GROUNDWATER POTENTIAL ZONE IDENTIFICATION USING GEOELECTRICAL SURVEY: A CASE STUDY OF GBONGAN, OSUN STATE, SOUTHWESTERN NIGERIA

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ABSTRACT

Hydrogeophysical study involving the use of Vertical Electrical Sounding (VES) technique was carried out in Ode-Omu palace area in Gbongan, Osun State with the aim of assessing the subsurface geology and groundwater potential zones. A total of twenty-seven (27) VES points were occupied across the study area using Schlumberger electrode configuration, with half electrode separation (AB/2) varying from 1 to 100 m. The depth to subsurface layers, their thicknesses, geologic structures and aquifer characteristics were determined with the electrical resistivity method. Three to five lithologic units were identified in the study from the quantitative interpretation of the VES data using curve matching with Orellana-Mooney master curves and modeling with WinResist 1.0^{TM} software. These include: topsoil (30-1992 $\Omega-\mathrm{m}$), clayey sand (23-60 $\Omega-\mathrm{m}$)/laterite(213-401 $\Omega-\mathrm{m}$), weathered Basement(15-164 $\Omega-\mathrm{m}$), fractured Basement(7-121 $\Omega-\mathrm{m}$) and fresh bedrock (415-13054 $\Omega-\mathrm{m}$) which are predominantly of the 'H' curve type (48.1%), followed by 'HA' type (14.8%), other curve types include: 'HKH' (7.4%), 'QH' (7.4%), 'KH' (7.4%), 'AKH' (3.7%), 'AK' (3.7%), 'AA' (3.7%) and HAA (3.7%). The weathered, partly weathered and the fractured Basement constitute the main aquifer units. The aquifers are of generally low resistivity values vis-à-vis below 100 Ω-m. The depths to fresh bedrock at the chosen VES locations vary from 2.8 to 23.4 m with a mean value of 8.81 m in the study area. The geoelectrical interpretation results have permitted the delineation of the study area into shallow north and moderately thick west, southwest, south and southeastern regions in terms of overburden thickness while the resistivity over the study area is generally low and might favour groundwater prospectivity (provided the low resistivity values are not caused by clay content). This study is expected to assist in future planning of groundwater resources.

Keywords: Basement complex, hydrogeophysical, lithology, vertical electrical sounding, weathered and fractured.

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INTRODUCTION

Groundwater has been proven to be free of contaminants, except in few places where they are contaminated due to the presence of elements such as arsenic and other heavy metals or by other sources of compromise such as leachate seeping into the aquifer [1]. The need for adequate, good-quality water has increased extensively due to awareness and technology. Thus, many people rely on the exploration and exploitation of groundwater [2]. Naturally, groundwater is being replenished by rain which infiltrates the soil or through secondary pores of the subsurface rocks [3].

The Vertical Electrical Sounding (VES) technique of electrical resistivity method is used mainly in the study of horizontal or near- horizontal interfaces. The current and potential electrodes are maintained at the same relative spacing and the whole spread is progressively expanded about a fixed point. Consequently, readings are taken as the current reaches progressively greater depths. The technique is extensively used in geotechnical surveys to determine overburden thickness while in hydrogeology, it is used to define horizontal zones of porous strata [4]. Generally, materials that lack pore spaces will show high resistivity. Materials whose pore spaces lack water will show high resistivity (e.g. dry sand or gravel). Materials whose water content is clean will show high resistivity (e.g. clean gravel or sand) even if saturated with water. Weathered rocks and clay will show medium to low resistivity. Frozen ground will show much higher resistivity than unfrozen ground [5].

Ode-Omu Palace area in Gbongan, Ayedaade Local Government Area (L.G.A.), Osun State is a fast-growing community in terms of population and business activities. Due to its enormous increasing population, the demand for potable and steady water supply is eminent. The most realistic source of groundwater in the area had been a few boreholes which could not meet the need of the residents. This work reports details of geoelectrical investigation for groundwater prospecting zones at the study area.

