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Assessment of Groundwater Potential in Ehime Mbano, Southeastern Nigeria

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Abstract The electrical resistivity method involving vertical electrical sounding procedure was employed in assessing the groundwater potentials of Ehime Mbano area with the aim of delineating aquifer for sustainable groundwater development. Over sixty vertical electrical sounding were acquired within the study area using the Schlumberger electrode configuration. The results show relatively less resistive northern portions and highly resistive southern parts based on the contrast in geoelectrical values. Occasional truncation of lateral continuity of the sands and sandstones by shaly sediments were observed around the southern parts of the study which influences groundwater circulation and may constitute a factor hindering the even distribution of groundwater resources in the area. Based on the results of the inverted resistivity models the depth to aquifer should be >90 m. The sands at this depth have the capacity to permit groundwater circulation. Dar Zarouk parameters were estimated and the results mimicked the geology of the area. Longitudinal conductance values were low in the southern portion dominated by sands and sandstones while the northern portion possessed high values of longitudinal conductance resulting from clays and shales. On the contrary, the transverse resistance show higher values in the northern part. Based on the sands and sandstones that dominate the southern portions and the values of the aquifer parameters estimated in the southern parts favours groundwater circulation and possesses good groundwater exploration prospects.

Keywords: *electrical resistivity, VES, groundwater potential, aquifer, Dar Zarouk parameters*

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1. Introduction

Groundwater has been the most reliable source of steady water supply for domestic, industrial and agricultural uses [1,2]. It has becomes the main water source for all purpose in rural and urban areas of West Africa, especially in the dry season when the rains ceases. The occurrence, storage and flow of groundwater are controlled by certain factors such as geology, geomorphology and subsurface structures (i.e., faults, joints and fractures). Based on the aforementioned factors, groundwater can be abundant in some areas and other areas can be deficient of the resources. This is the case with our study area, Ehime Mbano. Despite efforts made by some donor agencies such as the United Nations Children Emergency Fund (UNICEF) to resolve the water challenges in the area by introducing the Millennium Development Goal (MDG) with the mandate of providing water for all before the ending of year 2015, water supply has remained a major challenge to the dwellers of the area. Recently, the Imo State Water Development Agency (IWADA) and Sustainable Development Goal (SDG) initiative are still struggling to meet their declaration for sustainable and portable water supply by year 2020. At present both the rural and urban dwellers are still endangered by water shortages. Efforts made by private individuals to provide domestic boreholes end up abortive due to their shallow nature resulting from non adherence to prior geophysical investigation. Other geologic factors that can lead to borehole failure include thickness of clayey and/or shaly formation which were not considered during the process of borehole drilling. The rise in number of shallow sub-standard boreholes and the inability of public water supply systems to meet the water demand of Mbano people have led to series of water borne diseases in the region [3]. Here the rate of water well failure and abandonment is very high. Therefore, it is necessary to study the groundwater resource potentials of Ehime Mbano to assess the causes of borehole failures in the area.

Geophysical methods with special emphasis on the electrical resistivity methods have proven to enhance the success of groundwater exploration. Studies have shown that the geoelectrical resistivity techniques are reliable and can provide sufficient contrast in subsurface structures and variations in rock properties which can be exploited during groundwater investigations [4,5,6]. Its instrumentation is simple, field logistics are easy and the analysis of data is straight forward compared to other methods [7,8,9,10].

Electrical resistivity method offers a more economic and non-invasive alternative for estimating geohydraulic parameters necessary for the determination of prolific areas for siting productive boreholes in the study area [4]. Such parameters include; hydraulic conductivity and diffusivity [11], transmissivity [12], porosity [13] and Dar Zarouk parameters (longitudinal conductance and transverse resistance). The direct current electrical resistivity method is also useful in assessing other forms of hydrogeophysical problems including aquifer salinity mapping and its distribution [13,14], monitoring flow and groundwater dynamics [15], determination of aquifer characteristics and distribution [16] and assessment of vulnerability and depth to water table [12,17].

This study is aimed at assessing the groundwater potential of Ehime Mbano using the vertical electrical sounding (VES) technique with the objective of delineating productive aquifer sites for sustainable groundwater development.

2. Location, Physiography and Geology

The study area is located between Longitudes 7°14'and 7°22'E of the Greenwich Meridian and Latitudes 5°37' and 5°46' N of the Equator (Figure 1 and Figure 2). The area covers ~169 square kilometres and has a population of ~130,931 based on the 2006 population census and this figure was projected to be 204,340 in 2015. It is bounded to the North by Onuimo and to the south by Ahiazu Mbaise. It shares its eastern and western boundaries with Ihitte/Uboma and Isiala Mbano/Onuimo/Okigwe Local Government Areas.

The physiography is dominated by a segment of northwest-southeast trending Okigwe regional escarpment which stands at elevation of between 61m and 122m above sea level [18]. The area is within the tropical rain forest vegetation which is prevalent in southern Nigeria. Due to great demand of land in the area coupled with other human activities especially over grazing, the rainforest has been replaced by some economic crops such as oil palm forest. Soils are predominantly loamy with scattered pebbles [19]. Thick vegetative cover prevents soil erosion in the area. However, erosion is prominent in areas where road cuts, forest clearing and over-cropping have opened up the soil to erosional elements [20]. The dominant drainage pattern in the area is the dendritic pattern which is typical of sedimentary rock with uniform resistance and homogenous geology [21]. Tropical climate exist in the area and it experiences two air masses: equatorial maritime air masses, associated with rain bearing south-west winds from the Atlantic Ocean around March to September [22]. The second is the dry and dusty hamattan wind from the Sahara desert blowing around December to February. The annual total average rainfall is about 230mm and temperature ranges from 29°C during dry season to about 33°C in rainy season. The relative humidity in the area lies between 65% and 75% [22].

