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GEOELECTRIC MAPPING AND ASSESSMENT OF NEAR SURFACE HYDRO-GEOLOGIC UNITSFOR SUSTAINABLE GROUNDWATER DEVELOPMENT IN ORLU AREAIN IMO RIVER BASIN, NIGERIA.

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ABSTRACT

Twenty (20) Vertical Electrical Soundings (VES) were carried out using the Schlumberger electrode configuration with a maximum electrode spread of 700m in order to map and assess near surface hydro-geologic units for sustainable groundwater developmentin Orlu area of Imo State.The OHMEGA-500 resistivity meter was used to acquire field data which were interpreted using the Advance Geosciences Incorporation (AGI) 1D software and the Schlumberger automatic analysis version. The results show that the study area is underlain by multi-geoelectric layers with resistivity varying both vertically and laterally. The aquifer was delineated with depth to water table ranging from 53.68m at Amaifeke 2 to about 130m observed at Amaifeke 1 while the aquifer resistivity varied from 1.30Ωm obtained at Ihitteto 1208.50Ωm observed at Ihioma. The aquifer materials were interpreted to be sand, sandstone and sand intercalated with shale in some areas. Results obtained from analysis of pumping test and VES data reveal variation in aquifer parameters of transverse resistance, longitudinal conductance as well as transmissivity. Transmissivity values are moderate and fairly uniform indicating similar geologic setting in most parts andgood groundwater potential for the area. The groundwater flow pattern of the study area reveals that the central and southern parts of the study area form the convergent zones which are more promising for siting standard water wells for sustainable groundwater development.

Key words:Flow pattern, Geoelectric, Groundwater, Resistivity, Transmissivity.

INTRODUCTION

Orlu Metropolis and its environs is a difficult area for groundwater development due to the nature of the depositional environment. Greater part of the arealies in the OgwashiAsaba Formation and the depth to water table in most places is considerably high, which makes drilling of boreholes quite expensive and sometimes unsuccessful.There are few boreholes in the study area, some of which are non-functional. There are also failed private commercial water wells attributedto lack of proper pre-drilling geophysical survey. The main source of surface water is Orashi river which drains the North-eastern part of the area along the boundary with Ideato North Local Government Area. This is not a source of potable water owing to obvious reasons which include pollution arising from industrial and agricultural activities, indiscriminate dumping of refuse and household wastes as well as erosion. Adequate water supply is essential to public health and wellbeing(Nwosu*et al*., 2013) but unfortunately, majority of the residents of the area do not have access to potable water.

Assessment of water resources potential of a place relies on certain aquifer characteristics which includehydraulic conductivity (K), transmissivity (T) and storativity. They are needed to execute proper water planning and management and also in the determination of the natural flow of water through an aquifer and its response to fluid extraction (Nwosu*et al.,* 2013; Mbonu*et al.,*1991). Although these aquifer characteristics are best determined from pumping test (Mbonu*et al.,* 1991; Ekine and Iheonunekwu,2007), they can be computed from vertical electrical sounding data and thus obtain reliable result.Also important in the assessment of groundwater potential are aquifer parameters of Transverse resistance and Longitudinal conductance known as Dar Zarrouk parameters.These parameters have been proved to be powerful interpretational aids in groundwater survey (Zhody*et al*., 1974).

This study is aimed at mapping and assessing near surface hydro-geologic units for sustainable groundwater development in the study area using geo-electric investigation method.

LOCATION OF THE STUDY AREA

The study area is located in Orlu Local Government area of Imo state in the Imo River Basin. Imo state is one of the 36 states of the Federal Republic of Nigeria and lies in the southeast of the country. The study area lies between latitudes 5˚45'N to 5˚57'N and longitudes 7˚04'E to 7˚26'E and covers a total land area of approximately $3{,}150km^2$. The area lies in the northern part of Imo state (Fig. 1).

GEOLOGY OF THE STUDY AREA

Figure 2 shows the geological map of parts of Imo and Abia states which form the Imo River Basin. The following stratigraphic units can be identified:The Benin Formation, The Ogwashi-Asaba Formation, Ameki Formation, The Imo Shale Group, Nsukka Formation, and Ajali Formation.

The Benin Formation is of Paleocene to Miocene in age and consists of Coastal Plain Sands with minor clay beds. The Benin Formation is overlain by alluvium deposits and underlain by Ogwashi-Asaba Formation which is in turn underlain by Ameki Formation of Eocene to Oligocene age (Mbonu*et al.*,1991). The Benin Formation is composed of coarse grained gravelly sandstones with minor intercalations of clay and shale. The sand units which are mostly coarse grained pebbly and poorly sorted contains lenses of fine grained sands (Onyeagocha, 1980; Short and Stauble,1967). The Ogwashi-Asaba Formation is made up of variable succession of clay and grits with seams of lignite.The study area lies mainly in Ogwashi-Asaba Formation and partly in Benin Formation.

The Ameki Formation consists of greenish grey clayey sandstones, shale and mudstone with intercalated limestone. This formation in turn overlies the Imo Shale Group. The depth to the aquifer in this formation is often considerable, reaching as much as 581ft (178.9m) (Nwosuand Ndubueze, 2016).The BendeAmeki Formation is composed mainly of sands intercalated with shale. The sand parts have more or less same permeability as the Coastal Plain Sands but the transmissivity coefficient is lower because of high percentage of shale(Maduagwu,1990). 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 Nsukka Formation, Ajali Sandstones and NkporoShales(Maduagwu1990). The sediments of Imo Shale Formation consist of well laminated plane shale with a grey to light green colour. The shale contains occasional intercalations of thin bands of calcareous sandstones, marls and limestone. Groundwater exploitation is very difficult in this Formation (Nwosu and Nwosu, 2017). The Ajali Formation consists of thick friable, poorly sorted sandstones typically white in colour but sometimes iron stained. A marked banding of coarse and fine layer is displayed (Kogbe, 1989).

The Ajali Formation is often overlain by a considerable thickness of red earth, which consists of red, earthly sands formed by weathering and ferruginisation of the Formation (Kogbe,1989). The Ajali Formation extends through the North Eastern parts of the Stateand dips towards the South West. The rate of replenishment is about 250 million cubic metres per year. When compared with the other formations, it is the least prolific for groundwater (Maduagwu,1990).

