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

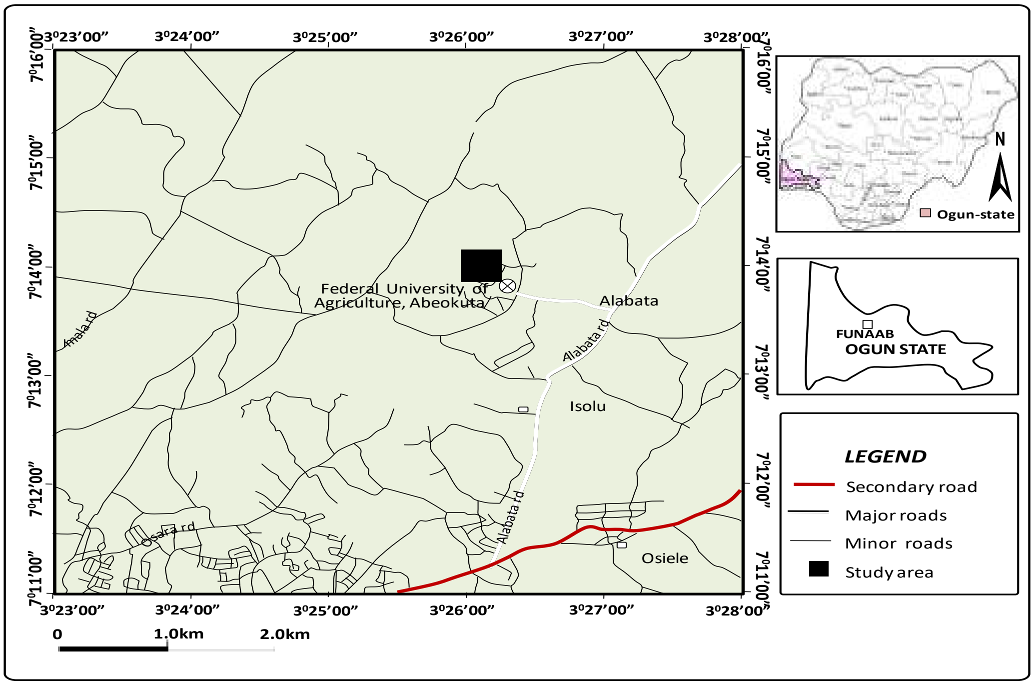

Figure 1: Location Map of the Study Area

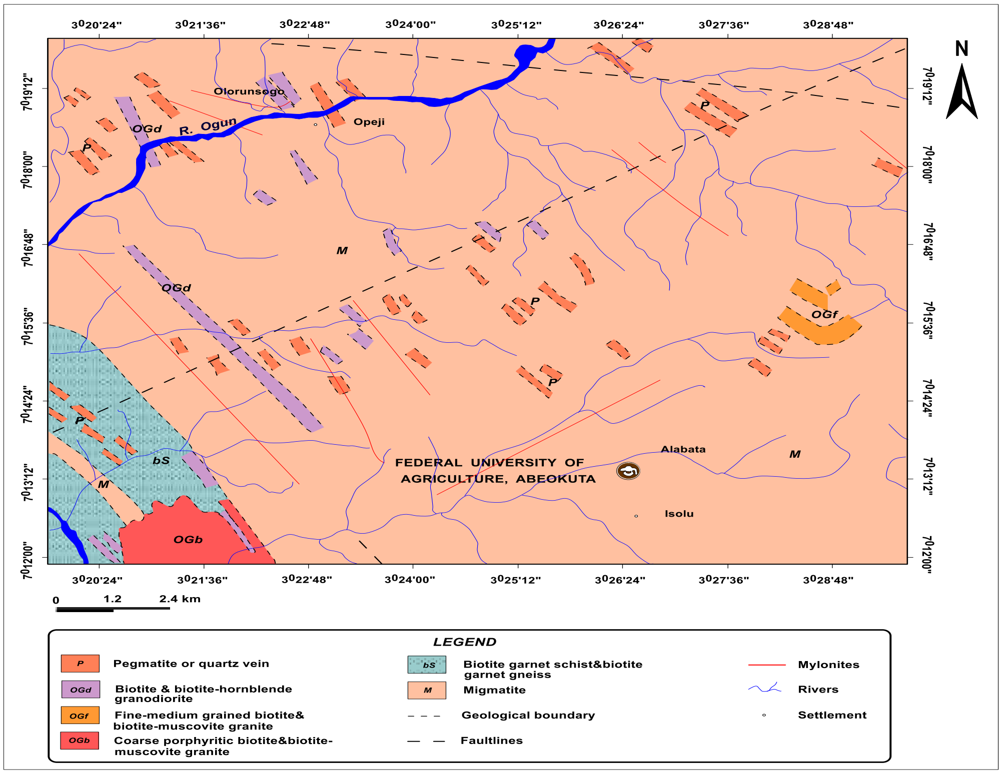

Figure 2: Geological map showing the rock type that underlies the study area (adapted from NGSA 2009)

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).

