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WATER RESOURCES

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COMMUNIQUE OF THE 3OTH ANNUAL CONFERENCE OF THE NIGERIAN ASSOCIATION OF HYDROGEOLOGISTS (NAH) HELD AT JUSTICE IDRIS LEGBO KUTIGI INTERNATIONAL CONFERENCE CENTRE MINNA, NIGER STATE, NIGERIA.

The 30th Annual General Meeting, Conference and workshop of the Nigerian Association of hydrogeologists was held at Justice Kutigi Idris Legbo International Conference Centre Minna, Niger State, Nigeria from 5 to 8 November, 2018 with over three hundred participants in attendance.

The theme of the conference was “Adapting Scientific and Innovative Approaches in promoting Access to clean and safe water supply’’ with the following Sub-themes:

1. Challenges of groundwater exploration, development and management
2. Managing occupational hazards in groundwater development
3. Groundwater pollution and environmental health
4. Equipment management in water resources development
5. Groundwater and irrigation

The conference was declared open by the Minister of Water Resources Engineer Suleiman H. Adamu, FNAH, FNSE. A total of Fifty-five (55) Technical papers were presented at the conference. A pre-conference panel discussion on the theme and sub-themes was held. The following observations were made by participants’ sequel to exhaustive discussions:

1. That there are several laudable government policies, initiatives and programmes currently put in place to attain sufficiency in provision of portable water supply to Nigerians, however, most of the policies and initiatives need implementation to the latter to achieve optimal targets.
2. That the sector is plagued with quackery as lots of people currently involved in executing various water projects in the country are not competent.
3. The emerging trends in the exploration and exploitation of groundwater globally has made most previous methods adopted to be relatively obsolete, unsuitable and require update.
4. That there is paucity of hydrochemical data in the country and where available, their integrity cannot be guaranteed.
5. That the significant contributions of donor agencies and development partners have led to improved access to safe potable water in the country.
6. Huge financial challenge is faced by operators in the sector in acquiring relevant modern equipment.
7. There are erroneous trending opinions on the relationship between boreholes drilling and tremor occurrence in parts of the country.
8. There is inadequate utilization of groundwater for irrigation in agriculture.

Consequently, the following recommendations were made:

1. There should be concerned efforts at enforcing regulations that have been put in place by governments in the water sector. All agencies charged with such responsibilities should be empowered and encouraged to ensure effective compliance.
2. The need to promote professionalism in the water sector by encouraging the engagement of competent persons in the execution of water projects.
3. The need to pursue aggressive and systematic acquisition of hydrochemical data and the development of hydrochemical data base across the country.
4. The adoption of innovative and emerging trends in the exploration, exploitation and management of water resources in the country.
5. The strengthening of the relationship between donor agencies, development partners and the various tiers of government in order to ensure appropriate provision of funds for the development of the water sector.
6. Provision of funding supports with favourable interest rate for acquisition of necessary modern equipment for operators in the sector.
7. There is need for sensitization and mobilization of policy makers and the general public on the actual scientific mechanism responsible for earth tremor to correct the trending erroneous belief.
8. Increased utilization of groundwater in irrigation to ensure national food security.

The Association expresses her sincere appreciation and immense gratitude to the Honourable Minister of Water Resources, Federal Ministry of Water Resources, the Government and good people of Niger State for their warm hospitality and support during the conference.

Mr. E.I.C. Olumese, FNAH
President Nigerian Association of Hydrogeologists
Dated 6 November, 2018

WATER

RESOURCS

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NIGERIAN ASSOCIATION OF HYDROGEOLOGISTS

The association is a specialized body of the Nigerian Mining and Geosciences Society. The Association is subject to those Articles statuses and by laws of the society that apply to the association and also to the society. It is affiliate to the International Association of Hydrogeologists.

Objectives and functions of the Association:

1 To provide a forum for the meeting of professionals in hydrogeology and allied disciplines.
2 To prescribe qualifications required for the practice of the profession of hydrogeology.
3 To standardize qualifications required for the practice of the profession.
4 To encourage the collection of data, research and dissemination of information on water resources
5 To advice the government and their agencies as well as the public on the need to control the investigation and development of our water resources.
6 To harmonize funds and support from the government and other bodies in their involvement in programmes to enhance the practice of hydrogeology.
7 To cooperate with other allied professional bodies connected with the water resources development.
8 To nominate any member or members as arbitrators or investigators on water resources problems when called upon to do so.
9 To establish forum and facilities for:
  a Annual conference and general meetings of the Association
  b Holding of symposia, seminars and workshops on water resources problems from time to time.
  c Publishing proceedings of annual conferences, symposia, seminars, workshops and hydrogeological papers.
  d Registering professional Hydrogeologists.
  e Advertising of curricular development on the training of hydrogeologists in higher institutions in the country.
  f Any other functions to promote the profession of hydrogeology.

Membership

Membership to the association is open to all practicing Hydrogeologists and allied disciplines. Institutional membership is open to all water resources departments, companies, institutions, research bodies and others.

Information about the association can be obtained from the secretary, Dr (Mrs.) Aisha A. Kana, Department of Geology and Mining, Nasarawa State University, P.M.B 1022, Keffi, Nasarawa State, Nigeria

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Application of Remote Sensing and GIS for Groundwater Exploration, Abeokuta Southwestern Nigeria.

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Abstract

The manifestation and dissemination of groundwater in the basement complex rocks of Abeokuta, Ogun State, critically hinge on secondary porosities, through faults and fractures of the underlying lithology. The problem of scarcity of water in Federal University of Agriculture Abeokuta which is in Odeda Local Government area of Abeokuta can be effectively tackled by adopting the combined of Remote Sensing (RS) together with Geographical Information System (GIS) in generating a groundwater potential map of the region. Hence, this study was aimed at verifying the reliability of Geographical Information System (GIS) and Remotely Sensed data in carefully delineating groundwater potential zones in parts of Odeda Local Government Area, Abeokuta. The satellite imageries and topo – sheet was integrated using Arc GIS 10.1 software to generate thematic maps of geology, slope, normalized differential vegetation index (NDVI), land use/ land cover, lineaments density, drainage, and lithology of the study area. The weighting factor were assign to each layer of the thematic maps ranges between 1 - 4 in accordance to their relative importance to availability and distribution of groundwater. The results obtained from the analysis of integration of the data revealed that groundwater potential map the study area are classified into five zones; 9.2%, 44.9%, 33.7%, 10.2%, 1.9% of the study area falls under region of Very high, high, moderate, low and poor potentiality respectively. The study revealed that remote sensing and GIS provided competent tools for mapping auspicious sites for groundwater exploration.

Keyword: Basement, exploration, fracturing, freshwater, groundwater.

Introduction

Water is unique natural resources to man. It is disproportionately distributed across the planet earth. About 97.5% of the world global water is unsuitable for human and livestock consumption restricted to world's oceans (Shahid and Nath, 1999, Shahid *et al*., 2000). Approximately 69.5% of the remaining 2.59% earth fresh water is coagulated glaciers and while 30.1% and 0.4% of the remaining earth water represent groundwater and atmospheric/surface water respectively (Fetter 2007, Finch, 1990, Egbai 2013). As a result of this, an assessment of earth fresh water resource is actually important for its sustainable management. However, in recent years, rapid increase in population, lack of advancement in exploration techniques and urbanization, the quest for freshwater have increased exponentially. In order to address this problem, an urgent need for the efficient management and exploration of ground and surface water is required to put up with the interminably rising populace (Zhu and Ierland, 2012). The movement and occurrence of groundwater are majorly controlled by permeability and porosity of the underlying lithology of geology formation of the area (Aller et al., 1987, 1990; Tizo et al., 2009; Edet, 1993, Shahid *et al*., 1999). Several geo-morphological and geological features affect recharge of groundwater in any geological region are faults and fracture. Areas underlain by the basement complex rocks are generally characterized by low groundwater prospect (Louis and Gambas, 2002). In a typical hardrock setting, the geological stratification normally encountered consists of hardrock basement overlain by variably thick unconsolidated materials referred to as the overburden or the regolith.

The overburden is further stratified into the vadose and phreatic zones, separated by the water table (Fetter, 1980; Hiscock, 2005). Fresh igneous and metamorphic bedrock which constitute the basement complex, occur at varying depths and mostly at low degree of decomposition, thus suggesting low porosity and permeability. This informed why groundwater prospects of aquifers within bedrocks are mostly rated low, or of minor hydro-geologic importance. Consequently, the major focus for groundwater development in hardrock terrain is the aquifer within the regolith material (Clark, 1985; Acworth, 1987; Das *et al.,* 2007). However, a borehole anticipated to provide long term good yield is one which penetrates fairly thick overburden and additionally intersects available fracture(s) within the underlying bedrock (Carruthers and Smith*,* 1992).

Groundwater is majorly recharged by percolation of water through pores, faults and fractures of the underlying lithology (Gogoi, 2013; Nejad, 2009). The basement terrain of Abeokuta which falls within southwestern Basement Complex of Nigeria and the accessibility of groundwater are seasonal. Residents of Northern part Abeokuta, south-western Nigeria, rely on groundwater as a major source of water for domestic, livestock, farming and commercial uses. However, boreholes in the area experience low success yield at the peak of dry season. During the dry season, the quantity of water exploited from wells and bore-holes range from very little to nothing at times. Unfortunately, this remains the only source of water as most streams and rivers dry up. The culprit in this concern is the discontinuous nature of the basement aquifer system which limits the distribution and movement of groundwater. The prospect of groundwater in a particular region is affected by many factors such as drainage soil type, slope, recharge zones and lithology of the area. The privation of wide understanding on the distribution and occurrence of groundwater in the study area has led to the construction of boreholes and wells in unsuitable zones. Therefore, in order to effectively tackle this problem, extensive knowledge on the formation, storage and distribution of groundwater must be acquired. The formation of groundwater occurs in two different zones namely; unsaturated and saturated zones. In crystalline basement complex area such as the area under consideration, the occurrence and movement of groundwater is determined by an extent of fracturing and weathering of the rocks (Oloruniwo and Olorunfemi 1987, Todd, 2004). Fracturing of rocks surfaces can be express lineaments which can be extracted from imagery of remotely sensed images. Consequently, this study is aimed to verify the reliability of integration of Remote Sensing (RS) and Geographical Information System GIS technologies mapping groundwater potential zones and the output will provide scientific facts to guide the sitting of borehole and hand-dug well for active exploitation of groundwater in area under consideration.

Description of the Study Area

The study area covers part of Odeda and its environs. It is situated in the southwestern region of Nigeria. The study area covers an area of approximately 20km from the Abeokuta which is the state capital. It is bounded by latitude $7^0 13' N$ to $7^0 15' N$ and longitude $3^0 24' E$ to $3^0 26' E$ and its terrain varies with altitude. Odeda has a population of 109,449(according to the 2006 population census figure) as shown in Figure 1.

Topography and Climatic Condition of the Study Area

Abeokuta is characterized by an undulating topography with elevation value ranging from 100-400m above sea level (Akanni, 1992, Oloruntola and Adeyemi, 2014). The amount of rainfall varies between 750mm-1000mm in the rainy season and 250mm-500mm during the dry season (Akanni, 1992). The mean monthly temperature ranges between 25.7^{0}C in July to 30.2^{0}C in February with the mean annual temperature of 26.6^{0}C. The study area falls within the basement complex formation of south western Nigeria.

Geology of the Study Area

The basement complex rock comprises of folded gneiss, schist quartzite, older granite and amplubolite/mica-schist (Jones and Hockes, 1964). Abeokuta belongs to the stable place which was not subjected to intense tectonics in the past (Ufoegbune et al., 2009). The northern side of Abeokuta is characterized by pegmatitic uncertain by granite while the southern part enters the transition zone with the sedimentary formation of the eastern Dahomey Basin as shown in Figure 2.

Hydrogeology of the study Area

The populaces in basement area depend mostly on surface water, which is supplied by the water corporations having their source from the River Ogun. This source of surface water can never meet the demand of populace due to logistic and effect of seasonal variation. This type of water source is major source of water intake in Abeokuta has a very low yield mainly for the duration of the dry season when the rate of evaporation is high precipitation is always lower than the average.

Generally, nearly all sachet water industries depend on the water from the state water corporations; this has amplified the problem of water shortage for this reason, the demand for the water turns into greater than the supply especially during dry season. Furthermore, people also use hand dug wells, on the other hand this stance difficult during dry season because the obligatory depth would not be gotten due to the terrain, because of these reasons, groundwater should have been a substitute source of water. But the problem about pinpointing high productive aquifers in several parts of Abeokuta is a great task because Abeokuta lies within the Basement Complex rocks of Southwestern Nigeria. These rocks are of Precambrian age to early Palaeozoic age and prolong from the north-eastern part of the Ogun state (which Abeokuta belongs) on the trot southwest ward and dipping towards the coast (Ako, 1979). The different rock has various hydrogeologic characteristics. The underground faulting system is minimal and this has contributed to the problem of underground water occurrence in this area. The southern part of Abeokuta goes into the transition zone with the sedimentary basin, characterized by impartially satisfactory hydro-geological history. Also, western part of Abeokuta is regarded as by granitic gneiss which is fewer porous (Key, 1992). Thus, this area is greatly problematic and it is predisposed to low-slung yield groundwater supply. Abeokuta terrain was characterized to have two kinds of landforms.; knolls of granite, other rocks of the basement complex and nearly flat topography sparsely distributed low hills. Abeokuta is sapped by rivers, Ogun and Oyan which are the two major rivers and many small streams. The study area also has two climatic conditions mainly; the rainy season long-lasting for between seven and eight months between April and October with an interruption in August, and the dry season; running through November till February.

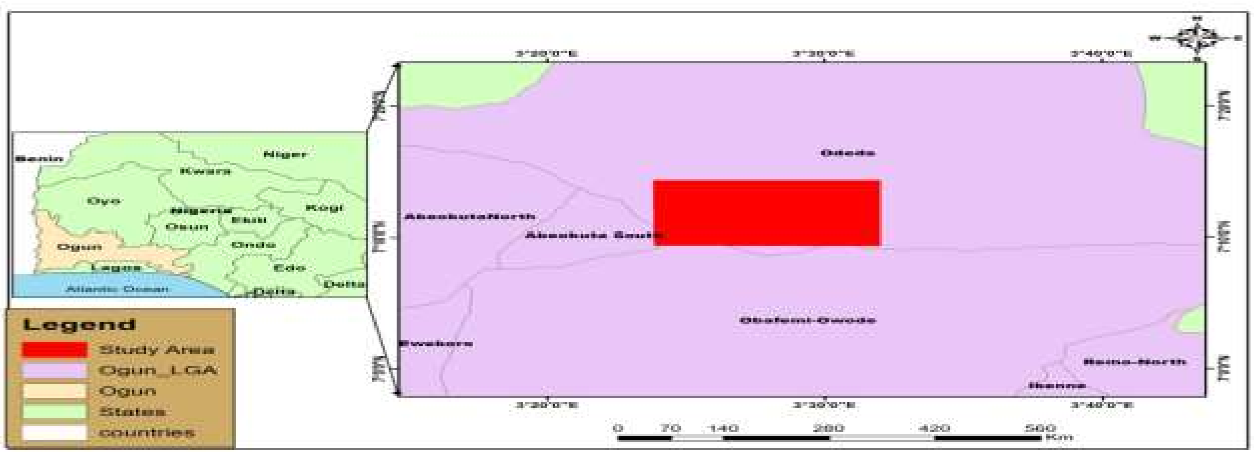

Figure 1: Location Map of the Study Area

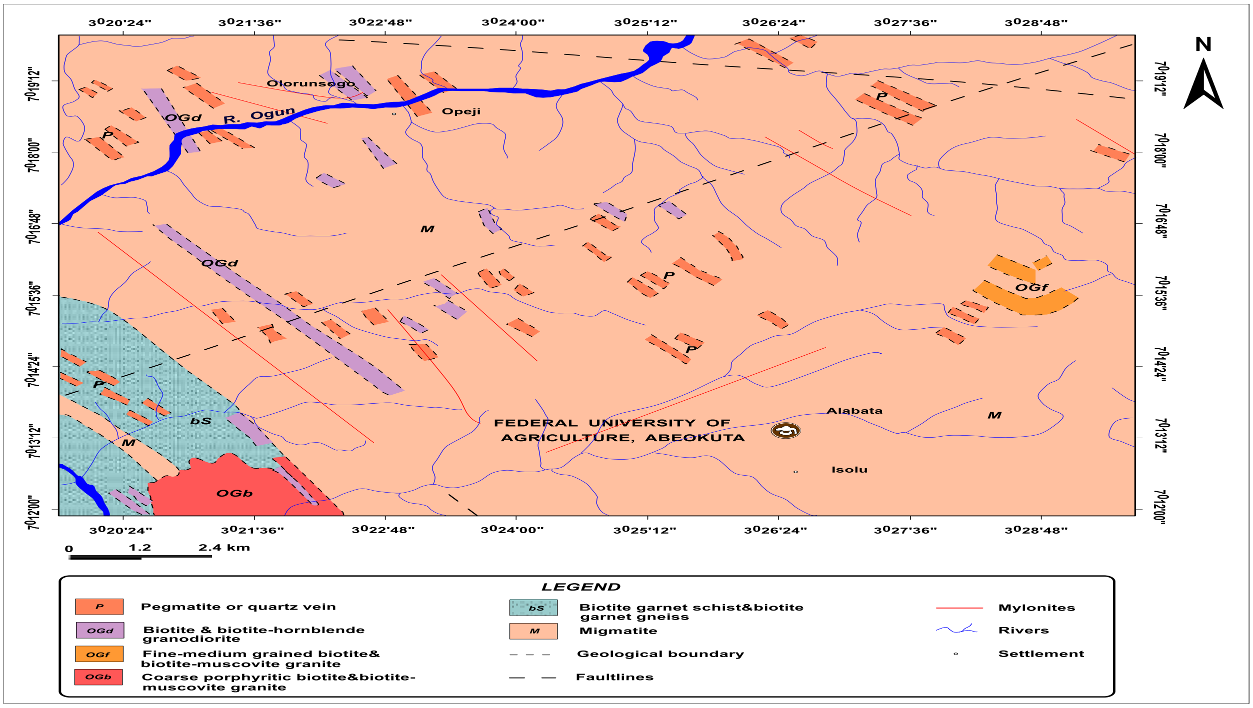

Figure 2: Geological Map of Abeokuta Showing the Study Area

Materials and Methods

In evaluating the study area, the groundwater prospective zone mapping is carried out by integrating satellite derived multi thematic maps using GIS technique and Digital Image Processing (DIP) of remote sensing data to identify the spectral class where layers of lithology, drainage patterns and lineaments were used to derive the most promising sites for groundwater exploration (Ibrahim and Ahmed, 2016, Waters et al., 1990, Goval et al., 2003). The GIS approach is based on the hypothesis that lineaments and drainage patterns important factors for evaluating the potential concentration of water in the fracture zone aquifer, while the second approach was proposed as a rapid method with minimum inputs for groundwater exploration.

Toposheets and high resolution satellite images acquired from Nigeria Geological Survey Agency and Google Earth respectively which were used for preparation of thematic maps. Seasonal Landsat Eight (8) images were used to prepare the thematic map as shown in the Table 1. All data used in this study were geo-referenced and projected to Geographic Coordinate System-World Geodetic System 1984 (GCS WGS) and Universal Transverse Mercator (UTM) zone 32 North for the easy handling in a GIS environment (Ibrahim and Ahmed, 2016, Jenson and Domingue, 1988). Satellites data were enhanced and processed for the better visualization. The toposheets were used as allusion maps for the preparation of thematic maps. Goggle Earth was used to update the individual maps from the current existing images in Google Earth over and done with the colour pattern and their look in the image. Also, weight was assigned to each thematic map according to their characteristics and interrelationships with groundwater as presented in Table 2.

Table 1: Data Acquisition

Sensor	Date of Acquisition	Spatial Resolution	Pathway	Source
Land sat TM	Dec 1984	30	191/055	Global land cover
Land sat ETM+	08 Nov 2000	30	191/055	United States Geological survey
Land sat OLI	19 Dec 2015	30	191/055	Global land cover facilities.
STRM (DEM)		30		Unites States Geological Survey
Soil map		1:7,945,418		FAO/ UNESCO

Table 2: Weighting of Each Thematic Layer

No	Parameter	Weight	Rating	Description	Remarks
1	Slope	**4**	4	Nearly flat	Good
			3	Gentle	Moderate
			2	Steep	Poor
2	Drainage density	**3**	4	Low	Poor
			3	Moderate	Fair
			1	High	Good
3	Land use/Land cover	**1**	1	Building	
			3	Outcrops	
			3	Vegetation	
			4	Wetlands	
4	Lineament density	**5**	4	Present	This is rather vague
			1	Absent	
5	Vegetation index	**2**	4	Dense	Good
			3	Moderate	Moderate
			2	Sparce	Poor
6	Lithology	**5**	1	Gneiss/Granite	Very poor
			2	Pink&Gray Granite	Very Poor – Poor
			3	Quartzite	Poor – Moderate
			4	Charnockitte	Good

Slope Map

Slope is an elevated geological formation of the earth's surface, and it is one of the most important features for the classification of groundwater potential zones. The higher the degree of slope, the higher the rate of surface runoff and erosion leading to a decrease in the recharge potential, whereas, plain slope or gently slope are favorable zones for groundwater due to the increase in the recharge rate, and low surface runoff (Du Wencai and Ye Deliao, 1993, Anon, 1990). The slope map was generated by importing processed Shuttle Radar Topographic Mission Digital Elevation Model (SRTM DEM) into Arc GIS 10.1 software using the spatial analysis tools. The generated slope map was then reclassified using its layers into appropriate class for the formation of groundwater prospect zones.

Lithology Map

The lithology map of the study area was acquired from the archive of Nigeria Geological Survey Agency (NGSA). The acquired map was extracted. Thereafter extracted map was geo-referenced and digitized using Arc GIS 10.1 software. The study area is covered by Abeokuta formation, coarse porphriticbiotite, biotite muscovite granite and prophoroblastic gneiss.

Lineament Map

The lineament map was generated from Land sat 8 and was expressed in lineament per unit area using the Arc GIS line density tool. In order to generate the lineament density of the area under consideration, the generated lineament from Land Sat 8alongsidewith lineaments gotten from Normalized Differential Vegetation Index (NDVI) and Digital Elevation Model (DEM) were overlaid, after which appropriate weightings were allocated to each layer of both the lithology and the lineament map of the study area.

Land Use/Land Cover Map

Land use /land cover map were generated by using high resolution imagery of consecutive three (3) years which are1984, 2000 and 2015 to as certain several changes that have occurred in the area under consideration. Four features were taking into consideration in analysis of land use and land cover map; building, wetlands (recharge zones), vegetation and outcrop. The thematic map was later reclassified and weighting of each training samples was based on their uses and how they influence the movement and occurrence of groundwater. Also, kind of land use provides necessary information on soil moisture, infiltration, surface water and groundwater. Regions having high groundwater potentiality encourage settlement, urbanization and agriculture while those having low potentiality discourage settlement, urbanization and agriculture.

Soil Map

Soil type of any expanse of area is an essential feature to be consideration in determining the rate of infiltration and aquifer depth of that specific region. The prerequisite in determining the irrigation system is the rate of infiltration in given area. Therefore, for this study, soil map of the study area was cropped from soil unit FAO/UNESCO/IS-RIC map of Nigeria. The study area is covered majorly by two soil association Egbeda and Ondo, and each having schist and fine grained Biotite gneisses, medium grained granites and gneisses as parent rocks.

Normalized Differential Vegetation Index Map

Normalized Differential Vegetation Index (NDVI) displays pixels (areas) with vegetation which was generated by using Band 4 that is Red (RED) and Band 5 that is Near Infrared (NIR) band of Land sat 8 given as Equation 1 using Arc GIS model builder. The result which ranges from -1 to +1 were adopted to reclassify various vegetation densities in the study area.

$$NDVI = \frac{NIR - RED}{NIR + RED} \quad \ldots 1$$

Drainage Density Map

Drainage density is a measure of the length of stream channel per unit area of the drainage watershed and also reflects subsurface formation as well as characteristics of the surface (Magesh *et al.,* 2012, Krishnamurthy et al., 1996, Batelaan et al., 1993). Low drainage density leads to decreases in rate of surface runoff subsequently give rise to a high recharge potential while high drainage density is promising for surface runoff thereby, resulting in low recharge potential. This clearly implies that drainage density is the reciprocal of permeability. Drainage map of the study area was generated by using the spatial analyst tool box in ArcGIS10.1 platform. Shuttle Radar Topographic Mission Digital Elevation Model (SRTM DEM) was processed to generate flow accumulation, flow direction, aspect, and stream order. The drainage density map of the study area was generated from stream network using focal statistics of the spatial analyst tool box in Arc GIS 10.1. Finally, the drainage density was reclassified and ranked according to its influence on groundwater.

Subsequently, all the above generated thematic maps were converted to Raster format and then assigned suitable weights in accordance to their relation to the occurrence and distribution of groundwater. All weighted thematic maps were integrated and processed in Arc GIS 10.1 to delineate the potential zones in the study area. The weighting adopted for this work was graphically presented in Figure 10.

Weighting

The various thematic maps used were assigned with a weighting value ranges from 1-4, depending on how they influence the movement, occurrence and distribution of groundwater. The weighting factor 1 represents very poor, 2 represents poor, 3 implies good, and lastly 4 denotes very good groundwater potentiality. The weighting value employed in this work was based on the respective importance of the various thematic maps to the occurrence and movement of groundwater following the approach of some selected research works done by (Mukherjee *et al.,* 2012;

Singh *et al.,* 2013; Saraf and Choudhary, 1998).

Data Integration

The seven thematic maps; Slope, Soil type, Lineament, Lithology, Drainage density, Normalized Differential Vegetation Index, Land Use/Land Cover were integrated using Arc GIS 10.1 software to generate groundwater potential index for the area under consideration. Hence, a complex groundwater potential index (GWPI) for the study area was produced using the Fuzzy overlay tool in Arc GIS software where the final potential map showing the prospect zones of the study area was acquired.

Result and Discussion

After the integration of seven thematic maps and extracted relevant information in the course of this study, it was discovered that several factors such as slope, drainage, soil, lithology and lineament affects the movement, distribution, storage and availability of groundwater in the study area.

Slope Map

From the analysis of the slope, the slope degree ranges from 0.0 to 10.7579298. The study area was divided into nine slope classes, with the areas having 0 – 1.0125-degree slope classified as very good because of its nearly flat terrain, which promotes relatively high infiltration because slope of any terrain is one of the factors allowing the infiltration of groundwater into subsurface or in other words groundwater recharge. The areas having a slope >7.299 degrees were considered as poor for groundwater storage due to their low infiltration and high surface runoff features as shown in Figure 3 (the thematic slope map of the study area).