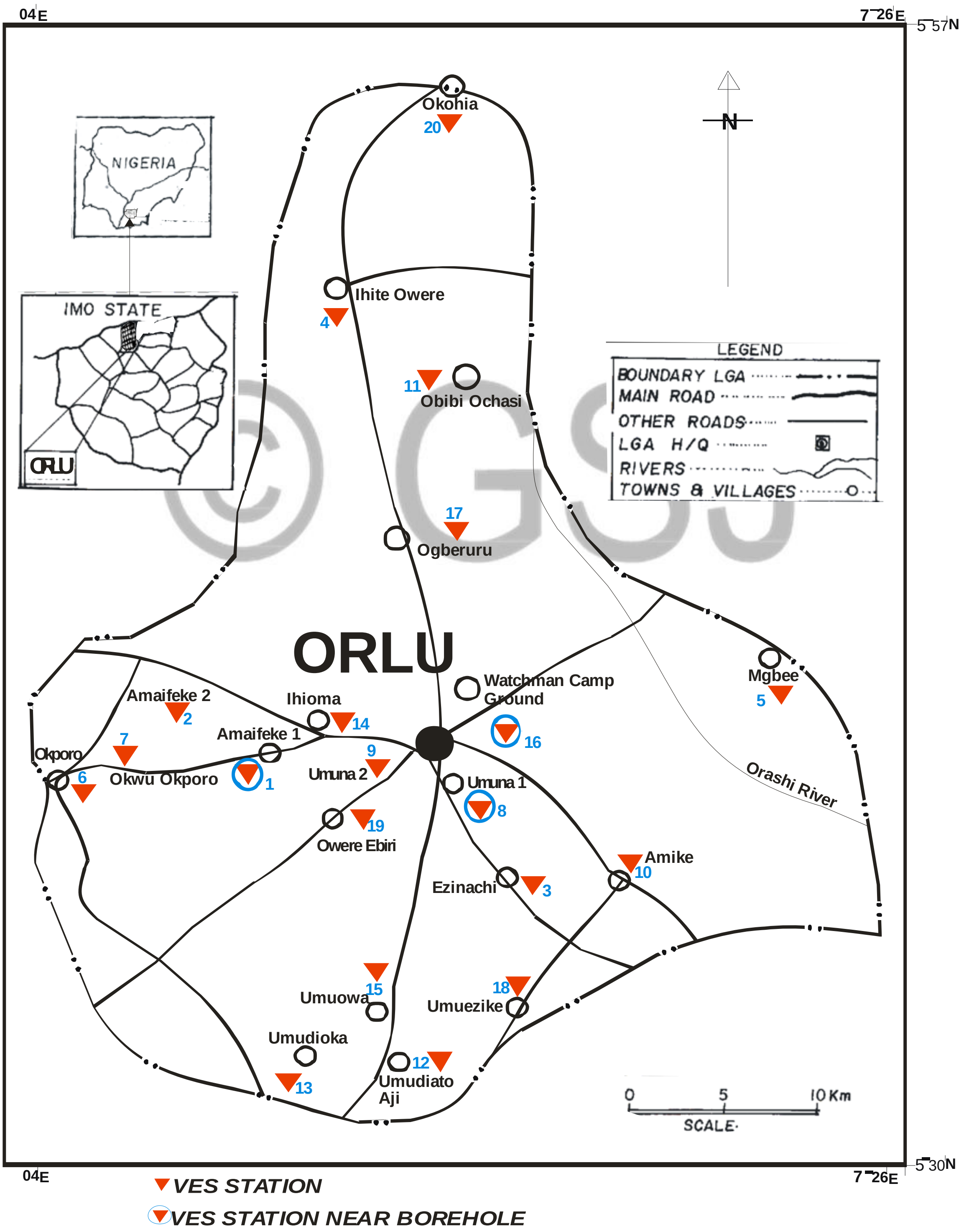


Fig. 1. Map of the study area showing the VES stations

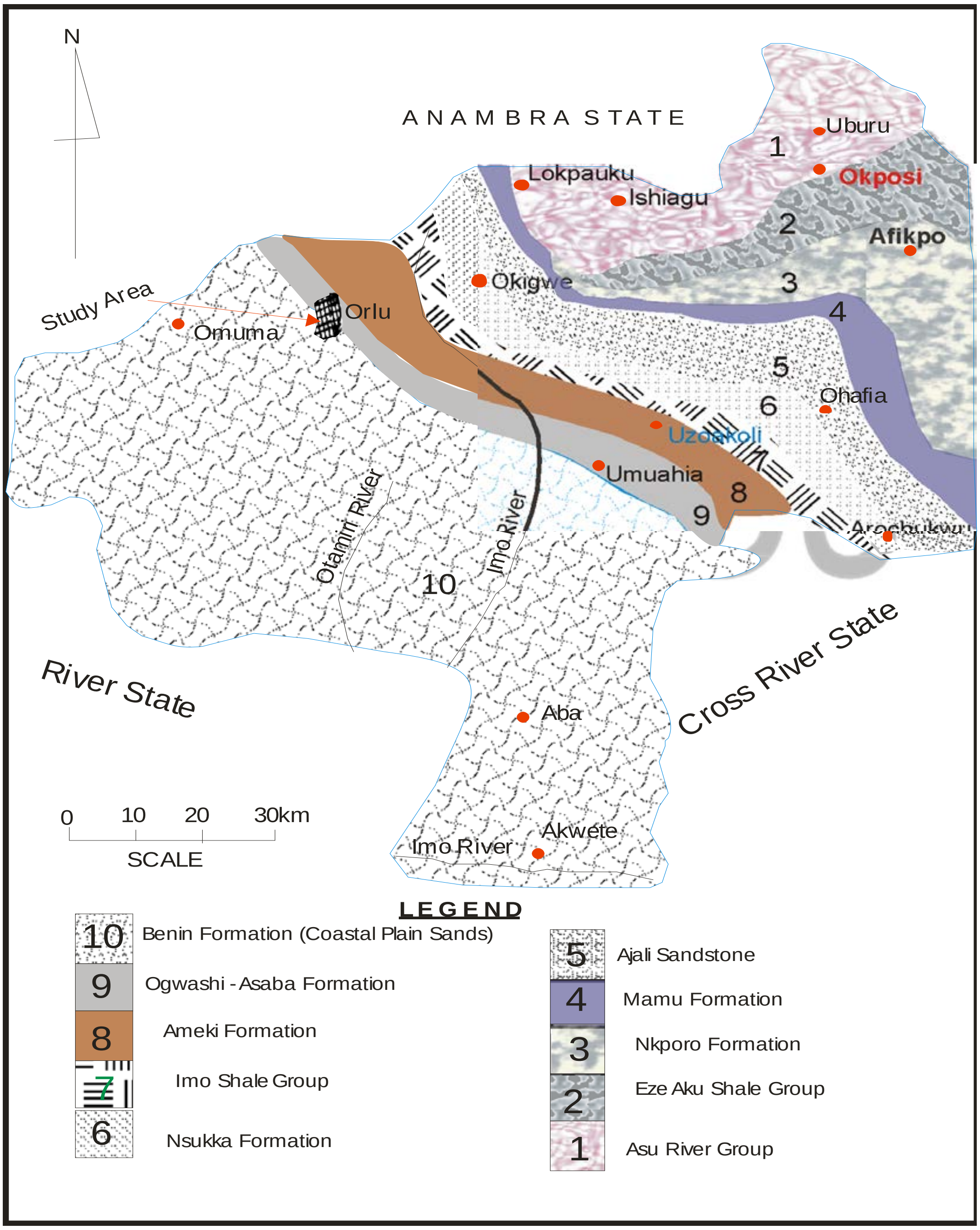


Fig.2. Geologic map of Imo and Abia states showing the study area(Adapted from Nwosuand Ndubueze, 2016).

LITERATURE REVIEW

Geo-electric surveys have been effective in the mapping and assessment of near surface hydro-geologic units for sustainable groundwater development and probing the variation of electrical properties of rocks with depth. It is possible to infer from VES results the subsurface stratification as well as identify possible aquifer (Egwebe*et al.,* 2004).Studies have been carried outon hydro-geologic and geoelectric investigation for determination of water table in hard rock terrain in Aule area of AkureOndo State(Igbago*et al.,* 2012).Thestudies concluded that there is a good correlation between hydrogeologic measurements and geo-electric sounding results.Vertical Electrical Sounding (VES) was used to investigate water table variation with surface elevation for mapping drill depths for groundwater exploitationin Owerri Metropolis, Imo State, Nigeria(Nwosu and Ndubueze, 2017).

In a previous study of the area, Opara*et al*. (2018) used vertical electrical sounding (VES) data to obtain aquifer apparent resistivity values ranging from 323 Ωm to 5200 Ωm with a mean value of 2943.1 Ωm. The depth to the water table ranged from 30m to 166.7m while aquifer thickness ranged from 13 to 67m.Ezomoand Aiyohuyin(2012) usedVESmethod to determine the geophysical properties andsub-surfacelithologies at Ekpomaarea of Edo State, Nigeria. The results obtained indicated the following lithologies: clays, shales, sandstones, limestones, sands, having resistivities varying from about 40Ωm to 60,000 Ωm.

In a study carried out by Nwosu and Nwankwo(2016)surface geo-electric survey was used in delineating aquifer horizon for sitting standard water wells in water problem area of Imo State, Southeastern Nigeria. The VES data obtained here were used to delineate area for siting productive boreholes.

MATERIALS AND METHODS

INSTRUMENTATION

The instruments used to acquire field data areOhmega–500 Electrical resistivity meter,
Four stainless steel electrodes (two potential and two current electrodes), a 12 volts d.c. power supply,Four reels of cables,Hammers, Measuring tapes, Clips and the Global positioning System (GPS).

FIELD PROCEDURE

The field procedure adopted in this study is Vertical Electrical Sounding (VES) using the Schlumberger electrode configuration. A total of 20 VES stations were occupied within the study area with maximum electrode spread of 700m. Four electrodes consisting of two current electrodes A and B, and two potential electrodes M and N were placed along a straight line on the land surface such that the current electrode spacing AB is greater than or equals five times that of the potential electrode MN. This technique involves the measurement of variations in ground apparent resistivity with depth at a fixed point of expanding spread.

The Ohmega-500 electrical resistivity meter was placed in between the potential electrode M and N and its terminals P1 and P2 were then connected to the terminals M and N respectively using the ABEM sounding set. The current electrodes A and B were connected to the terminals C1 and C2 respectively using the ABEM sounding current cables wound on two separate metal reels mounted on the stand. After setting up the equipment, the electrodes which are about 0.7m long were driven to a reasonable depth into the ground using a hammer.

During the data acquisition, necessary precautions were taken to avoid current leakage and creep which can reduce the attainable accuracy and sensitivity and thus the depth of penetration. The potential electrodes were fixed while the current electrode spacing was expanded in opposite direction on a straight line for subsequent measurements. However, the potential electrode spacing was increased whenever the value of measured resistance became too small to be reliable while the length of the configuration was generally increased. At each VES location the elevation and coordinates were measured using the Global Positioning System (GPS).

The field data acquired werefirst subjected to manual computation and finally to computer processing techniques.The interpretation of the field data was carried out by applying the Advanced Geosciences Incorporation (AGI) ID resistivity analytical software. The Analytical result presented by the AGI ID software and the Schlumberger Automatic analysis package revealed12 geoelectric layers with their various resistivity values and depths and laterwere constrained to between seven to ten layers depending on the significant value of the resistivity and thickness. The lithologic units were inferred using the borehole information obtained from the bore holes located in the study area(Fig. 3).

ESTIMATION OF AQUIFER PARAMETERS FROM PUMPING TEST DATA

Pumping test data obtained for the area (Table 1) were used to calculate the aquifer parameters to enable evaluation of the groundwater potential of the study area. Using equations 1, 2 and 3 the aquifer hydraulic conductivity, K and Transmissivity, T were computed.

Usingthe pumping test data with drawdown values in Table 1, the aquifer parameters were determined based on Logan (1964) method as follows:

The hydraulic conductivity was computed using equation 1.

$$K = \frac{1.18Q}{hs_{mw}} \qquad 1$$

where Q = well discharge

S_{mw} = maximum draw down

h = Screen length

The Transmissivity is obtained using equation 2

$$T = Kh \qquad 2$$

For VES data, the hydraulic conductivity is determined from equation 3

$$K = \frac{T}{h} \qquad 3$$

where T = average transmissivity from pumping test analysis

h = aquifer thickness.

The Transmissivity of the aquiferous layers is calculated from the analytical relationship derived by Niwas and Singhal(1981) given by equation 4

$$T = K \sigma R \qquad 4$$

whereσ= electrical conductivity of the aquiferous layer

R = transverse resistance of the aquiferous layer.

Dar Zarroukparameters ofLongitudinal conductance, S and Transverse resistance, R are determined using equations 5 and 6 respectively

$$S = \frac{h}{\rho} \qquad 5$$

$$R = \rho h \qquad 6$$

whereρ is aquifer resistivity and h is aquifer thickness

TABLE 1.EXISTING BOREHOLE (BH) /PUMPING TEST DATA IN ORLU METROPOLIS (BOREHOLE DATA).(Source: IWADA, 1999)

S/No	Location	DD (m)	Casing diameter (m)	Screen Diameter (m)	Casing depth (m)	Screen Length (m)	Static Water Level (m)	Yield Q (m^3/day)	Draw down (m)
1	Mgbee BH	120.0	0.3375	0.20	123.00	21.00	64.50	3815.70	15.00
2	Orlu Recreation Club Umuna 2 BH	120.0	0.3125	0.20	93.00	18.00	60.00	3270.60	18.60
3	Amaifeke BH	109.5	0.3000	0.20	90.00	12.00	51.00	3633.99	22.30
4	IhitteOwerre BH	108.6	0.3000	0.20	63.00	12.00	69.00	3724.85	-