MATERIALS AND METHODS

Location, geomorphology and physiography

The study area is located at Ode-Omu Palace area, Gbongan, Ayedaade L.G.A., Osun state. It is situated within Latitude 7.465°N to 7.490°N and Longitude 4.330°E to 4.375°E, with area of approximately 13.12 km^2 (Figure 1). 'The climate is subequatorial with two peaks of rainfall (July and September), mean annual rainfall of about 1,300 mm, relative humidity of about 70% and an average annual temperature of about 20°C' [6].

Geology and hydrogeology.
The area lies in the Precambrian Crystalline Basement Complex of Southwestern Nigeria, which consists of a wide variety of metamorphic and igneous rocks and has been shown to be polycyclic, with isotropic ages ranging from 2800 Ma to 4500 Ma [7, 8, 9]. On a local scale, the study area is underlain by migmatite and pegmatised schists which are juxtaposed and trend in the north-south direction (Figure 2).

Rocks of the Basement Complex, when not weathered are practically impermeable and have no storage capacity. However, appreciable porosity and permeability might have been developed in the rocks through fracturing and weathering processes [10, 11].

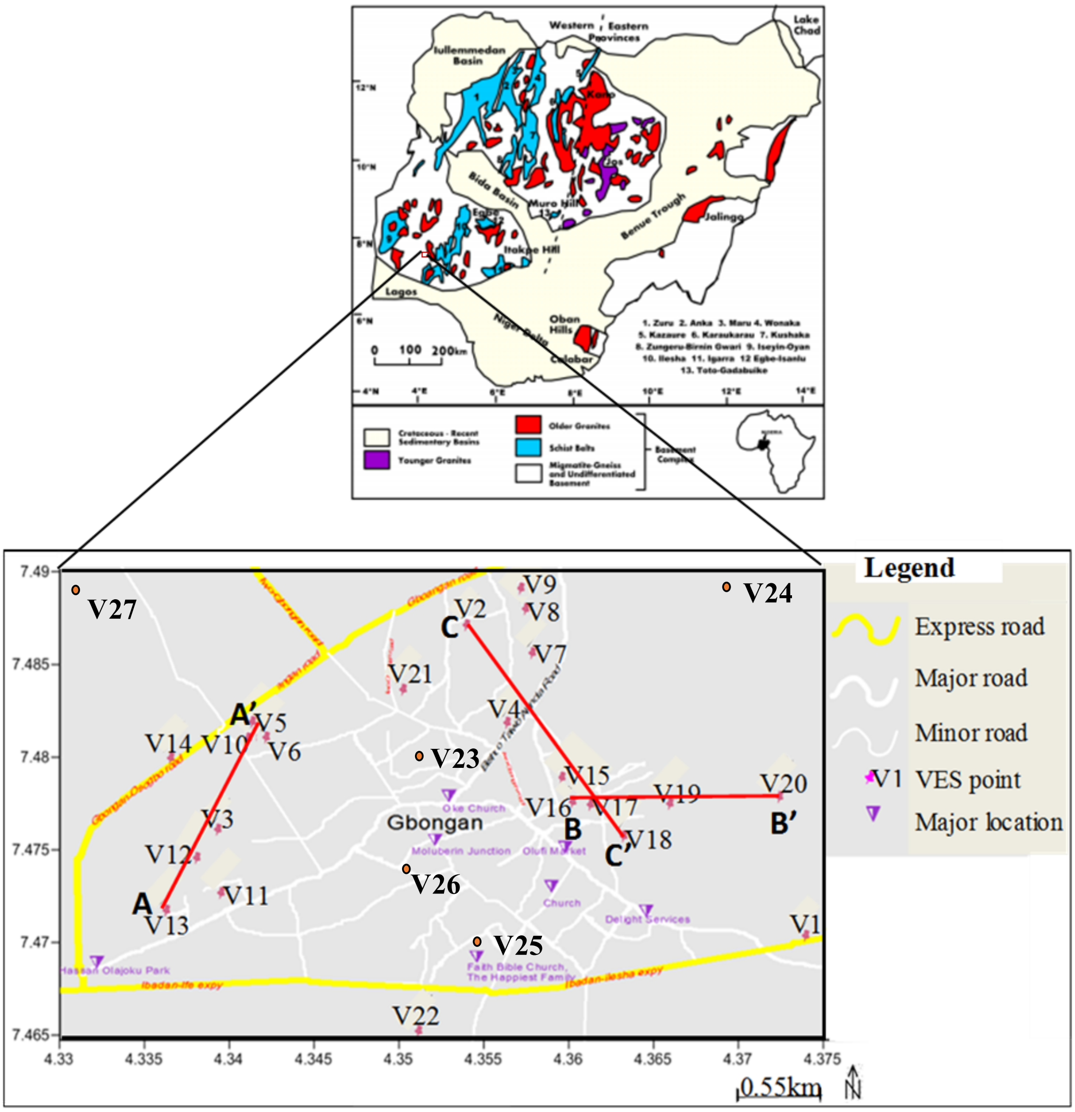

Figure 1: Base map of the study area. Inset is the Geological Map of Nigeria [12].

