

# DELINEATION OF GROUNDWATER POTENTIALS USING DAR ZARROUK PARAMETERS IN OTUKPO AND ENVIRONS, BENUE STATE, NIGERIA

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## ABSTRACT

*Water shortage is a major challenge to inhabitants of Otukpo and its environs for decades especially during dry season period. Geophysical survey was carried out to delineate the groundwater potential of the study area using Dar-Zarrouk Parameters to determine possible areas of drilling boreholes. A total of thirty (30) Vertical Electrical Soundings were carried out using Schlumberger array of electrode configuration with maximum electrode spacing,  $AB/2 = 215\text{m}$ . The field data were analyzed using interperx 1x1-D computer software. The results show that the aquifer longitudinal conductance value ranges from  $0.112\Omega^{-1}$  to  $2.52\Omega^{-1}$  with mean value of  $1.12\Omega^{-1}$ . Similarly, the transverse resistance value ranges from  $1047.35\Omega\text{m}^2$  to  $18468.52\Omega\text{m}^2$  with mean value of  $3945.66\Omega\text{m}^2$ . Additionally, the transmissivity ranges from  $41.79\text{m}^2/\text{day}$  to  $1231.94\text{m}^2/\text{day}$  with mean value of  $522.58\text{m}^2/\text{day}$ . Furthermore, the hydraulic conductivities of the aquifers range from  $7.63\text{m}/\text{day}$  to  $234.26\text{m}/\text{day}$  with mean value of  $36.02\text{m}/\text{day}$ . Classification of groundwater potential on the basis of transmissivity reveals that 50% of the aquifer has high underground water potential, 40% has moderate underground water potential while the remaining 10% has low underground water potential. Considering the results obtained, the location of establishments which are sources of underground water contamination should be discouraged in areas of moderate aquifer protective capacities. It is, therefore, recommended that for economic and environmental considerations, predrilling investigation should be carried out in the study area.*

**Keywords:** Otukpo, Groundwater potential, Dar-Zarrouk parameters, Boreholes, Transmissivity

## 1 INTRODUCTION

Groundwater is a vital resource, especially in arid and semiarid areas. Sufficient groundwater with high quality is required to meet increasing domestic, agricultural and industrial needs. Groundwater withdrawals exceeding naturally renewable storage bring about environmental problems such as forming a cone of depression and extracting non-renewable groundwater [1, 2, 3]. Groundwater is the subsurface water which fully saturates the pores and behaves in response to gravitational force. Surface and groundwater resources are abundant in Nigeria. According to Oteze [4], the water resources master plan for Nigeria which was prepared by the Japan International Co-operation Agency (JICA) in 2006 indicates

an estimated surface water resource of about  $2.67 \times 10^{11} \text{ m}^3/\text{year}$  and groundwater storage of about  $0.52 \times 10^{11} \text{ m}^3/\text{year}$ . He emphasised that these figures greatly outweigh the country's total water demand of about  $0.42 \times 10^{11} \text{ m}^3/\text{year}$ . Surface water is frequently found to be grossly degraded in quality because of its exposure to physical, biological or chemical contaminants [5]. This necessitates the need to seek alternative means of purer water. Groundwater on its own has less of a degree of contamination when compared with surface water and this has contributed to an increase in the number of boreholes drilled by the government, non-governmental organizations and individuals in Nigeria [6]. The inhabitants of Otukpo suffer from acute water shortage, especially during the dry season. Although efforts have been made to drill boreholes to address the water needs of the people in the area, it is common to hear people lament that the yields of such boreholes are low and, in some cases, the borehole failed almost immediately. The inhabitants of Otukpo depend, mostly on hand dug swells since surface water source cannot meet their water needs due to the distance from rivers and streams. Also, government's efforts at providing pipe-borne water for the people are below expectation. Unfortunately, not all the hand dug wells can survive dry season period. The people live in constant fear of contacting water related diseases as a result of the consumption of the untreated water from the hand dug wells. The water tankers which supplement the water need of the people go long distances to get the water which as a result become difficult for the people to afford. Geophysical survey to determine the groundwater potential of the study area is scanty. Hence, there is need to determine the groundwater potential of the study area that will give baseline information for drilling wells and boreholes in the area. The Vertical Electrical Soundings (VES) has proved very popular with groundwater studies due to simplicity of the technique. Groundwater has become immensely important for human water supply in urban and rural areas in developed and developing countries [7]. Exploration of groundwater in hard rock terrain is a very challenging and difficult task when the promising groundwater zones are associated with fractured and fissured media. In this environment, the groundwater potentiality depends mainly on the thickness of the weathered/fractured layer overlying the basement [8]. The electrical geophysical survey method is the detection of the surface effects produced by the flow of electric current inside the earth. The electrical techniques have been used in a wide range of geophysical investigations such as mineral exploration, engineering studies, geothermal exploration, archeological investigations, permafrost mapping and geological mapping [9, 10]. Using this method, depth and thickness of various subsurface layers and their water yielding capabilities can be inferred. Ali *et al.* [10], Ankidawa and Seli [11] used the concept of Dar Zarrouk parameters to delineate the groundwater potential zones in Geriyo Irrigation Floodplain of River Benue, Adamawa State, and Northeastern Nigeria. The research area is part of the Benue Trough. It is underlain by the Cretaceous sediments of the Benue Trough; located in the Southern area of Benue valley. Lower Cretaceous sediments are presumed to overlie Precambrian basement rocks unconformable along the Benue valley [12, 13]. The Benue Trough was originated from rift faulting and the folding of the Cretaceous associated with a basement flexuring is seen as direct consequences of the opening of the South Atlantic Ocean [12, 14]. According to Offodile [15], the area is made up of the Arufu limestone and the Awe formation consisting mostly of fine sandstones with carbonaceous shales. The following geological formations are outlined in the investigation carried out in Otukpo area. They are namely: Asu River formation, Eze-Aku formation and the Awgu formation. Much of Benue State falls within the intra cratonic sedimentary basin known as the Benue Trough which is believed to be structurally developed. The Benue Trough is a linear sedimentary basin which is filled with Cretaceous rocks whose ages range from Middle Albian to Maastrichtian. It is bounded on either side by granite and gneisses which make up the crystalline basement [16]. Najime [17], described the Benue Trough as a NE – SW trending intracratonic basin ranging between 150km wide and 800km long. Lithologies identified in the Benue Trough include; the Ezeaku shale, the Makurdi Formation, the Ajali Formation, the Agwu Formation and the alluvial deposit. The deposition of the Ezeaku Formation is attributed to the beginning of the marine transgression in the Cenomanian [18]. The Ezeaku Formation consists of thick flaggy calcareous and non-calcareous shale, sandy or shally limestone and calcareous Sandstones. Outcrops of this occur in the area south of Otukpo (Egede – Oju area). It is reported to be 304.8m thick in this region and ranges up to 609.6m towards the

south of the state [19]. Survey has shown that clay lenses are predominantly interbedded with mudstones/siltstones and muddy limestone's [13]. Hence has poor groundwater bearing capacity. The clays can be fractured and contain significant discontinuities which enhance recharge in some locations. Exploratory boreholes strike groundwater only from fractures and or weathered layer in the Asu River Formation at depths between 11m and 36m [13]. The sediments are too soft for small stress- release fractures caused by weathering-denudation to remain open. Drilling at Adum East into Makurdi sandstone showed that the sandstone is complex, highly variable and interlayered with thick mudstones [14]. Sandstone porosity is enhanced within the weathered zone by dissolution of feldspar crystals leading to the formation of intergranular voids. Unfortunately, these voids may not be well interconnected so that although porosity is high, hydraulic conductivity is often low. Negligible portable groundwater exists within the Awgu shales. The mudstones are too soft to contain open fractures. Sufficient groundwater for rural water supply is only found within thin sandstone layers and dolerite intrusions [13, 14]. The research is aimed at determining groundwater potential using Dar Zarrouk Parameter in Otukpo and environs which will be used as baseline information in the study area.