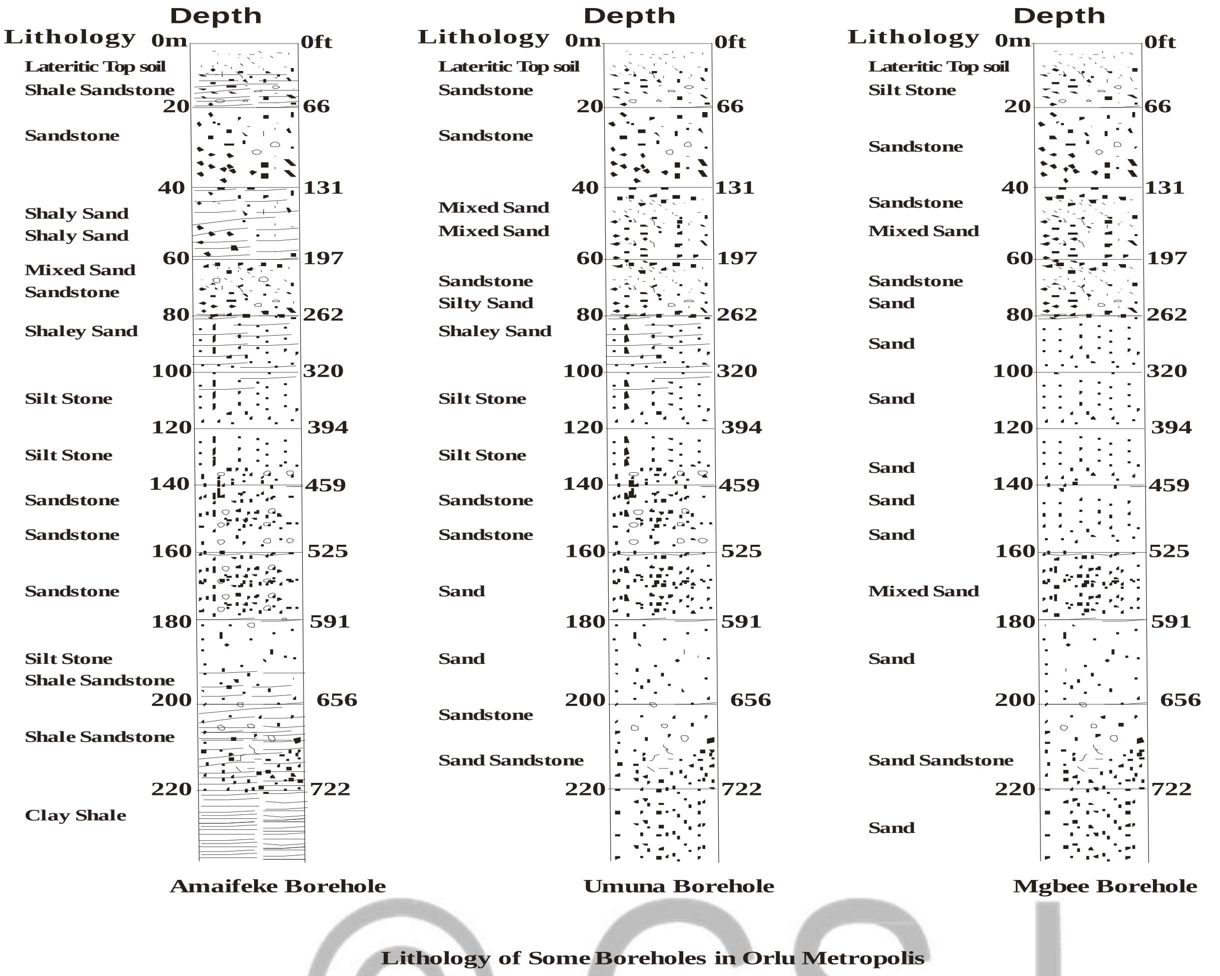


Fig. 3. Lithology of boreholes located in the study area. (Source: IWADA, 2002)

RESULTS AND DISCUSSION

RESULTS

Typical modeled results of VES data interpretation are shown Figs 4 to 7 for IhitteOwerre, Amaifeke,Mgbee and Umuowa locations while Tables 1 to 4 display the corresponding analytical results obtained. Table 5 is the summary of the modelled results and Table 6 is the summary of the aquifer characteristics obtained for all the sounding stations. The aquifer was delineated with depth to water table ranging from 53.68m at Amaifeke 1 to about 130m observed at Amaifeke 2. This wide difference observed atAmaifeke underscores the complex nature of the depositional environment as the community could be within the transition Zone of the Benin Formation and Ogwashi-Asaba Formation. The aquifer resistivity varied from 1.30Ωm obtained at Ihitte to 1208.5Ωm measured at Ihioma.Aquifer characteristics determined from pumping test analysis and VES results are quite good and favorable for groundwater development.

The high transmissivity values recorded agree with the geology of the Coastal Plain Sands (Benin Formation) which consist of fine to medium to coarse grain sands. It also indicates that greater part of the study area has uniform geological setting. These findings have led to the delineation of the aquifer zones in the study area into distinct geological zones. This is in conformity with the geology of the study area which revealed two stratigraphic units of Benin and Ogwashi-Asaba Formations, with the area underlain by the Benin Formation having a more prolific aquifer. These findings are in agreement with the results of similar studies by(Mbano*et al*., 1991) in parts of Umuahia located in the Imo River Basin also.Low resistivity values were recorded in areas around IhitteOwerre, Mgbee, OkwuOkporo, Amike, ObibiOchasi, Umuowa and Ogberuru with resistivity values of 120Ωm or below. Higher values of aquifer resistivity were observed in areas aroundUmudioka, OwerreEbiri, Okohia, Umuna2, Umuna1 and Okporo with value of 640Ωm and above(Fig.9).The study area cantherefore bedemarcated into three zones A, B and C which are areas with prolific yield, medium yield and low yield respectively.

Zone A is prolific in groundwater yield. It covers the areas OwerreEbiri, Amaifeke2, IhitteOwerre, Ezinachi, Amaifeke1, Mgbee, OkwuOkporo, Amike, ObibiOchasi, Aji, Umudioka, Umuowa,Ogberuru, Umuezike, and Okohia. The mean aquifer resistivity and thickness are 22.56Ωm and 149.84m respectively. Transmissivity is high in this zone.

Zone B covers areas with medium yield and include Okporo and Umuna1. The mean aquifer resistivity and mean thickness are 914Ωm and 50.51m respectively. This area is characterized by high transmissivity values.

Zone C covers areas with low yield likeUmuna 2 with aquifer resistivity 900Ωm and aquifer thickness of 10.70m. It is recommended that standard water wells be sited only in zones A and B.

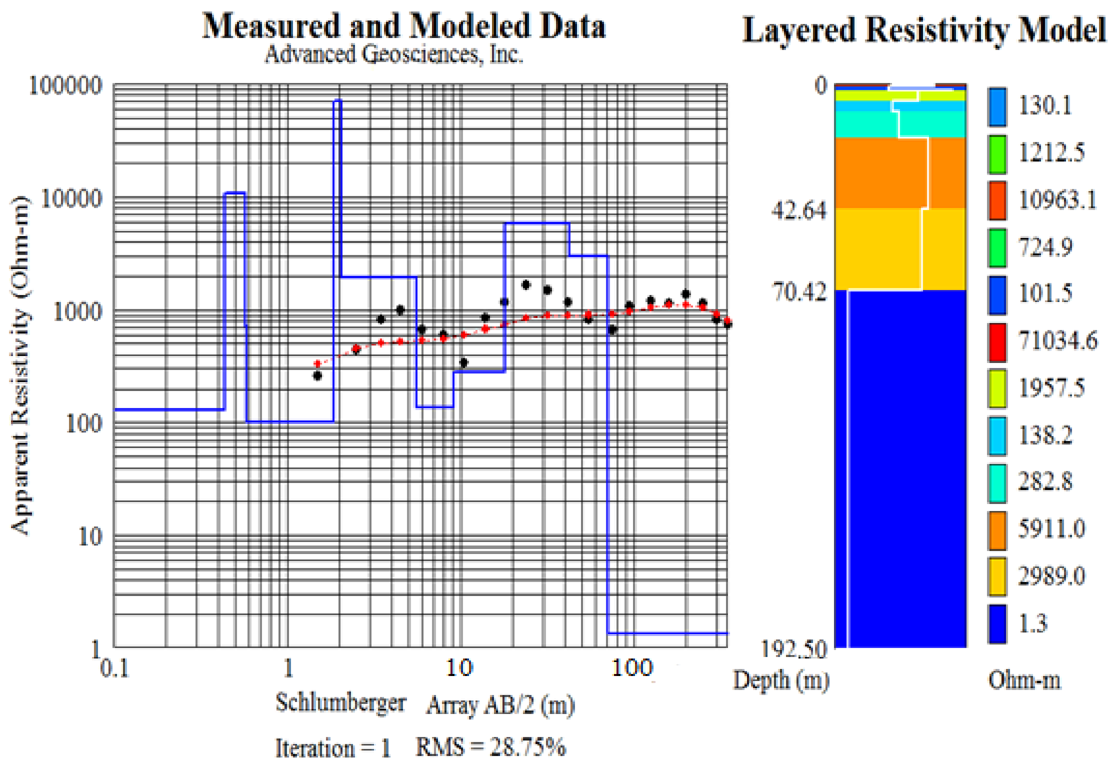


Fig 4 Model result for VES location at IhitteOwerre, Orlu

Table 1: Analytical result presented by the AGI 1D Software and the Schlumberger Automatic analysis package reveals eight sub-layers at

IhitteOwerreOrlu as follows:

LAYER	DEPTH (m)	RESISTIVITY (Ohm-m)	LITHOLOGY	COLOR
1	0.57	724	Topsoil lateritic	Green
2	1.8	101	Sand	Blue
3	5.5	1957	Siltstone*	Orange
4	9.1	138	Sand	Blue
5	18	282	Sand	Light Blue
6	42.6	5911	Shale-Siltstone	Brown
7	70	2989	Sandstone	Yellow
8	>195	1.3	Sand (Prospective unit))	Blue