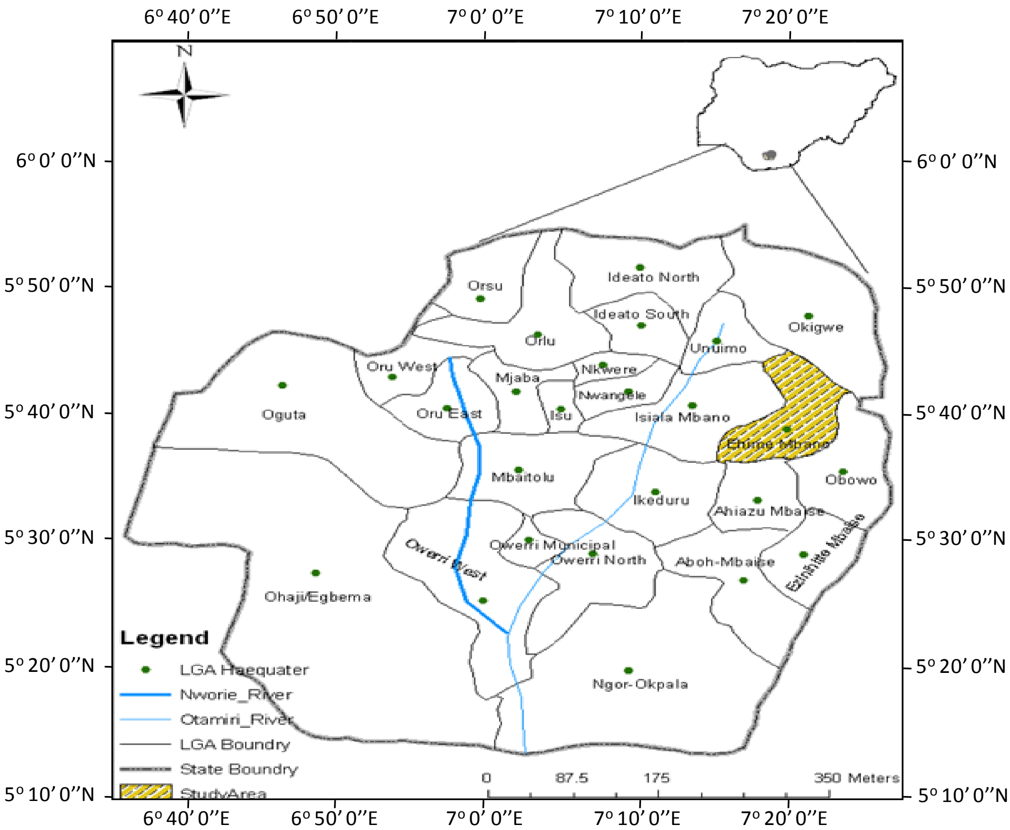

Figure 1. Map of Imo State showing Ehime Mbano

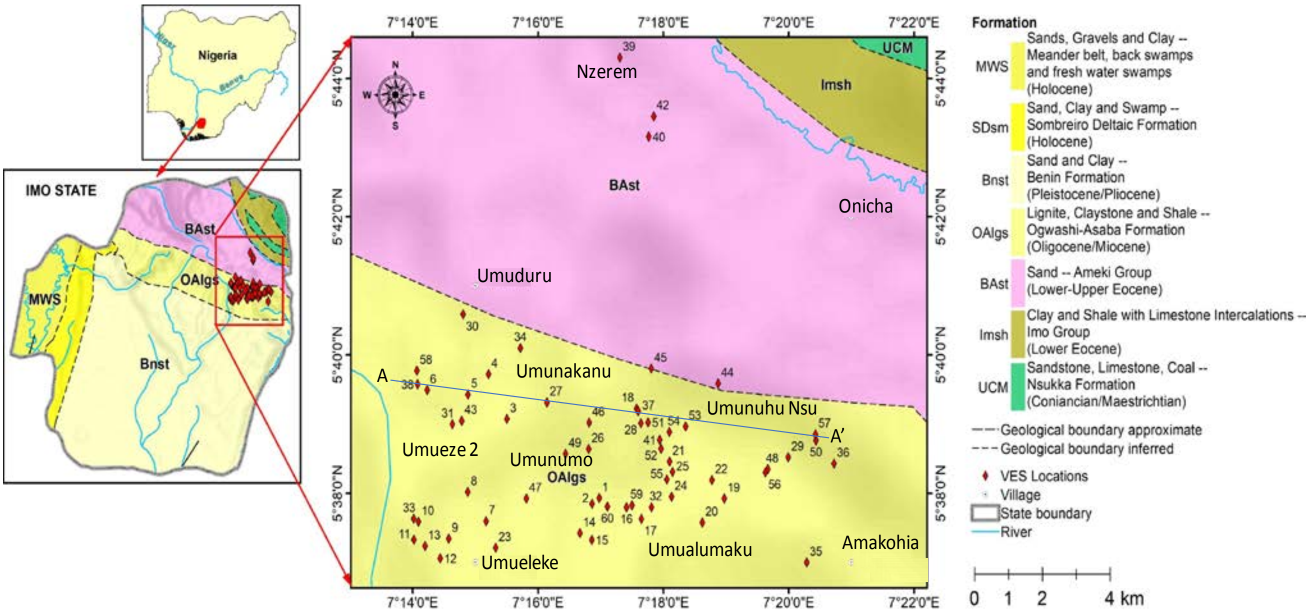

Figure 2. Geologic map of the study area showing VES points

Table 1. Stratigraphic sequence in southeastern Nigeria [28]

AGE		Formation	Lithlogy	Depositional environment
Quaternary		Benin formation	Sandstones, Clay, Shales	Continental
Tertiary	Plicoene			
	Miocene			
	Oligocene	Ogwashi-asaba formation	Clay, Shales, Sandstones, Lignite	Continental
	Eocene	Ameki group	Sandstones, Clay, Shales, Limestones	Estuarine, Shallow marine
	Plaeocene	Imo formation	Clay, Shales, Limestones Sandstones, Marl	Shallow marine, deltaic
Upper Cretaceous	Maastrichtian	Nsukka formation	Sandstones, Clay, Shales Coals, Limestones	Fluvio-deltaic
		Ajali formation	Sandstones, Claystones	Fluvio-deltaic
		Mamu formation	Sandstones, Clays, Coals	Shallow marine, deltaic
	Campanian	Enugu/nkporo/owelli formation	Shales, Sandstones, Clay, Ironstones, Siltstones	Shallow marine, deltaic
		Major unconformity		
	Santonian	Awgu formation	Sandstones, Limestones, Clays Coals, Siltstones	Shallow marine, deltaic
	Conician			
Middle cret.	Turonian	Eze-aku formation	Shales, Limestones, Sandstones	Shallow marine
	Cenomanian	Odukpani formation	Sandstones, Limestones, Shales	Shallow marine
Lower Cret.	Albian	Asu river group	Shales, Limestones, Sandstones	Shallow marine
Lower Paeozoic		Major unconformity		
		Basement complex	Granites, Gneisses, Schists, Migmatites	Igneous, Metamorphic