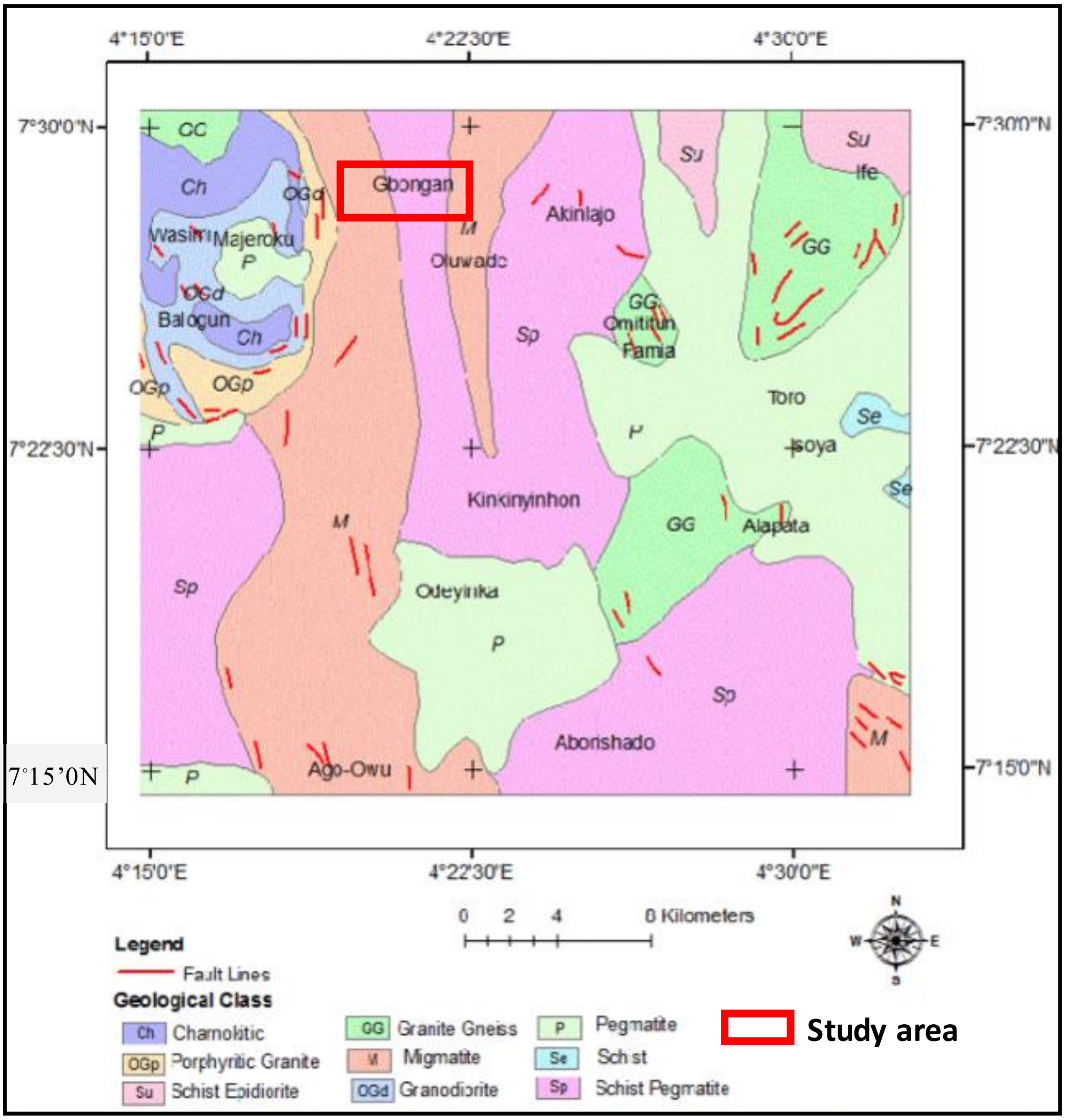

Figure 2: Geological map of Ile-Ife and environs showing the Gbongan study area [13].

METHODOLOGY

In the study area, Ohmega™ earth resistivity meter was employed in the acquisition of twenty- seven (27) VES data using the Schlumberger array in the study area (Figure 1). The maximum current electrode separation (AB) for the study was 200m which is adequate for good penetration into the basement rock. The electrode spreading followed the description [4] where half electrode spacing (AB/2; Figure 3) range of 1 – 100 m was used to generate maximum information about the subsurface lithology and overburden thickness. Apparent resistivity (ρ_a) for the Schlumberger array (Figure 3) is computed from the equations (1 and 2) below [4]:

$$\rho_a = \frac{\pi(L^2 - x^2)^2}{2l(L^2 - x^2)} \frac{\Delta V}{I} \qquad \text{Eqn. (1)}$$

where x is the separation of the mid-points of the potential and current electrodes. When used symmetrically, x = 0, so

$$\rho_a = \frac{\pi L^2}{2l} \frac{\Delta V}{I} \qquad \text{Eqn. (2)}$$

The VES data were first interpreted by using the conventional partial curve matching technique with two-layer master curves in conjunction with an auxiliary curve. This procedure gave an estimate of the layer resistivity and thickness, which were used as input data for computer-assisted interpretation with RESIST software to obtain the true resistivity and thickness of the various layers [3].

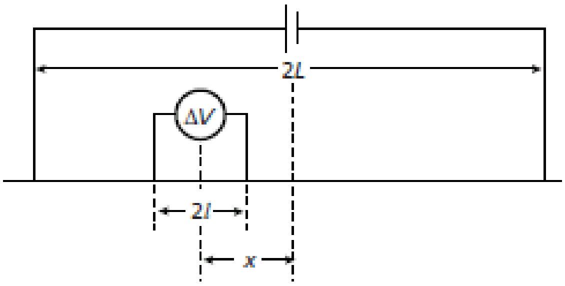