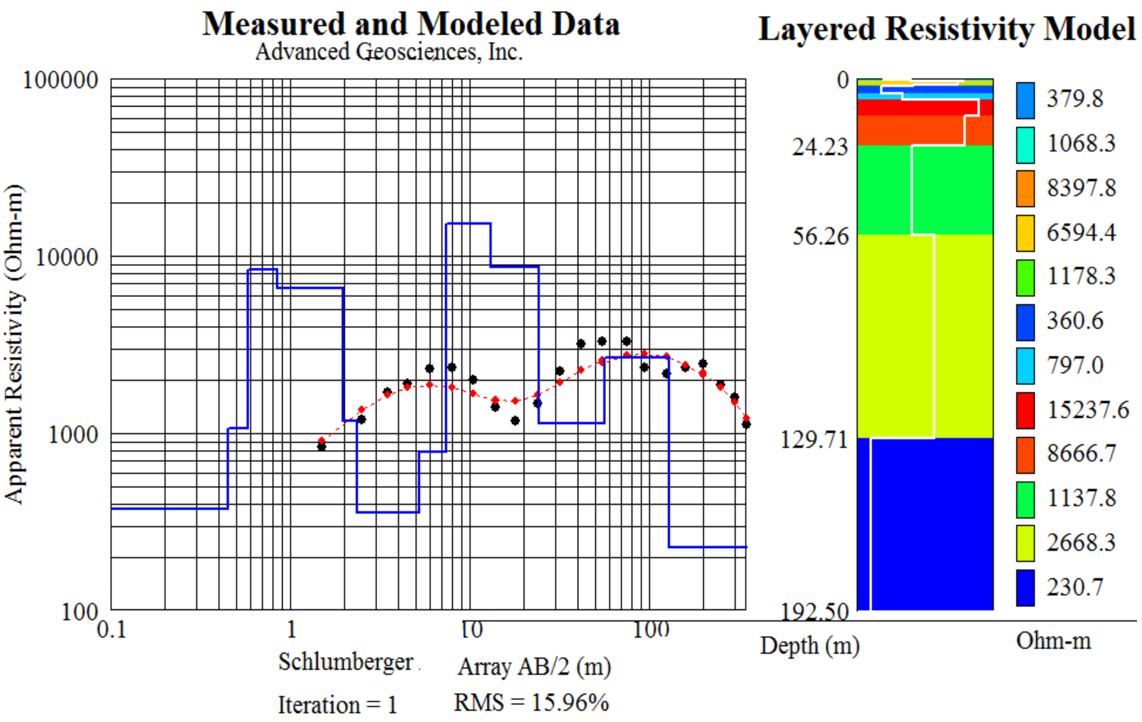


Fig. 5 Model result for VES at Amaifeke

TABLE 2: Analytical result presented by the AGI 1D Software and the Schlumberger Automatic analysis package reveals nine sub-layers at Amaifeke

LAYER	DEPTH (m)	RESISTIVITY	LITHOLOGY	COLOR
1	0.5	380	Topsoil- Lateritic	Mixed Blue
2	2	8397	Sand	Red-Brown
3	7	1178	Shale-Sandstone	Green
4	13	797	Mixed sand	Blue
5	20	15237	Shale-Sandstone	Red
6	24	8666	Sandstone	Off red
7	56	1137	Shally sand	Green
8	130	2668	Siltstone	Orange
9	>192	230	Prospective unit	Blue

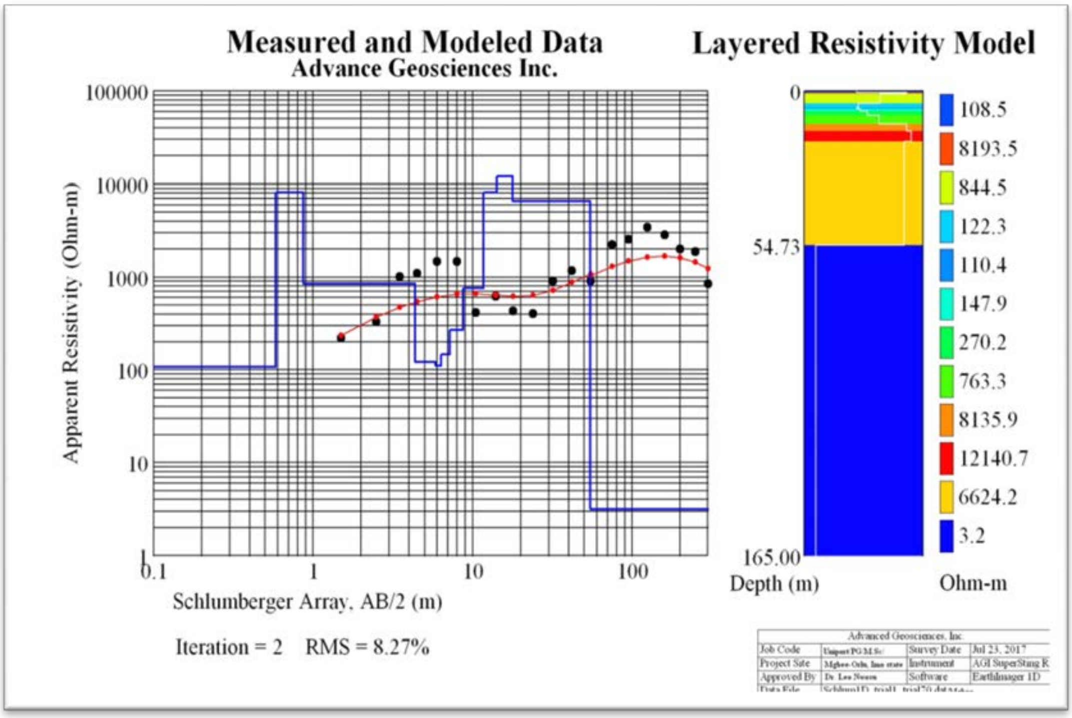


Fig. 6 model result for VES at Mgbee

TABLE 3: Analytical result presented by the AGI 1D Software and the Schlumberger Automatic analysis package reveals nine sub-layers at Mgbee

Layer	Resistivity Ωm	Depth (m)	Lithology	Colour
1	108.50	0.584	Topsoil	Blue
2	8193.46	0.871	Sand	Orange
3	844.54	4.360	Mixed sand	Light Green
4	270.19	8.720	Silt sand	Green
5	763.33	11.709	Mixed sand	Green
9	8135.91	14.192	Sandstone	Orange
10	12140.73	17.870	Shale Sandstone	Red
11	6624.24	54.728*	Water table	Yellow
12	3.18		Sand aquifer unit	Blue

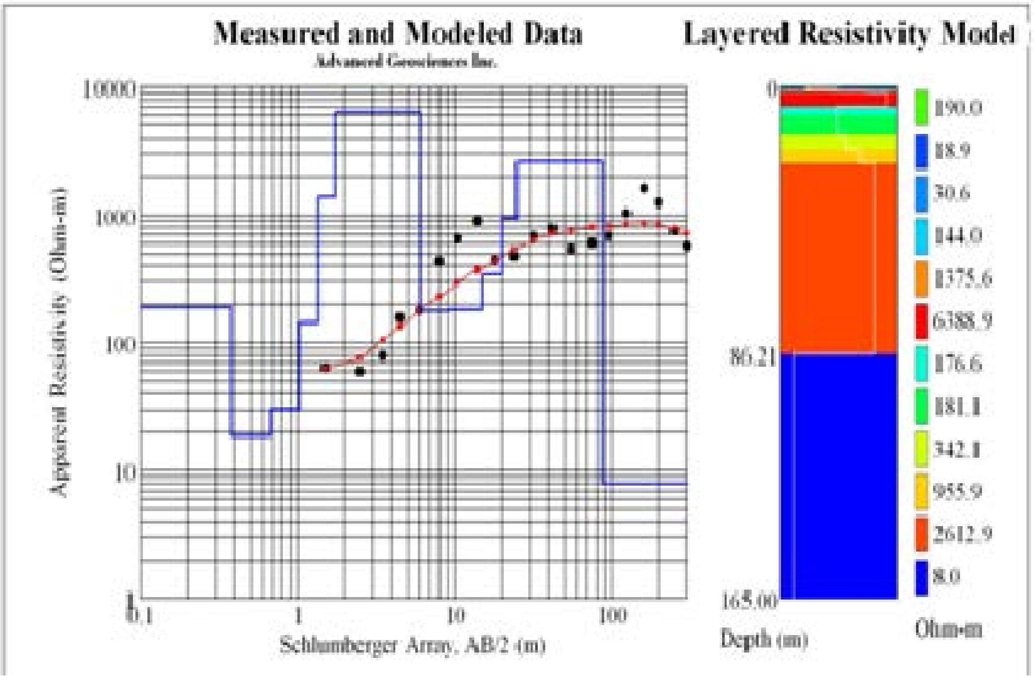


Fig. 7 model result for VES at Umuowa

TABLE 4: Analytical result presented by the AGI 1D Software and the Schlumberger Automatic analysis package reveals seven sub-layers at Umuowa.

Layer	Ohm-m	Bottom Depth (m)	Lithology
1	1375.65	1.728	Topsoil
2	6388.86	6.082	Sandstone
3	176.59	9.028	Sandy clay
4	181.08	14.805	Siltysand
5	342.09	20.117	Sandy-shale
6	955.86	24.776	Shale
7	2612.85	86.208	Siltstone Water Table
	8.03	SATURATED AQUIFER UNIT >165 M	

Table 5Summary of the modeled VES results for Orlu metropolis

VES NO.	VES Location	Latitude (Degree)	Longitude (Degree)	Elevation (Ft)	Water Table (m)	Resistivity of Aquifer (Ωm)	Aquifer Thickness (m)
1	Amaifeke 1	5.7984	7.0188	602	129.71	230.00	63.79
2.	Amaifeke 2	5.7925	7.0115	590	53.68	297.70	111.32
3.	Ezinachi	5.7625	7.0650	708	74.56	90.60	90.44
4.	IhitteOwerre	5.7812	7.0132	450	70.42	1.30	122.00
5.	Mgbee	5.8080	7.0599	221	64.73	3.20	100.27
6.	Okporo	5.8000	6.9843	543	68.65	746.20	54.97
7.	OkwuOkporo	5.7907	6.9913	547	87.07	12.80	109.43
8.	Umuna 1	5.7746	7.0616	574	112.42	788.00	52.58
9.	Umuna 2	5.7835	7.0541	606	64.25	900.00	10.70
10.	Amike	5.7773	7.0641	662	67.70	113.50	124.80
11.	ObibiOchasi	5.8146	6.9919	454	101.00	30.70	119.00
12.	Aji	5.7337	7.0045	575	98.59	124.10	93.91
13.	Umudioka	5.7479	7.0510	593	95.01	866.80	97.50
14.	Ihioma	5.7108	7.0979	423	66.10	1208.50	44.00
15.	Umuowa	5.7632	7.0293	568	86.20	8.00	79.00
16.	Watchman camp ground	5.8752	6.9911	535	101.00	308.00	91.46
17.	Ogberuru	5.8389	7.0230	565	95.00	9.70	97.50
18.	Umuezike	5.7576	0.7472	596	74.56	90.60	90.44
19	OwerreEbiri	5.7820	7.0308	600	84.21	760.10	908.29
20	Okohia	5.8833	7.0167	231	94.19	645.90	98.31

Table 6Summary of Aquifer characteristics for all the sounding stations in OrluMetropolis