Ehime Mbano and environs falls within Anambra–Imo sedimentary basin of south-eastern Nigeria [23]. The major aquifer formation is the Benin Formation. The interplay between geology, geomorphology and climate gives rise to the hydrogeological environments [24]. The major sedimentary sequences of the study area (Figure 2) are the Benin Formation, the Ogwashi-Asaba Formation, the Bende-Ameki Formation, the Imo Shale and the Nsukka Formation [25]. The presence of Benin Formation is a contributory factor to soil erosion especially where they are exposed and unprotected by vegetation [26]. The Benin Formation is overlain by lateritic overburden and underlain by the Ogwashi–Asaba Formation which is in turn underlain by the Bende-Ameki Formation of Eocene to Oligocene age [27]. It has typical outcrops around Benin, Onitsha and Owerri. The Ogwashi--Asaba Formation is made up of variable succession of clays, sands and grits with streaks of lignite (Table 1). The Bende-Ameki Formation of Eocene Oligocene ages consists of greenish-grey clayey sandstones, shales and mudstones with inter-bedded limestones. This formation in turn overlies the impervious Imo Shale group characterized by lateral and vertical variations in lithology. The Imo Shale of Paleocene age is laid down during the transgressive period that followed the Cretaceous. It is underlain in succession by the Nsukka Formation, Ajali Sandstones and Nkporo Shales. Due to the porous and permeable nature of the Benin Formation coupled with the overlying lateritic earth and the weathered top of this formation as well as the underlying clay/shale member of the Bende-Ameki series, this geologic zone provides the hydrologic conditions that favour aquifer formation [27].

However, the fact that the study area lies within the transition zone of the Benin Formation and the Ogwashi-Asaba Formation makes groundwater prospecting difficult. Siting of productive borehole depends largely on proper preliminary geophysical survey.

3. Materials and Methods

The geophysical exploration for groundwater in the study area involved the application of vertical electrical sounding (VES) procedure using the Schlumberger electrode configuration. The measurements were carried out with SAS 1000 model of ABEM terrameter from ABEM Instruments, Sweden. Maximum current electrode spread (AB) of 740 m which corresponds to half-current electrode spacing ($^{AB}/_{2}$) 370 m was used. A total of sixty VES stations were performed randomly around areas accessible to us due to valleys, gullies and residential buildings. Four stainless steel electrodes of about 50 cm in length were used as both current and potential electrodes. The electrodes are arranged collinearly and symmetrically placed with respect to the centre. In this type of arrangement, the potential electrode separation is very small compared to the current electrode separation (usually less than 1/5). In order to increase measurable potential as the current electrode separation is reasonably increased, the distance between the potential electrodes is also increased. The apparent resistivity (ρ_a) measured by Schlumberger array at a single location with systematically varying electrode spacing is given by

$$\rho_{a(s)} = R\pi\left(\frac{a^2}{b} - \frac{b}{4}\right)(\Omega\text{m}) \qquad (1)$$

where a is half current electrode spacing (AB/2), b is spacing between potential electrodes (MN). The resistance (R) is derived from the current (I) and potential difference (V) values using the relation.

$$R = \frac{V}{I}. \qquad (2)$$

Equation (1) can be written in terms of the geometrical factor, $K = \pi\left(\frac{a^2}{b} - \frac{b}{4}\right)$ as

$$\rho_{a(s)} = K \times R(\Omega\text{m}). \qquad (3)$$

The geometrical factor depends on the arrangement of the electrodes in the ground and can be calculated for any configuration.

The resistivity data obtained was processed and modelled using the WinRESIST code version 1.0 to determine the layer parameters. Apparent resistivities were plotted on bilogarithmic graphs and interpreted manually and were later inputted into the WinRESIST code to perform the inverse modelling [29]. The available lithological data from well closed to the VES points were used as constraint during the inversion process. The WinRESIST code performed some calculations based on the observed and theoretical data and represented the difference as root mean square error after few iterations (Figure 3). The geoelectric layer parameters were contoured using the SURFER 11 software from Golden Software Inc., USA.

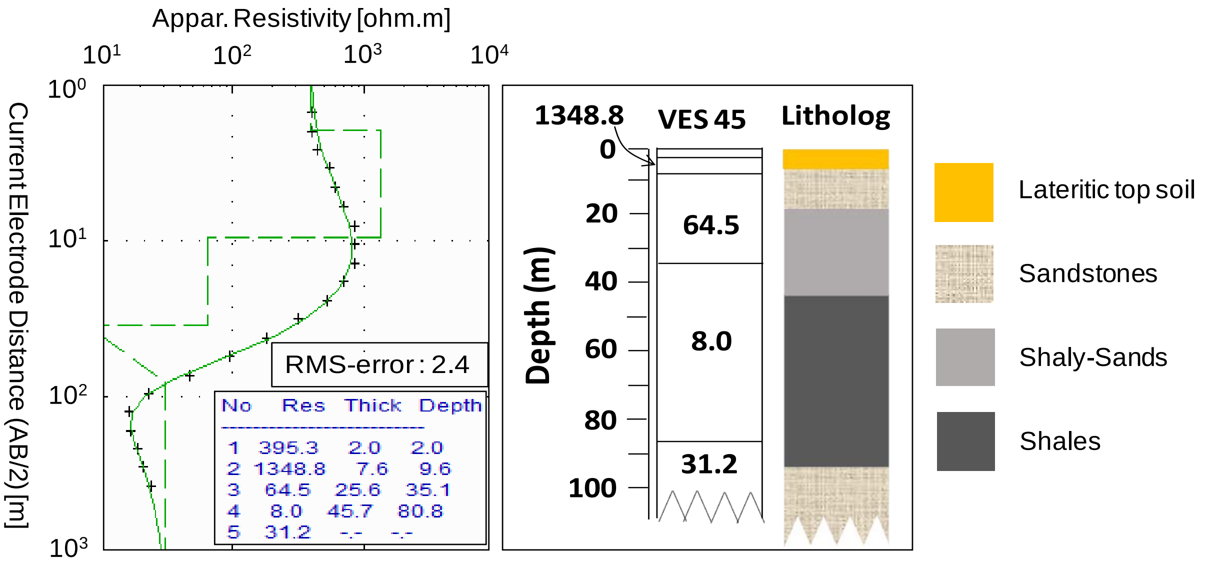

Figure 3. Sample of inverted VES data constrained using lithologic description from a nearby borehole