Figure 3: Schlumberger electrical configuration (Modified from Kearey *et al.* [4]).

RESULTS AND DISCUSSIONS

The VES Curves

The typical VES curves are displayed in Figure 4. The summary of the result from interpretation of VES data is presented in Table 1. From the interpretation of the VES curves, three (3) to five (5) geoelectric layers were identified as possible lithologies within the study area. These include: topsoil (30-1992$\Omega-\mathrm{m}$), clayey sand (23-60$\Omega-\mathrm{m}$)/laterite(213-401$\Omega-\mathrm{m}$), weathered Basement(15-164$\Omega-\mathrm{m}$), fractured Basement(7-121 $\Omega-\mathrm{m}$) and fresh bedrock (415-13054$\Omega-\mathrm{m}$) which are predominantly of the 'H' curve type (48.1%), followed by 'HA' type (14.8%), other curve types include: 'HKH' (7.4%), 'QH' (7.4%), 'KH' (7.4%), 'AKH' (3.7%), 'AK' (3.7%), 'AA' (3.7%) and HAA (3.7%). The weathered, fairly weathered and fractured basements constitute the main aquifer units and have varying resistivities and thicknesses.

The iso-depth contour and 3D surface maps of depth to bedrock

The iso-depth contour map of depth to bedrock and its equivalent 3D surface map in the study area (Figures 5 and 6 respectively), show that the deepest parts (11 to 23 m) occur at the western, southwestern, southern and south eastern regions. The other regions are generally shallow. Generally, groundwater prospect is very good in the study area if it is preceded with adequate geophysical surveying.