VES NOs.	VES Location	Aquifer Resistivity (Ωm)	Depth to water table (m)	Acquifer thickness (m)	Electrical Conductivity σ ($\Omega^{-1}m^{-1}$)	Transverse Resistance R (Ω)	Longitudinal Conductance S (m Ω^{-1})	Hydraulic conductivity K (m/day)	Transmissivity (m^2/day)	K σ
1	Amaifeke1	230.00	129.7	63.79	0.0044	14671.70	0.2775	3.712	234.747	.0160
2.	Amaifeke 2	297.70	53.68	111.32	0.0034	33139.96	0.3740	2.127	236.950	0.0072
3.	Ezinachi	90.60	74.56	90.44	0.0110	8193.86	0.9985	2.618	236.802	0.0289
4.	IhitteOwerre	1.30	70.42	122.00	0.7692	158.60	93.8424	1.941	236.790	1.4930
5.	Mgbee	3.20	64.73	100.27	0.3125	320.86	31.3344	2.368	237.436	0.7400
6.	Okporo	746.20	68.65	54.97	0.0013	41018.61	0.0736	4.308	236.677	0.0056
7.	OkwuOkporo	12.80	87.07	109.43	0.0781	1400.70	8.5465	2.164	236.718	0.1690
8.	Umuna 1	788.00	112.42	52.58	0.0013	41433.04	0.0668	4.504	236.996	0.0057
9.	Umuna 2	900.00	64.25	10.70	0.0011	9630.00	0.0119	22.132	236.898	0.0246
10.	Amike	113.50	67.70	124.80	0.0088	164.80	1.0995	1.898	236.552	0.0167
11.	ObibiOchasi	30.70	101.00	119.00	0.0326	3653.30	3.8758	1.990	236.734	0.0648
12.	Aji	124.10	98.59	93.91	0.0081	11654.23	0.7567	2.522	236.581	0.0203
13.	Umudioka	866.80	95.01	97.50	0.0012	84513.00	0.1125	2.429	236.636	0.0028
14.	Ihioma	1208.50	66.10	44.00	0.0008	53174.00	0.3638	5.382	236.624	0.0045
15.	Umuowa	8.00	86.20	79.00	0.1250	632.00	9.8750	2.998	236.842	0.3748
16.	Watchman camp ground	308.00	101.00	91.46	0.0033	28169.68	0.2972	2.589	237.019	0.0084
17.	Ogberuru	9.70	95.00	97.50	0.1031	945.75	10.0513	2.429	236.816	0.2504
18.	Umuezike	90.60	74.56	90.44	0.0110	8193.86	0.9985	2.616	236.803	0.0289

19	OwerreEbiri	760.10	84.41	108.29	0.0013	82311.23	3.1425	2.187	237.056	0.0029
20	Okohia	645.90	94.19	98.31	0.0016	63498.43	0.1521	2.408	236.214	0.0037

The elevation map of the study area (Fig 7) shows areas with high and low elevation. Most of the VES locations such as Ezinachi, OwerreEbiri, Umuna2 lie on the topographic high with deep aquifers except Mgbee and Okohia which lie on the topographic low corresponding to the Orashi river valley. Deeper aquifer is observed in areas of high elevation. Research findings of Nwosu and Ndubueze(2017) recorded that topographichighareas will require high drill depth while topography lowareas will require low drill depth for groundwater development in an area with geological setting similar to that of the present study.

The aquifer depth values are characteristics of the geology of the study area. The aquifer depth contour map (Fig.8) reveals that areas around Amaifeke 2 have shallow aquifer with depth to water table of 53.6m and elevation of 590ft. Deeper aquifers are recorded in the North-central to North-western and southern part of the area.

The variation of the aquifer thickness within the study area is shown by the Isopach map (Fig.10). The highest value of 124.80m is recorded at Amike while the least value of 10.70m is recorded at Umuna2. Amaifeke2, Ihitteowerre, Amike, ObibiOchasi and OwerreEbiri having relatively high aquifer thickness than the others. These areas correspond to high groundwater potential areas. They are promising sites for standard water borehole of high yield expectation. The transverse resistance contour map (Fig.11) shows that Northern and some parts of the central and southern parts of the area are underlain by high resistance aquifer materials.

The contour map of the longitudinal conductance is shown in Figure 12. Itshowed that around Southern part of the study area, the aquifer longitudinal conductance values are low whereas the values are high in the Northern part of the study area around IhitteOwere, which are underlain by the Benin Formation. The Northern part of the study area and other zones of high values are probably underlain by thick layers of conducting sediments. These could either be fully saturated zones or areas with high percentage of conducting clays or both. The relatively low resistivity of the aquiferous zones could account for the higher values of longitudinal conductance in these areas.It has been observed that areas underlain by relatively resistive (low longitudinal conductance) aquifer materials may not be good prospects for drilling of boreholes with high yield expectations(Mbonu*et al.*,1991). On the other hand, areas underlain by thick and conductive aquifer materials are good prospects. Accordingly, areas around Amaifeke,Mgbee, OwerreEbiri, ObibiOchasi and greater part of the study area are good prospects for drilling water wells with high yield expectation.

The transmissivity contour map (Fig.14) shows that transmissivity values are fairly high and uniform implying that greater part of the area have similar geologic setting and are good prospects for groundwater development. The diagnostic conductivity product (Kσ) (Fig.13) divides the study area into zones based on Kσ values. The 1st zone covers the areas around the North Central underlying IhitteOwerre and the East Central part covering Mbgee while the remaining parts form the 2nd zone.

These zones correspond to area with similar geologic setting and similar water quality as the Kσ value remained fairly constant within these zones (Niwas andSinghal, 1981).

