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Archives of Applied Science Research, 2012, 4 (4):1609-1617
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ISSN 0975-508X
CODEN (USA) AASRC9

Surface Geophysics Character of Maastrichtian - Danian Sediments in parts of Udi - Ezeagu Area, Southern Anambra Basin, Nigeria

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ABSTRACT

Safe and sustainable development of groundwater resources is a key element of the Millennium Development Goals (MDGs). Pursuant to this, surface geophysics involving the Vertical Electrical Sounding (VES) technique was deployed to determine subsurface rock types and their thicknesses with the aim of delineating depths to potable groundwater in parts of Udi – Ezeagu area of Southeastern Nigeria. The terrain rises from as low as 61.0 meters in Mgbagbu-Owa to 457.0 meters in Abia as a dome-shaped hill with highly indented ridges and gullies. Underlying the study area are three conformable geologic formations namely the Lower Maastrichtian Mamu Formation, loose and cross-bedded Upper Maastrichtian Ajali Sandstone and the Danian Nsukka Formation. Geoelectric data indicate multiple layer curves which were interpreted as successions of lateritic topsoil, clay, shale, siltstone and sandstone which is consistent with the known lithologies of the three identified geologic formations in the area. An isopach map of overburden thickness to saturated horizons shows that the target aquifer, commonly the saturated Ajali Sandstone can be sufficiently accessed at depths of 180.0 meters around communities central to the cuesta and gets shallower from the slopes towards the plains where it is almost 85.0 meters yielding a symmetric profile indicative of a probable recharge around the cuesta and a radial drainage at the foothills giving rise to the Ajali and Nyaba rivers in the southwest and southeast axes respectively. It is expected that the results of this study will impact positively on the quest for sustainable development of water resources and form baseline data for the mitigation and management of some of the geotechnically-induced environmental challenges in the area.

Key words: Surface geophysics, geoelectric, groundwater, Mamu Formation, Ajali Sandstone, Nsukka Formation, Anambra Basin.

INTRODUCTION

Anambra Basin is one of the major inland sedimentary basins in Nigeria. It extends from Onitsha area in Anambra State of southeastern Nigeria to Lokoja area in Kogi State of north central Nigeria. The basin is located at the southwestern end of the Benue Trough and bounded on the eastern and southwestern flanks by the Abakaliki Anticlinorium and the Benin Hinge line respectively. It stretches for about 300 kilometers in a northeast – southwest direction and has width of 160 km at the southeast tip and 48km in the northeast extremes [1].

Located in the southern part of the Anambra Basin, the Udi – Ezeagu study area is defined by latitudes 6°17′ N and 6°27′ N and longitudes 7°23′ E and 7°26′ E. The dominant topographic features of the area are the ridges that form parts of the Nsukka-Udi-Okigwe Cuesta (Figure 1). The terrain rises from as low as 61.0 meters in Mgbagbu-Owa to 457.0 meters in Abia town as a dome shaped hill with many outliers, highly indented ridges and gullies [2]. With the growing concentration of industries in the area, it becomes pertinent to provide information on the lithology and groundwater potentials that would form part of the sustainable development of the emerging industrial nexus and safe management of the ever-increasing human population in the area.

Figure 1: Panoramic view of topography in the study area.

GEOLOGY OF THE AREA

The area is underlain by three conformable geologic formations namely the Lower Maastrichtian Mamu Formation, loose and friable Upper Maastrichtian Ajali Sandstone and the Danian Nsukka Formation. Figure 2 is the geologic map of southeastern Nigeria showing the formations in the study area.

The Mamu Formation is characterized by a distinctive assemblage of sandstone, shale, mudstones and sandy shale with coal seam at various horizons [3, 4, 5]. The sandstone is fine to medium-grained with white or yellowish colour while the shales and mudstones are dark blue or grey. The shale and mudstone frequently alternate with thin bands and lenses of sandstone to form a characteristic striped succession. Overlying Mamu Formation is the cross-bedded Ajali Sandstone which consists of thick, friable, poorly sorted sandstone typically white in colour but sometimes iron-stained [6]. The sand grains and larger fragments are sub-angular in shape with a sparse cement of white clay. Saturated horizons of the Ajali Sandstone constitute the most-sought-after aquifer in the area [7]. Ajali Sandstone is often overlain by a considerable mass of red earth formed by weathering and ferruginisation. Nsukka Formation lies conformably on the Ajali Sandstone and is marked by the deposition of alternating succession of sandstone, dark shale with thin coal seams and ironstone bands at various horizons [4, 8]. The formation represents a phase of fluvio-deltaic sedimentation that began close to the end of the Maastrichtian and continued during Danian and Paleocene ages [9]. The foregoing discussion on the geology of the area provides insight to the fact that the rock types and their distribution is such that could form both confined and unconfined aquifers depending on the configuration of the lithotypes.