Electrical resistivity of Earth materials varies with changes in temperature, lithology, porosity, degree of saturation and the resistivity of pore fluid [4]. However, for a partially saturated aquifer in which the pore fluid is the only medium of electrical conduction, a quantitative relationship between some of these variables and bulk resistivity (ρ_b) can be expressed in terms of Archie's equation [30] as

$$\rho b = a\rho_w \phi^{-m} S^n \quad (4)$$

where ρ_w is the resistivity of pore fluid measured directly from borehole water samples, ρ_b is the bulk resistivity of the rock, φ is the porosity of the rock (approximate volume of water filling the pore space) and is known as apparent porosity a and m are certain empirical constants which depends on the geologic formation under investigation. The constant a is sometimes referred to as tortuosity, whereas m is called the cementation index and n is saturation exponent [31]. The bulk resistivity values of geologic formations are influenced by the type of rock and soils, porosity, degree of saturation, nature of the saturating fluid and also the diagenetic cementation factor [32]. However, most rocks have typical values of a and m to vary between 0.62–2.45 and 1.08-2.15 respectively [33]. The formation factor (F), bulk resistivity of the saturated geologic formation and the resistivity of the infill pore fluid are empirically related in the equation below

$$\rho_b = F\rho_w. \quad (5)$$

In theory, stratified conductors possess certain fundamental parameters that are necessary in both interpretation and understanding of the geoelectric layer [34]. These parameters are related to different combinations of ρ and h for each geoelectric layer in the model [35,36]. These parameters include the Dar Zarouk (DZP) which is made up of the longitudinal conductance (S) and the transverse resistance (TR). S is the ratio of h of the individual geoelectric layer to its corresponding ρ value [37,38]. It is expressed as;

$$S = \frac{h_i}{\rho_i}. \quad (6)$$

This parameter is used to quantitatively assess the properties of a thin conducting layer. More so, studies have shown that hydraulic conductance has an inverse relationship with electrical resistivity values, thus high groundwater potential aquifers are usually characterized by high conductance values [39]. TR of a geoelectric layer is defined as the product of h and its corresponding ρ [16,40]. Thus,

$$TR = h_i \rho_i. \quad (7)$$

These parameters are based on the consideration of a column of unit square cross-sectional area (m^2) cut out of a group of layers of infinite lateral extent [41,42].

4. Results and Discussion

Most of the sounding curves in Ehime Mbano showed the presence of four geoelectric layers. The types of curve obtained are mainly HK-curve, KAQ-curve and AK-curve (Figure 4). The 2D resistivity cross section (Figure 5) show lateral and vertical variation in electrical resistivity. The top layer composed of lateritic cover show resistivity of the range 314 to 1384 Ωm and thicknesses of layer one generally less than 10 m. Highly resistive materials were observed around Umueze, Umuanuchiama and UmuokiriAkwuoche areas suspected to be consolidated sandstone (Table 2). Several hydro-researchers have reported similar elevated values within the area [43,44,45]. The highly resistive sands are truncated by an extensive thick shale formation. The apparent resistivity of the shale formation ranged between 41 to 55 Ωm. The thick (~ 35 m) shaly formation which was observed around Umuezeala and Umonumo areas tend to shield the underlying aquifer from surface contaminants. Below the shaly layer is a relatively high resistive sand layer which is the exploration target for groundwater in the area. The apparent resistivity of this layer varies between 138 to 597 Ωm and occurs at depths below 70 m. The static water levels from post drilling reports in the area reveal depth of about 70 – 80 m [43] which correlates well with this sand unit. UmunuhuNsu and environs show relatively low resistive sediments which extend to depths of ~90 m. These thick low resistive materials could be the reason for the failed boreholes and water shortages experienced by the people.

The results obtained for the Dar Zarouk parameters estimated from 1-D electrical resistivity inversion and hydrogeologic measurements of the borehole water samples is shown in the table above. The aquifer thickness map, longitudinal unit conductance map and the hydraulic conductivity map were produced using SURFER 11 contouring software from Golden Software Inc., USA. The transverse resistance increased towards the south and south-western portions of the study area in tandem with the regional geology (Figure 6). The area shows dominance of sandy materials of the Benin Formation. Such areas with relatively high transverse resistance (200000 – 800000 Ωm^2) values are high potentials of groundwater circulation. The northern and north-eastern parts have relatively lower values (<50000) which may be due to the presence of clays and shales of the Imo and Ameke Formations and may have less successful boreholes.

The longitudinal conductance values across the area revealed that areas around the northern and north-eastern parts have relatively high values of conductance (1.7 – 5.7 mho) which may be attributed to the clay and shaly Formations (Figure 7). The lower values (< 0.9 mho) which corresponded to areas with high transverse resistances were observed within the southern portion of the area.

The DZP estimated which has tendency of influencing the estimated transmissivity, which also depends on the aquifer thickness and the rocks the serves as aquifer conduit. The longitudinal unit conductance map (Figure 7) shows that the southern parts of the area is dominated by lower values of longitudinal conductance (<1.7). The implication is that the resistivity values are relatively high when compared to their corresponding thickness. On the other hand, the transverse resistance map (Figure 7) show high values within the southern part of the study area that is dominated by sands and sandstones. Based on the results of the inverted resistivity models the depth to aquifer should be >90 m. At this depth, aquifer systems are well protected and groundwater circulation can sustain water wells in the area all year round.