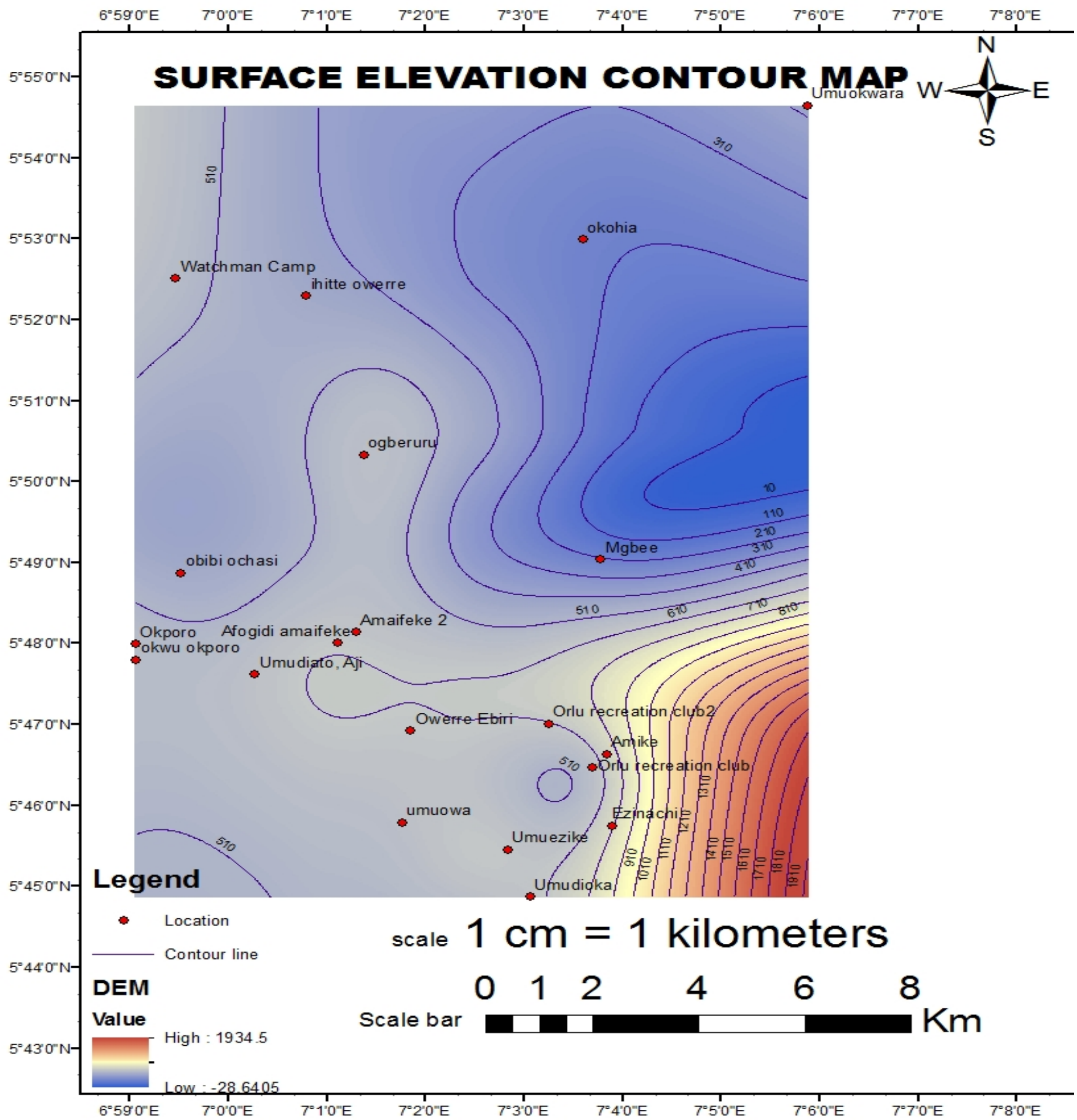


Fig .7. SURFACE ELEVATION CONTOUR MAP

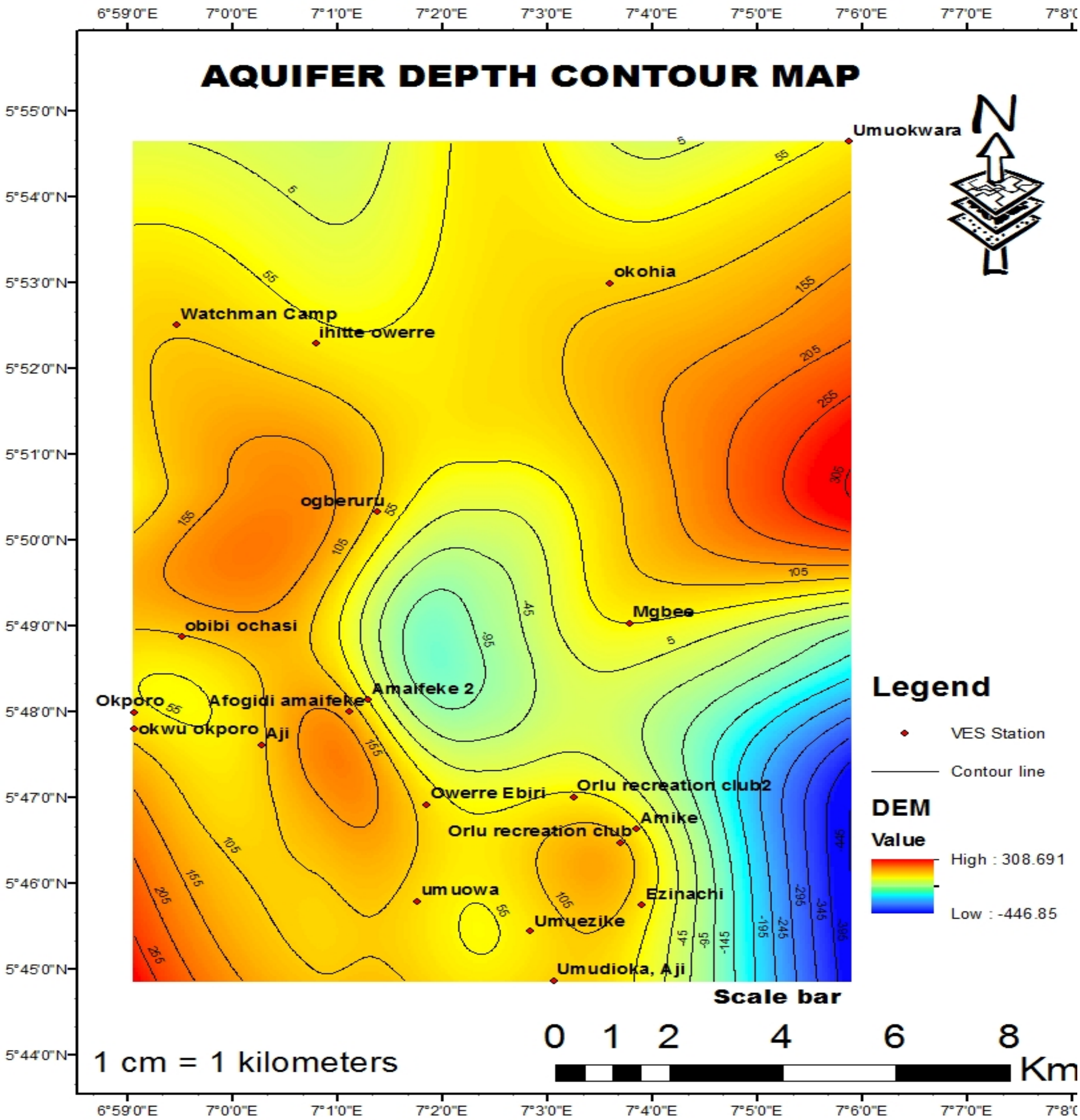


FIG. 8. AQUIFER DEPTH CONTOUR MAP

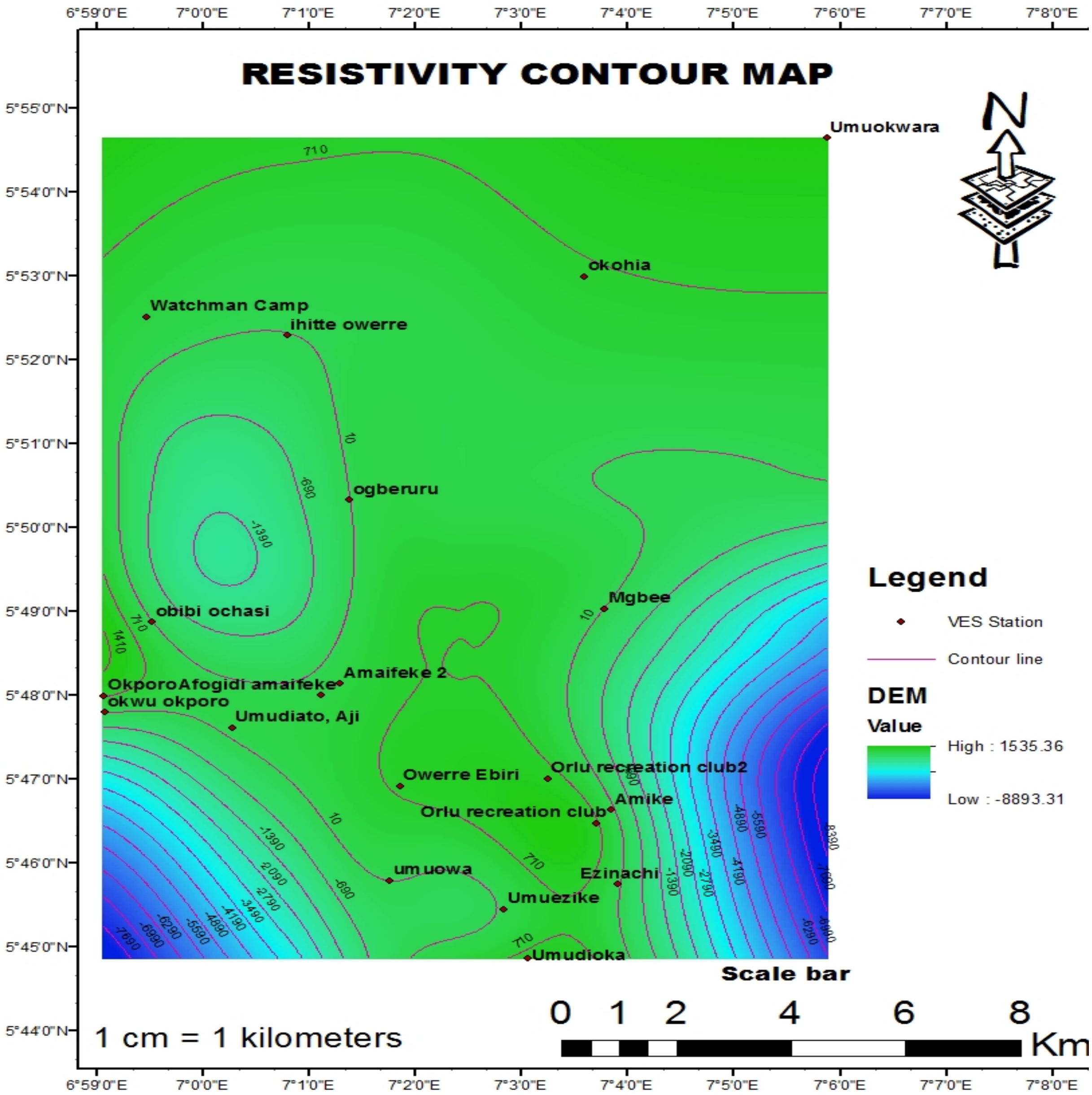


Fig. 9.RESISTIVITY CONTOUR MAP

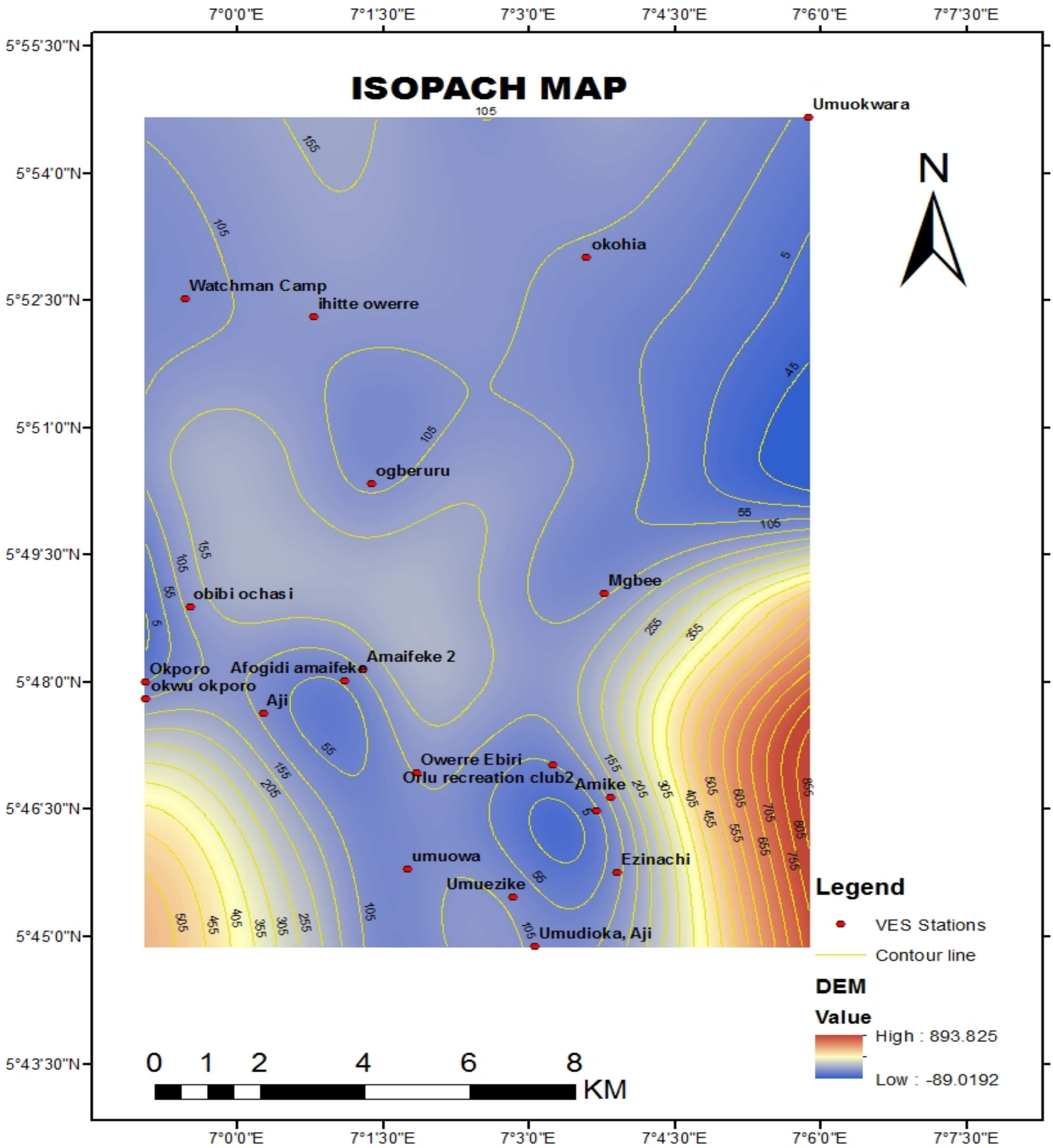


Fig. 10.ISOPACH MAP OF THE AQUIFEROUS ZONE.