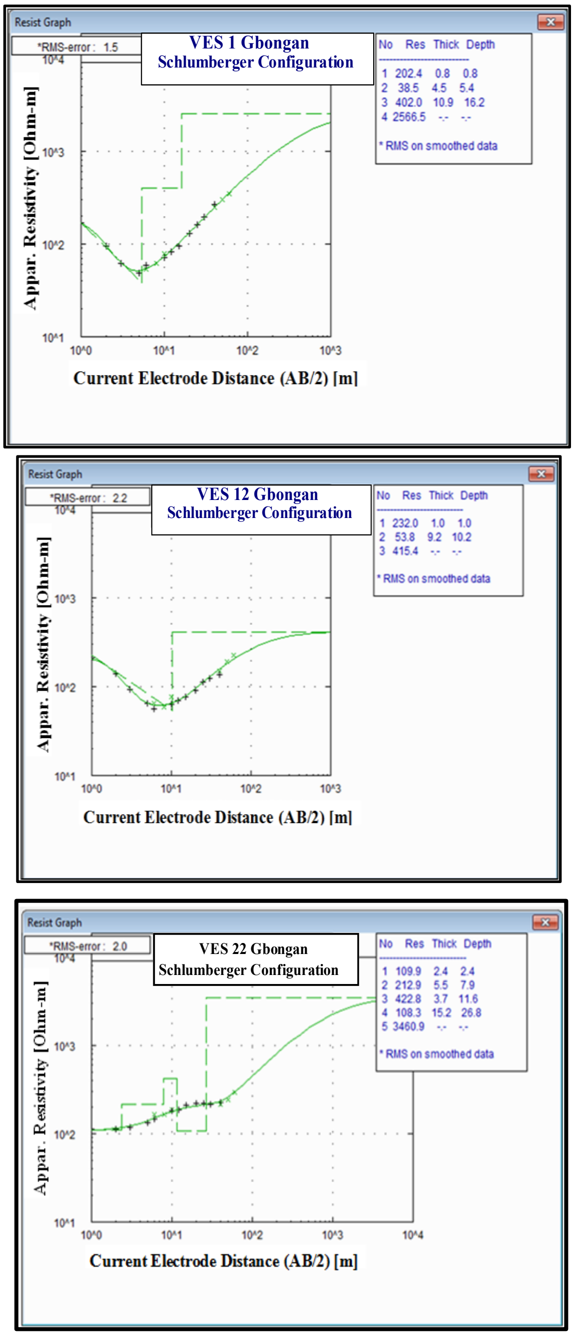

Figure 4: Typical VES curves for some locations in the study area

Table 1: Summary of Results of the VES data Interpretation for V1 to V27

VES	Lon. (deg.)	Lat. (deg.)	Resistivity (ℓ_1, ℓ_2)	Thickness (t_1, t_2)	Depth to Bedrock (m)	Aquifer Thickness	Curve Type	Probable Lithology (Layers 1, 2, ..)*
V1	4.37389°	7.47008°	202,39, 402,2567	0.8,5,11, α	-16.8	16	HA	T, Wb, Pwb, Frbd
V2	4.35390°	7.48684°	49,65, 581,1305	0.7,6.6,3.5, α	-10.8	10.1	AA	T, Wb, Pwb, Frbd
V3	4.33925°	7.47581°	164,60, 138,528	0.7,1.9,12.8, α	-15.4	14.7	HA	T, Cls, Wb, Frbd
V4	4.35630°	7.48157°	348,7, 1382	1.4,2.2, α	-3.6	2.2	H	T, W/Fb, Frbd
V5	4.34140°	7.48151°	75,65,291, 717	0.7,2.5, 1.5, α	-4.8	4.0	HA	T, Wb, Pwb, Frbd
V6	4.34210°	7.48078°	55,17, 5565	0.8,2, α	-2.8	2.0	H	T, Wb, Frbd
V7	4.35778°	7.48533°	175,164, 499	0.7,5.3, α	-6.0	5.3	H	T, Wb, Frbd
V8	4.35739°	7.48771°	157,68, 1672	0.7,4.8, α	-5.4	4.8	H	T, Wb, Frbd
V9	4.35717°	7.48872°	251,24, 2770	1.3,3.2, α	-4.5	3.2	H	T, Wb, Frbd
V10	4.34133°	7.48073°	80,70, 4402	0.4,10.2, α	-10.5	10.2	H	T, Wb, Frbd
V11	4.33944°	7.47239°	121,95,349,51, 1801	1.0,1.9,5.0,11.1, α	-19	18.0	HKH	T, Wb, Pwb,F/W b, Frbd
V12	4.33801°	7.47428°	232,54, 415	1.0,9.0, α	-10.2	9.0	H	T, Wb, Frbd
V13	4.33622°	7.47144°	225,61, 2832	1.2,11.5, α	-12.7	11.5	H	T, Wb, Frbd