## **2 MATERIALS AND METHODS**

### **2.1 The Study Area**

The study area is Otukpo local government areas of Benue State in north central Nigeria. The area is covered by sheet 270 of the 1:100,000 scale topographical map. Otukpo is in Benue south senatorial district in the lower Benue trough. The area is bounded by longitude 8° 00' E to 8°30'E and latitude 7° 00' N to 7° 30'N respectively. The local government area has a total land area of about 3,025Km<sup>2</sup> and has 13 council areas [13]. There are networks of main pathways connecting minor roads that run throughout the local government areas. The minor roads join the main road in Otukpo town leading to Makurdi, the state capital to the North and Enugu to the South. The state is endowed with a tropical climate. The rainy season starts from April and lasts till October while the dry season begins from November and ends in March. The mean annual rainfall is between 1,500mm to 1,800mm. Temperature fluctuates between 25°C to 33°C most of the year [13]. Geographically the area is generally a low-lying plain with few hills that reach a height of 275m above mean sea level as shown in figure 4. The plains range from 58m to 153m and are gently undulating. Ferrallitic and ferruginous soils supporting savannah woodland type vegetation cover much of the area. The combination of climate, soil and geology produce distinctive hydrology. During the wet season, short-term flash floods result in rapid surface water run-off. Most of the rivers and streams are seasonal, drying up soon after the rains stop. The largest and only perennial river is Okpokwu river that flows north-south west across the local government area. The main crops grown in the study area include yams, cassava, rice, sorghum, maize, groundnuts, oranges and plantain [13]. The climate of the study area classifies as tropical dry and tropical hinterland climate [20]. The amount of solar radiation increases progressively from South to Northern part of the area and ranges from 2,700 hours in the South to 3,000 hours in the North. The tropical maritime air mass and the tropical continental air mass play a major role in determining the characteristics of the season within the study area. The relative humidity is controlled by the prevailing air masses; relative humidity is high in the month of August and lowest in the month of February and varies between 60% and 70%. In the morning, relative humidity could reach 80% or more and drops massively in the afternoon. Relative humidity is high during the raining season and very low during the dry season [21]. Annual rainfall is between 1,500mm to 1,800mm. There are seven months of rainfall from April to early November, lasting to a period of about 190days with peak rainfall recorded around July and September. Mean monthly rainfall could reach 220mm in raining months, and could be dropped to 180mm in months of dryness period. Rainfall is conventional and is influenced by the south-west trade wind (tropical maritime air mass, M<sub>T</sub>). As the tropical maritime air mass advances northwards, Otukpo starts receiving rainfall in small amount in the month of April. The north-east trade wind influences the dry season and harmattan weather experienced within the area. The period of dry season is about five

months and starts in the month of November and last till the month of March. Both winds are controlled by North and south advances of the inter-tropical convergence zone [22].

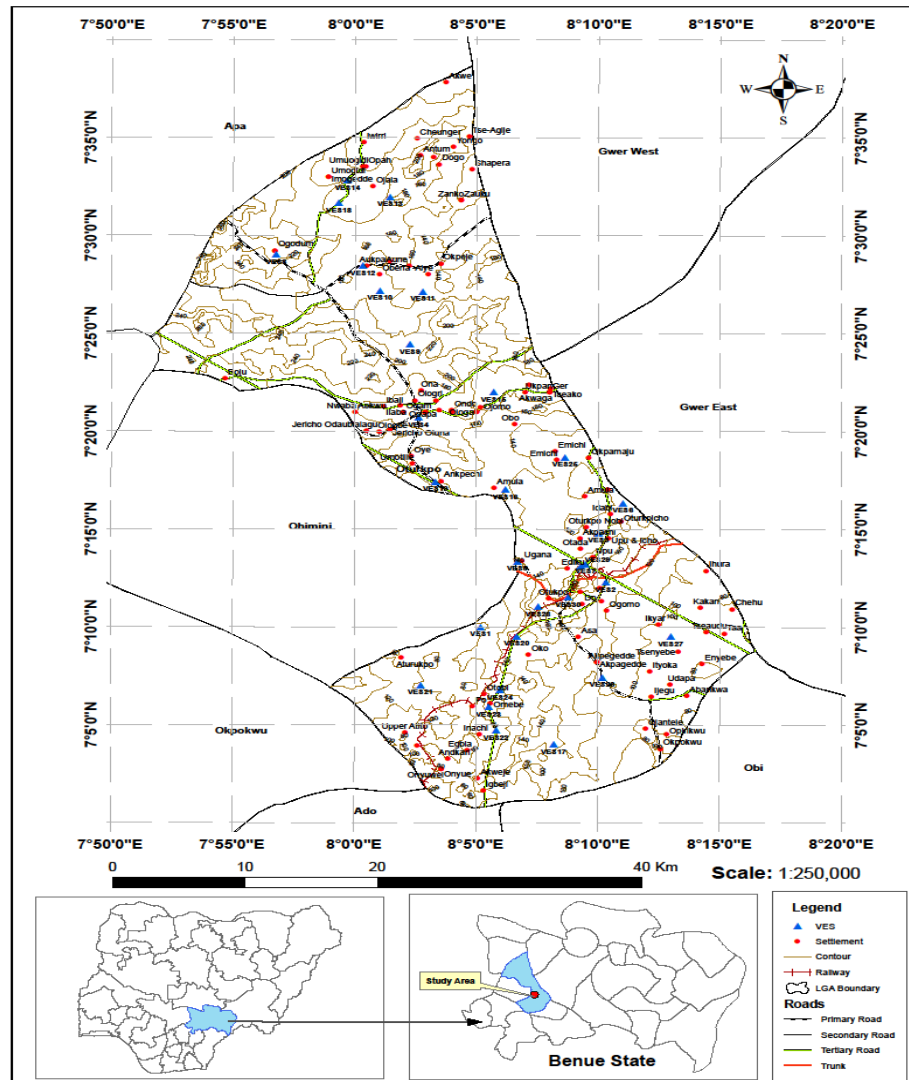


Figure 1. Topographic map of the study area

## 2.2 Methods

Thirty Schlumberger Vertical Electrical Sounding (VES) were used in the study area using a maximum spread (AB/2) of 215m and a maximum potential electrode spacing MN/2 = 14m which are normally arranged in a straight line, with the potential electrode placed in between the current electrodes. This configuration is mostly used to provide sub-surface information considering the depth of penetration which ranges 1/3 and 1/4 of the total separation. The data was collected by a team of 5-personal using digital averaging equipment as the resistant-measuring device. A portable 12.5V car battery was used as current source while four stainless metal stakes were used as electrodes. A saline solution was used to reduce the electrode resistance at each location. A GPS receiver was used to determine the coordinates and elevations of the sounding locations. Where possible, the soundings were made close to existing hand-dug wells. The standard error of measurements was set to 5% in the instrument. The meter displayed the resistance and the corresponding root mean square error (RMS) which were equal to or less than 5%

throughout the survey. The electrical resistances obtained were multiplied by the corresponding geometric factor (k) for each electrode separation to obtain the apparent resistivity ( $\rho = kR$ ) in ohm-meter. The geometric factor K was estimated using equation 1.

$$K = \frac{\pi}{2l} (L^2 - l^2) \quad (1)$$

Where L= half current electrode spacing (AB/2), l= potential electrode spacing (MN). The Dar Zarrouk parameters were estimated: longitudinal conductance (S) was computed using equation 2.

$$S = h/p \quad (2)$$

Transverse Resistance Tr ( $\Omega m^2$ ) can be expressed using equation 3.

$$R = hp \quad (3)$$

Where h= thickness of the saturated layers (m), p=resistivity of the saturated layers (Ohm-m) [23]. The transmissivity for all the sounding location was determined by using the relationship between the Dar-Zarrouk parameter (transverse resistance) and transmissivity, equation 4.

$$T = K\sigma R \quad (4)$$

Where T = aquifer transmissivity ( $m^2/day$ ), R= Transverse resistance ( $\Omega m^2$ ) of the aquifer [23].

### 3 RESULTS AND DISCUSSION

Table 1 shows the curve type distribution of the 30 VES points in the study area. The table indicates that there are three (3) curve types. It was observed that VES 1, 6, 8, 10, 11, 13, 14, 16, 19, 20, 21, 25, 26, 27, and 28 are H-curve type, VES 2, 3, 4, 5, 7, 9, 12, 15, 17, and 18 are KH-curve type while VES 22, 23, 24, 29 and 30 are HA-curve type. The H-curve type makes up 50.00% of the VES points, the KH-curve type makes up 33.33% of the VES points while the HA-curve type makes up the remaining 16.67%. The VES curves were interpreted in terms of the subsurface geoelectric parameters (layer resistivity and thickness) at each location. These will enable the determination of the geoelectric layer depths to the alluvial sediment beneath the VES stations [10, 11].

