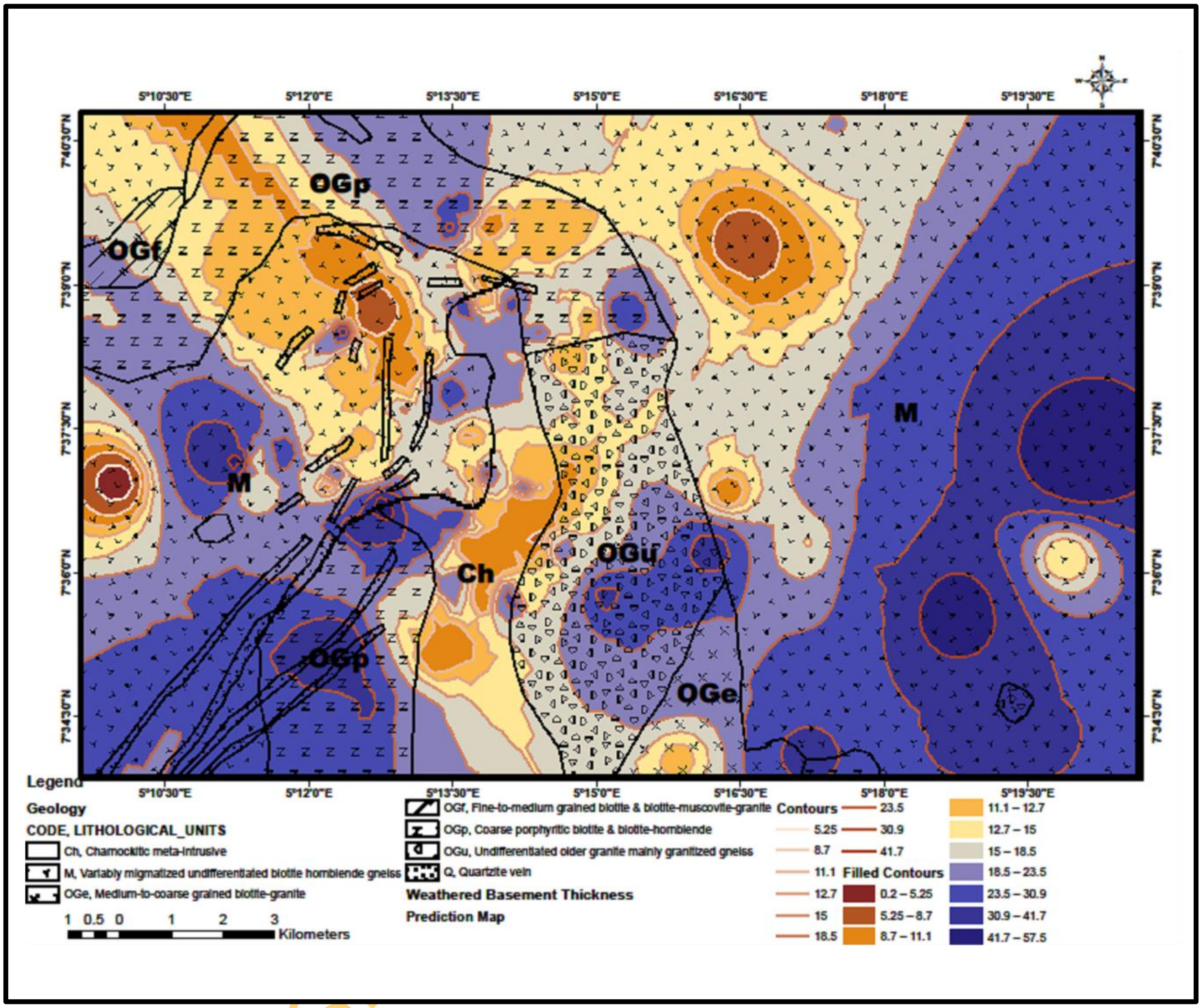


Figure 5.18: Weathered Basement Thickness map

The weathered basement layer is seen to be thickest around the Southern/South western portions with isolated portions along the Western/North western portions of the study area (Figure 5.19). As the weathered basement layer is believed to be the major aquifer, the said regions offer strong appeal for groundwater development.

Mallam and Emenike (2008) observed up to a maximum thickness of 52 m in the basement area of FCT, Abuja. Mogaji *et al.* (2011) obtained thickness between 0.8 and 53.1 m with average thickness of 13.8 m across the layer in the basement complex areas of Ondo State, Southwestern Nigeria. Adiat *et al.* (2009) obtained the thickness of this aquifer unit as varying from 2 m to 34 m in a similar hard rock terrain of Oda, near Akure and accorded more preference in groundwater development to areas characterized by thickness between 10m and 34m in cognizance of the significant role of thickness of aquiferous unit in groundwater abstraction.

5.2.4 The Bedrock Resistivity Distribution Map of the Study Area

The basement rocks in the area of study were observed to be variably fractured as shown by the bedrock resistivity distribution map (Figure 5.20). The bedrock resistivity varies greatly across the area of study. It is infinitely resistive at some points and remains generally very high at several other points. The variations are indicative of the great variability and the unpredictability of the nature of basement aquifers. Localized variations may be attributed to differences in the bedrock mineralogy and structures (Mallam and Emenike, 2008, Olorunfemi *et al*., 1999). Olayinka and Olorunfemi (1992) remarked that an economic aquifer may be encountered if the geoelectric basement has a fairly low resistivity. The fairly low bedrock resistivity values are indicative of the presence of the fractures and hence the water contained within the fissures at such locations.

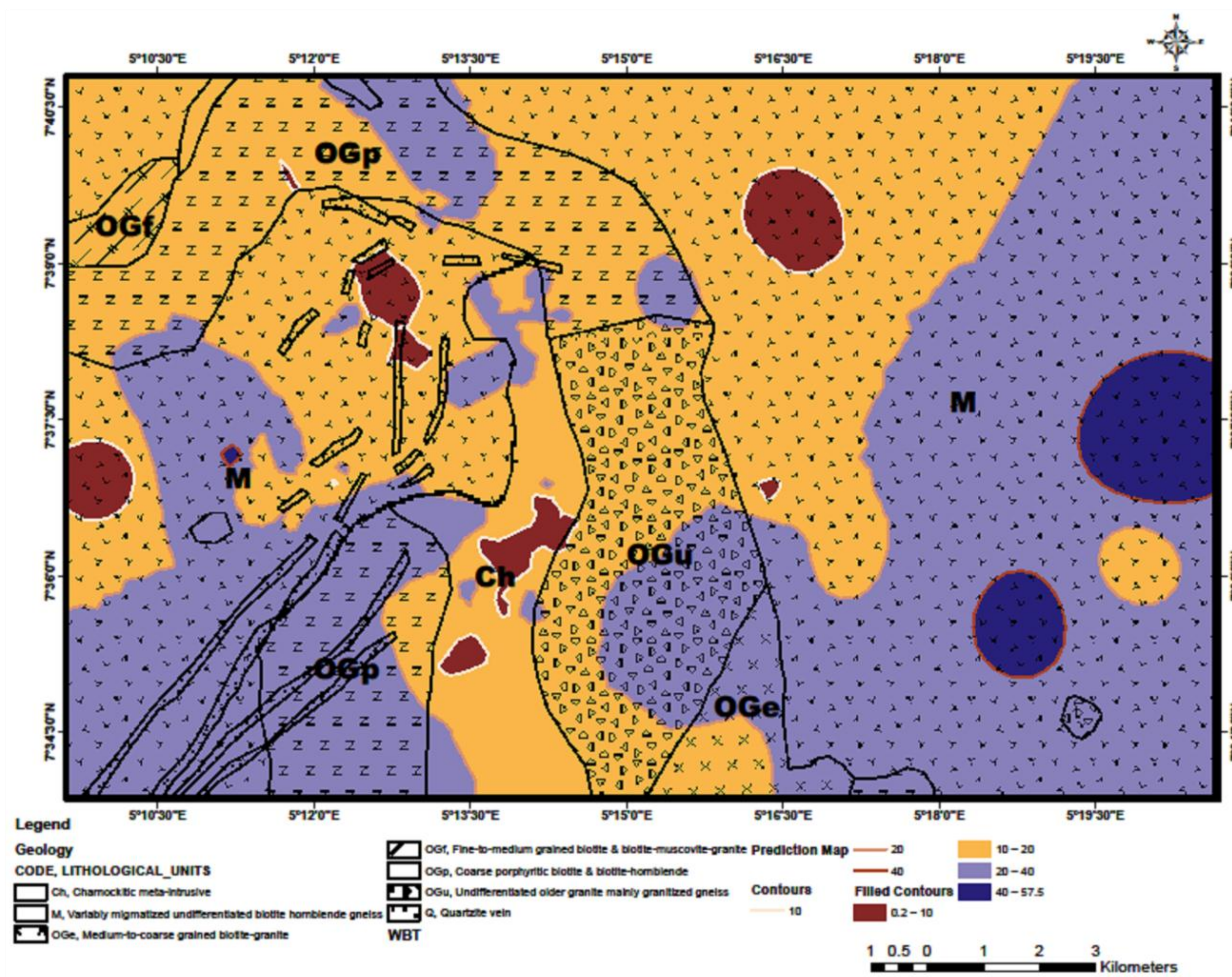


Figure 5.19: Weathered Basement Thickness Classification Map

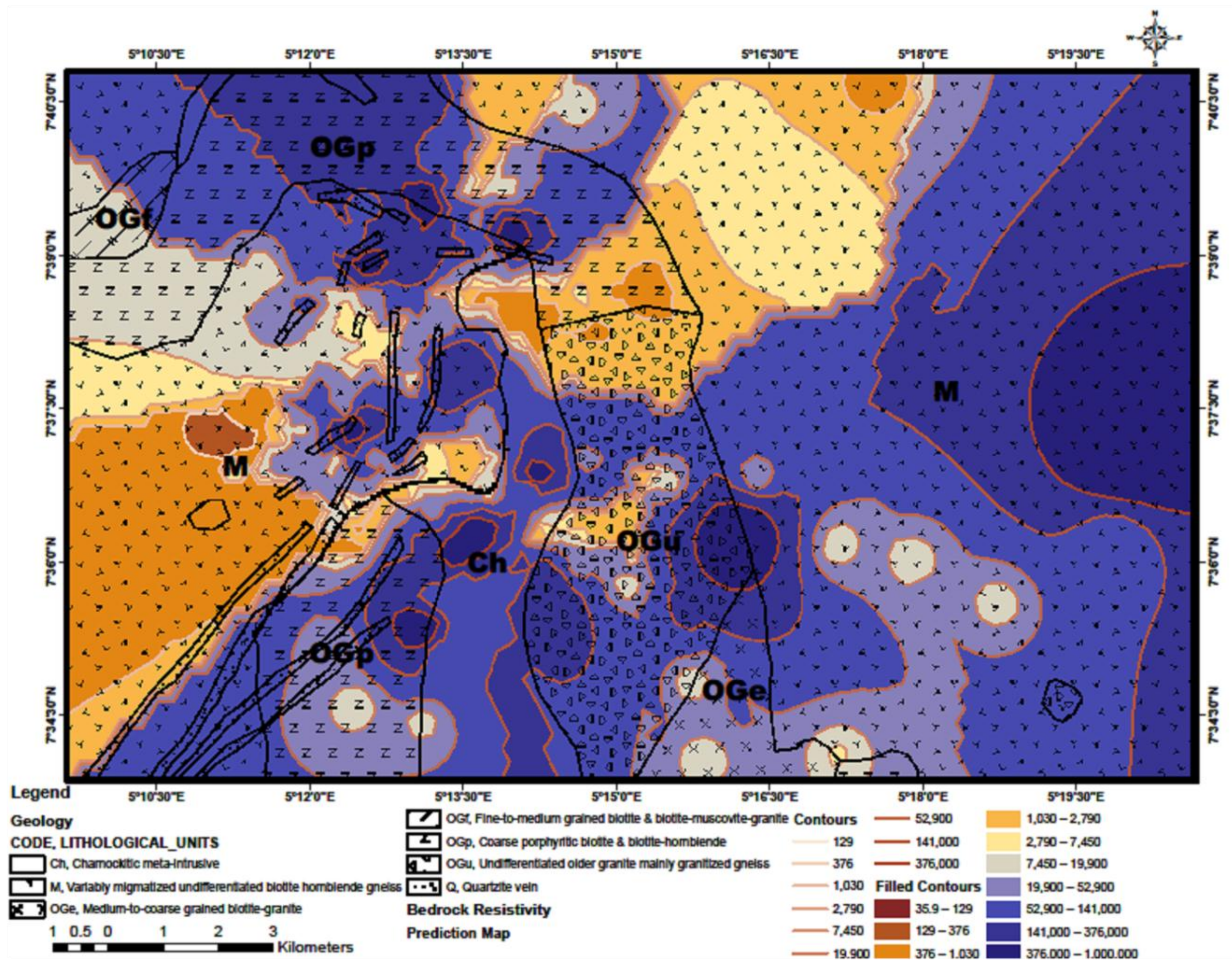


Figure 5.20: Bedrock resistivity map

Beacon and Jones (1988) adjudged VES points characterized by very high values of bedrock resistivity, probably unfractured, as unfavourable for siting productive borehole. Also a too clayey weathered zone as indicated by a low resistivity values would not support any water abstraction scheme.

Mohammed *et al.* (2008) reported a range of bedrock resistivity values of 1000 – 20000 Ωm across the crystalline basement rocks of the central part of Minna. Mogaji and Oladapo (2008) observed a range of 416 – 55557 Ωm as bedrock resistivity values in the Hydro-geophysical Studies conducted at the College of Agriculture, Akure. The fractured nature of the rocks is displayed by low bedrock resistivity values particularly where the bedrock is fractured/sheared and saturated with fresh water. Bedrock Resistivity value of less than 750 Ωm is indicative of high fracture and permeability as a result of weathering with high aquifer potential. Reduced influence of weathering is felt in areas of resistivity values 750 – 1500 Ωm and hence medium aquifer potential. A resistivity range of 1500 – 3000 Ωm with a resultant low aquifer potential, reflects fairly low effect of weathering. Bedrock characterized by resistivity of >3000 Ωm is suggestive of little or no weathering of the bedrock with negligible aquifer potential.

The bedrock resistivity classifications of the study area, Figures 5.21 and 5.22, in terms of groundwater potential revealed coverage of 37.8%, 18.9%, 12.6% and 30.7% for high aquifer potential, medium aquifer potential, low aquifer potential and negligible Groundwater potential respectively. Fractured bedrock is an important component of the composite aquifers found in hard rock terrains as it increases well yield significantly. Aquiferous units in the basement complex terrain are mainly found in the thick and porous weathered overburden and the fractured part of the bedrock (Mogaji *et al.*, 2011 and Jayeoba and Oladunjoye, 2013).

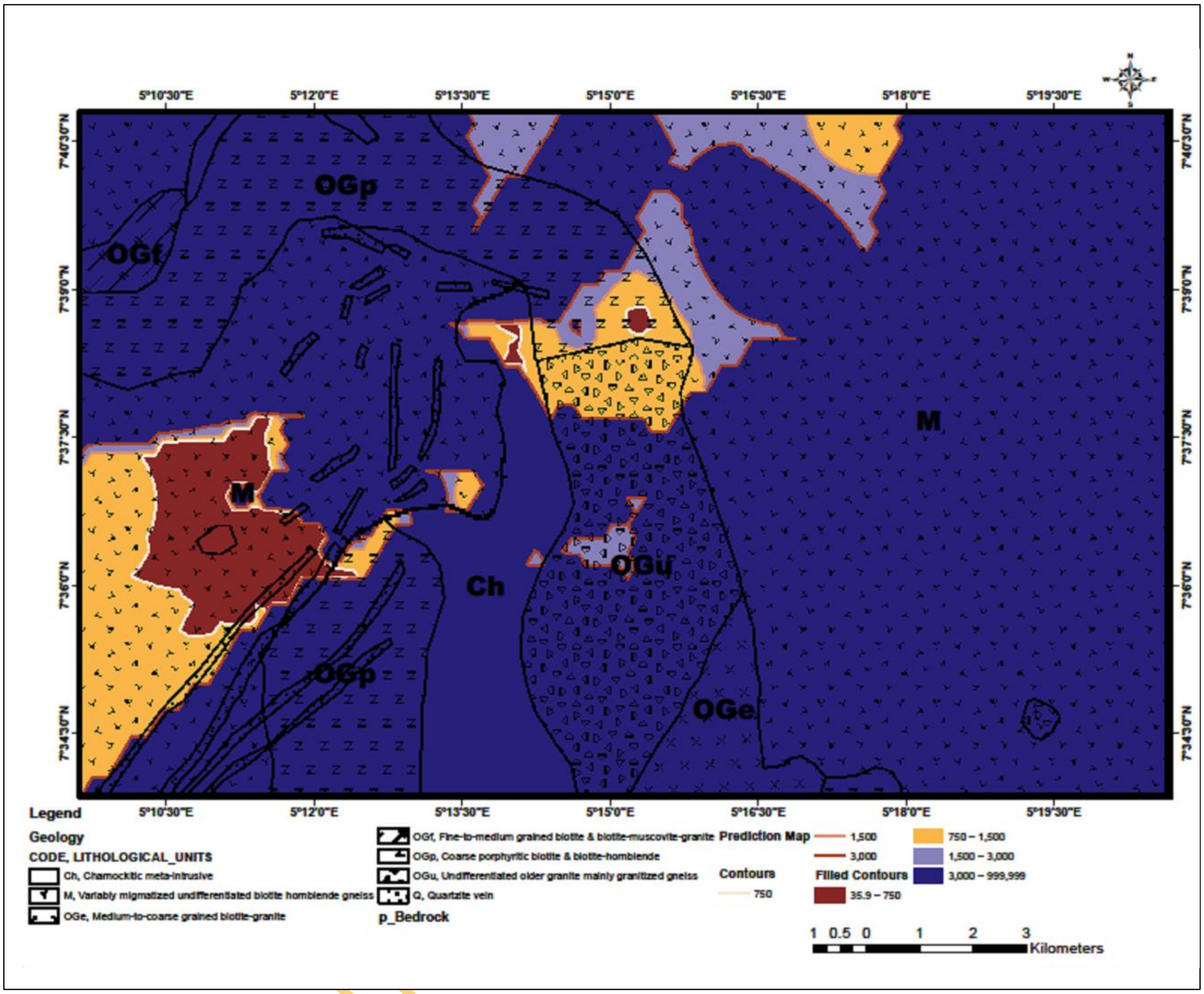


Figure 5.21: Bedrock Resistivity Classification Map

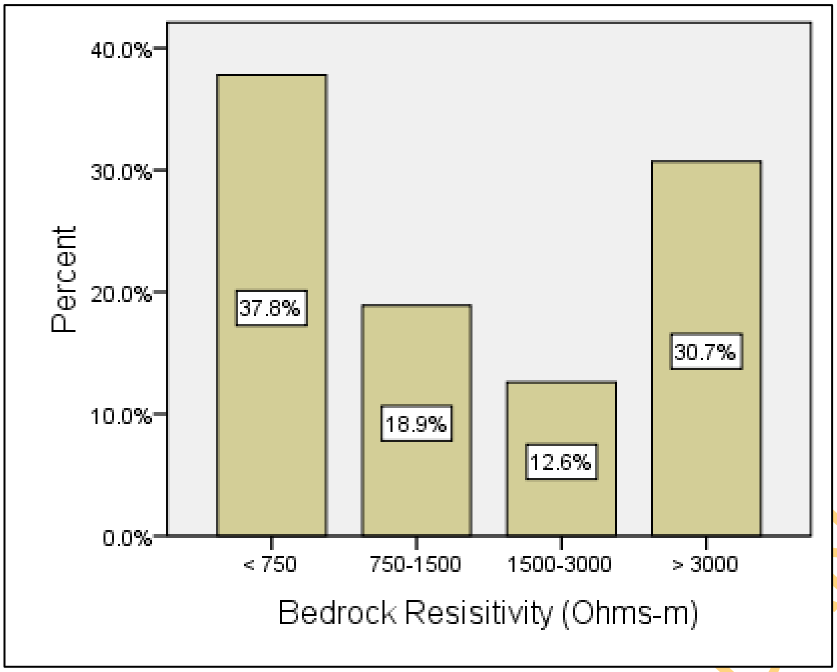


Figure 5.22: Bedrock Resistivity Classification of Ado-Ekiti

5.2.5 The Overburden Thickness in the study area

The overburden encompasses all materials above the presumably fresh bedrock. It is defined as the total depth from the surface to the top of bedrock at each of the VES stations. This depth is zero where the basement rocks outcropped (Olorunfemi and Okhue, 1992 and Mallam and Emenike, 2008). The Overburden Thickness in the study area varies from 1.0 to 79.9 m with a mean of 25.24 m ± 17.2 m. The result agrees with the findings of Okhue and Olorunfemi (1992) which obtained overburden thickness of between 4.0 and 82.8m at Ile-Ife; Olayinka and Olorunfemi, (1992) which observed depth of geoelectrical basement ranging from 0.3 – 72 m in Okene Area and Mallam and Emenike (2008) which obtained overburden thickness varying from 1m to 60 m in the basement area of the Federal Capital Teritory, Abuja. Ariyo and Adeyemi (2009) reported the depth to bedrock within a range of 7.5 and 52.5m in the hard rock areas of Fidiwo/Ajebo, Southwestern Nigeria.

The isopach map of the Overburden in the study area, Figure 5.23, provides a general view of the geometry of the aquifers in the study area. The contour pattern is characterized by isolated closures typical of discontinuous basement aquifer system (Olorunfemi *et al*., 1999). Pockets of such points occur in the western, southwestern and central parts of the area. Closed contour curves of maximum depth- to- bedrock are indicative of basement depression zones. The zones are diagnostic of troughs which are groundwater collecting centres or groundwater convergent zones. Conversely, zones with relatively thin overburden are indicative of basement highs/ridges. Such zones are diagnostic of crests. They are thus groundwater radiating zones or groundwater divergent zones. Basement highs/ridges are observed along northern/central/south central portions and northwestern/northeastern/southeastern flanks.

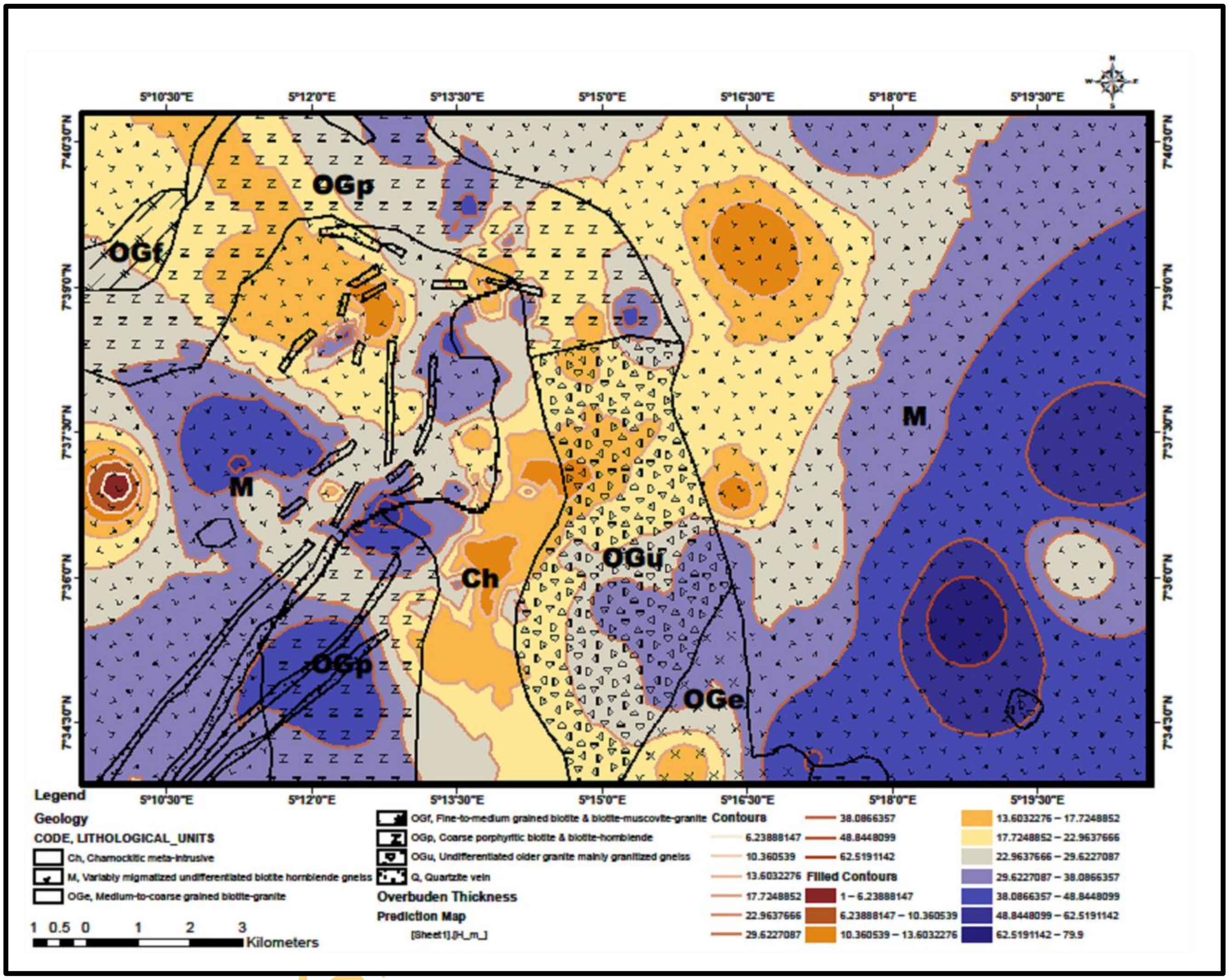


Figure 5.23: Isopach Map of the Overburden

Generally, areas with thick overburden cover and less percentage of clay in which the intergranular flow has either dominant or important role are known to have high groundwater potential particularly in the basement complex area. These points are priority zones for groundwater development in the study area (Olorunfemi and Okhue, 1992 and Mallam and Emenike, 2008).

White *et al*. (1988) suggested a minimum of 10 m of regolith thickness to ensure an adequate yield. Olayinka *et al*. (1997) recommended value of overburden thickness ranging between 20 and 30 m for a productive well. Olorunfemi and Okhue (1992) and Oladapo, *et al*. (2004) also prescribed a minimum overburden thickness of 25 m for a productive well. A minimum overburden thickness of between 20 and 25 m requirement before siting a borehole has been reported in the basement areas of Zimbabwe (Wright, 1992). The mean value of 25.2 m observed in the study area is thus supportive of groundwater development. Drilling might proceed beyond the base of the overburden if the bedrock indicates a weak structural disposition. For instance, Olayinka and Olorunfemi(1992) reported a field example from Okene Area in which a total depth of drilling of up to 76.5 m was recorded at a location whose depth-to-bedrock was 23.6 m. The first water strike was at 17.8 m near the base of the weathering profile while the bedrock fractures were intersected in the depth interval 41 – 45 m. A total depth of drilling of 76.5 m was accomplished with the borehole giving an air lift yield of 5.9 l/s. After pump testing, transmissivity of 10 m^2/day was recorded with static water level of 2.4 m and drawdown 25.0 m. Water was encountered largely from fractures within the bedrock.

The Classification of the overburden thickness in terms of groundwater prospects is presented in Figures 5.24 and 5.25. The belt of overburden thickness < 10 m accounts for 18.1% with the least prospect for groundwater development. About 28.3% of the study area falls within the

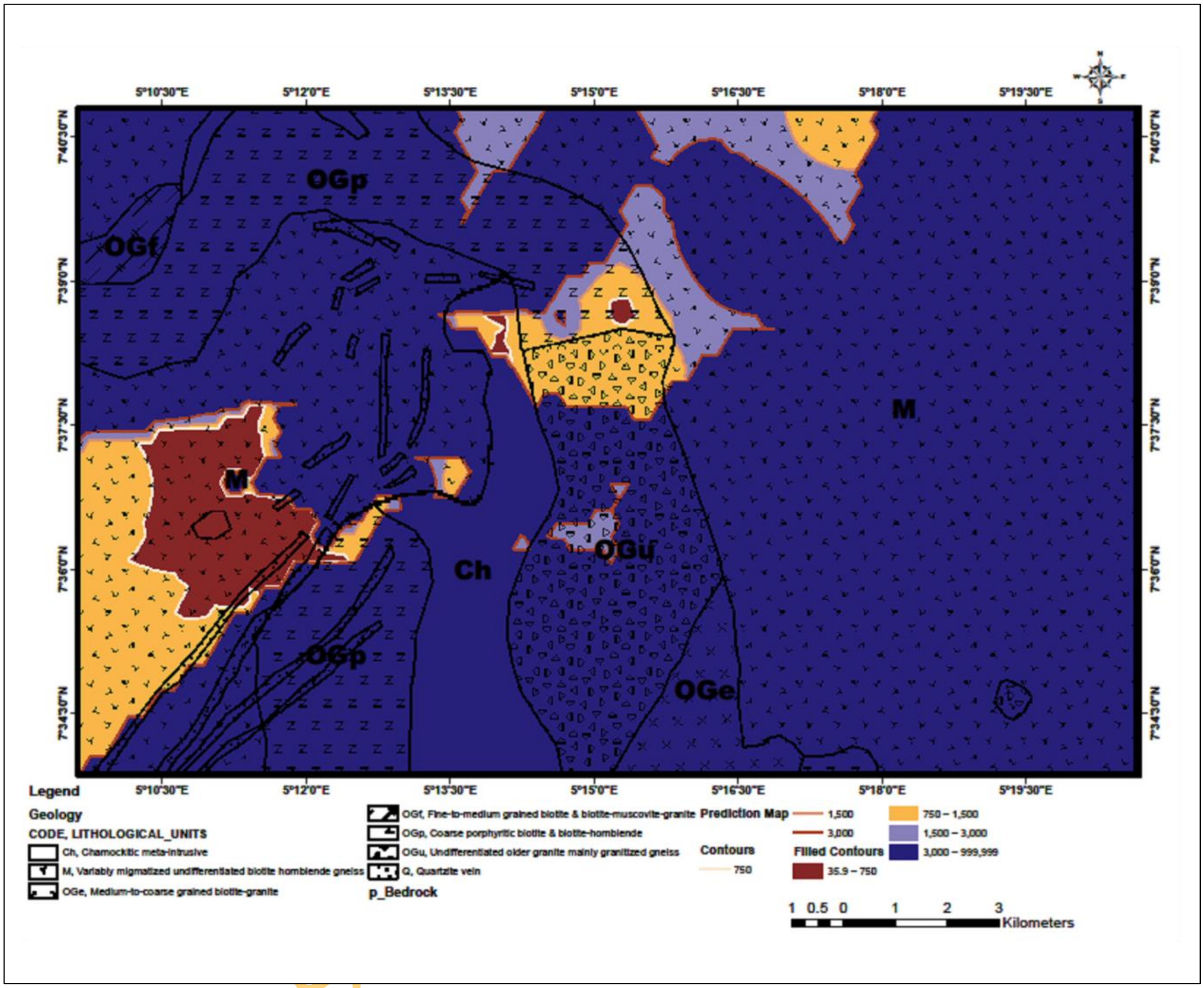


Figure 5.24: Overburden Thickness Classification Map

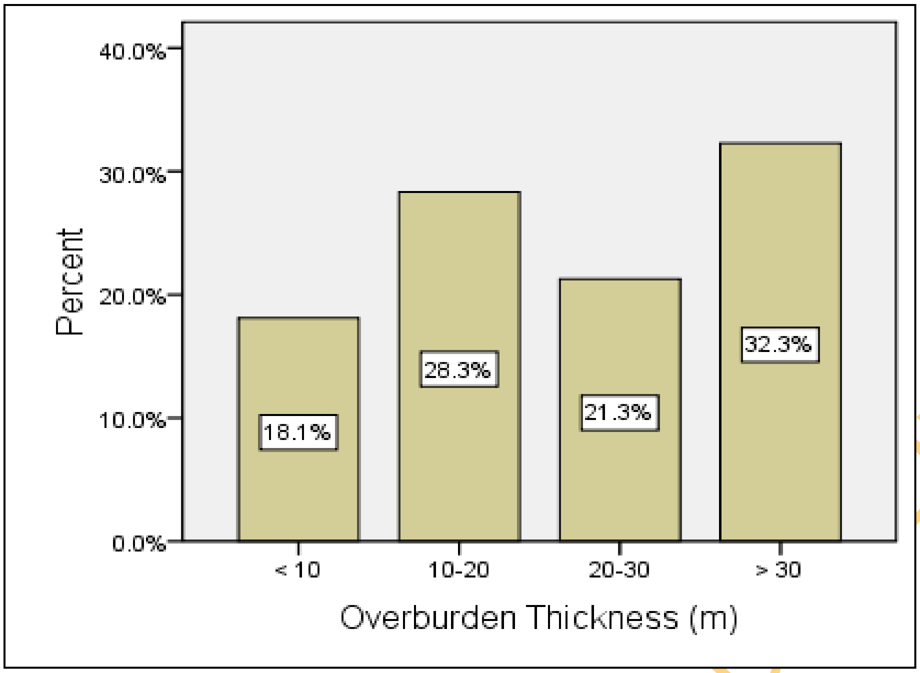


Figure 5.25: Overburden Thickness Classification of Ado-Ekiti

range of 10 – 20m overburden thickness. Average/medium groundwater potential could be ascribed to these zones. The range of overburden thickness of 20 – 30 m accounts for 21.3% with a promisingly good groundwater potential. The highest groundwater potential is expected in areas characterized by overburden thickness of > 30 m. This belt accounting for 32.3% of the study area offers strong appeal for groundwater development. For optimum yields, a water abstraction borehole should penetrate the maximum possible thickness of the regolith to ensure adequate storativity , transmissivity and drawdown.