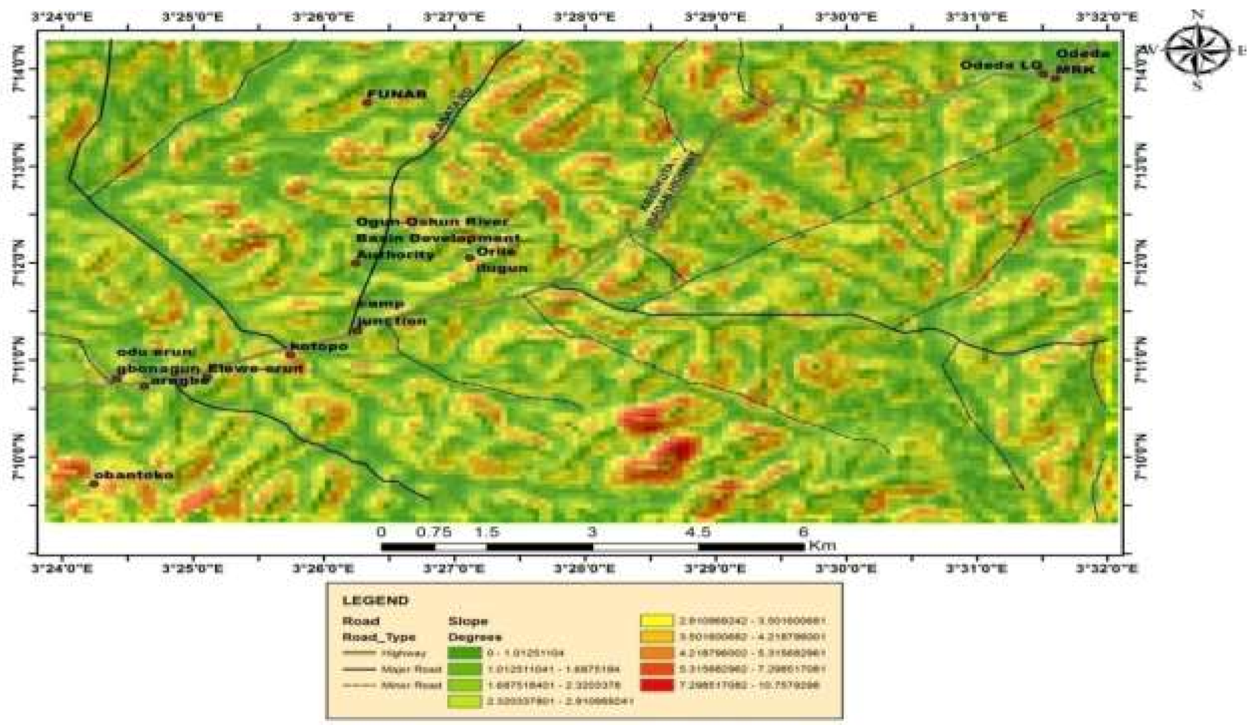

Figure 3: Slope of the study area

Drainage Density Map

The drainage density of the study area is categorized into five classes: From the analysis, areas with drainage density ranging from 1- 41km/km^2 are considered areas of good groundwater potentiality because of their low surface runoff and high rate of infiltration. Moderate groundwater potentialities are assigned to areas with drainage density ranging from 41 to 62 km/km^2. Areas having drainage density greater than or equal to 66 km/km^2 were considered zones of low groundwater potentiality because of their high surface runoff and low infiltration. The thematic map of drainage density is shown in Figure 4.

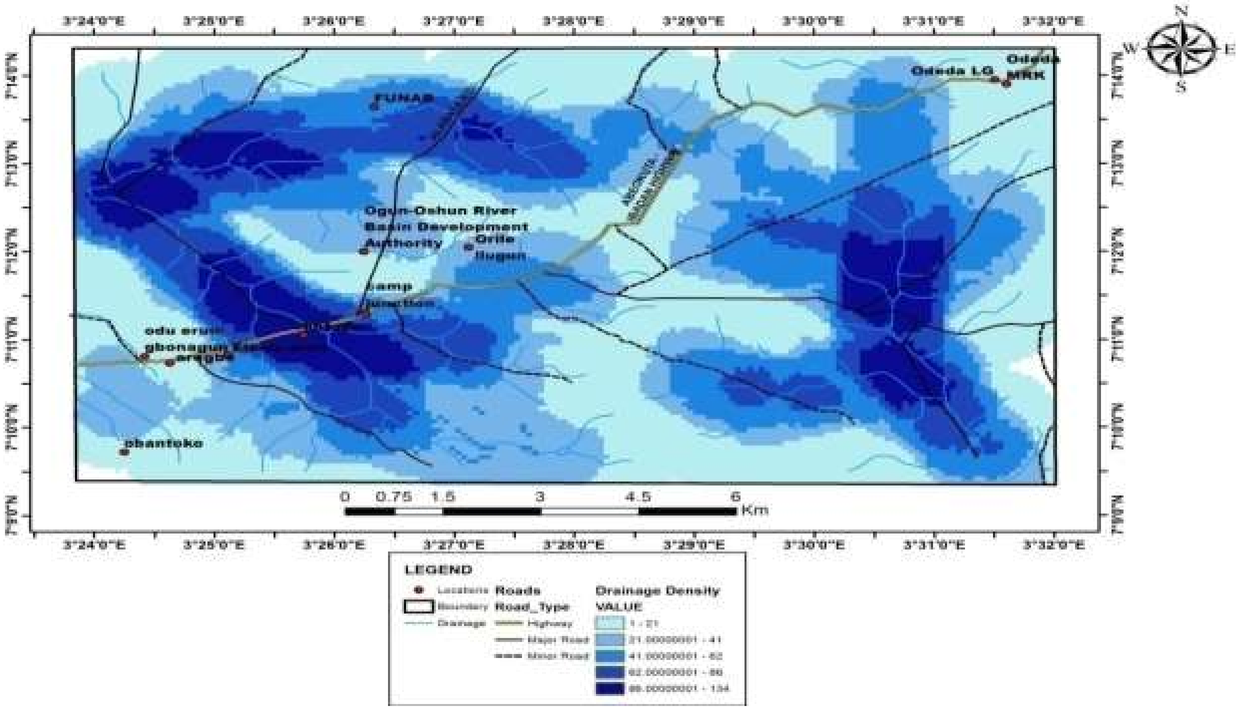

Figure 4: Drainage density of the study area.

Lineament Density Map

Lineaments are underlying geological features such as faults, pores and fractures. They are responsible for secondary porosity and permeability. The lineament of an area describes the groundwater zones present there, owning to the fact that they serve as openings for aquifers. The lineament density of the study area ranges from 0 km^{-1} to 7.9548 km^{-1}with the lineament being well distributed the analysis of lineament, have revealed that areas having lineament are good potential zones while areas without it denoted poor potential zone as shown in Figure 5. The rose diagram (Figure 6) of the faults and fractures of the lineament map shows the length and direction of the lineaments in the study area under consideration.

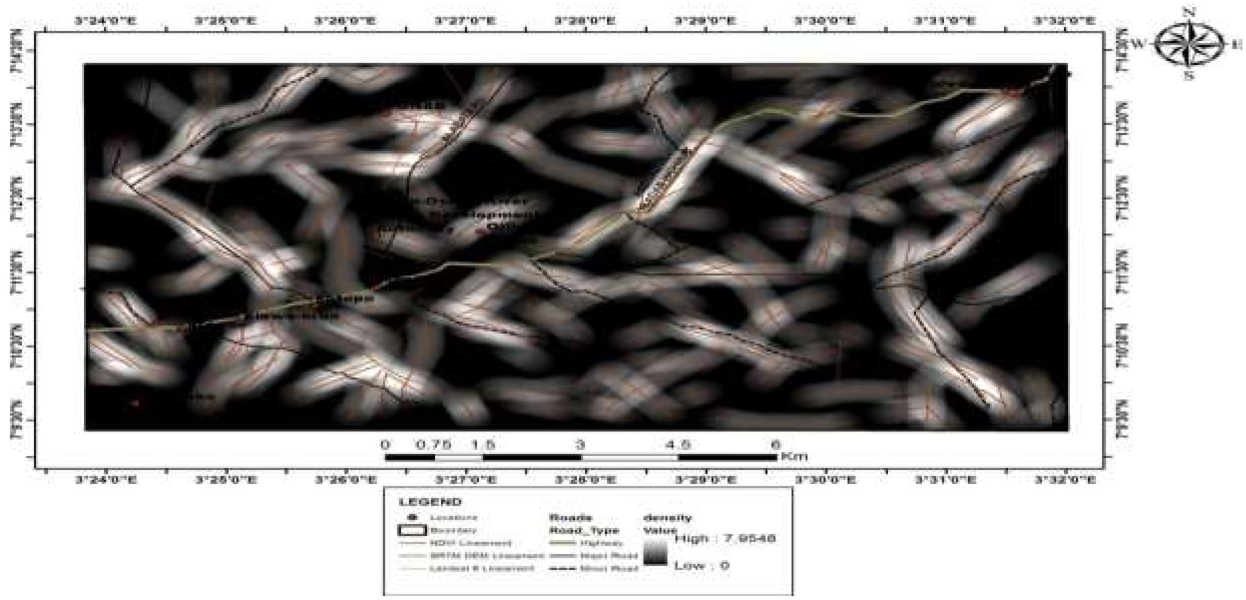

Figure 5: Lineament density of the study area

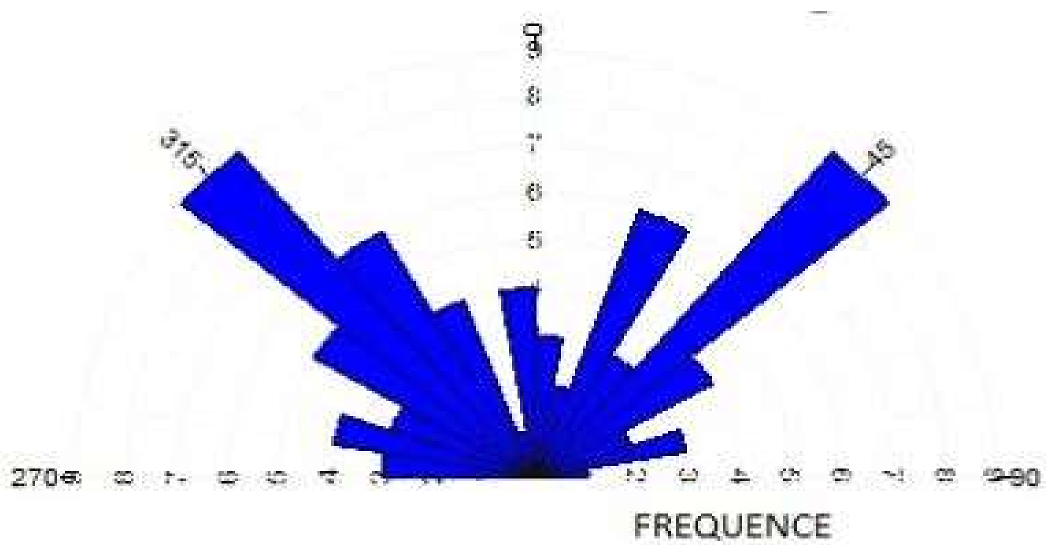

Figure 6: Rose diagram of lineaments in the study area.

Land Use/ Land Cover Map

Land use/land cover is an important feature in mapping groundwater, its feature influences groundwater in terms of its distribution, quality and quantity. Four training samples were obtained for the land use/ land cover map; bare soil, settlement, vegetation and wetlands. The analysis of land use/land cover map of the year 1984, 2000 and 2015, (Figures 7, 8 and 9) have revealed the various changes that have affected the training samples over the period of 31 years. Figures 10, reveals the changes in the training samples as presented in Figure 10. The various changes in the training samples of the three consecutive years were determined. It was observed that there is decrease in vegetation and an increase in bare soil from the year 1984 to 2000 which could be as a result of various human activities such as building and deforestation. People tend to settle in areas that favorable zones. The percentage increase in wetland training samples from 0.12% in 1984 to 3.4% in 2015, is as a result of deforestation and settlements. In 1984 the percentage of vegetation in the study area was 63.5% leading to most of the water coming from the recharge zones to be used for photosynthesis. This has made the wetlands to cover as small as 0.12%. In 2015, the percentage of area covered by wetlands have increased to 3.4% due to the fact that various human activities has been encouraged and the movement of water to different parts of the study area is now encouraged.

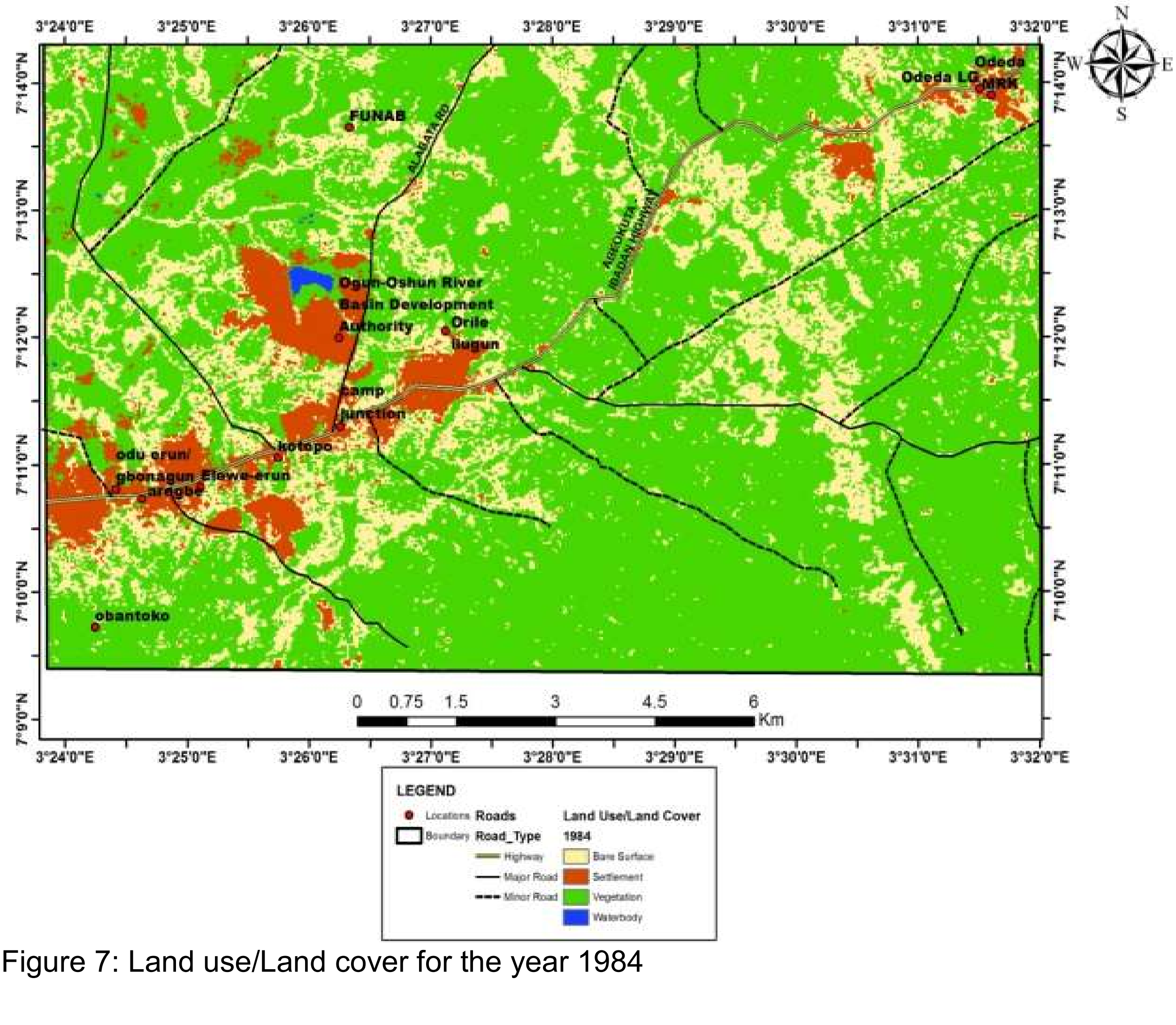

Figure 7: Land use/Land cover for the year 1984

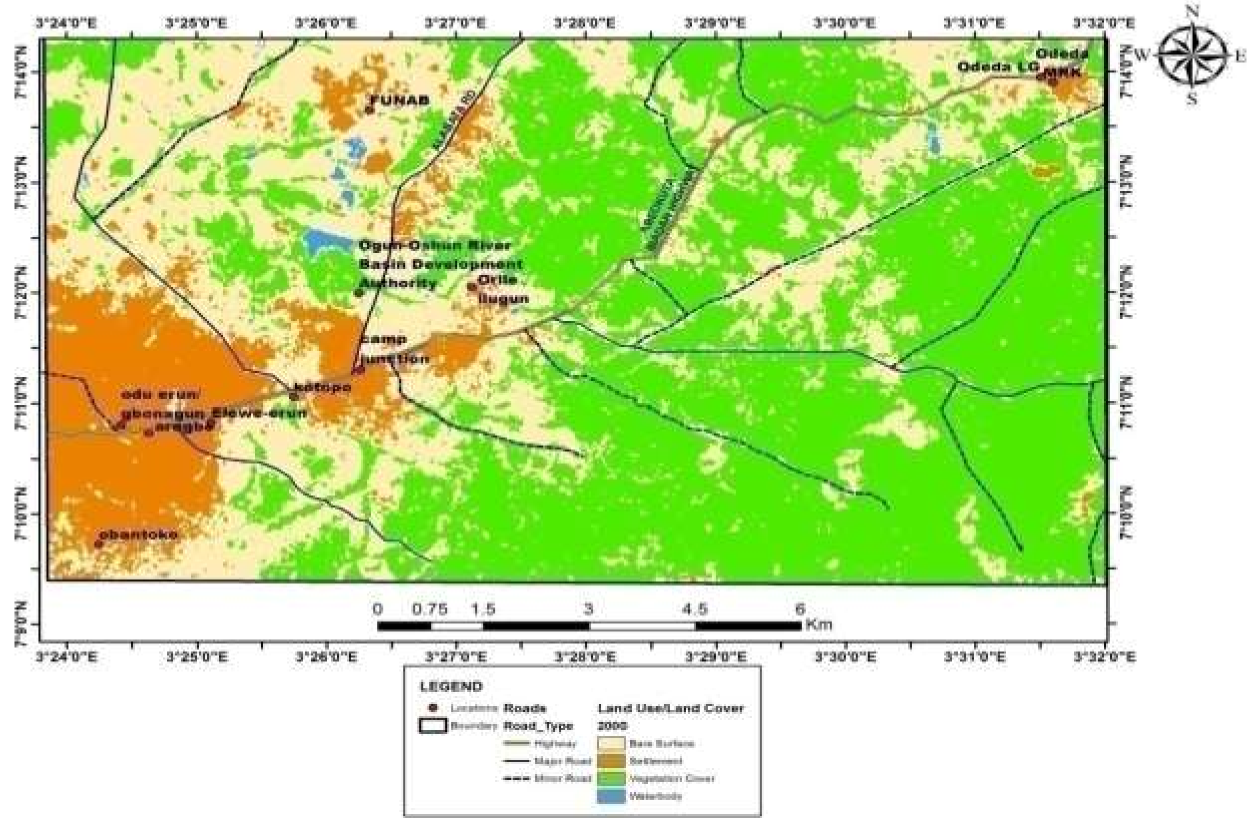

Figure 8: Land use/Land cover for the year 2000

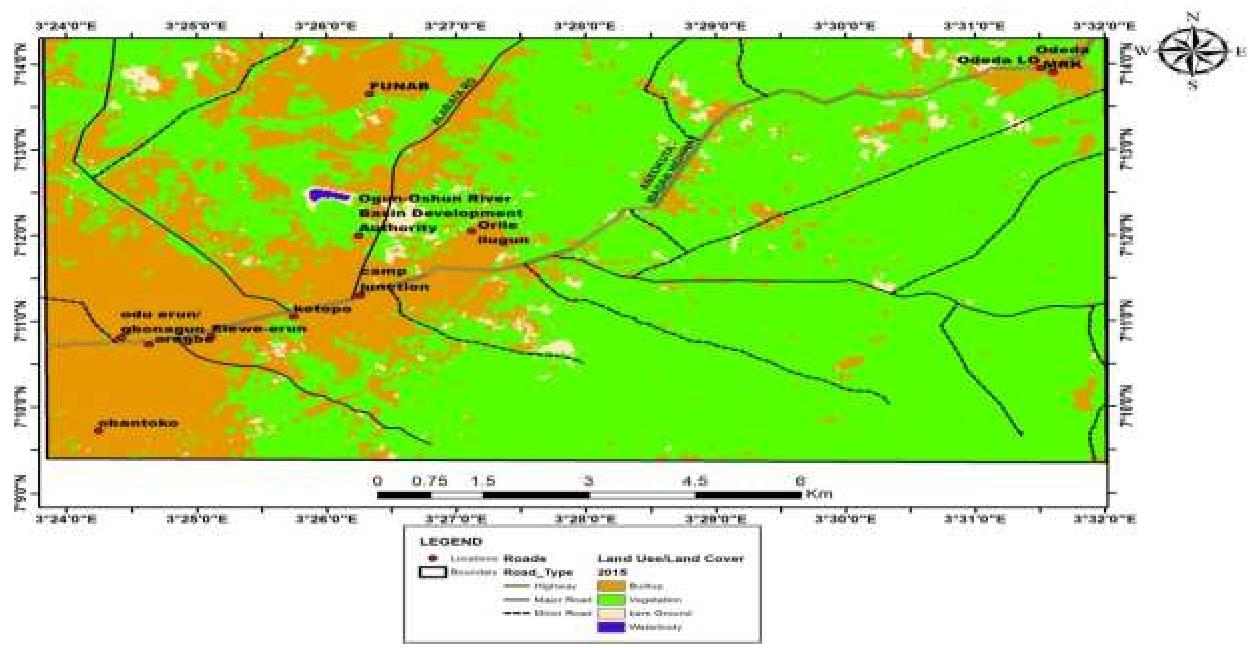

Figure 9: Land use/Land cover for the year 2015.

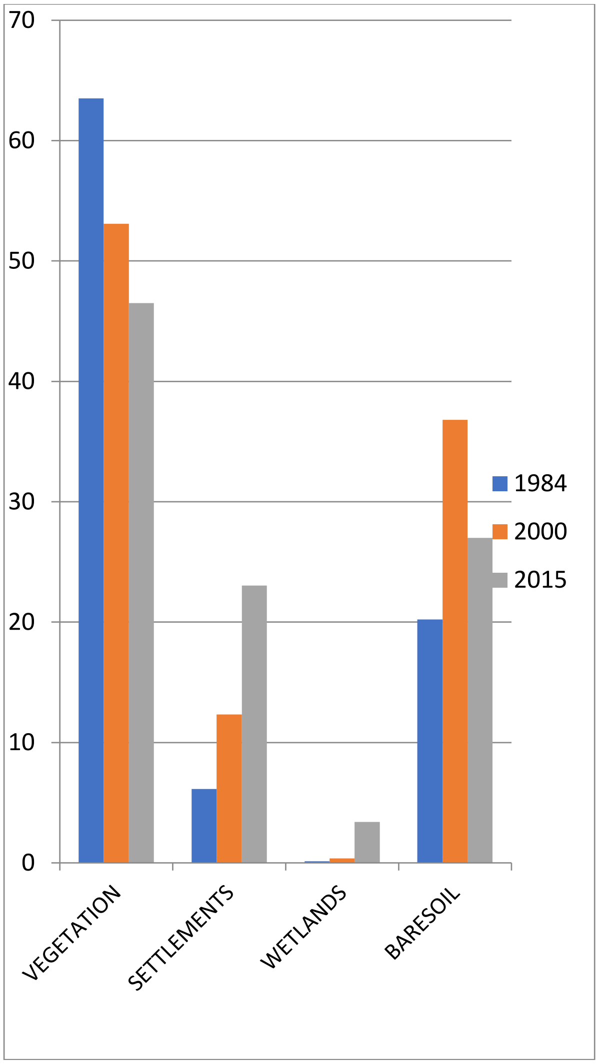

Figure 10: Chart showing the various changes in land use /land cover of the study area from 1984, 2000 to 2015.

Soil Map

Soil is an important parameter for modelling groundwater potential zones. Soil type and texture of a region determines the rate of infiltration and surface runoff. Regions covered with highly porous soil sample denote high groundwater potentiality while the reverse is for region of low groundwater potentiality (Rajasekhar et al., 2014). The analysis of soil of the study area reveals that the study area is majorly covered with well-drained soil of ferruginous soil associated with fine, medium granite and gneiss as their parent rock (Figure 11). These associations are categorized as soils for groundwater recharge and discharge due to their porous nature.

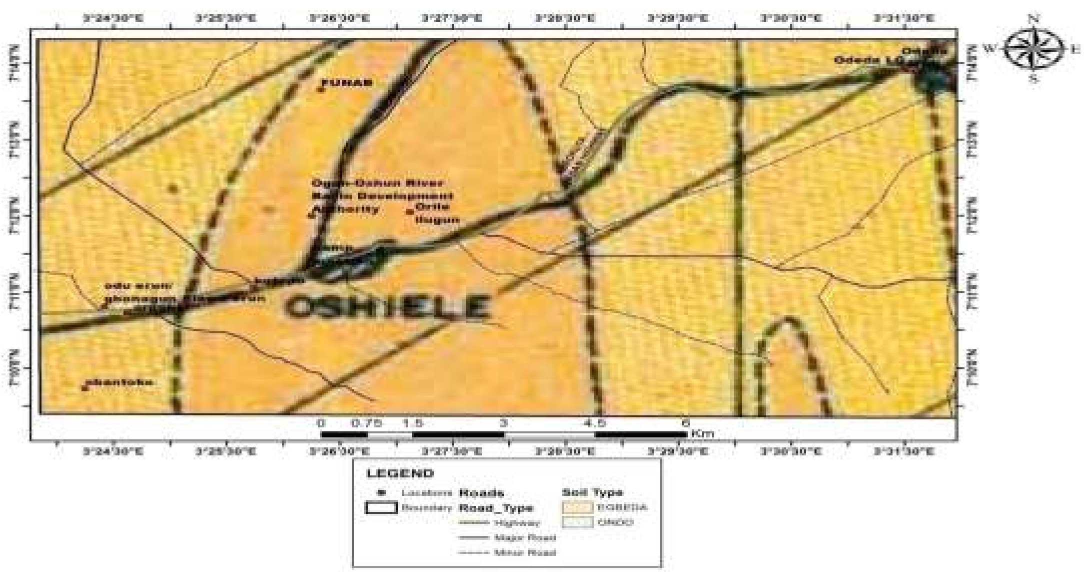

Figure 11: Soil map of the study area.

Normalized Differential Vegetation Index Map

Normalized differential vegetation index is the reflection of vegetation in the red and near infrared region. Figure 12 reveals the greenness and density of the vegetation. The type of vegetation cover in an area shows the potentiality of such areas. Densely vegetated areas are usually characterized with high groundwater potentiality and vice versa. The Normalized Differential Vegetation Index values of the study area ranges from 0.0582 to 0.3282. The analysis revealed that areas having a low Normalized Differential Vegetation Index value of 0.0582are bare soil, watersheds and rock outcrops. Shrubs, grasslands, annual and perennial vegetation have a high Normalized Differential Vegetation Index value of 0.3282.

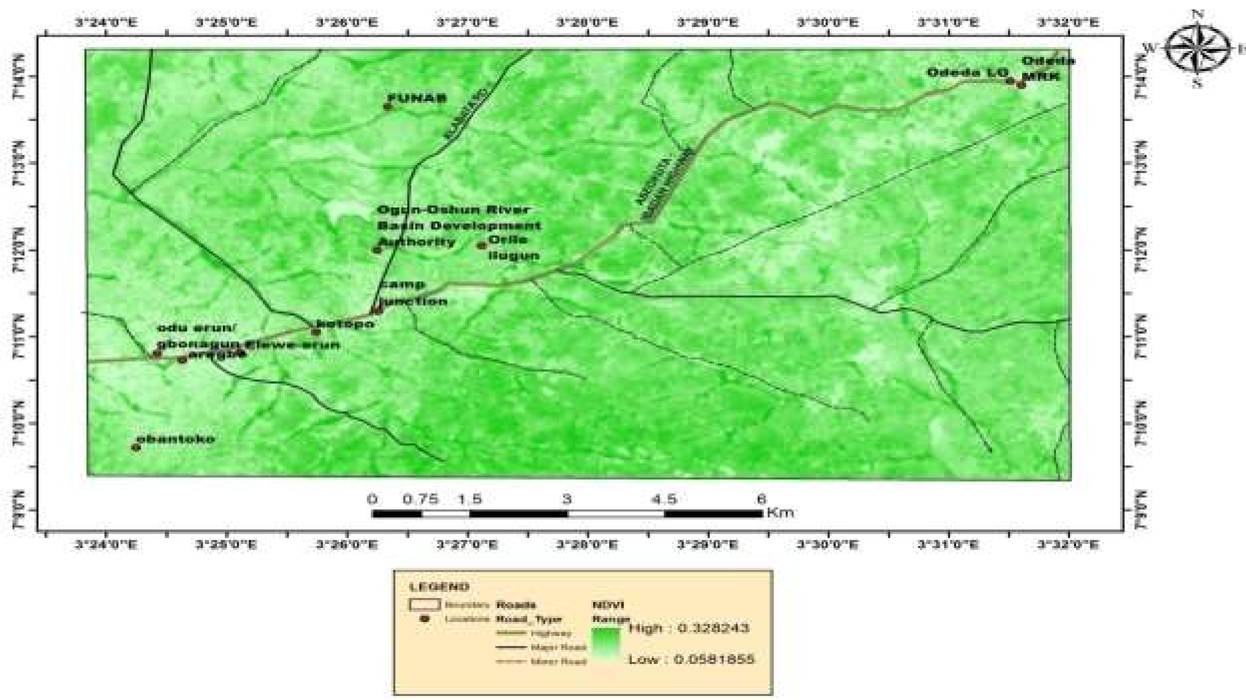

Figure 12: Normalized Differential Vegetation Index of the study area

Lithology

The underlying lithology of the study revealed that the study area was dominated with porphoblastic gneiss with an intrusion of coarse porphyritic biotite and biotite Muscovites granite with clear disposition of different zone with distinct anomaly ranges as shown in Figure 13. Figure 13 shows that the dominated region is related to basement structure (weathered layer) having sufficient faults and fractures are denoted as having good groundwater potentiality while poor fractured lithology is categorized as regions of low groundwater potentiality.