Table 1. Curve type distribution of the 30 VES points in the study area

S/no	Number of layers	VES Points	Curve type	Percentage (%)
1	3	1, 6, 8, 10, 11, 13, 14, 16, 19, 20, 21, 25, 26, 27, 28.	H	50.00
2	4	2, 3, 4, 5, 7, 9, 12, 15, 17, 18.	KH	33.33
3	4	22, 23, 24, 29, 30.	HA	16.67

Isoresistivity gives an insight into vertical resistivity distribution with depth. The maps display variation in overburden thickness distribution [24]. The Iso-map reveals the heterogeneity in the composition of the subsurface at a depth of 6 to 8m which is the depth of penetration at AB/2 =24m. It shows resistivity from 39 to 89 $\Omega m$ . The resistivity values are typical clay silt, sand clay and clean sand [24]. It was observed that the study area has anomalies high at Otobi (south), Ogobia (Central) and Aukpa (Northeast) part with resistivity reaching a maximum value of 89 $\Omega m$ . Major low anomalies were depicted at Otada (Central) part of the study area with maximum value of 47 $\Omega m$  (Figure 2). The Iso-map reveals the heterogeneity in the composition of the subsurface at a depth of 24 to 32m which is the depth of penetration at AB/2 =95m. The magnitude of resistivity is typical sand clay [24]. It shows resistivity from 26 to 127 $\Omega m$ , the resistivity is clay and clean sand [24]. It was observed that the study area has anomalies high at Omebe (Southwest), Otukpo (Central) part with resistivity reaching a maximum value of 127 $\Omega m$ . Major low

anomalies were depicted at Omogidi (North), Akpagede (Southeast), Otukpo Icho (Central) and Adoka (North) part of the study area with maximum value of  $47\Omega\text{m}$  (Figure 3). The Figure 4 shows the heterogeneity in the composition of the surface at a depth of penetration at  $AB/2 = 215\text{m}$ . The Iso-map reveals the heterogeneity in the composition of the subsurface at a depth of 54 to 72m, it shows resistivity from 77 to  $253\Omega\text{m}$  the resistivity is clay and clean sand [24]. It was observed that the study area has anomalies high at Otukpo (Central), Aturukpo (Central) part with resistivity reaching a maximum value of  $181\Omega\text{m}$ . Major low anomalies were depicted at Adoka (North), Ogobia (North), Akpagede (Southeast) and Otukpo Icho (Central) part of the study area with maximum value of  $105\Omega\text{m}$ .

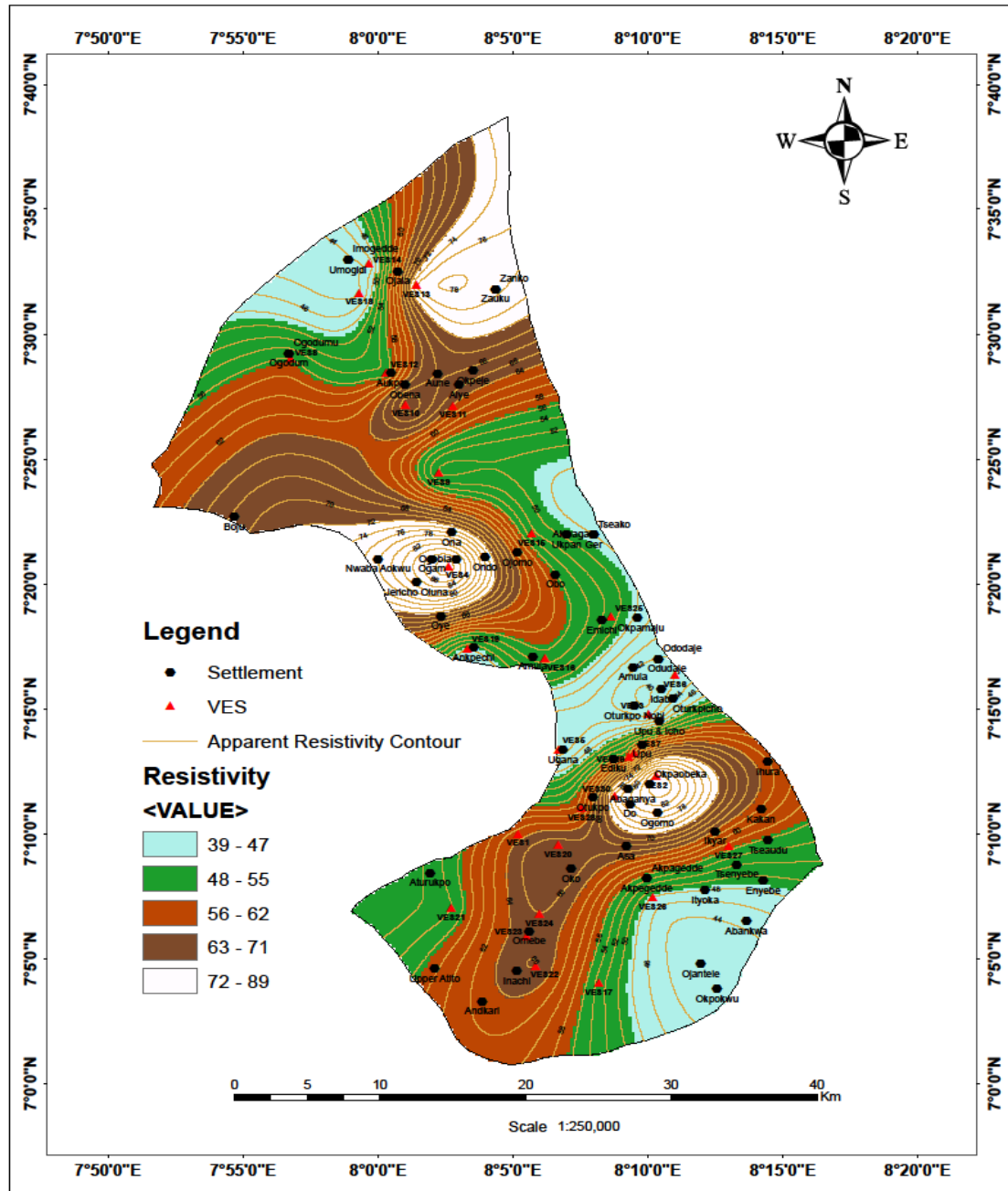


Figure 2. Iso-resistivity contour map for  $AB/2 = 24\text{m}$  (Contour interval =  $2\Omega\text{m}$ )

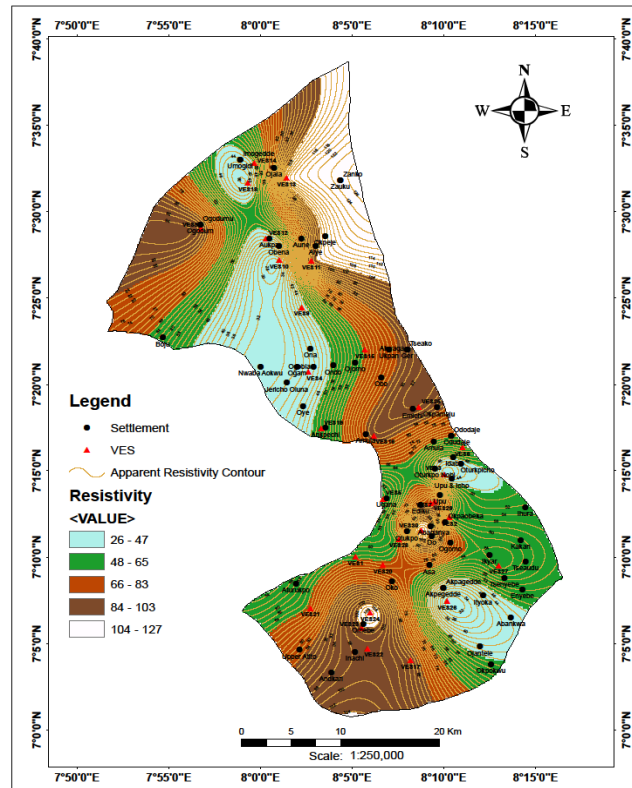


Figure 3. Iso-resistivity contour map for  $AB/2 = 95\text{m}$  (Contour interval =  $2\Omega\text{m}$ )