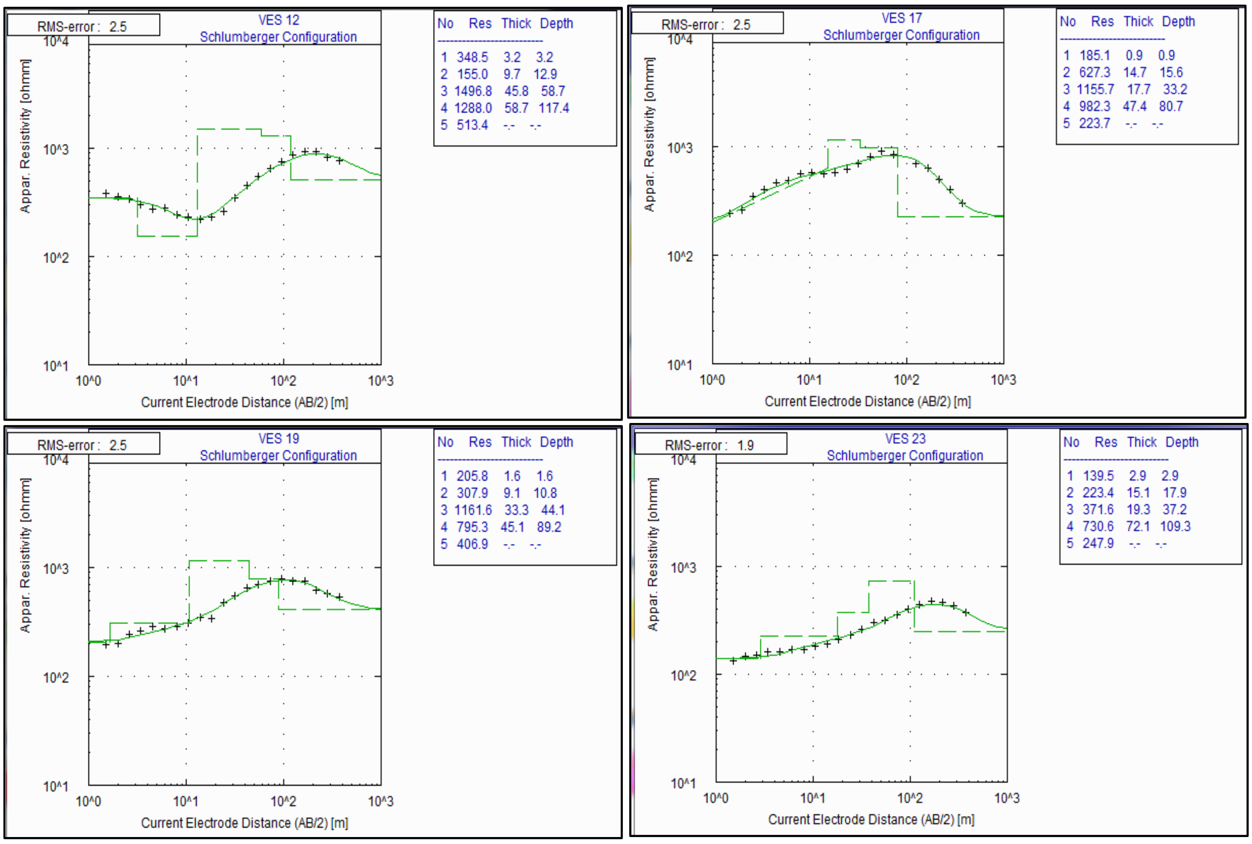

Figure 4. Samples of some of the inverted VES models

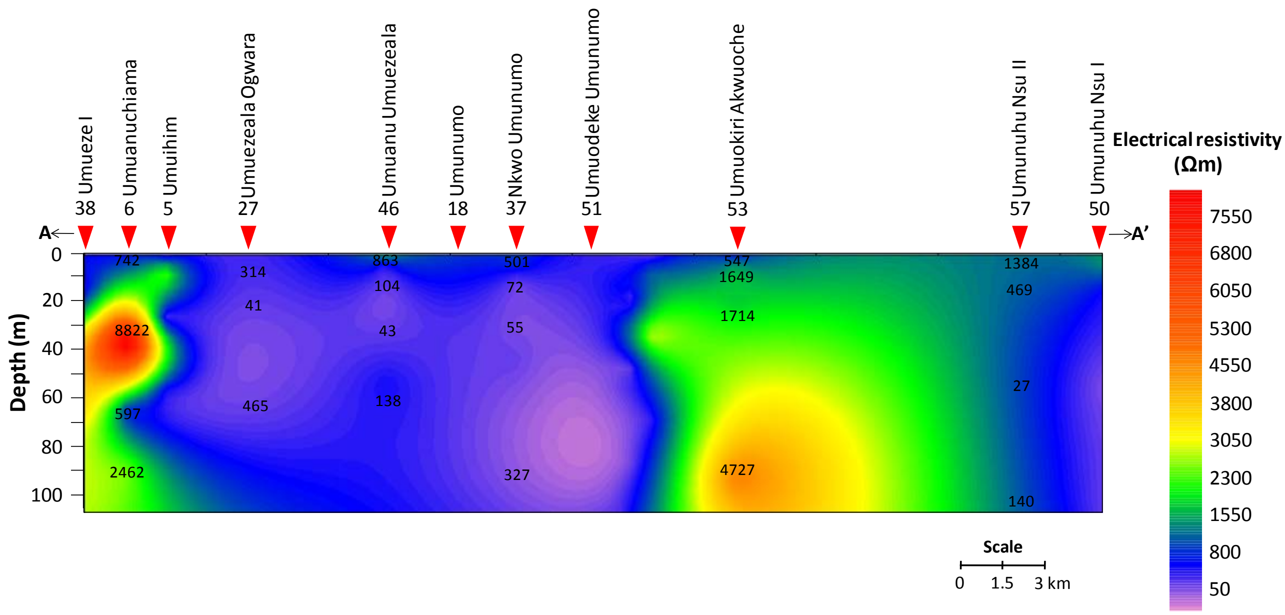

Figure 5. 2D resistivity cross section along profile AA'

Table 2. Summary of geoelectrical parameters

VES point	Location	Coordinate in degrees		Elevation (m)	Electrical resistivity (Ωm)					Thickness (m)			
		Longitude	Latitude		ρ_1	ρ_2	ρ_3	ρ_4	ρ_5	h_1	h_2	h_3	h_4
1	UMUEZEALA OWERRE OPP. EHIME MBANO HQTRS.	7.283	5.632	183	252.3	398	436.5	536.8	686	5	21.2	36.5	58.4
2	UMUEZEALA OWERRE BEHIND EHIME MBANO HQTRS.	7.281	5.631	173	274.9	535.1	532.3	616.9	792.4	4.3	22.9	38.8	49.4
3	UMUNAKANU AMA COMMUNITY SCHOOL	7.258	5.651	143	385.9	1338.6	805.6	1458.2	11745.1	1.1	18	29.2	19.3
4	AMAZIAMA UMUNAKANU	7.254	5.662	151	87.3	1153	347.4	746.9	4431.2	1.1	14.7	31.7	32.7
5	UMUIHIM UMEZE 1	7.248	5.657	167	73.1	2452.2	228.2	464.5	6166.1	1	6.6	19.1	28.6