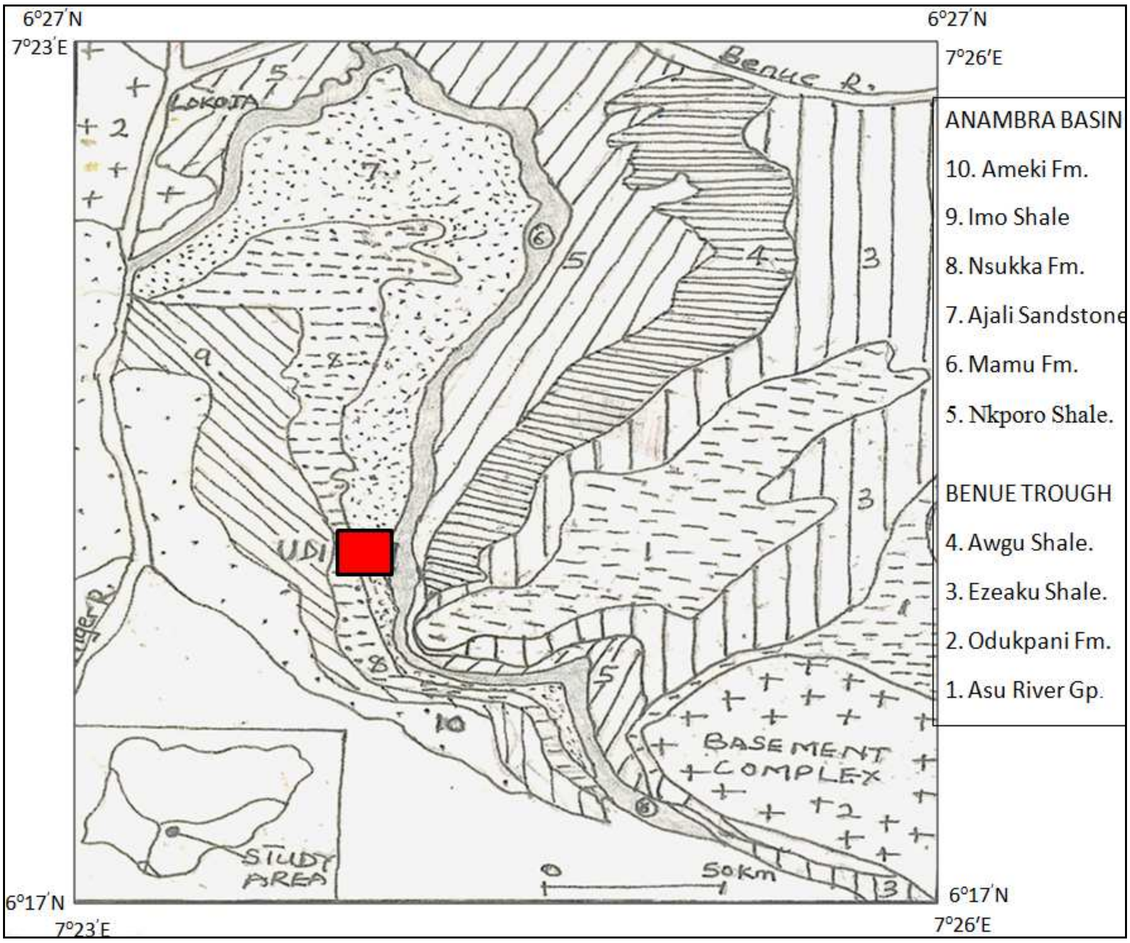

Figure 2: Section geologic map of Nigeria showing the study area. (Source: Reyment, 1965)