A comparative study of the isopach map of the overburden and the weathered basement resistivity distribution map of the study area indicated that areas which fall within the zones recognized to have high potential for groundwater development coincide with the areas identified as high groundwater potential zones on the isopach map of the overburden; indicating high degree of correlation between the sets of maps.

5.2.6 The Bedrock Relief Map of the study area

The bedrock relief map predicts an uneven bedrock surface with significant implications on the groundwater potential and perhaps groundwater flow. It reflects the bedrock topography and its structural disposition (Figure 5.26)

The map delineates a series of bedrock ridges and depressions within the surveyed area. The bedrock ridges are the basement highs showing relatively thin overburden cover while the depressions are characterized by thick overburden. The depressions also exhibit low resistivity values. Naturally, the groundwater flows from areas of high pressure (such as bedrock ridge) to area of low pressure (such as bedrock depression).

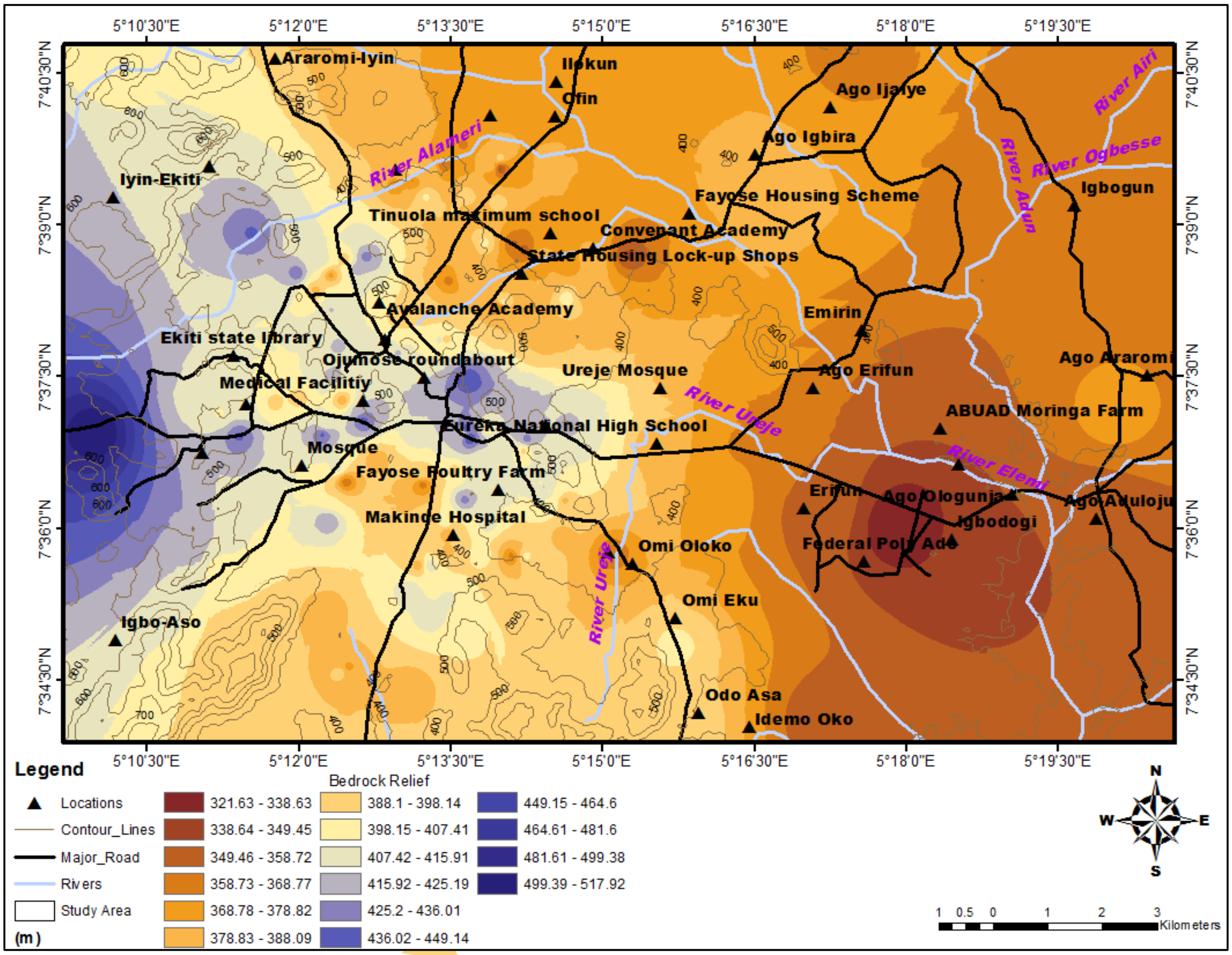


Figure 5.26: Bedrock Relief map

The studies of Olorunfemi *et al*. (1999), Bala and Ike (2001) and Omosuyi *et al*. 2003 affirmed that depression zones in the basement terrain serve as groundwater collecting troughs especially water dispersed from the bedrock crests. The bedrock depressions are diagnostic of groundwater collecting centres. They are thus demarcated as priority areas for groundwater development.

The bedrock ridges are the basement highs showing relatively thin overburden cover (H < 10 m). The depressions are characterized by thick overburden. They also exhibit low resistivity values. The depressions thus possess high groundwater potential **(**Olorunfemi and Idornigie, 1992, Mallam and Emenike, 2008 and Adiat *et al*., 2009).

5.2.7 The Total Longitudinal Unit Conductance Map

Figure 5.27 shows the spatial distribution of Longitudinal Unit Conductance across the study area. The Longitudinal unit conductance varies widely with a minimum value of 0.01 mhos and a maximum value of 4.44 mhos. This follows the trends observed by and Oladapo *et al.* (2004). Longitudinal unit conductance values varying from 0.43 to 2.56 mhos were observed in the hard rock terrain of Eastern Ghats, Andhra Pradesh (Rao *et al.,* 2003).

The total longitudinal unit conductance values can be utilized in evaluating overburden protective capacity in an area. The qualitative use of this parameter is to demarcate changes in total thickness of low resistivity materials; hence its utilization for evaluating the protective capacity of overburden units in an area (Obiora *et al*., 2015 and Oki *et al.*, 2016).

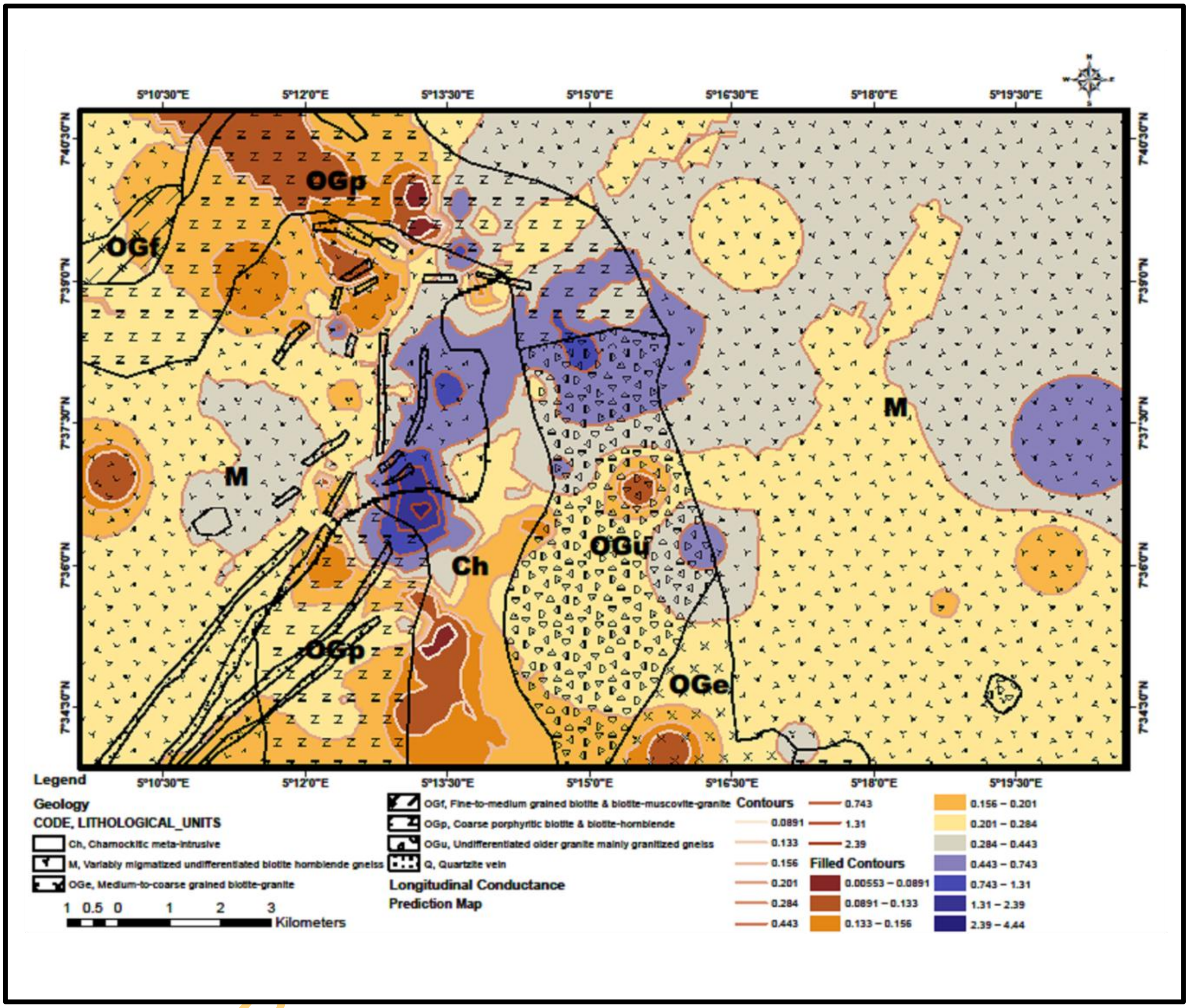


Figure 5.27: Longitudinal conductance map

The total longitudinal unit conductance values can be utilized in evaluating overburden protective capacity in an area. Henriet (1975) described the protective capacity of an overburden overlying an aquifer as being proportional to its hydraulic conductivity. Overburden of high clay content would impede fluid movement as it is generally characterized by low resistivity values and low hydraulic conductivity. Conventionally, the earth medium acts as a natural filter to percolating fluid. Its ability to retard and filter percolating fluid is a measure of its protective capacity (Olorunfemi *et al*., 1999, Oladapo *et al*., 2004 and Obiora *et al*., 2015).

5.2.8 The Transverse Unit Resistance Map

The Transverse unit resistance map (Figure 5.28) shows the spatial distribution of Transverse unit resistance across the area of study. Rao *et al*. (2003) reported values from 3000 to 9000 Ohm.m^2 across hard rocks occurring at shallow depth in the hard rock terrain of Eastern Ghats, Vizianagaram District, Andhra Pradesh. Occurrence of hard rock at shallow depth implies thin overburden cover with the consequence of very low/negligible groundwater potential. According to the authors, the range of values of T from 600 to 1200 Ohm.m^2 could be considered as a criterion for identification of aquifer zones. The geological setting is similar to the geological scenario of Ado-Ekiti with the upper catchment of the river basin covered by porphyritic granite gneiss and the lower catchment by garnet biotite gneiss. West of Andra, huge hill ranges consist of khondalite rocks. Quartzite is present as alternate bands within khondalite rock at places. Migmatite outcrops are exposed west of Andra village. In this area, a shear zone separated the khondalite suite of rocks from Migmatite gneiss. An intrusive charnockite massif is located near Pedabantupalle. Delineation of groundwater aquifers in this hard rock terrain has been accomplished by employing the DZ parameters.

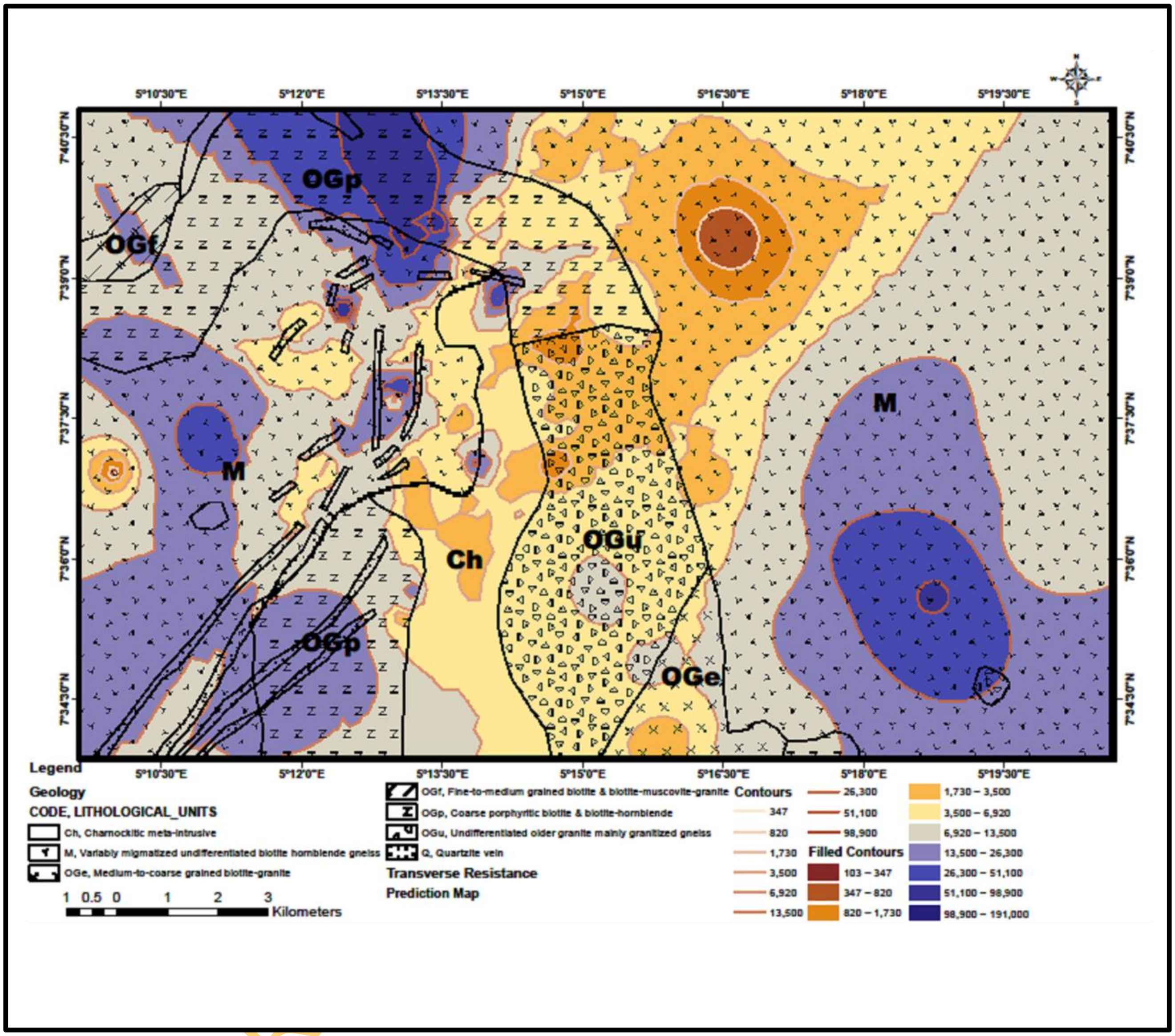


Figure 5.28: Transverse Resistance map

Jaiyeoba and Oladunjoye (2013) also reported Total Transverse Resistance values of between 437.68 and 12 315.55 Ω m^2 at Alabata near Ibadan, South-western Nigeria.

5.2.9 Coefficient of Anisotropy Map

The spatial distribution of coefficient of anisotropy (Figure 5.29) indicates values varying from 1.00 to 3.00. Olorunfemi and Olorunniwo (1985) reported anisotropy coefficients of overburden columns of productive boreholes and wells varying from 1.39 to 1.66 across the basement complex of the Southwest, Nigeria. These values fall within the middle range of the observed values of between 1.0 and 3.0. The study of Rao *et al*. (2003) considered areas around 1.5 anisotropy values and ranked the zones high for groundwater development with characteristic high porosity and permeability. These permeable zones are of appreciable thickness. Occurrence of compact rock at shallow depth increases the coefficient of anisotropy.

5.2.10 Soil Corrosivity and Aquifer Protective Capacity of the Overburden Units

Performance of Civil Engineering construction works including utility pipes requires knowledge of the soil corrosivity. Buried pipes are susceptible to corrosion and subsequent failure if the host soil medium is corrosive and aggressive. Pipelines leakage or rupture could constitute hazards to the environment (Agunloye, 1984 and Akintorinwa and Abiola, 2011). Soil corrosivity depends largely on the composition of the soil and other environmental factors, including the presence and abundance of moisture and oxygen. High moisture content, high electrical conductivity and high dissolved-salt content will promote corrosivity.

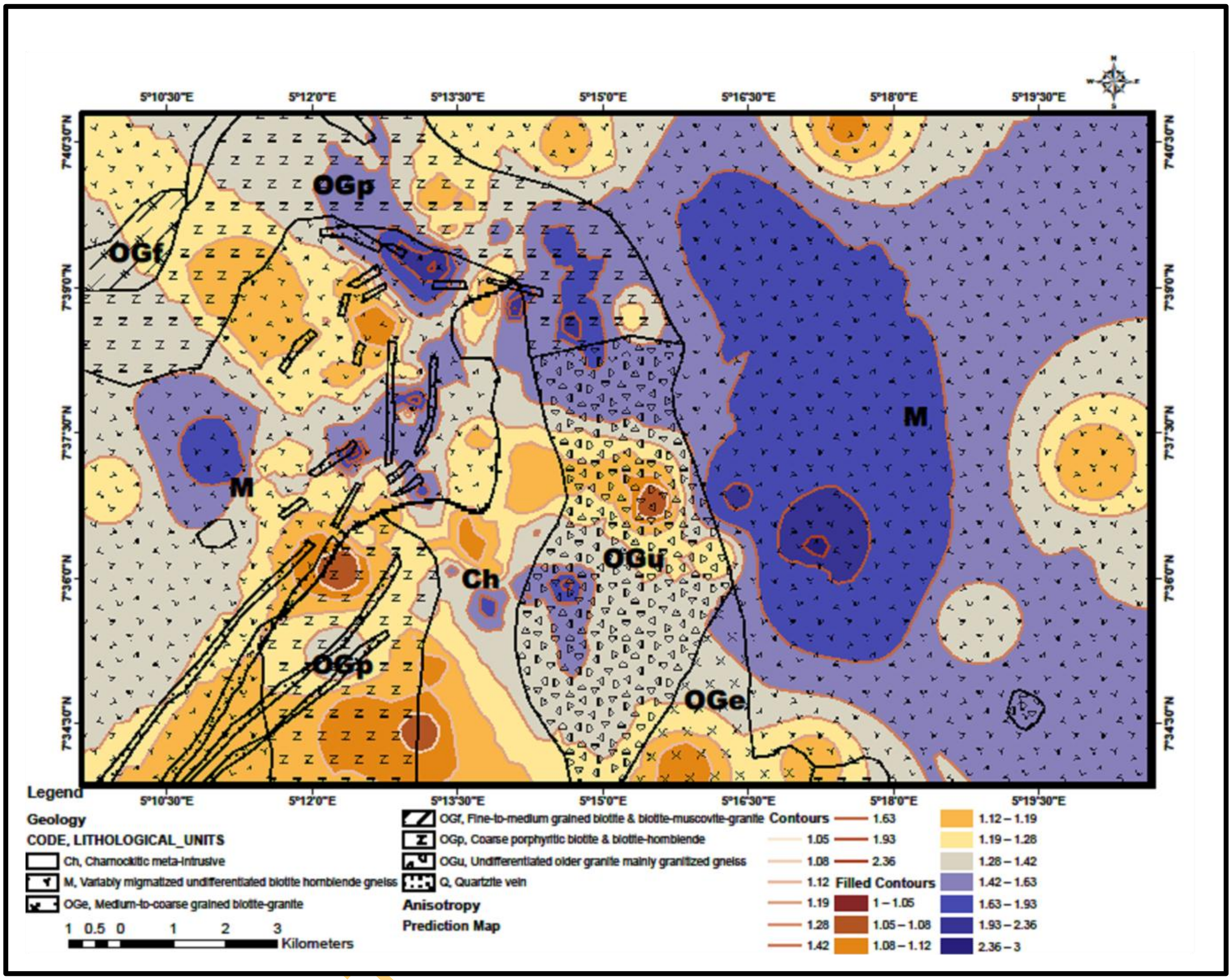


Figure 5.29: Coefficient of anisotropy map

Soil media characterized by high electrical conductivity or low resistivity is associated with high degree of corrosivity. Electrical resistivity depends on porosity, degree of electrolyte saturation or concentration of dissolved salts in soils (Adesida *et al.,* 2002 and Gopal, 2010).

Contamination of the hydrogeologic system in metropolitan areas is fast becoming a critical issue in groundwater quality considerations. Installation of facilities, though essential but capable of provoking permanent damage of the underlying aquifers particularly in areas where residents rely mostly on groundwater mandates an understanding of the aquifer protective capacity of the overburden units of the host soil medium. Urbanization and industrialization remain the predominant contributors of contaminants to the hydrological systems. Leachate from dumpsites, mining activities, buried petroleum pipes/tanks, septic tanks and the widespread use of chemical products such as pesticides, herbicides and solvents portend risks to the groundwater quality status (Braga *et al.*, 2006 and Adeniji *et al.*, 2014)

The earth media (composed of different subsurface layers) act as natural filter to infiltrated water arising from surface pollutants. The ability of the overburden to retard and filter percolating fluid is a measure of its protective capacity and a function of transmissivity. Estimating these properties from the traditional methods of pumping tests can be very expensive and time consuming. The electrical resistivity method is significant in *in-situ* determination of subsoil characteristics and conditions, as the electrical resistivity of earth materials depends on environmental parameters such as mineral and fluid content, degree of water saturation in the rock/soil, permeability and grain size (Mohammed *et al.,* 2012)

The traditional purpose of electrical resistivity survey is to determine the subsurface resistivity distribution by taking measurements on the ground surface. The resistivity of the Earth is related to the mineral and fluid content, porosity and degree of water saturation in the subsurface.

The electric conduction in most rocks is essentially electrolytic. Electric conduction is through interstitial water in pores and fissures. Groundwater filling the pore spaces of a rock is a natural electrolyte with a considerable amount of ions. The more porous or fissured a rock is, the larger is its groundwater content, the higher is the conductivity and the lower is the resistivity (Ojo *et al.*, 2015 and Mohammed *et al.*, 2012). It is noted that burial of utilities and underground storage tanks are restricted to shallow depths. Hence, the need to assess the corrosivity and protective capacity offered by the overburden units in the study area.

5.2.10.1 Evaluation of Soil Corrosivity

Table 5.3 (a & b) shows Soil Resistivity Classification in terms of Corrosivity. The frequency distribution of corrosivity level within the topsoil is presented in Figure 5.30. Topsoil materials indicating corrosivity levels of PNC (Practically Non-Corrosive), SC (Slightly Corrosive) and MC (Moderately Corrosive) had coverage of 48.87%, 39.1% and 12.03% respectively.

A large portion of the metropolis (% frequency of 48.87%) is practically non-corrosive (with resistivity, $\rho > 180\ \Omega m$) within the topsoil particularly areas overlain by lateritic hardpan with relatively high resistivity values. Relatively low resistivity values are indicative of high tendency for corrosivity. Slightly corrosive materials (with $60 < \rho < 180\ \Omega m$) occupy 39.10% of the topsoil and are observed at the eastern, southern, northeastern flanks and the central portion. Moderately corrosive topsoils (with $10 < \rho < 60\ \Omega m$) are delineated around Eureka/Oke Ureje (Figure 5.31).

The soil corrosivity within the second layer indicates a frequency distribution (Figure 5.32) of 1.5%, 30.08%, 31.58% and 36.84% for VSC, MC, SC and PNC levels respectively. Figure 5.33 shows that the second layer is constituted by moderately corrosive/slightly corrosive materials

Table 5.3(a): Soil Electrical Resistivity Classification (BS – 1377)

Soil Resistivity (Ohm-m)	**Soil Corrosivity**
< 10	Severe
10 – 50	Corrosive
50 - 100	Moderately corrosive
>100	Slightly corrosive

Table 5.3(b): Classification of soil resistivity in terms of corrosivity (Agunloye, 1984, Mohammed *et al*., 2012 and Adeniji *et al*., 2014)

Soil resistivity (Ωm)	**Soil Corrosivity**
< 10	Very strongly corrosive (VSC)
10–60	Moderately corrosive (MC)
60–180	Slightly corrosive (SC)
> 180	Practically noncorrosive (PNC)

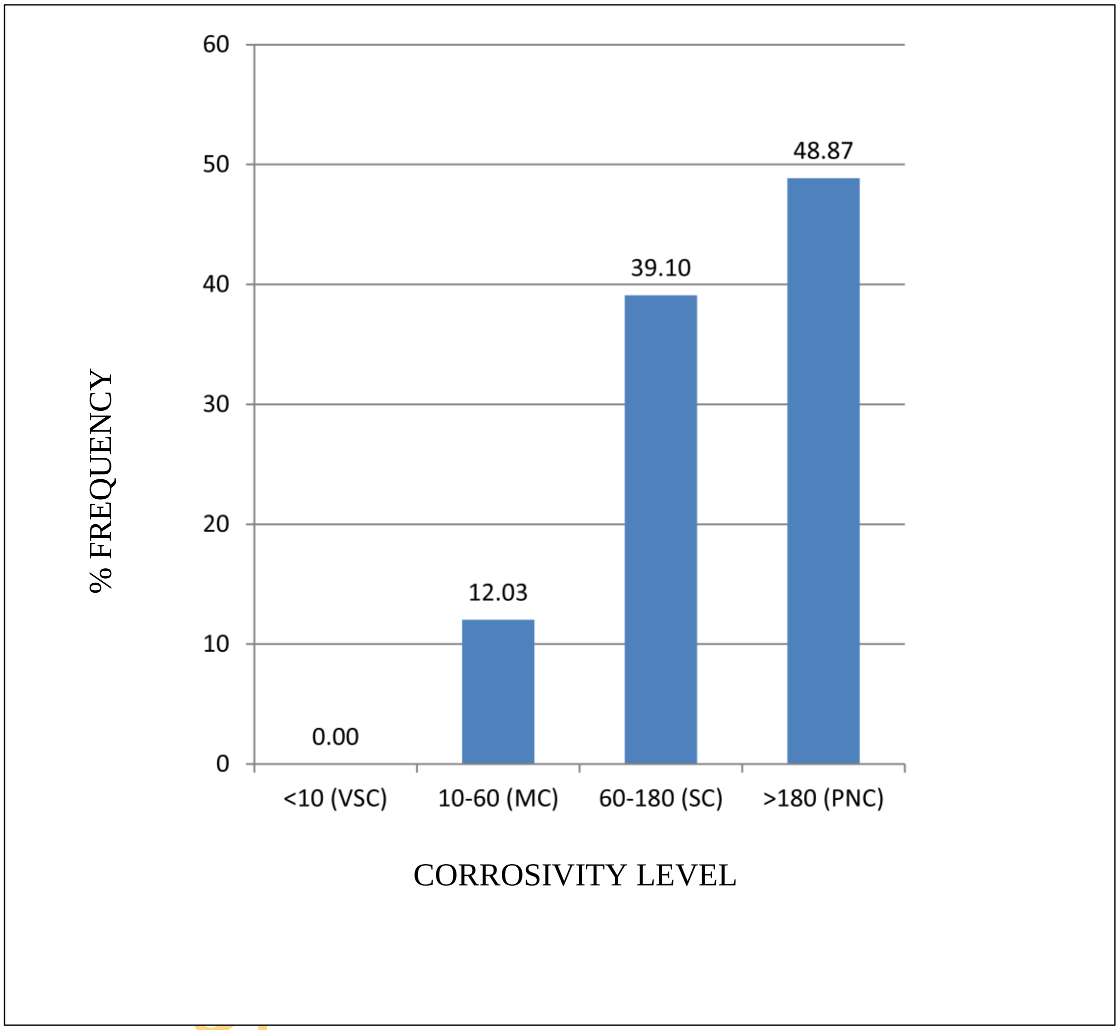


Figure 5.30: Topsoil Corrosivity Level

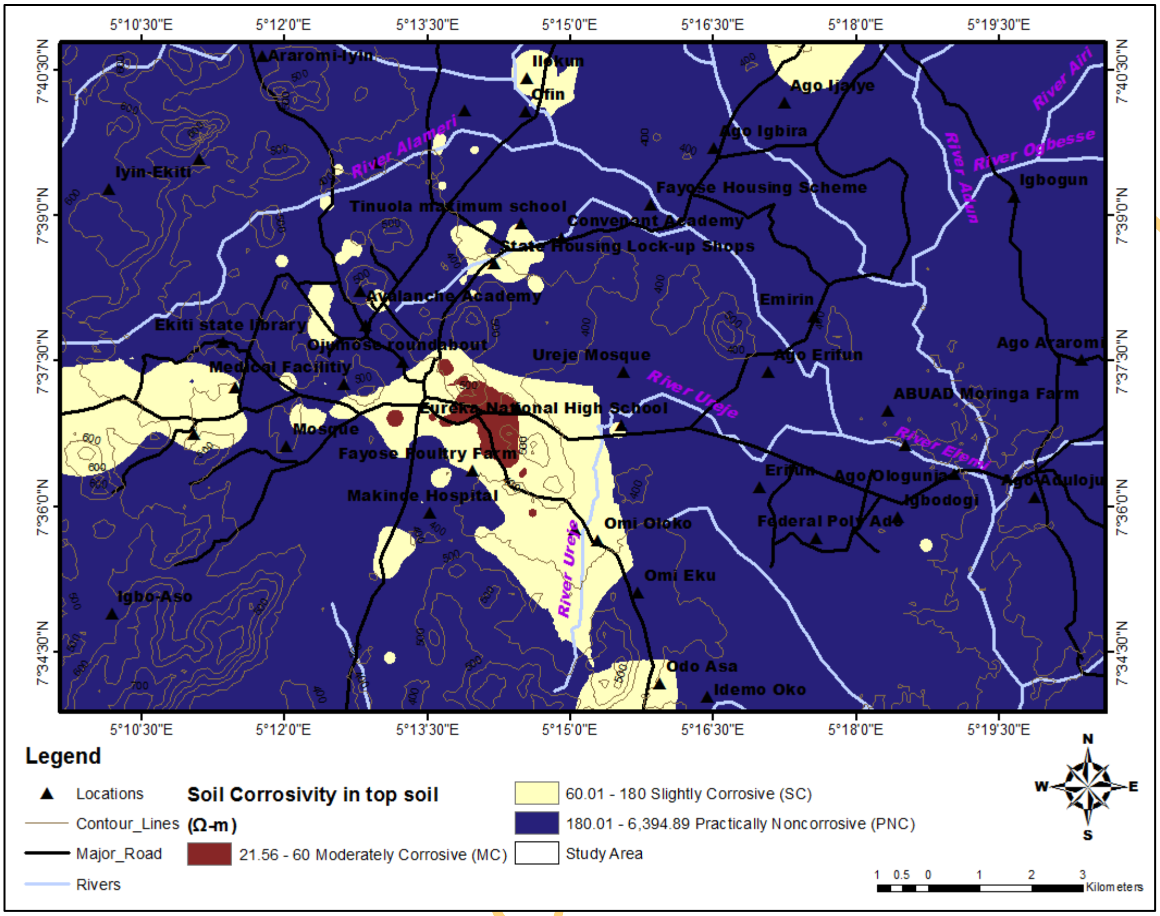


Figure 5.31: Soil Corrosivity Map (Topsoil)