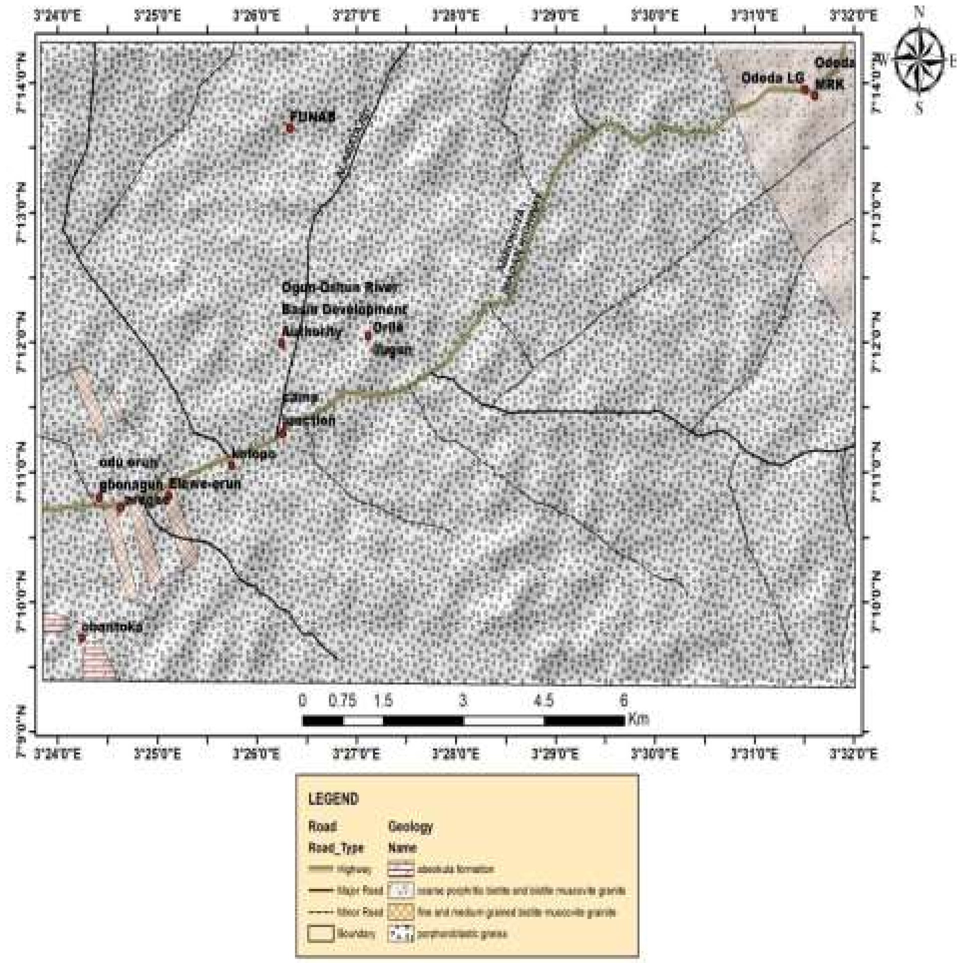

Figure 13: Lithology of the study area

Groundwater Potential Zones

In this study, groundwater potential zones of the study area were delineated using the integration of different thematic layer by Fuzzy Logic approach. The obtained potential zones from the Fuzzy Logic approach were used for the classification of the study as; Poor, Low, Moderate, High and Very High. The final potential map is graphically and statistically represented in Figures 14 and 15 respectively.

From the analysis, it was discovered that about 1.9%, 10.2%, 33.7%,44.90% and 9.2% of the study area are categorize as regions having poor, low, moderate, high and very high groundwater potentiality respectively.

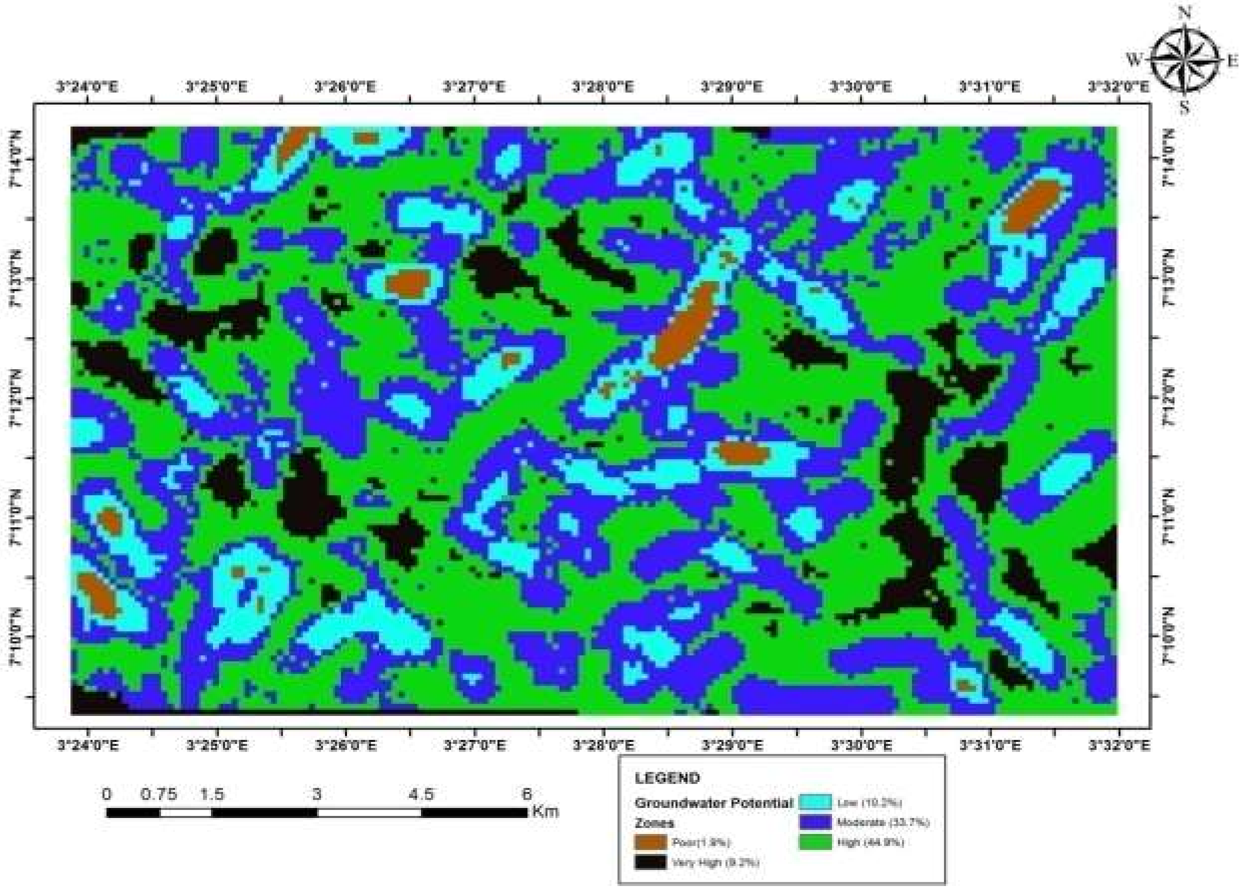

Figure 14: Groundwater Potential Zones Map

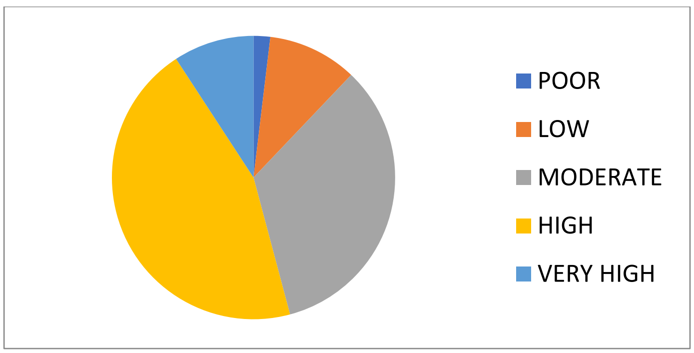

Figure 15: Percentage of groundwater potential zones (GWP).

Conclusion

Groundwater mapping is one of the main tools for efficient and controlled development of groundwater resources. These maps are used by decision makers to allocate, develop and manage groundwater within a national water policy.

Integrated RS and GIS techniques prove to be rather satisfactory options for groundwater mapping in Odeda. A remote Sensing (RS) and GIS technique are found efficient to minimize time, labour and money and thereby enables quick decision making for sustainable water resources management. Satellite imageries, topographic maps and conventional data were used to prepare the thematic layers of drainage density, lithology, lineament density, land use/land cover, soil type, water bodies density, normalized difference vegetation index (NDVI), slope, The various thematic layers are assigned proper weightage and then integrated in the GIS environment to prepare the groundwater potential zone map of the study area.

The use of Remote Sensing (RS) and Geographical Information System (GIS) in delineating groundwater potential zones in parts of Odeda within Abeokuta, Ogun State, have revealed that about 1.9%, 10.2%, 33.7%,44.90% and 9.2% of the study area are categorize as regions having poor, low, moderate, high and very high groundwater potentiality respectively. It can also be concluded that, parts of the study area having well fractured lithology were considered areas with little influence due to the presence of high drainage and slope. However, areas having low drainage density and slope resulted in good groundwater potentially owing to the fact that the lithology of the study area is well fractured. This research work would be used as a guide for effective conservation, exploration and exploitation of groundwater in the study area.

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Hybrid Wenner-Schlumberger Electrical Resistivity Investigation for Groundwater at Nasarawa State University Keffi, Keffi Sheet 208 NE, North-Central Nigeria.

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Abstract

Geological traversing at Nasarawa State University Keffi, part of Keffi Sheet 208NE, North-central Nigeria, revealed that the area is underlain by the Basement Complex rocks consisting of biotite gneiss, granitic gneiss and schist. The structural trends are mostly in NNW-SSE and NE-SW directions and foliation in the NE-SW direction. Surface geophysical investigation was conducted using the new hybrid Wenner-Schlumberger array, where fifty (50) stations were investigated along seven established profiles to determine the groundwater potential of the area. Six curve types were observed; HA, KA, QH, HAK and KHA; QHA-types has the highest frequency of occurrence while KA and HAK-types has the least. Results revealed that the top soil being the 1st layer with resistivity (62-5800 Ωm) and thickness (1-2 m). Laterite is the 2nd layer with resistivity (20-5550 Ωm), and thickness (2-7 m). The weathered basement is the 3rd layer with resistivity (43-2080 Ωm) and thickness (5-20 m). The fractured basement is the 4thlayer in the five (5) geoelectric layer case with resistivity (115-1700 Ωm) and thickness (25-50 m); while the partially weathered/fractured basement forms the 4thlayer in the six (6) geoelectric layer case with resistivity (66-2059 Ωm) and thickness (10-30 m). The fresh basement forms the 5thlayer in the five (5) geoelectric layer case with resistivity (312-2170 Ωm), while the fractured basement forms the 5thlayer in the six (6) geoelectric layer case with resistivity (139-2800 Ωm), and thickness (10-50 m). The fresh basement forms the 6thlayer in the six (6) geoelectric layer case with resistivity (310-3800 Ωm). The depth to fresh basement or overburden thickness range from 29-79.5 m, which implies that the area is generally good for groundwater development, especially places with distinctive weathered and/or fractured layers thicknesses. Groundwater potentials were zoned into low, medium and high potentials for groundwater development. Wenner data extracted and interpreted have a good degree of correlation with the Schlumberger results, the structural trends observed on the geological structures and with existing geology.

Keyword: Geological, geophysical, groundwater, geoelectrical section and Borehole

Introduction

The study area is located at the Nasarawa State University Keffi, part of Keffi Sheet 208NE, North-central Nigeria. It lies within latitudes N08˚50'56'' to N08˚49'34'' and longitudes E7˚53'40'' to E7˚55'00'', covering about 4.74 km^2; and can be accessed through the Keffi-Akwanga road(Figure1).The demand for potable water for human consumption and other usage has increased immensely as a result of population growth and hence, the need to evaluate her groundwater potentials for proper harnessing and sustainable supply, due to the fact that the aquifer in the Basement Complex are known to be discontinuous in nature. Sources of water supply in the area come from Mada water works, hand dug wells, hand pumps, streams and boreholes drilled in high weathered and/or fractured basement rocks. Most groundwater explorations have failed due to inadequate pre-drilling information (Gomes, 2006). Electrical resistivity hybrid Wenner-Schlumberger survey was adopted in the groundwater exploration and useful in reviling the geology of the subsurface layer of the study area for a well plan water development and management schemes.

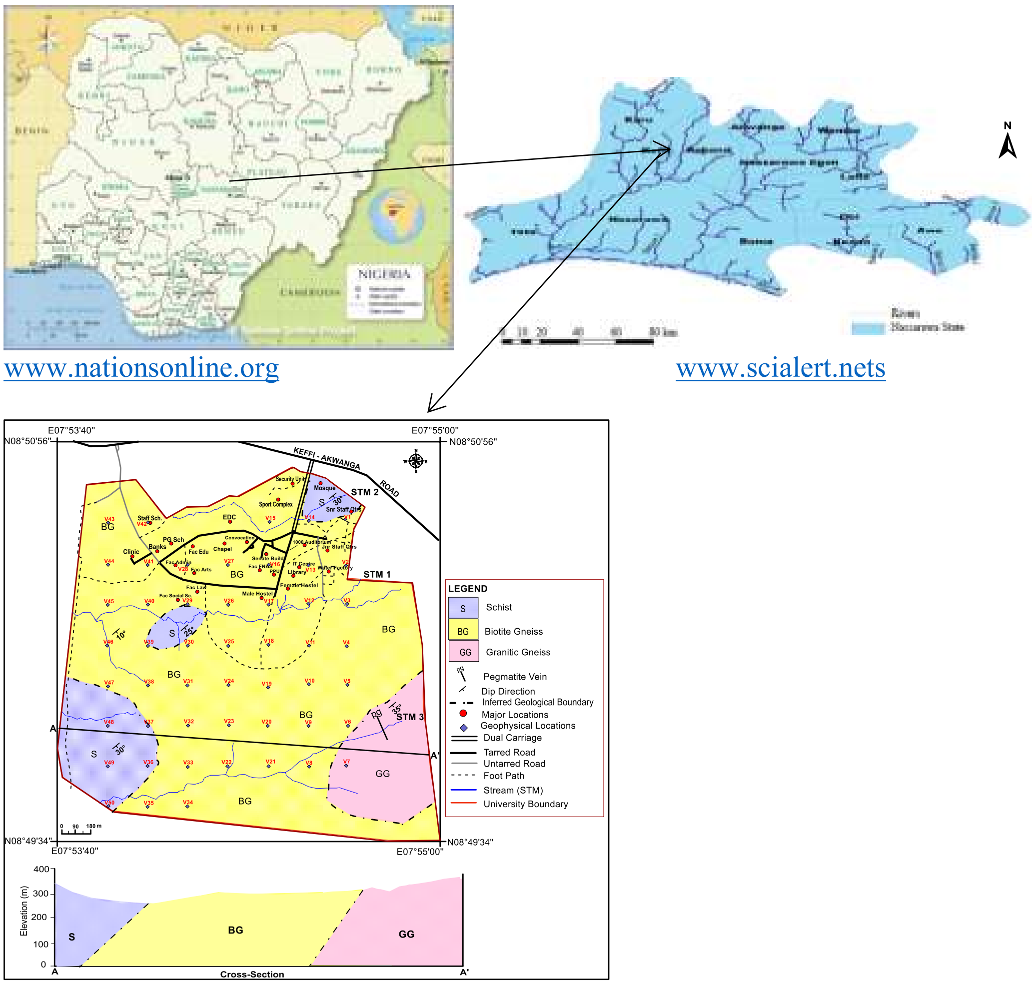
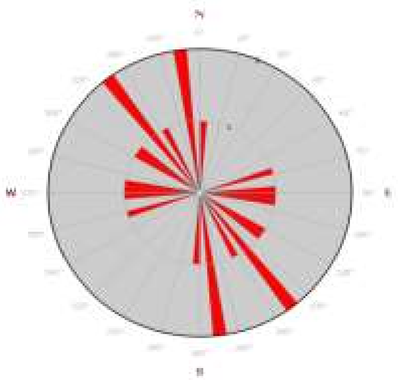


Figure 1: Location, accessibility, geophysical investigating points and geologic map of the study area (Mamza, 2018).

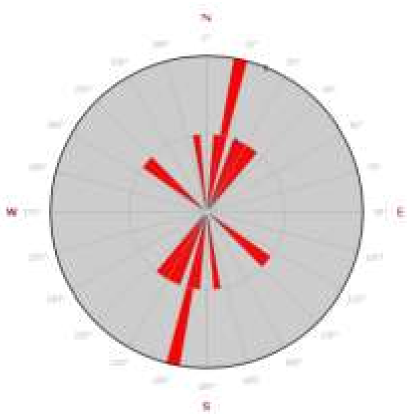
Geology of the Study Area

Geological mapping showed that the Basement Complex rocks present in the study area comprises of the following rock units; Biotite Gneiss (BG), Granitic Gneiss (GG) and Schist (S), where Biotite Gneiss

(BG) predominantly underlies the study area covering more than 80 % (Figure 1). The structural features found within the study area are veins (quartz and quartzo-feldspathic) trending NNW-SSE, joints trending NE-SW and foliations in the NE-SW direction, which corresponds with the major structural trends in Basement rocks (Jatau *et al.,* 2014; Ancho, 2015).



2a



2b

Figures 2a & b: Rosette diagram (2a) Vein (NNW-SSE) and (2b) Joint (NE-SW)

Methodology

A geological mapping of the area was carried and the Electrical Resistivity method of geophysical survey was conducted, using hybrid Wenner-Schlumberger array (Pazdirek and Blaha,1996). It is defined by K=(N+1) a where K is the geometric factor and "n' is the ratio of the distances between the C1-P1 (orP2-C2) electrodes to the spacing between the P1-P2 potential pair. The sensitivity pattern for the Schlumberger array is slightly different from the Wenner array with a slight vertical curvature below the centre of the array and slightly lower sensitivity values regions between the C1 and P1 (and also C2 and P2) electrodes. There is a slightly greater concentration of high sensitivity values below the P1-P2 electrodes. This means that this array is sentive to both horinzontal and vertical structures. In areas where both types of geological structures are expected, this array might be a good compromise between the Wenner and the dipole –dipole array (Pazdirek and Blaha, 1996). This involved a combination of both Vertical Electrical Sounding (VES) using Schlumberger array and Constant Separation Traversing (CST) using Wenner array in the study area. For every point or station that a VES reading was taken while spreading-out the cables, a CST reading was taken likewise while rolling back the cables. Fifty (50) VES and CST readings were taken coherently, with 200m station interval (Figure1). The field results were interpreted using IX1D and Surfer-12 computer software. Qualitative data were contoured using Surfer 12 software to produce piezometric, true aquifer resistivity, Wenner iso-resistivity, isopach or depth to fresh basement maps from the quantitative data and geo-electric sections were deduced and correlated with existing geology.

Results and Discussion

The quantitative data for Schlumberger array and qualitative data for Wenner were deducted as shown in Tables1 and 2

Table 1. Quantitative Interpretation of Data for Vertical Electrical Sounding (VES) Results

S/N	Sample ID	VES No	Coordinate	Thickness of Layers (m)							Total Depth (m)	Resistivity of Layers (Ωm)							No of Layers	Curve Type
				h1	h2	h3	h4	h5	h6	h7		ρ1	ρ2	ρ3	ρ4	ρ5	ρ6	ρ7		
1	V1	VES 1	N 8°50'37.0" E 7°54'40.0"	1	3.5	5	20	15	-	-	44.5	850	280	130	258	370	900	-	6	QHA
2	V2	VES 2	N 8°50'29.0" E 7°54'40.0"	1	3.5	5	10	25	-	-	44.5	406	135	78	68	151	340	-	6	QHA
3	V3	VES 3	N 8°50'21.0" E 7°54'40.0"	1	3.5	5	20	15	-	-	44.5	81	31	43	121	174	520	-	6	HA
4	V4	VES 4	N 8°50'13.0" E 7°54'40.0"	1	3.5	5	20	15	-	-	44.5	688	138	114	323	465	840	-	6	QHA
5	V5	VES 5	N 8°50'05.0" E 7°54'40.0"	2	2	5	10	25	-	-	44	270	170	150	180	291	717	-	6	QHA
6	V6	VES 6	N 8°49'57.0" E 7°54'40.0"	2	7	20	15	15	-	-	59	778	300	239	281	313	409	-	6	QHA
7	V7	VES 7	N 8°49'49.0" E 7°54'40.0"	1	3.5	5	20	30	-	-	59.5	234	20	50	575	139	702	-	6	HAK
8	V8	VES 8	N 8°49'49.0" E 7°54'32.0"	2	7	5	30	-	-	-	44	3237	150	92	213	404	-	-	5	QHA
9	V9	VES 9	N 8°49'57.0" E 7°54'32.0"	1	1.5	7	10	25	-	-	44.5	771	329	111	110	267	747	-	6	QHA
10	V10	VES 10	N 8°50'05.0" E 7°54'32.0"	1	3.5	5	20	15	-	-	44.5	688	227	133	153	230	473	-	6	QHA
11	V11	VES 11	N 8°50'13.0" E 7°54'32.0"	1	3.5	5	20	30	-	-	59.5	835	83	49	132	201	567	-	6	QHA
12	V12	VES 12	N 8°50'21.0" E 7°54'32.0"	1	3.5	5	20	15	-	-	44.5	656	147	124	177	217	389	-	6	QHA
13	V13	VES 13	N 8°50'29.0" E 7°54'32.0"	1	3.5	5	20	15	-	-	44.5	414	360	306	125	155	360	-	6	KHA
14	V14	VES 14	N 8°50'37.0" E 7°54'32.0"	1	3.5	5	20	15	-	-	44.5	287	99	200	583	888	2070	-	6	HA
15	V15	VES 15	N 8°50'37.0" E 7°54'23.5"	2	7	10	40	-	-	-	59	558	95	92	199	350	-	-	5	QHA
16	V16	VES 16	N 8°50'29.0" E 7°54'23.5"	1	3.5	5	10	30	-	-	49.5	1779	695	128	66	150	352	-	6	QHA

17	V17	VES 17	N 8˚50'21.0" E 7˚54'23.5"	1	3.5	5	20	15	-	-	44.5	840	381	99	111	140	371	-	6	QHA
18	V18	VES 18	N 8˚50'13.0" E 7˚54'23.5"	1	3.5	5	20	30	-	-	59.5	62	34	44	126	260	565	-	6	HA
19	V19	VES 19	N 8˚50'05.0" E 7˚54'23.5"	1	3.5	5	20	15	-	-	44.5	1480	234	77	122	165	407	-	6	QH
20	V20	VES 20	N 8˚49'57.0" E 7˚54'23.5"	1	3.5	5	20	50	-	-	79.5	656	289	163	139	277	367	-	6	QH
21	V21	VES 21	N 8˚49'49.0" E 7˚54'23.5"	1	3.5	5	20	30	-	-	59.5	4701	668	191	378	689	1200	-	6	QH
22	V22	VES 22	N 8˚49'49.0" E 7˚54'15.0"	1	3.5	10	15	15	-	-	44.5	1288	487	273	293	345	617	-	6	QH
23	V23	VES 23	N 8˚49'57.0" E 7˚54'15.0"	1	3.5	10	15	30	-	-	59.5	322	181	168	190	245	345	-	6	QH
24	V24	VES 24	N 8˚50'05.0" E 7˚54'15.0"	1	3.5	5	20	15	-	-	44.5	1142	227	197	418	667	1450	-	6	QHA
25	V25	VES 25	N 8˚50'13.0" E 7˚54'15.0"	1	3.5	5	20	15	-	-	44.5	321	188	110	130	160	310	-	6	QHA
26	V26	VES 26	N 8˚50'21.0" E 7˚54'15.0"	1	3.5	10	15	50	-	-	79.5	112	69	60	73	212	310	-	6	QHA
27	V27	VES 27	N 8˚50'29.0" E 7˚54'15.0"	1	3.5	5	20	15	-	-	44.5	346	140	177	370	450	810	-	6	HA
28	V28	VES 28	N 8˚50'29.0" E 7˚54'07.0"	1	3.5	5	20	30	-	-	59.5	216	232	183	243	370	673	-	6	KA
29	V29	VES 29	N 8˚50'21.0" E 7˚54'07.0"	1	3.5	10	15	15	-	-	44.5	1652	578	183	329	495	1145	-	6	QHA
30	V30	VES 30	N 8˚50'13.0" E 7˚54'07.0"	1	3.5	5	20	15	-	-	44.5	201	135	74	188	261	733	-	6	QHA
31	V31	VES 31	N 8˚50'05.0" E 7˚54'07.0"	1	3.5	5	20	30	-	-	59.5	760	295	211	253	331	442	-	6	QHA
32	V32	VES 32	N 8˚49'57.0" E 7˚54'07.0"	1	3.5	5	20	30	-	-	59.5	780	193	153	196	291	514	-	6	QHA
33	V33	VES 33	N 8˚49'49.0" E 7˚54'07.0"	1	3.5	10	15	30	-	-	59.5	3246	3330	1800	2059	2800	3800	-	6	KHA
34	V34	VES 34	N 8˚49'41.0" E 7˚54'07.0"	1	3.5	5	20	15	-	-	44.5	293	152	145	261	418	1200	-	6	QHA
35	V35	VES 35	N 8˚49'41.0" E 7˚53'59.0"	1	3.5	5	20	15	-	-	44.5	1340	340	115	235	363	867	-	6	QHA
36	V36	VES 36	N 8˚49'49.0" E 7˚53'59.0"	1	3.5	5	20	30	-	-	59.5	1595	539	290	227	297	430	-	6	QHA
37	V37	VES 37	N 8˚49'57.0" E 7˚53'59.0"	1	3.5	10	15	30	-	-	59.5	400	195	143	171	240	350	-	6	QHA

38	V38	VES 38	N 8°50'05.0" E 7°53'59.0"	1	3.5	5	20	15	-	-	44.5	1127	237	119	208	256	500	-	6	QHA
39	V39	VES 39	N 8°50'13.0" E 7°53'59.0"	1	3.5	5	20	15	-	-	44.5	2979	352	168	376	535	1612	-	6	QHA
40	V40	VES 40	N 8°50'21.0" E 7°53'59.0"	1	3.5	10	30	-	-	-	44.5	1100	354	70	115	312	-	-	5	KHA
41	V41	VES 41	N 8°50'29.0" E 7°53'59.0"	1	3.5	5	20	15	-	-	44.5	758	277	197	275	372	576	-	6	QHA
42	V42	VES 42	N 8°50'37.0" E 7°53'59.0"	1	3.5	15	40	-	-	-	59.5	1563	571	110	175	342	-	-	5	QHA
43	V43	VES 43	N 8°50'37.0" E 7°53'50.5"	2	2	5	10	10	-	-	29	5800	5550	2080	342	320	1100	-	6	QH
44	V44	VES 44	N 8°50'29.0" E 7°53'50.5"	2	7	20	50	-	-	-	79	1043	224	650	1700	2170	-	-	5	HA
45	V45	VES 45	N 8°50'21.0" E 7°53'50.5"	1	3.5	5	20	30	-	-	59.5	720	250	158	300	600	1010	-	6	QHA
46	V46	VES 46	N 8°50'13.0" E 7°53'50.5"	1	3.5	5	20	15	-	-	44.5	330	190	153	275	366	650	-	6	QHA
47	V47	VES 47	N 8°50'05.0" E 7°53'50.5"	1	3.5	10	30	35	-	-	79.5	2296	350	160	253	474	623	-	6	QHA
48	V48	VES 48	N 8°49'57.0" E 7°53'50.5"	2	4.5	7.5	30	-	-	-	44	731	264	184	220	368	-	-	5	KHA
49	V49	VES 49	N 8°49'49.0" E 7°53'50.5"	1	6	12.5	25	-	-	-	44.5	332	162	210	323	526	-	-	5	HA
50	V50	VES 50	N 8°49'41.0" E 7°53'50.5"	1	3.5	5	35	-	-	-	44.5	1173	350	200	277	760	-	-	5	QHA

NOTE: For 5 Layers; the 1st Layer is Topsoil, 2nd Layer is Laterite, 3rd Layer is Weathered basement, 4th Layer is Fractured basement and the 5th Layer is Fresh basement.