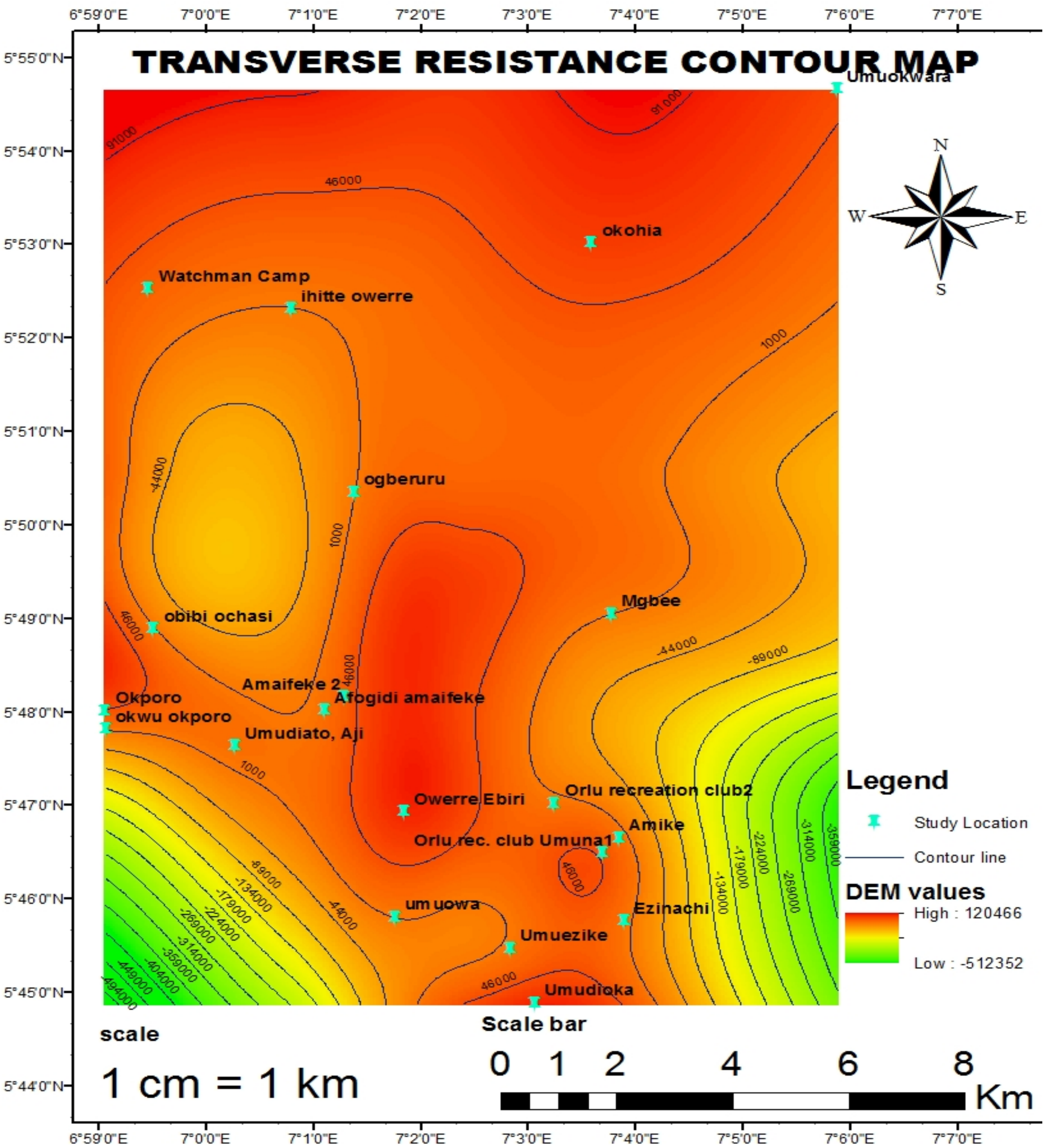


Fig. 11. TRANSVERSE RESISTANCE CONTOUR MAP

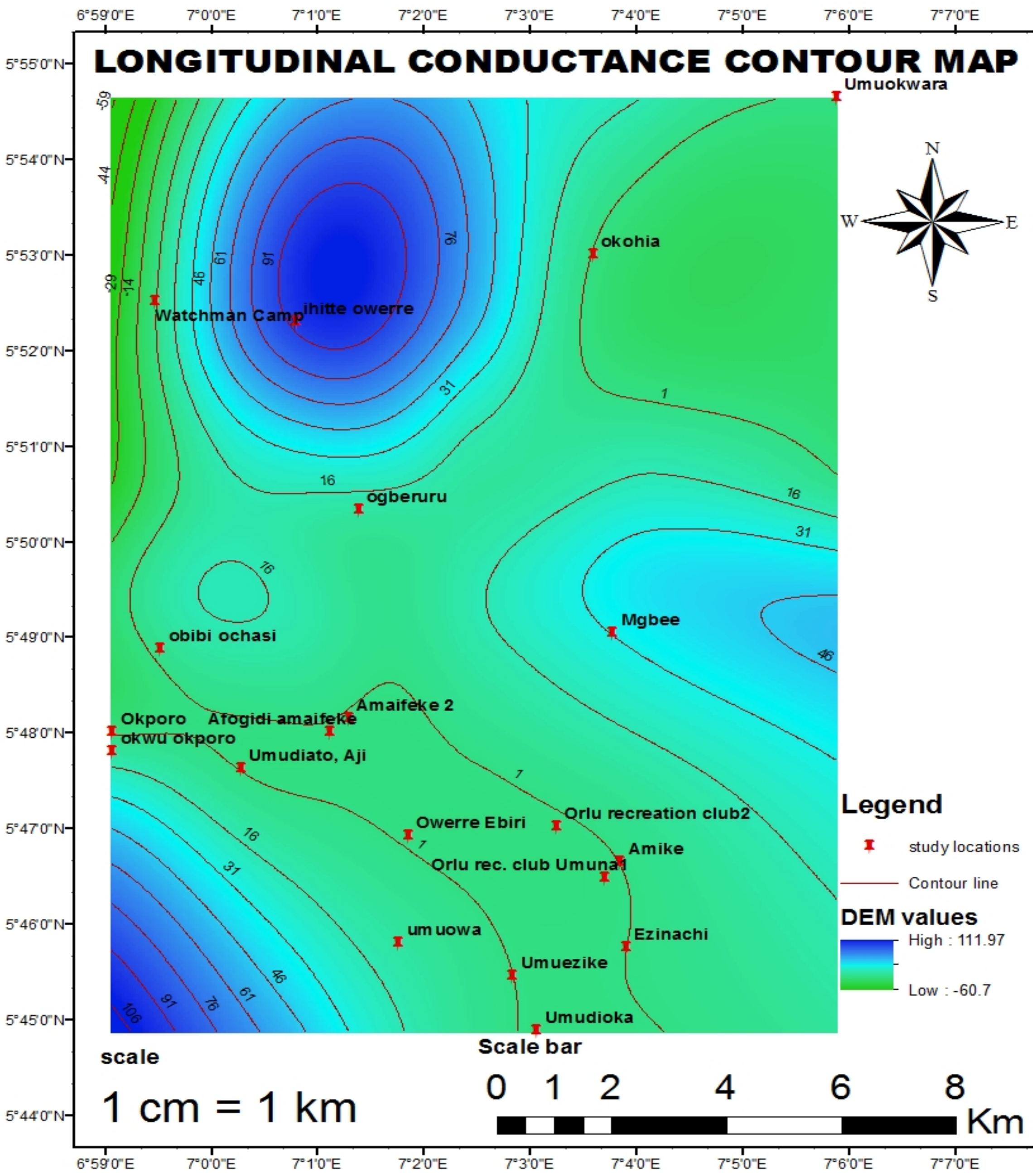
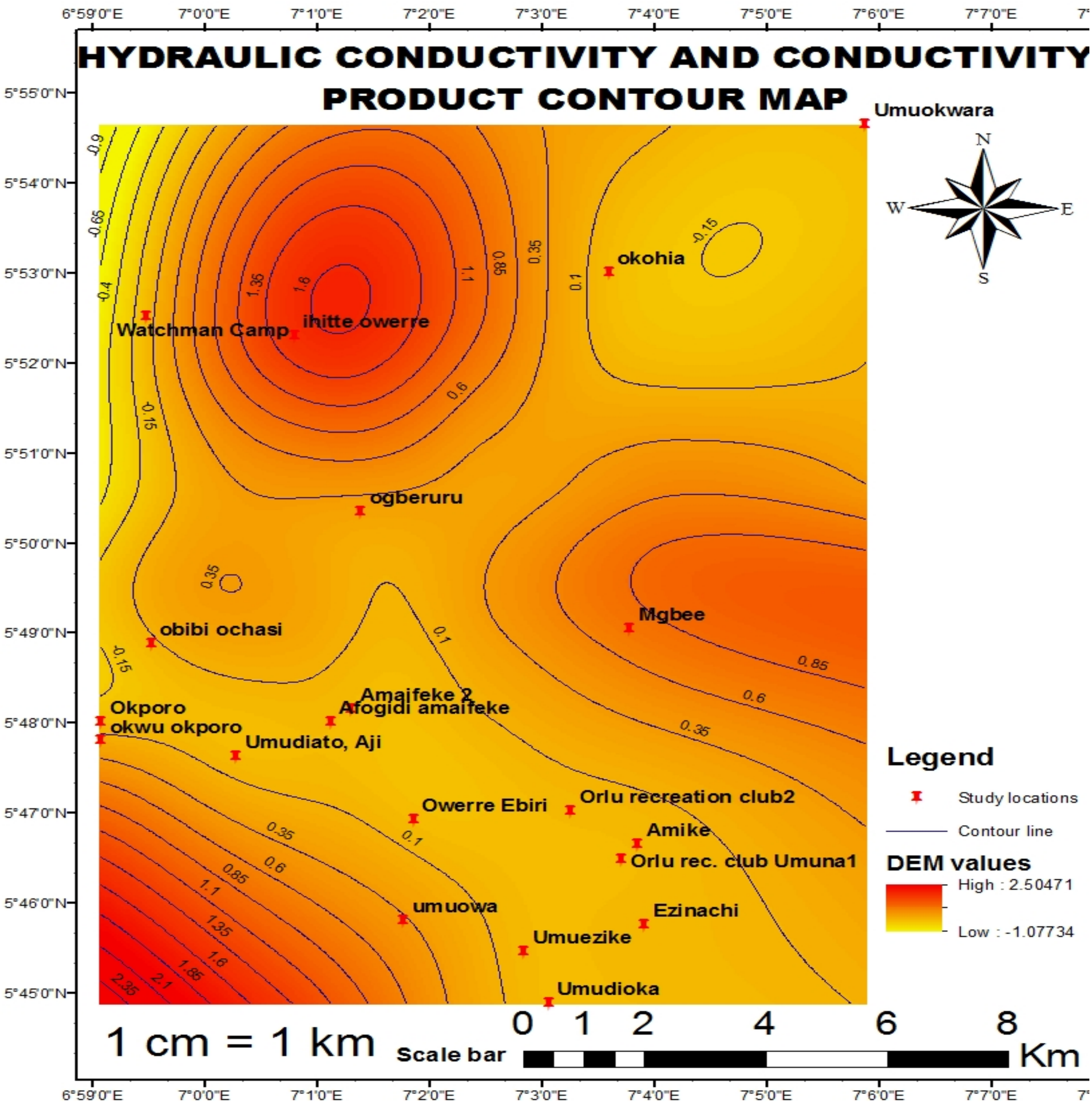