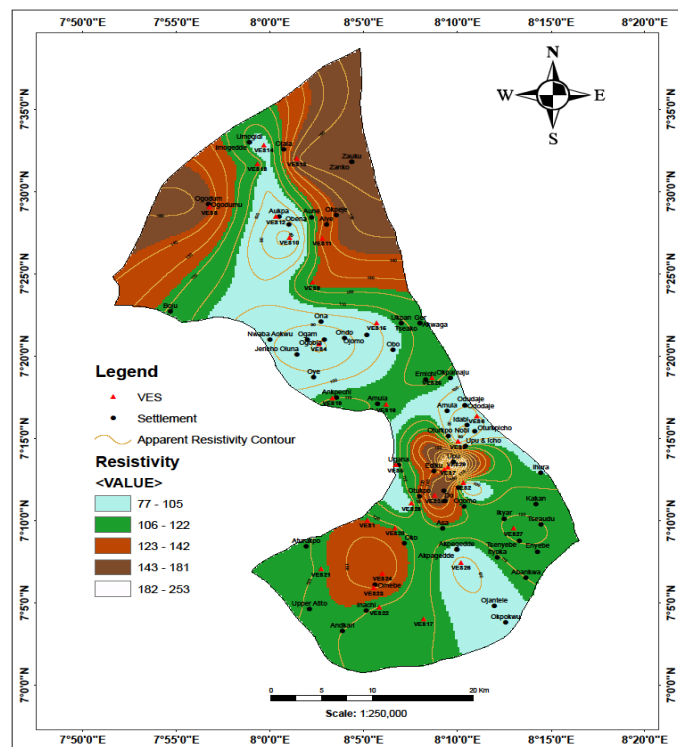


Figure 4. Iso-resistivity contour map for  $AB/2 = 215\text{m}$  (Contour interval =  $10\Omega\text{m}$ )



### 3.1 Geo-Electro Stratigraphic Sections of the VES points

The VES interpretation results were used to prepare geoelectric sections. These sections were obtained using interpreted results at various VES stations along the corresponding sections. They are three sections that is, A-A<sup>1</sup>, B-B<sup>1</sup> and C-C<sup>1</sup> profile section (Figure 5).

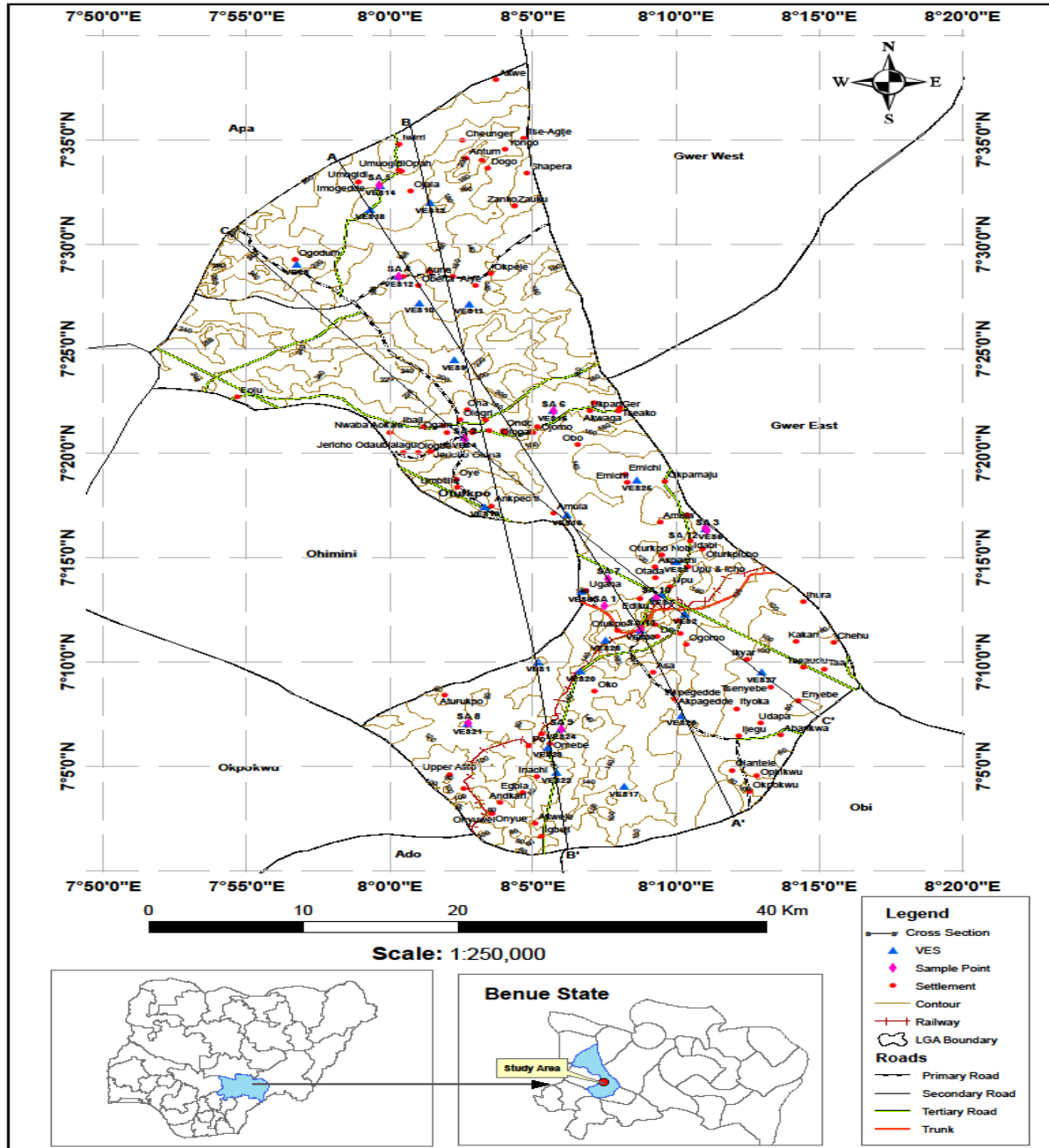


Figure 5. Map showing the cross-section of the VES points in the study area

Geo-electric Section along A-A<sup>1</sup> reveals the presence of six geo-electric layers, Top soil, clay, weathered/ fractured sandstone, shale, consolidated sandstone and clayey sand (Figure 6). The first Layer is the top soil. It has a resistivity ranging from 96.9Ωm to 154.4Ωm and thickness of 1m to 3m. The second



layer is clay with resistivity of  $40.8\Omega\text{m}$  and thickness of 2m. The third layer is the weathered/fractured sandstone. It has resistivity ranging from  $48.3\Omega\text{m}$  to  $88.5\Omega\text{m}$  with thickness of 3m to 40m. The fourth layer is shale with resistivity of  $7.5\Omega\text{m}$  and thickness of 10m. The fifth layer is the consolidated sandstone with resistivity of  $8881.1\Omega$  and has infinite thickness. The sixth layer is clayey sand with resistivity ranging from  $126.3\Omega\text{m}$  to  $194.8\Omega\text{m}$  and infinite thickness. The VES points found along this section are VES16, VES18 and VES30. The VES points have layers consisting of overburden top soil, weathered aquiferous basement and fresh basement as observed by Seli *et al.* [25].