METHODOLOGY

The study adopted combined geological and geophysical methods incorporating a reconnaissance survey during which a panoramic view of the topographic elements and geologic outcrops was taken. The geologic mapping involved detailed lithologic description of outcrops as well as surface water bodies. The area is drained mainly by the Ajali and Nyaba rivers together with their tributaries and distributaries. The outcrop data served as stratigraphic control in the course of the interpretation. The geophysical approach involved the Vertical Electrical Sounding (VES) technique which is popular for studies of this nature [10, 11, 13, 14]. The technique determines the apparent and true resistivities of the various geologic units as well as their thicknesses. Resistivity soundings covering thirteen (13) localities were conducted using the ABEM SAS 300 Terrameter on a Schlumberger electrode configuration with potential electrodes progressively spaced from 0.5m to 15m and maximum half-current electrode array (AB/2) that ranged from 300 m to 500 m depending on ease of measurements and desired depth of probe. The current electrode traverses were made to proceed along routes of minimal interference and best access such as foot paths and earth roads as identified during the reconnaissance operation keeping in mind the need to maintain a spacing ratio of at least 1:5 between the current electrodes and the potentials. The field data were keyed into the computer and plotted with RES-I and OFFIX software. The curves (figs. 3 to 5) generated were processed into geoelectric layers (Table 1) giving the true resistivities and thicknesses of the vertically varying strata. Data from the various geoelectric sections were further evaluated to produce the isopach map of overburden thickness to saturated zones (Fig. 6) and the geoelectric water table map (Fig.7) in the area.

DATA INTERPRETATION

Interpretation of VES data typically proceeds with qualitative matching of apparent resistivity variations with thicknesses of probable geoelectric layers identified on the sounding curves. This first pass gives valuable ideas on the layer successions and continuity of individual layers. However, uncertainties associated with this approach calls for more iteration. Computer interpretation of geoelectrically stratified layers of different resistivities is generally not meaningful without some reliable stratigraphic control [15, 16, 11]. This is particularly true as regards deeper layers which are more affected by equivalence and suppression. Hence, an integration of the lithologies described on the outcrops with the geoelectric sections formed a reliable check for the study.