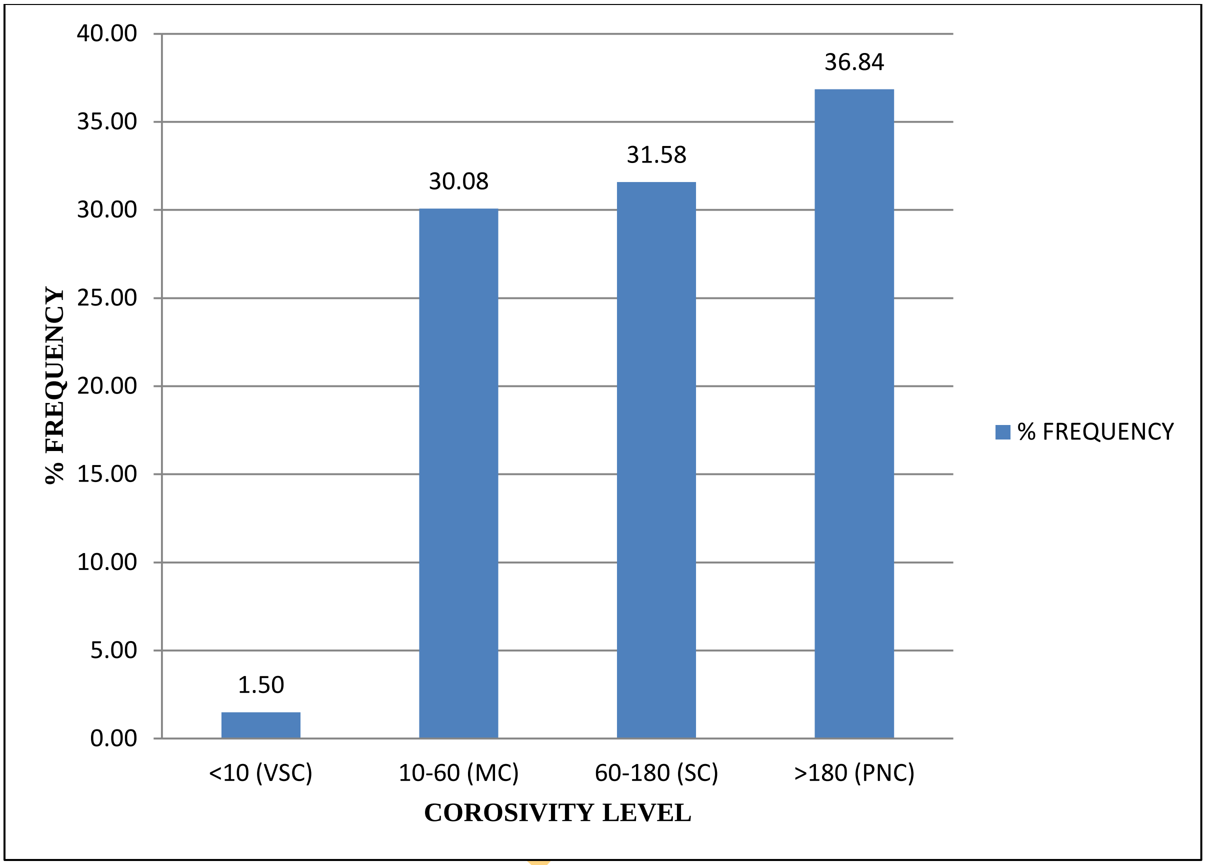


Figure 5.32: 2nd Layer Corrosivity Level

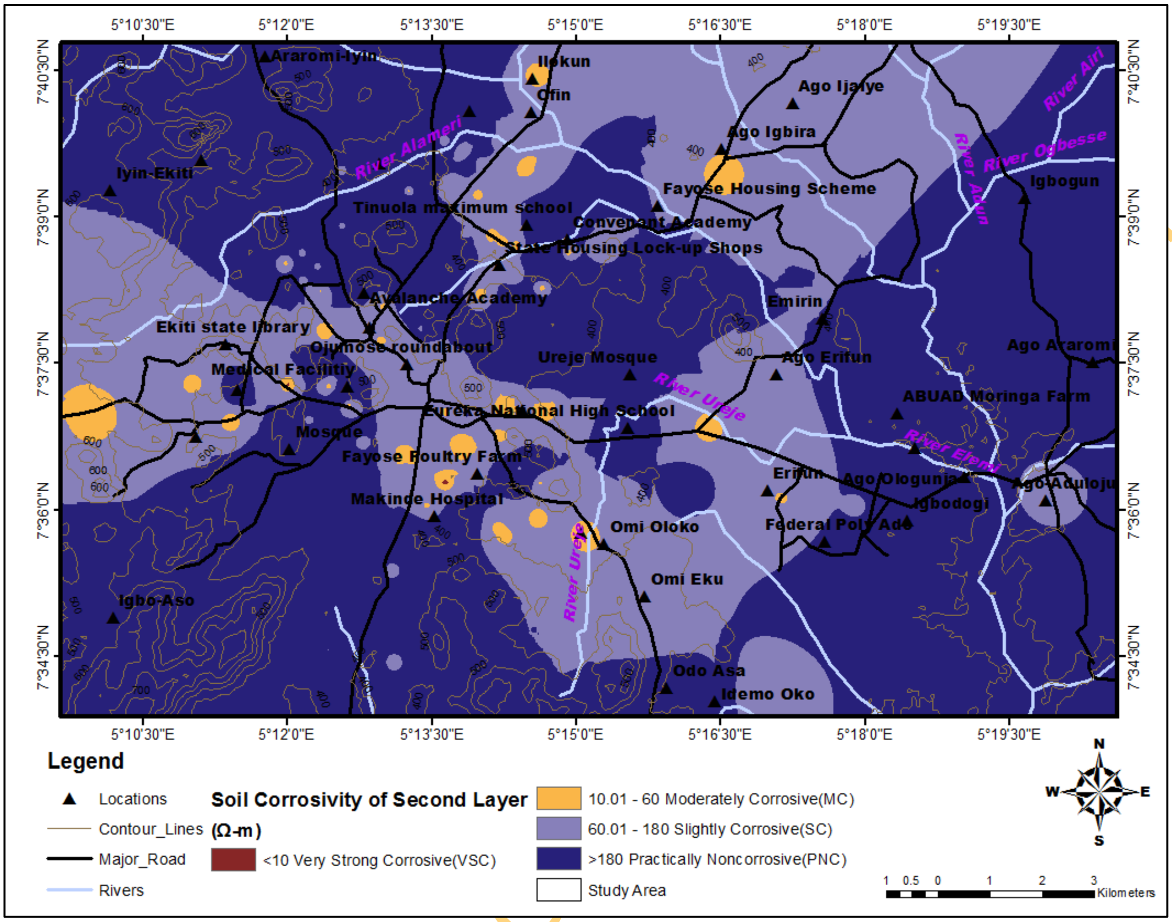


Figure 5.33: Soil Corrosivity Map (2nd Layer)

around the eastern, southern and northeastern flanks. The northwestern, southeastern, Eastern and central parts of the metropolis are practically non-corrosive with resistivity values, ρ > 180 Ohm-m; indicating reduced porosity, negligible fluid content and degree of saturation.

Soil corrossivity assessment is germane to pipe network design as it provides a useful guide in the selection and prescription of the subsurface steel pipes for a given project and perhaps any required treatment to forestall economic waste and varied hazards associated with rupture of corroded pipes. Use of corrosion-resistant pipes is recommended according to the corrosivity level and the design specifications.

5.2.10.2 Evaluation of the Aquifer Protective Capacity

Oladapo *et al*., (2004), Braga *et al*., (2006) and Ehirim and Nwankwo (2010) demonstrated the applications of the Longitudinal Unit Conductance as an effective way of evaluating aquifer protective capacity of the overburden units without interfering with the hydrogeologic system. The longitudinal unit conductance presents a combination of the thickness and resistivity of the geoelectric layers into a single variable. A clayey overburden which is highly impervious presupposes relatively high longitudinal conductance and offers effective protection to the underlying aquifer (Obiora *et al*., 2015 and Oki *et al.*, 2016). The protective capability is a function of the clay content of the overburden (Table 5.4).

The Protective Capacity offered by the Overburden Units in the study area is presented in Figure 5.34 with the frequency distribution in Figure 5.35. Zones where the conductance is greater than 0.7 mhos are considered zones of good protective capacity. The portions having conductance values ranging from 0.2 to 0.69 mhos are classified as zone of moderate protective capacity;

Table 5.4**:** Longitudinal Conductance / Protective Capacity Rating (Henriet, 1975 and Oladapo *et al.*, 2004)

Longitudinal Conductance(mho)	Protective Capacity Rating (APC)
> 10	Excellent
5 - 10	Very Good
0.7 - 4.9	Good
0.2 - 0.69	Moderate
0.1 - 0.19	Weak
< 0.1	Poor

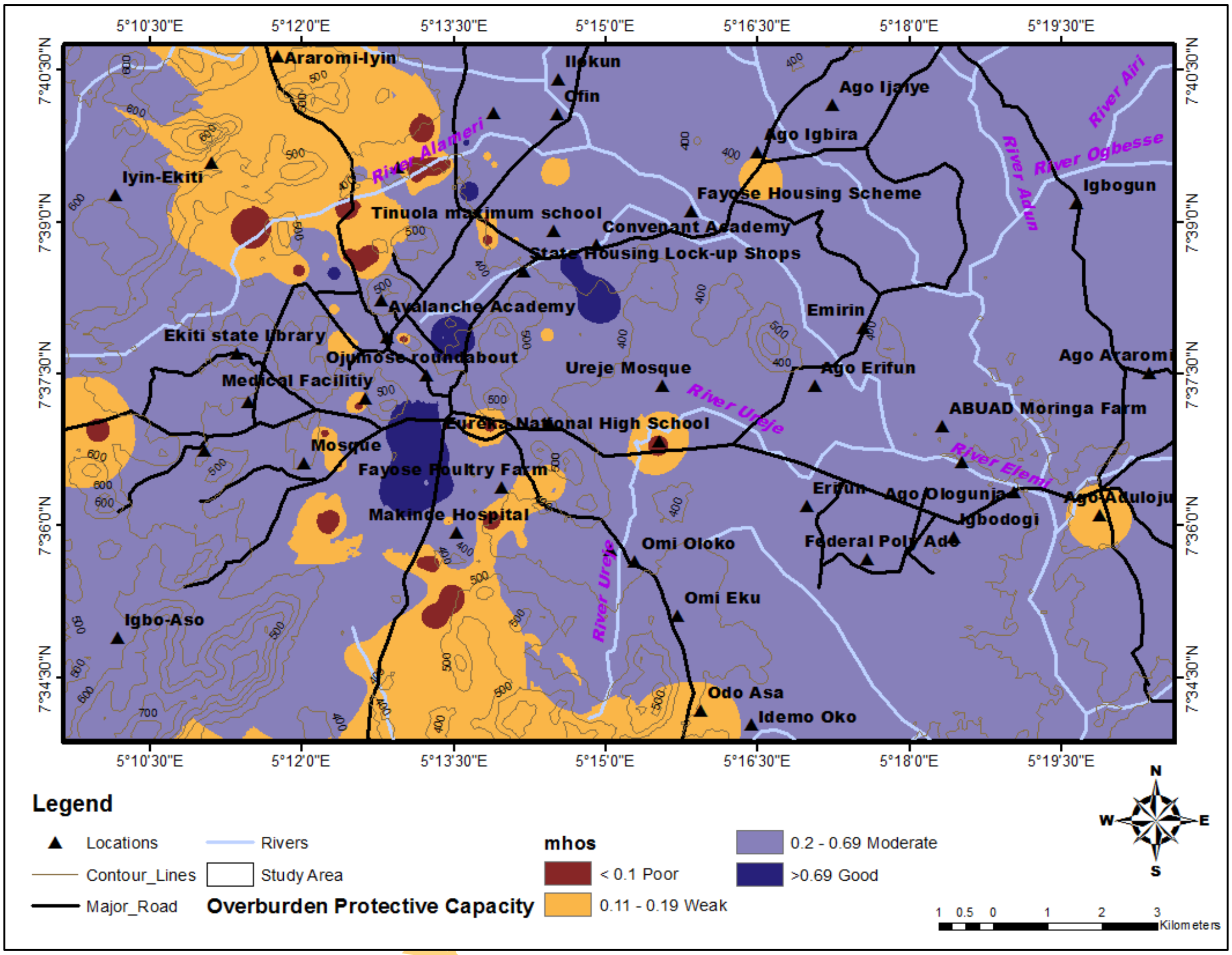


Figure 5.34: Overburden protective capacity map of the study area

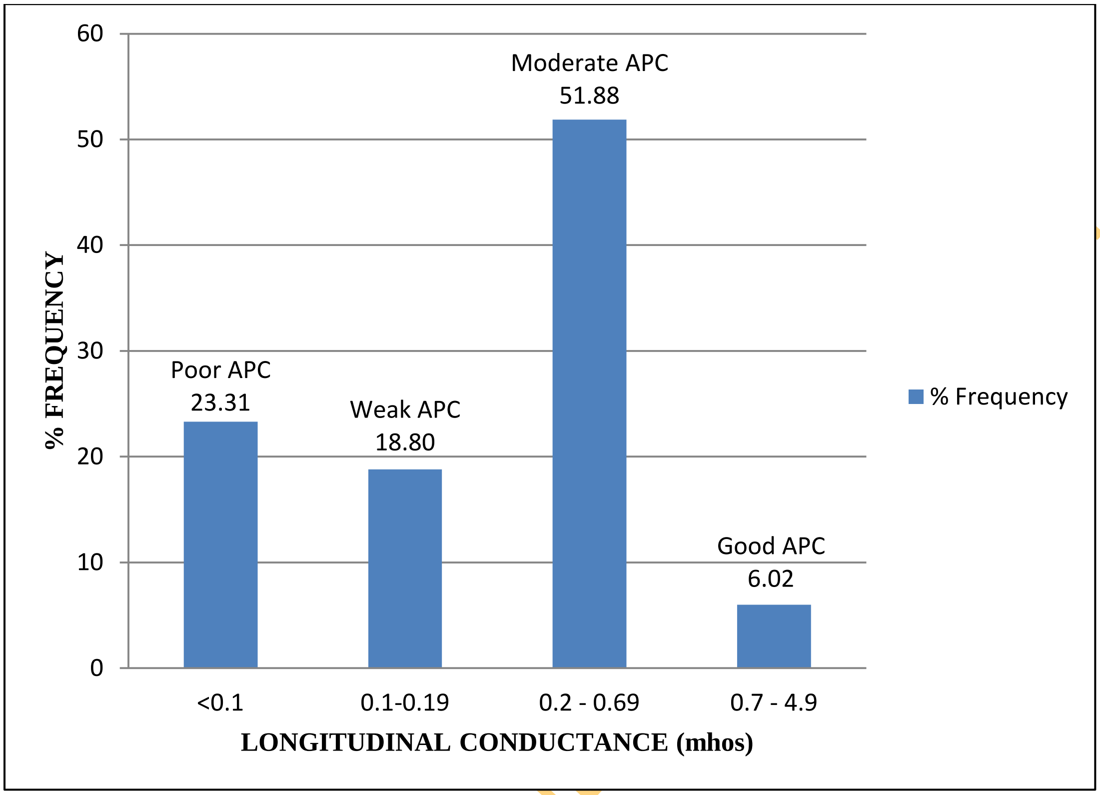


Figure 5.35: Frequency Distribution of Aquifer Protective Capacity

areas with values ranging from 0.1 to 0.1 9 mhos are classified as areas of weak protective capacity and the zones where the conductance values are less than 0.1 mhos are demarcated as regions of poor overburden protective capacity. The study area is characterized by overburden materials of poor, weak and moderate protective capacity, accounting for 23.31%, 18.80% and 57.9%, respectively. Only 6.02% of the area indicates good overburden protective capacity.

5.3 Hydrostatic Level Measurements

5.3.1 The Map of Static Water Level

The spatial distribution of depths to the static water level within Ado-Ekiti metropolis is presented in Figure 5.36. The contour pattern is characterized by isolated closures typical of discontinuous basement aquifer system (Olorunfemi *et al*., 1999 and Olayinka, 2010). The static water level is relatively deep in northwestern, southwestern, central parts and the Eastern flanks of the metropolis and mainly shallow within the northwest, central and southern parts.

5.3.2 The Groundwater Head Map

The groundwater head values were computed from the acquired depths of hydrostatic level of the wells and used to generate the groundwater head map for the study area, Figure 5.37. It is essentially a relief map showing zones of high groundwater head and low groundwater head values.

Zones of high groundwater head values which are zones of low static water level translate to crests/high rise. They are thus groundwater radiating zones or groundwater divergent zones. Low groundwater head characterize areas of high static water level values or deep static water level.

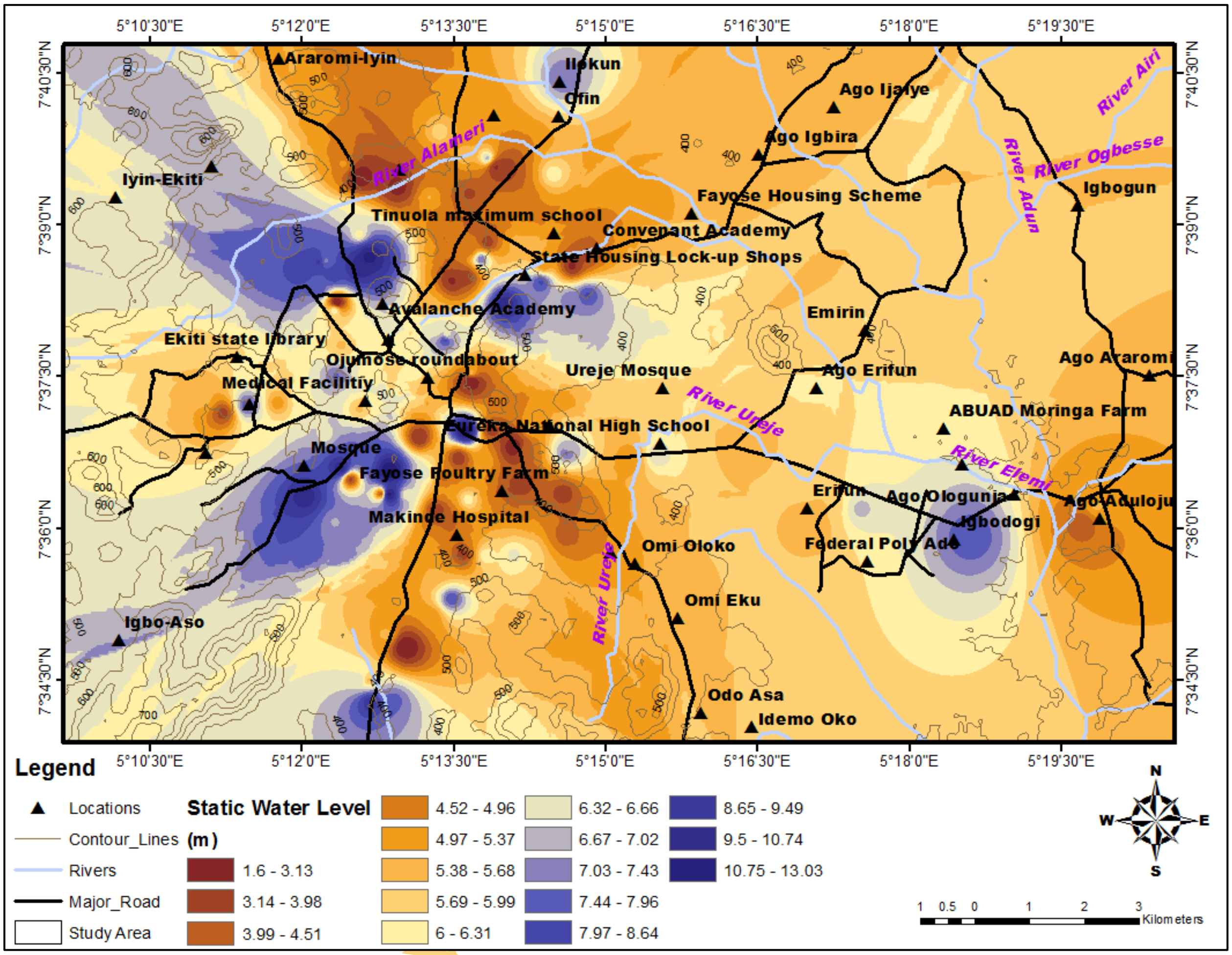


Figure 5.36: Static water level map

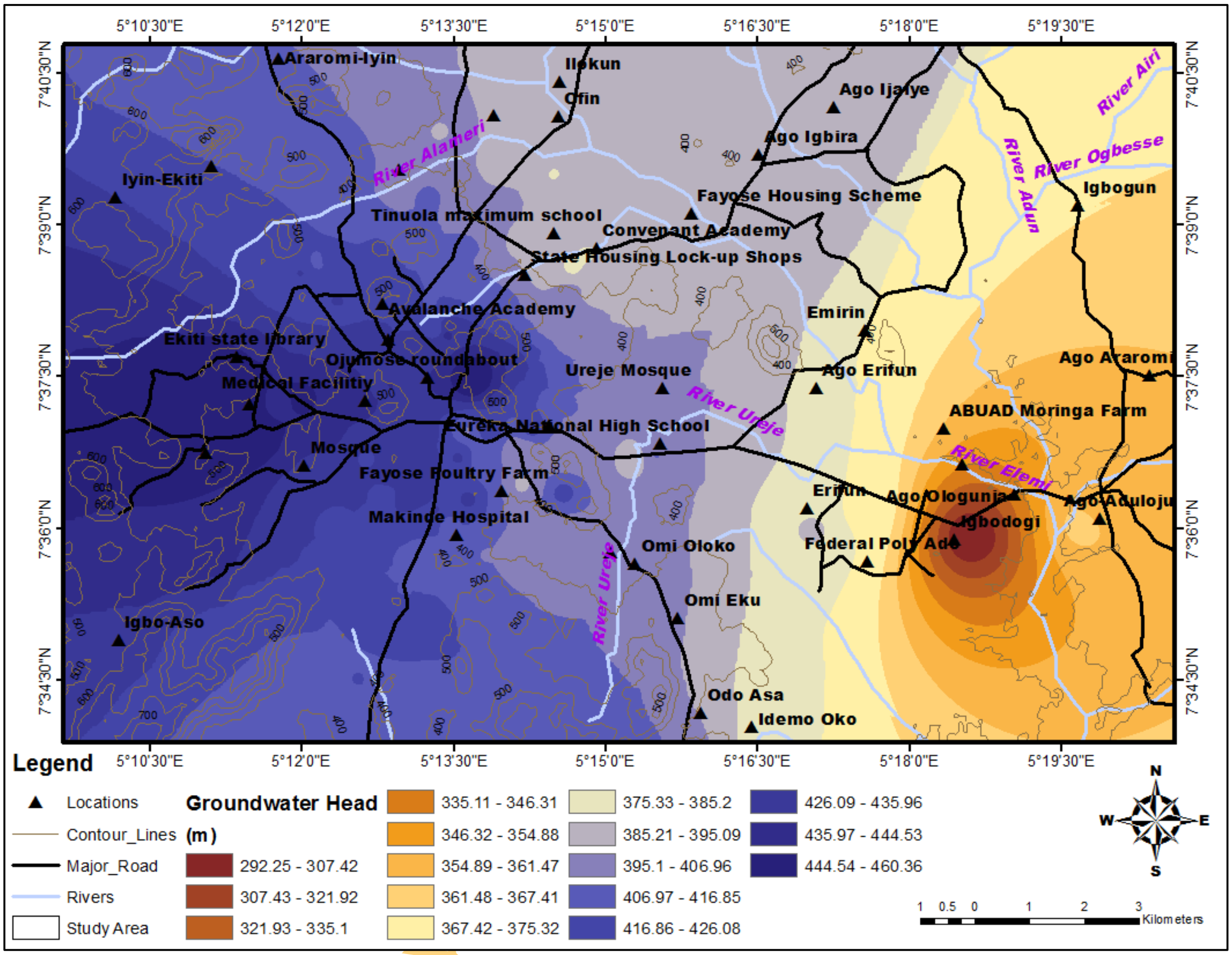


Figure 5.37: Groundwater head map

The zones are diagnostic of troughs, which are groundwater collecting centres or groundwater convergent zones. It is evident that groundwater flows away from the high groundwater head/ hydraulic head zones towards the low groundwater head/ hydraulic head zones. Depressions on the map are thus points with good groundwater potential (Olorunfemi *et al*., 1999 and Oseji *et al*., 2009).

Groundwater flows in the direction determined by the slope of the water table essentially from high hydraulic head to low hydraulic head. The flow is thus from regions of increasing head to that of decreasing head. Closed contour curves of maximum groundwater head in the flow domain indicate presence of sinks or discharge zones. Closed contour curves of minimum groundwater head in the flow domain are indicative of the presence of sources or groundwater recharge zones at that portion.

Recharge is the process by which groundwater is replenished. A recharge area is where water from precipitation is transmitted downward to an aquifer. Recharge is promoted by natural vegetation cover, flat topography, permeable soils, a deep water table and the absence of confining beds. Discharge areas are the locations at which groundwater leaves the aquifer and flows to the surface (Dai *et al*., 2001 and Oseji *et al*., 2009).

It is observed that the main groundwater flow direction in the study area lies along the northwest – southeast direction. Occurrence of local sinks or discharge zones between the central and south – eastern portions of the study area and similar occurrence lying approximately southwest between the high groundwater head portions of the western flank and the central parts of the metropolis are indicative of groundwater divides and sub domains. A groundwater divide indicates distinct groundwater flow regions within an aquifer. Groundwater divides often occur where aquifers are shallow and strongly influenced by surface water flow. The groundwater divide is indicated on groundwater head contour map by a curve in horizontal plane, which separates the flow domain into sub domains, such that all groundwater from a sub domain drains out through a separated outlet such as spring, river, stream, etc (Olorunfemi *et al*., 1999 and Buddermeier and Schloss, 2000).

The groundwater divergent/convergent zones and the flow domains (the major groundwater recharge / discharge zones, the regional groundwater flow direction and the groundwater divides in Ado-Ekiti) must be devoid of environmentally unfriendly activities such as location of landfills, dunghills and waste disposal sites to prevent leachate from reaching the water table and the aquifer zone with the attendant consequences of groundwater quality degradation. Regional groundwater pollution must be forestalled since contaminants generally move in the direction of groundwater flow.

Groundwater as the common water source in the metropolis for both domestic and drinking purposes must be protected especially from contamination induced by soil particles eroded during heavy downpours on which water-impairing substances like nitrates and phosphates are washed into the wells. Indiscriminate refuse dumping must be discouraged in the metropolis. Monitoring wells should be installed along the groundwater flow directions and the groundwater divides such that Water samples from these wells are subjected to regular comprehensive water quality analysis to ensure overall protection of the groundwater resource.

5.4 Structural / Geologic Features and Groundwater Pockets

In the regional consideration, geologic features delineated from the distribution of the subsurface resistivity are the bedrock depressions and the basement anticlines (or ridges). These are shown in Figures 5.38, 5.39 and 5.40 in the planar view of the bedrock relief, overburden thickness and the groundwater head maps respectively.

Areas of basement trough (depression) on the relief map, with substantively thick overburden and aquifer thickness are of significant hydro-geologic importance. They are demarcated as good groundwater potential zones. Areas identified to be associated with the basement anticlines (or ridges) are recognized as areas of poor groundwater potential, with characteristic thin overburden and aquifer thickness.

The groundwater head map also delineated the groundwater discharge and recharge zones. Ado-Ekiti enjoys a mean annual total rainfall of 1367 mm with a low coefficient of variation of about 10% (Ebisemiju, 1993 and Bankole, 2010). This high annual rainfall favours significant recharge of the basement aquifers through surface precipitation. The discontinuous nature of basement aquifers (evidenced on the maps as isolated closed contours) would reduce the influence of recharges through lateral groundwater flow (Olorunfemi *et al*., 1999 and Ojo *et al*., 2015).