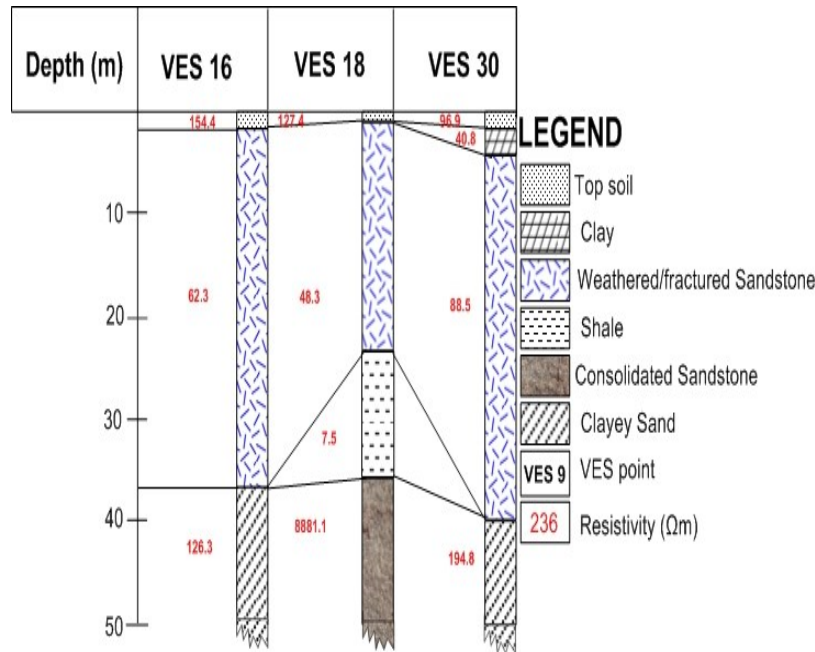


Figure 6. Geo-electric Section along A – A' of the Study Area

Geo-electric Section along B-B' reveals the presence of six geo-electric layers, Top soil, clay, weathered/ weathered sandstone, consolidated sandstone and clayey sand (Figure 7). The first layer is the top soil with resistivity from  $82.7\Omega\text{m}$  to  $201.8\Omega\text{m}$  and thickness from 1m to 5m. The second layer is the clay with resistivity ranging from  $31.0\Omega\text{m}$  to  $124.0\Omega\text{m}$  and thickness of 1.5m to 3m. The third layer is the weathered/fractured sandstone with resistivity ranging from  $49.5\Omega\text{m}$  to  $81.7\Omega\text{m}$  and thickness ranging from 15m to 75m. The fourth layer is the consolidated sandstone with resistivity of  $18254.6\Omega\text{m}$  and infinite thickness. The fifth layer is the clayey sand with resistivity ranging from  $134.7\Omega\text{m}$  to  $174.3\Omega\text{m}$  with infinite thickness. The VES points along this section are VES1, VES13, VES22 and VES23. This finding is similar to results obtained by Ali *et al.* [10] and Seli *et al.* [25] in Ganye and environs, North-Eastern Nigeria and study by Kwami *et al.* [26] in Gombe and environs North-Eastern, Nigeria. The VES points have layers consisting of overburden top soil, weathered aquiferous basement and fresh basement.

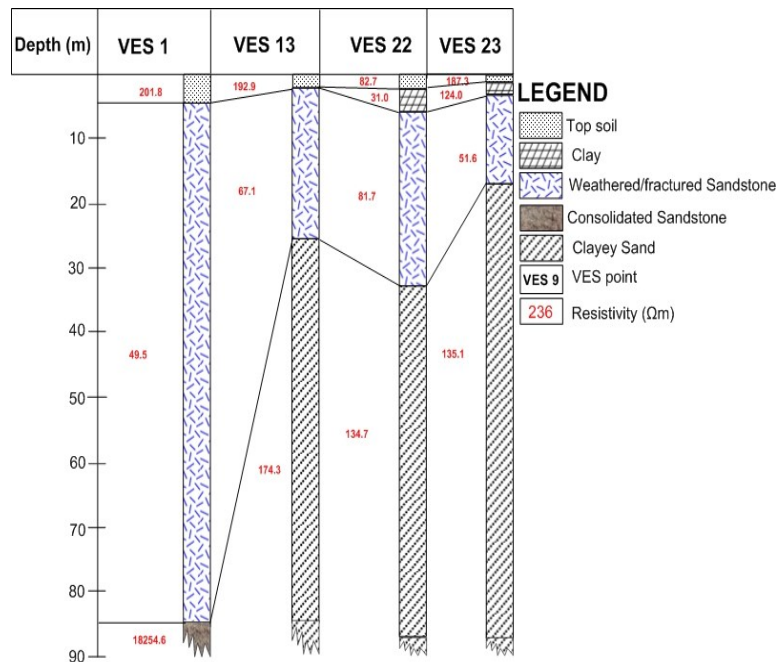


Figure 7. Geo-electric Section along B – B' of the Study Area

Geo-electric Section along C-C<sup>1</sup> reveals the presence of five geo-electric layers, Top soil, weathered/ fractured sandstone, shale, consolidated sandstone, clayey sand (Figure 8). The first layer is the top soil with resistivity ranging from 90.6Ωm to 191.7Ωm and thickness ranging from 1.5m to 3m. The second layer is the weathered/fractured sandstone with resistivity ranging from 32.8Ωm to 91.0Ωm. The third layer is the shale with resistivity ranging from 17.1Ωm to 18.0Ωm and thickness from 3m to 5m. The fourth layer is the consolidated sandstone with resistivity ranging from 8482.0Ωm to 9913.0Ωm and infinite thickness. The fifth layer is the clayey sand with resistivity ranging from 423.9Ωm to 907.2Ωm and infinite thickness. The VES points along this section are VES2, VES4, VES10 and VES27. The VES points have layers consisting of overburden top soil, weathered aquiferous basement and fresh basement.

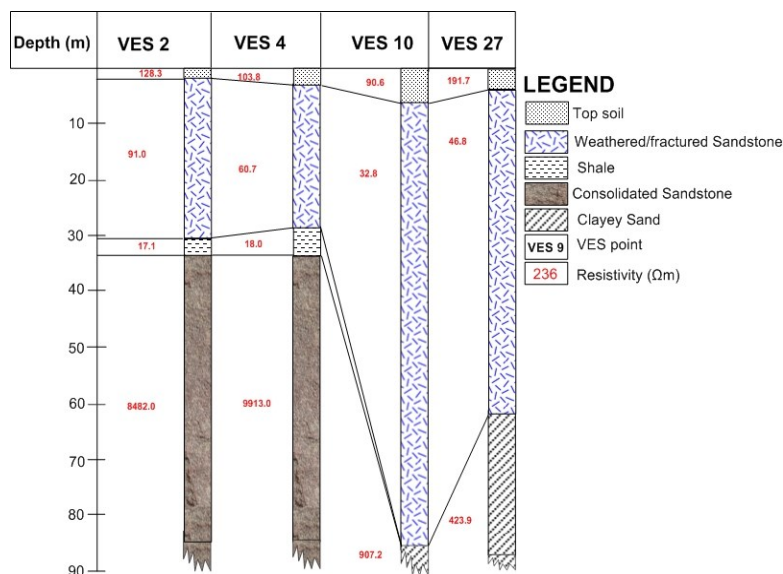


Figure 8. Geo-electric Section along C – C' of the Study Area

The Dar-Zarrouk parameters longitudinal conductance (S) and Transverse resistance (T) are used in aquifer protection studies and evaluation of hydraulic properties of aquifer. The total longitudinal conductance was used in evaluating the protective capacity in an area. This is because the earth medium acts as natural filter to percolating fluids. The ability to the percolating fluid is a measure of the proactive capacity. Oladapo and Akintoriwa [27] showed that aquifer protection capacity rating can be classified on the basis of the total longitudinal unit conductance ( $\Sigma S$ ) as excellent ( $S > 10$ ), very good ( $5 \leq S \leq 10$ ), good ( $0.7 \leq S \leq 5$ ), moderate ( $0.2 \leq S \leq 0.7$ ), weak ( $0.1 \leq S \leq 0.2$ ), very poor ( $S < 0.1$ ). From the result obtained 50% (VES 1, 6, 8, 11, 13, 14, 16, 19, 20, 21, 25, 26, 27, 28) showed high potential while (VES 2, 3, 4, 5, 7, 9, 12, 15, 17, 18, 22, 23, 24, 29, 30) showed moderate potential. Therefore, the Dar-Zarrouk parameters were calculated as shown in Table 2. From the calculated total longitudinal unit conductance (S) in (Table 2), 73.33% have good aquifer protection capacity while 26.67% have moderate protection capacity. From the map of the longitudinal conductance (Figure 9), relative higher longitudinal conductance is observed at Ogobia, Ojomo areas in the northern part, Otukpo Icho in the central part and Akpagede area in the southern part of the map. Relatively low longitudinal conductance is observed at Otukpo in the central part, Zaku in the north-eastern part and Otobi in the southern part. It should be noted at this juncture that the order of aquifer vulnerability to contamination is poor-weak-moderate-good-very good-excellent i.e., aquifer with excellent protection capacity has the least vulnerability to contamination and vice versa. Study by Egbai *et al.* [28] evaluated aquifer transmissivity using total longitudinal conductance Abudu, Edo State, Nigeria and observed similar findings to the result obtain in the present study. Also, research by Ali *et al.* [10] in Girei area and Seli *et al.* [25], obtained good aquifer protection capacity in Ganye area, Adamawa State, Nigeria, there findings is similar to what was obtained in the present study.