Fig. 12. LONGITUDINAL CONDUCTANCE CONTOUR MAP



Fig, 13. HYDRAULIC CONDUCTIVITY AND ELECTRICAL CONDUCTIVITY PRODUCT (Kσ) MAP

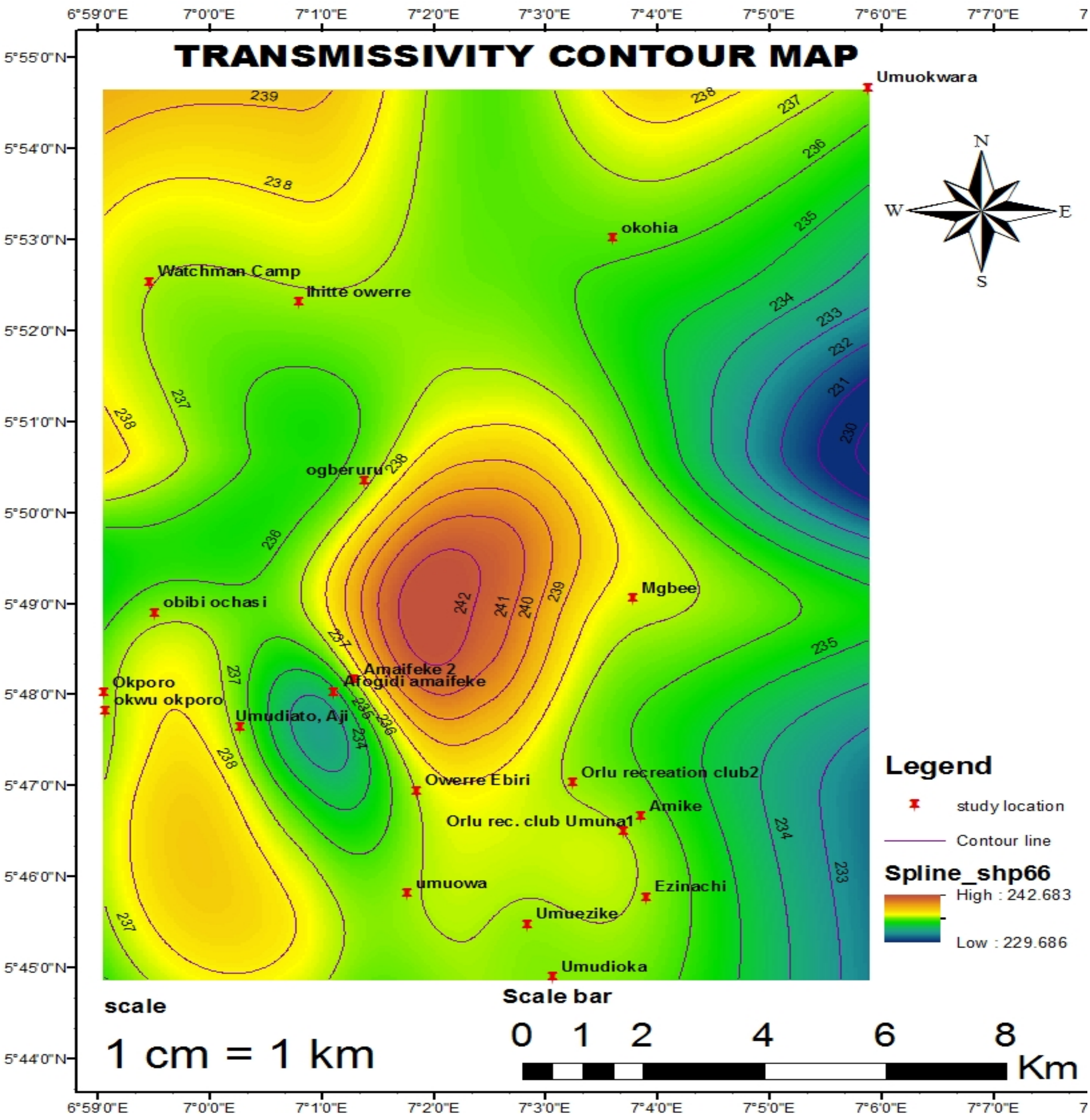


Fig. 14. TRANSMISSIVITY CONTOUR MAP

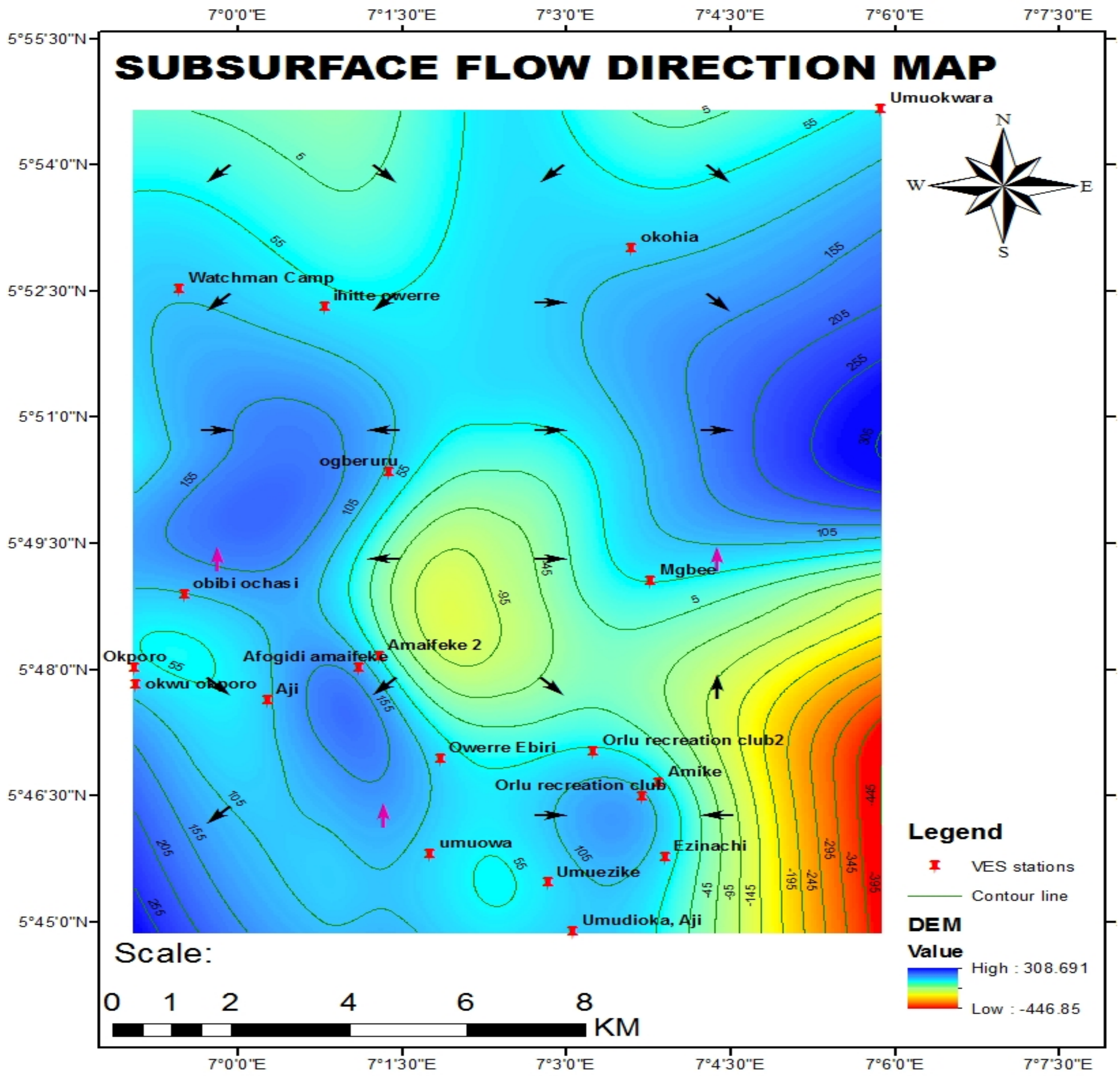


Fig .15. SUBSURFACE FLOW DIRECTION MAP

Figure 15 displays the groundwater flow pattern in the study area. Based on the direction of the stream lines, there arethree convergent centres in the study area which can be identified: The areas around Okohia, Watchman camp ground and IhitteOwerre.Areas around Amaifeke and areas covering Ezinachi, Amaike, and Orlu recreation club as well as Umudioka.

The central part of the study area and South Eastern part form the divergent or recharge zones. As groundwater flows from divergent zones to convergent zones these convergence centres are more promising for siting standard water wells for sustainable groundwater development.

CONCLUSION

Assessment of near surface hydrogeologic units has successfully been carried out for sustainable groundwater development in the study area. Groundwater flow pattern has been mapped out in Orlu metropolis resulting in delineation of convergent centre. Thesecentres are promising for siting standard water wells for sustainable groundwater development.The water table map has established the depth to aquifer in the study area. This has implications on proper planning and execution of both private and public water development projects.

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