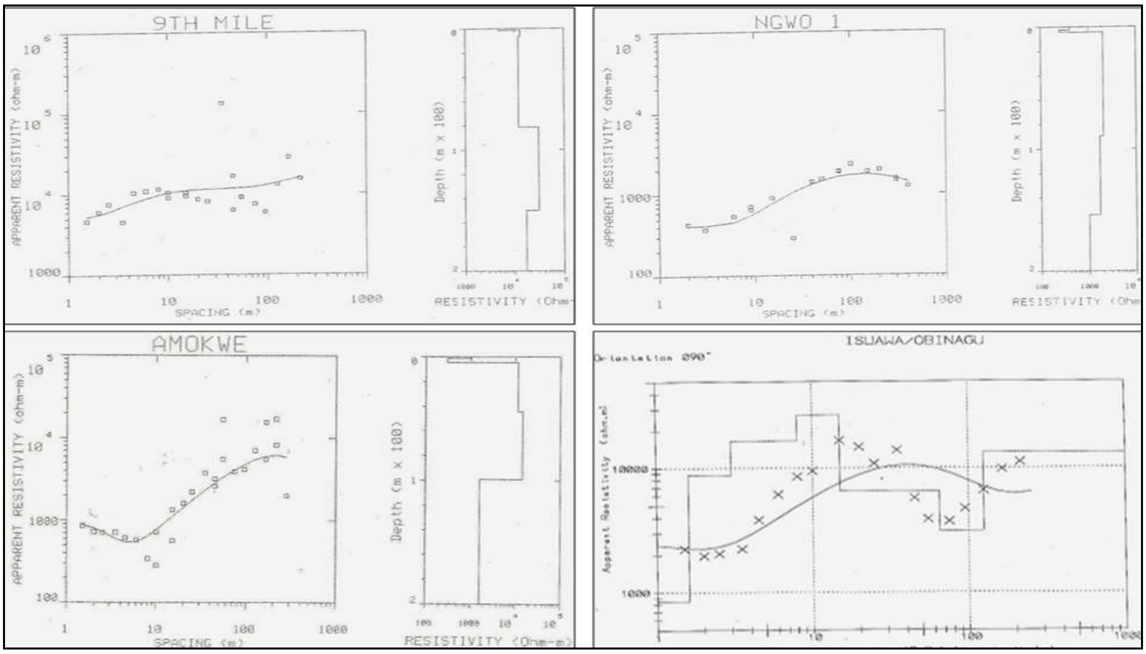

Figure 3: Resistivity sounding curves in Ngwo and Udi area

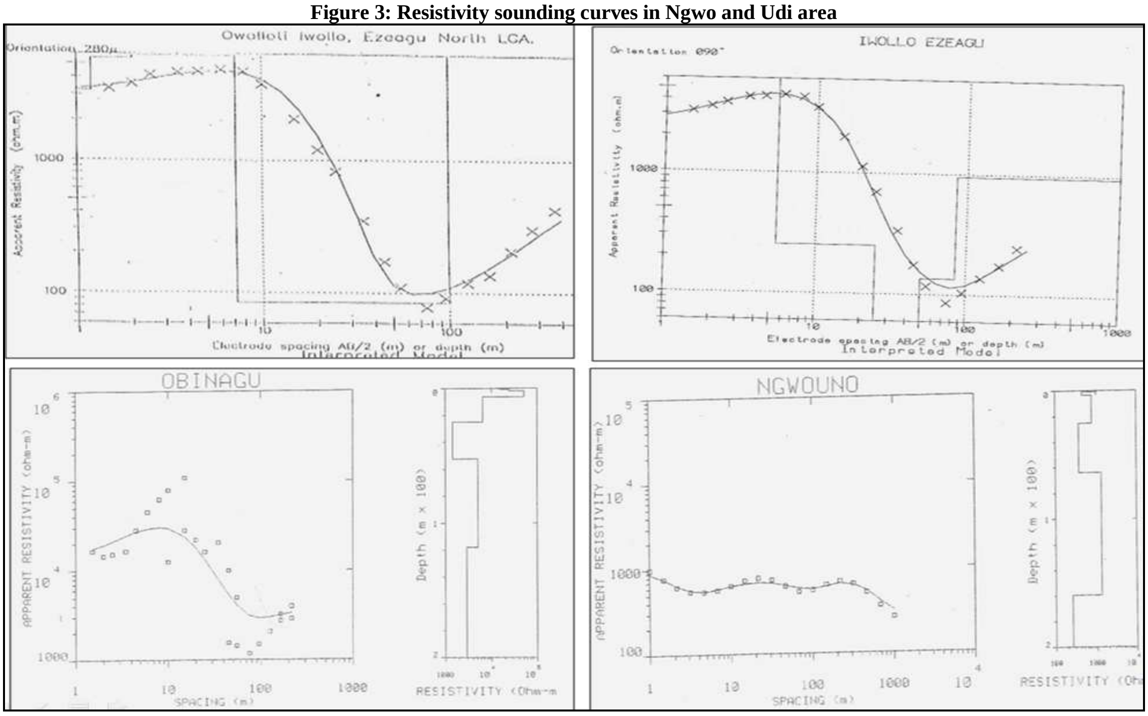

Figure 4: Resistivity sounding curves in Ezeagu, Obinagu and Ngwo.