For 6 Layers; the 1st Layer is Topsoil, 2nd Layer is Laterite, 3rd Layer is Weathered basement, 4th Layer is Partially Weathered/Fractured basement 5th Layer is Fractured basement and the 6th Layer is Fresh basement.

. Table 2. Qualitative Interpretation of Data for Wenner Reslts

					Spacing / depth			
S/N	Sample ID	LONGDD	LATDD	Elevation (m)	a=15	a=20	a=30	a=40
1	V1	7.9111	8.8436	306	115	380	1856	2209
2	V2	7.9111	8.8414	307	197	200	262	331
3	V3	7.9111	8.8392	300	122	172	287	397
4	V4	7.9111	8.8369	306	254	459	594	683
5	V5	7.9111	8.8347	310	271	357	517	622
6	V6	7.9111	8.8325	309	269	247	329	354
7	V7	7.9111	8.8303	300	112	170	258	367
8	V8	7.9089	8.8303	310	173	394	285	510
9	V9	7.9089	8.8325	309	199	219	281	339
10	V10	7.9089	8.8347	306	216	241	336	448
11	V11	7.9089	8.8369	312	538	1531	2306	2871
12	V12	7.9089	8.8392	302	210	240	308	410
13	V13	7.9089	8.8414	312	206	220	235	359
14	V14	7.9089	8.8436	300	200	660	950	1768
15	V15	7.9065	8.8436	302	143	154	264	290
16	V16	7.9065	8.8414	306	200	104	1943	2400
17	V17	7.9065	8.8392	309	181	172	170	389
18	V18	7.9065	8.8369	310	215	348	281	436
19	V19	7.9065	8.8347	310	120	175	298	370
20	V20	7.9065	8.8325	310	195	206	264	438
21	V21	7.9065	8.8303	303	526	152	594	2834
22	V22	7.9042	8.8303	299	399	388	497	606
23	V23	7.9042	8.8325	300	170	245	341	434
24	V24	7.9042	8.8347	303	202	449	700	1667
25	V25	7.9042	8.8369	298	150	226	288	524
26	V26	7.9042	8.8392	300	130	171	302	342
27	V27	7.9042	8.8414	304	409	492	552	900
28	V28	7.9019	8.8414	306	299	473	1185	640
29	V29	7.9019	8.8392	299	200	340	523	1250
30	V30	7.9019	8.8369	306	188	183	373	451
31	V31	7.9019	8.8347	306	191	351	388	448
32	V32	7.9019	8.8325	309	222	319	342	469
33	V33	7.9019	8.8303	310	256	273	850	2430
34	V34	7.9019	8.8281	300	150	254	396	2726
35	V35	7.8997	8.8281	297	154	287	1098	635
36	V36	7.8997	8.8303	300	293	908	300	325
37	V37	7.8997	8.8325	309	621	379	532	655
38	V38	7.8997	8.8347	306	326	443	1952	497
39	V39	7.8997	8.8369	308	436	501	692	1549
40	V40	7.8997	8.8392	290	209	275	350	987
41	V41	7.8997	8.8414	297	310	336	482	2314
42	V42	7.8997	8.8436	294	165	259	342	362
43	V43	7.8974	8.8436	295	302	279	712	558
44	V44	7.8974	8.8414	294	264	338	413	528
45	V45	7.8974	8.8392	292	258	353	480	765
46	V46	7.8974	8.8369	296	352	452	604	660
47	V47	7.8974	8.8347	300	232	459	443	617
48	V48	7.8974	8.8325	302	289	386	485	607
49	V49	7.8974	8.8303	300	337	454	499	637
50	V50	7.8974	8.8281	290	539	263	386	523

Field curves

The six curve types identified in the study are HA, KA, QH, HAK and KHA; QHA-types which correlates (Keller & Frischknecht, 1966). The curve type with the highest frequency of occurrence is the QHA-type, while the HA and HAK-types has the lowest frequency of occurrence in the study area.

Geoelectric Section

Geoelectric section along profile NE-SW (based on geological structures in the study area), revealed 5-6 geoelectric layers which correlates with the works of (Olatokunbo-Ojo & Akintorinwa, 2016). The first layer consists of the top soil from 1-2 m with resistivity value range of 112-1779 Ωm. The second layer consists of laterite with thickness of 3.5-4.5 m and is characterized by resistivity value range of 69-695 Ωm. The third layer is weathered basement with thickness of 5-10 m and is characterized by resistivity value range of 60-200 Ωm. The fourth layer is partially weathered/fractured basement with thickness of 10-20 m and is characterized by resistivity value range of 66-583 Ωm. The fifth layer is the fractured basement with thickness of 15-50 m and is characterized by resistivity value range of 150-888 Ωm, while the sixth layer is the fresh basement with thickness ranging to infinity and resistivity range of 310-2070 Ωm. Generally, the thickness of the overburden or depth to basement is highest towards north central of this profile line (Figure 4).Furthermore, V16 (Biotite Granite) and V48 (Schist) shows that the aquiferous layer (weathered and/or partially weathered/fractured basement layer is not very thick to warrant good accumulation of groundwater; while V26 (Biotite Granite) has the thickest aquiferous layer, though could be susceptible to surface water infiltration and high contamination risk due to its proximity to the stream when correlated with the geology of the area (Figure 1). The lithology log of an existing borehole at BH 3 (Fac. FNAS) showed good correlation with geophysical data (Figures 3and 4).

Geoelectric section (Figure 5) along profile NW-SE (based on geological structures in the study area), revealed 5-6 geoelectric layers. The first layer consists of the top soil from 1-2 m with resistivity value range of 234-5800 Ωm. The second layer consists of laterite with thickness of 2-7 m and is characterized by resistivity value range of 20-5550 Ωm. The third layer is weathered basement with thickness of 5-10 m and is characterized by resistivity value range of 50-2080 Ωm. The fourth layer is partially weathered/fractured basement with thickness of 10-20 m and is characterized by resistivity value range of 122-575 Ωm. The fifth layer is the fractured basement with thickness of 10-30 m and is characterized by resistivity value range of 139-495 Ωm, while the sixth layer is the fresh basement with thickness ranging to infinity and resistivity range of 310-1145 Ωm. Generally, the thickness of the overburden or depth to basement is highest towards southeast of this profile line. Furthermore, V8 (Biotite Granite) shows that the aquiferous layer (weathered and/or partially weathered/fractured basement layer is not very thick to warrant good accumulation of groundwater; while V29 (Biotite Granite) has the thickest aquiferous layer, though could be susceptible to surface water infiltration and high contamination risk due to its proximity to the stream when correlated with the geology of the area (Figure 1). The lithology log of an existing borehole at BH 3 (Fac. FNAS) showed good correlation with geophysical data (geoelectric section), (Figure 4).

Isoresistivity and Isopach Map of the Aquifer

This reveals the observed resistivity values of the aquifer (weathered or fractured basement), and the observed thickness of the aquifer (weathered basement and/or fractured basement) this plays an important role in identifying or zoning groundwater potential in the Basement Complex terrain (Olatokunbo-Ojo & Akintorinwa, 2016). The resistivity of the aquiferous layer ranges from 110-1800 Ωm at V9 and V33 respectively, but generally less than 300 Ωm. This reveals the heterogeneous variation in the composition of the weathered or fractured basement layer from sandy clay, laterite, lateritic clay, weathered and fractured gneiss when compared with the lithology log at BH 3 (Figure 4). The study area has a moderate resistivity, green-lemon green in colour; with areas of few high resistivity in brown-light yellow-blue in colour at the south (Figure 5a).

The Isopach Map reveals the variation in thickness of the weathered or partially weathered/fractured basement layer. It ranges from 7-55 m, but generally less than 36 m. The areas with deep purple colour (less than 10 m) indicate thin aquifer thickness of low groundwater potential, in part of northcentral, east and northeast, northwest and south. Light purple indicates moderate aquifer thickness (10-32 m) and of medium groundwater potential, towards the northwest, south, east and part of north, northcentral, northeast, southeast and southwest; while yellowish-brown colour indicates thick aquifer (34-56 m) of high groundwater potential, occur in part of the north, northwest, northcentral, northeast, southeast and southwest. It implies that the major aquifer units in the study area is moderately thick and of high groundwater yield. Therefore, the groundwater potential of this research can be zoned into low, medium and high potentials (Omosuyi *et al.,* 2003; Jatau *et al.,* 2014; Anudu *et al.,* 2014; Olatokunbo-Ojo & Akintorinwa, 2016) as observed in Figure 5b.

Isopach Map of Depth to Fresh basement

The depth to fresh basement is also known as the overburden thickness; reveal the thicknesses of each of the layers encountered to the top of the fresh basement beneath the sounding stations (Jatau *et al.,* 2014; Olatokunbo-Ojo & Akintorinwa, 2016). This include the top soil, laterite, weathered basement, fractured basement; and partially weathered/fractured basement (for 6-layer case). The depth to fresh basement ranges from 29-79.5 m. The areas whose overburden thickness is thin, implies that the fresh basement is very close to the surface. Generally, the study area has moderately thick overburden at portion with blue-army green-light green in colour, towards the north, northeast, part of northwest, northcentral and south, east, southeast and southwest. Thick overburden can also be observed at portion of yellow-red colour towards the west and part of northwest, north central and south (Figure 7); hence the study area is of moderate-high groundwater potential.

Resistivity Map of the Basement

This reveals that the resistivity of the basement ranges from 310-3800 Ωm at V25/V26 and V33 respectively, but generally with less than 800 Ωm (Figure 5). The green and light green colour are dominant within the study area with 400-800 Ωm implying fractured basement (Olayinka & Olorunfemi, 1992). Yellow-brown colour (1000-2200 Ωm) occur towards the south and trend northwest-southeast, northeast-southwest; and light-deep blue (2400-3800 Ωm) occur in part of the south (Figure 7). From 1000-3800Ωm signify fresh basement geoelectric units (Olayinka & Olorunfemi, 1992).

Piezometric Map

The Piezometric map was obtained when the total depth is subtracted from the elevation values for each VES station (Jatau *et al.,* 2014). It ranges from 215-267.5 m. Portions with blue colour have the least values, areas with yellow are moderate; and red colour for high piezomettric values. This indicates that areas with low-moderate piezometric values (blue and yellow colour), trending west-east (top of the map), and northwest-southeast are towards stream 2 and; 1 and 3 respectively, which serves as convergence zones for surface and groundwater flow; while high piezometric value areas towards the northeast, east, northcentral and part of the south, form ridges and divergence zones for surface and groundwater flow (Figure 8). This geophysical interpretation correlates with the geology of the study area.

Bedrock Relief Map

The 3-D bedrock relief map of the study area ranges in elevation from 291-311 m (Figure 9). It reveals the uneven nature of the bedrock comprising of ridges (areas of high relief) and depressions (areas of low relief). Low relief areas are represented by purple-blue colour, medium relief represented by lemon green-yellow colour; and high relief are represented by red colour. Areas of low-medium reliefs trending west-east at the top, northwest-southeast and part of the northeast-southwest, acts as convergence zones for good groundwater flow/accumulation; while areas of high reliefs in part of the northeast, west and eastern portion of the study area acts as divergence zones for groundwater flow/accumulation due to the presence of the ridges and also serves as structural control to the streams, which correlates with the works of (Jatau *et al.,* 2014; Omosuyi*et al.,* 2003). The bedrock relief map also correlates to structural trends, observed on the geological structures as also observed in (Jatau *et al.,* 2013).

Isoresistivity Map for Wenner at 15 m depth

The isoresistivity map at 15 m depth (Figure 10) ranges from 112-621 Ωm (Table 2). Portions with dark purple colour (100-200 Ωm) have the low resistivity values, areas with light purple (220-380 Ωm) are moderate; and yellow-brown colour (400-620 Ωm) have high resistivity values. Areas with low-moderate resistivity values (dark-light purple colour), trending northwest-southeast and northeast-southwest, indicates high conductivity for groundwater accumulation vertically, at 15 m depth in the study area; which also correlates with structural trends, observed on the geological structures and isopach map of the true aquifer (Schlumberger data); while areas with high resistivity values (yellow-brown colour), part of the east, west, southwest and south indicates low conductivity and shows how extensive and near the fractured/fresh basement is at 15 m depth; which correlates with the works of (Jatau &Bajeh, 2007).

Isoresistivity Map for Wenner at 20 m depth

The isoresistivity map at 20 m depth (Figure 11) ranges from 104-1531 Ωm (Table 2). Portions with dark purple colour (100-350 Ωm) have the low resistivity values, areas with light purple (400-850 Ωm) are moderate; and yellow-brown colour (900-1600 Ωm) have high resistivity values. Areas with low resistivity values (dark purple colour), trending northwest-southeast and northeast towards northcentral, indicates high conductivity for groundwater accumulation vertically, at 20 m depth in the study area; which also correlates with structural trend, observed on the geological structures and isopach map of the true aquifer (Schlumberger data); while areas with moderate resistivity values (light purple colour), occur in part of northeast, north, northwest, west, southwest and east, indicate moderate conductivity for groundwater accumulation; while high resistivity values (yellow-brown colour), part of the east, indicates low conductivity and shows how near the fractured/fresh basement is at 20 m depth; which correlates with previous work of (Jatau &Bajeh, 2007).

Isoresistivity Map for Wenner at 30 m depth

The isoresistivity map at 30 m depth (Figure 12) ranges from 170-2306 Ωm (Table 2). Portions with dark purple colour (100-500 Ωm) have the low resistivity values, areas with light purple (600-1200 Ωm) are moderate; and areas with yellow-brown colour (1300-2300Ωm) have high resistivity values. Areas with low resistivity values (dark purple colour), trending northwest-southeast and northeast-southwest, indicates high-moderate conductivity for groundwater accumulation vertically, at 30 m depth in the study area; which also correlates with structural trends, observed on the geological structures and isopach map of the true aquifer (Schlumberger data); while areas with moderate-high resistivity values (light purple - yellow-brown colour), occur in part of north, northeast, west, southwest and east which indicate low-extremely low conductivity for groundwater accumulation and shows how near the fresh basement is at 30 m depth.

Isoresistivity Map for Wenner at 40 m depth

The isoresistivity map at 40 m depth (Figure 13) ranges from 290-2871 Ωm (Table 2). Portions with dark purple colour (200-600 Ωm) have the low resistivity values, areas with light purple (700-1600 Ωm) are moderate; and areas with yellow-brown colour (1700-2900 Ωm) have high resistivity values. Areas with low resistivity values (dark purple colour), trending northeast-southwest, southeast towards northcentral and part of the north, indicates moderate-low conductivity for groundwater accumulation vertically, at 40 m depth in the study area; which also correlates with structural trend, observed on the geological structures and isopach map of the true aquifer (Schlumberger data); while areas with moderate-high resistivity values (light purple - yellow-brown colour), occur in part of north, northeast, northwest, northcentral, east and south which indicate extremely low-negligible conductivity for groundwater accumulation and shows how near the fresh basement is at 40 m depth this correlates well with the work of (Jatau & Bajeh, 2007)

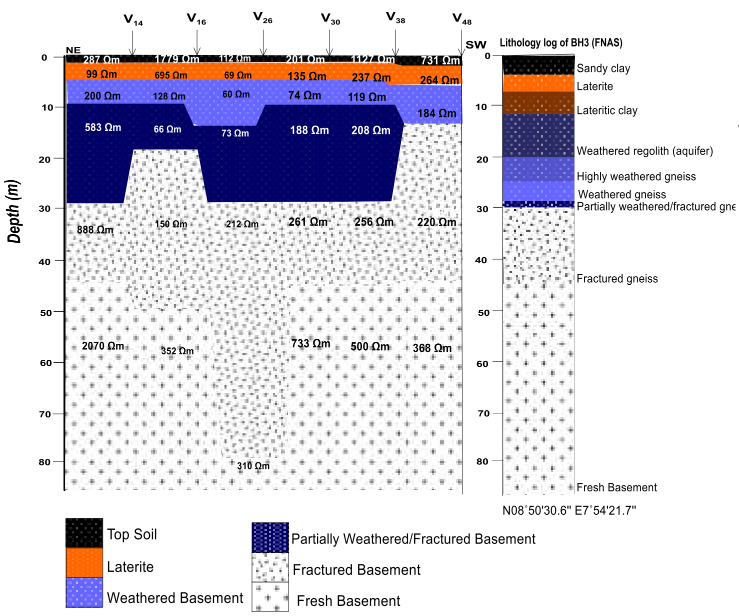


Figure 3: Geoelectric section along Profile NE-SW

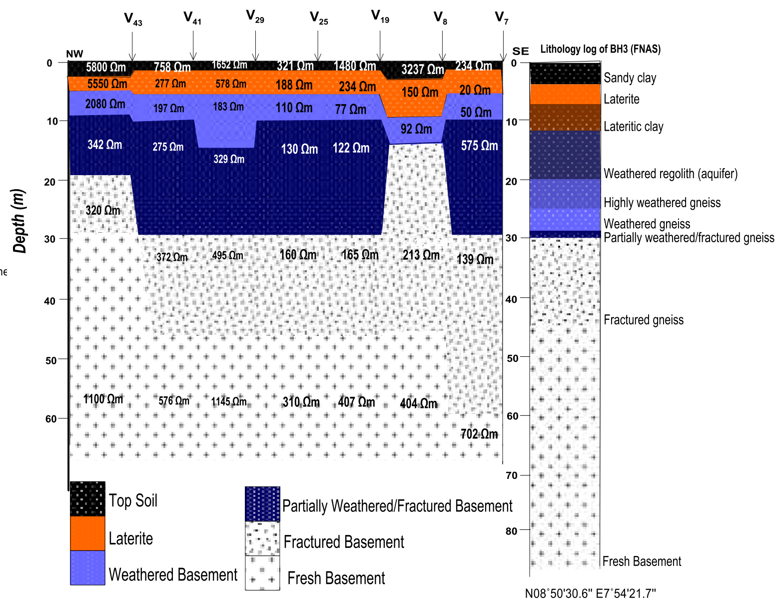


Figure 4: Geoelectric section along Profile NW-SE

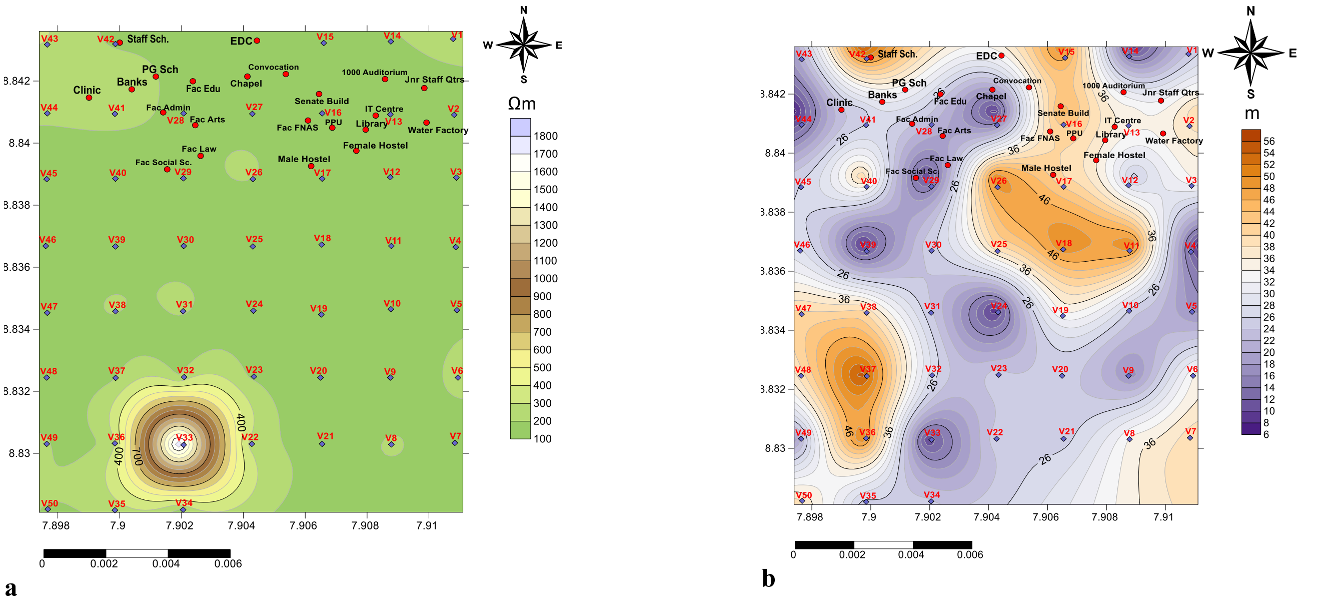


Figure 5: (a) Isoresistivity and (b) Isopach map of the Aquifer

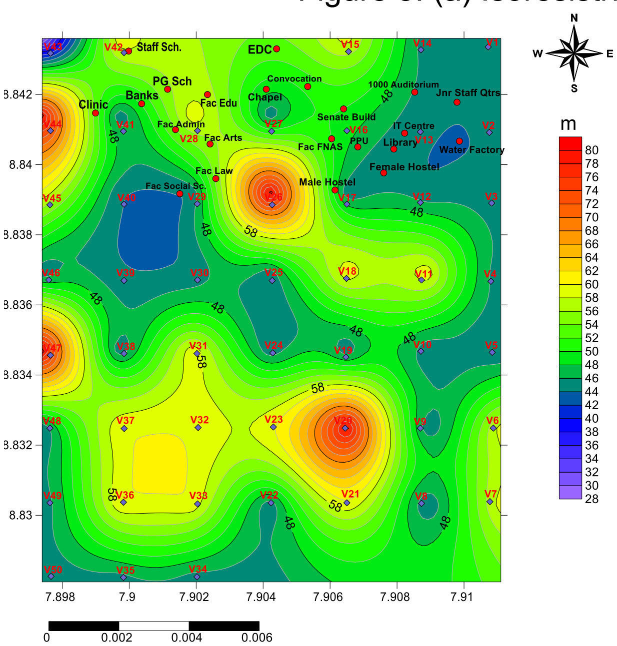


Figure 6: Isopach map of Depth to Basement

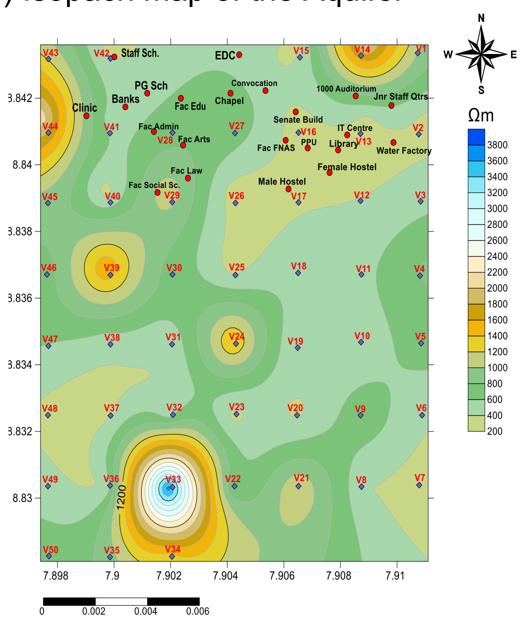


Figure 7: Resistivity map of the Basement

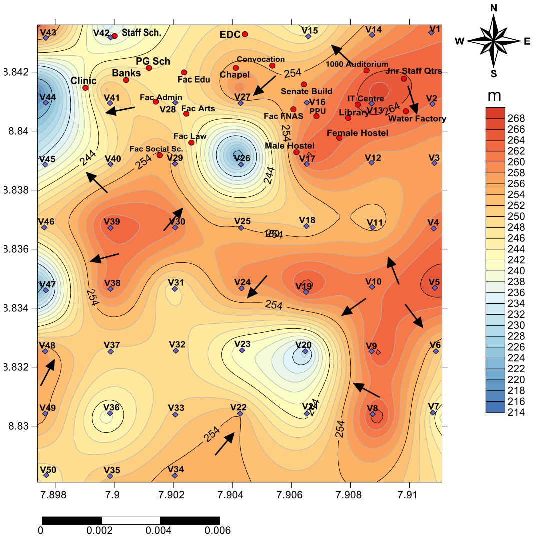


Figure 8: Piezometric Map

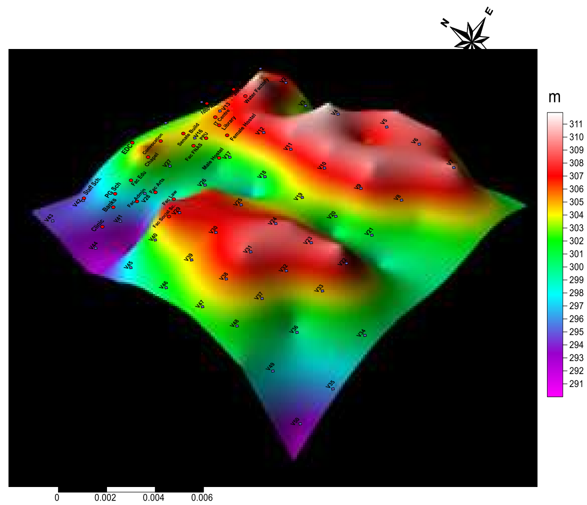


Figure 9: 3-D Bedrock Relief Map

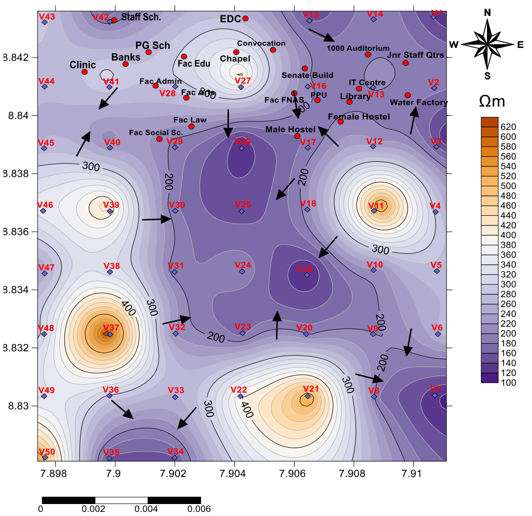


Figure10: I soresistivity map for Wenner at 15m depth

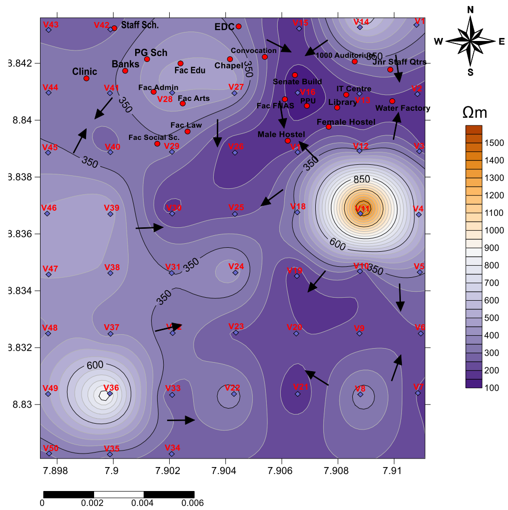


Figure11: Isoresistivity map for Wenner at 20 m depth

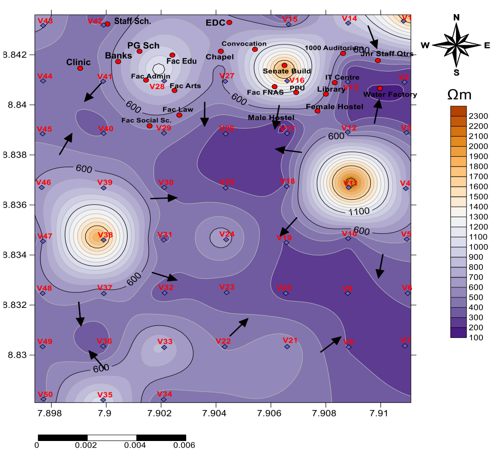


Figure 12: Isoresistivity map for Wenner at 30 m depth

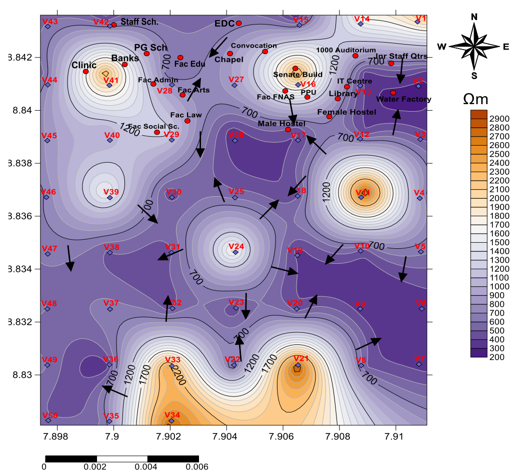


Figure 13: Isoresistivity map for Wenner at 40 m depth

Conclusion

Geophysical survey revealed 5-6 geoelectic layers comprising of top soil, laterite, weathered basement, partially weathered/fractured basement, fractured basement and fresh basement; which gave rise to the weathered and fractured aquifer that are peculiar to the Basement Complex terrain. The depth to fresh basement or overburden thickness ranged from 29-79.5 m, which implies that the area is generally good for groundwater development, especially places with distinctive weathered and/or fractured layers thicknesses. Boreholes drilled through these stations, may provide sufficient water for sustainable supply. The groundwater potential of this research can be zoned into low, medium and high potentials. Wenner quantitative and qualitative data correlated well with Schlumbergers' results, while the structural trends observed on the geological structures have a good degree of correlation with the subsurface geophysical structures and with existing geology.