VES point	Location	Coordinate in degrees		Elevation (m)	Electrical resistivity (Ωm)					Thickness (m)			
		Longitude	Latitude		ρ_1	ρ_2	ρ_3	ρ_4	ρ_5	h_1	h_2	h_3	h_4
6	UMUAWUCHIAMA UMUEZE 1	7.237	5.658	180	742.4	8822.9	596.5	2462.2	303.7	3.3	32.9	27.2	23.8
7	UMUELEKE SECONDARY SCHOOL	7.253	5.627	183	180.7	1260.2	3092.3	928.9	263.4	1.1	14	35.7	39.8
8	UMUELEKE	7.248	5.634	175	245.5	513.2	581.4	604.2	665	2.4	21.1	47.6	59
9	UMUDURUEGWELLE UMUEZE 11	7.243	5.622	175	18.8	190	326.7	2304.7	1315	0.8	25.1	16.6	47.7
10	OKWEOWERRE UMUEZE 11	7.235	5.626	161	74.8	306.9	1510.2	711.5	1342.5	1.1	9.4	31.4	42.6
11	UMUAWARAFA OKEOWERRE UMUEZE 11	7.234	5.622	166	781.5	992.6	3282.9	1305.8	368.6	4.5	24.2	45.9	69.7
12	UMUDURUEGWELLE UMUEZE 11	7.241	5.618	182	348.5	155	1496.8	1288	513.4	1.2	5.1	27.6	62.6
13	OKWEOWERRE UMUEZE 11	7.237	5.621	188	105.7	122.4	259.1	1442.2	756.8	1.6	10.6	12.1	56.4
14	UMUOPARA UMUEZEALA	7.278	5.624	168	205.3	1054.4	664.7	1167.7	608.5	1.2	5.1	27.6	62.6
15	UMUOPARA UMUEZEALA	7.281	5.622	154	154.2	577.7	1167.4	781.8	973.6	1	16.9	48.1	70.1
16	UMUIHIM UMUALUMAKU	7.290	5.630	179	212.8	464.7	613.2	1065.6	1102.6	2	6.6	26.5	58.6
17	UMUDIBIA ALAIYI UMUALUMAKU	7.294	5.627	178	185.1	627.3	1155.7	982.3	223.7	0.9	14.7	17.7	47.4
18	UMUNUMO	7.293	5.654	153	314.6	615.5	193.5	248.8	742.3	2.8	13.7	35.7	52.6
19	UMUAKAGU NSU	7.316	5.632	175	205.8	307.9	1161.6	795.3	406.9	1.6	9.1	33.3	45.1
20	UMUONYIA MBARA UMUALUMAKU	7.310	5.626	165	239.7	494.8	807.6	1728.6	-	4.3	12.7	64.9	-
21	ST.MICHAEL'S CHURCH UMUARO UMUNUMO	7.302	5.641	186	72.4	1183.36	777	2479.7	357.5	1	8.3	14.4	57.1
22	UMUAKAGU NSU	7.313	5.637	201	286.8	267.7	635.4	775.5	380.6	6.7	15.2	29.1	45.3
23	UMUELEKE	7.255	5.620	197	139.5	223.4	371.6	730.6	247.9	2.9	15.1	19.3	72.1
24	UMUIHIM UMUALUMAKU	7.302	5.633	199	130.4	637.1	127.7	1186.7	-	0.9	8.8	61.1	-
	UMUOKIRI UMUNUMO	7.302	5.638	195	373.7	54.2	1566.7	4358	1160.3	0.9	2.8	13.3	77.3
26	UMUEZEALA OGWARA	7.280	5.644	170	575.9	79.8	34.7	385.7	-	9.6	12.7	56.4	-
27	UMUEZEALA OGWARA	7.269	5.655	147	1772.9	313.7	40.6	462.3	1025.6	1.7	2.5	16.1	32.3
28	UMUODEKE UMUCHIOKE UMUNUMO	7.294	5.650	178	1767.4	899.2	157.1	374.3	107.9	3.2	2.3	18.7	37.8
29	UMUDURUEHI EZEOKE NSU	7.333	5.642	204	118.2	1630.5	3217.1	4391.6	810.8	1.5	5.7	18.3	54.3
30	UMUEZEALA AMA	7.247	5.677	158	368.6	976.9	311.5	29.9	293.9	0.9	4.3	29.8	53.7
31	UMUNUMO NSU	7.244	5.650	163	533.7	608	116	12.8	63.9	3.3	4.6	47.6	58.7
32	ST.JOSEPH CATH.CHURCH UMUALUMAKU	7.297	5.630	210	160.9	438.4	169.9	595.7	1734.4	1.8	11.9	28.1	37.8
33	UMUOKWE UMEZE 11	7.234	5.627	181	244.9	901	3155	9192.5	1660.7	0.8	18.4	14.2	48.8
34	UMUAGHA UMUEZEALA AMA	7.262	5.668	192	232.5	1710	183.3	64.6	333.6	1.5	12.7	30.8	79.5
35	MT.OLIVE'S SEMINARY UMUEZEALA NSU	7.338	5.617	208	479.9	2386.1	3097.4	6673.4	2706.5	4.7	11.8	22.1	72.2
36	UMUDURJI DURUEWURU UMUEZEALA NSU	7.345	5.641	175	2168.9	157	535	20.7	363.8	3.9	8.8	15.4	64.8
37	NKWO UMUNUMO	7.293	5.653	165	501.3	72	55	21	327.2	8.2	10.9	27	39
38	UMUEZE 1	7.235	5.660	180	654.6	338.9	1624.2	3341.5	609.8	6.3	8.6	9.8	40
39	IKPEM	7.288	5.738	126	221.6	36.1	14.5	12.2	208.9	3.5	7	30.9	31.5
40	IKWEII ODUDARA DIOKA NZEREM	7.296	5.719	126	1089.3	434.8	90.1	36.5	1006.5	5.8	2.5	18	39.6
41	UMUDURUOKORO UMUNUMO	7. 25299	5.646	180	534.9	175.7	8615.8	1615.7	-	1.2	2.8	60.4	-
42	OBOLLO DIOKA NZEREM	7.297	5.724	159	2280	504	175.2	10.5	472.1	4.9	10.8	10.7	40
43	UMUOLUMA UMUAWUCHI OWERRE UMUEZE 1	7.246	5.651	178	84.3	847.3	5016.2	839.2	-	2.1	12.9	65.3	-
44	UMUOPARA NSU	7.315	5.660	153	168.2	563.7	50.9	237.6	-	1.7	22.9	48	-
45	UMUEBO UMNUMO	7.297	5.663	103	395.3	1348.8	64.5	8	31.2	2	7.6	25.6	45.7
46	UMUMANU UMUEZEALA OGWARA	7.280	5.650	164	862.9	103.8	42.8	138.1	3192.7	4.2	7	19.1	13.5
47	UMUEZEALA UHU UMUNAKANU OWERRE	7.264	5.632	211	139.4	2097.3	871.9	5208.7	848.2	0.7	9.8	39.3	47
48	UMUOBU AGBAGHARA NSU	7.328	5.639	196	103.1	114	575.4	10816.1	5871.2	2.7	3.6	5.5	77.2
49	UMUOBU UMUEZEALA OGWARA	7.274	5.643	187	1687.8	3140.4	4119.9	4842.6	235.1	1.9	6.2	14.8	41.1
50	UMUANUNU NSU	7.341	5.646	170	190.2	2438.6	2512.7	7746	1011.2	0.8	3.9	15.4	40.1
51	UMUODEKE UMUNUMO	7.296	5.650	135	134.2	1104.2	2839.4	360	217.6	3.1	3	27.1	34.1
52	UMUDURUOKORO UMUNUMO	7.299	5.644	185	1137.8	6381.3	3461.5	8312.5	1589	1.1	21.5	15.6	59.3
53	UMUOKIRI AKWUOCHA	7.306	5.649	220	547	1649	1713.9	4727.4	904.3	1.8	4.2	14.5	69.9
54	UMUOKIRI UMUNUMO	7.302	5.648	194	2498.2	1533.6	6036.7	1754.8	-	4.6	16.1	59.4	-
55	UMUARO UMUNUMO	7.301	5.637	196	1211.1	900.8	1378.5	4470.5	1336.6	6.3	2.9	11.5	62.7
56	UMUOBU AGBAGHARA NSU	7.327	5.638	195	182.7	417.8	1359	3364.7	9403.1	2.9	4.4	19.1	43.3
57	UMUNUHU NSU	7.340	5.648	163	1384.1	469.7	26.6	139.7	44.5	4.9	10.8	37.3	50.7
58	UMUEZE 1	7.234	5.663	186	222.1	30.5	5149.1	1402.5	163.4	1.3	2.4	25.9	32.9
59	UMUALUMAKU UMUEZE	7.292	5.630	191	285.1	997.2	1296.6	3519	1184.4	1.4	15.6	10.6	55
60	UMUEGWELLE UMUDIBIA UMUALUMAKU	7.285	5.630	210	258	1436.4	1379.2	4310.1	1075.3	1.3	10.1	9	70.2