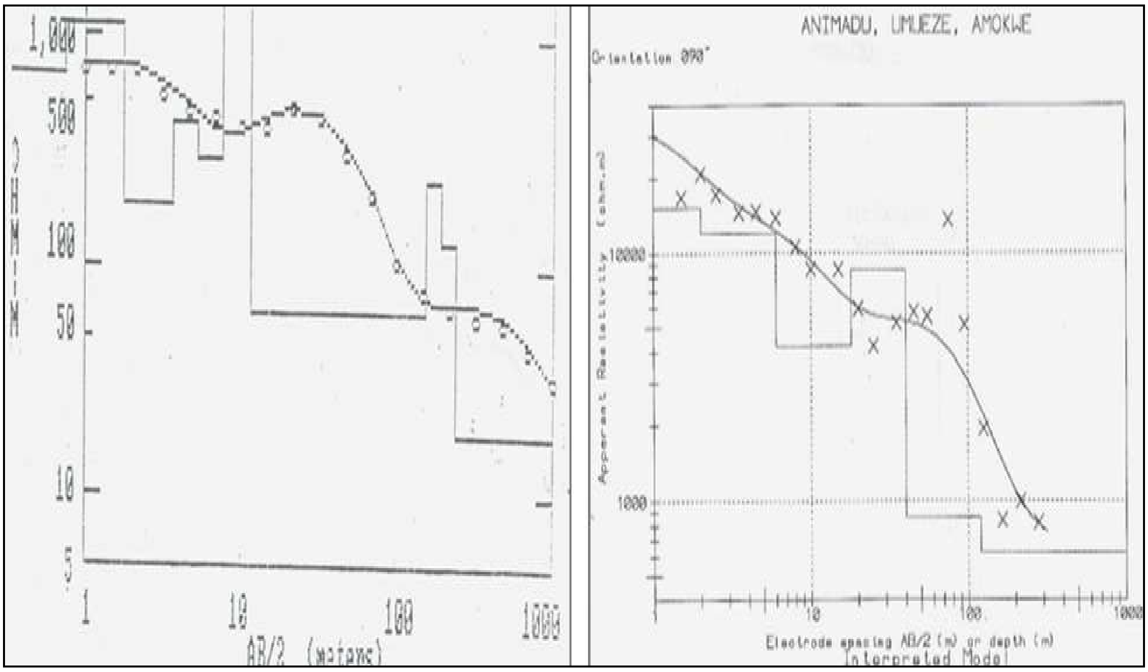

Figure 5: Resistivity sounding curves in Nsude and Amokwe

Table 1: Summary of Geoelectric model at the sounding stations

Location	Layer thickness (m x10)								Layer resistivity (Ωm x 1000)							
	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8
9th Mile	0.1	0.2	0.8	0.7	-	-	-	-	4.8	12.9	11.6	30.0	16.7	-	-	
Ameke I	0.3	0.2	8.5	6.4	-	-	-	-	0.42	0.25	2.0	1.7	1.0	-	-	
Ngwo	0.1	0.3	2.2	3.9	9.6	-	-	-	1.0	0.45	0.77	0.37	1.3	0.25	-	
Iwollo	0.1	0.1	0.4	2.0	2.5	3.5	-	-	2.6	6.9	6.0	0.25	0.05	0.14	0.95	
Owolloti	0.1	0.1	0.5	9.3	-	-	-	-	3.2	5.5	5.8	0.09	1.0	-	-	
Nsude	0.1	0.1	0.2	0.2	0.2	0.4	14.0	-	0.67	1.08	0.19	0.42	0.29	2.6	0.06	0.2
Obinofia	0.05	0.95	2.0	10.0	-	-	-	-	0.5	12	3.5	12	8	-	-	-
Ezeagu	0.12	0.13	0.25	0.5	2	2	8.5	-	1.04	15.2	17.5	9.5	4.3	0.65	2.3	1.02
Amokwe	0.14	0.34	3.97	5.47	-	-	-	-	0.96	0.3	11.6	14.8	1.6	-	-	-
Animadu	0.07	0.13	0.4	1.2	2.2	8.0	-	-	35.1	16.2	12	4.2	8.5	0.86	0.62	-
Obinagu	0.09	0.19	0.45	1.88	2.72	6.58	-	-	1.45	23.6	51.7	6.5	1.45	5.1	2.96	-
Isuawa	0.1	0.06	0.14	0.5	0.7	5	6	-	2.51	0.85	8.76	16.6	26.9	6.52	0.31	1.33
Agbudu	0.1	0.4	1.0	4.5	4.5	7.5	-	-	1.45	2.5	3.2	8.0	25	20	2	-

RESULTS AND DISCUSSION

Geoelectric interpretation: Across the localities studied, the VES data are characterized by varying resistivities of low to high magnitudes probably reflecting the subsisting lithology and degree of water saturation. The largest resistivity values from topsoil to substratum were noted in 9th Mile Corner. The progressively decreasing nature of the curves in Nsude and Amokwe could be attributed to presence of a dry highly resistive topsoil or sandstone underlain by more conductive materials. Saturated sands of various grain sizes and textures often could result in a more resistive substratum as seen variously across the area. Five to eight geoelectric layers were deduced from the interpreted curves with largely not-too-dissimilar features. Each bed is definable over some boundary thickness with single resistivity value. These include lateritic topsoil, clay, shale, siltstone, sandstone and some of their gradational heteroliths. Five layers were obtained at Ngwo I, 9th Mile corner, Owolotti Iwollo, Obinofia Ndiuno and Amokwe while Nsude, Nkwo-Ezeagu and Isuawa Obinagu had eight geoelectric units. Seven units were recognized at Iwollo Ezeagu, Animadu Amokwe, Obinagu and Agbudu while only Ngwo Uno displayed six. Main features of the composite geoelectric layers are described as follows:

Layer 1: The resistivity of the topmost units of the geoelectric sections ranges from 416.4 ohm-meters at Ameke Ngwo to 35124 ohm-meters at Animadu Amokwe, giving an average topsoil resistivity of 5323.77 ohm-m. This weathered lateritic topsoil has thickness values in the range of 0.5m at Obinofia Ndiuno to 2.58m at Ameke Ngwo. The anomalously high resistivity of the topsoil at Ameke Ngwo may be due to the presence of dry ferruginised sandstones and discrete gravels.