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Integrated Geophysical and Geochemical Methods for Environmental Impact Assessment of a municipal dumpsite in King Williams town, Eastern Cape, South Africa

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Abstract

Electrical resistivity surveys and physico-chemical analysis were carried out on a landfill site to assess the impact of leachate pollution on groundwater quality. 2-D resistivity imaging and vertical electrical sounding were done across three profile lines (A, C and E) on the landfill. Physico-chemical properties of water samples from the leachate pond and two boreholes, BH1 and BH2, located at 80m, 130m and 200m respectively from the edge of the landfill were analysed. The results revealed that the surrounding soil and groundwater have been contaminated to a depth of 75m, well within the aquiferous zone. The soil stratigraphy showed high permeability which has significantly influenced the high level of infiltration of contaminants. High EC and TDS values observed in the groundwater samples indicate a downward transfer of leachate in to the groundwater. The difference in EC and TDS values for BH2 and BH1 (9892µS/cm/ 4939 mg/L and 6988 µS/cm/ 3497 mg/L respectively), indicated that concentration of contaminants decreased with increase in distance from the center of the landfill. Groundwater flow direction is towards the south-western part of the landfill along the direction of flow of the leachate, towards the built–up areas**.** In the absence of a leachate recovery system, the uncontrolled accumulation of leachate over time at the landfill over time, will pose a great threat to the groundwater quality. There is need to improve waste management practices in the study area to mitigate the effects of pollution.

Keyword: Landfill, Leachate, Groundwater, Electrical resistivity, contaminants

Introduction

In the South African context, waste is any undesirable or superfluous by- product of emissions or residue of any process or activity which has been discarded, normally accumulated or stored for the purpose of discarding or further processing through treatment (DEAT, 2001). Waste disposal dumps are common phenomena especially in industrial and highly populated cities where dumps are generated in tons on a daily basis and thus becomes a more important and efficient way of maintaining a clean environment in urban settings. In developing countries, unregulated landfills are commonly located adjacent to large cities, releasing harmful contaminants into a leachate and thereby polluting underlying aquifers (Mcfarlane *et al.,* 1983).

Municipal solid waste landfills/dumpsites have been identified as major environmental problem when located at high proximity to inhabited areas (Mor *et al.,* 2006). In most cases, dumpsites were originally located far from urban areas, but increasing expansion due to ever- increasing population and urbanization have resulted in development of land adjacent to dumps as either public buildings or residential houses. Humans are therefore exposed to a range of environmental hazards but particularly percolation of polluted leachate into the shallow aquifers which is the main source of drinking water in developing countries. In most cases in developing countries, disposal sites are not properly planned. Thus, periodical environmental auditing exercises become an inevitable task to ascertain the conditions of waste site with view to gain the knowledge of possible interaction between its dumps and the environment. The environmental challenges of waste dumps include: contamination of groundwater by pollutants generated by the dumps; migration of the pollutants away from the site via groundwater, surface water, or air routes; a combination of these, fire and explosion at the site, and direct contact with hazardous substances (Dimitriou *et al.,* 2008).The most common approach for investigating leachate plume migration from a dumpsite is to drill a network of monitoring wells around the site, these wells are however expensive to construct and maintain (Bernstone and Dahlin, 1997). Additionally, limited information on subsurface hydrogeology and/ or budget limitations frequently compels the sighting of monitoring wells at random. This approach is both technically and economically inefficient because monitoring wells give point measurements, whereas leachate plumes tend to migrate along preferential pathways, determined by subsurface heterogeneity" (Bernstone and Dahlin,1997). Therefore, even with a network of closely spaced monitoring wells, the risk that some contaminants could go undetected remains high. For these reasons, there is widespread interest in applying non-invasive and relatively inexpensive geophysical techniques, such as electrical resistivity imaging (ERI), electromagnetic methods, electrical conductivity (EC) logging, and seismic surveys, as means for mapping the occurrence and movement of leachate and for facilitating decision making regarding the location of monitoring wells (Busell and Lu, 2009; Butler *et al.,* 1999). This article reports the application of the electrical geophysical method involving the vertical electrical sounding (VES) and 2D profiling (Dipole-Dipole) techniques to map possible leachate distribution and migration processes from the landfill site in King Williams Town, Eastern cape, south Africa. The two techniques are based on the response of underground geologic features to a current flow field and are capable of detecting different subsurface units on the basis of the contrasts in electrical resistivity of earth materials (Zume *et al*., 2006). They are fast and cost effective. The former measures the vertical variations in resistivity of the subsurface earth while the latter involves the measurement of lateral and vertical variations of the apparent resistivity of the subsurface earth. The integrated use of geophysical and hydro physiochemical methods are often recommended in landfill studies (Bensoil *et al.,* 1983, Mathias *et al.,* 1994, Kayabali *et al.,* 1998). The specific objectives of this study, therefore, were to delineate groundwater contamination, identify lithologic layers, locate possible leachate plumes, and assess the risk of groundwater pollution as a result of the dumpsite. This is with the view of assessing the risk associated with the groundwater abstraction in the area. The outcomes of this study will help appropriate decision-making on how and where to abstract underground water and remediation methods to adopt.

Location of the Study Area

The Eastern Cape Province lies on the south-eastern seaboard of South Africa (Figure 1). It is the second largest Province with an area of 169 580 km², representing 13.9% of South Africa's total landmass (Statistics South Africa, 2003) Waste management services in the Eastern Cape rely heavily on landfills for the disposal of waste, which account for the majority of licensed waste facilities. This is despite the existence of a range of alternative disposal technologies, (SAEO, 2012). Waste disposal facilities like landfill sites, waste storage facilities, recycling facilities, materials recovery facilities and waste transfer facilities, are crucial indicators in determining where municipal solid waste material ends up.

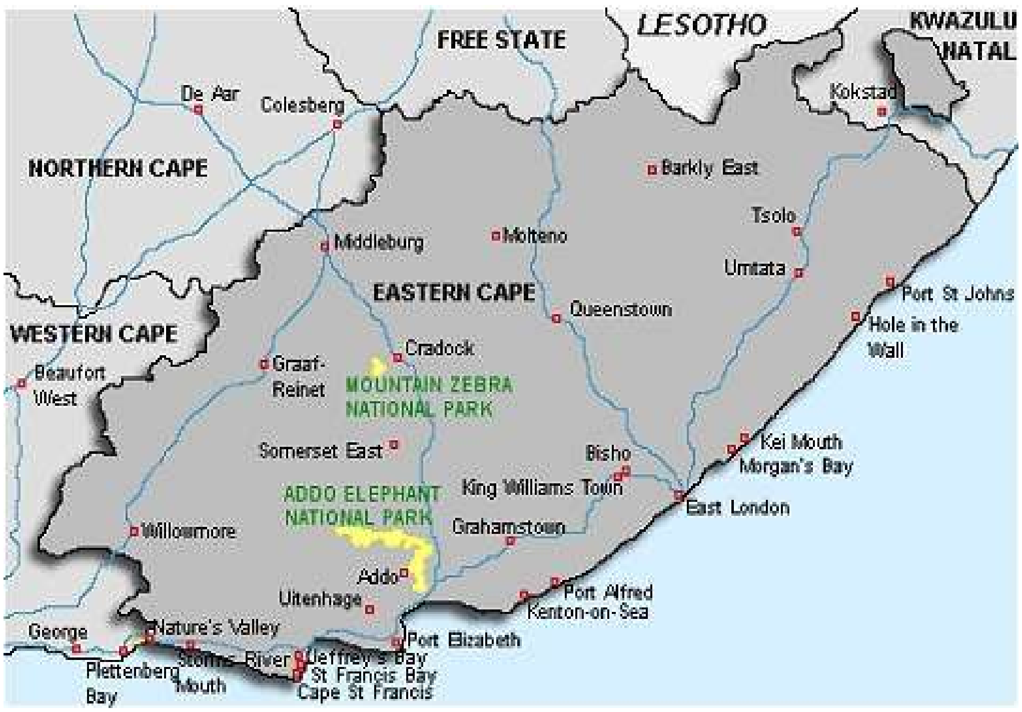


Figure 1: Map of Eastern Cape neighbouring communities

Based on the findings of the investigation (DEAT, 2001), it was revealed that there were 101operational waste disposal sites in the Eastern Cape Province, 74 sites reported from questionnaires, 7 sites from permitting records and 20 sites estimated by projection. It is estimated that only 8% of landfills in the Eastern Cape Province complied with DWAF minimum requirements (DWAF, 1998), 54% could potentially comply and 38% are currently unacceptable. Of the 37 landfill permits applied for, 43% had been granted. Only 19% of landfills in the Eastern Cape Province are permitted (DEAT, 2001).

The Buffalo City Metropolitan Municipality which is the catchment area of this research owns and operates two licensed landfill sites: one at King Williams Town, and the other called Round Hill at Berlin. The landfill site in King Williams Town is located around West Bank Primary School between longitudes27.394 – 29.3915 ° E and latitudes 32.8525 – 32.8495° S, covering an area of about 0.30km$^{2.}$ (Figure 1a – 1d). The landfill is an abandoned quarry in which landfilling started in 1983 by open dumping. The land fill receives a mixture of municipal, commercial, and mixed industrial wastes with hazardous and non-hazardous constituents. These often go into the landfill unsorted and releases large amount of gases, particles, and leachate into the surrounding soil and ground water.

Figure 1a: Dumpsite surface composition viewed from the South

Figure 1b: Dumpsite surface composition viewed from the East

Figure 1c: Groundwater monitoring borehole located south of the landfill

Figure 1d: Leachate pond located south-west of the landfill

Water containing dissolved contaminants from the landfill is collected and contained in the leachate pond. There are two groundwater monitoring borehole located south and southeast of the site respectively (Figure 2). The landfill site is characterised by steep topography with the direction of dip in the Northeast- Southwest direction

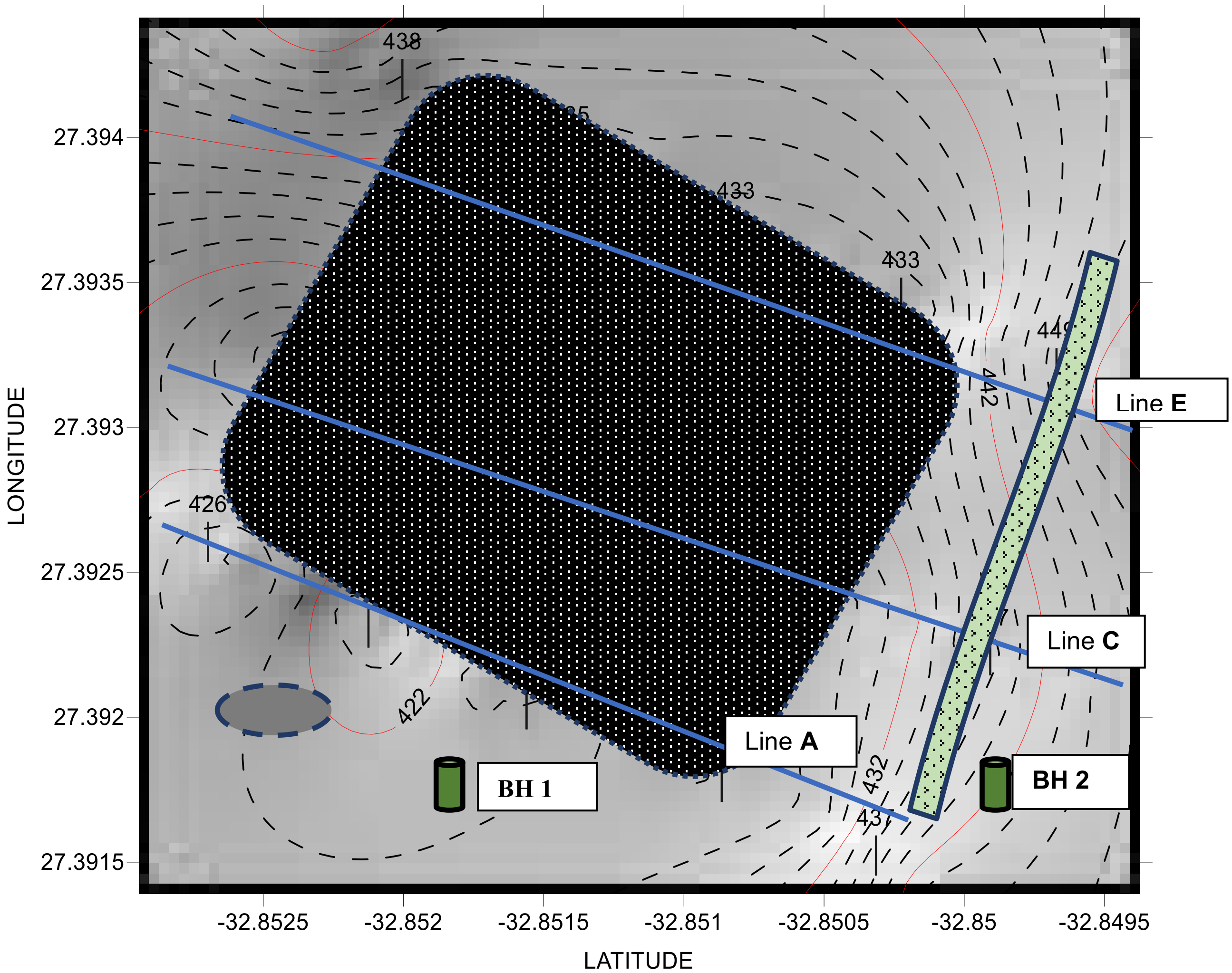
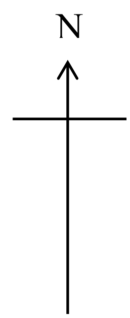


Figure 2: Data acquisition map of the area

KEY

-------	Minor contour lines
	Major contour lines
	Leachate pond
	Boreholes
	Traverse lines
	Active Landfill area
	Access road



Geology of the Study Area

The study area is geologically setting within the Beaufort group, Karoo Super group which is the dominant stratigraphic sequence in the Eastern Cape, South Africa. It consists of a sequence of units, mostly of non-marine origin, deposited between the late Carboniferous and early Jurassic, a period of about 120 million years ago (Schulter, 2008). The strata consist mostly of shale and sandstones (Hamilton and Finlay, 1928). Other groups under the Karoo Super group include;

The Dwyka Group; This is the earliest and lowest of the Karoo Super group of sedimentary deposits. They consist of diamictite, varved shale and mudstone. (Schulter, 2008). The total thickness of the group is about 600-700m (SACS, 1980)

- Ecca Group; This consist largely of shale and turbidites
- Beaufort Group; It is composed of a monotonous sequence of shale and mudstone with some interbedded sandstone (Trustwell, 1977)
- Stormberg Group; Stromberg group contains fossil remains with a remarkable array of insect and plant fossil found in the strata
- Drakensberg Group; forms the uppermost layer of the Karoo super group, forming about 1400m of the great escarpment. It consists mainly of dolerite sills at various depths (Trustwell, 1977).

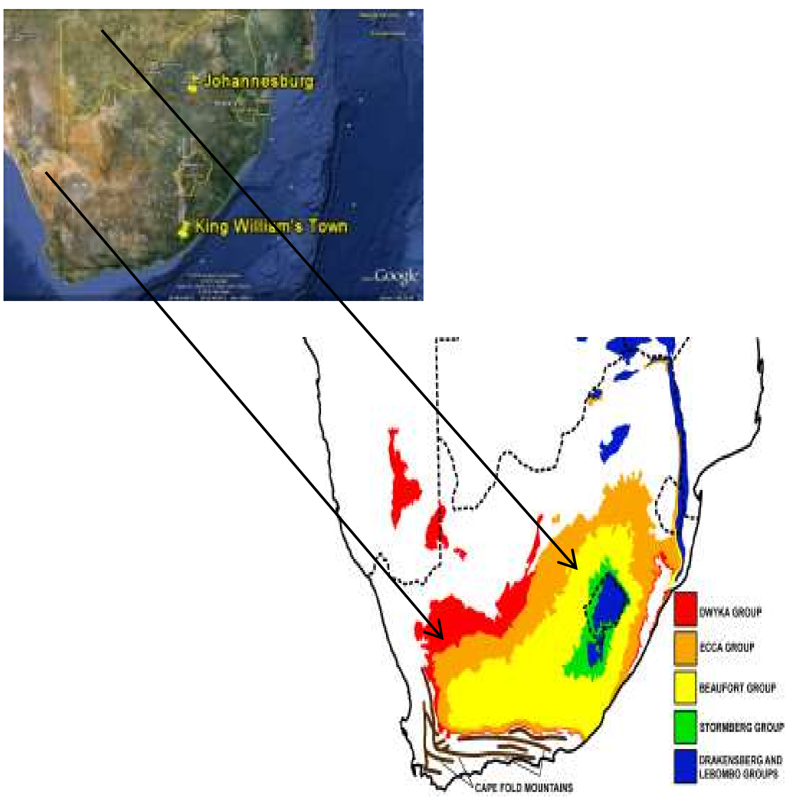


Figure 3: Geological map of the Eastern Cape Province

The local geology of the of the landfill site consists of superficial deposits of alluvium, the Balfour formation made up of grey to reddish mudrocks intruding into fine grained sandstones. The bedrock formation is made up of dolerite sills which are more pronounced at the southern parts of the landfill site.

The lithological formations of the landfill site are characterised by low porosity and permeability, consequently affecting the hydraulic properties of aquifers around the landfill site.

Materials and methods

The electrical resistivity method and physico-chemical analysis of water samples from the leachate pond and boreholes within the vicinity of the landfill was carried out to investigate possible contamination to groundwater by leachate from the dumpsite. Two dimensional

(2-D) and vertical electrical sounding (VES) were carried out using a multi-channel resistivity meter (SYSCAL –PRO). Three parallel profiles (A,C, and E) were ran at inter – profile spacing of 100 meters and a profile length of 360 meters in the East-West direction.

(Figure 2). There is an access road about 10meters wide on the eastern flank of the site which runs in a North – south direction. Measurements were made at increasing offset distance (a-spacing) of 10 meters which also runs over the access road in order to image the subsurface around the immediate vicinity of the landfill site.

The measurement protocol is computer controlled using a laptop microcomputer together with an electronic switching unit used to automatically select the relevant four electrodes for each measurement. Selection of minimum electrode spacing was based on the target (Leachate). Werner electrode configuration was chosen for its relative sensitivity to vertical changes in the sub- surface resistivity below the centre of the array and for its ability to resolve vertical changes that is. horizontal structures (Loke, 2004). The measured 2 – D resistivity data were processed using RES2DINV inversion software (Loke, 1999). The program uses the least – squares inversion scheme to minimize the difference between the calculated and measured apparent resistivity values, by iterative process. The results are displayed as inverted sections of the true resistivity of the subsurface rocks (Figures 4 a - c). The sections were subsequently, visually inspected to delineate areas of anomalously high or low resistivities related to subsurface structures.

The Vertical Electrical Sounding (VES) field data were measured using the Schlumberger array which also measures simultaneously with the 2-D resistivity data on the multi-channel resistivity meter and the interpretations were also done with the RES2DINV program. In this case, this computer program automatically generates model curves using initial layer parameters (resistivities and thickness) derived from partial curve matching of the field curves with standard curves, and calculates the true layer parameters of the geo-electric section. The results are presented in terms of the resistivities, thicknesses and depths of the geo-electric section for the VES positions (Figures 5a-c)

In-situ data which reflects the physico-chemical properties of the water samples were also taken. The leachate pond is about 80 meters from the edge of the landfill while the two boreholes BH1 and BH2 are at a range of 130 -200 meters from the landfill respectively. Parameters of the water samples such as temperature, Ph, Electrical conductivity, total dissolved solids, salinity and turbidity were measured using the PHARO-100 spectrophotometer. This is a device that measures chemical or physical properties of samples by influencing a substrate to determine the presence of possible contamination and the degree. The degree of contamination will be determined by juxtaposing the results obtained with threshold values which are usually World Health Organization (WHO) standards.

Results and Interpretation

2-D Resistivity Imaging

The resistivity distribution derived from the 2-D inversion in the West – East direction is given in Figures 4a –c.

Profile A;
This profile lies at about 30m from the south edge of the landfill and point elevation of 420m. The low resistivity zones with resistivity between1.59-14.4 ohm-m (deep blue) occurs at surface points between 120-230m, around the mid-point of the section. This low resistivity values show an infiltration of leachate into the subsurface to a depth of about 47m. This is interpreted to be mudstones and sandstones saturated with leachate. The high resistivity zones (brown to purple) with resistivity values between 1172- 3520 ohm-m at the flanks of the section indicates non-conductive, impermeable layer formed by part of the road sub-base to the east and doleritic bedrock to the west. Sandwiched between these zones of low and high resistivity anomaly is an intermediate zone (light green to yellow), showing rock materials having varying moisture content and composition.

Profile C;
Profile C is located at about 100m from profile A around the center of the landfill site at point elevation of about 415m. The low resistivity zones (< 7.39 ohm-m) are more pronounced on this profile. The most dominant of this low resistivity anomaly occurs at 30-230m surface points at a depth of 75m to the west of the profile. This is interpreted as mud and sandstone saturated with contaminant leachate. The shape of the leachate plume showed movement of low resistivity materials leaking towards the south-western edge of the landfill. A major reason for this is the dipping topography between line A and C. Two high resistivity anomalies were identified on this profile - a high resistivity zone at surface points 240-290 m and depth of 45m to the east of the profile (light brown colour). This is interpreted as landfill gases, probably methane, ammonia or carbon dioxide, released by the decomposing leachate materials. The

high resistivity zone to the west of the profile shows the continuation of the bedrock from line A.

Profile E:

This lies towards the edge of the landfill at 200m and 100m from profiles A and C respectively. The low resistivity is less pronounced when compared with the other profiles. This is due to the higher point elevation of the profile (450m). The natural soil conditions are returning at this line which possibly implies escape of chemical components into the atmosphere with increased distance from the center of the landfill. There is a reduced depth of contaminant pollution (35m).

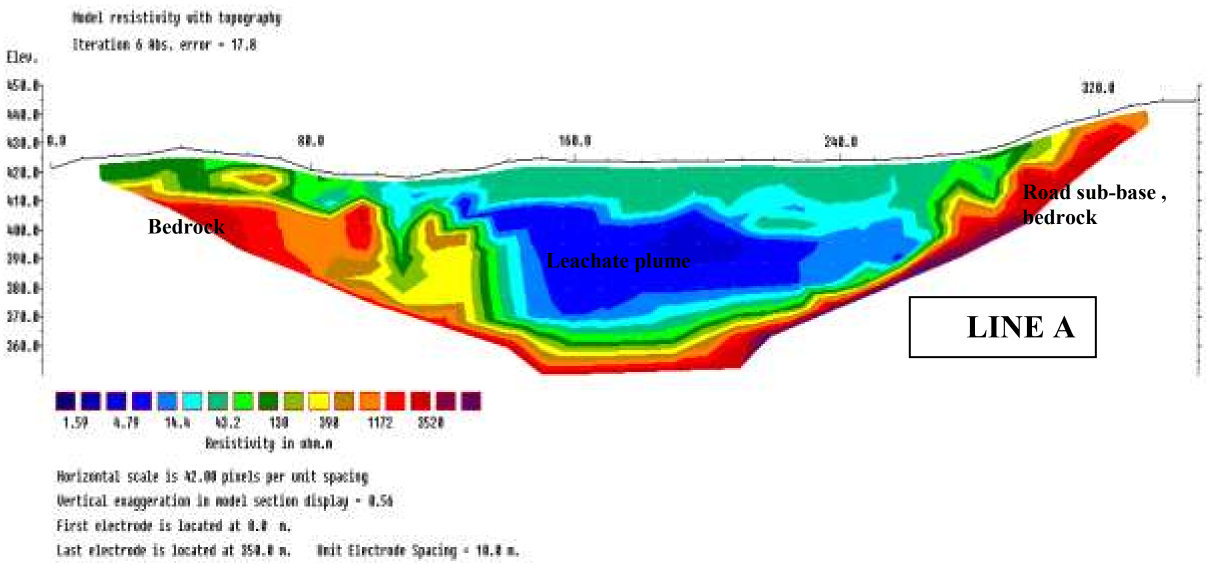


Figure 4a: Dipole-dipole resistivity data along Line A

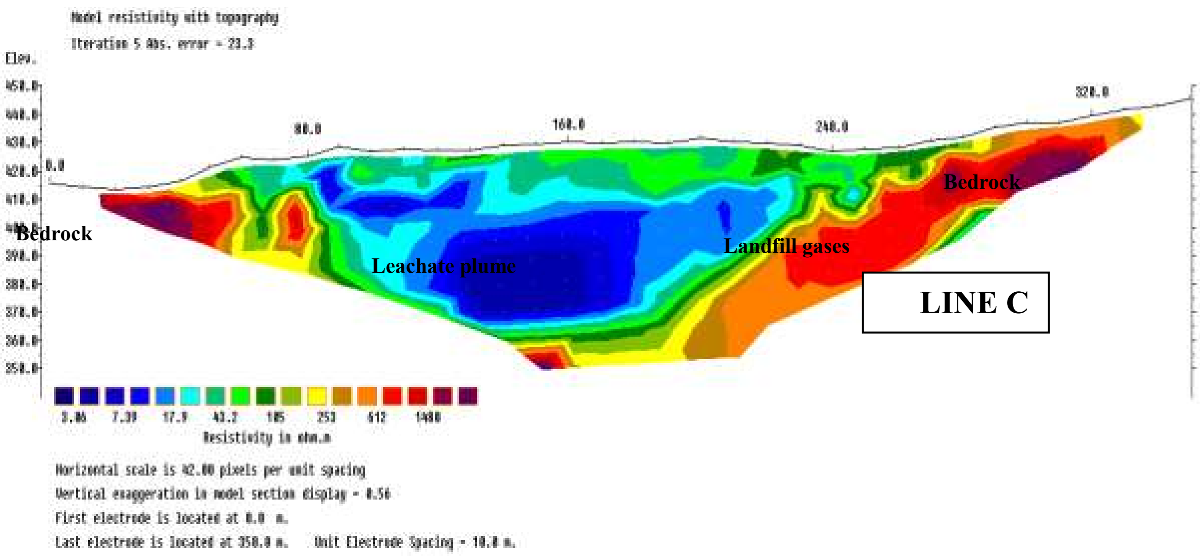


Figure 4b: Dipole-dipole resistivity data along Line C

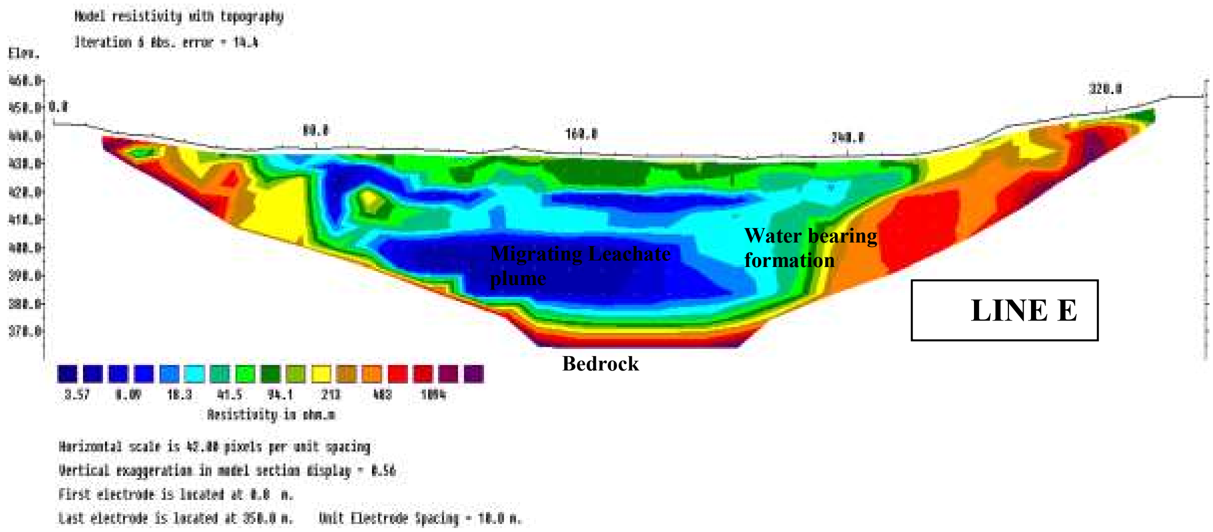


Figure 4c: Dipole-dipole resistivity data along Line E

Vertical electrical sounding (VES) Interpretation

Results of the VES data were modelled to generate geoelectric sections along the profile lines as shown in Figure 5a – c.