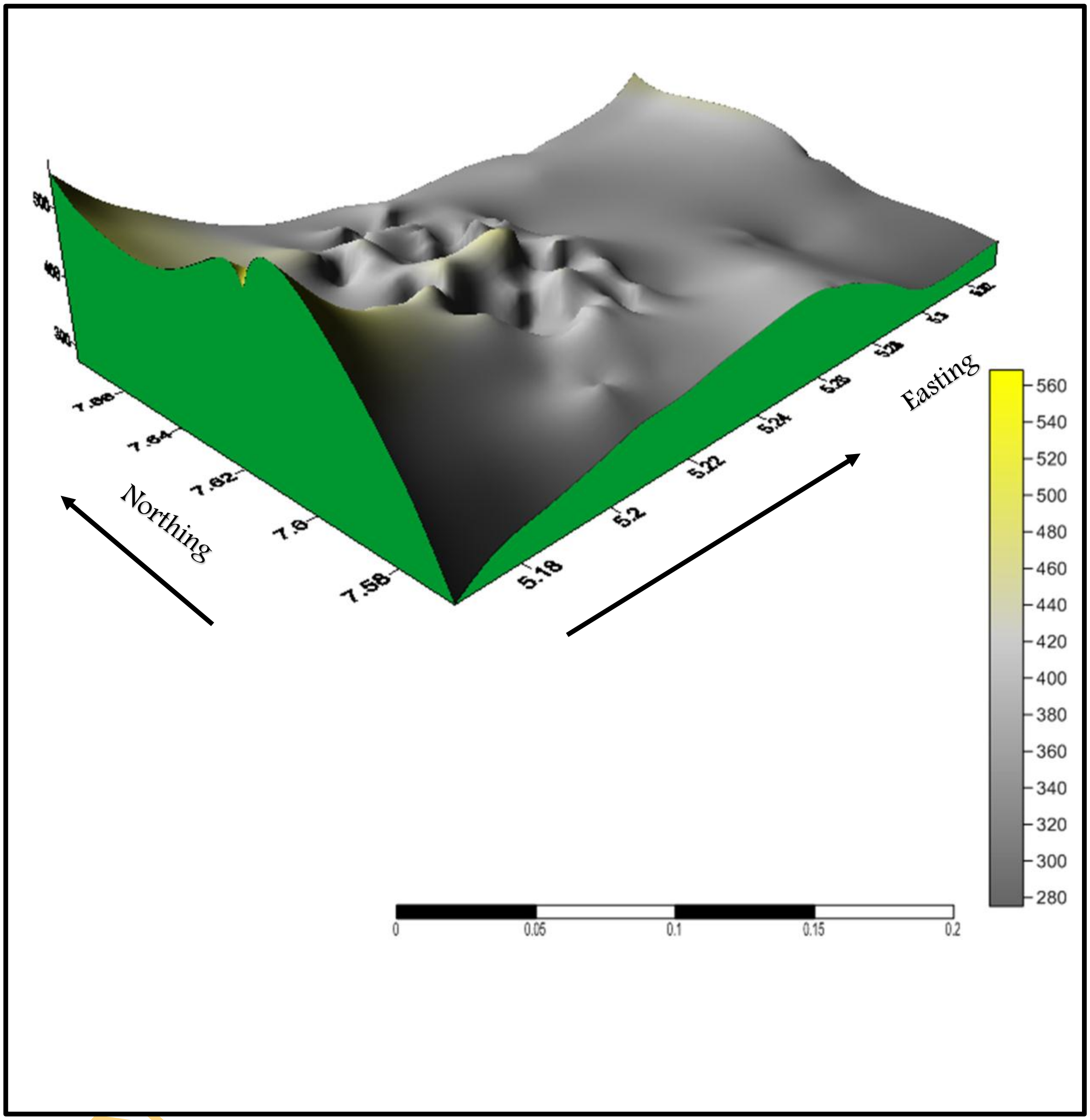


Figure 5.38: The 3D Surface Map of the Bedrock Relief of the study area

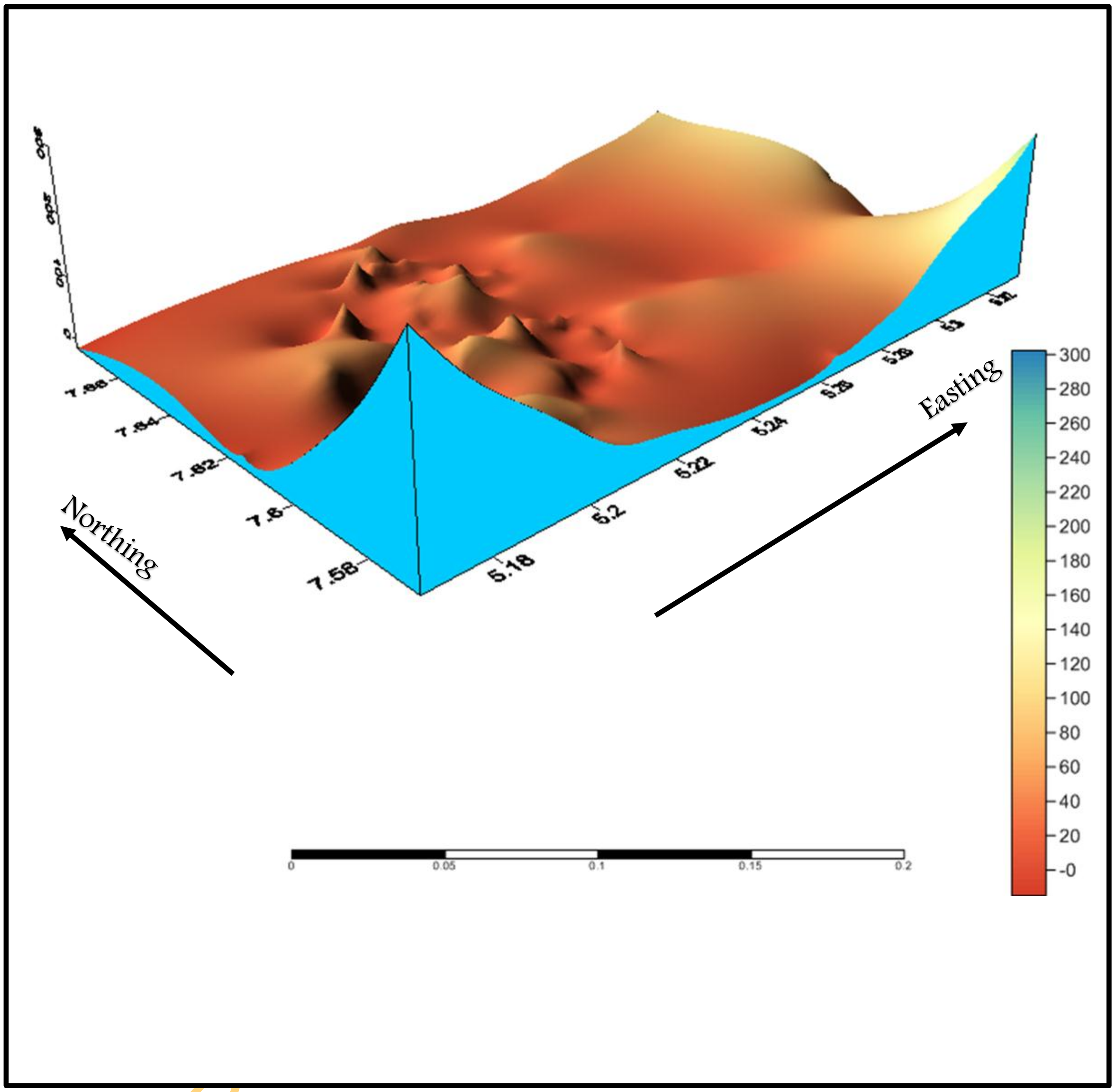


Figure 5.39: The 3D Surface Map of the Overburden Thickness of the study area

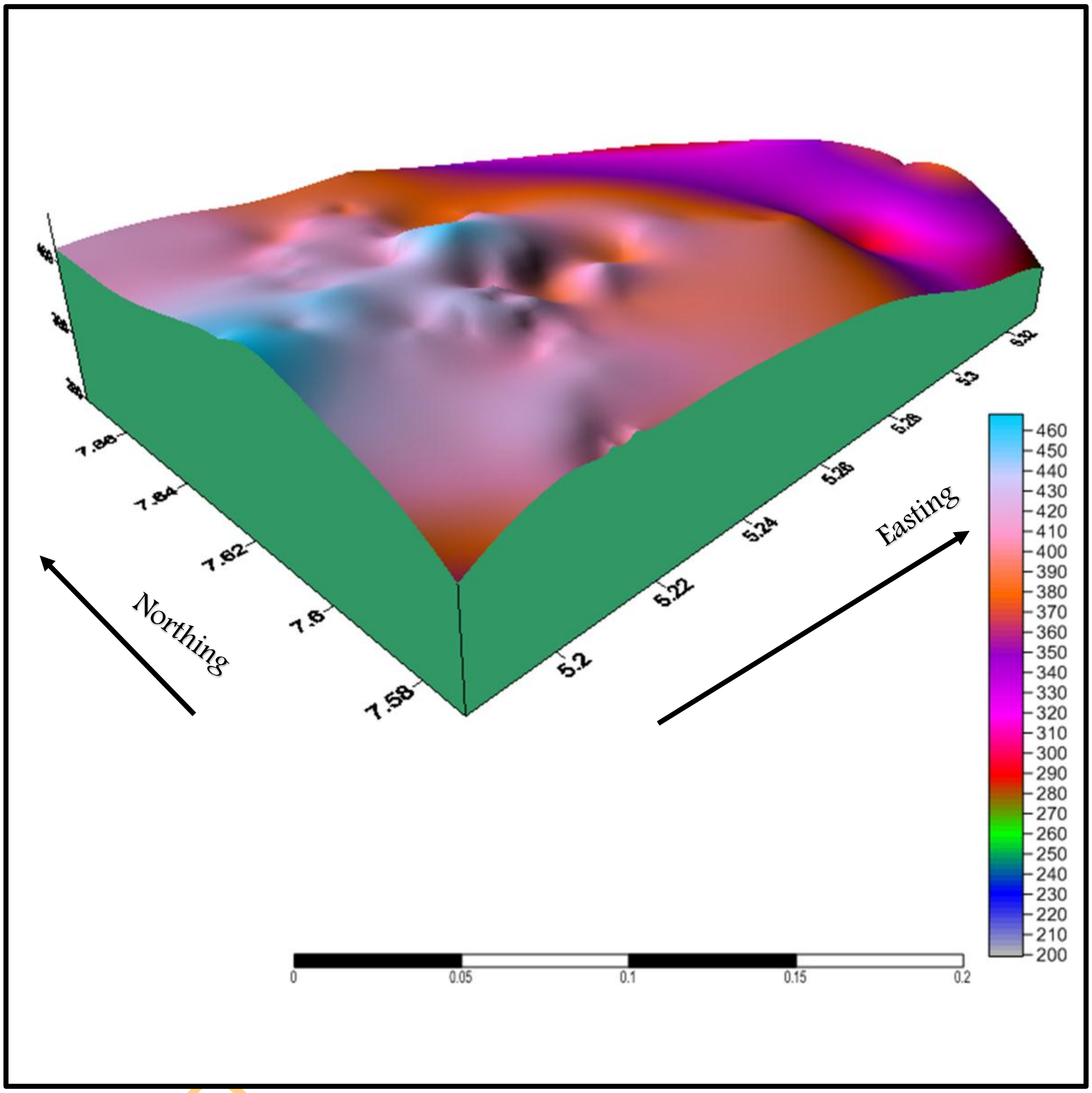


Figure 5.40: The 3D Surface Map of the Groundwater head of the study area

5.5 Groundwater Potential Evaluation

5.5.1 Groundwater Potential Evaluation (Based on RS – GIS)

The modelling involves integration of lithology, lineaments, lineament density, lineament intersection, lineament intersection density, geomorphology, slope and soil thematic layers. ArcMap 10.2.2 was employed for geo-referencing and derivation of the thematic layers. The maps were prepared and re-classified for spatial analysis. Weights ranging from 1 to 5 were assigned to the classes in terms of their importance with respect to groundwater occurrence. In each thematic map, highest weight is given to the class that is most favourable to groundwater accumulation and lowest weight is given to the class with least groundwater prospect.

The thematic maps were synthesized in a GIS environment using weighted indices for groundwater potential map development according to the works of Rao and Jugran (2003), Talabi and Tijani (2011) and Fashae *et al*. (2014). The resulting groundwater potential possibility maps were subjected to validation against the existing borehole yield data and the yield classification in Table 5.5. The weighting combination (Table 5.6) which gave the highest correlation of 56.7% was subsequently adopted thereby producing the groundwater potential map (Figure 5.41) on the account of only remotely sensed data. The map classifies the study area into very low, low, moderate and high groundwater potential zones.

The rather low % correlation between the output of RS and the yield data underlines the need to follow up with Ground Geophysics. Bagyaraj *et al.* (2013) had noted that Remote Sensing would serve as the preliminary inventory method to understand groundwater potential and help in delineating areas where further explorations need to be taken up through hydrogeological and geophysical methods.

Table 5.5: Classification of Borehole Yield in terms of Groundwater Potential in the Basement Complex (Adapted from: Carruthers and Smith 1992 and Olorunfemi, 2008)

Borehole Yield Range (l/s)	Groundwater Potential
0 – 0.49	Very Low
0.5 – 0.99	Low
1.0 – 1.49	Moderate
1.5 – 2.5	High
> 2.5	Very High

Table 5.6: Classification of themes for delineation of Groundwater Potential Zones

Parameters	Classes	Scale Value	Rank
LINEAMENT DENSITY	VERY LOW	1	20
	LOW	2	
	MEDIUM	3	
	HIGH	4	
	VERY HIGH	5	
DRAINAGE DENISTY	VERY LOW	5	15
	LOW	4	
	MEDIUM	3	
	HIGH	2	
	VERY HIGH	1	
GEOMORPHOLOGY	VALLEY FILLS	5	15
	ALLUVIUM	4	
	PEDIPLAIN	3	
	PEDIMENT	2	
	HILL AND RIDGES	1	
GEOLOGY	VARIABLY MIGMATISED UNDIFFERENTIATED BIOTITE-HORNBLENDE-GNEISS	3	20
	CHANOCKITE META INTRUSIVE	1	
	UNDIFFERENTIATED OLDER GRANITE MAINLY GRANITIZED GNEISS	3	
	COARSE PORPHYRTIC BIOTITE & BIOTITE-HORNBLENDE	3	
	FINE-TO-MEDIUM GRAINED BIOTITE & BIOTITE-MUSCOVITE-GRANITE	3	
	MEDIUM-TO-COARSE GRAINED BIOTITE-GRANITE	3	
	QUARZITE VEIN	5	
SLOPE	VERY GENTLE	5	15
	GENTLE	4	
	MEDIUM	3	
	STEEP	2	
	VERY STEEP	1	
LANDUSE / LANDCOVER	OUTCROP	3	15
	WETLAND/WATERBODY	1	
	BUILTUP	3	
	VEGETATION	5	

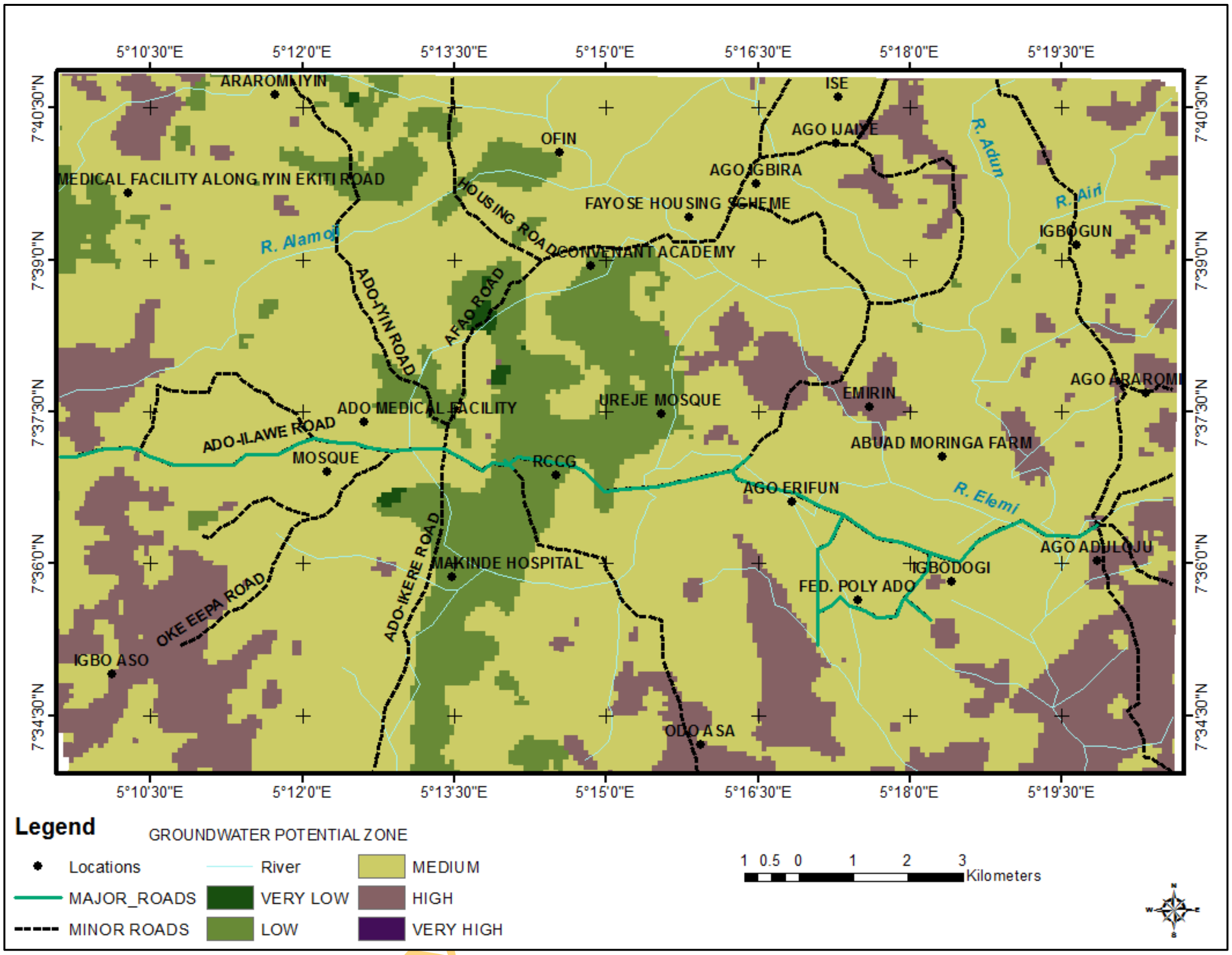


Figure 5.41: Groundwater Potential Map (Based on RS – GIS)

5.5.2 Groundwater Potential Evaluation (Based on VES - GIS)

The modelling involves delineation of groundwater potential zones based on Olayinka (2010) which incorporated aquifer potential as a function of the depth to bedrock, saprolite resistivity and the fractured bedrock resistivity.

ArcMap 10.2.2 was employed for re-classification and derivation of the thematic layers. With the weighting of Table 5.7, groundwater potential map was developed. Validation Procedure against the existing borehole yield data was applied giving a maximum % Correlation of 60. A model based on the weighting combination of Table 5.8 gave the highest % correlation of 66.7. Thematic layers of geology, weathered basement thickness and overburden coefficient of anisotropy were introduced and accorded weighting to generate the model. In particular, Geology received the highest ranking of 25%. The resulting groundwater potential map on the account of only geoelectic data is presented in (Figure 5.42). The map classifies the study area into very low, low, moderate and high goundwater potential zones.

Olorunfemi *et al.* (1999) acknowledged that the groundwater potential of a basement complex area is determined by a complex inter-relationship between the geology, post emplacement tectonic history, weathering processes and depth, nature of the weathered layer, groundwater flow pattern, recharge and discharge processes. The properties of the weathered aquifer especially its storage and discharge capacities based on its porosity and permeability and the underlying fractured basement column strongly influence the groundwater yield in the basement complex terrain. When the overlying layer is clayey with low layer resistivities (<100 ohm-m), the yield of the borehole is low.

Table 5.7: Classification of themes for delineation of groundwater potential zones (Olayinka, 2010).

Geoelectric Parameters	Classes	Scale Value	Rank
Bedrock Resistivity	<750	4	30
	750-1500	3	
	1500-3000	2	
	>3000	1	
Weathered Basement Resistivity	<20	1	40
	20-100	2	
	100-150	3	
	150-300	4	
	>300	1	
Overburden Thickness	<10	1	30
	10-20	2	
	20-30	3	
	>30	4	

Table 5.8: Classification of themes for delineation of groundwater potential zones (Modified after Olayinka, 2010)

Parameters	Classes	Scale Value	Rank
ANISOTROPY	1.0 -1.12	1	15
	1.12 -1.19	2	
	1.19 -1.30	2	
	1.30 -1.80	3	
	1.80 - 3.00	2	
OVERBURDEN THICKNESS	<10	1	20
	10-20	2	
	20-30	3	
	>30	4	
WEATHERED BASEMENT RESISTIVITY	<20	3	30
	20-100	5	
	100-150	4	
	150-300	2	
	>300	1	
BEDROCK RESISTIVITY	<750	4	20
	750-1500	3	
	1500-3000	2	
	>3000	1	
WEATHERED BASEMENT THICKNESS	<10	1	15
	10-20	2	
	20-40	3	
	>40	4	

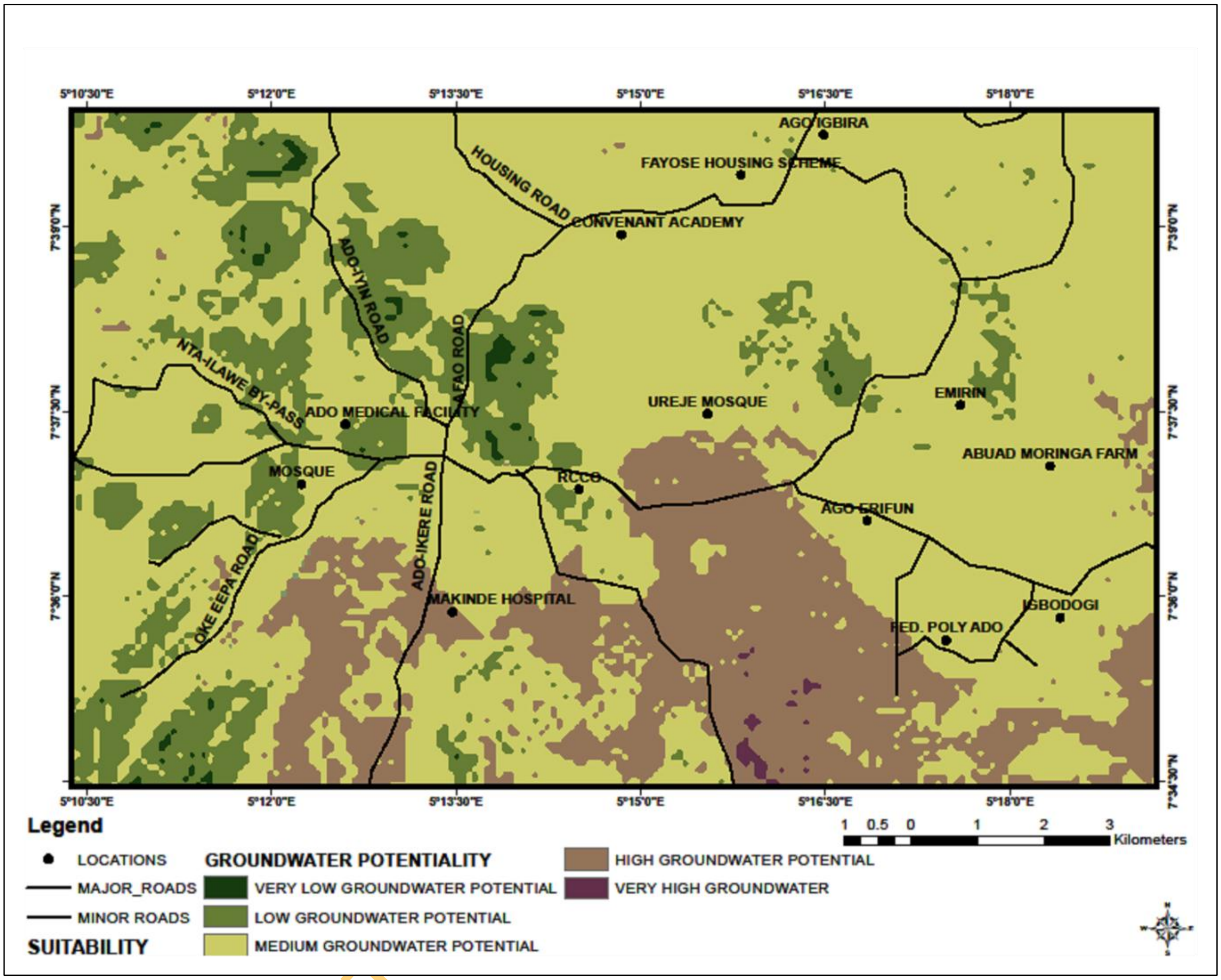


Figure 5.42: Groundwater Potential Map (Based on VES - GIS)

5.5.3 GIS Modelling For Integration of Remotely Sensed Data and Geoelectric Data Sets

The preceding sections offered groundwater potential zonation based on exclusive application of remote sensing and geophysical methods. The deficiencies of these independent approaches become apparent particularly on regional consideration of groundwater targeting and management. The thematic layers derived from remote sensing and geoeletric investigations were thus subjected to integration in a GIS environment. Attempts were made using the outline of Ojo *et al*. (2015) which incorporated Lineament, Geology, Geomorphology, Slope, Aquifer thickness and Anisotropy and Bayowa *et al.* (2014) which harmonized hydrogeomorphology, Lineament density, Lineament Intersection density and coefficient of anisotropy. The resulting Groundwater potential possibility maps were checked for reliability. Improvement was recorded with the weighting combination in Table 5.9 which produced the groundwater potential map (Figure 5.43) with the maximum % correlation of 73.3. The groundwater potential map obtained by integration of remotely sensed data and geoeletrical data demarcates the study area into very low, low, medium and high groundwater potential zones covering areal extent of 61.4 km^2, 118.9 km^2, 38.2 km^2, and 16.8 km^2 respectively (Table 5.10).

The marked improvement recorded in % correlation affirms the usefulness of the integrated approach involving remotely sensed data and geoelectric data in groundwater potential evaluation. The limitations of geoelectric investigation such as limited accessibility, spatial extent thereby limiting number of feasible sounding points and relative cost are met by the application of remote sensing. It is apparent that groundwater potential evaluation is a thorough mix of the multiple groundwater accumulation attributes. Optimal Results cannot be achieved based on any single index of groundwater potential.

Table 5.9: Classification of various themes for delineation of groundwater potential zones (Integrated Approach)

Parameters	Classes	Scale Value	Rank
Bedrock Resistivity	<750 750-1500 1500-3000 >3000	4 3 2 1	15
Weathered Basement Resistivity	<20 20-100 100-150 150-300 >300	1 2 3 4 1	20
Overburden Thickness	<10 10-20 20-30 >30	1 2 3 4	10
Lineament Density	Very low low medium high very high	1 2 3 4 5	15
Geology	Migmatised Biotite Hornblende Gneiss Chanockite Granized Gneiss with Migmatite Porphyrtic Granite Biotite Muscovite Granite Biotite Granite Quarzite	3 1 3 2 2 2 4	20
Geomorphology	Hill and Ridges Pediment Pediplain Alluvium Valley Fill	1 2 3 4 5	10
Anisotropy	<1.12 1.12-1.19 1.19-1.3 1.3-2.0	1 2 3 4	10

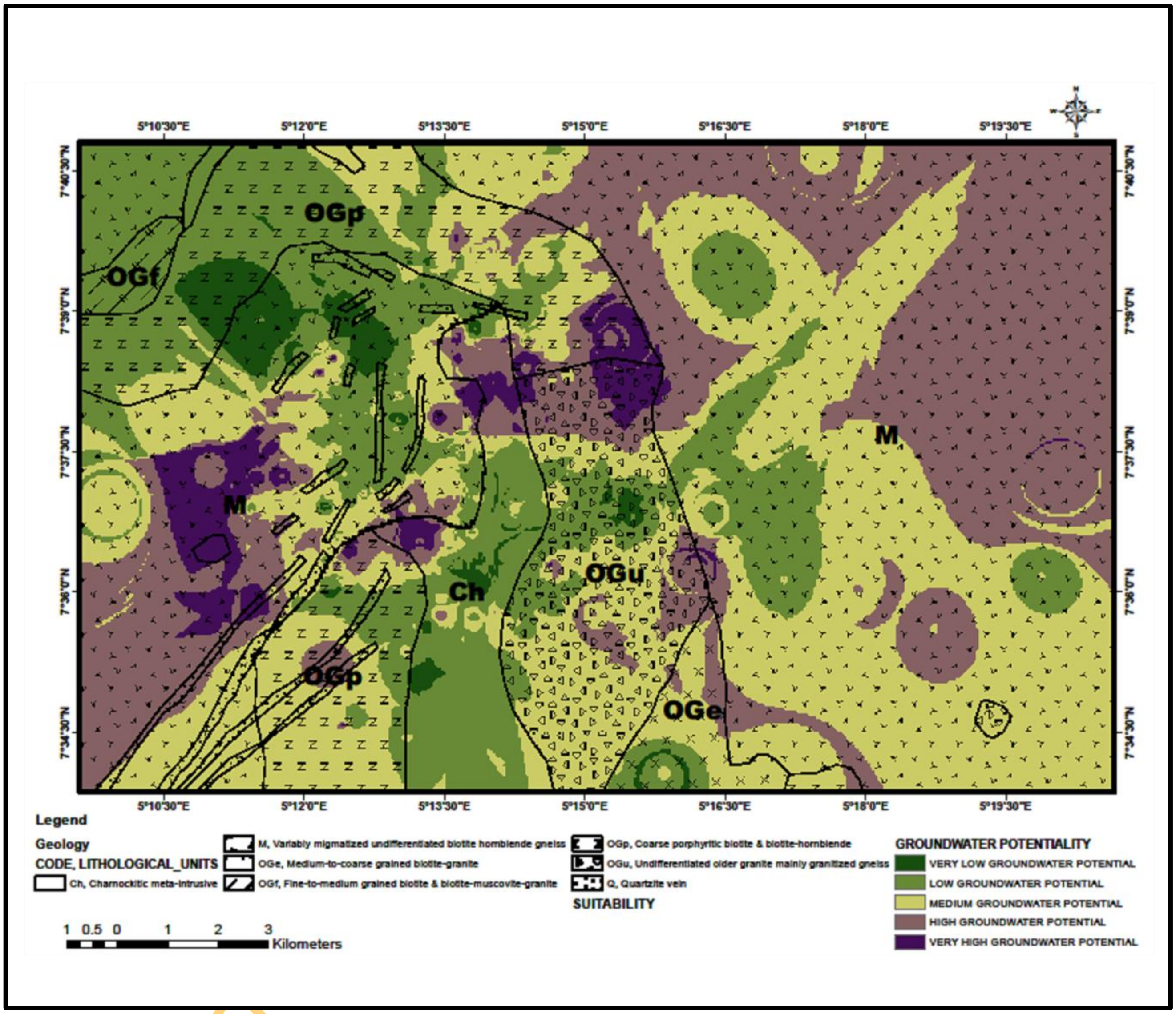


Figure 5.43: Groundwater Potential Map of Ado-Ekiti

Table 5.10: Classification of Groundwater Potential Zones

Groundwater Potential Zone (GWP)	Area in Km^2
Very Low GWP	61.4
Low GWP	118.9
Medium GWP	38.2
High GWP	16.8

5.6 Evaluation Of Groundwater Quality

Malomo *et al*. **(**1990**)**, Taiwo *et al*. (2010) and Tijani *et al*. (2014) stressed the need for the evaluation of groundwater quality in a given study area as the majority of the population derive their potable water from the shallow aquifers since pipe-born water supply facilities are usually inadequate. The shallow aquifers are potentially vulnerable to pollution from agricultural (fertilizers), domestic (waste dumps, latrines) and industrial sources, except where surface layers are of poor permeability and afford some protection of the underlying aquifers.

All the sampled wells have their values for colour lying within the WHO recommended belt except for the well samples W019 and W035 with the value of 60. Colour in water is attributable to materials in solution. It may be indicative of dissolved organic material. Inorganic contaminants, such as metals, are also common causes of colour. Affected wells can be treated by coagulation, activated carbon and chlorination

Turbidity is a measure of suspended minerals, bacteria, plankton, and dissolved organic and inorganic substances. Such materials may also include dust particles and colloidal organic matter. The very high value of turbidity in a couple of wells might be due to high sediment discharge from run - off as suggested by corresponding high colour values.

Other possible causes of the turbidity may also include improperly installed casing, cracked casing, or missing well cap. Toxic contaminants can cling to suspended particles, which in turn may be ingested by humans and cause health problems. Treatment includes mixing with a substance such as alum that causes coagulation of the suspended materials followed by sand filter filtration (Gbadebo *et al.,* 2010 and Ayodele, 2012).

Total dissolved solids (TDS) give a direct measurement of the interaction between ground water and subsurface minerals. High TDS, greater than 1000 mg/L, is commonly objectionable or offensive to taste. TDS levels over 2000 mg/L are generally considered undrinkable due to strongly offensive taste. A higher concentration of TDS usually serves as no health threat to humans until the values exceed 10,000 mg/L. At this level the water is considered brine and defined as undrinkable. A high TDS (levels above 1,000 mg/L) may cause corrosion of pipes/ plumbing systems and appliances. To remove TDS to acceptable levels, a water softener with a reverse osmosis (R/O) system is usually effective.

The conductivity of a solution depends on the quantity of dissolved salts present. It relates closely to the total dissolved solids (mineral) content of water. High values of Electrical conductivities imply high salinity. Treatment with reverse osmosis is effective for drinking water purposes (Ayodele, 2012 and Ishaku *et al.*, 2015).

Temperature is basically important for the chemical and biological reactions of organisms in water. The increase in temperature decreases the potability of water because at elevated temperature carbon dioxide and other volatile gases, which impart taste, are expelled (Karunakaran *et al.*, 2009)

Most of the sampled wells are within the WHO/SON limit for pH values. A few wells are observed to be slightly acidic. pH is a measure of the hydrogen ion concentration in water. It indicates level acidity or alkalinity (Venkateswarlu *et al.*, 2014).

Drinking water with a pH between 6.5 and 8.5 generally is considered satisfactory. Waters with a pH above 8.5 may have a bitter or soda-like taste. A low pH is acidic ($pH < 7$). The primary cause of a low pH is the addition of acidic rain water. Other ions found in groundwater such as nitrates and sulphates may result in lower pH. The negative effects of acidic water are many. Highly acidic water may result in pipe corrosion, causing the possible release of iron, lead, or copper into the tap water. A low pH may discolour the water and give it a bitter taste. Treatment could be achieved by using a neutralizer filter.

Total Hardness, made up of temporary hardness and permanent hardness, is due to the presence of certain salts, such as carbonates, bi-carbonates, chlorides and sulphates, of calcium and magnesium dissolved in it. While temporary hardness could be removed by boiling water and by adding lime to water permanent hardness requires special methods of water softening. Excessive hardness is objectionable as a great deal of soap is required for washing. Formation of scales in boilers/heating systems, corrosion and incrustation of pipelines and plumbing fissures are also promoted (Rao and Jugran, 2003 and Ifabiyi, 2008).

High concentrations of chloride ions can cause water to have an objectionable salty taste and corrode hot-water plumbing systems. High-chloride waters have a laxative effect for some people. An upper limit of 250 mg/l has been set for chloride ions. An increase in the normal chloride content of water may indicate possible pollution from human sewage, animal manure or industrial wastes. Treatment includes reverse osmosis

Natural nitrate levels in groundwater are generally very low (typically less than 10 mg/l NO_3)but nitrate concentrations grow due to human activities, such as agriculture, industry, domestic effluents and emissions from combustion engines. Possible sewage pollution may be a factor responsible for high nitrate contents where it occurs (SON, 2007)

Bicarbonate and carbonate cause alkalinity of groundwater. In Carbonate and Bi-carbonate Alkalinity considerations, nearly all the well samples have low values. The bi-carbonate alkalinity values are however noticeably high in a few well samples. Bicarbonate and carbonate cause alkalinity of ground water. Most of the well waters are potable since the concentrations of ions in majority of the samples are below the maximum permissible level indicated in the World Health Organization (WHO) and SON standards.

Simple treatment involving the addition of chlorine, alum and perhaps boiling and filtration should be encouraged among the residents as harmful bacterial could be removed by boiling and/or by adding water-treating chemicals. Shitta and Oyedele (2007) has encouraged the use of water filters, which are quite affordable. Indiscriminate siting of refuse dumps and other waste disposal facilities should be discouraged in the area to avoid the unpleasant consequences of polluting the near surface/shallow hand – dug wells.

5.7 Hydro-geochemical Contour Maps

The results of the Physico-Chemical Analysis of the water samples from the wells are presented in the form of hydro-geochemical Contour Maps to demonstrate the regional dispersion of the dissolved ions (Figures 5.44 - 5.49)

Almost all the hydro-geochemical maps of the measured parameters show fairly similar patterns. The peripheral parts of the study area have low values and the contours are widely spaced. Contour spacings irregularly decrease towards the centre of the metropolis. The irregular spacings indicate uneven distribution of ions probably due to uneven rate of water movement within the aquifer. This is a consequence of differential soil permeability from one point to another which is characteristic of aquifers in the basement complex (Malomo *et al.*, 1990).

The contours cut across geological boundaries indicating the reduced influence of geology in determining the water chemistry. The contours seem to follow the demography of the area. High values are found in the densely populated parts of the study area while low values are found in the outskirt and sparsely populated parts (Ifabiyi, 2008).