Table 3. Summary of aquifer characteristics

VES point	Location	Coordinate in degrees		Tranverse resistance	Longitudinal conductance
		Longitude	Latitude		
1	UMUEZEALA OWERRE OPP. EHIME MBANO HQTRS.	7.283	5.632	56980.5	0.2655
2	UMUEZEALA OWERRE BEHIND EHIME MBANO HQTRS.	7.281	5.631	64564.0	0.2114
3	UMUNAKANU AMA COMMUNITY SCHOOL	7.258	5.651	76186.1	0.0658
4	AMAZIAMA UMUNAKANU	7.254	5.662	52481.3	0.1604
5	UMUIHIM UMEZE 1	7.248	5.657	33900.9	0.1616
6	UMUAWUCHIAMA UMUEZE 1	7.237	5.658	367548.5	0.0634
7	UMUELEKE SECONDARY SCHOOL	7.253	5.627	165206.9	0.0716
8	UMUELEKE	7.248	5.634	74740.2	0.2304
9	UMUDURUEGWELLE UMUEZE 11	7.243	5.622	120141.5	0.2462
10	OKWEOWERRE UMUEZE 11	7.235	5.626	80697.3	0.1260
11	UMUAWARAFA OKEOWERRE UMUEZE 11	7.234	5.622	269237.0	0.0975
12	UMUDURUEGWELLE UMUEZE 11	7.241	5.618	123149.2	0.1034
13	OKWEOWERRE UMUEZE 11	7.237	5.621	85941.8	0.1875
14	UMUOPARA UMUEZEALA	7.278	5.624	97067.5	0.1058
15	UMUOPARA UMUEZEALA	7.281	5.622	120873.5	0.1666
16	UMUIHIM UMUALUMAKU	7.290	5.630	82186.6	0.1218
17	UMUDIBIA ALAIYI UMUALUMAKU	7.294	5.627	76404.8	0.0919
18	UMUNUMO	7.293	5.654	29308.1	0.4271
19	UMUAKAGU NSU	7.316	5.632	77680.5	0.1227
20	UMUONYIA MBARA UMUALUMAKU	7.310	5.626	59727.9	0.1240
21	ST.MICHAEL'S CHURCH UMUARO UMUNUMO	7.302	5.641	162674.0	0.0624
22	UMUAKAGU NSU	7.313	5.637	59610.9	0.1844
23	UMUELEKE	7.255	5.620	63626.0	0.2390
24	UMUIHIM UMUALUMAKU	7.302	5.633	13526.3	0.4992
25	UMUOKIRI UMUNUMO	7.302	5.638	358198.6	0.0803
26	UMUEZEALA OGWARA	7.280	5.644	8499.2	1.8012
27	UMUEZEALA OGWARA	7.269	5.655	19384.1	0.4753
28	UMUODEKE UMUCHIOKE UMUNUMO	7.294	5.650	24810.2	0.2244
29	UMUDURUEHI EZEOKE NSU	7.333	5.642	306808.0	0.0342
30	UMUEZEALA AMA	7.247	5.677	15420.7	1.8985
31	UMUNUMO NSU	7.244	5.650	10831.0	5.0100
32	ST.JOSEPH CATH.CHURCH UMUALUMAKU	7.297	5.630	32798.2	0.2672
33	UMUOKWE UMEZE 11	7.234	5.627	510169.3	0.0335
34	UMUAGHA UMUEZEALA AMA	7.262	5.668	32847.1	1.4126
35	MT.OLIVE'S SEMINARY UMUEZEALA NSU	7.338	5.617	580683.5	0.0327
36	UMUDURJI DURUEWURU UMUEZEALA NSU	7.345	5.641	19420.7	3.2171
37	NKWO UMUNUMO	7.293	5.653	7199.5	2.5158
38	UMUEZE 1	7.235	5.660	156615.7	0.0530
39	IKPEM	7.288	5.738	1860.7	4.9227
40	IKWEII ODUDARA DIOKA NZEREM	7.296	5.719	10472.1	1.2958
41	UMUDURUOKORO UMUNUMO	7.299	5.646	521528.2	0.0252
42	OBOLLO DIOKA NZEREM	7.297	5.724	18909.8	3.8942
43	UMUOLUMA UMUAWUCHI OWERRE UMUEZE 1	7.246	5.651	338665.1	0.0532
44	UMUOPARA NSU	7.315	5.660	15637.9	0.9938
45	UMUEBO UMUNUMO	7.297	5.663	13058.3	6.1201
46	UMUMANU UMUEZEALA OGWARA	7.280	5.650	7032.6	0.6163
47	UMUEZEALA UHU UMUNAKANU OWERRE	7.264	5.632	299725.7	0.0638
48	UMUOBU AGBAGHARA NSU	7.328	5.639	838856.4	0.0745
49	UMUOBU UMUEZEALA OGWARA	7.274	5.643	282682.7	0.0152
50	UMUANUNU NSU	7.341	5.646	358972.9	0.0171
51	UMUODEKE UMUNUMO	7.296	5.650	29117.4	0.0354
52	UMUDURUOKORO UMUNUMO	7.299	5.644	685380.2	0.0160
53	UMUOKIRI AKWUOCHA	7.306	5.649	363207.2	0.0291
54	UMUOKIRI UMUNUMO	7.302	5.648	394762.7	0.0222
55	UMUARO UMUNUMO	7.301	5.637	306395.4	0.0308
56	UMUOBU AGBAGHARA NSU	7.327	5.638	174016.6	0.0533
57	UMUNUHU NSU	7.340	5.648	19929.8	1.7917
58	UMUEZE 1	7.234	5.663	179865.9	0.1130
59	UMUALUMAKU UMUEZE	7.292	5.630	223244.4	0.0444
60	UMUEGWELLE UMUDIBIA UMUALUMAKU	7.285	5.630	329824.9	0.0349