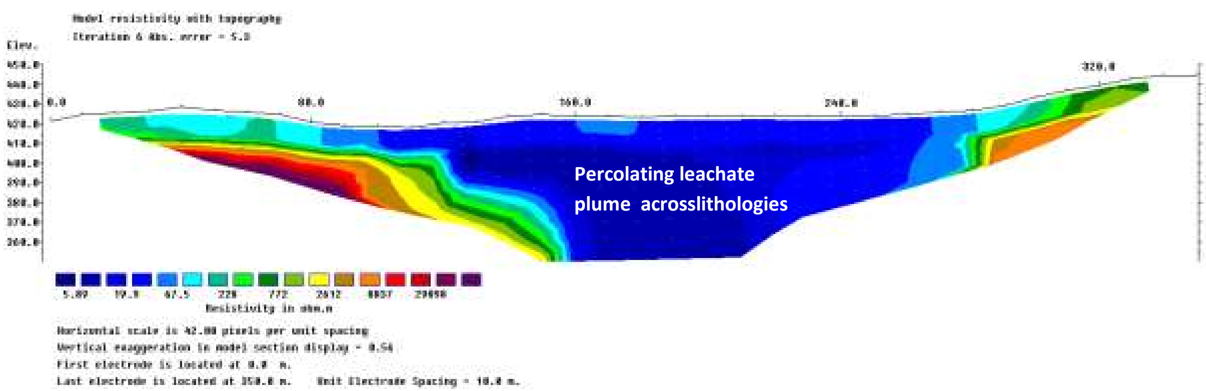


Figure 5a: Schlumberger array resistivity data along Line A

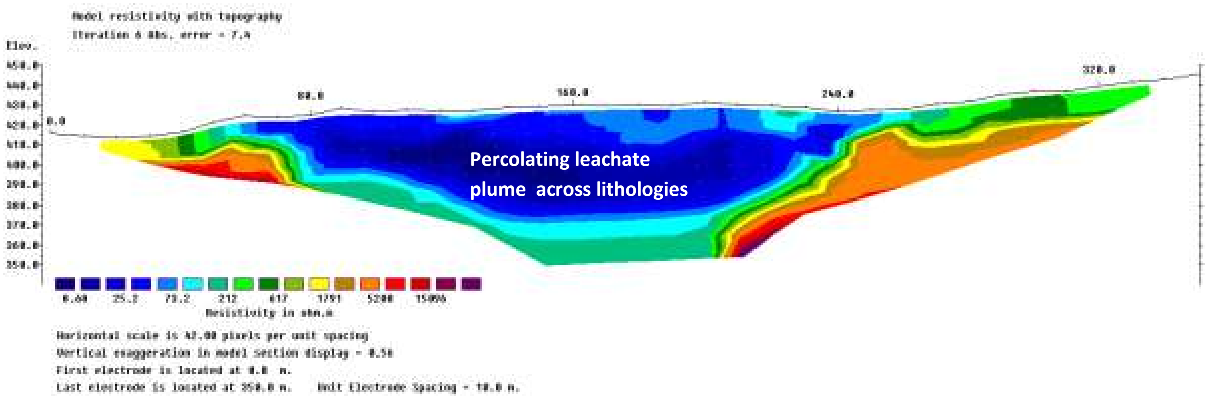


Figure 5b: Schlumberger array resistivity data along Line C

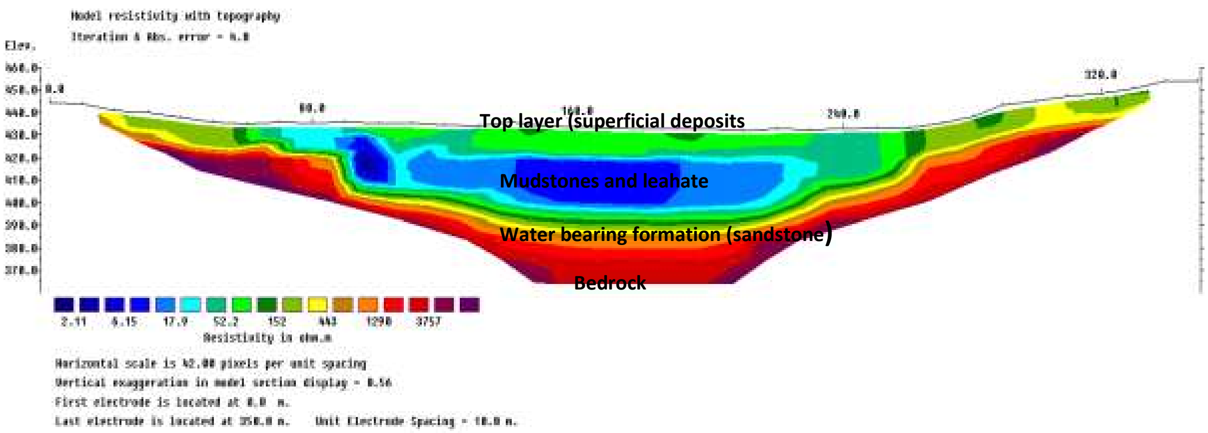


Figure 5c: Schlumberger array resistivity data along Line E

Figures 5a- c showed a 4-layer geoelectric section with varying thicknesses and resistivity across the profile lines. The composition of the lithologic layers has been considerably altered by the percolating leachate. The underlying water bearing formation is also not spared from the contamination effects (Figures 5a and 5b).

Across line E, towards the northern edge of the landfill, contamination effects were not as pronounced as the other two profiles. This is as a result of the increasing distance from the center of the landfill and higher point elevation as compared to the other two profiles (Figure 5c). from this profile the top layer, consisting mainly of superficial deposits has an average resistivity of 52-152 ohm-m and thickness between 7-10m. The underlying mudrock has an average resistivity of 6.5 -17.9 ohms–m. the low resistivity values are due to the permeating leachate plume. The average thickness of this layer is 25-30m. The water bearing sandstone formation underlying the mudstones has an average resistivity of 152-443 ohm-m and thickness of about 15-20 m. the depth to the bedrock layer is estimated to be about 85 m.

Hydro-physicochemical analysis

Many authors have noted that, besides the vertical in- filtration of leachate from the solid waste, the hydro- logical groundwater flow also play a prominent role in contaminant distributions beneath the subsurface of a landfill or dumpsite, (Pastor and Hernandez, 2012; Ahel et.al 1998). This accounts for the contamination of groundwater aquifer not directly or vertically located on dumpsites or landfills across the globe.

Water samples from the leachate pond (LP), having an area of about $20m^2$, located south-west of the landfill and two boreholes (BH1) and (BH 2), located at the south and south-west of the landfill with depths to the top of the water column of 2.5m and 1.5m respectively were collected and analysed on the site for their physico-chemical properties using the PHARO-100 spectrophotometer. The obtained results were then compared with world health organization (WHO) standards (WHO, 1997), to determine the degree of contamination of the water samples. The summary of the results is given Table 1.

Measurements of the physico-chemical properties of the water samples were made at an average temperature of 25^0c. pH. Of groundwater samples from the boreholes ranged from 6.87 – 7.47 while the leachate pond has a pH of 7.65. These values are within the limits of the WHO standard for water. The low salinity of the water samples is as a result of the freshwater nature of their source.

However, specific conductance of the samples showed high ion concentration well above the permissible limits. This is influenced by the presence of inorganic dissolved solids such as chloride, nitrates, phosphates etc. TDS values ranged from 3497 -4939 mg/l in the groundwater samples. This is above the threshold for potable water, while the leachate pond has the least TDS of 3298 mg/l. A possible reason for this is due to an increase in the percolation of leachate with depth. High TDS values produce toxic effect on living organisms through high alkalinity and hardness thus causing living cells to shrink. The oxidation reduction potential which is a measure of the cleanliness of the water samples showed positive values for the three water samples collected. A direct implication of this is an increase in the oxidizing properties of the samples, thus making them unfit for consumption.

Discussion of Results

Results of the 2-D resistivity imaging and physico- chemical analysis showed the presence of contaminants in the groundwater systems due to the landfilling. The leachate generated from the landfill has maximum impact on the groundwater quality in the locality. The soil stratigraphy being predominantly mud and sandstones has high permeability and this has significantly influenced the high level of infiltration of contaminants into the water bearing formation to a depth of 75m. High resistivity values encountered indicated the presence of non-conductive waste materials and the road sub-base towards the east of the profiles.

The very high electrical conductivity and total dissolved solids (TDS) values observed in the groundwater samples suggests a downward transfer of leachate into groundwater. The difference in electrical conductivity and TDS values for BH1 and BH2 indicates that the concentration of the contaminants normally decreases with increase in distance from the center of the pollution source.

In the absence of a leachate recovery system, the uncontrolled accumulation of leachate over time at the landfill site will pose a great risk to the groundwater quality. This will be further compounded by the steep topography of the landfill base which showed groundwater movement in the south-west direction as water moves from regions of high altitude and concentration towards the built–up areas around the landfill which are lying in the region of lower concentration and altitude.

Table 1; Physico-chemical properties of water samples from the landfill site

PARAMETER	BH2	LP	BH1	WHO,2007
Ph voltage (mVpH)	-34.6	-79.7	-69.4	-
pH (pH)	6.87	7.65	7.47	6.5 –8.5
Oxidation-Reduction Potential (mVORP)	104.1	58.7	73.1	0- -400
Electrical conductivity EC (µS/cm)	6988	6580	9892	500 – 5000
(µS/m^A)	70.36	66.49	99.84	5 – 50
Molar conductivity(mΩ$^-$cm)	0.0001	0.0002	0.0001	-
Total dissolved solids (TDS) (mg/L)	3497	3298	4939	500
Salinity (PSU)	3.83	3.60	5.55	2- 42
Surface tension(σt)	0.0	0.0	1.1	
Temperature (℃)	25.35	25.45	25.50	25
Pressure (psi)	13.758	13.758	13.758	
Dissolved oxygen (DO) (mg/L)	0.91	0.63	7.24	
Turbidity (NTU)	19.4	2.46	1.46	

Recommendations

The impacts of landfilling action on biological constituents and geotechnical properties of the underlying soil have not been considered in this study. It is therefore recommended that detail studies focusing on these aspects, as a complement to this work should be carried out. However, based on the negative impact already identified by this study, a total closure of the site and evacuation of the waste is also recommended. This is in addition to a suggested improved environment-friendly waste management strategy.

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Characterisation of Aquifer for Water Supply to a cultivated farm land in a Basement complex using Geoelectrical Techniques.

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Abstract
Exploration of groundwater in Abeokuta and its environ is a thought provoking task due to the heterogeneity of the geological formation of the study area. Hence, proper understanding of the geological formation of the area using geo-electrical investigation is necessary for successful prospects for groundwater resources and the protective capacity of the study area through the assessment of longitudinal conductivity value on the cultivated farmland. The study was conducted on a cultivated farmland situated inside the Federal University of Agriculture, Abeokuta (FUNAAB) which lies between latitude 7°13'N to 7°15'N and longitude 3°24'E to3°26'E. In this study, the geological formation of the subsurface, aquifer characteristics of the groundwater potential and protective capacity in cultivated farmland at Federal University of Agriculture Abeokuta (FUNAAB) South-Western Nigeria were explored using Vertical Electric Sounding (VES). This research was done on the cultivated farmland to investigate using 1-D electrical resistivity survey and soil laboratory analysis (bulk density, porosity, hydraulic conductivity and textural analysis). Six vertical electrical soundings (VES) were conducted within the study area. The iteration curves, the real resistivity of the layers, the thicknesses (h) and real depth of overburden on the aquifer were obtained using WINRESIST. Two resistivity sounding curve types were obtained from the survey area and mostly H-types ($\rho_1 > \rho_2 < \rho_3$) except at VES 1 which has KH type($\rho_1 < \rho_2 > \rho_3 < \rho_4$). The percentage frequency of the curve types is 83.33% for H-type and 16.67% for KH type. The range of the values of thicknesses of each layer for all the selected six VES points are given as: topsoil ranges between 0.4 – 1.3mm clayey sand layer between 0.4 – 1.1m and weathered basement between 1.1 0 14.0m. The output from the electrical survey data were used to assess the prospective risk of groundwater pollution and define the protective properties of geologic layers as well as pinpointing suitable areas with poor, moderate, and high aquifer protective capacity rating.

Keyword: Abeokuta, aquifer, bulk-density, exploration, groundwater and topsoil

Introduction
Groundwater is a crucial commodity for the good fortune of human societies. Quality of groundwater plays major role in the water paucity regions, especially for drinking water supply (Al Hallaq2002). During the recent decades, the groundwater exploitation has dramatically increased and hence the agricultural use of water has full-grown rapidly, while the amassed concentration of populations in metropolitan area has meant that all-encompassing well fields have been developed for metropolitan water supply. These circumstances make the groundwater more easily susceptible to

contamination. In addition, vulnerability is the degree to which human or environmental systems are likely to experience harm due to stress and can be recognized for a stated system and cluster of hazards (Popescu et al., 2008). The contaminants may originate from a rock containing arsenic and contribution from human activities such as; spraying of insecticides, application of agricultural fertilizers, spills and chemical sprays (Liggett and Talwar2009). In addition, evaluation of vulnerability is also influential educational tools for educating public wakefulness of groundwater protection issues (Nowlan2005). In 2002, Foster et al. (2002), they discovered that contamination of groundwater take place when the capacity of contaminants on the ground or leachates generated by urban and human activities is not properly managed and definite components surpass the natural diminution capability of subsoil and cover layers. Thus, vulnerability investigation has become a vital tool for groundwater protection and environmental management (Vias et al. 2005, Focazio et al., 2002).

The availability of water at proper depth for suitable plant evolution is of great importance to farming system. For this reason, in order to provide an adequate water supply for growing crop on cultivated farmland, knowledge of soil moisture content as well as monitoring of its changes is highly important. Soil moisture content has important applications in soil ecology, hydrology, waste water infiltration, meteorology and agriculture (Pan et al, 2012). Thorough study of soil moisture dissemination within the soil profile to evaluate soil water availability have strong effects on plant physiology (Brillante et al, 2015, Piccolo and Mbagwu, 1999; Ereje et al.,2005). Electrical resistivity method has various important applications in hydrological science and related field investigations (Golekar et al, 2014, AbdelAal et al., 2010).

Geo-electrical resistivity method is one of geophysical methods that can be used to map and characterize spatial and temporal variations of soil physical properties (Sudha et al., 2009, Aizebeokhai, 2014). Electrical resistivity method is found to be cheap, quick, easy to operate, quick and reliable tool to classify and easy prediction of physical properties of soil (Dafalla and Alfouzan,2012) and to identify between fresh and saline water zones (Majundar and Pal,2005, Pethkar et al,2001; Aiezebeokhai,2014). Electrical resistivity method provides a good means of thorough study of vertical water movement in the unsaturated soil zone and helps in assessing the boundary conditions for infiltration modeling (Benderitter and Schott,1999). Vertical electrical sounding (VES) and 2D electrical resistivity tomography are geo-electrical method to understand subsurface lithology and delineate groundwater potential zones (Gracia-Montiel et al, 2008, Golekar et al, 2014). Several researchers have employed the use of VES and 2D ERT in monitoring soil water content (Garcia-Montiel et al, 2008; Michot et al, 2003, Garre et al., 2012) Olayinka and Oladunjoye, 2013, Jakalia et al., 2015, Karim et al., 2013, Brillante et al., 2015, Besson et al., 2004, Agunbiade and Ojoawo, 2014, Rings et al., 2008). - using combined method of vertical electric sounding and laboratory experiments on estimation of some selected physical parameters of soil to effectively characterize the topsoil of the cultivated farmland at FUNAAB

Study area description

The study area is an agricultural farm and training farm managed by Directorate of University Farm(DUFARM), Federal University of Agriculture, Abeokuta (FUNAAB). The study area is agricultural farm located within latitude 7°13'N to 7°15'N and longitude 3°24'E to 3°26'E Southwestern part of Nigeria as shown in Figure 1. Abeokuta experiences two local climates which are rainy and dry seasons. The wet season spin from March-October while the dry season occurs from November-March when the area is under the influence of North - Eastern winds (Badmus and Olatinsu, 2010). The amount of rainfall varies between 750mm-1000mm in the rainy season and 250mm-500mm during the dry season (Akanni, 1992). Abeokuta is characterized by an undulating topography with elevation value ranging from 100-400m above sea level (Akanni, 1992, Oloruntola and Adeyemi, 2014). The mean monthly temperature ranges between 25.7^{0}C in July to 30.2^{0}C in February with the mean annual temperature of 26.6^{0}C.

Geology of the study area

The study area falls within the Basement Complex of south western Nigeria. The Basement Complex rock comprises of folded gneiss, schist quartzite, older granite and amplubolite/mica-schist (Jones and Hockes, 1964). Abeokuta belongs to the stable place which was not subjected to intense tectonics in the past (Ufoegbune et al., 2009). The northern side of Abeokuta is characterized by pegmatitic uncertain by granite while the southern part enters the transition zone with the sedimentary formation of the eastern Dahomey Basin. But the problem about pinpointing high productive aquifers in several parts of Abeokuta is a great task because Abeokuta lies within the Basement Complex (Figure 2) of Southwestern Nigeria. These rocks are of Precambrian age to early Palaeozoic age and prolong from the north-eastern part of the Ogun state (which Abeokuta belongs) on the trot southwest ward and dipping towards the coast (Ako, 1979). The different rock has various hydrogeologic characteristics. The underground faulting system is minimal and this has contributed to the problem of underground water occurrence in this area. The southern part of Abeokuta goes into the transition zone with the sedimentary basin, characterized by impartially satisfactory hydro-geological history. Also, western part of Abeokuta is regarded as by granitic gneiss which is fewer porous (Key, 1992). Thus, this area is greatly problematic and it is predisposed to low-slung yield groundwater supply. Abeokuta terrain was characterized to have two kinds of landforms.; knolls of granite, other rocks of the basement complex and nearly flat topography sparsely distributed low hills. Abeokuta is sapped by rivers, Ogun and

Oyan which are the two major rivers and many small streams

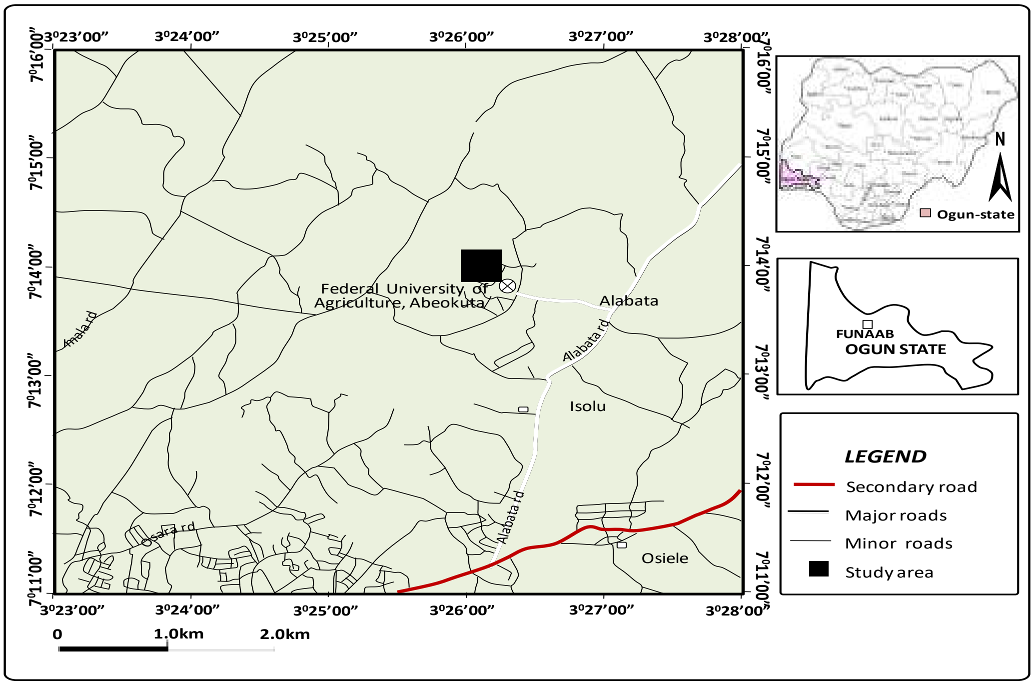

Figure 1: Location Map of the Study Area

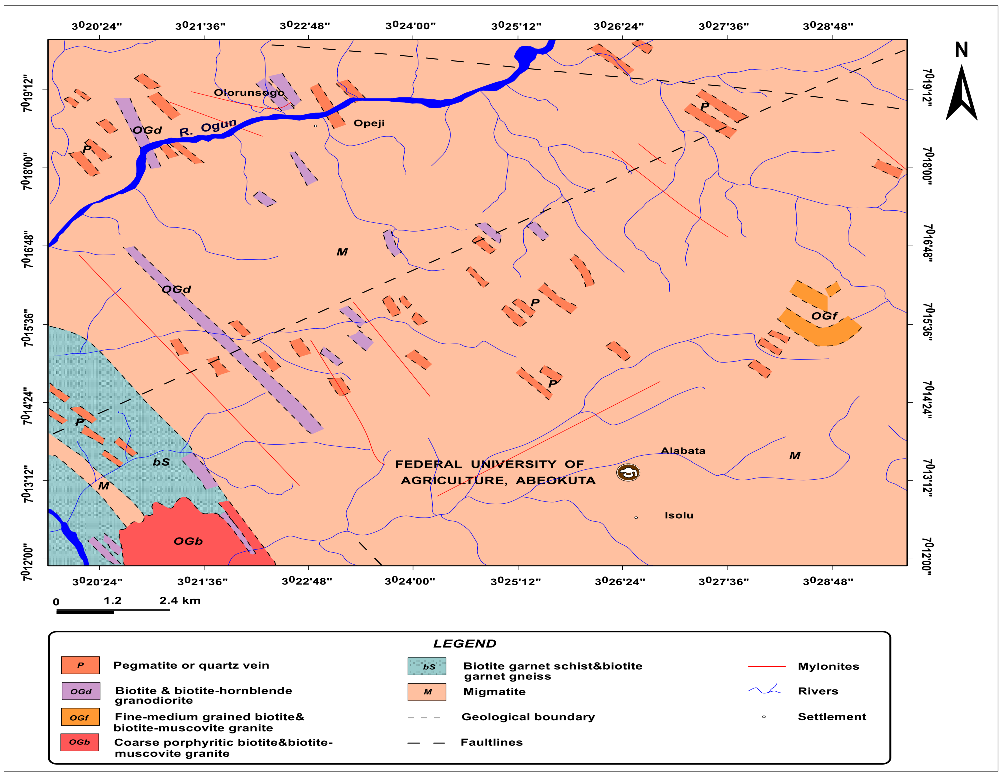

Figure 2: Geological map showing the rock type that underlies the study area (adapted from NGSA 2009)

Methodology-VES survey

In this study, the following equipment were used in carrying out this research: using campus Tigre tetrameter; four steel electrodes (two electrodes used as the potential electrodes and the other two electrodes for the current electrodes); four cable reels with metal clips attached to the wires; two measuring tapes; and hand held Global Positioning System (GPS). The geologic features observed during reconnaissance visits to the site included flood plain and rock outcrop. Electrical resistivity method which employs the Schlumberger electrode configuration with maximum current electrode separation (AB/2) of 110 m was used in acquiring VES data at seasonally cultivated farmland using campus Tigre tetrameter. Specified amounts of electric current was injected into the ground through a pair of current electrodes and then with the aid of potential electrodes, measure the potential difference between two points at the surface caused by the flow of the electric current in the subsurface. From the measured current (I) and the voltage (V) values, the ensuing resistivity is determined. Figure 3 shows a simplified diagram of the Schlumberger array. The GPS coordinates of each sounding point was captured and recorded against each point.

From the Schlumberger configuration, both current and potential pairs of electrodes have mutual mid-point, but the separation distances in the middle of adjacent electrodes differ. Assuming that the separations of the current and potential electrodes are given as *L* and *a*, respectively (Lowrie, 2007).
The Schlumberger array employed for VES Survey was done with a maximum electrode separation of 110m. For the VES Survey, the resistivity data obtained on the field and the electrode separation (AB/2) of 55m were partially curve matched and plotted against each other on a bi-logarithmic scale before being computer iterated with WINRESIST software with a R.M.S error less than 5.0 in order to obtain the true resistivity and layer parameter of depth. The iterated geo-electric parameters obtained were used to generate geo-electric sections layers. The iterative optimization method make an effort to reduce the dissimilarities occurred between the measured resistivity values and calculated resistivity values with the inversion model. The accuracy of fit in expressed in terms of RMS error (Loke and Barker, 1996).