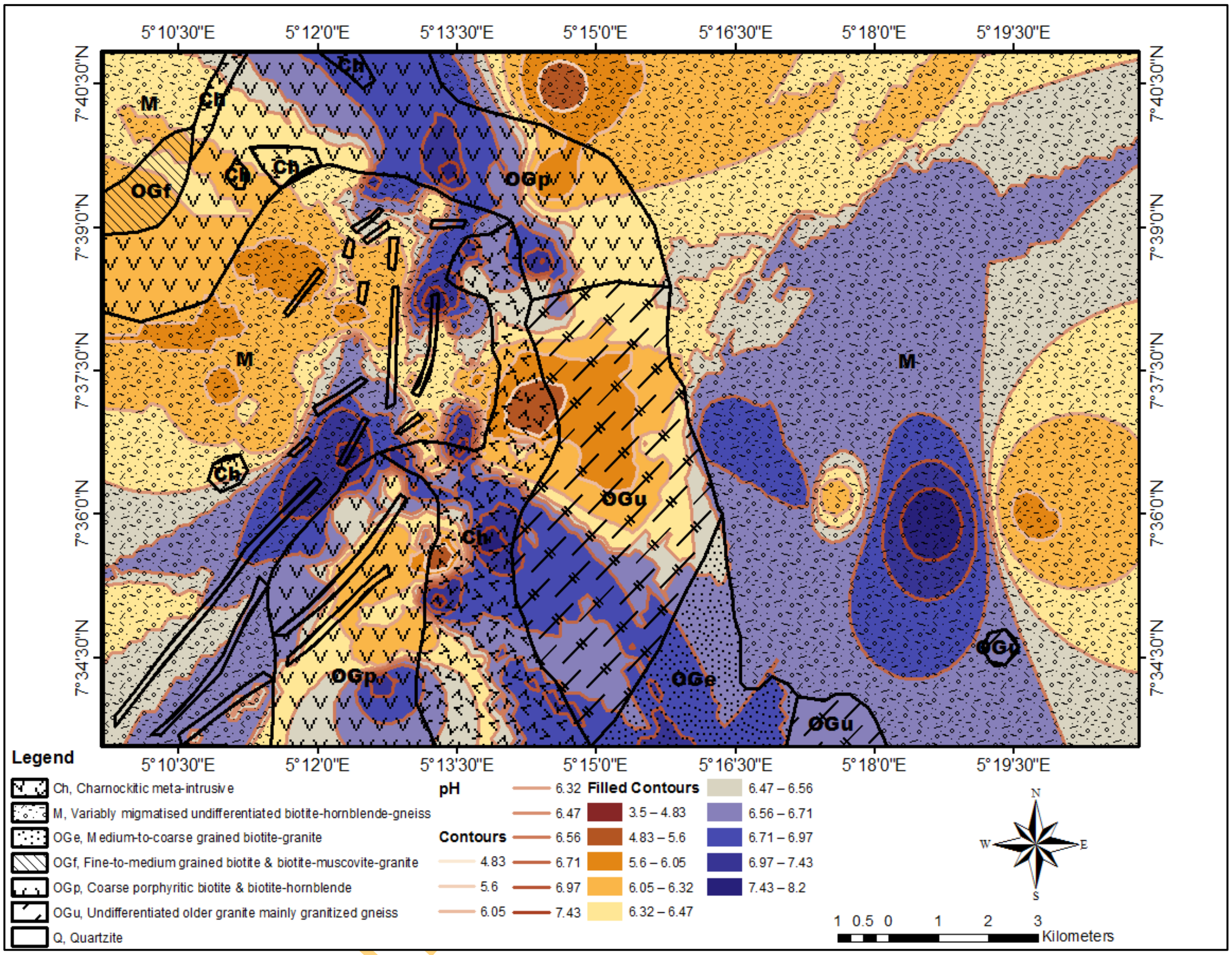


Figure 5.44: pH map

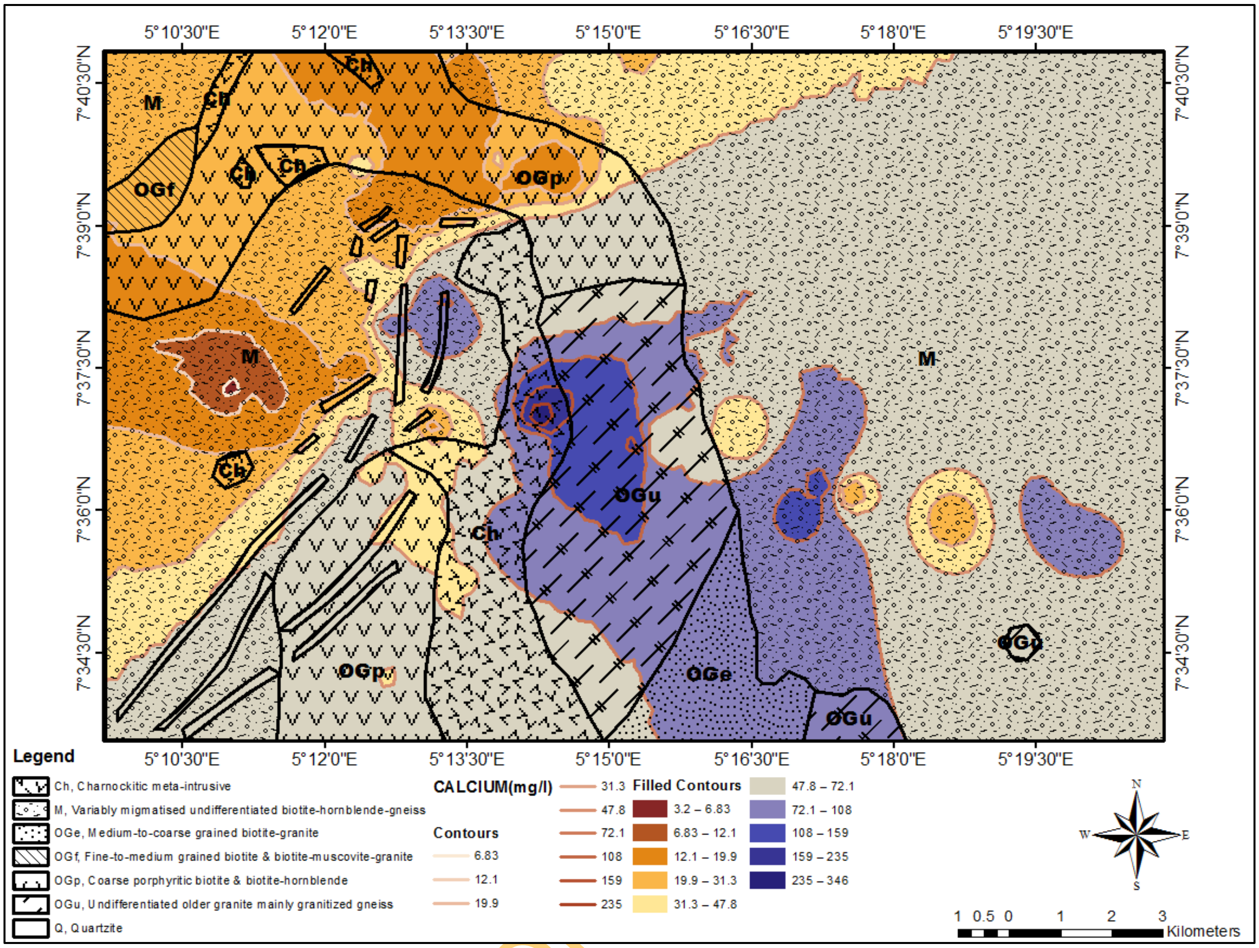


Figure 5.45: Calcium map

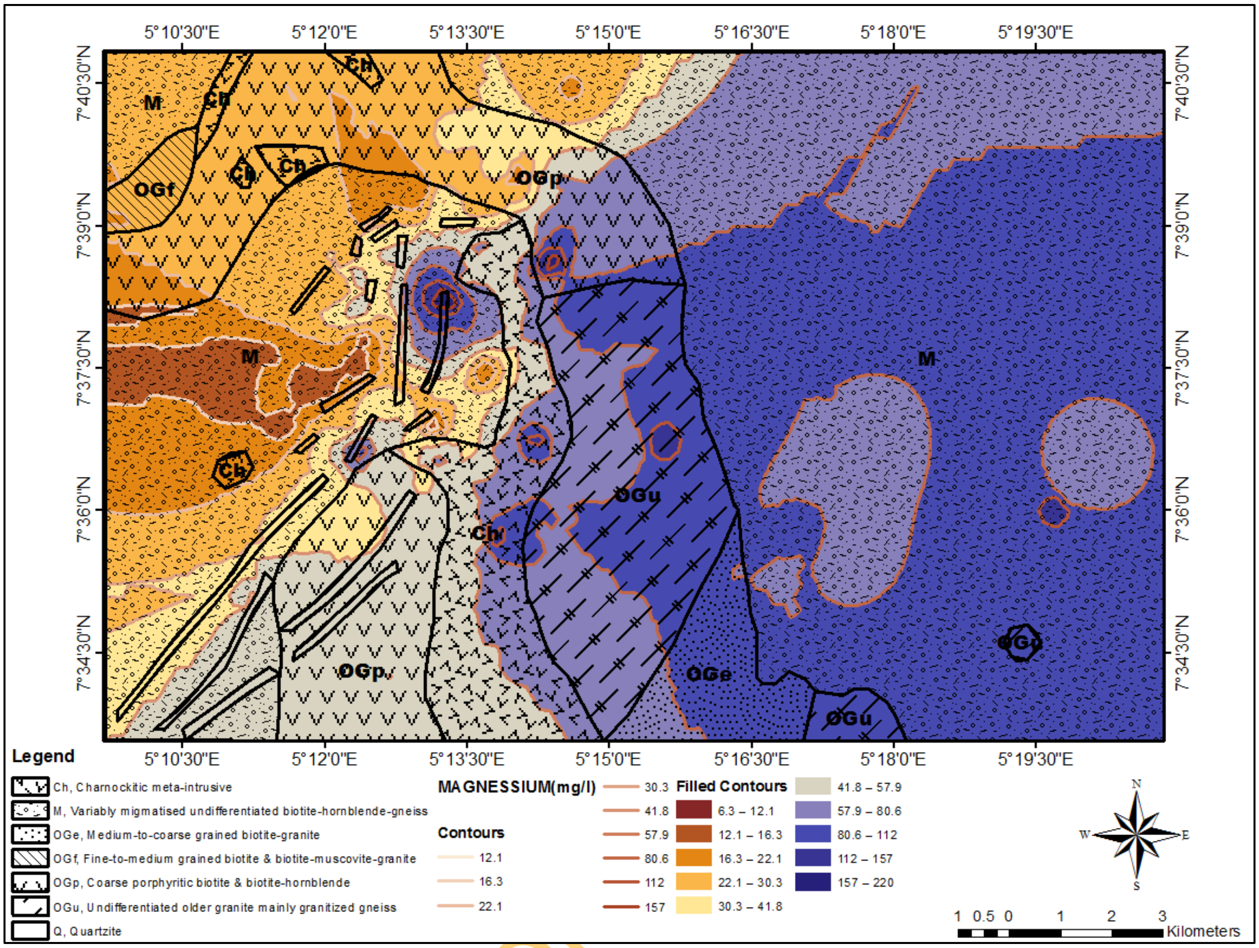


Figure 5.46: Magnesium map

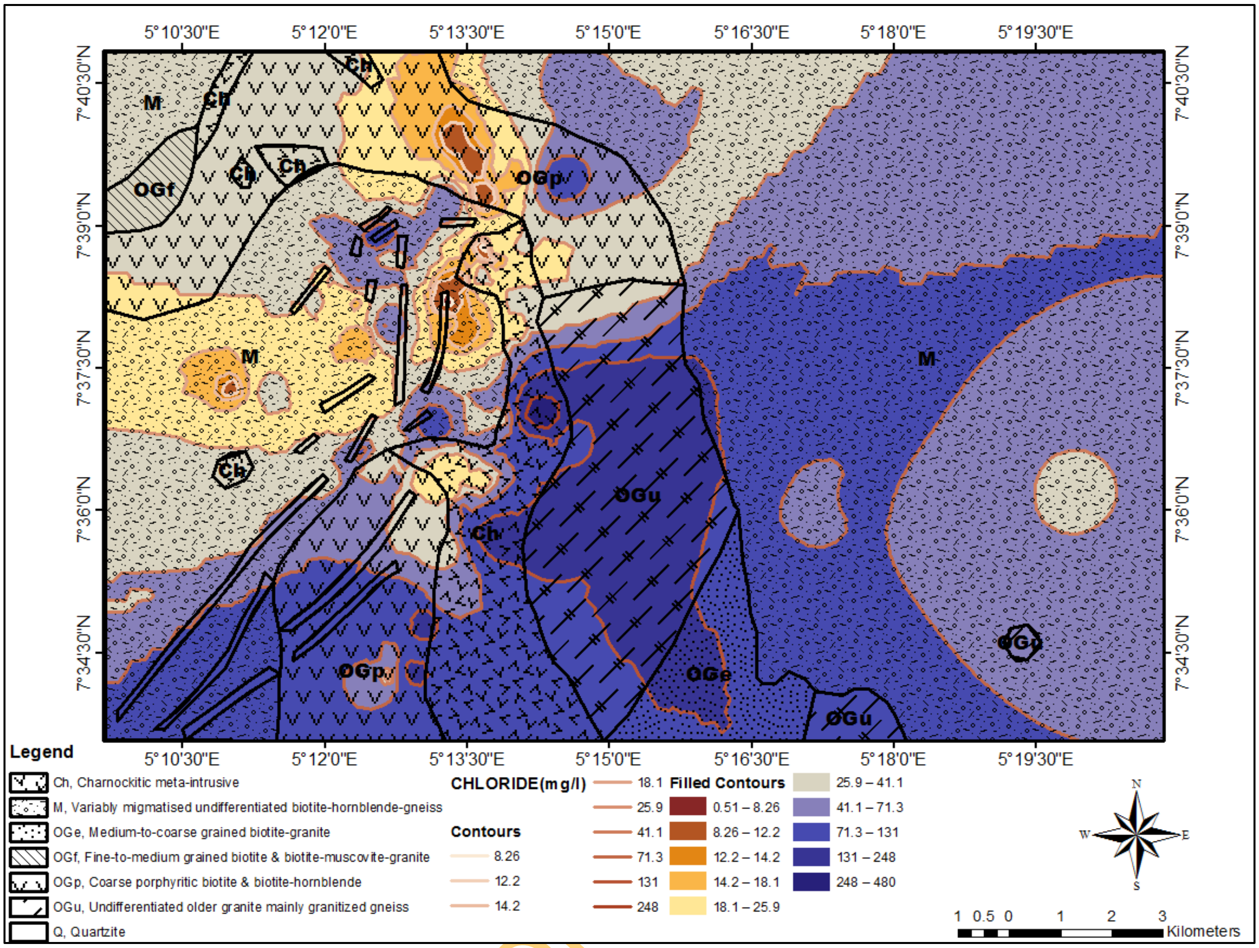


Figure 5.47: Chloride map

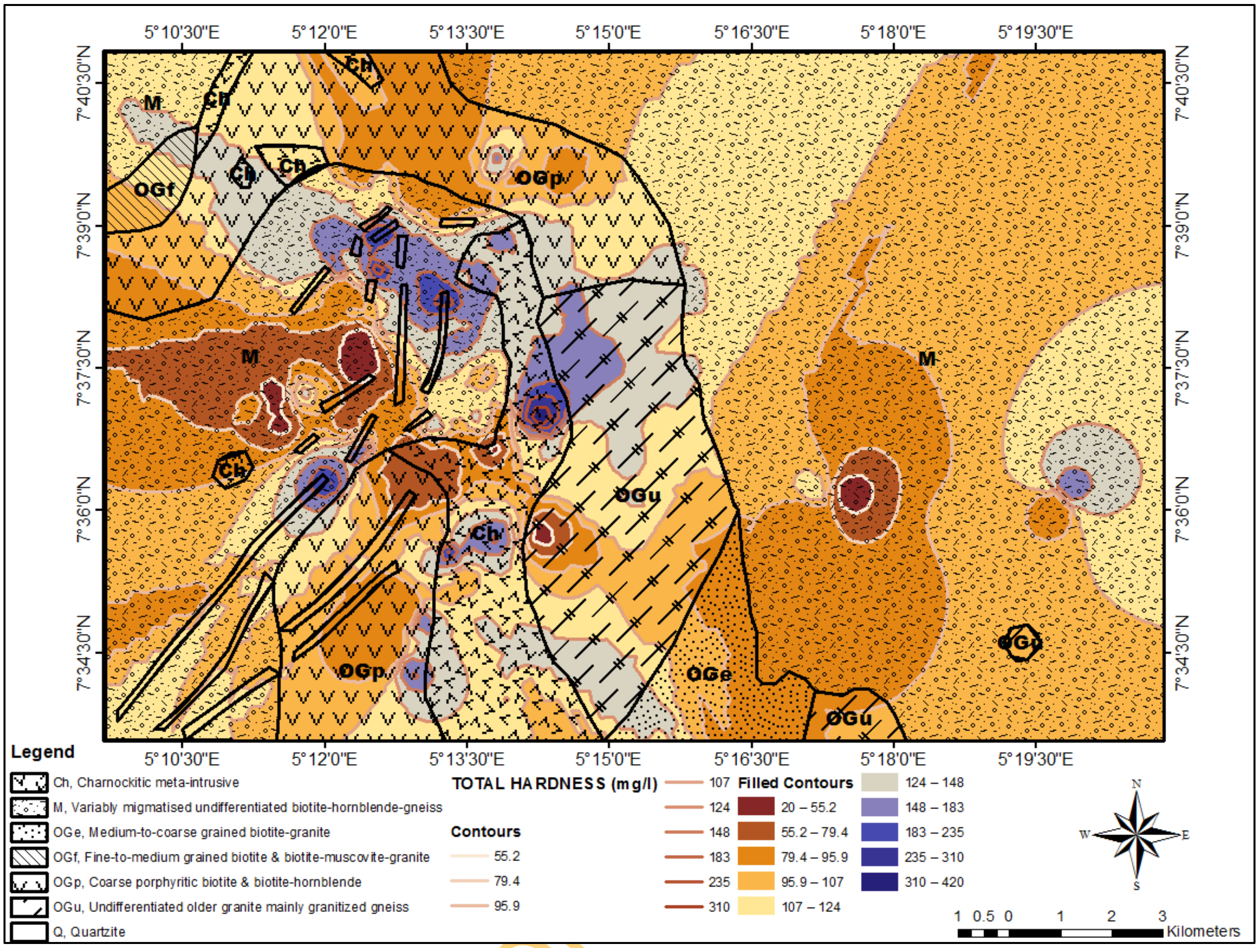


Figure 5.48: Total hardness map

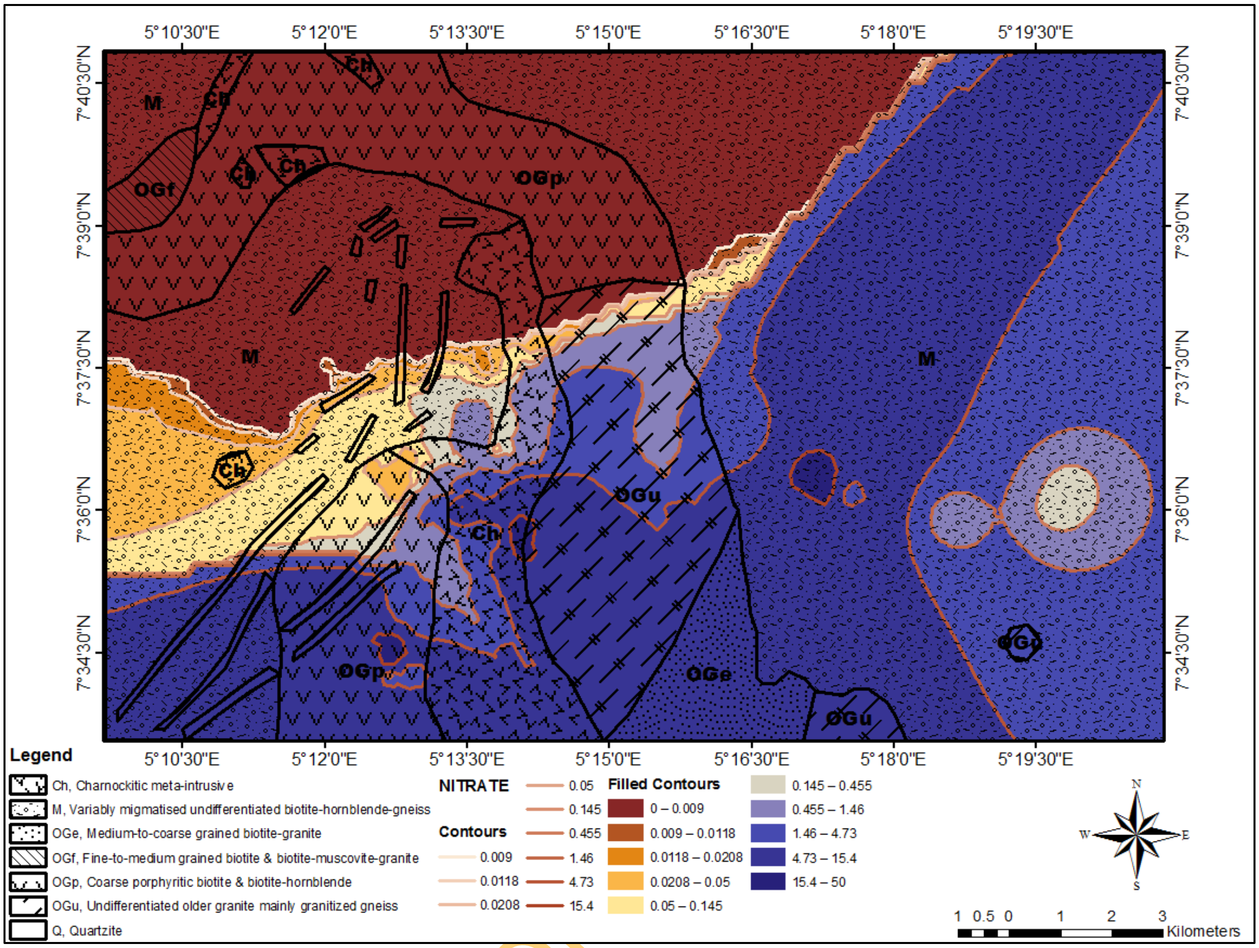


Figure 5.49: Nitrate Map

5.8 The Groundwater Quality Map

The groundwater quality map (Figure 5.50) of the study area was produced by integrating thematic layers of Nitrate, pH, Total Hardness, TDS, Chloride and Calcium using the weighting of Table 5.11. The map revealed that the potable groundwater in the study area covered an areal extent of 248.87 km^2. Non-potable groundwater is observed over an area of 9.73 km^2 occurring at portions along the northwestern, southwestern, southeastern flanks and the central region.

Spatial analysis of the landuse/landcover and its associated impacts on groundwater quality is essential for a proper understanding of the present environmental challenges and a projection into the future. Hence, the groundwater quality map was subsequently overlayed on the built-up layer of the Landuse/Landcover map as shown in Figure 5.51. Non-potable groundwater is observed at the built-up areas. Regions adjacent to streams and rivers commonly have records of non-potable groundwater. These observations are consistent with the processes of urbanization, industrialization and fast population growth in Ado-Ekiti. It is observed that houses have been built very close to the banks of the rivers and streams. Such streams are used for disposal of domestic, industrial and urban wastes. The natural attenuation effects of the streams might have been over- stretched. Consequently the groundwater quality might be compromised (Tinuola and Owolabi, 2007, Ige and Adetunji, 2014 and Venkateswarlu *et al*., 2014).

Table 5.11: Classification of Themes for Groundwater Quality for Domestic Purposes

Parameters	Classes	Scale value	Rank
pH	<7 Acidic 7 Neutral >7 Alkaline	1 3 1	20
Calcium	<75mg/l most desirable 75mg/l-200mg/l maximum allowable >200mg/l	3 2 1	15
Chloride	<250mg/l most desired limit >250mg/l maximum allowable limit	3 1	15
Total Hardness	<75mg/l soft 75mg/l-150mg/l moderately hard 150mg/l-300mg/l hard >300mg/l very hard	4 3 2 1	15
Total Dissolved Solid	<300mg/l Excellent 300mg/l-377mg/l Good	3 1	10
Nitrate	<45mg/l >45mg/l	3 1	25

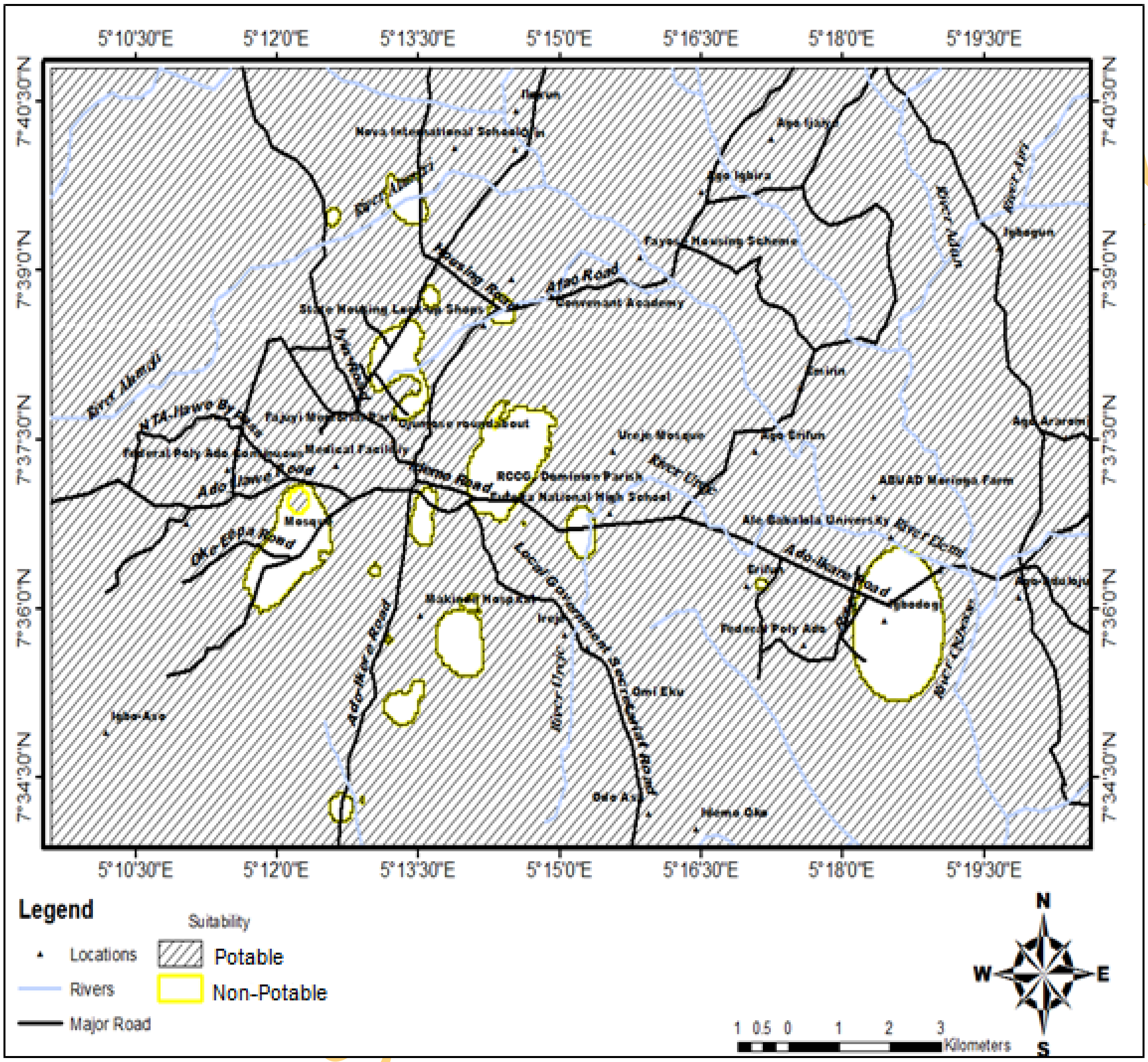


Figure 5.50: Groundwater Quality Map

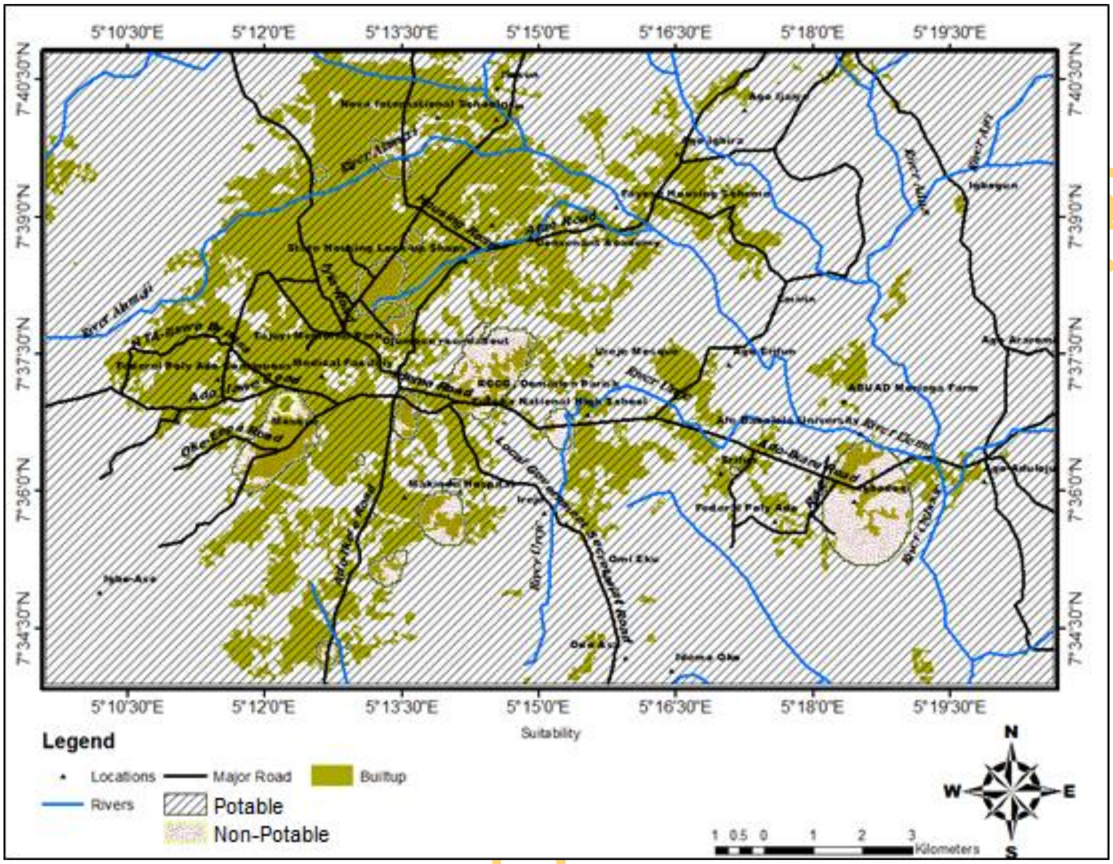


Figure 5.51: Groundwater Quality Map on Built-up Areas

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Use of integrated methods (involving Hydrogeophysics, Remote Sensing and Physicochemistry) for delineating groundwater resource in Ado-Ekiti, Southwestern Nigeria has been carried out in a GIS environment. The integration of various data sets in the study has greatly assisted in evaluating the groundwater prospects, potability and groundwater protection in the study area.

The structural lineaments mapped were analysed to give the lineament, lineament density, lineament intersection, lineament intersection density. The lineaments show predominantly NNW-SSE, ENE-WSW and NNE-SSW orientations and subsidiary NW-SE and W-E trends.

Areas within the hydrogeomorphological units of valley fills, the pediplain with alluvium, pediplains, pediment and hills and ridges are classified as having tendency for very high, high, moderate, low and very low groundwater prospect respectively.

Topographic slopes within the study area were classified as nearly level, very gentle, gentle, moderate, strong, moderately steep to steep, and very steep with the slope / surface gradients varying from 0 - 49^0. The runoff, recharge and movement of surface water are influenced by the slope.

Landuse/landcover classes in the study area are vegetation, water body, built-up, and outcrops. Built-up land (dense, medium and sparse residential areas) comprises of 68.6 km^2 of the total study area. Coverage of 52.4 km^2, 13.5 km^2 and 2.7 km^2 is recorded for dense, medium and sparse residential areas respectively. The light vegetation/bare soil has an area extent of 110.9 km^2 with the outcrops located in the northwestern and southwestern parts covering a total area of 14.9 km^2.

The geoelectrical identification of the subsurface lithology in relation to basement aquifer occurrence indicated that the area under study has both weathered layer aquifers and fractured layer aquifers occurring in distinguishable combinations. The distinct combinations of these two major aquiferous zones include weathered aquifer, weathered/fractured (unconfined) aquifer, weathered/fractured (confined) aquifer, weathered/fractured (unconfined) / fracture (confined) aquifer and fractured (confined) aquifer.

The isopach map of overburden discriminated between zones of thick and thin overburden. The zones of thick overburden were delineated as basement depressions. These are diagnostic of troughs which are groundwater collecting centres or groundwater convergent zones. They occur mainly in the western, southwestern and central parts of the area. Zones with relatively thin overburden indicating ridges were also delineated. Such zones are diagnostic of crests or basement highs. They are thus groundwater radiating zones or groundwater divergent zones. Basement highs/ridges are seen along northern/central/south central portions and northwestern/northeastern/southeastern flanks.

The weathered basement layer is seen to be thickest around the southern/south western portions with isolated portions along the western/north western portions of the study area. These regions offer strong appeal for groundwater development. In particular, average weathered basement layer thickness of about 35.00 m recorded at some VES points demarcates those zones of the study area as promising aquifers.