Table 2. Aquifer Parameters Estimated from Geophysical data

S/NO	VES points	Coordinate		Aquifer thickness (m)	Aquifer resistivity ( $\Omega\text{m}$ )	Transverse resistance ( $\Omega\text{m}^2$ )	Longitudinal conductance ( $\Omega^{-1}$ )	Hydraulic conductivity (m/day)	Transmissivity ( $\text{m}^2/\text{day}$ )	Groundwater potential
		Northing	Easting							
1	VES1	7°12'11.12"N	8°5'21.18"E	81.73	49.55	4050.7	1.64	10.1356	828.3827	High potential
2	VES2	7°12'17.57"N	8°10'18.56"E	2.89	1.71	2675.7	0.322	234.2563	677.0008	High potential
3	VES3	7°12'44.45"N	8°5'29.11"E	64.35	29.40	1892.2	2.19	16.49372	1061.371	High potential
4	VES4	7°20'43.22"N	8°2'36.28"E	4.12	1.8	7.44	2.28	223.3116	920.0438	High potential
5	VES5	7°13'21.70"N	8°6'41.07"E	2.64	1.86	4.94	1.41	216.5845	571.7831	High potential
6	VES6	7°16'21.01"N	8°11'01.19"E	24.46	29.25	715.7	0.836	16.57261	405.3661	Moderate potential
7	VES7	7°13'13.29"N	8°9'29.47"E	30.87	49.07	1515.0	0.629	10.22806	315.7401	Moderate potential
8	VES8	7°29'02.32"N	8°56'19.77"E	51.07	58.58	2992.6	0.871	8.670167	442.7854	Moderate potential
9	VES9	7°24'27.06"N	8°2'15.11"E	16.15	10.92	176.4	1.47	41.54817	671.0029	High potential
10	VES10	7°27'43.83"N	7°29'3.43"E	82.86	32.86	2723.2	2.52	14.86771	1231.939	High potential
11	VES11	7°27'8.11"N	8°2'46.57"E	32.89	66.80	2197.9	0.492	7.670627	252.2869	Moderate potential
12	VES12	7°28'26.68"N	8°0'18.27"E	66.11	31.09	2056.0	2.12	15.65582	1035.006	High potential
13	VES13	7°31'58.10"N	8°1'24.97"E	23.28	67.13	1563.0	0.346	7.635447	177.7532	Moderate potential
14	VES14	7°32'48.81"N	7°59'39.72"E	60.01	32.03	1922.7	1.87	15.22679	913.7598	High potential
15	VES15	7°22'0.53"N	8°5'41.36"E	126.2	58.37	7370.6	2.16	8.699262	1097.847	High potential
16	VES16	7°15'14.05"N	8°4'27.31"E	35.36	62.30	2203.2	0.567	8.186247	289.4657	Moderate potential
17	VES17	7°13'57.36"N	8°5'37.45"E	5.86	35.22	206.6	0.166	13.93624	81.66636	Moderate potential
18	VES18	7°31'39.68"N	7°59'18.71"E	11.42	7.59	86.69	1.50	58.33392	666.1734	High potential
19	VES19	7°17'25.51"N	8°3'19.10"E	64.13	35.10	2251.5	1.82	13.98068	896.581	High potential
20	VES20	7°9'32.43"N	8°6'40.28"E	92.70	56.70	5257.3	1.63	9.938039	828.5562	High potential
21	VES21	7°7'02.10"N	8°2'43.02"E	84.63	56.10	4748.8	1.5	9.02718	763.9702	High potential
22	VES22	7°4'42.32"N	8°5'49.61"E	3.48	31.04	108.0	0.112	15.67934	54.5641	Low potential
23	VES23	7°5'54.01"N	8°5'30.92"E	14.99	51.62	773.8	0.290	9.75594	146.2415	Moderate potential
24	VES24	7°6'46.96"N	8°5'58.93"E	2.64	21.20	56.12	0.124	22.37645	59.07383	Low potential
25	VES25	7°18'40.69"N	8°8'37.85"E	22.34	54.97	1228.0	0.406	9.200165	205.5317	Moderate potential
26	VES26	7°7'26.45"N	8°10'11.15"E	91.35	38.00	3471.7	2.40	12.98278	118.977	Moderate potential
27	VES27	7°9'30.43"N	8°12'59.38"E	57.52	46.86	2696.0	1.22	10.67733	614.16	High potential
28	VES28	7°11'1.72"N	8°7'32.42"E	26.43	61.73	1631.6	0.428	8.256737	218.2256	Moderate potential
29	VES29	7°13'5.64"N	8°9'17.68"E	4.89	26.07	127.5	0.187	18.45093	90.22505	Moderate potential
30	VES30	7°11'31.71"N	8°8'46.12"E	3.44	40.80	140.4	0.0843	12.14968	41.79491	Low potential
Average				39.69	38.19	1895.0	1.120	36.01627	522.5758	

The ratio of different layer to their respective resistivity is called longitudinal conductance. The properties of a conducting layer can be determined in terms of longitudinal conductance while the resistance of the layer can be determined by transverse resistance. Relative higher transverse resistance (Figure 9) is observed at Otukpo, Edikwu in the central part of the map, Akpagede in the southern part and Ojomo in the northern part. Conversely, relatively low transverse resistance is observed at Imogidi, Ogobia in the northern part, Otukpo Icho in the central part and Otobi in the southern part. The total longitudinal conductance in the study area ranges from 0.3 to  $2.75\Omega^{-1}$  with mean value of  $1.44\Omega^{-1}$ . As the conductance increases, the resistivity normally decreases, pointing towards groundwater potential aquifers. It can be inferred that the areas with low longitudinal conductance values are vulnerable to contamination and hence are highly conductive as a result of seepage of contaminant into the groundwater system [10, 25, 27]. Areas with high conductivity mean fracture/weathered zones at depth.