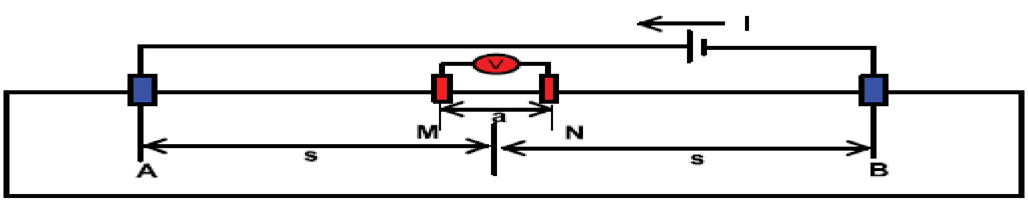

Figure 3. Diagram of Schlumberger Array (Lowrie, 2007)

Aquifer protective capacities and evaluation

The foremost link between the vulnerability of aquifer and electrical conductivity built on the significant principal known as clay content of the material which is related to hydraulic conductivities of soils (Schefferand Schachtschabel 1984) and impacts on the electrical resistivity or conductivity. High clay content in general correlates with resistivity's and hydraulic conductivities values becoming low while increasing clay content leads to reduction on electrical resistivity or to amassed electrical conductivity (Sen et al. 1988). Aquifer Vulnerability Index (AVI) was adopted in this study which is broadly used to evaluate the aquifer vulnerability to surface contaminants (Van Stempvoort et al., 1992). This approach enumerates groundwater vulnerability by hydraulic resistance to vertical flow of waste water through the unsaturated layers. Therefore, hydraulic resistance (C) which is equivalent to Integrated Electrical Conductivity (IEC) also known as Longitudinal Conductance (S)can be obtained using equation 1 (Van Stempvoort et al., 1992)

$$S = IEC = \sum_{i=1}^{n} \frac{h_i}{\rho_i} \quad 1$$

Where h_i, and ρ_i are thickness and resistivity respectively.

The Total Transverse Unit Resistance (TTUR), is defined mathematically as given by equation 2

$$TTUR = \sum_{i-1}^{n} h_i \rho_i \quad 2$$

Using equation 2, the Average Longitudinal Resistivity (ALR) for VES curve is given by equation 3,

$$\rho_L = \frac{H}{IEC} = \frac{\sum_{i=1}^{n} h_i}{\sum_{i=1}^{n} \frac{h_i}{\rho_i}} \quad 3$$

The Average Transverse Resistivity (ATR) can be calculated using equation 4;

$$\rho_t = \frac{TTUR}{H} = \frac{\sum_{i=1}^{n} h_i \rho_i}{\sum_{i=1}^{n} h_i} \quad 4$$

Therefore, the Anisotropy is defined as the square root of ratio of Average Transverse Resistivity (ρ_t) to Average Longitudinal Resistivity (ρ_l) for the VES curve given by equation 5

$$\lambda = \sqrt{\frac{\rho_t}{\rho_l}} \quad 5$$

The classification of the protective capacity of the overburden into excellent, very good, good, moderate, weak and poor protective capacity zones by Oladapo et al., 2004; Oladapo and Akuntorinwa, 2007; Abiola et al., 2009 was adopted in this study (Table 1)

Table 1: Longitudinal conductance /protective capacity rating Abiola et al., 2009

Longitudinal Conduction	Protective Capacity Rating
< 0.1	Poor
0.1 – 0.19	Weak
0.2 – 0.69	Moderate
0.7 - 4.9	Good
5 -10	Very Good
>10	Excellent

Soil samples collection

Soil samples were collected along each resistivity profile with four (4) samples on each profile laid within cultivated farmland in FUNAAB with the use of soil auger together with core samplers. For the purpose of determinations of soil moisture contents, soil samples were collected at the depths of 0.5, 1.0, 1.5 and 2.0m at the interval of 0.5m. The collected soil samples were analyzed at the Soil Science laboratory of Federal University of Agriculture Abeokuta, Nigeria. Physical parameters of interest were; soil pH, soil temperature, particle size distribution, porosity, soil moisture content, water holding capacity, soil hydraulic conductivity and bulk density. Hydraulic conductivity of soil was measured using the constant head method based on Reynelds and Elrick, 2002. pH meter was used to determine the value of pH each soil sample based on ASTM G51-Q5 standard while the soil temperature was measured by put in two sensors into the soil to determine temperature values. Soil moisture content was determined using the weight loss method based on ASTM porosity 04959-07 standard. Textural classification was carried out using the USDA textual classification. The determination of bulk density was carried out by gravimetric soil cure method with the particle density assumed to be 2.65 g/cm^3. The porosity (P) in percentage % was calculated using equation 6,

$$P = 1 - \frac{BD\left(g/cm^3\right)}{2.65\left(g/cm^3\right)} \qquad 6$$

Where p and BD are porosity and Bulk density respectively

Results and discussion

Results of Vertical Electrical Sounding (VES)

The application and analysis of Vertical Electrical Sounding (VES) measurements carried out within the cultivated farm land at Federal University of Agriculture Abeokuta allowed both thickness and resistivity of the aquifer to be achieved. The result of VES shows the variation in the apparent resistivity of the layers, thicknesses (h) and depth of overburden on the aquiferous were presented in Figures 4 and 5. The study area is underlain by four layers of different lithologies. Two resistivity sounding curve types were obtained; VES 2, VES 3, VES 4, VES 5and VES 6 are H-types ($\rho_1 > \rho_2 < \rho_3$) while VES 1 has KH type($\rho_1 < \rho_2 > \rho_3 < \rho_4$). The percentage frequency of the curve types are 83.33% for H-type and 16.67% for KH type. The range of the values of thicknesses of each layer for all the six VES points are given as: Topsoil ranges between 0.5 – 1.3 m, clayey sand layer between 1.1 – 11.9 m and weathered basement between 1.1 - 14.0 m as presented in Table 2. The topsoil resistivity values ranged from 78.0 – 1094.0 Ωm while the layer thickness ranged from 0.5 – 1.9 m. The range of resistivity values obtained for the topsoil for VES 1, 2, 5 and 6 were between 78.0 – 349.0 Ωm which is within that of sandy-loam soil class, while VES 3 has topsoil resistivity values of 1094.0 Ωm. The variations in topsoil resistivity could be as a result of different degree of compaction due to reworking activities at the farmland.

The clayey sand layer resistivity values range from 110.0 – 275.0 Ωm with thickness values from 1.1 - 11.9 m. The weathered basement resistivity values lie between 19.0 – 274.0 Ωm while the layer thickness varies between 1.1 - 14.0 m. The fractured basement has resistivity values ranging between 160.0 – 893.0 Ωm. The fractured basement columns were delineated beneath VES 1, 2, 3 and 4 while partially fractured basement was delineated beneath VES 5 and 6.

The cross section between VES 1 and 2 that functions as entrances to the cultivated farm land in FUNAAB as shown in Figure 6. Figure 6 reveals that the study area is underlain by four layers representing the topsoil, clayey sand, sandy clay and fractured basement. The first two units in the section is the overburden with resistivity and thickness values ranging from 78.0 – 349.0 Ωm /0.5 - 1.1m and 26.0 – 98.0 Ωm/1.1 - 5.7 m respectively. The lowermost fractured basement resistivity values ranged from 160.0 - 475.0 Ωm. The VES results show that the topsoil of the study was made of relatively thin sandy loam and sandy clay loam. Furthermore, lateral and vertical variation in depth and thickness of the subsurface layers was revealed with the help of geo-electric sections. The geo – electric sections showed that the study area is underlain by geologic (lithological) sequence consisting of the topsoil, thin clayey sand, sandy clay and fractured basement.

The geo - electric section across the profiles within the farmland is presented in Figure 7. The resistivity values of the topsoil ranges from 112.0 – 1094.0 Ωm while the weathered basement ranges from 18.0 – 274.0 Ωm. The clay with resistivity value less than 30.0 Ωm in both VES 5 and 6 are similar while that of VES 3 and 4 (clayey sand) are also identical in nature. The fractured basement resistivity value varies from 181.0 - 893.0 Ωm. The topography of this section is uneven with thickness range of 3.9- 14.0 m and depth range of 4.8- 15.3 m. The basement is much closer to the surface with a depth of 4.8 m occurring at offset 7.0 m towards the east axis. The fractured basement model resistivity is less than 500 Ωm in VES 5 and 6 justifying the fractured nature and incompetent (Aina*et al*., 1996). The resistivity values of fractured layer beneath VES 3 and 4 is >500 Ωm. The highest resistivity value of fractured layer with 893.0 Ωm occurs at VES 3.

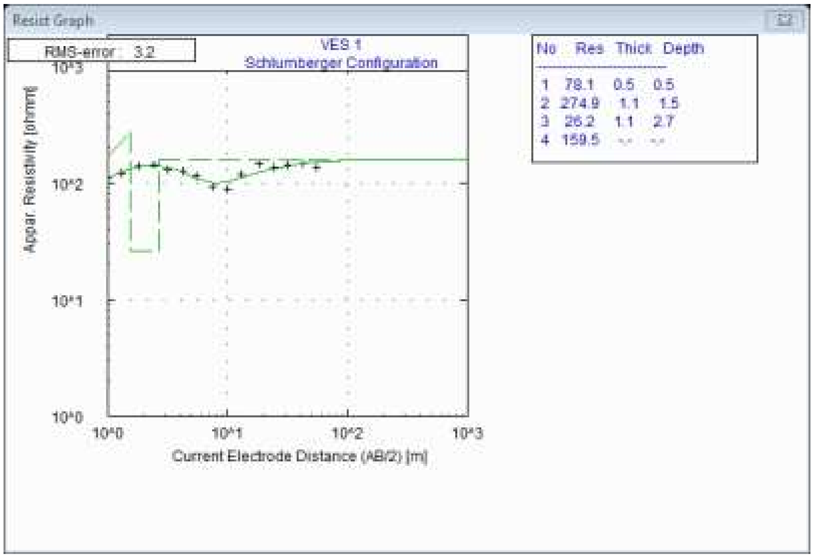

Figure 4: Resistivity field curve of VES 1

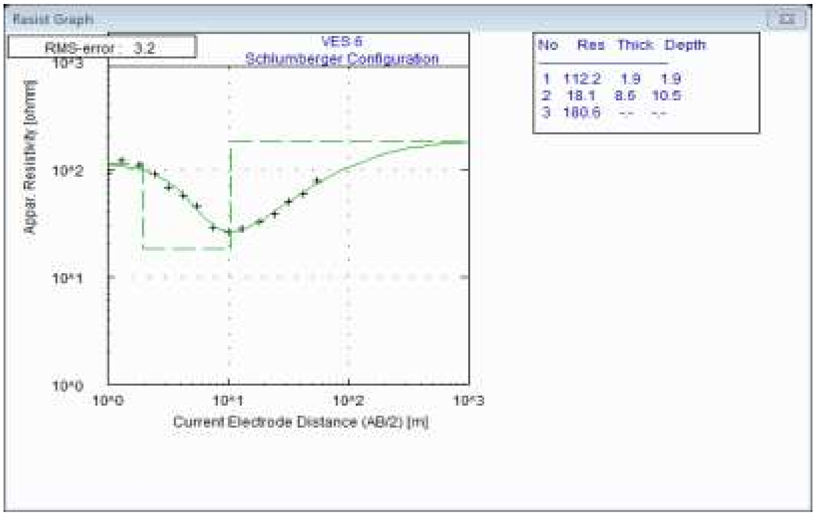

Figure 5: Resistivity field curve of VES 6

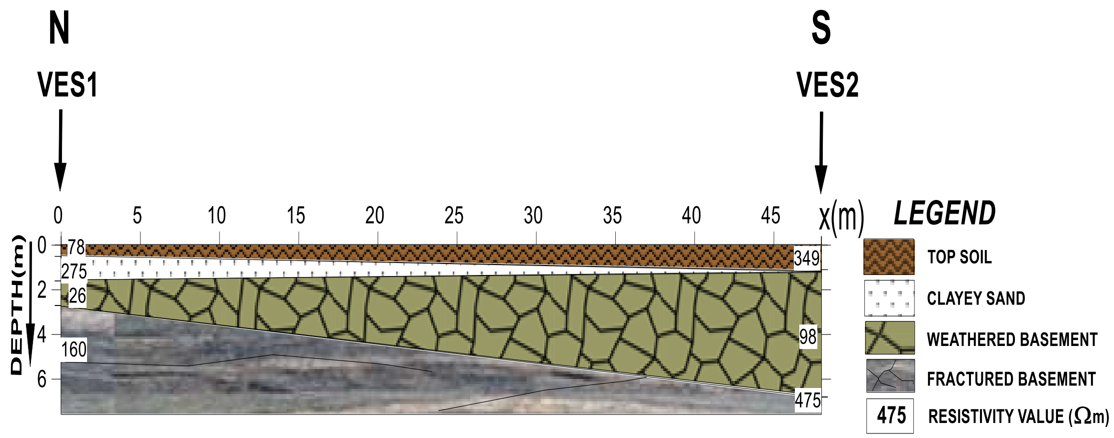

Figure 6: The Geo-electric Section of VES 1 and 2

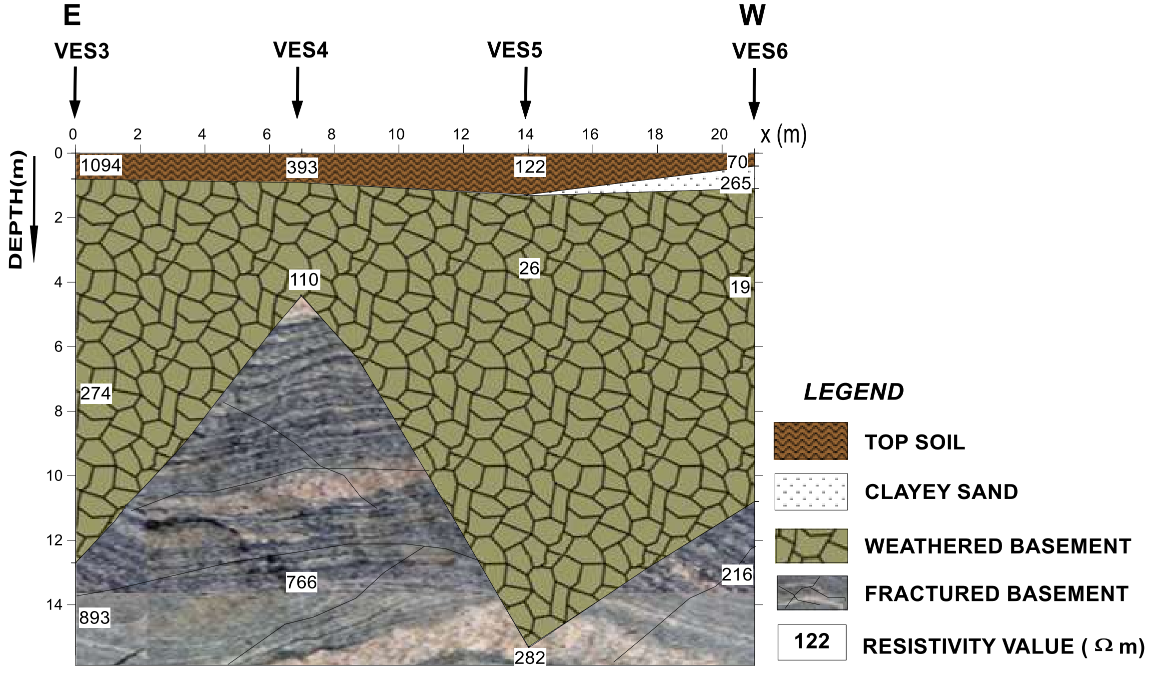

Figure 7: The Geo-electric Section of VES 3, 4, 5 and 6

Table 2: Showing the summary of the geo-electric parameter of VES curve obtained

Station	Layer No	Resistivity value (Ωm)	Thickness(m)	Depth(m)	Curve Type	Reflection Coefficient	Probable Lithology
VES 1	1 2 3 4	78 275 26 160	0.5 1.1 1.1 -	0.5 1.6 2.7 -	KH	0.72	Top soil Clayey sand Clay Fractured basement
VES 2	1 2 3	349 98 475	1.1 5.7 -	1.1 6.8 -	H	0.65	Top soil Clay Fractured basement
VES 3	1 2 3	1094 274 893	0.8 11.9 -	0.8 12.7 -	H	0.53	Top soil Clayey Sand Fractured basement
VES 4	1 2 3	393 110 766	0.9 3.9 -	0.9 4.8 -	H	0.75	Top soil Clayey Sand Fractured basement
VES 5	1 2 3	122 26 282	1.3 14.0 -	1.3 15.3 -	H	0.83	Top soil Clay Partially Fractured basement
VES 6	1 2 3	112 18.1 180.6	1.9 8.6 -	1.9 10.5 -	H	0.82	Top soil Clay Partially fractured basement

Evaluation of aquifer vulnerability

Aquifer protective capacity (APC) is the capability of the overburden unit to slow down and sifter seep into ground surface leaching fluid from entering into the aquiferous unit (Olorunfemi et al., 1999). The aquifer protective capacity characterization is based on the values of the Integrated Electrical Conductivity (longitudinal unit conductance (S)) of the overburden rock units in the cultivated farmland at FUNAAB. The geo-electric parameters were calculated using equations 1, 2, 3 and 4. The results of geo-electric parameters were presented in Table 3. The longitudinal unit conductance (*S*) values obtained from the study area range from 0.04 to 0.55 mhos as presented in Table 3. Clayey overburden with reasonably high longitudinal conductance provides safeguard to the underlying aquifer. The portion having conductance values less 0.1 mhos covered about 83.33 % of the study area and was classified as zone of poor protective capacity; the value between 0.2 and 0.69 mhos covered about 16.67% and was categorized as of moderate protective capacity.

VES 1, 2, 3, 4 and 6 falls within the poor protective zones and are prone to surface and near-surface leachate, while VES 5 falls within the moderately protected zones, the aquifer is properly secure from leachate seep into fluids.

Table 3: Aquifer Characteristics for all the VES station

VES STATION	IEC 1(S)	IEC 2(S)	IEC 3(S)	IECTotal (S)	TTUR	ρ_l	ATR(ρ_T)
1	0.0064	0.0040	0.0423	0.052718	370.1	51.21	137.074
2	0.0032	0.0582	-	0.061315	942.5	110.9027	138.603
3	0.0007	0.0434	-	0.044162	4135.8	287.57	325.653
4	0.0023	0.0355	-	0.037745	782.7	151.0133	142.309
5	0.0107	0.5385	-	0.549117	522.6	27.862	108.875
6	0.0100	0.0366	-	0.067656	1366.0	155.19	130.095

Soil analysis

The result of analysis of physical parameters of the soil samples from the cultivated farmland in FUNAAB are presented in Table 4. The values of average bulk density (g/cm^3) ranged from 0.3846 – 1.3960 g/cm$^{3\,w}$ with mean 1.0218. It was observed that obtained bulk density values for the analysed soil samples did not reach the critical bulk density values for plant growth according to Jones, 1983. The evaluated porosity values of soil samples on all profiles ranged from 49.2 % - 85.5% with mean value of 61.75%. The calculated values of saturated hydraulic conductivity ranged from 0.0042 cm/s to 0.0073cm/s. The variability of soil hydraulic conductivity within a particular soil type may be due to different amount of macrospores and pore continuity in the analyzed soil samples (Cameira et al, 2003, Ahuja et al, 1984). The soil textural class according to USDA textural triangle classification of all profiles belongs to sandy loan soil. It was further observed that there is significant increase in soil moisture at 1.5 – 2.0 m depth. This corresponds with the transition from high resistivity near surface layer to relatively low resistivity weathered layer.

Conclusion

The detailed characteristics of geo-electric section accurately delineated based on the comprehensive VES resistivity data interpretation using both major and minor geo-electric parameters and along with the analysis of some selected physical parameters of soil samples from the cultivated farm land. The geo-electric survey revealed that the values of resistivity, thickness and depths from the sounding curve ranged between 19 Ωm – 1094 Ωm, 0.4 m – 14 m and 0.4 m - 15.3 m respectively. The reflection coefficient ranged between 0.5 – 0.83. The analysis of results obtained from the aquifer protective (APC) reveals that VES 1, 2, 3, 4 and 6 were classified as zone of poor protective capacity which represents 83 percent of the total VES points while VES 5 belongs to zone of moderate protective capacity. Based on the standard textural classification of soil all the soil samples collected along the profiles of VES point belongs to sandy loan soil. Therefore, the study has succeeded in delineating groundwater potential of the cultivated farmland in FUNAAB and evaluating the groundwater vulnerability using combined method of vertical electric sounding and laboratory experiments on estimation of some selected physical parameters of soil to effectively characterize the topsoil.

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Geology and Hydrogeophysical Appraisal of Angwan-Doruwa, Parts of Jama'a Sheet 188 NE, Central Nigeria

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Abstract
Fresh water is essential for living but not readily available for use everywhere especially in most rural communities. Inhabitants of Angwan Doruwa and its environs, within latitude N8°56'37" to N8°59'45" and longitude E8°10'00 " to E8°13'23" parts of Jama'a Sheet 188 NE, in North Central Nigeria depend largely on surface water from streams which is prone to contamination and could lead to a rise in ill health already being experienced by the people. This prompted the need to conduct geological and hydrogeophysical studies to locate suitable underground aquifers where potable groundwater can be exploited in the area. Three methods employed in this study include; geological mapping, thin section analysis and electrical resistivity geophysical survey. Schlumberger configuration was used to investigate 15 stations within the area. Geological mapping revealed that the area comprises of migmatitic gneiss, biotite gneiss and leucocratic granite with joints trending in the NNE – SSW principal direction. Result of petrographic analysis showed presence of biotite, quartz, orthoclase, plagioclase, muscovites, perthite, microcline and amphibole as the common rock forming minerals in the area. Interpreted geophysical data revealed maximum of five and minimum of three geo-electrical layers: topsoils (TS), lateritic soils (LT, LS), weathered basement (WB) layer consisting of weathered rock fragments or regolith (R), fractured layer (FRB) and fresh basement layer (FB). The weathered and fractured basement layers have sufficient thicknesses (10 m to 30 m) to retain and transmit groundwater and therefore constitute the aquifers in the study area. The fractured basement layer at a depth of 40 m to 50 m constitutes the main aquifer in Angwan Doruwa with a very good groundwater potential while the weathered basement layer at a depth of 25 m to 35 m constitutes a good aquifer in adjoining villages. Drilling can best be achieved through the use of down-hole hammering method.

Keyword: electrical resistivity, groundwater, aquifer and geological mapping

Introduction
There is no gain saying that water is life and keeping pace with the rising demand for water is more easily achieved for groundwater than surface water (Novotny and Olem, 1994). Angwan Doruwa is an agricultural settlement from where large quantities of grains such as maize, groundnuts, and guinea corn are produced and sold out to urban areas. On a careful survey around the village, it was discovered that there is no single existing borehole as at the time of the study and the inhabitants rely mainly on surface water which is highly prone to contamination. Without doubt, there is a water problem in the area and hence, a need to investigate suitable locations and depths where potable groundwater can be exploited. Thus, the research will significantly

improve knowledge on the geology, petrography, and suitable locations (depths) of groundwater aquifers within the study area hence proffering a solution to the existing water problem in the area.

The application of geophysical methods has been used successfully used in earth studies owing to the fact that it uses some physical properties such as the earth's magnetism, conductivity, density and velocity to give information on likely subsurface features or conditions (Capenter *et. al,* 2012). The electrical resistivity method being employed in this study depends on the conductivity responses of the earth materials. It is largely dependent on the porosity, permeability, fluid contents and mineral composition (type) of rocks.

The study area is Angwan Doruwa and its environs in Akwanga, North Central region of Nigeria. It is geographically sited within latitude N8°56'37" to N8°59'45" and longitude E8°10'00 " to E8°13'23 "parts of Jama'a sheet 188 NE, published by the Office of the Surveyor General of the Federal Republic of Nigeria (2008). A total area of about 30 km^2 was covered (Figure 1). The area is accessible through the Akwanga - Keffi – Abuja highway and other minor roads linking it to other adjoining villages such as Moroa. Some parts of the area are not accessible due to thick vegetation cover. Two contrasting climatic conditions characterises the study area, namely; the dry season and raining season. The dry season, with little or no rainfall is usually experienced from November to early/mid-April. The Harmattan (dry and dusty wind) experienced from November-January also characterises the dry season. April marks the beginning of the rainy season with a progressive increase and attains its peak in July (NIMET, 2018).

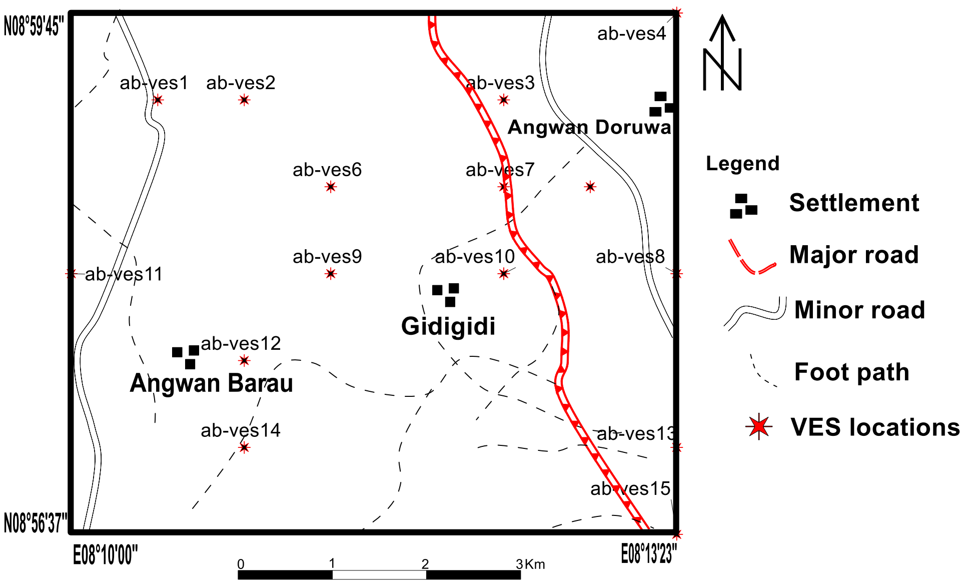

Figure 1: Location map of the Study area (digitized from Jama'a sheet 188 NE, published by the Office of the Surveyor General of the Federal Republic of Nigeria, 2008).

Methodology

Methods employed for this study include; geological mapping, thin section analysis and electrical resistivity geophysical survey.

Geological mapping

A detailed geological mapping of the study area was carried out to delineate the nature of rocks as this is crucial to the research problem. This was done after a desk study of previous works that have been carried out covering the area of study.

The mapping exercise was achieved by taking ground traverses through township roads and foot paths to rock exposures where observations were made. At each exposure, keen attention was paid to physical characteristics of rocks such as colour, texture, mineral contents and structures present. Where possible, all field measurements were taken on the rocks and structures.

Information obtained from the field mapping was used to produce a geological map of the study area (Figure 2) which shows the different rock types with their inferred boundaries. Also, the geological history of the area was deduced from this information. Orientations of joints were measured and recorded in the field. It was used to produce a rose diagram, which shows the principle direction of joints in the area.

Thin Section Analysis

Three rock samples obtained during the geological mapping exercise were analysed in the laboratory, using the thin section analytical technique. A thin section is a slice of rock 30 micrometres thick affixed to glass plate or slide with a resin called Canada Balsam. Most minerals are transparent in slices and can be viewed in transmitted light at various magnifications. Many minerals have properties that vary with the direction in which the light passes through them.

Rocks are viewed in a petrographic microscope in polarized light (plane and cross polarized light) on a rotating stage so that the various colour and refractive indices become apparent as the stage is rotated. The Balsam upon which the rock is mounted on has a refractive index of 1.538 Minerals whose refractive index is higher than 1.538 appear to stand out from the surface slide like hills and are said to have positive relief appeared as pits in the slide.

Electrical Resistivity Survey

Geophysical methods have been widely employed in earth studies over time. It involves the use of the principles of physics as it relates with the physical properties of the earth such as density, velocity, gravity, conductivity and magnetism. There are various geophysical methods which measures these different properties of the earth. Measurements are being taken at or near the surface of the earth which is influenced by the distribution of these physical properties beneath the earth.

For this study, the electrical resistivity method which explores both vertical and horizontal discontinuities in the earth based on its electrical properties was used. The earth possesses a good electrical property which is being exploited using the resistivity survey method. For instance, rocks are made up of various mineral constituents with varying electrical responses. Groundwater is also a very good conductor of electricity and could therefore be explored using the electrical resistivity method.

15 VES stations were investigated using the Schlumberger configuration. This array makes use of a pair of current electrodes and another pair of potential electrode arranged in a linear pattern with the currents electrodes spread at distance AB apart and the potential electrodes spread apart at distances MN. Using this configuration, the distance between the current electrodes AB is usually made to be equal to or greater than five times that of the potential electrodes MN. A typical field arrangement for Schlumberger array is presented in figure 3.2 below;

Results and Discussions

Petrography

Three different rock samples (S1, S2 and S3) obtained within the study area were subjected to microscopic studies using thin section analysis.