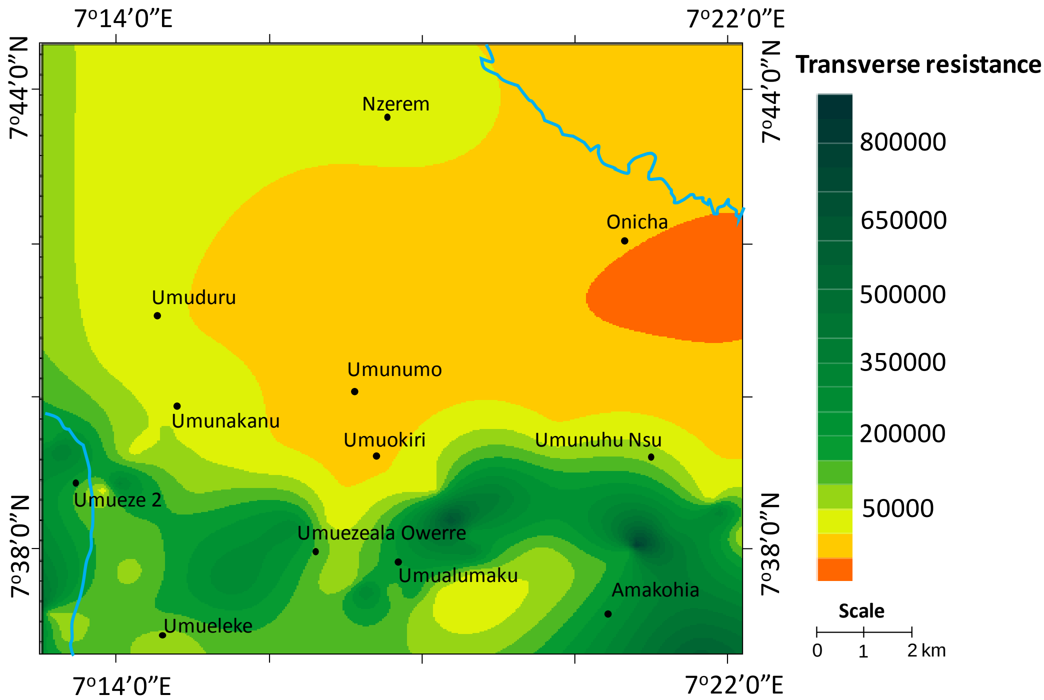

Figure 6. Transverse resistance map

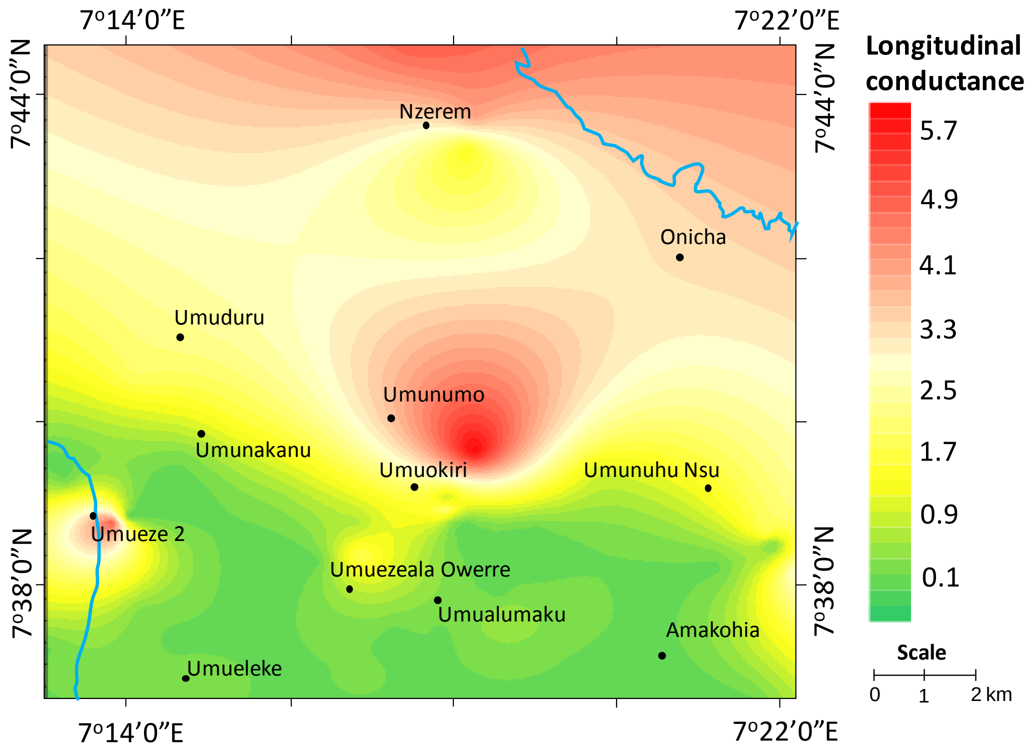

Figure 7. Longitudinal conductance map

5. Conclusion

The vertical electrical sounding techniques have again been proven to be a veritable tool for groundwater resource potential evaluation. The results have clearly distinguished the highly resistive areas from the less resistive areas based on the contrast in geoelectrical values. Truncation of the lateral continuity of the sands and sandstones by shaly sediments were also delineated in the study. This truncation influence groundwater circulation in the area and could be a factor affecting the even distribution of groundwater resources in the area. The Dar Zarouk parameters estimated divided the entire area into two domains, i.e., the north and south. Longitudinal conductance is low in the southern portion dominated by sands and sandstones while the northern portion possessed high vales of longitudinal conductance resulting from clays and shales. Conversely, the transverse resistance tends to increase towards the south where it has its highest value. The sediments in the southern parts of the study area which is dominated by sands and sandstones can favour groundwater circulation and possesses good groundwater exploration prospects. Although, geophysical based results are plagued with ambiguities, when constrained using lithologic information, it can provide a reliable result that precedes a more detailed investigation.

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