Layer 2: Typical of a varying succession of sands and clays/shales, this layer is of two varieties in the area. It occurs as highly conductive in Ameke, Ngwo, Amokwe and Isuawa with values in the range of 50 Ωm to 368.5 Ωm and maximum thickness of 3.4 m at Amokwe. The relatively low resistivity values may be indicative of fine grained sediments or predominance of matrix materials and was interpreted as clay. Elsewhere in the study area it is a layer of relatively high resistivity and interpreted as dry sandstone.

Layer 3: Lowest resistivity value of 190 Ωm was recorded for this layer at Nsude indicating fine grained sediments or matrix materials and was interpreted as clay / shale in Nsude; siltstone at Ngwo and Isuawa then clayey sandstone at Obinofia. Apart from these four areas, the other locations read this as sandstone. This is consistent with the outcrop study that depicts lateral changes in lithology from clay to clayey sandstone and sandstones.

Layer 4: The lateral lithologic change is still prevalent with minimum resistivity values being measured only at Owolloti and Ngwo and interpreted as clay / shale. At Iwollo, Nsude and Amokwe, this is interpreted as siltstone and clayey sandstone / fine sandstone respectively. Elsewhere in the study area, this layer is generally made of medium to coarse sandstone with a maximum thickness of 100 m at Obinofia and occurs as water saturated fine-grained sandstone at Ameke Ngwo.

Layer 5: This moderate to high resistivity layer mainly consists of sandstones and more often saturated with water in places like 9th Mile Corner, Ameke Ngwo, Owolloti, Obinofia and Amokwe with its maximum thickness being reached at Ngwo. It however occurs as a low resistivity layer interpreted as clay at Iwollo, sandy clay at Nsude and clayey sandstone at Nkwo Ezeagu. Observed wide variation in resistivity values of the saturated intervals may be due to concentration levels of conductive substances.

Layer 6: This is recorded only at eight sounding locations. Minimum resistivity value of 140 Ωm for this layer comes from Iwollo where it occurs as shale followed by the siltstones at Nkwo Ezeagu. Maximum thickness for this layer is 80 m in Animadu Amokwe where it occurs as water saturated sandstone with a corresponding resistivity of 860 Ωm and thinnest at Nsude where it measures 4 m with a resistivity of 2600 Ωm.

Layer 7: The current electrode spread only allowed the base of this stratum to be accessed at just three locations. The layer is characterized by resistivity values that range as low as 90 Ωm in Nsude to 2960 Ωm in Obinagu with a maximum thickness of 85 m at Ezeagu. It occurs as wet clay aquitard in Nsude and Isuawa, shaly sandstone at Iwollo and saturated sandstone at Animadu Amokwe, Obinagu and Agbudu.

Layer 8: The resistivity values of this layer range from 200 Ωm to 1330 Ωm, the thicknesses however could not be achieved. It occurs as a sandy aquiclude in Isuawa and as water saturated sandstone in Nkwo Ezeagu and Nsude. The exceptionally low value of 200 Ωm at Nsude may be due to the presence of clay or high concentration of constituent conductive materials.

Table 2: Computed geoelectric depth to saturated horizons in the area

VES No.	Location	Spot height (m)	Overburden thickness to saturated layers (m)	M.S.L elevation (m)
1	Ninth Mile Corner	368.1	150	218.1
2	Ameke Ngwo	365.85	153	212.85
3	Ngwo-Uno	381.1	159	222.1
4	Iwollo-Ezeagu	228.66	85	143.66
5	Owolloti-Iwollo	243.9	100	143.9
6	Nsude	518.29	150	368.29
7	Ndiuno-Obinofia	182.93	135	47.93
8	Nkwo-Ezeagu	182.93	85	97.93
9	Amokwe	314.02	100	214.02
10	Animadu-Amokwe	320.12	120	200.12
11	Obinagu	411.59	125	286.59
12	Isuawa-Obinagu	228.66	118	110.66
13	Agbudu	426.83	180	246.83

As a recap, it could be noted that the resistivity values for the shales and clays in the area vary between 50 Ωm and 368.5 Ωm. On the other hand, higher resistivity readings were generated for dry sandstones and aquiferous sands with an average value of 9044.7 Ωm and 5222.23 Ωm respectively. The observed higher values reflect the coarse-grained nature of the sandstones with the attendant high porosities typical of Ajali Sandstone. The depth to saturated horizons as shown in table 2 varies between 85 m to 180 m.