Table 1: Description of Minerals under Plane Polarized Light (PPL)

Mineral	Description
Biotite	appeared as lath-like, brown to dark brown in colour, shows strong pleochroism, high relief and one cleavage parallel to the alignment of the mineral grains
Muscovite	Appeared as lath-like, colourless, non-pleochroic, it has low relief and some grains appeared to have one distinctive cleavage
Quartz	Appeared as colourless, non pleochroic, showed very low relief relative.
Plagioclase	Appeared to be colourless, non pleochroic with low relief and no distinctive cleavage but showed a systematic fracture.
Perthite	Appeared as colourless, non-pleochroic has low relief, showed two cleavages not at right angle to one another and forms large subhedral crystals
Amphibole	Showed greyish-brown colour, non-pleochroic, has moderate relief, with no distinctive cleavage.
Orthoclase	It appeared as colourless, non-pleochroic, showed low relief; show no distinctive cleavage and have a subhedral crystal form.
Microcline	It showed first order white and grey interference colour, showed strong cross-hatch twinning which is a distinctive optical property of microcline, showed no alteration and does not undergo extinction on 360^0 rotation of the microscope stage.

Table 2: Description of Minerals under Cross Polarized Light (XPL)

Mineral	Description
Biotite	Biotite showed brown, no sign of alteration, has no twinning, and goes extinct at about 900 on 3600 rotation of the microscope stage.
Muscovite	Muscovite showed yellowish-brown and purple third order interference colour, showed no sign of alteration, no twinning and goes extinct at about 900 on rotation of the microscope stage.
Quartz	Quartz showed white to yellow first order interference colour, showed no sign of alteration, no twinning and goes extinct at about 900 on rotation of the microscope stage.
Plagioclase	Showed first order grey interference colour, with albite twinning which is a distinctive optical property of plagioclase, and also does not show sign of alteration.
Perthite	It showed dark-grey interference colour with slight light lamellae which are probably sodium-rich feldspar, and does not show any distinct extinction angle.
Amphibole	It showed dark brown interference colour, showed no twinning, no sign of alteration and does not show any distinctive extinction angle.

Microscopic Description of Sample S1

In thin section, the rock is seen to compose of Biotite, Plagioclase, Quartz, Amphibole, Perthite and Muscovites. Table 3 shows the estimated modal composition of each mineral in the rock sample.

Table 3: Estimated Modal Composition of S1

S/N	Mineral	Percentage Composition (%)
01.	Biotite	48
02.	Quartz	22
03.	Amphibole	15
04.	Plagioclase	8
05.	Perthite	4
06.	Muscovite	1
07.	Others	1
	Total	**99**

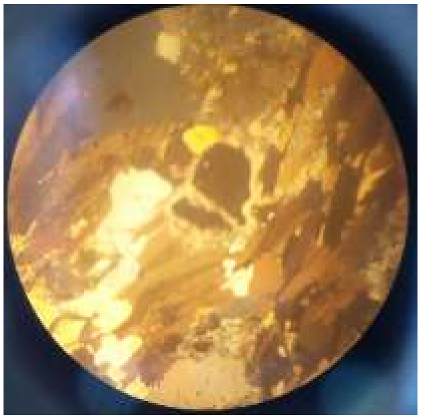

Plate I: Photomicrograph of S1 under Plane Polarized Light (using X4 Objective Lens)

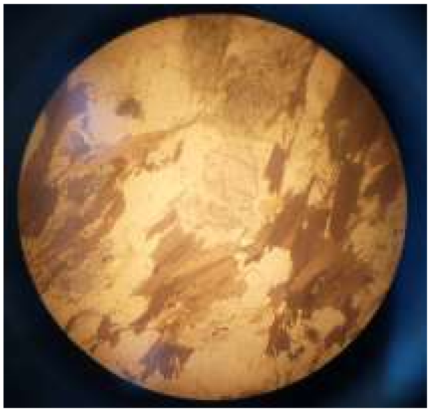

Plate II: Photomicrograph of S1 under Crossed Polarized Light (using X4 Objective Lens)

On the basis that this rock sample has strong alignment (foliation) of mineral grains and biotite minerals occurring in enormous quantity, and the presence of amphibole, suggest that this rock has been influenced strongly by metamorphism and has reached the grade of medium amphibolite facies. This information suggests that the rock is a Migmatitic Gniess.

Microscopic Description of Sample S2

Table 4: Estimated Modal Composition of S2

Mineral	Percentage Composition (%)
Biotite	32
Orthoclase	25
Quartz	21
Muscovite	12
Plagioclase	6
Others	4
Total	100

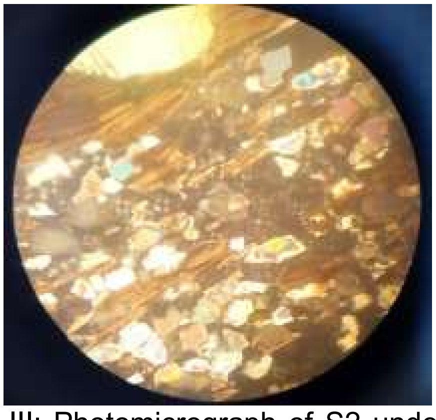

Plate III: Photomicrograph of S2 under Crossed Polarized Light (using X4 Objective Lens)

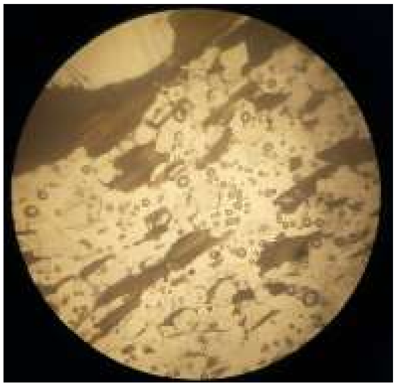

Plate IV: Photomicrograph of S2 under Cross Polarized Light (using X4 Objective Lens)

This rock sample has strong alignment (foliation) of mineral grains and biotite minerals occurring in enormous quantity, suggesting that this rock has been influenced by metamorphism. The rock is most probably a Biotite Gneiss.

Microscopic Description of Sample S3

The rock sample is seen to be made up of Biotite, Plagioclase, Quartz, and Microcline in thin section. Table 5 shows the estimated modal composition of each mineral in the rock sample.

Table 5: Estimated Modal Composition of S3

S/N	Mineral	Percentage Composition (%)
01.	Microcline	48
02.	Quartz	42
03.	Biotite	6
04.	Plagioclase	4
	Total	100

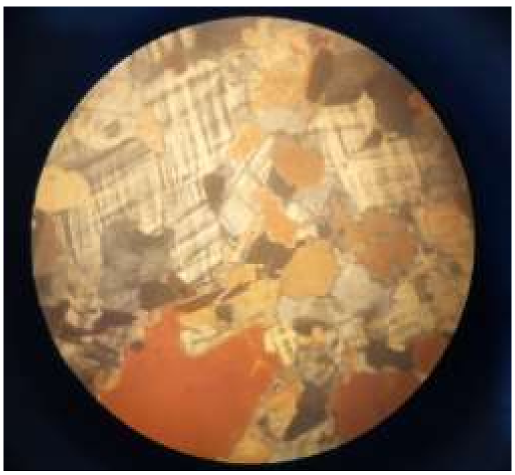

Plate V: Photomicrograph of S3 under Plane Polarized Light (using X4 objective lens)

Plate VI: Photomicrograph of S3 under Cross Polarized Light (using X4 objective lens)

No foliation was observed in thin section and the minerals does not show strong elongation of mineral grains, it can be suggest that this rock has probably not undergone partial melting and thus granitic in nature. Leucocratic Granite is suggested to be the name of the rock due to the preponderance of light coloured minerals.

Thin section analysis carried out on three rock samples obtained reveals that the area covered in this study composes of three rock types namely: Migmatite Gneiss, Biotite Gniess and Leucocratic Granites, all of which are typical Basement rocks (Figure 4.1). The ability of these rocks to retain appreciable amounts groundwater will be dependent on the amount of structures present on them.

Geology of the Study Area

The three different rock types were mapped in the study area. They include; Migmatitic Gneiss, Biotite Gneiss and Leucocratic Granites. Other minor rock units include Quartzo – Feldspartic veins and Pegmatite dykes (Figure 2).

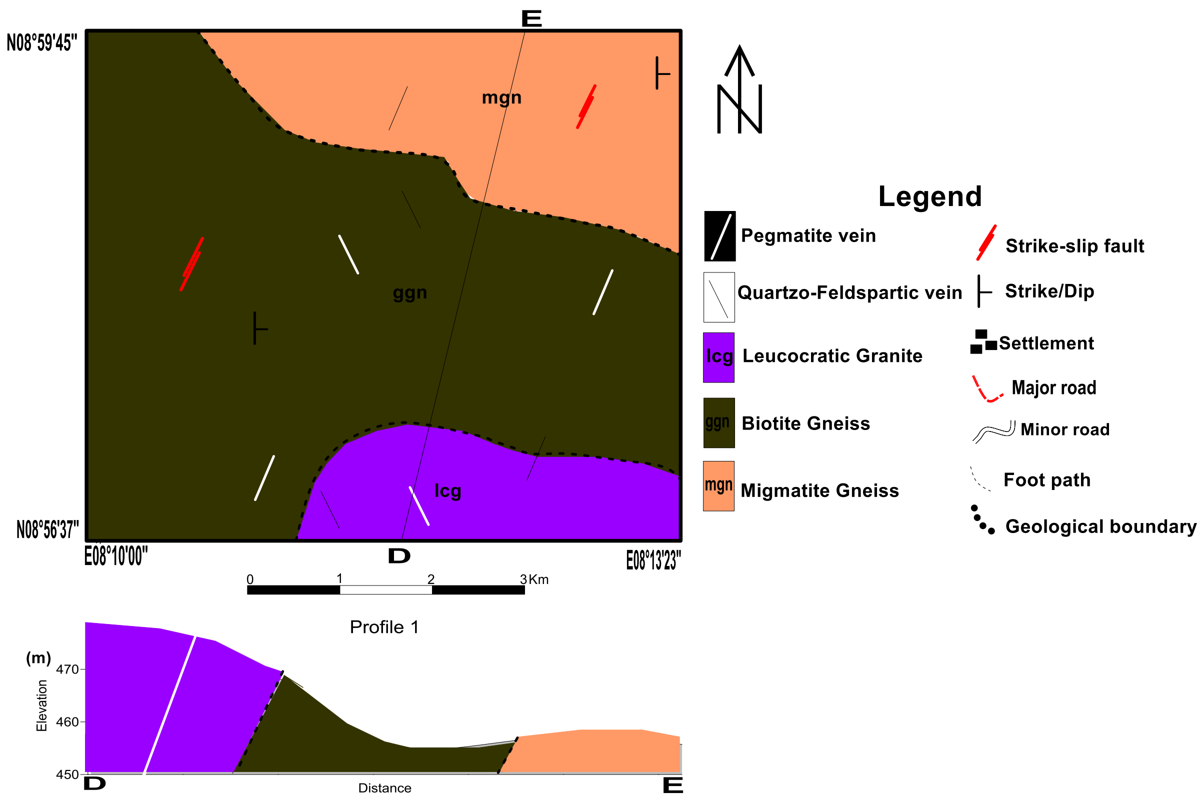

Figure 2 Geological Map of the Study Area

Migmatitic Gneiss

Migmatite Gneiss in the area mostly occurs as low lying outcrops and as boulders in few other places. They are notable in Angwan Doruwa and Angwan Dahariya and are generally medium grained with minerals such as feldspars, biotites and quartz, clearly visible on them. They appear with joint structures with pronounced alternating light and dark mineral bands (Plate VII). They are being intruded concordantly in some places by quartz – feldspartic veins and pegmatite dykes.

Plate VII: Migmatitic Gneiss exposed at Angwan Doruwa (N8°58'57" E8°13'23")

Plate VIII: Biotite Gneiss exposed at Angwan Maigini (N8°58'02" E8°11'29")

Biotite Gneiss

Outcrops of Biotite Gneiss were observed in Angwan Maigini and Angwan Barau. They are low lying and well foliated (Plate VIII) with presence of quartz veins and joints. Visible mineral grains include quartz, feldspars and biotite of medium grained sizes which are all aligned in a defined pattern.

Leucocratic Granites

They occur as intrusions, cutting across their surrounding country rocks. A prominent granitic exposure in the area is exposed in Angwan Television, bordering the study area. It is a quite massive exposure composed of minerals of medium to coarse grained sizes, bounded by gneiss in inferred areas. Mineral compositions of the rock include quartz, feldspars, biotites, muscovites with preponderance of feldspars and quartz (Plate IX). The rocks are jointed, faulted quite appreciably on the surface.

Pegmatite Veins

Pegmatite occurs as coarse grain light coloured materials. They are of great significance because they may host some economic minerals such as tourmaline, aquamarine or topaz. Here, they occur as infillings in a gneiss exposure, a little about 6cm in width in Angwan Jatau.

Prominent structures encountered in the area during the mapping exercise include; faults, joints, and veins. The presence of structures on rocks of the study area plays a very important role on its hydrogeology. In crystalline rocks, porosity of the rocks is solely dependent on the structures such as joints and faults. A dip slip fault showing a downward displacement at an angle of 14ºE (Plate XII) was noted in the area.

Veins are recognised on the field as infillings of fractured rocks by later hydrothermal fluids which then crystallize along the fracture paths. The veins observed in this study contain mostly quartz, feldspars and pegmatite. They may be short or continuous veins mostly depending on the fracture (Plate XIII) and may range in size from just a few streaks to thousands of feet. It is important to note that veins may contain diverse types of valuable minerals other than the ones here mentioned.

Joints are recognised on the field as fractured rocks showing no displacement. They are the most common structural features observed in the area on virtually all exposures and are mostly closed joints (Plate XIV). The joint orientation readings (Table 4.4) were obtained from various exposures and were used to produce a rosette diagram (Figure 4.2) showing the principle strike directions of the joints to be NE – SW.

Plate IX: Leucocratic Granite exposed at N8°58'57" E8°10'20"

Plate XI: Pegmatite Vein at Angwan Doruwa (N8°58'35" E8°10'48")

Plate XII: A Dip Slip fault at Angwan Dahariya (N8°59'04" E8°13'55")

Plate XIV: Joints at N8°55'45" E8°13'22"

Table 6 Strike reading for Joints in the Study Area

S/N	Strike Values (°)	S/N	Strike Values (°)	S/N	Strike Values (°)
1	16	2	172	23	18
2	60	3	24	24	36
3	32	4	50	25	32
4	64	5	108	26	28
5	70	6	28	27	310
6	12	7	22	28	28
7	16	8	24	29	32
8	20	9	122	30	36
9	30	10	18	31	26
10	18	11	28	32	40
11	38	12	42	33	63

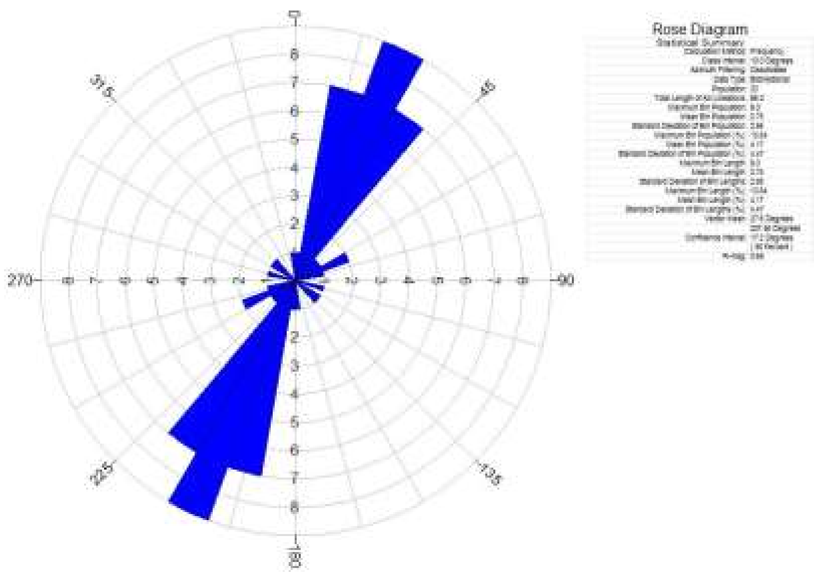

Figure 3: Rosette Diagram of Joints in the Study Area

Angwan Doruwa area falls under the North-Central Nigerian Basement Complex believed to be Precambrian in age. As observed from field studies, it comprises of Migmatite-Gneisses, Biotite Gneisses and Granites. The granite rocks can be said to be the youngest units in the area which intruded the pre-existing Gneisses. The Biotite Gneisses after undergoing the process of metamorphism and migmatization as a result of the injection of magma, graded into Migmatite-Gneisses.

Granites are said to be formed during the Pan African orogeny (Grant, 1878) which did not only change the mineralogy of the parent rocks but also led to the formation of different structures. Therefore, the structures present on the rocks in the study area may be attributed to the Pan African event which may have had a great effect on the topography of the area through formation of new hills in some parts and tilting some of the rocks. The most predominant structural trend in the area is towards the NE-SW direction which conforms to the N-S and NE-SW direction given by Grant, (1878) as the structural trend of the Pan African deformation.

Geo – electrical Survey Interpretations

Fifteen Vertical Electrical Sounding (VES) stations were surveyed in the study area. Strategic points were selected in the village for the survey. Field resistivity data was processed using IPI 2WIN computer program which produced sounding curves. The field apparent resistivity data and log – log graphs of apparent resistivity versus depth for all the VES stations are presented in appendix 1 and 2 respectively.

Results of the interpreted VES curves are shown in table 4.5 and table 4.6 from where it can be observed that the most predominant curve type obtained in the study area is the H curve ($\rho 1 > \rho 2 < \rho 3$). A maximum of five and minimum of three geo-electrical layers were delineated for VES stations in the study area namely: the topsoils (TS), which consists of sand materials with varying resistivity range of 337 Ωm to 706 Ωm and thickness range of 0.2 m to 2.5 m. The layer of lateritic soils (LT, LS) has resistivity range of 776 Ωm to 2141 Ωm and thickness range of 0.2 m to 2 m. The weathered basement (WB) layer constitutes of weathered rock fragments or regolith (R) which could serve as an aquifer in the area with a promising resistivity range of 16.6 Ωm to 466 Ωm with thickness ranging from 2 m to 14 m. The fractured layer (FRB) has resistivity range of 50 Ωm to 471 Ωm and thickness of 8.2 m to 35.2 m. The fractured rocks layer is the main aquiferous layer in the study area, and should be the target main during drilling. The fresh basement layer (FB) has a high resistivity value of greater than 20, 000 at depths of about 60 m in the study area implying that the layer is an undisturbed one, lying in its fresh state as its name implies.

Studies have shown that the resistivity value of fresh bedrock often exceeds 1000 Ωm. However, where it is fractured/sheared and saturated with fresh water, the resistivity often reduces below 1000Ωm (Olayinka and Olorunfemi, 1992). This might probably be the case for the study area. Based on the above interpretations, the area is hydrogeologically promising, although the quantity of groundwater obtainable will vary from one location to another.

Figure 4 and 5 shows the isoresistivity maps for the aquiferous weathered and fractured rock layers in the study area respectively. The area can be classified into two in terms of groundwater potentiality: good and very good. The isoresistivity map of the weathered basement layer shows that Angwan Barau has very good groundwater potential compared areas around Gidigidi and Angwan Doruwa with good groundwater potential. Figure 6 further indicates that areas around Angwan Barau have appreciably thick weathered rock layer (above 15 m) which constitutes the main aquifer. The weathered layer should be the main target when drilling particularly in Angwan Barau.

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Table 7: Interpreted Resistivity Result for Vertical Electrical Sounding (VES 1-9)

VES No.	No. of Layers	Resistivity (Ωm)	Layer Thickness	Curve Type	Remark
	1	418	0.76		TS
1	2	1743	0.59	H	LT
	3	I6.6	1.56		WB
	4	138	11.6		FRB
	5	14225	-		FB
	1	337	1.02		TS
2	2	823	1.08	HA	LT
	3	54.4	2.59		WB
	4	315	31.6		FRB
	5	21737	-		FB
	1	377	0.91		TS
3	2	752	0.86	H	LT
	3	66.1	13.3		WB
	4	26026	-		FB
	1	514	3.36		TS
4	2	74.5	4.45	H	WB
	3	676.9	-		FB
	1	780.9	0.6		TS
6	2	466.8	2.5	H	WB
	3	235	35.3		FRB
	4	56177	-		FB
	1	5746	0.2		LT
7	2	692	4.9	H	WB
	3	76.3	9.4		FRB
	4	44395	-		FB
	1	6207	0.2		TS
8	2	737	4.7	H	R
	3	111	14		FRB
	4	23101	-		FB
	1	1766	2.1	H	LS
9	2	51.9	13.8		WB
	3	16011	-		FB

TS – Top Soil LS – Lateritic Soils L – Laterite WB – Weathered Basement FRB – Fractured Rock FB – Fresh Basement R - Regolith

Table 8: Interpreted Resistivity Result for Vertical Electrical Sounding (VES 10-15)

VES NO.	NO. OF LAYERS	RESISTIVITY (Ωm)	LAYER THICKNESSS	CURVE TYPE	REMARK
	1	771	2.5		LS
10	2	348	22.6	H	FRB
	3	I170	-		FB
	1	771	2.5		LS
11	2	348	22.6	HA	FRB
	3	1165	-		FB
	1	3214	0.3		TS
12	2	1042	1.7	H	LT
	3	199	20.2		WB
	4	3121	-		FB
	1	706	0.3		TS
13	2	2141	0.9	H	LS
	3	76	17.3		WB
	4	34575	-		FB
	1	192.2	0.4		TS
14	2	568.9	17.9	H	LS
	3	144.4	18.7		WB
	4	15389	-		FB
15	1	328	0.8		TS
	2	673	09		LT
	3	143	5.9	K	WB
	4	55.7	8.2		FRB
	5	21779	-		FB

TS – Top Soil LS – Lateritic Soils L – Laterite WB – Weathered Basement FRB – Fractured Rock FB – Fresh Basement R – Regolith

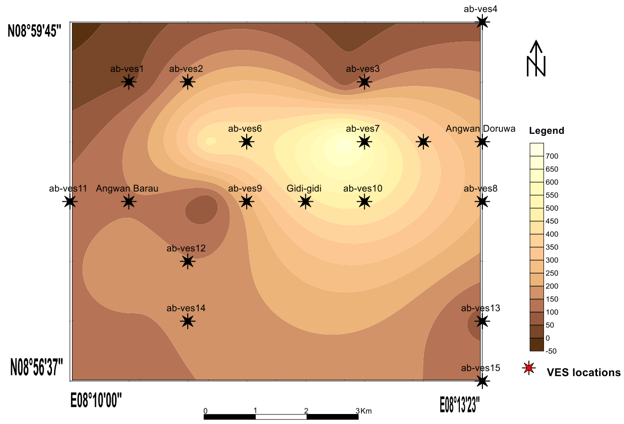

Figure 4: Isoresistivity map of weathered layer in the study area

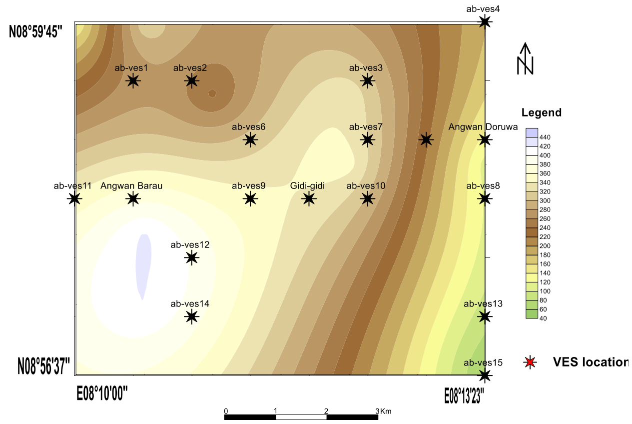

Figure 5: Isoresistivity Map of fractured basement in the study

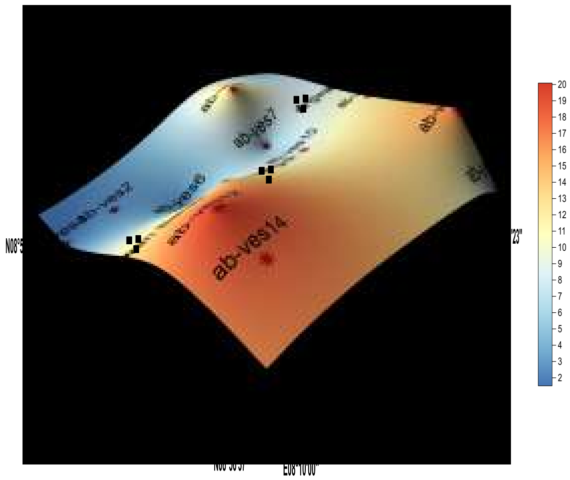

Figure 6: 3D Thickness Surface of the Weathered Basement rocks in the study area

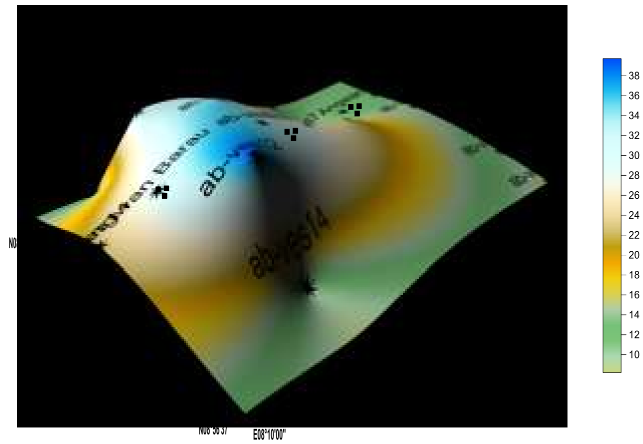

Figure 7: 3D Thickness Surface of Fractured Basement Rocks in the study area

Gidigidi and Angwan Doruwa tend to have a very good groundwater potential with aquifer thickness of 20 m to 30 m therefore the fractured rock layer constitutes the main aquifer to be targeted during drilling at a depth of 45 m to 50 m.

Conclusion

The main Rock types in the area consist of Migmatitic Gneiss with minerals such as biotite, quartz, amphibole, plagioclase, perthite and muscovite; Biotite Gneiss with minerals such as biotite, orthoclase, quarts, muscovites and plagioclase; Leucocratic Granites with minerals such as plagioclase, microcline, biotite and quartz. Structures present in the rocks include faults, veins and joints trending in the NNE – SSW principal direction. Secondary porosity in structures in the area favours the accumulation of and transmission of groundwater.

A maximum of five and minimum of three geo-electrical layers were delineated for

VES stations in the study area namely: the topsoils (TS), which consists of sand materials with varying resistivity range of 337 Ωm to 706 Ωm and thickness range of 0.2 m to 2.5 m. The layer of lateritic soils (LT, LS) has resistivity range of 776 Ωm to 2141 Ωm and thickness range of 0.2 m to 2 m. The weathered basement (WB) layer constitutes weathered rock fragments or regolith (R) with resistivity range of 16.6 Ωm to 466 Ωm and thickness ranging from 2 m to 14 m. The fractured layer (FRB) has resistivity range of 50 Ωm to 471 Ωm and thickness of 8.2 m to 35.2 m. The fresh basement layer (FB) has a high resistivity value of greater than 20, 000 at depths of about 60 m in the study area implying that the layer is an undisturbed one, lying in its fresh state as its name implies. Weathered and fractured basement layers have sufficient thickness (greater than 30 m) to retain and transmit groundwater. They therefore constitute the aquifers in the study area. The weathered basement layer constitutes the main aquifer in Angwan Barau with very good groundwater potential. The aquifer is appreciably thick (above 15 m) to hold and transmit groundwater while the fractured basement layer constitutes the main aquifer in Gidigidi and Angwan Doruwa with a very good groundwater potential. Aquifer thickness ranges from 20 m to 30 m. The application of geological mapping and geoelectrical resistivity survey is therefore a useful tool in delineating suitable aquifers.

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WATER RESOURCES

Journal of the Nigerian Association of Hydrogeologists

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