The basement rocks were observed to be variably fractured. The highest groundwater yield is to be found in area where thick, weathered layer overburden (saprolite zone) with relatively low resistivity overlies the fractured basement. These zones were delineated in the study area.

The bedrock relief map delineated series of ridges and depressions within the study area. The isopach map of the overburden showed relatively high overburden thicknesses (of up to 56.2 m) within the depressions. The bedrock depressions being the groundwater collecting centres are priority areas for groundwater development.

On a regional consideration, 23.31%, 18.80% and 57.9% of the study area is characterized by overburden materials of poor, weak and moderate protective capacity, respectively. Only 6.02% of the area indicates good overburden protective capacity.

The hydrostatic maps enabled the delineation of the major groundwater recharge / discharge zones, the groundwater flow direction and the groundwater divides with the regional tendency of the underground flow approximately lying along the northwest – southeast direction and groundwater divides along the south – eastern/ south – western axes of the central portion. Within this regional tendency approximately along the northwest – southeast direction are local variations. Local variations to the regional flow are observed along the south – eastern/ south – western axes of the central portion. The variations are traceable to directional changes of groundwater flow, associated with the occurrence of a superficial clay layer or local geology.

Application of RS – GIS produced an ultimate groundwater potential map which gave the highest % correlation of 56.7 while the groundwater potential evaluation using geoelectric data and GIS yielded a groundwater potential map whose validation against the existing borehole yield data gave a maximum % Correlation of 60. Integration of the thematic layers derived from remote sensing and geoelectric investigations involving bedrock resistivity, weathered basement resistivity, overburden thickness, lineament density, geology, geomorphology and anisotropy in the GIS environment gave a groundwater potential map with a marked improvement of 73.3% correlation with borehole yield data.

This improvement affirms the effectiveness of the integrated approach involving remotely sensed data and geoelectric data in groundwater potential evaluation. The limitations of geoelectric investigation such as limited accessibility, spatial extent thereby limiting number of feasible sounding points and relative cost are met by the application of remote sensing.

The deficiencies of exclusive application of remote sensing or geophysical methods for groundwater potential zonation become apparent particularly on regional consideration of groundwater targeting and management. The data sets offer improved information with ardent reliability when duly integrated in a GIS platform with appropriate factor. Cost effectiveness without sacrifice to details and reliability can be achieved if this integrated approach is adopted.

The spatial analysis and interpretations of the groundwater quality of the study area further demonstrates that the applied GIS methodology is a powerful tool in evaluation and mapping of the groundwater characteristics. The overlay of groundwater quality map on the built-up layer of the landuse/landcover map revealed non-potable groundwater at the built-up areas and regions adjacent to streams and rivers. Human activity imprints were observed on the hydro-geochemistry of the study area. Densely populated regions have groundwater with high concentration of dissolved ions while the areas of low population exhibit low concentration of dissolved ions.

The study has led to the delineation of areas where groundwater occurrences are most promising for sustainable supply. The study area has been demarcated into very low, low, medium and high groundwater potential zones covering areal extent of 61.4 km^2, 118.9 km^2, 38.2 km^2, and 16.8 km^2, respectively.

This study has demonstrated GIS as an effective tool for storing large volumes of data that can be correlated spatially and retrieved for the IDW spatial model, able to take temporal changes into account and to provide the final, more reliable, and current version of outputs.

The comprehensive use of hydrogeophysics, remote sensing and physichochemistry in a GIS environment resulted in the development of an efficient and effective methodology of spatial data management and manipulation with a holistic data base on groundwater occurrence and quality.

The integration and analyses of various thematic maps and image data proved efficient and effective for the delineation of zones of groundwater potential and zones of groundwater quality suitable for domestic purposes. This will facilitate quick decision-making for sustainable groundwater development and management.

6.2 Recommendations

Additional hydro-geophysical investigation data points covering additional localities, VES and borehole yield data are recommended to improve the data density. This will further improve the resolutions. Individual site selection for groundwater development should take into consideration other site-specific ground-truthing methods particularly geophysical exploration methods as the heterogeneous and discontinuous nature of basement aquifers makes local variation possible.

Comparison of results could be made using Radar and Landsat imageries for lineament mapping. This should take cognizance of the issue of differential resolution and energy sources.

REFERENCES

Aboh, H. O. and Osazuwa, I. B. 2000. Lithological deductions from Regional Geoelectric Investigation in Kaduna, Kaduna State Nigeria. *Nigerian Journal of Physics* 12: 1 - 7

Adefemi, O. S., Asaolu, S. S and Olaofe, O. 2007. Assessment of Physico-Chemical Status of Water Samples from Major Dams in Ekiti State, Nigeria. *Parkistan Journal of Nutrition*, 6(6):657-659.

Adelusi, A.O., Adiat, K.A.N. and Amigun, J.O. 2009. Integration of Surface Electrical Prospecting Methods for Fracture detection in Precambrian Basement rocks of Iwaraja area southwestern Nigeria. *Ozean Journal of Applied Sciences*, 2(3): 265-280.

Adelusi, A.O., Ayuk, M.A. and Oyedele, A.A. 2004. Hydrogeophysical Analysis of Owode Area around Oba-Ile near Akure, SW Nigeria. *African Journal of Development Studies* 4(1&2):11–14.

Ademilua, L.O. and Olorunfemi, M.O. 2000. A Geoelectric/Geologic Estimation of the Groundwater Potential of the Basement Complex area of Ekiti and Ondo States of Nigeria. *The Journal of Technoscience* 4: 4-18.

Ademola, A and Afeikhena, J. 2006. Utility privatization and the poor: Nigeria in focus. *HBS Global Issues* 12

Adeniji, A. E., Omonona, O. V., Obiora, D. N and Chukudebelu, J. U. 2014. Evaluation of soil corrosivity and aquifer protective capacity using geo-electrical investigation in Bwari basement area; Abuja. *Journal of Earth Systems and Science*, 123(3): 491–502.

Adesida, A., Faleye, E.T and Fatoba, J. 2002. Electrical Resistivity Survey for Corrosive Soils at WAPCO, Ewekoro Factory, Ogun State, Nigeria. *Journal of Science and Technology research*, 1(1): 22-32.

Adeyeye, E.I and Abulude, E.O. 2004. Analytical Assessment of some surface and groundwater resources in Ile–Ife, Nigeria. *Journal of Chemical Society of Nigeria*, 98-103.

Adiat, K. A. N, Olayanju, G. M., Omosuyi G.O and Ako B.D. 2009. Electromagnetic Profiling and Electrical Resistivity Soundings in Groundwater Investigation of a Typical Basement Complex – A Case Study of Oda Town Southwestern Nigeria. *Ozean Journal of Applied Sciences*, 2(4): 333-359.

Afolayan, J.F., Olorunfemi, M.O. and Afolabi, O. 2004. Geoelectric/Electromagnetic VLF Survey for Groundwater in a Basement Terrain: A Case Study. *Ife Journal of Science*, 6(1):74-78.

Agunloye, O. 1984. Soil aggressivity along steel pipeline route at Ajaokuta, southwestern Nigeria. *J. Mining Geol.* 21: 97–101.

Ajayi, O and Adegoke-Anthony, C.W. 1988. Groundwater prospects in the basement complex rocks of Southwestern Nigeria. *Journal of African Earth Sciences*, 7(1): 227-235.

Akintorinwa, O. J and Abiola, O. 2011. Sub-soil evaluation for pre-foundation study using geophysical and geotechnical approach, *J. Emerging Trends Eng. Appl. Sci*. 2(5): 858–863.

Ako, B. D. 1996. *Applied Geophysics*. Obafemi Awolowo University Press Limited, Ile-Ife, Nigeria

Al Saud, M., 2010. Mapping potential areas for groundwater storage in Wadi Aurnah basin, western Arabian Peninsula, using remote sensing and geographic information system techniques. *Hydrogeology Journal*, 18 (6):1–15

Amadi, A.N and Olasehinde, P.I. 2010. Application of remote sensing techniques in hydrogeological mapping of parts of Bosso Area, Minna, North-Central Nigeria. *International Journal of Physical Sciences*, 5(9): 1465–1474.

Ariyo, S.O. and Adeyemi, G.O. 2009. Role of Electrical Resistivity Method for Groundwater Exploration in Hard Rock Areas: A Case Study from Fidiwo/Ajebo Areas of Southwestern Nigeria. *The Pacific Journal of Science and Technology*, 10(1): 483 – 486.

Asiyanbola, R.A. 2014. Remote Sensing in Developing Country-Nigeria: An Exploration. *Journal of Geography and Geology*, 6(1): 110 -128

Ayodele, O.S. 2012. Groundwater Quality Appraisal of Some Hand-Dug Wells and Boreholes around Okemesi and Ikoro Area, Southwestern Nigeria. *Transnational Journal of Science and Technology*, 2(8):43-67

Badamasi, S., Sawa, B.A and Garba, M.L. 2016. Groundwater Potential Zones Mapping Using Remote Sensing and Geographic Information System Techniques (GIS) in Zaria, Kaduna State, Nigeria, *American Scientific Research Journal for Engineering, Technology and Sciences*, 24(1): 51-62.

Bagyaraj, M., Ramkumar, T., Venkatramanan, S., Gurugnanam, B. 2013. Application of remote sensing and GIS analysis for identifying groundwater potential zone in parts of Kodaikanal Taluk, South India. *Frontiers of Earth Science*, 7(1):65–75

Bala, A.E. and Ike, E.C. 2001. The Aquifer of the Crystalline Basement Rocks in Gusau Area, North-Western Nigeria. *Journal of Mining and Geology*, 37(2): 177 – 184.

Balakrishnan, P., Saleem, A and Mallikarjun, N.D. 2011. Groundwater quality mapping using geographic information system (GIS): A case study of Gulbarga City, Karnataka, India. *African Journal of Environmental Science and Technology*, 5(12):1069-1084

Bankole, B. O. 2010. The Geographical Distribution of Water Supply in Ekiti State. *African Research Review*, 4(2): 71-79

Bayowa, O.G, Olorunfemi, O.M, Akinluyi, O.F and Ademilua, O. L. 2014. A Further Comprehensive Approach to Assessing the Groundwater Potential of the Basement Complex Terrain of Ekiti State, Southwestern Nigeria, *International Journal of Scientific & Technology Research*, 3(7): 35-46

Beacon, S and Jones, C.R.C. 1988. The Combined EMT/VES Geophysical Method for Sitting Boreholes. *Groundwater*, 26: 56 - 63.

Braga, A.C.O., Filhow, W.M and Dourado, J.C. 2006. Resistivity (DC) Method Applied To Aquifer Protection Studies. *Brazilian Journal of Geophysics*, 24(4): 573-581.

Buddermeier, R.W and Schloss, J.A. 2000. Groundwater Storage and Flow. Retrieved Feb. 15, 2012, from http://www.kgs. Ukans.edu/Hight plains/atlas//apgengw.htm

Carruthers, R.M. and Smith, I.F. 1992. The use of Ground Electrical Survey Methods for Sitting Water Supply Boreholes in Shallow Crystalline Basement Terrains, In Wright, E. R. and Burgess, W.G. (Eds.), The Hydrogeology of Crystalline Basement Aquifers in Africa, 203 – 220.

Chowdhury, A., Jha, M.K., Chowdhury ,V.M and Mal, B.C. 2009. Integrated remote sensing and GIS-based approach for assessing groundwater potential in West Medinipur district, West Bengal, India. *International Journal of Remote Sensing*, 30:231–250

Chowdhury, A., Jha, M.K, Chowdary, V.M. 2010. Delineation of groundwater recharge zones and identification of artificial recharge sites in West Medinipur district, West Bengal, using RS, GIS and MCDM techniques. *Environmental Earth Science*, 5:1209–1222

Chuma, C, Orimoogunje, O.O.I, Hlatywayo, D.J and Akinyede, J.O. 2013. Application of Remote Sensing and Geographical Information Systems in Determining the Groundwater Potential in the Crystalline Basement of Bulawayo Metropolitan Area, Zimbabwe. *Advances in Remote Sensing*, 2, 149-161

Clark, L. 1985. Groundwater Abstraction from Basement Complex Areas of Africa. *Journal of Engineering Geology*, 18: 25 - 34.

Dai, F.C., Lee, C.F. and Zhang, X.H. 2001. GIS-based geo-environmental evaluation for urban land-use planning: a case study, *Engineering geology*, 61(4): 257-271.

Dewashish K. S. N., Rai, S. T and Kumari, Y. R. 2014. Evaluation of heterogeneous aquifers in hard rocks from resistivity sounding data in parts of Kalmeshwar Taluk of Nagpur District, India, *Current Science*, 107(7): 1137 – 1145

Ebisemiju, F.S. 1993. *Ado-Ekiti Region* - A Geographical Analysis and Master Plan. *Alpha Prints*, 142 p.

Eduvie, M.O. and Olabode, O.T. 2001. Evaluation of aquifer potential in the crystalline basement using geoelectric sounding data from the southern part of Kaduna State, Nigeria. *Water Resour. J.*, 12(2): 56-61.

Eduvie, M.O. and Olaniyan, I.O. 2013. Groundwater quality appraisal in southern parts of Kaduna State, Nigeria. *American Journal of Environmental Engineering*, 3(1): 77-83,

Eggleton, R.A. (ed.). 2001. The regolith glossary. Perth: CRC LEME

Ehirim, C.N. and Nwankwo, C.N. 2010. Evaluation of aquifer characteristics and groundwater quality using geoelectric method in Choba, Port Harcourt. *Archives of Applied Science Research*, 2(2):396-403

Ekiti State Department of Population Activities. 2004. Population Projections by Towns and Villages (2000 –2005), Governor's Office, Ado-Ekiti, Nigeria.

Fabiyi, S. 2004. Application of Geographic Information Systems (GIS) and Land Information Systems (LIS) in Urban and Regional Planning. *MCPDP. NITP and TOPREC*

Fadahunsi, J.T. 2010. A Perspective View on the Development and Applications of Geographical Information System (GIS) in Nigeria. *Pacific Journal of Science and Technology*, 11(1):301-308.

Falconer, R. 2003. Water: The Most Precious Resource. *Cardiff Univ., Mag*. 3: 14-15

Fashae, O. A., Tijani, M. N., Talabi, A. O. and Adedeji, O. I. 2014. Delineation of groundwater potential zones in the crystalline basement terrain of SW-Nigeria: an integrated GIS and remote sensing approach, *Applied Water Science*, 4:19–38

Forkuor, G., Pavelic, P., Asare, E. and Obuobie, E. 2013. Modelling potential areas of groundwater development for agriculture in northern Ghana using GIS/RS. *Hydrological Sciences Journal*, 58 (2): 437–451

Gbadebo, A.M., Oyedepo, J.A. and Taiwo, A.M. 2010. Variability of Nitrate in Groundwater in Some Parts of Southwestern Nigeria. *The Pacific Journal of Science and Technology*, 11(2): 572-584.

Ghosh, P.K., Bandyopadhyay, S and Jana, N.C. 2016. Mapping of groundwater potential zones in hard rock terrain using geoinformatics: a case of Kumari watershed in western part of West Bengal, *Modeling Earth Systems and Environment*, 2:1-12

Goni, I.B. 2006. The challenges of meeting domestic water supply in Nigeria. *Journal of Mining and Geology*, 42(1): 51–55.

Gopal, M. 2010. Corrosion Potential Assessment, The Geology of part of South-western Nigeria. *Geological Survey of Nigeria*, 31-87.

Gumma, M.K and Pavelic, P. 2013. Mapping of groundwater potential zones across Ghana using remote sensing, geographic information systems, and spatial modelling. *Environmental Monitoring and Assessment*, 185(4):3561–3579

Gupta, M. and Srivastava, P.K. 2010. Integrating GIS and remote sensing for identification of groundwater potential zones in the hilly terrain of Pavagarh, Gujarat, India. *Water International*, 35(2): 233–245

Hazell, J.R.T., Cratchley, C.R. and Preston, A.M. 1988. The location of aquifers in crystalline rocks and alluvium in Northern Nigeria using combined electromagnetic and resistivity techniques. *Quarterly Journal of Engineering Geology*, 21: 59- 175.

Henriet, J.P. 1975. Direct applications of the Dar Zarrouk parameters in ground water surveys. *Geophysical Prospecting*, 24: 344–353.

Hung, L.Q., Batelaan, O. and De Smedt, F. 2005. Lineament extraction and analysis, comparison of LANDSAT ETM and ASTER imagery. Case study: Suoimuoi tropical karst catchment, Vietnam. *Proc. of SPIE*, 5983, 59830T

Idowu, O. A., Martins, O. and Ajayi, O. 1998. Groundwater occurrence in southwestern Nigeria: a comparison of two geological environments, *Water resources*, 9: 33-40.

Ifabiyi, I.P. 2008. Depth of Hand – dug Wells and Water Chemistry: Example from Ibadan Northeast Local Government Area (L.G.A.), Oyo-State, *Nigeria. Journal of Social Sciences* 17(3): 261-266

Ige, S. O. and Adetunji, A. A. 2014. On Some Socio-Economic Factors Affecting Household Sanitation in Ado-Ekiti, Ekiti State, Nigeria. *Journal of Environment and Earth Science*, 4(9): 21- 29

Ikeji, C.C. 2013. Rural Infrastructural Development in Nigeria: Policies and Implementation Strategies, *Developing Country Studies*, 3(.6): 122 – 128

Ishaku, J.M., Ankidawa, B.A and Abbo, A.M. 2015. Groundwater Quality and Hydrogeochemistry of Toungo Area, Adamawa State, North Eastern Nigeria, *American Journal of Mining and Metallurgy*, 3(3): 63-73

Jayeoba, A. and Oladunjoye, M. A. 2013. Hydro-geophysical evaluation of groundwater potential in hard rock terrain of southwestern Nigeria, *RMZ – M&G,* 60, 271–285

Karunakaran K, Thamilarasu P, Sharmila R. 2009. Statistical study on physicochemical characteristics of groundwater in and around Namakkal, Tamilnadu, India. *E-Journal of Chemistry*, 6(3): 909-914.

Kearey, P and Brooks, M. 1991. *An Introduction to Geophysical Exploration*. 2nd ed.,Blackwell, Scientific Publications, Oxford

Lobo-Ferreira, J.P. 1999. The European Union experience on groundwater vulnerability assessment and mapping. *COASTIN A Coastal Policy Research Newsletter*, 1: 8–10

MacDonald, A.M. and Davies, J. 2000. A brief review of groundwater for rural water supply in sub-Saharan Africa. *British Geological Survey Technical Report* WC/00/33

MacDonald, A. M., Calow, R. C., Nicol, A. L., Hope, B and Robins, N. S. 2001. Ethiopia: water security and drought. *British Geological Survey Technical Report* WC/01/02

Magesh, N.S, Chandrasekar, N and Soundranayagam, J.P. 2012. Delineation of groundwater potential zones in Theni district, Tamil Nadu, using remote sensing, GIS and MIF techniques. *Geoscience Frontiers,* 3(2): 189 -196

Mallam, A. 2004. Fresh Basement: Revealed from Resistivity Method; *Zuma Journal of Pure and Applied Science*, 6(1): 6-9.

Mallam, A. and Emenike, E. A. 2008. Preliminary Findings of Subsurface Characteristics From Direct Current Resistivity Survey of The Federal Capital Territory (FCT), *Nigeria. International Journal of Pure and Applied Sciences,* 2(2): 68-76.

Malomo, S., Okufarasin, V.A., Olorunnio, M. A and Omode, A. 1990. Groundwater Chemistry of Weathered Zone Aquifers of an area Underlain by Basement Complex Rocks. *Journal of African Earth Science*, 11(3&4): 357-371.

Mancosu, N., Snyder, R.L., Kyriakakis, G and Spano, D. 2015. Water Scarcity and Future Challenges for Food Production, *Water,* 7: 975-992

Mogaji, K. and Oladapo, I. 2008. Hydrogeological Evaluation of Federal College of Agriculture, Akure Campus, Ondo State. *Online Journal of Earth Sciences,* 2(2):78-85.

Mohammed, I. N, Aboh, H. O and Emenike, E. A. 2008. Hydrogeophysical Investigation for Groundwater Potential In Central Minna, Nigeria. *Science World Journal* 3(4):49-54.

Mogaji, K. A., Olayanju, G. M. and Oladapo, M. I. 2011. Geophysical evaluation of rock type impact on aquifer characterization in the basement complex areas of Ondo State, Southwestern Nigeria: Geo-electric assessment and Geographic Information Systems (GIS) approach. *International Journal of Water Resources and Environmental Engineering*, 3(4):77-86

Mohammed, M. Z, Olorunfemi, M.O and Idonigie, A.I. 2012. Geoelectric Sounding for Evaluating Soil Corrosivity and the Vulnerability of Porous Media Aquifers in Parts of the Chad Basin Fadama Floodplain, Northeastern Nigeria, *Journal of Sustainable Development*, 5(7):111 -126

Momoh, J. J. and Oladebeye, D. H. 2010. Assessment of awareness, attitude and willingness of people to participate in household solid waste recycling programme in Ado-Ekiti, Nigeria. *Journal of Applied Sciences in Environmental Sanitation,* 5(1): 93-105.

Nas, B and Berktay, A. 2010. Groundwater quality mapping in urban groundwater using GIS. *Environmental Monitoring and Assessment*, 160(1–4): 215–227.

Ndatuwong, G and Yadav, G.S. 2014. Integration of Hydrogeological Factors for Identification of Groundwater Potential Zones Using Remote Sensing and GIS Techniques. *Journal of Geosciences and Geomatics*, 2(1):1-16

Obiora, D.N, Ajala, A.E and Ibuot, J.C. 2015. Evaluation of aquifer protective capacity of overburden unit and soil corrosivity in Makurdi, Benue state, Nigeria, using electrical resistivity method, *Journal of Earth Systems and Sciences,* 124(1): 125–135

Offodile, M. E. 2002. Groundwater Study and Development in Nigeria. Nigeria. 2nd Ed. Macon Geology and Engineering Services Ltd. *In: C. A. Kogbe (ed.), Geology of Nigeria*. Elizabethan Publication. RD. Minna.

Ogundana, A. K., Aladesanmi, A. O., Okunade, A and Olutomilola, O. O. 2015. Causes of Borehole Failure in Complex Basement Terrains: ABUAD Case Study, Southwestern Nigeria. *American Journal of Engineering Research*, 4(10):192-201

Ojo J.S., Olorunfemi M.O., Akintorinwa O.J., Bayode S., Omosuyi G.O. and Akinluyi F.O. 2015. GIS Integrated Geomorphological, Geological and Geoelectrical Assessment of the Groundwater Potential of Akure Metropolis, Southwest Nigeria. *Journal of Earth Sciences and Geotechnical Engineering,* 5(14): 85-101

Okhue, E.T and Olorunfemi, M.O. 1991. Electrical Resistivity Investigation of a Typical Basement Complex Area -The Obafemi Awolowo University Campus Case Study. *Journal of Mining and Geology*, 27(2): 63 - 69.

Oki, O. A., Egai, A. O and Akana, T. S. 2016. Soil Corrosivity Assessment in the Pre-Design of Sub-Surface Water Pipe Distributary Network in Yenagoa, South-South Nigeria Using Electrical Resistivity, *Geosciences*, 6(1): 13-20.

Okolie, E.C., Osemeikhian, J.E.A., Oseji, J.O., and Atakpo, E. 2005. Geophysical Investigation of the source of River Ethiope. Ukwuani Local Government area of Delta State. *Nigeria Institute of Physics*, 17.

Oladapo, M.I., Mohammed, M.Z., Adeoye, O.O. and Adetola, B.A. 2004. Geoelectrical Investigation of the Ondo State Housing Corporation Estate, Ijapo Akure, Southwestern Nigeria. *Journal of Mining and Geology* 40(1): 41-48

Olajire, A.A. and Imeokparia, F.E. 2001. Water quality assessment of Osun River: Studies on inorganic nutrients. *Environmental Monitoring and Assessment*, 69(1): 17-28.

Olajuyigbe, A. E. 2010. Sustainable Water Service Delivery: An Assessment of a Water Agency in a Rapidly Urbanizing City in Nigeria. *Journal of Sustainable Development*, 3(4): 210 – 219

Olaniyan, I.O and Gwary, M.G. 2015. Hydrogeologic Conditions of Crystalline Basement Aquifers in Kauru Area of Kaduna, Nigeria, *International Journal of Scientific & Engineering Research*, 6(11):147 – 152.

Olanrewaju, V.O. 1987. Charnockite-granite Association in Southwest Nigeria. Rapakivi granite type and charnokitic plutonism in Nigeria. *Journal of African Earth Science*, T (1): 67 - 77

Olayinka, A.I. 1992. Geophysical siting of boreholes in crystalline basement areas of Africa. *Journal of African Earth Sciences*, 14, 197-207

Olayinka, A.I. 2010. *Imaging the Earth's Subsurface, An Inaugural Lecture.* University of Ibadan, 161 p.

Olayinka, A.I., Akpan, E.J. and Magbagbeola, O.A. 1997. Geoelectric sounding for estimating aquifer potential in the crystalline basement area around Shaki, Southwest Nigeria, *Water Resources*, 8(1 & 2): 71 – 81.

Olayinka, A.I and Barker, R.D. 1990. Borehole siting in crystalline basement areas of Nigeria with a microprocessor-controlled resistivity traversing system. *Groundwater*, *28*: 178 -183.

Olayinka, A.I. and Olayiwola, M.A. 2001. Integrated use of geoelctrical imaging and hydrochemical methods in delineating limits of polluted surface and groundwater at a landfill site in Ibadan area, Southwestern Nigeria. *Journal of Mining and Geology*, 37 (1):53-68

Olayinka, A.I and Olorunfemi, M.O. 1992. Determination of Geoelectric Characteristics in Okene Area and Implications for Borehole Siting. *Journal of Mining and Geology*, 28(2): 403 - 411.

O'Leary, D.W., Friedman, J.D. and Poh, H.A. 1976. Lineaments, linear, lineations: some standards for old terms. *Geol Soc Am Bull* 87:1463–1469

Olorunfemi, M. O. 2008. Voyage on the skin of the Earth: A Geophysical Experience. Inaugural Lecture series 211, *Obafemi Awolowo University Press Ltd; Ile-Ife. Nigeria*. pp. 1-2.

Olorunfemi, M.O. 2009. Groundwater Exploration, Borehole Site Selection and Optimum Drill Depth in Basement Complex Terrain, *Special Publication series 1. Nigerian Association of Hydrogeologists*,. 20 p.

Olorunfemi, M.O and Idornigie, A.I. 1992. A Geoelectric Mapping of Basement Structures of South – Central Part Of Bida Basin, and its Hydrogeological Implication. Journal of Mining and Geology, 28: 94 – 98.

Olorunfemi, M.O. and Fasuyi, S.A. 1993. Aquifer Types and the Geoelectric/Hydrogeologic Characteristics of Part of Central Basement Terrain of Nigeria (Niger State). *African Journal of Earth Science*, 16(3): 309-317.

Olorunfemi, M.O and Okhue, E.J. 1992. Hyrogeologic and Geologic significance of a Geoelectric Survey at Ile – Ife, Nigeria. *Journal of Mining and Geology* 28: 242-350.

Olorumfemi, M.O. and Olanrewaju. 1991. On Electrical Anisotropy and Groundwater Yield in a Basement Complex Area of South-western Nigeria. *African Journal of Earth Science* 12(3):467-472.

Olorunfemi, M.O., Ojo, J.S. and Akintunde, O.M. 1999. Hydrogeophysical Evaluation of the Groundwater Potential of Akure Metropolis, South-Western Nigeria. *Journal of Mining and Geology*, 35(2): 207 – 228.

Olorunfemi, M.O. and Olorunniwo, M.A. 1985. Parameters and aquifer characteristics of some parts of SW. Nigeria. *Geologic Applica E. Hydrogeological* XX Part 1: 99-109.

Oloruntola, M. O and Adeyemi, G O. 2014. Geophysical and Hydrochemical Evaluation of Groundwater Potential and Character of Abeokuta Area, Southwestern Nigeria. *Journal of Geography and Geology*, 6(3):162-177

Omosuyi, G.O., Ojo, J.S. and Enikanselu, P.A. 2003. Geophysical Investigation for Groundwater around Obanla – Obakekere in Akure Area within the Basement complex of South-Western Nigeria. *Journal of Mining and Geology*, 39(2):109 – 116.

Oseji, J.O., Ujuanbi, O. and Merrious, O. 2009. Determination of Groundwater Flow Direction in Ndokwa Land Area of Delta State Nigeria, using Combined Drilled Hole and Global Positioning System. *Pacific Journal of Science and Technology* 10(2):649-656.

Owen, R.J., Gwavava, O. and Gwaze, P. 2006. Multi-electrode resistivity for groundwater exploration in the Harare greenstone belt, Zimbabwe. *Hydrogeology Journal* 14: 244-252.

Oyedele, E.A.A. 2009. Physico-Chemical Status of Water Samples from Hand-Dug Wells in Ajebamidele Area of Ado-Ekiti, Southwest, Nigeria, *International Journal of Biological and Chemical Sciences,* 3(5): 957-966

Palacky, G. J. 1989. Resistivity characteristics of Geologic Targets. In M.N. Nabighion (ed) Electromagnetic Methods in Applied Geophysics, *Society of Exploration Geophysicist*, 1(3): 53 - 129

Prabu, P and Rajagopalan, B. 2013. Mapping of Lineaments for Groundwater Targeting and Sustainable Water Resource Management in Hard Rock Hydrogeological Environment Using RS- GIS, *Climate Change and Regional/Local Responses*, 10: 235 - 247

Prasad, R. K., Mondal, N. C., Banerjee, P., Nandakumar, M. V. and Singh, V. S. 2008. Deciphering potential groundwater zone in hard rock through the application of GIS. Environmental Geology, 55:467–475

Rahaman, M. A. 1988. Recent advances in the study of the Basement Complex of Nigeria. In Oluyide *et.al*. (eds) Precambrian Geology of Nigeria, *Publication Geological Survey of Nigeria, Kaduna*, 157-163.

Rao, N.S. 2006. Groundwater potential index in a crystalline terrain using remote sensing data. Environmental Geology, 50:1067–1076

Rao, Y.S and Jugran, D.K. 2003. Delineation of groundwater potential zones and zones of groundwater quality suitable for domestic purposes using remote sensing and GIS. *Hydrol Sci J.,* 48(5):821–833

Rao, P.J., Rao, B.S., Rao, M.J and Harikrishna, P. 2003. Geo-electrical Data Analysis to Demarcate Groundwater Pockets and Recharge Zones in Champavathi River Basin, Vizianagaram District, Andhra Pradesh. *Journal of Indian Geophysical Union* 7(2):105 – 113.

Reynolds, J. M., 1997. *An introduction to Applied and Environmental Geophysics*. John Wiley and Sons Ltd., England.

Sander, P. 2006. Lineaments in Groundwater Exploration: a review of applications and Limitations. *Hydrogeology Journal*, 15(1): 71-74

Schiffler, M. 2002. Global Water and Food Scarcity: Are the Gloomy Prediction Righ? *Agricultural and Rural Development Journal*, 9(2):26

Selvam, S., Magesh, N.S., Sivasubramanian, P., Soundranayagam, J.P., Manimaran, G and Seshunarayana, T. 2014. Deciphering of groundwater potential zones in Tuticorin, Tamil Nadu, using remote sensing and GIS techniques. *J Geol Soc India*, 84: 597–608

Shaban, A., Khawlie, M., and Abdallah, C. 2006. Use of remote sensing and GIS to determine recharge potential zones: the case of Occidental Lebanon. *Hydrogeology Journal*, 14(4): 433–443.

Shaw, G. A. and Burke, H. K. 2003. Spectral Imaging for Remote Sensing. *Lincoln Laboratory Journal, 14*(1): 3-28.

Shemang, E. N-Jnr. 1993. Groundwater Potentials of Kubanni River Basin, Zaria, Nigeria from DC Resistivity Study. *Water Resources* 4(1&2): 36-42.

Sheriff, M. A., Malgwi, D. I. and Hassan, H. 2002. Geoelectrical Depth Sounding Using Schlumberger Array in Yimirshika Area of Borno State, Nigeria. *Zuma Journals of Pure and Applied Sciences,* 4(2):127-133

Shitta, M.B.O. and Oyedele, E.A.A. 2007. Production of Water Filters using Local Raw Materials. *Journal of Biological and Physics Sciences*, 4: 94-99.

Singh, P., Thakur, J. K., and Kumar, S. 2013. Delineating groundwater potential zones in a hard-rock terrain using geospatial tools. *Hydrological Sciences Journal*, 58 (1): 213–223

SON. 2007. Nigerian Standards for Drinking Water Quality. *Standard Organization of Nigeria (SON) Publ.* NIS-554, 30 p.

Srinivas, Y., Oliver, D. H., Raj, A.S and Chandrasekar,N. 2013. Evaluation of groundwater quality in and around Nagercoil town, Tamilnadu, India: an integrated geochemical and GIS approach. *Applied Water Science,* 3:631–651

Srivastava, R. K and Singh, S. 2008. Geoinformatics in Ground Water Potential Evaluation and Management - Case Study of District Allahabad. *The 12th International Conference of International Association for Computer Methods and Advances in Geomechanics (IACMAG.)* 2300 -2306.