In order to visualize the lateral variations in required drill-depths to the target aquifers commonly the saturated Ajali Sandstone, the various geoelectric sections were integrated into geoelectric profiles. These profiles were used to generate composite data on lateral variations in hydraulic head and flow direction and finally presented as the isopach map of overburden thickness (Fig. 6) to the saturated horizons.

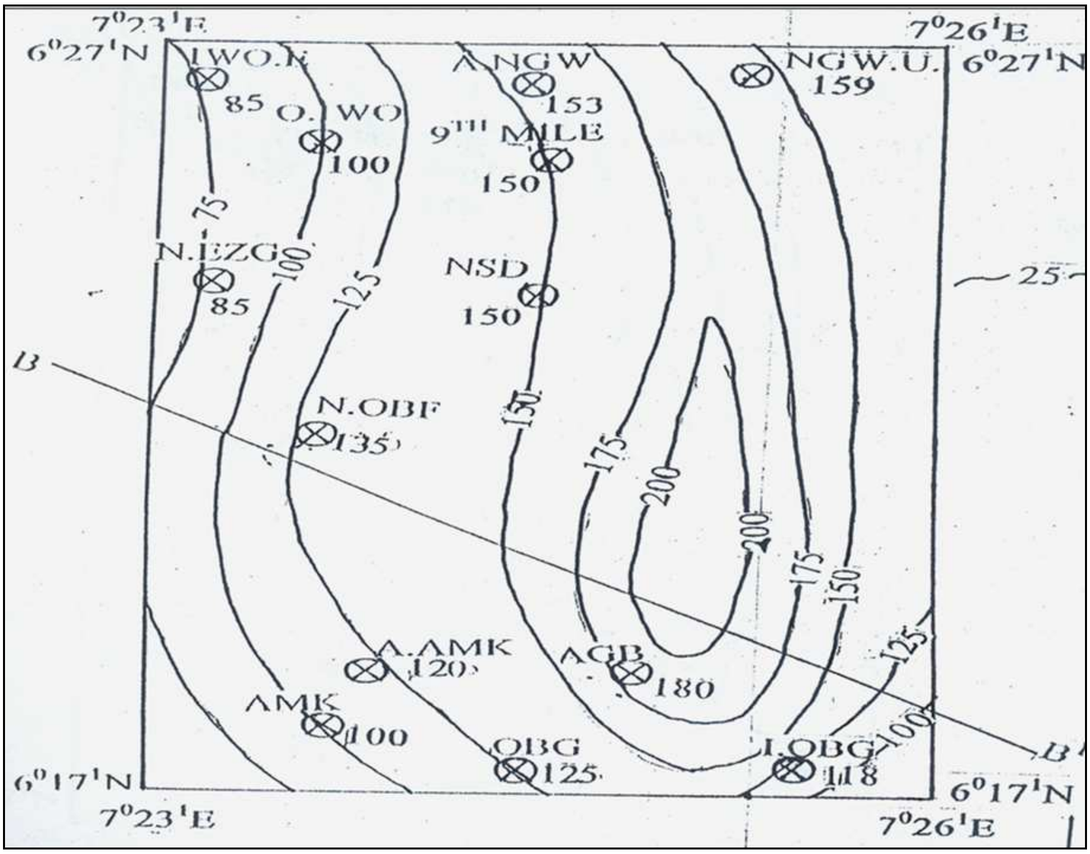

Figure 6: Isopach map of overburden-down-to water table in the area. Note that the overburden is thickest in areas central to the cuesta.

The map shows the greatest depths (180m) to be at the base of the cuesta decreasing to as low as 85m and 118m in the northwest and southeast directions respectively. The water table map (Fig. 7) indicates a northwest and southeast groundwater flow directions corresponding to the two major water divides of Ajali and Nyaba rivers respectively. The profile is symmetric with a median peak at the central portions of the cuesta and lowest at the two river plains. This suggests the central portions of the cuesta as the zones of recharge while the discharge is at the foothills towards the river plains. This further explains the observed radially-dendritic drainage pattern in the study area.