V14	4.33648°	7.47966°	635,117,288,70, 1147	0.3,3.0,7.4,12.7, α	-23.4	23.1	HKH	T, Wb, Pwb, F/ Wb,Frbd
V15	4.35970°	7.47865°	60,13, 2002	1.1,2.3, α	-3.4	2.3	H	T, Wb, Frbd
V16	4.36016°	7.47730°	30,27, 42,950	1.8,2.2, 9.9, α	-13.9	12.1	HA	T, Wb, Fb, Frbd
V17	4.36121°	7.47715°	66,15, 434	1.4,1.9, α	-3.3	1.9	H	T, Wb, Frbd
V18	4.36317°	7.47545°	251,114,34,2766	0.7,2.0, 6.4, α	-9.1	8.4	QH	T, Wb, Fb, Frbd
V19	4.36589°	7.47720°	253,50, 1040	0.9,5.1, α	-6.0	5.1	H	T, Wb, Frbd
V20	4.37235°	7.47757°	124,26, 1165	0.7,3.3, α	-4.0	3.3	H	T, Wb, Frbd
V21	4.35017°	7.48336°	78,22, 1034	1.0,5.9, α	-6.9	5.9	H	T, Wb, Frbd
V22	4.35108°	7.46493°	110,213,423,108,3461	2.4,5.5, 3.7,15.2, α	-15.2	18.9	AKH	T, Lly, Pwb, Wb, Frbd
V23	4.35178°	7.47909°	42,144,13,3558	0.7,1.0,4.0, α	**-5.7**	5.0	KH	T,Wb,Fb, Frbd
V24	4.36957°	7.48936°	1992,401,123,13002	0.6,0.5,10, α	-11.1	10	QH	T,Lly,Wb, Frbd
V25	4.35498°	7.46942°	37,38,216,121	1.3,2.0,1.5, α	-4.8	3.5	AK	Cs,Wb,Pwb,Fb
V26	4.35091°	7.47362°	680,23,45,50,428	1.1,0.6,0.2,3.7, α	-5.6	3.9	HAA	T,Cs,Wb,Fb,Frbd
V27	4.33323°	7.48905°	42,53,13,426	0.7,0.9,1.4, α	-3.0	2.3	KH	T, Wb, Fb, Frbd

*T=Topsoil, Wb=Weathered basement, Pwb=Partly weathered basement, Fb=Fractured basement, Frbd=Fresh bedrock, Cls= Clayey sand, Lly=Lateritic layer