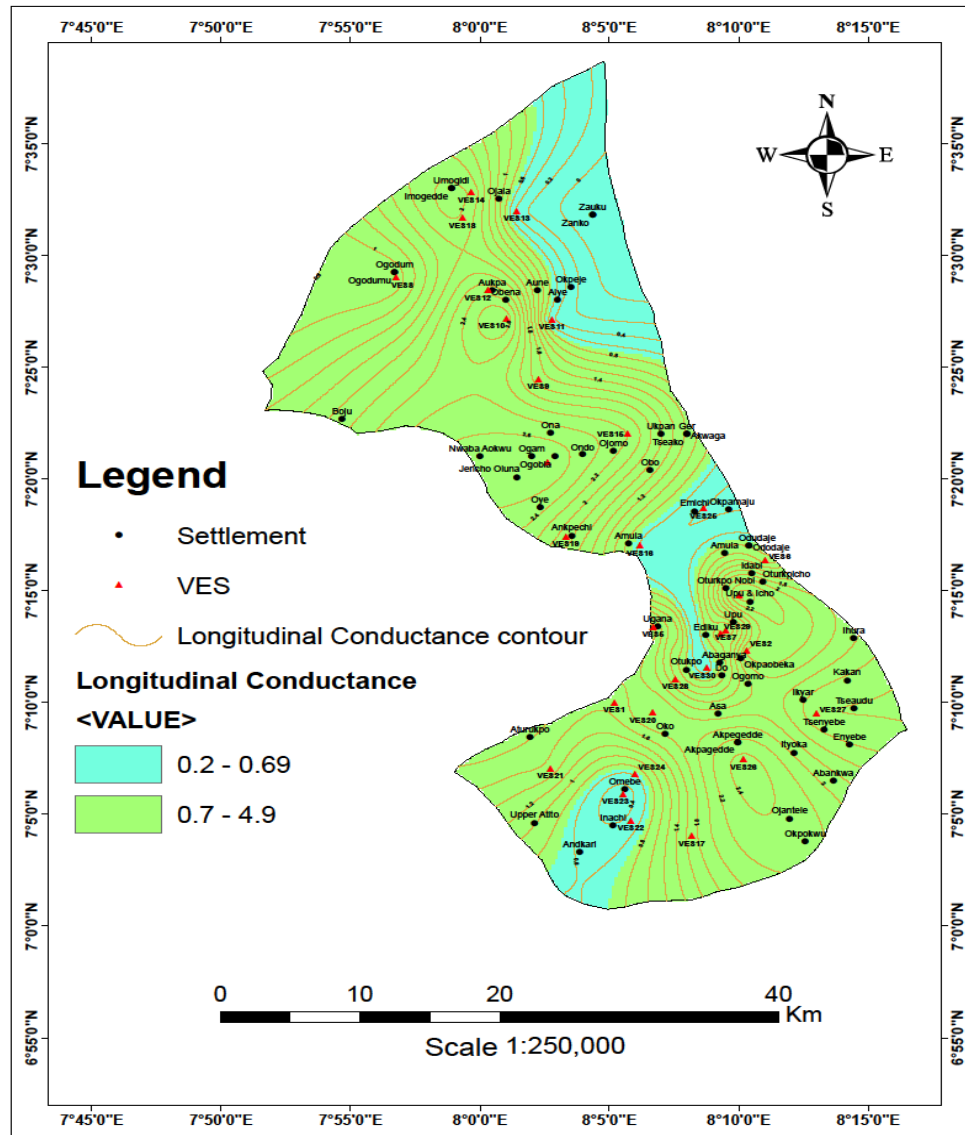


Figure 9. Map of Longitudinal Conductance of the VES Points in the Study Area

The transverse resistance in the study area ranges from 1047.35 to 18468.52 $\Omega m^2$  with average value of 3945.66 $\Omega m^2$  (Figure 10). The transverse resistance used to define areas of good groundwater potential. Transverse resistance has a direct relationship with transmissivity and the highest values reflect most likely the highest transmissivity values of the aquifers or aquiferous zones [27].



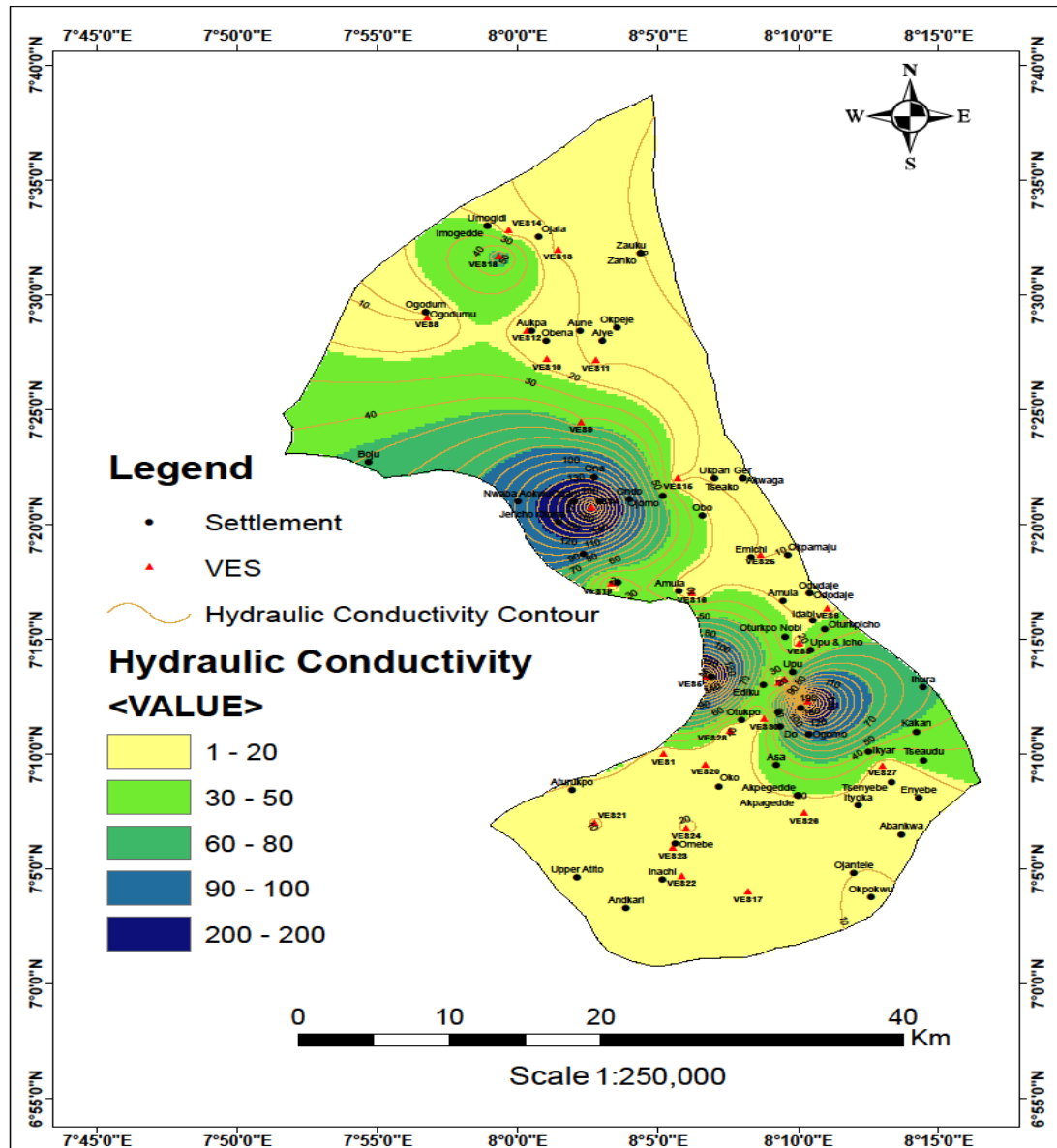


Figure 11. Map of Hydraulic Conductivity of the Study Area

For characterization of rocks as a water bearing media, transmissivity is a major property. The rating of the aquifers' transmissivity as high, moderate and low. Transmissivity values obtained from VES method for the aquifers ranges from  $41.79491\text{m}^2/\text{day}$  to  $1231.939\text{m}^2/\text{day}$  with an average value of  $522.5758\text{m}^2/\text{day}$ . VES 10 has the highest transmissivity indicating large groundwater potential in the zone. High transmissivity is observed at northern part (Ona, Ogobia and Imogidi) and south-west (Aturukpo) and Otukpo Icho in the central part. Relatively low transmissivity is observed in Zaku in the northern-eastern part and the south-southern part of the map. The other areas are of moderate transmissivity (Figure 12). The same trend was observed with the transverse resistance of the study area. This in line with the work of [27, 30]. The areas of high transverse resistance transmissivity are areas of good groundwater potential while areas of low transverse resistance and transmissivity are areas of low groundwater potential.