Taiwo, A.M., Adeogun, A.O., Olatunde, K.A. and Adegbite, K.I. 2011. Analysis of Groundwater Quality of Hand-Dug Wells in Peri-Urban Area of Obantoko, Abeokuta, Nigeria for Selected Physico-Chemical Parameters. *Pacific Journal of Science and Technology* 12(1): 527-534.

Talabi, A.O and Tijani, M.N. 2011. Integrated remote sensing and GIS approach to groundwater potential assessment in the basement terrain of Ekiti area southwestern Nigeria, *RMZ – Materials and Geoenvironment,* 58(3): 303–328

Taylor, G and Eggleton, R.A. 2001. Regolith Geology and Geomorphology. John Wiley & Sons Ltd, Chichester. 375 p.

Teeuw, R., Whiteside, M., McWilliam, N., Zukowskyj, P., Hourigan, D., Mount, N., and Jonathan, R. 2005. Field Techniques: GIS, GPS and Remote Sensing. *Geography Outdoors, Royal Geographical Society (with IBG), London*, p. 67

Tijani, M.N, Oke, S.A and Olowookere, A.T. 2014. Hydrogeochemical characterization of a shallow groundwater system in the weathered basement aquifer of Ilesha area, southwestern Nigeria. *Evolving Water Resources Systems,* IAHS Publ. 364, 475-489

Tinuola, F. R. and Owolabi, J. T. 2007. Issues in Environmental Pollution in Ekiti State, *Research Journal of Applied Sciences,* 2(5): 544-547

UNICEF, 2006. Water, Sanitation and Hygiene Strategies. United Nations, New York, U. S. A.

Vander Velpen, B.P.A. 1988. *Resist Version 1.0. M.Sc. Research Project*. ITC: Delft, Netherlands.

Venkateswaran, S., Prabhu, M.V and Karuppannan. S, 2014. Delineation of Groundwater Potential Zones Using Geophysical and GIS Techniques in the Sarabanga Sub Basin, Cauvery River, Tamil Nadu, India. *International Journal of Current Reseach and Academic Review*, 2(1): 58 -75

Venkateswarlu, G., Jayasankar, G and Saradhi, B.V. 2014. Impact Assessment of Land Use Change on Ground Water Quality Using Remote Sensing & GIS for Zone V under Municipal Corporation Hyderabad, *Journal of Mechanical and Civil Engineering*, 11(1): 36-42

Waller, R. M. 1982. Groundwater and the Rural Homeowner, Pamphlet, U.S. Geological Survey

WHYMAP, 2008. Groundwater Resources of the World. BGR/ UNESCO. Retrieved May 11, 2015, from http://www.whymap.org.

Woodford, A., Rosewarne, P., and Girman, J., 2006. How much groundwater does South Africa have? Retrieved May 11, 2015 from http://www.srk.co.uk/groundwater

World Health Organization, Safe water and Global Health, 2008. Retrieved Feb. 15, 2012, from www.who/int/features/qa/70/en/index.htm

Wright, C. P, 1992. *The Hydrogeology of Crystalline Basement Aquifers in Africa*. In: C. P. Wright and W. C. Burgess (eds). Hydrogeology of Crystalline Basement aquifer in Africa. *Geological Society of London Special Publication*, 66: 1 – 27

Yammani, S. 2007. Groundwater quality suitable zones identification: application of GIS, Chittoor area, Andhra Pradesh, India. *Environmental Geology*, 53(1): 201–210.

Zohdy, A. A. R., Eaton, G. P. and Mabey, D. R. 1974. Application of surface geophysics to groundwater investigation. In *Techniques of Water Resources Investigations*, US Geological Survey, Washington, 116 p.

APPENDIX I
HYDROSTATIC DATA

Well No	Well Elevation (m)	SWL (m)	TD (m)	Groundwater Head (m)	Water Column (m)
1	403	4.5	4.9	398.5	0.40
2	403	6.6	6.8	396.4	0.20
3	413	7.8	7.9	405.2	0.10
4	414	6.64	6.71	407.36	0.07
5	396	5.5	6.6	390.5	1.10
6	391	5.05	5.35	385.95	0.30
7	380	5.3	5.4	374.7	0.10
8	383	6.1	6.2	376.9	0.10
9	395	5.4	5.54	389.6	0.14
10	378	6.8	6.82	371.2	0.02
11	380	7.8	7.81	292.2	0.01
12	369	4.15	4.25	364.85	0.10
13	362	5.43	5.75	356.57	0.32
14	430	5.5	5.76	424.5	0.26
15	427	3.61	3.68	423.39	0.07
16	413	5.35	5.61	407.65	0.26
17	417	12	12.58	405	0.58
18	431	3.3	3.65	427.7	0.35
19	406	6	6.22	400	0.22
20	408	6.5	7.9	401.5	1.40
21	412	6.25	6.37	405.75	0.12
22	418	3.6	3.7	414.4	0.10
23	417	9.2	9.7	407.8	0.50
24	426	6.5	6.57	419.5	0.07
25	417	5.59	6.15	411.41	0.56
26	418	7.65	8.95	410.35	1.30
27	419	1.55	2.6	417.45	1.05
28	428	5.5	5.6	422.5	0.10
29	427	5.05	6.38	421.95	1.33
30	424	7.91	7.97	416.09	0.06
31	422	5.1	5.15	416.9	0.05
32	422	5.64	5.7	416.36	0.06
33	417	4.4	4.49	412.6	0.09
34	435	6.2	7.25	428.8	1.05
35	435	3.1	3.22	431.9	0.12

36	438	6.35	7.7	431.65	1.35
37	441	6.5	6.55	434.5	0.05
38	426	4.34	5.38	421.66	1.04
39	430	3.33	3.45	426.67	0.12
40	414	5.03	5.04	408.97	0.01
41	443	5.62	8.01	437.38	2.39
42	451	7.5	9.2	443.5	1.70
43	435	5.6	7.01	429.4	1.41
44	433	7.9	8.57	425.1	0.67
45	455	6.2	7.86	448.8	1.66
46	444	5.13	5.29	438.87	0.16
47	460	7.8	9.3	452.2	1.50
48	464	3.61	4.5	460.39	0.89
49	459	5.49	5.56	453.51	0.07
50	459	6.16	6.18	452.84	0.02
51	429	8.5	9.05	420.5	0.55
52	430	1.7	3.1	428.3	1.40
53	429	6.45	7.76	422.55	1.31
54	433	6.26	6.36	426.74	0.10
55	427	3.97	4.4	423.03	0.43
56	435	11.5	12.3	423.5	0.80
57	449	13.12	14.1	435.88	0.98
58	431	7.6	7.8	423.4	0.20
59	432	3.65	4.8	428.35	1.15
60	430	6.98	7.3	423.02	0.32
61	439	10.2	11.15	428.8	0.95
62	439	10.3	10.5	428.7	0.20
63	449	6.5	7.55	442.5	1.05
64	424	10.2	10.8	413.8	0.60
65	403	8.1	8.22	394.9	0.12
66	384	2.8	6.2	381.2	3.40
67	414	7.3	8.2	406.7	0.90
68	401	8.05	8.32	392.95	0.27
69	388	3.8	4.27	384.2	0.47
70	391	4.96	6.5	386.04	1.54
71	393	5.5	5.67	387.5	0.17
72	408	3.5	4.7	404.5	1.20
73	413	7.5	7.55	405.5	0.05
74	416	4.56	6.1	411.44	1.54
75	412	3.4	4.4	408.6	1.00

76	417	2.9	3.07	414.1	0.17
77	421	5.4	5.65	415.6	0.25
78	425	6.45	6.7	418.55	0.25
79	443	8.4	8.5	434.6	0.10
80	446	6.2	6.35	439.8	0.15
81	462	1.6	2.6	460.4	1.00
82	460	5.65	5.7	454.35	0.05
83	410	2	3	408	1.00
84	418	5.02	5.3	412.98	0.28
85	414	6.3	6.5	407.7	0.20
86	428	7.2	9.1	420.8	1.90
87	435	8.4	8.7	426.6	0.30
88	420	8.85	9.1	411.15	0.25
89	428	10.51	11.3	417.49	0.79
90	435	11.5	13.65	423.5	2.15
91	421	6.1	6.5	414.9	0.40
92	400	2.5	3	397.5	0.50
93	417	5.4	5.9	411.6	0.50
94	405	4.5	4.67	400.5	0.17
95	400	5.9	8	394.1	2.10
96	406	3.83	4.3	402.17	0.47
97	404	5.67	6.4	398.33	0.73
98	400	6.9	7.2	393.1	0.30
99	391	2.9	3.8	388.1	0.90
100	396	3.28	3.6	392.72	0.32
101	391	6.2	7.2	384.8	1.00
102	393	7.4	11.3	385.6	3.90
103	398	4.75	13.65	398.25	8.90
104	395	3.5	5.75	391.5	2.25
105	403	4.28	4.9	398.72	0.62
106	403	1.7	2.4	401.3	0.70
107	426	3.55	5.65	422.45	2.10

APPENDIX II
GEOELECRIC DATA

VES No	H (m)	S (Ω^{-1})	T (Ω m^2)	λ	ρ_{bedrk} (Ω m)	ρ_{WBR} (Ω m)	h_{WBT} (m)	BDR (m)
1	18.8	0.24	11393.24	2.80	13030.0	1077.8	8.9	400.2
2	27.1	0.31	12844.29	2.23	10988.9	726.3	13.1	374.9
3	18.2	0.91	2143.04	2.43	4271.8	18.9	17.2	371.8
4	16.4	1.34	881.15	1.81	805.1	9.3	12.3	384.6
5	27.1	0.05	21586.17	1.18	191.7	1057.1	17.3	417.9
6	23.5	0.05	19999.84	1.29	64.3	1267.7	13.5	428.5
7	49.8	0.54	8077.61	1.59	5067.0	267	12.5	365.2
8	31.4	0.52	4758.66	1.59	8184.7	290.9	10.2	388.6
9	23.9	0.42	1795.40	1.14	490.0	54	22.1	387.1
10	35.2	0.41	4251.82	1.18	494.6	80.8	32.5	380.8
11	5.9	0.04	858.34	1.01	87.6	152.6	4.7	402.1
12	6.38	0.04	1078.30	1.03	151.0	185	5.18	421.62
13	5	0.03	637.05	1.01	88.8	161.7	3.8	430
14	14.5	0.41	637.05	1.11	865.2	36.9	7	405.5
15	7	0.57	263.02	1.75	633.0	9.4	5.1	419
16	6.3	0.67	199.32	1.84	813.2	6.5	4.2	393.7
17	12.1	0.41	585.36	1.28	104.8	23.3	7.7	423.9
18	47	0.27	13533.23	1.29	1459.7	122.4	27.3	383
19	13.3	0.03	6902.65	1.05	237.2	572.3	10.9	437.7
20	14.4	0.11	2942.18	1.23	35.9	222.6	12.6	417.6
21	38.4	0.44	8056.05	1.54	95.0	52	13.5	407.6
22	48.3	0.44	7901.63	1.21	104.7	53.2	13.4	409.7
23	54.5	0.19	50081.52	1.81	250.0	1007.5	49.4	406.5
24	46.8	0.23	39921.98	2.06	165.0	1010.6	39.1	409.2
25	21.4	0.21	5532.41	1.58	9875.1	450.4	9.8	390.6
26	8.3	0.11	661.91	1.01	22908.5	79.9	5.5	417.7
27	23.9	0.21	3502.20	1.14	1974.9	192.4	14.8	398.1
28	11.3	0.66	250.72	1.14	670.0	14.8	9	447.7
29	41.8	0.02	93428.12	1.14	762.4	2372.9	38.8	359.2
30	25	0.01	117761.16	1.02	2297.0	4911	22.8	381
31	30.5	0.49	3559.41	1.36	1847.4	161.6	17.8	372.5
32	11.5	0.33	729.51	1.35	274.5	27.9	8.8	394.5
33	56.2	0.32	18083.28	1.36	5008.6	435.9	20.8	344.8
34	11.1	0.12	3045.54	1.74	4590.1	77.2	8.9	382.9
35	6.5	0.14	1105.33	1.90	7032.5	36.5	4.9	403.5

36	14.6	0.06	4029.73	1.05	2120.1	206.7	8.9	412.4
37	11.8	0.04	4871.83	1.23	1151.7	182.8	5.9	409.2
38	6.3	0.36	135.18	1.11	1211.6	15.6	5.3	395.7
39	30	0.05	34328.64	1.33	6019.0	1214	28	400
40	5.6	0.34	106.64	1.07	2321.5	13.9	4	419.4
41	4	0.15	115.30	1.05	726.0	22.6	3	416
42	8.4	0.35	221.90	1.04	999999.0	23	7.7	401.6
43	16.8	0.33	1198.80	1.19	999999.0	60	13.2	429.2
44	68.5	1.51	7598.50	1.56	7650.0	31	43.1	375.5
45	32.8	0.18	8634.40	1.20	79.0	356	21	387.2
46	45.3	0.28	8645.50	1.08	122.0	211	38.8	364.7
47	3.8	0.55	262.20	1.00	999999.0	69	3.8	428.2
48	13.8	0.08	5885.20	1.58	999999.0	519	11	404.2
49	6	0.03	1652.10	1.18	3500.0	321	4.9	415
50	42.9	4.44	886.90	1.46	152.0	6	22.2	397.1
51	23.5	1.90	909.60	1.77	7693.0	8	13.1	410.5
52	7	0.19	369.40	1.19	999999.0	28	4.4	413
53	12.2	0.28	603.00	1.07	999999.0	42	11.9	392.8
54	7.6	0.25	400.29	1.32	10000.0	27.7	6.9	412.4
55	2	0.04	115.05	1.11	94445.4	38.7	1.5	433
56	15	0.13	2807.26	1.28	2646.0	87.7	10.5	413
57	8.1	0.32	257.39	1.12	2243.1	23.5	7.3	382.9
58	36.9	0.15	62802.96	2.67	528.2	2162.9	28.8	357.1
59	21.1	0.27	15132.67	3.00	7574.7	1133.4	13	358.9
60	79.9	0.20	54829.79	1.30	4213.6	330.2	51.4	342.1
61	31.4	0.08	22505.66	1.37	143.3	992.7	20.6	382.6
62	6.2	0.14	798.95	1.73	4636.8	29.7	4.1	384.8
63	16.4	1.04	512.21	1.41	925.2	11.4	10.9	391.6
64	13.4	0.04	6063.52	1.11	212.4	501.8	11.6	401.6
65	27.2	0.09	9657.98	1.08	58.1	296	23.3	411.8
66	10.4	0.06	2730.36	1.21	53.3	368.8	6.1	438.6
67	24	0.34	2067.46	1.10	1182.2	62.9	17.2	371
68	54.5	1.10	4329.31	1.26	2998.5	43.7	46.7	374.5
69	49	0.56	6040.22	1.18	3057.3	65.6	30.7	395
70	21.2	0.36	5478.96	2.09	1470.9	359.9	14.8	382.8
71	23.8	0.11	17660.99	1.82	123.6	1316.3	13.1	404.2
72	7.6	0.15	427.29	1.04	1012.6	46	5.9	417.4
73	12.4	0.14	2839.78	1.58	6656.0	504.6	4.7	417.6
74	19.7	0.16	3715.44	1.24	761.1	413.4	5.8	403.3
75	10.5	0.24	722.77	1.24	3114.8	38.1	7	409.5

76	17.5	0.09	3844.40	1.07	1641.8	233.4	16.1	405.5
77	19.8	0.08	4918.90	1.00	865.9	250.5	19.3	380.2
78	9.2	0.21	1647.72	2.01	1059.0	40.5	8.4	367.8
79	26.8	0.23	4906.81	1.26	681.9	227.1	18.6	351.2
80	45.4	0.21	35663.87	1.89	1719.8	188.8	31.2	321.6
81	21.1	0.15	6235.21	1.43	1140.8	357.4	11.2	350.9
82	13.8	0.11	1969.81	1.06	886.6	123.2	11.3	396.2
83	49.4	0.29	10530.95	1.12	5054.2	265.2	32.5	350.6
84	31.6	0.22	7531.00	1.29	1657.5	310.8	21.1	401.4
85	38.4	0.23	10032.93	1.25	1538.9	285	34.7	358.6
86	38.2	0.37	5833.77	1.22	488.6	181.4	30.0	383.8
87	24.2	0.25	4458.15	1.39	1936.2	241.8	17.2	401.8
88	15.9	0.14	7009.65	1.97	3861.7	561.3	12.0	387.1
89	49	0.53	6193.80	1.17	675.6	149.8	36.6	353
90	41.3	0.59	3003.19	1.02	677.9	67.7	39.5	365.7
91	9.6	0.30	889.56	1.69	819.5	26.4	7.7	388.4
92	35.1	0.31	4549.67	1.09	782.4	181.7	18.6	364.9
93	8	0.15	165.07	1.98	5809.1	42.2	6.3	387
94	44.3	0.31	7969.53	1.12	450.9	211.3	32.1	347.7
95	41	0.61	4761.97	1.31	605.5	163.4	22.0	354
96	10.4	0.08	1542.96	1.05	1149.1	124.4	9.0	387.6
97	39.6	0.40	5909.14	1.14	357.9	437.4	26.6	378.4
98	4.2	0.02	1292.72	1.08	642.8	234.5	3.4	412.8
99	27.8	0.40	3391.65	1.32	2155.8	62.5	24.3	384.2
100	35.6	0.20	7042.52	1.05	1234.3	171.4	32.9	394.4
101	61.3	0.08	191390.60	1.97	999999.0	587	37.8	366.7
102	21	0.13	6766.40	1.43	1250.0	140	18.3	380
103	22.3	0.17	3143.10	1.03	1260.0	126	20.1	398.7
104	60.7	0.61	7015.60	1.07	999999.0	96	57.5	374.3
105	39.5	0.57	3399.40	1.12	999999.0	64	35.8	372.5
106	26.9	0.11	7087.10	1.04	259.0	294	21.2	382.1
107	36.6	0.46	3134.80	1.03	10138.0	78	35	363.4
108	12.1	0.01	60329.23	2.41	118.0	5717	10.5	405.9
109	54.5	0.53	6893.90	1.10	120.0	180	25.4	418.5
110	5.3	0.09	428.40	1.19	2500.0	92	4.5	452.7
111	26.4	0.24	3093.60	1.04	999999.0	120	25.6	429.6
112	11.9	0.53	351.50	1.15	1780.0	21	11.1	418.1
113	20.32	0.19	16570.50	2.78	999999.0	72	6	379.68
114	15.9	0.02	18290.70	1.06	230.0	1197	15.1	387.1
115	10.8	0.01	20440.00	1.06	999999.0	2000	10	399.2

116	23.8	0.01	103120.00	1.10	15800.0	3500	10	391.2
117	55.5	0.75	4591.20	1.06	180.0	61	32.8	366.5
118	1	0.02	102.80	1.34	420.0	18	0.2	459
119	15.2	0.37	752.47	1.10	999999.0	35.9	12.3	415.8
120	31	0.50	2162.00	1.06	250.0	70	6	389
121	20.8	0.48	1151.20	1.13	280.0	42	20	417.2
122	35.5	0.32	4480.90	1.06	150.0	93	21.2	391.5
123	49.9	0.10	28181.43	1.09	4881.3	430.5	42.3	376.1
124	63.2	0.28	14976.14	1.02	825.4	251.4	53.2	379.8
125	58.7	0.49	12212.75	1.32	1011.1	95.1	44.5	362.3
126	63	0.30	29422.51	1.48	959.2	165.5	46.3	382
127	14.6	0.02	9103.46	1.00	236.7	631.3	13.4	425.4
128	28.6	0.32	3095.24	1.10	349.2	79	23.9	408.4
129	7.9	0.50	164.60	1.14	802.2	14.6	7	438.1
130	3.3	0.09	178.24	1.21	1029.5	28.9	2.4	518.7
131	48.3	0.44	8276.32	1.25	83.8	50.1	13.8	392.7
132	18.1	0.15	3887.59	1.31	4342.7	87.5	7.3	383.9
133	28.5	0.46	2343.20	1.15	290.0	72	6.3	440.5

APPENDIX III
PHYSICO-CHEMICAL ANALYSIS

Well No	COLOUR (H.U)	TURBIDITY (NTU)	TEMP (°C)	ELCTRICAL CONDUCTIVITY (µS/cm)	TOTAL SOLID (mg/l)	SUSPENDED SOLID (mg/l)	DISSOLVED OXYGEN (PPM)	DISSOLVED SOLID	pH
1	5	1.02	31.0	18.6	3.5	0	5.0	3.5	6.8
2	10	2.52	31	22.0	8.5	0	4.50	8.5	4.8
3	5	1.05	31	20.0	6.9	0	7.05	6.9	7.5
4	5	2.0	31	18.55	9.0	0	6.6	9	6.5
5	5	1.35	32	7.5	2.9	0	7.8	2.9	7.0
6	5	1.25	31.5	25.01	12.0	0	5.5	12	5.5
7	5	1.0	31	8.5	2.7	0	6.0	2.7	7.8
8	5	25.02	4.25	22.5	35.5	0	5.6	35.5	6.0
9	10	4.25	31	23	3.8	3.8	4.5	0	6.5
10	5	1.05	31.5	7.75	4.7	0	4.5	4.7	6.0
11	5	1.22	32	5.4	2.0	0	4.5	2	8.0
12	5	2.55	31.0	6.02	7.5	0	8.3	7.5	5.8
13	5	1.45	32.0	3.55	3.4	0	6.65	3.4	6.2
14	10	8.5	30.0	7.91	12	6.0	4.05	6	3.5
15	5	12.5	31.0	16.34	40	2.0	11.57	38	5.5
16	10	15.5	31.0	5.00	56.0	4.1	12.22	51.9	6.0
17	5	12.05	31.0	7.85	4.9	2.0	11.76	2.9	7.5
18	15	7.9	31.0	6.66	7.2	1.5	11.06	5.7	8
19	60	38	31.0	34.40	22.2	12.15	4.1	10.05	6.5
20	10	55	31.0	25.75	320.0	200	4.96	120	7.5
21	40	30.7	31.0	15.50	185	90	4.78	95	8.2
22	40	24.75	31.0	20.40	14.8	5.0	4.58	9.8	6.5
23	5	25.5	31	18.2	9.0	1.5	4.84	7.5	7.5
24	10	21.7	31	11.5	41.0	12.0	4.65	29	6.2
25	15	35.7	31	5.75	25.0	9.0	4.84	16	5.8
26	5	29.1	31	16.5	100	2.0	4.78	98	7.0
27	5	25.5	31	20.55	145.0	8.8	11.65	136.2	5.5
28	5	18.55	32	15.5	90	4.9	4.93	85.1	6.5
29	20	5.58	31	5.02	25.0	0.75	6.75	24.25	7.8
30	15	4.0	32	5.00	55	0.25	4.60	54.75	7.2
31	20	5.55	31	4.90	61.7	27.5	4.89	34.2	5.5
32	10	30.0	31	25.0	230	130	4.35	100	3.5
33	20	40	32	11.55	210	45	8.90	165	6.5
34	20	12.05	31	7.55	48	17	5.0	31	6.8
35	60	105.5	32	33.05	420	160	4.87	260	5.8
36	5	5.7	31	4.5	5.5	2.5	8.0	3	7.2
37	10	1.05	31	8.50	12.5	4.2	7.55	8.3	6.0
38	25	1.55	31	2.6	5.9	2.0	6.9	3.9	6.5

39	20	2.05	32	5.55	70.5	10.0	8.88	60.5	6.8
40	20	4.05	31	6.65	25	9.2	7.05	15.8	7.2
41	25	4.70	31	7.01	20.1	5.2	6.00	14.9	6.5
42	30	10.55	31	2.0	42.5	5.9	4.92	36.6	6.6
43	5	2.75	31	6.0	10.2	2.0	5.60	8.2	6.8
44	10	6.55	31	2.0	8.85	2.6	4.89	6.3	6.6
45	5	33.99	31	1.5	6.5	2.5	6.50	4	6.5
46	5	5.5	31	8.6	30.2	10.2	4.97	20.05	6.2
47	10	4.97	31	10.5	29.9	10.4	6.10	19.5	6.2
48	5	6	31	2.9	40	15.0	5.00	25	6.5
49	5	4.05	30.5	12.6	50	15.0	4.96	35	5.8
50	20	8.99	31	20.0	30.55	10.5	4.92	20.05	5.8
51	30	12.55	30	3.0	80.5	21.0	5.00	59.5	6.8
52	5	2.65	30	1.3	9.05	4.1	6.23	5	6.8
53	35	12.55	31	25.0	109.2	21.0	5.60	88.2	5.0
54	20	12	31	3.6	50.9	10.2	5.20	40.68	6.0
55	25	12	31	4.6	88.01	12.5	4.00	75.51	6.8
56	30	11.09	31	2.5	12.90	2.5	4.89	10.4	5.5
57	5	1.07	31	5.79	6.5	2.5	9.55	4	6.5
58	5	2.65	31	1.55	9.9	2.0	4.55	7.9	7.5
59	10	3.05	32	2.55	7.55	2.05	7.55	5.5	6.8
60	5	0.95	31	12.05	12.5	0.55	8.99	11.95	7.0
61	20	17.90	31	19.5	55	12.6	4.90	42.4	6.0
62	20	35.5	31	15.00	26.5	0.7	5.50	25.8	7.8
63	25	45.0	31	45.55	43.5	35.0	10.5	8.5	8.0
64	15	12.05	31	8.55	6.5	1.05	8.5	5.45	7.5
65	25	8.55	31	2.70	11.5	9.0	4.98	2.5	6.5
66	5	2.70	31	8.99	12.0	1.50	4.99	10.5	6.0
67	10	9.0	30.5	2.66	9.5	1.5	4.99	8.0	6.8
68	20	10.55	31	3.53	7.55	1.05	4.99	6.5	6.8
69	5	2.35	31	2.0	6.25	0.55	5.02	5.7	6.0
70	5	2.33	31	0.99	50	0.2	5.0	49.8	6.2
71	35	27.0	32	77	400	16.5	68	383.5	7.8
72	5	3.26	31	15.0	50	40	4.98	10	6.8
73	20	10.05	31	15.50	49.9	22.5	4.98	27.4	6.2
74	25	9.55	31	5.55	15.5	7.5	5.0	8.0	6.8
75	20	10.55	31	8.55	15.0	0.15	4.98	14.85	7.4
76	10	8.99	31	42.0	9.0	2.2	4.98	6.8	5.5
77	30	12.00	32	5.20	12.0	2.50	6.63	9.5	7.5
78	40	15.55	31	50.15	100.5	42.0	4.97	58.5	8.2
79	5	2.70	31	70	77	21	5.01	56	6.0
80	25	10.55	32	3.55	8.0	0.5	4.99	7.5	6.0
81	10	12.0	32	18.06	24.5	2.9	4.99	21.6	7.2
82	20	8.15	31	15.5	45.9	12.5	4.91	33.4	5.6
83	5	2.99	31	5.50	12.5	2.5	5.94	10.0	6.8

84	5	4.88	32	13.5	42.5	20.7	4.92	21.8	7.2
85	40	12.55	32	36.21	99.5	42.0	4.95	57.5	6.0
86	5	3.55	32	12.0	21.5	6.55	5.30	14.95	6.6
87	5	0.77	32	3.00	2.05	0.5	4.50	1.55	6.5
88	20	20.54	32	16.55	5.22	3.5	3.6	1.72	5.2
89	30	10.55	32	23.55	10.05	16	3.99	405	6.2
90	40	40	31	25.05	23.55	455	4.99	19.0	4.5
91	20	13.0	31	3.25	15.55	12.0	4.99	3.5	6.2
92	20	12.77	31	16.00	12.51	3.52	4.00	8.99	6.6
93	25	12.99	31	6.78	1.05	0.50	5.0	0.55	6.8
94	20	21.55	31	10.00	2.10	0.65	4.25	1.45	6.0
95	5	1.25	31	10.50	3.50	1.00	4.95	2.50	8.0
96	10	0.95	31	2.44	5.00	2.56	3.37	2.44	7.0
97	5	0.65	31	0.79	0.5	0.2	4.94	0.3	6.8
98	5	3.55	31	1.25	2.05	0.5	5.03	1.55	6.8
99	10	3.75	31	2.55	15.59	6.75	5.0	8.84	6.8
100	5	2.00	31	0.98	1.05	0.05	4.96	1.00	6.5
101	15	10.00	31	3.45	9.00	1.55	5.2	7.45	6.8
102	40	32.55	33	14.05	12.75	3.05	3.95	9.75	5.5
103	30	15.99	31	45.55	10.00	3.02	3.55	6.98	5.2

Well No	CALCIUM(mg/l)	MAGNESSIUM (mg/l)	CHLORIDE (mg/l)	AMMONIA	TOTAL HARDNESS (mg/l)	ACIDITY (mg/l)	CARBONATE ALKALINITY	NITRATE	BI-CARBONATE ALKALINITY
1	40	135	80	1.0	100	1.5	Nil	Nil	97.6
2	240	70.0	100	0.1	60	0.3	Nil	10.0	70.5
3	15.0	41.5	80	0.1	140	10.4	Nil	0.1	45.5
4	4.7	140.3	140	2.0	100	10.3	Nil	0.15	97.6
5	16.8	96.0	120	0.1	100	10.4	Nil	Nil	146.4
6	180.0	52.5	355.0	2.0	140	0.2	48.0	1.6	120
7	5.6	43.5	85.0	0.1	180	0.3	Nil	1.0	122.0
8	222.0	82.1	46.85	0.2	60	0.3	Nil	48.1	2.05
9	138	95.5	60	2.0	80	0.1	Nil	1.0	40
10	4.0	76.3	75	0.1	20	0.3	Nil	1.0	35
11	18.40	82.1	60	0.1	100	0.2	Nil	Nil	102
12	96.00	135	40	1.0	60	0.4	Nil	0.10	90
13	56.00	42.0	32.5	0.1	180	0.3	Nil	0.10	35
14	346.00	56	480	1.5	420	2.5	Nil	0.50	245
15	75.00	45	10.5	1.0	60	0.1	Nil	Nil	42
16	60.00	60.0	74	0.1	40	0.1	Nil	Nil	75
17	45.00	40	24.0	0.0	140	0.2	40.0	1.00	60
18	25.00	32.5	50.0	0.0	80	0.2	Nil	1.60	140.0
19	60.00	78	240	0.1	20	0.1	38	1.60	304
20	146.00	88	75.9	2.0	100	0.5	Nil	40.50	70.15
21	98.50	140	245	0.2	200	2	Nil	1.00	200
22	56.00	27	142	1.0	160	1.5	Nil	0.30	75
23	42	40.5	10.9	0.75	100	0.5	Nil	0.3	45
24	70	55.0	100	1.0	80	0.2	25	1.0	75
25	42	70	32	1.00	40	0.1	10	50	69
26	60	45	175	1.00	200	2	25	1.0	150
27	40	60.0	190	0.75	180	1.5	35	1.5	255
28	92	40	100.0	0.75	20	1.5	1.2	1.00	60
29	45	61.5	12.0	0.1	100	0.2	Nil	0.15	45
30	40	50	60	0.00	80	0.2	Nil	1.00	35
31	55	60	25.0	0.3	100	0.5	Nil	1.60	40
32	45	51.2	15	0.2	240	1.0	Nil	0.30	266
33	70.50	48.7	75.9	1.0	120	0.2	Nil	15.70	48
34	59.00	60.5	9.15	1.0	100	0.4	20.1	1.50	48.5
35	14.14	9.5	132	0.6	140	2	15	0.15	160
36	10.00	21	4.5	0.1	80	1	Nil	0.15	30
37	40.00	71	15.5	0.1	60	0.2	Nil	0.15	20
38	51.90	40.3	12.5	0.1	80	0.1	Nil	0.05	32.5