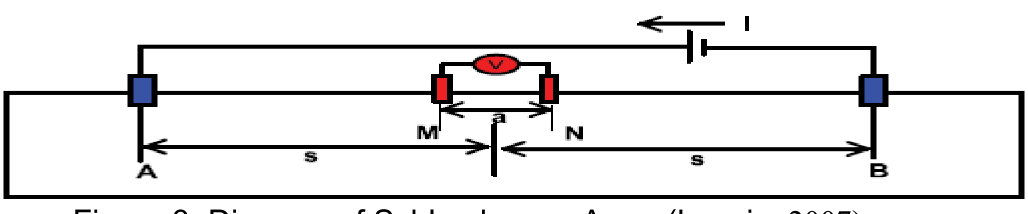

Figure 3. Diagram of Schlumberger Array (Lowrie, 2007)

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)

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

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

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

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

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

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

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

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

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

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.

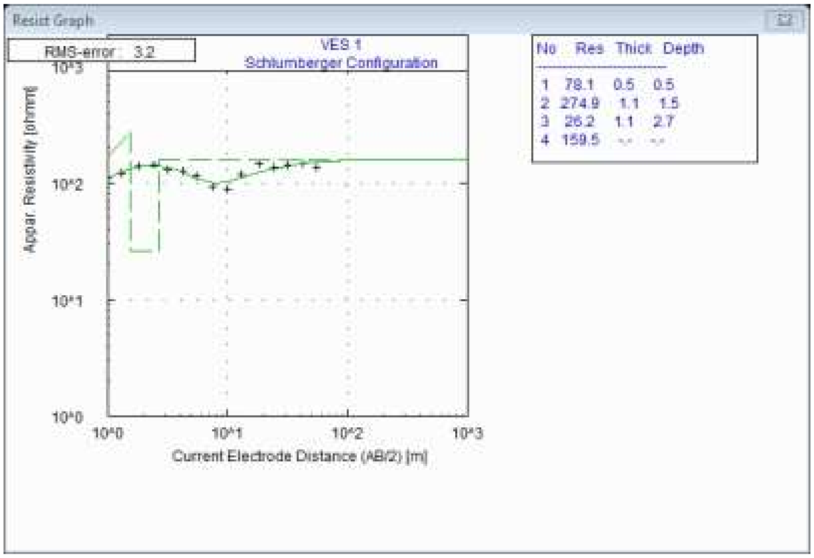

Figure 4: Resistivity field curve of VES 1

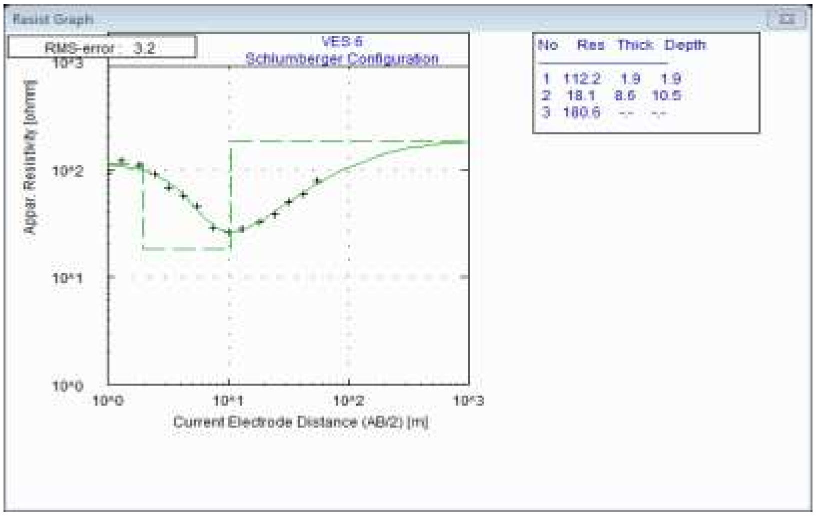

Figure 5: Resistivity field curve of VES 6

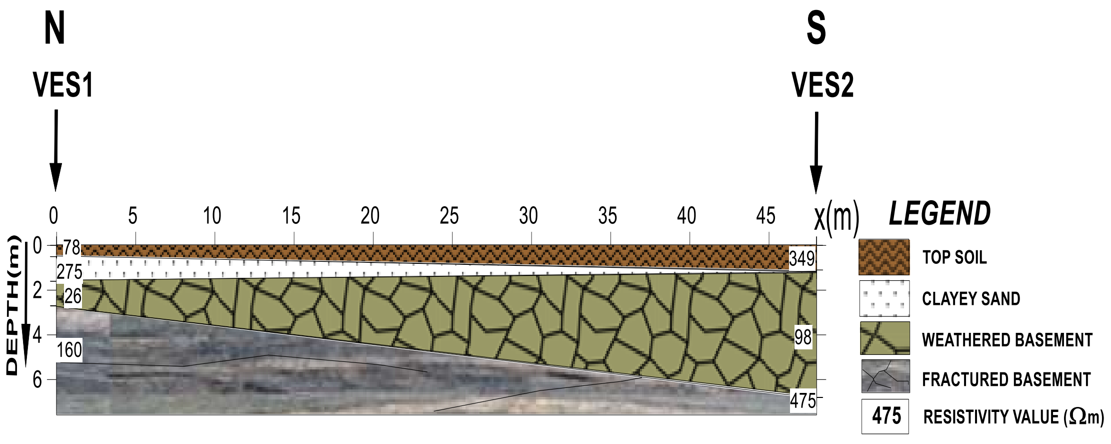

Figure 6: The Geo-electric Section of VES 1 and 2

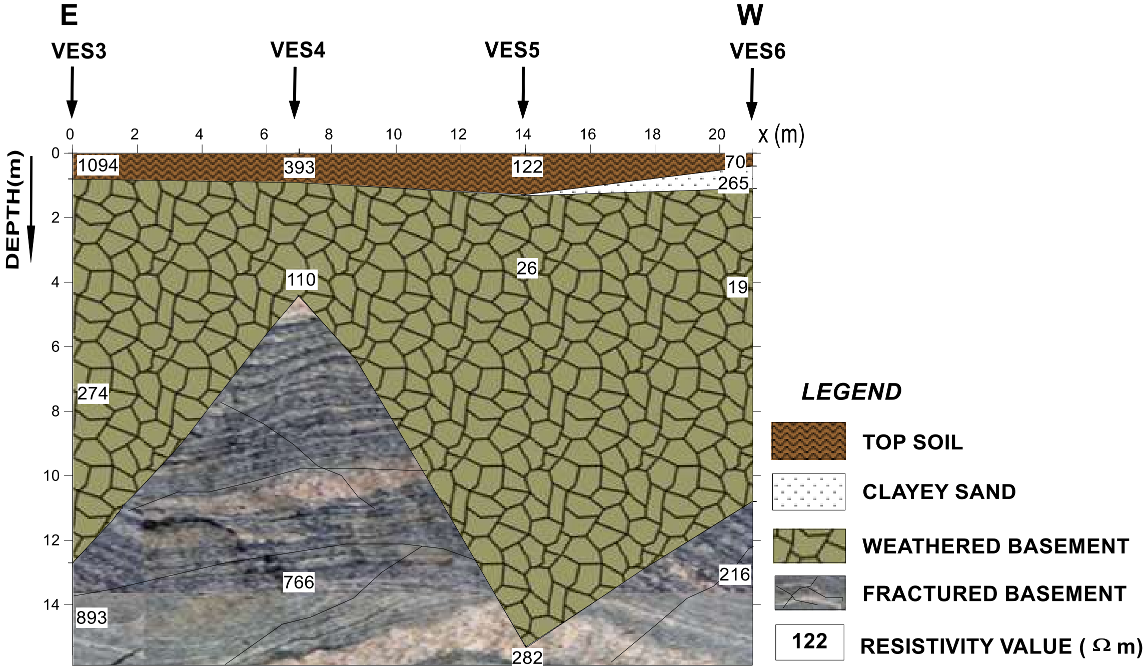

Figure 7: The Geo-electric Section of VES 3, 4, 5 and 6

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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