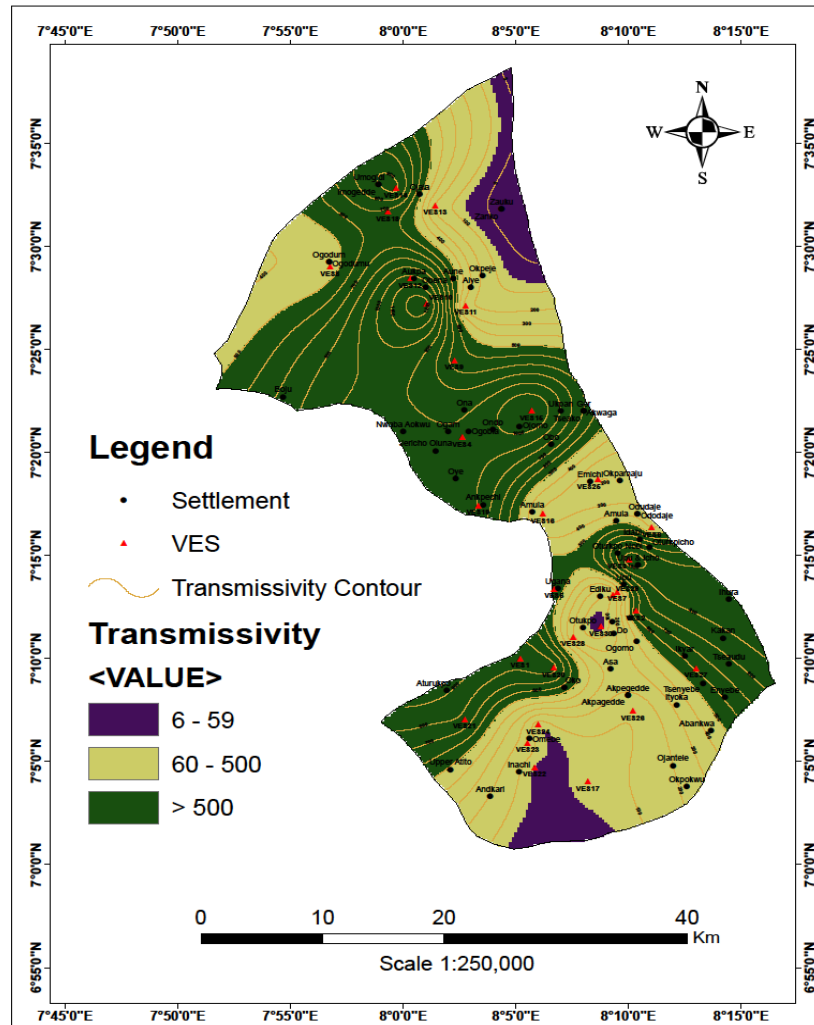


Figure 12. Map showing Transmissivity of the Study Area

### 3.2 Groundwater Flow Direction in the Study Area

Hydraulic head is the measurement of water pressure above a geodetic datum. It is normally measured as a water surface elevation. It is expressed in units of length. Hydraulic head is the sum of three components, the pressure head, elevation head and velocity head. Therefore, the distribution of hydraulic head through an aquifer system determines where groundwater will flow. Where the hydraulic head is constant, there is no flow. However, if there is a difference in the hydraulic head from the top to the bottom due to draining from the bottom, the water will flow downward, due to the hydraulic gradient. To determine the direction of flow of an aquifer in the study area, groundwater level measurement; relative geographic position of the wells and elevation were collected and contoured in map perspectives, (using surfer 12 software), hence generating groundwater surface maps. The direction of groundwater movement can be understood due the fact that groundwater always flows in the direction of decreasing head. This water table contour map is an important tool in groundwater investigations as one can derive from it the gradient of the water table and the direction of the groundwater flow. Generally, the pattern of groundwater flow follows the surface topography with seasonal variations in water levels marked by rising water levels during the wet months and declining water levels during the dry months. Hydraulic head map of the area was produced by joining points of equal hydraulic heads to indicate groundwater flow direction of the area. The hydraulic head map of distribution of the study area indicates regional groundwater flow from the recharge area at Adoka, Otukpo Icho, Otukpo and Omebe (Figure 13). The water flow from this point radially. Discharge zones were found at Ogodumu, Emichi. Similar pattern of groundwater flow was observed by Ankidawa and Seli [11] on the floodplain of River Benue, Adamawa State, Northeastern Nigeria and by Seli *et al.* [25] in in Ganye and environs, Adamawa State, Northeastern Nigeria.

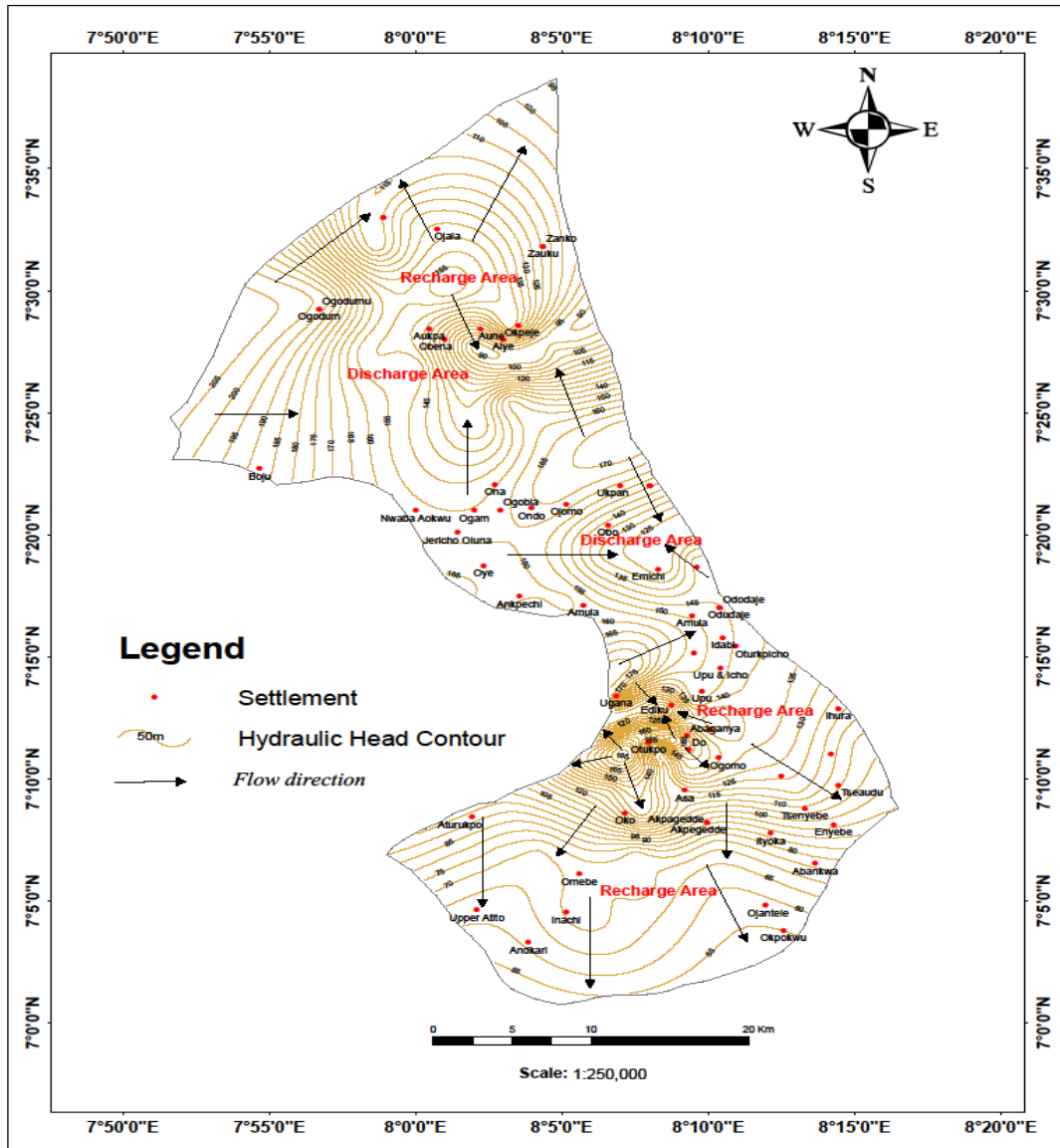


Figure 13. Groundwater flow direction of the study area

#### 4 CONCLUSIONS

The groundwater potential of the study area has been successfully delineated based on the hydraulic conductivities and transmissivities computed from the VES data. The study revealed that 50% of the aquifers have high underground potential, 40% has moderate underground potential while the remaining 10% has low underground water potential. The area with low resistivities and high transmissivity are the potential zones for groundwater exploration at that depth of penetration. Based on the available information at the maximum depth of penetration, it can be concluded that areas around Otukpo in the central part, Zaku in the north-eastern part and southern parts of the study area have low groundwater potential while areas with relatively high groundwater potential are Otukpo Icho, Aturukpo and Ogobia. Recharge zones were observed at Adoka, Otukpo Icho, Otukpo and Omebe areas while discharge zones were observed at Ogodumu, Emichi.

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