39	48.00	65	14.5	0.1	60	0.2	Nil	0.10	48
40	20.60	42	10.1	0.1	80	0.3	0	0.15	50
41	55.00	36	7.5	0.1	80	0.2	Nil	0.05	40
42	6.25	11.07	20.4	1.0	20	0.5	Nil		60
43	23.00	12.12	0.51	0.0	20	0.5	0		47.2
44	6.40	6.30	9.70	0.1	20	0.1	Nil		80.4
45	15.5	12.5	21.30	0.1	100	0.2	20		45
46	16.00	12.88	18.0	0.1	140	0.1	Nil		55.0
47	6.70	22.5	42.5	0.1	20	0.1	Nil		140
48	14.14	15.28	20.1	0.1	100	0.2	Nil		48.9
49	4.8	11.4	9.20	0.1	60	0.3	Nil		75.0
50	12.80	11.44	19.0	0.1	40	0.2	Nil		23.0
51	60.0	60.70	103.0	2.0	120	0.5	19		16.0
52	31.00	40.5	13.2	Nil	60	0.2	30		9.20
53	9.25	60.98	14.85	2.0	120	1.5	Nil		170.5
54	91.9	21.44	75.0	0.01	140	1.0	Nil		35.00
55	100.0	99.0	62.2	1.0	80	0.3	Nil		75.0
56	20.8	22.90	40.0	0.1	60	0.4	33.0		140.0
57	45	49	20.5	0.1	80	0.2	Nil	0.05	75.4
58	40.5	35	50.0	0.1	40	0.3	20.5	0.01	64.0
59	50.5	41.5	12.0	0.1	80	0.3	Nil	0.15	35.0
60	24	51.50	9.2	0.1	60	0.1	Nil	0.00	29.9
61	55	14.8	102.5	0.1	100	0.4	Nil	0.15	100
62	60.9	25.5	27.5	0.1	240	1.5	30	0.15	210
63	75.9	100	96.6	1.0	200	1.0	Nil	0.15	190
64	51	26	12.5	1.0	60	0.3	Nil	0.15	147.0
65	22.5	48.0	30.0	0.00	100	0.5	Nil		78.88
66	70.0	45.9	28.41	0.1	140	0.2	Nil		48
67	59.9	60.5	35.0	0.0	120	0.3	Nil		40.55
68	69.0	90.55	26.6	0.00	180	0.2	Nil		210
69	45	99.5	40.0	0.1	120	0.2	30		45
70	96	60.5	13.5	0.4	80	1.0	15		70
71	80	220	7.8	1.0	180	0.5	40		120
72	66.5	38.9	30.0	1.0	140	0.3	Nil		72
73	54	48	30.55	0.00	180	0.1	Nil		66
74	75	8.8	8.07	1.0	100	0.5	Nil		77.8
75	57	68	5.77	1.0	140	0.3	Nil		99.5
76	49	55	40.25	0.1	200	0.3	Nil		50
77	48.8	50.0	6.99	0.00	120	0.2	Nil		60.5
78	121.5	216	5.05	0.1	280	1.5	Nil		99.5
79	69	88	20	0.1	100	0.2	55		100
80	102	12.0	8.88	0.1	220	1.2	60		200
81	75	126.5	7.8	0.1	120	1.2	Nil		36
82	81.5	10.96	31.0	2.0	80	0.4	Nil		47.20
83	7.80	20.5	22.4	Nil	120	0.3	Nil		50.70

84	3.20	16.40	9.20	1.0	120	1.0	Nil		100.5
85	42.80	20.96	20.0	1.0	60	1.0	Nil		80.0
86	6.40	11.44	13.2	0.01	100	0.1	44.0		20.50
87	15.5	9.77	10.2	0.1	80	0.3	Nil		70.5
88	40.0	25.0	17.9	1.0	120	0.5	Nil		140
89	30.55	41.0	60.75	2.0	280	0.5	Nil		240
90	46.5	26.5	50.9	2.0	280	1.0	Nil		278
91	12.7	50.5	15.6	Nil	100	0.1	Nil		25.5
92	27.0	40.15	140.05	0.1	260	0.3	41.5		100
93	10.20	12.00	7.20	0.1	60	0.2	Nil		24.5
94	12.00	42.00	90.0	1.0	80	0.3	Nil		70
95	15.00	20.00	12.22	0.1	80	0.1	Nil		30.5
96	12.92	35.02	9.02	0.1	60	0.2	Nil		68.0
97	7.55	12.05	2.95	0.1	80	0.1	Nil		40.95
98	9.90	25.50	3.55	0.1	100	0.2	Nil		15.0
99	46.0	65.55	22.8	0.1	200	0.2	Nil		200.5
100	20.05	21.09	20.99	_	80	0.3	15.5		40.5
101	9.02	10.0	6.90	0.1	80	0.1	Nil		115.5
102	4.20	60.00	120.0	2.0	80	1.5	30		78
103	41.00	20.8	49.9	1.0	100	1.0	Nil		120

APPENDIX IV
PHYSICO-CHEMICAL ANALYSIS AND LANDUSE/LANDCOVER

Well No	LANDUSE LANDCOVER CLASSES	COLOUR (H.U)	TURBIDITY (NTU)	TEMP (°C)	ELCTRICAL CONDUCTIVITY (µS/cm)	TOTAL SOLID (mg/l)	SUSPENDED SOLID (mg/l)	DISSOLVED OXYGEN (PPM)	DISSOLVED SOLID	pH
1	Built up Area with medium density housing	5	1.02	31.0	18.6	3.5	0	5.0	3.5	6.8
2	Close to an outcrop	10	2.52	31	22.0	8.5	0	4.50	8.5	4.8
3	Close to an outcrop	5	1.05	31	20.0	6.9	0	7.05	6.9	7.5
4	Built up Area with medium density housing	5	2.0	31	18.55	9.0	0	6.6	9	6.5
5	Vegetative area	5	1.35	32	7.5	2.9	0	7.8	2.9	7.0
6	Close to river	5	1.25	31.5	25.01	12.0	0	5.5	12	5.5
7	Built up Area with low density housing	5	1.0	31	8.5	2.7	0	6.0	2.7	7.8
8	Built up Area with medium density housing	5	25.02	4.25	22.5	35.5	0	5.6	35.5	6.0
9	Vegetative area close to road	10	4.25	31	23	3.8	3.8	4.5	0	6.5
10	Vegetative area	5	1.05	31.5	7.75	4.7	0	4.5	4.7	6.0
11	Baresurface	5	1.22	32	5.4	2.0	0	4.5	2	8.0
12	Vegetative area	5	2.55	31.0	6.02	7.5	0	8.3	7.5	5.8
13	Dryland	5	1.45	32.0	3.55	3.4	0	6.65	3.4	6.2
14	Built up Area with medium density housing	10	8.5	30.0	7.91	12	6.0	4.05	6	3.5
15	Close to an outcrop	5	12.5	31.0	16.34	40	2.0	11.57	38	5.5
16	Built up Area with medium density housing	10	15.5	31.0	5.00	56.0	4.1	12.22	51.9	6.0
17	Baresurface	5	12.05	31.0	7.85	4.9	2.0	11.76	2.9	7.5
18	Baresurface	15	7.9	31.0	6.66	7.2	1.5	11.06	5.7	8
19	Built up Area with low density housing(2)	60	38	31.0	34.40	22.2	12.15	4.1	10.05	6.5

20	Baresurface	10	55	31.0	25.75	320.0	200	4.96	120	7.5
21	Baresurface	40	30.7	31.0	15.50	185	90	4.78	95	8.2
22	Builtup area with medium density housing	40	24.75	31.0	20.40	14.8	5.0	4.58	9.8	6.5
23	Baresurface	5	25.5	31	18.2	9.0	1.5	4.84	7.5	7.5
24	Built up Area with low density housing(2)	10	21.7	31	11.5	41.0	12.0	4.65	29	6.2
25	Built up Area with low density housing(2)	15	35.7	31	5.75	25.0	9.0	4.84	16	5.8
26	Vegetative area	5	29.1	31	16.5	100	2.0	4.78	98	7.0
27	Builtup area with low density housing(2)	5	25.5	31	20.55	145.0	8.8	11.65	136.2	5.5
28	Builtup area with low density housing; close to texaco filling station	5	18.55	32	15.5	90	4.9	4.93	85.1	6.5
29	Builtup area with low density housing(2)	20	5.58	31	5.02	25.0	0.75	6.75	24.25	7.8
30	Baresurface with light vegetation	15	4.0	32	5.00	55	0.25	4.60	54.75	7.2
31	Builtup area with medium density housing	20	5.55	31	4.90	61.7	27.5	4.89	34.2	5.5
32	Builtup area with medium density housing	10	30.0	31	25.0	230	130	4.35	100	3.5
33	Built up Area with low density housing(2)	20	40	32	11.55	210	45	8.90	165	6.5
34	Baresurface close to farmland	20	12.05	31	7.55	48	17	5.0	31	6.8
35	Built up Area with medium density housing	60	105.5	32	33.05	420	160	4.87	260	5.8

36	Built up Area with medium density housing	5	5.7	31	4.5	5.5	2.5	8.0	3	7.2
37	Built up Area with medium density housing	10	1.05	31	8.50	12.5	4.2	7.55	8.3	6.0
38	Close to river	25	1.55	31	2.6	5.9	2.0	6.9	3.9	6.5
39	Builtup Area with low density housing(2)	20	2.05	32	5.55	70.5	10.0	8.88	60.5	6.8
40	Baresurface with light vegetation	20	4.05	31	6.65	25	9.2	7.05	15.8	7.2
41	Built up Area with low density housing(2)	25	4.70	31	7.01	20.1	5.2	6.00	14.9	6.5
42	Builtup area with low density housing(2)	30	10.55	31	2.0	42.5	5.9	4.92	36.6	6.6
43	Close to river; has thick vegetation	5	2.75	31	6.0	10.2	2.0	5.60	8.2	6.8
44	Built up Area with low density housing(2)	10	6.55	31	2.0	8.85	2.6	4.89	6.3	6.6
45	Built up Area with medium density housing	5	33.99	31	1.5	6.5	2.5	6.50	4	6.5
46	Built up Area with medium density housing	5	5.5	31	8.6	30.2	10.2	4.97	20.05	6.2
47	Built up Area with low density housing(2)	10	4.97	31	10.5	29.9	10.4	6.10	19.5	6.2
48	Builtup area with thick vegetation	5	6	31	2.9	40	15.0	5.00	25	6.5
49	Builtup area with medium density housing	5	4.05	30.5	12.6	50	15.0	4.96	35	5.8
50	Vegetated area with no density housing	20	8.99	31	20.0	30.55	10.5	4.92	20.05	5.8
51	Builtup area with vegetation	30	12.55	30	3.0	80.5	21.0	5.00	59.5	6.8
52	Builtup area with low density housing(2)	5	2.65	30	1.3	9.05	4.1	6.23	5	6.8

53	Builtup area with low density housing(2)	35	12.55	31	25.0	109.2	21.0	5.60	88.2	5.0
54	Builtup area with medium density housing	20	12	31	3.6	50.9	10.2	5.20	40.68	6.0
55	Builtup area with low density housing(2)	25	12	31	4.6	88.01	12.5	4.00	75.51	6.8
56	Builtup area with medium density housing	30	11.09	31	2.5	12.90	2.5	4.89	10.4	5.5
57	Builtup area with low density housing(2)	5	1.07	31	5.79	6.5	2.5	9.55	4	6.5
58	Builtup area with medium density housing	5	2.65	31	1.55	9.9	2.0	4.55	7.9	7.5
59	Builtup area with low density housing(2)	10	3.05	32	2.55	7.55	2.05	7.55	5.5	6.8
60	Uncompleted construction	5	0.95	31	12.05	12.5	0.55	8.99	11.95	7.0
61	Builtup area with low density housing(2)	20	17.90	31	19.5	55	12.6	4.90	42.4	6.0
62	Builtup area with low density housing(2)	20	35.5	31	15.00	26.5	0.7	5.50	25.8	7.8
63	Baresurface with light vegetation	25	45.0	31	45.55	43.5	35.0	10.5	8.5	8.0
64	Baresurface	15	12.05	31	8.55	6.5	1.05	8.5	5.45	7.5
65	Builtup area with low density housing(2)	25	8.55	31	2.70	11.5	9.0	4.98	2.5	6.5
66	Builtup area with medium density housing	5	2.70	31	8.99	12.0	1.50	4.99	10.5	6.0
67	Builtup area with low density housing(2)	10	9.0	30.5	2.66	9.5	1.5	4.99	8.0	6.8
68	Vegetativee area with footpath	20	10.55	31	3.53	7.55	1.05	4.99	6.5	6.8
69	Vegetative area	5	2.35	31	2.0	6.25	0.55	5.02	5.7	6.0
70	Builtup area with low density h(2)	5	2.33	31	0.99	50	0.2	5.0	49.8	6.2

71	Baresurface	35	27.0	32	77	400	16.5	68	383.5	7.8
72	Builtup area with low density housing(2)	5	3.26	31	15.0	50	40	4.98	10	6.8
73	Builtup area with low density housing(2)	20	10.05	31	15.50	49.9	22.5	4.98	27.4	6.2
74	Builtup area with low density housing(2)	25	9.55	31	5.55	15.5	7.5	5.0	8.0	6.8
75	Builtup area with low density housing(2)	20	10.55	31	8.55	15.0	0.15	4.98	14.85	7.4
76	Builtup area with low density housing(2)	10	8.99	31	42.0	9.0	2.2	4.98	6.8	5.5
77	Builtup area with low density housing(2)	30	12.00	32	5.20	12.0	2.50	6.63	9.5	7.5
78	Builtup area with low density housing(2)	40	15.55	31	50.15	100.5	42.0	4.97	58.5	8.2
79	Builtup area with medium density housing	5	2.70	31	70	77	21	5.01	56	6.0
80	Builtup area with medium density housing	25	10.55	32	3.55	8.0	0.5	4.99	7.5	6.0
81	Builtup area with medium density housing	10	12.0	32	18.06	24.5	2.9	4.99	21.6	7.2
82	Close to an outcrop	20	8.15	31	15.5	45.9	12.5	4.91	33.4	5.6
83	Builtup area with low density housing(2)	5	2.99	31	5.50	12.5	2.5	5.94	10.0	6.8
84	Close to river; has thick vegetation	5	4.88	32	13.5	42.5	20.7	4.92	21.8	7.2
85	Builtup area with low density housing(2)	40	12.55	32	36.21	99.5	42.0	4.95	57.5	6.0
86	Builtup area with low density housing(2)	5	3.55	32	12.0	21.5	6.55	5.30	14.95	6.6

87	Builtup area with low density housing (2)	5	0.77	32	3.00	2.05	0.5	4.50	1.55	6.5
88	Builtup area with medium density housing	20	20.54	32	16.55	5.22	3.5	3.6	1.72	5.2
89	Close to river; has thick vegetation	30	10.55	32	23.55	10.05	16	3.99	405	6.2
90	Builtup area with low density housing(2)	40	40	31	25.05	23.55	455	4.99	19.0	4.5
91	Builtup area with low density housing(2)	20	13.0	31	3.25	15.55	12.0	4.99	3.5	6.2
92	Builtup area with medium density housing	20	12.77	31	16.00	12.51	3.52	4.00	8.99	6.6
93	Builtup area with medium density housing	25	12.99	31	6.78	1.05	0.50	5.0	0.55	6.8
94	Builtup area with medium density housing	20	21.55	31	10.00	2.10	0.65	4.25	1.45	6.0
95	Builtup area with medium density housing	5	1.25	31	10.50	3.50	1.00	4.95	2.50	8.0
96	Builtup area with low density housing(2)	10	0.95	31	2.44	5.00	2.56	3.37	2.44	7.0
97	Builtup area with medium density housing	5	0.65	31	0.79	0.5	0.2	4.94	0.3	6.8
98	Builtup area with medium density housing	5	3.55	31	1.25	2.05	0.5	5.03	1.55	6.8
99	Builtup area with MDH	10	3.75	31	2.55	15.59	6.75	5.0	8.84	6.8
100	Builtup area with LDH (2)	5	2.00	31	0.98	1.05	0.05	4.96	1.00	6.5
101	Builtup area with LDH(2)	15	10.00	31	3.45	9.00	1.55	5.2	7.45	6.8
102	Builtup area with MDH	40	32.55	33	14.05	12.75	3.05	3.95	9.75	5.5
103	Builtup area with MDH	30	15.99	31	45.55	10.00	3.02	3.55	6.98	5.2

APPENDIX V
PHYSICO-CHEMICAL ANALYSIS SORTED BY LANDUSE/LANDCOVER

BARESURFACE

	SN	EC (µS/cm)	TOTAL SOLID (mg/l)	SUSPENDED SOLID (mg/l)	DISSOLVED SOLID	pH	CALCIUM (mg/l)	MAGNESSIUM (mg/l)	CHLORIDE (mg/l)	TOTAL HARDNESS (mg/l)	NITRATE
	1	5.40	2.0	0	2	8.0	18.40	82.1	60	100	0.0
	2	7.85	4.9	2.0	2.9	7.5	45.00	40	24.0	140	1.00
	3	6.66	7.2	1.5	5.7	8	25.00	32.5	50.0	80	1.60
	4	25.75	320.0	200	120	7.5	146.00	88	75.9	100	40.50
	5	15.50	185	90	95	8.2	98.50	140	245	200	1.00
	6	18.20	9.0	1.5	7.5	7.5	42	40.5	10.9	100	0.3
	7	5.00	55	0.25	54.75	7.2	40	50	60	80	1.00
	8	7.55	48	17	31	6.8	59.00	60.5	9.15	100	1.50
	9	6.65	25	9.2	15.8	7.2	20.60	42	10.1	80	0.15
	10	45.55	43.5	35.0	8.5	8.0	75.9	100	96.6	200	0.15
	11	8.55	6.5	1.05	5.45	7.5	51	26	12.5	60	0.15
	12	77.00	400	16.5	383.5	7.8	80	220	7.8	180	0.00
MIN		5	2	0	2	6.8	18.4	26	7.8	60	0
MAX		77.0	400.0	200.0	383.5	8.2	146.0	220.0	245.0	200.0	40.5
MEAN		19.14	92.18	31.17	61.01	7.60	58.45	76.80	55.16	118.33	3.95

BUILTUP AREA WITH LOW DENSITY HOUSING

	SN	EC (µS/cm)	TOTAL SOLID (mg/l)	SUSPENDED SOLID (mg/l)	DISSOLVED SOLID	pH	CALCIUM (mg/l)	MAGNESSIUM (mg/l)	CHLORIDE (mg/l)	TOTAL HARDNESS (mg/l)	NITRATE
	1	8.5	2.7	0	2.7	7.8	5.6	43.5	85.0	180	1.0
	2	34.40	22.2	12.15	10.05	6.5	60.00	78	240	20	1.60
	3	11.5	41.0	12.0	29	6.2	70	55.0	100	80	1.0
	4	5.75	25.0	9.0	16	5.8	42	70	32	40	50
	5	20.55	145.0	8.8	136.2	5.5	40	60.0	190	180	1.5
	6	15.5	90	4.9	85.1	6.5	92	40	100.0	20	1.00
	7	5.02	25.0	0.75	24.25	7.8	45	61.5	12.0	100	0.15
	8	11.55	210	45	165	6.5	70.50	48.7	75.9	120	15.70
	9	5.55	70.5	10.0	60.5	6.8	48.00	65	14.5	60	0.10
	10	7.01	20.1	5.2	14.9	6.5	55.00	36	7.5	80	0.05
	11	2.0	42.5	5.9	36.6	6.6	6.25	11.07	20.4	20	0.00
	12	2.0	8.85	2.6	6.3	6.6	6.40	6.30	9.70	20	0.0
	13	10.5	29.9	10.4	19.5	6.2	6.70	22.5	42.5	20	0.00
	14	1.3	9.05	4.1	5	6.8	31.00	40.5	13.2	60	0.00
	15	25.0	109.2	21.0	88.2	5.0	9.25	60.98	14.85	120	0.00
	16	4.6	88.01	12.5	75.51	6.8	100.0	99.0	62.2	80	0.00
	17	5.79	6.5	2.5	4	6.5	45	49	20.5	80	0.05
	18	2.55	7.55	2.05	5.5	6.8	50.5	41.5	12.0	80	0.15
	19	19.5	55	12.6	42.4	6.0	55	14.8	102.5	100	0.15
	20	15.00	26.5	0.7	25.8	7.8	60.9	25.5	27.5	240	0.15
	21	2.70	11.5	9.0	2.5	6.5	22.5	48.0	30.0	100	0.00
	22	2.66	9.5	1.5	8.0	6.8	59.9	60.5	35.0	120	0.00
	23	0.99	50	0.2	49.8	6.2	96	60.5	13.5	80	0.0
	24	15.0	50	40	10	6.8	66.5	38.9	30.0	140	0.00
	25	15.50	49.9	22.5	27.4	6.2	54	48	30.55	180	0.00
	26	5.55	15.5	7.5	8.0	6.8	75	8.8	8.07	100	0.00
	27	8.55	15.0	0.15	14.85	7.4	57	68	5.77	140	0.00
	28	42.0	9.0	2.2	6.8	5.5	49	55	40.25	200	0.00
	29	5.20	12.0	2.50	9.5	7.5	48.8	50.0	6.99	120	0.00
	30	50.15	100.5	42.0	58.5	8.2	121.5	216	5.05	280	0.00
	31	5.50	12.5	2.5	10.0	6.8	7.80	20.5	22.4	120	0.00
	32	36.21	99.5	42.0	57.5	6.0	42.80	20.96	20.0	60	0.00
	33	12.0	21.5	6.55	14.95	6.6	6.40	11.44	13.2	100	0.00
	34	3.00	2.05	0.5	1.55	6.5	15.5	9.77	10.2	80	0.00
	35	25.05	23.55	455	19.0	4.5	46.5	26.5	50.9	280	0.00
	36	3.25	15.55	12.0	3.5	6.2	12.7	50.5	15.6	100	0.00
	37	2.44	5.00	2.56	2.44	7.0	12.92	35.02	9.02	60	0.00
	38	0.98	1.05	0.05	1.00	6.5	20.05	21.09	20.99	80	0.00
MIN		0.98	1.05	0	1	4.5	5.6	6.3	5.05	20	0
MAX		50.15	210	455	165	8.2	121.5	216	240	280	50
MEAN		11.63	39.67	21.34	29.88	6.6	44.18	45.85	39.91	106	1.86

BUILTUP AREA WITH LOW DENSITY HOUSING

	SN	EC (µS/cm)	TOTAL SOLID (mg/l)	SUSPENDED SOLID (mg/l)	DISSOLVED SOLID	pH	CALCIUM (mg/l)	MAGNESSIUM (mg/l)	CHLORIDE (mg/l)	TOTAL HARDNESS (mg/l)	NITRATE
	1	8.5	2.7	0	2.7	7.8	5.6	43.5	85.0	180	1.0
	2	34.40	22.2	12.15	10.05	6.5	60.00	78	240	20	1.60
	3	11.5	41.0	12.0	29	6.2	70	55.0	100	80	1.0
	4	5.75	25.0	9.0	16	5.8	42	70	32	40	50
	5	20.55	145.0	8.8	136.2	5.5	40	60.0	190	180	1.5
	6	15.5	90	4.9	85.1	6.5	92	40	100.0	20	1.00
	7	5.02	25.0	0.75	24.25	7.8	45	61.5	12.0	100	0.15
	8	11.55	210	45	165	6.5	70.50	48.7	75.9	120	15.70
	9	5.55	70.5	10.0	60.5	6.8	48.00	65	14.5	60	0.10
	10	7.01	20.1	5.2	14.9	6.5	55.00	36	7.5	80	0.05
	11	2.0	42.5	5.9	36.6	6.6	6.25	11.07	20.4	20	0.00
	12	2.0	8.85	2.6	6.3	6.6	6.40	6.30	9.70	20	0.0
	13	10.5	29.9	10.4	19.5	6.2	6.70	22.5	42.5	20	0.00
	14	1.3	9.05	4.1	5	6.8	31.00	40.5	13.2	60	0.00
	15	25.0	109.2	21.0	88.2	5.0	9.25	60.98	14.85	120	0.00
	16	4.6	88.01	12.5	75.51	6.8	100.0	99.0	62.2	80	0.00
	17	5.79	6.5	2.5	4	6.5	45	49	20.5	80	0.05
	18	2.55	7.55	2.05	5.5	6.8	50.5	41.5	12.0	80	0.15
	19	19.5	55	12.6	42.4	6.0	55	14.8	102.5	100	0.15
	20	15.00	26.5	0.7	25.8	7.8	60.9	25.5	27.5	240	0.15
	21	2.70	11.5	9.0	2.5	6.5	22.5	48.0	30.0	100	0.00
	22	2.66	9.5	1.5	8.0	6.8	59.9	60.5	35.0	120	0.00
	23	0.99	50	0.2	49.8	6.2	96	60.5	13.5	80	0.0
	24	15.0	50	40	10	6.8	66.5	38.9	30.0	140	0.00
	25	15.50	49.9	22.5	27.4	6.2	54	48	30.55	180	0.00
	26	5.55	15.5	7.5	8.0	6.8	75	8.8	8.07	100	0.00
	27	8.55	15.0	0.15	14.85	7.4	57	68	5.77	140	0.00
	28	42.0	9.0	2.2	6.8	5.5	49	55	40.25	200	0.00
	29	5.20	12.0	2.50	9.5	7.5	48.8	50.0	6.99	120	0.00
	30	50.15	100.5	42.0	58.5	8.2	121.5	216	5.05	280	0.00
	31	5.50	12.5	2.5	10.0	6.8	7.80	20.5	22.4	120	0.00
	32	36.21	99.5	42.0	57.5	6.0	42.80	20.96	20.0	60	0.00
	33	12.0	21.5	6.55	14.95	6.6	6.40	11.44	13.2	100	0.00
	34	3.00	2.05	0.5	1.55	6.5	15.5	9.77	10.2	80	0.00
	35	25.05	23.55	455	19.0	4.5	46.5	26.5	50.9	280	0.00
	36	3.25	15.55	12.0	3.5	6.2	12.7	50.5	15.6	100	0.00
	37	2.44	5.00	2.56	2.44	7.0	12.92	35.02	9.02	60	0.00
MIN		0.98	1.05	0	1	4.5	5.6	6.3	5.05	20	0
MAX		50.15	210	455	165	8.2	121.5	216	240	280	50
MEAN		11.63	39.67	21.34	29.88	6.6	44.18	45.85	39.91	106	1.86

BUILTUP AREA WITH MEDIUM DENSITY HOUSING

	SN	EC (µS/cm)	TOTAL SOLID (mg/l)	SUSPENDED SOLID (mg/l)	DISSOLVED SOLID	pH	CALCIUM (mg/l)	MAGNESSIUM (mg/l)	CHLORIDE (mg/l)	TOTAL HARDNESS (mg/l)	NITRATE
	1	20.40	14.8	5.0	9.8	6.5	56.00	27	142	160	0.30
	2	4.90	61.7	27.5	34.2	5.5	55	60	25.0	100	1.60
	3	25.0	230	130	100	3.5	45	51.2	15	240	0.30
	4	12.6	50	15.0	35	5.8	4.8	11.4	9.20	60	0.00
	5	3.6	50.9	10.2	40.68	6.0	91.9	21.44	75.0	140	0.00
	6	2.5	12.90	2.5	10.4	5.5	20.8	22.90	40.0	60	0.0
	7	1.55	9.9	2.0	7.9	7.5	40.5	35	50.0	40	0.01
	8	8.99	12.0	1.50	10.5	6.0	70.0	45.9	28.41	140	0.00
	9	70	77	21	56	6.0	69	88	20	100	0.00
	10	3.55	8.0	0.5	7.5	6.0	102	12.0	8.88	220	0.0
	11	18.06	24.5	2.9	21.6	7.2	75	126.5	7.8	120	0.00
	12	16.55	5.22	3.5	1.72	5.2	40.0	25.0	17.9	120	0.0
	13	16.00	12.51	3.52	8.99	6.6	27.0	40.15	140.05	260	0.00
	14	6.78	1.05	0.50	0.55	6.8	10.20	12.00	7.20	60	0.00
	15	10.00	2.10	0.65	1.45	6.0	12.00	42.00	90.0	80	0.00
	16	10.50	3.50	1.00	2.50	8.0	15.00	20.00	12.22	80	0.00
	17	0.79	0.5	0.2	0.3	6.8	7.55	12.05	2.95	80	0.00
	18	1.25	2.05	0.5	1.55	6.8	9.90	25.50	3.55	100	0.00
	19	2.55	15.59	6.75	8.84	6.8	46.0	65.55	22.8	200	0.00
	20	14.05	12.75	3.05	9.75	5.5	4.20	60.00	120.0	80	0.00
	21	45.55	10.00	3.02	6.98	5.2	41.00	20.8	49.9	100	0.00
MIN		0.79	0.50	0.20	0.30	3.50	4.20	11.40	2.95	40.00	0.00
MAX		70.00	230.00	130.00	100.00	8.00	102.00	126.50	142.00	260.00	1.60
MEAN		14.05	29.38	11.47	17.91	6.15	40.14	39.26	42.28	120.95	0.11

BUILTUP AREA WITH THICK VEGETATION

	SN	EC (µS/cm)	TOTAL SOLID (mg/l)	SUSPENDED SOLID (mg/l)	DISSOLVED SOLID	pH	CALCIUM (mg/l)	MAGNESSIUM (mg/l)	CHLORIDE (mg/l)	TOTAL HARDNESS (mg/l)	NITRATE
	1	2.9	40	15.0	25	6.5	14.14	15.28	20.1	100	0.00
	2	3.0	80.5	21.0	59.5	6.8	60.0	60.70	103.0	120	0.00
MIN		2.9	40.0	15.0	25.0	6.5	14.1	15.3	20.1	100.0	0.0
MAX		3.0	80.5	21.0	59.5	6.8	60.0	60.7	103.0	120.0	0.0
MEAN		2.9	60.3	18.0	42.3	6.7	37.1	38.0	61.6	110.0	0.0

VEGETATED AREA WITH NO DENSITY HOUSING

	SN	EC (µS/cm)	TOTAL SOLID (mg/l)	SUSPENDED SOLID (mg/l)	DISSOLVED SOLID	pH	CALCIUM (mg/l)	MAGNESSIUM (mg/l)	CHLORIDE (mg/l)	TOTAL HARDNESS (mg/l)	NITRATE
	1	20.0	30.55	10.5	20.05	5.8	12.80	11.44	19.0	40	0.0
	2	7.5	2.9	0	2.9	7.0	16.8	96.0	120	100	0
	3	7.75	4.7	0	4.7	6.0	4.0	76.3	75	20	1.0
	4	6.02	7.5	0	7.5	5.8	96.00	135	40	60	0.10
	5	16.5	100	2.0	98	7.0	60	45	175	200	1.0
	6	2.0	6.25	0.55	5.7	6.0	45	99.5	40.0	120	0.00
	7	23	3.8	3.8	0	6.5	138	95.5	60	80	1.0
	8	3.53	7.55	1.05	6.5	6.8	69.0	90.55	26.6	180	0.00
MIN		2.0	2.9	0.0	0.0	5.8	4.0	11.4	19.0	20.0	0.0
MAX		23.0	100.0	10.5	98.0	7.0	138.0	135.0	175.0	200.0	1.0
MEAN		10.8	20.4	2.2	18.2	6.4	55.2	81.2	69.5	100.0	0.4

CLOSE TO AN OUTCROP

	SN	EC (µS/cm)	TOTAL SOLID (mg/l)	SUSPENDED SOLID (mg/l)	DISSOLVED SOLID	Ph	CALCIUM (mg/l)	MAGNESSIUM (mg/l)	CHLORIDE (mg/l)	TOTAL HARDNESS (mg/l)	NITRATE
	1	22.0	8.5	0	8.5	4.8	240	70.0	100	60	10.0
	2	20.0	6.9	0	6.9	7.5	15.0	41.5	80	140	0.1
	3	16.34	40	2.0	38	5.5	75.00	45	10.5	60	0
	4	15.5	45.9	12.5	33.4	5.6	81.5	10.96	31.0	80	0.00
MIN		15.5	6.9	0.0	6.9	4.8	15.0	11.0	10.5	60.0	0.0
MAX		22.0	45.9	12.5	38.0	7.5	240.0	70.0	100.0	140.0	10.0
MEAN		18.5	25.3	3.6	21.7	5.9	102.9	41.9	55.4	85.0	2.5

CLOSE TO RIVER

	SN	EC (µS/cm)	TOTAL SOLID (mg/l)	SUSPENDED SOLID (mg/l)	DISSOLVED SOLID	pH	CALCIUM(mg/l)	MAGNESSIUM (mg/l)	CHLORIDE(mg/l)	TOTAL HARDNESS (mg/l)	NITRATE
	1	25.01	12.0	0	12	5.5	180.0	52.5	355.0	140	1.6
	2	2.6	5.9	2.0	3.9	6.5	51.90	40.3	12.5	80	0.05
	3	6.0	10.2	2.0	8.2	6.8	23.00	12.12	0.51	20	0.00
	4	13.5	42.5	20.7	21.8	7.2	3.20	16.40	9.20	120	0.00
	5	23.55	10.05	16	405	6.2	30.55	41.0	60.75	280	0.00
MIN		2.55	5.9	0	3.9	5.5	3.2	12.12	0.51	20	0
MAX		25.01	42.5	20.7	405	7.2	180	52.5	355	280	1.6
MEAN		14.122	16.13	8.14	90.18	6.44	57.73	32.464	87.592	128	0.33

DRYLAND

SN	EC (µS/cm)	TOTAL SOLID (mg/l)	SUSPENDED SOLID (mg/l)	DISSOLVED SOLID	pH	CALCIUM(mg/l)	MAGNESSIUM (mg/l)	CHLORIDE(mg/l)	TOTAL HARDNESS (mg/l)	NITRATE
1	3.55	3.4	0	3.4	6.2	56.00	42.0	32.5	180	0.10

UNCOMPLETED CONSTRUCTION

SN	EC (µS/cm)	TOTAL SOLID (mg/l)	SUSPENDED SOLID (mg/l)	DISSOLVED SOLID	pH	CALCIUM(mg/l)	MAGNESSIUM (mg/l)	CHLORIDE (mg/l)	TOTAL HARDNESS (mg/l)	NITRATE
1	12.05	12.5	0.55	11.95	7.0	24	51.50	9.2	60	0.00