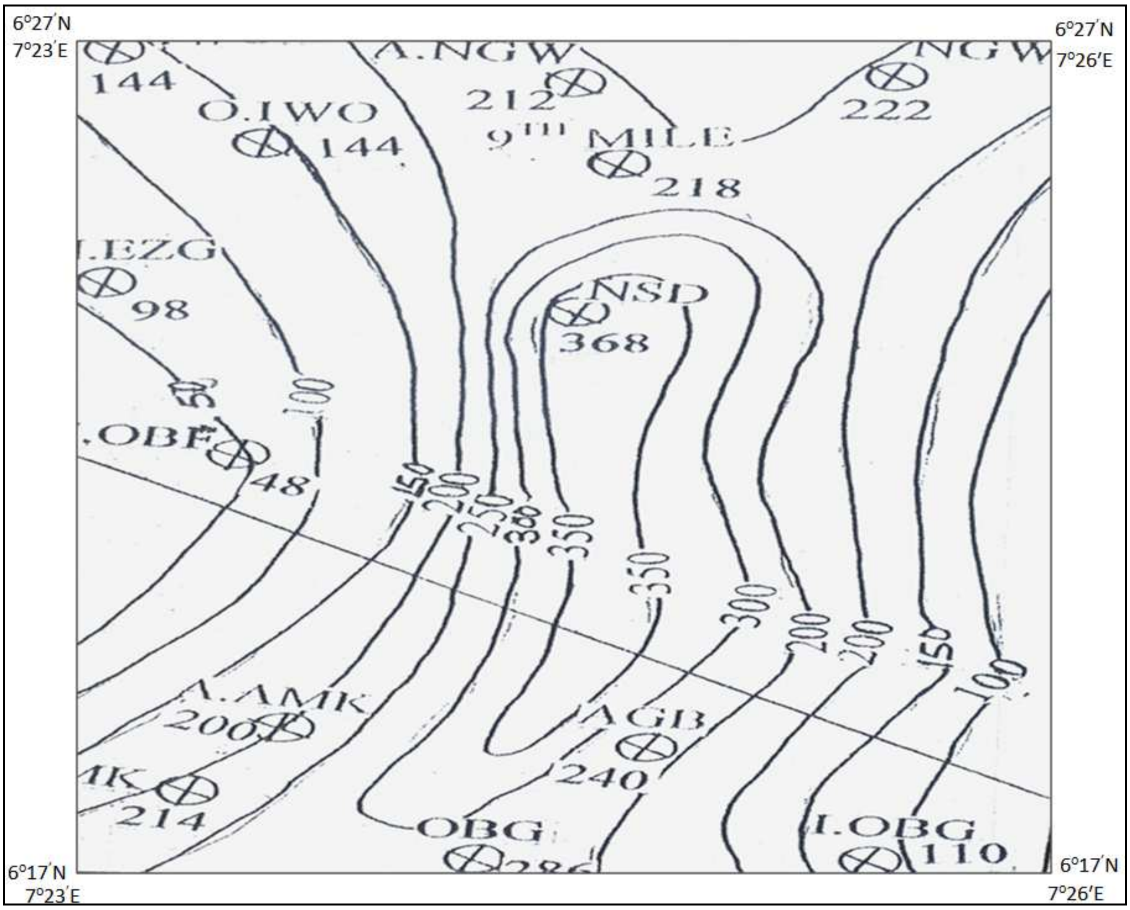

Figure 7: Water table map for the study area as established from the interpreted VES data.

CONCLUSION

The study shows that Udi-Ezeagu area is underlain by three geologic formations namely the Mamu Formation, Ajali Sandstone and Nsukka Formation. The vertical variations in electrical resistivity were captured as multiple layer curves. These yielded between five to eight geoelectric units. The inferred lithologies from the geoelectric sections include lateritic top soil, clay, shale, siltstone, sandstone and their respective gradational heteroliths. The geoelectric depth to the prolific aquifer ranges from as low as 85m at the marginal plains to 180m at the central areas of the cuesta. The symmetric groundwater profile suggests a central recharge with a radial-dendritic drainage pattern. It is expected that these findings will impact positively on the sustainable development of water resources in the area and form baseline data for further researches that will aid the control and management of some of the geotechnically related environmental problems bedeviling the area.

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