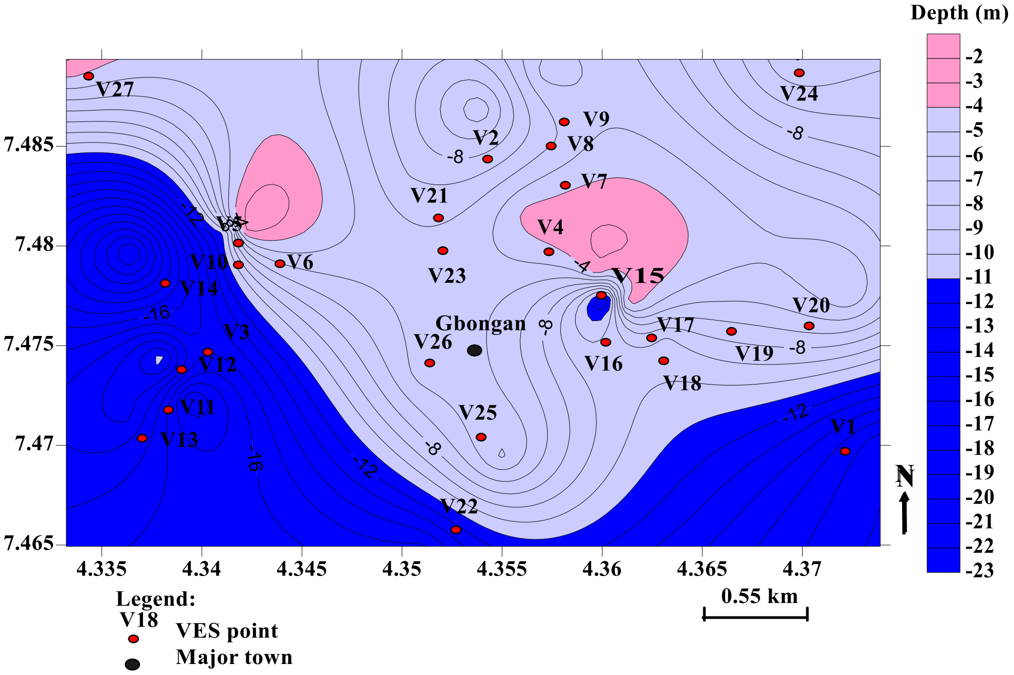

Figure 5: Contour map of depth to bedrock

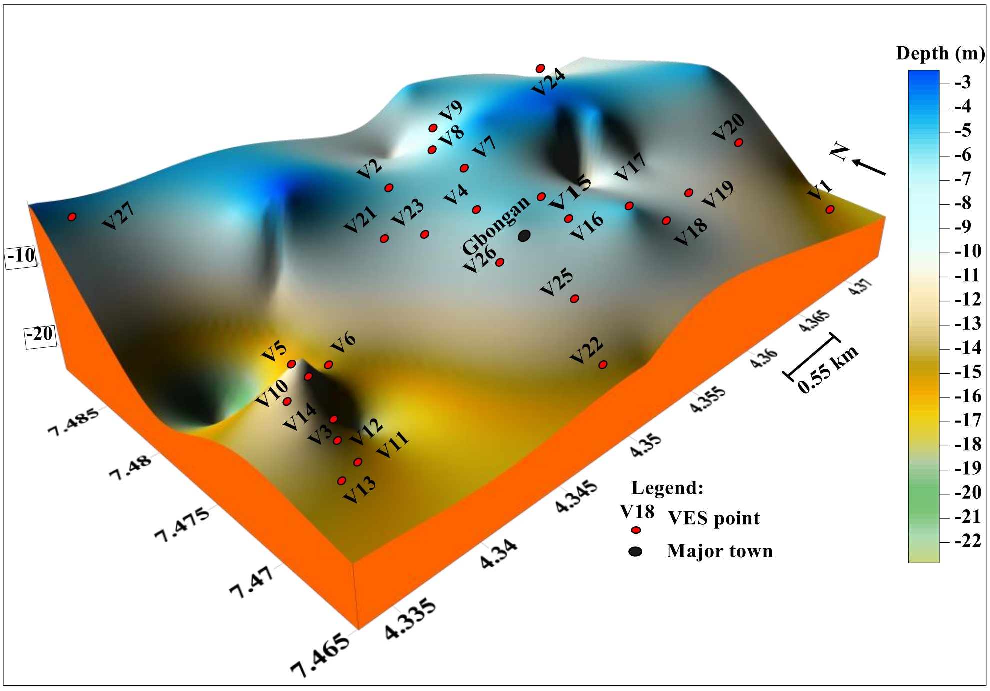

Figure 6: 3D surface map of depth to bedrock

The contour map of aquifer thickness

Figure 7 shows the contour map of aquifer thickness distribution in the study area. The aquifer thickness distribution follows the overburden thickness and the thickest (11-23 m) parts occur at the western, southwestern, southern and southeastern regions. Since the aquifers in the northern region are not as thick as those at the identified areas, it is therefore envisaged that the areas demarcated are better for future major groundwater resources development.

The geoelectrical section of profiles AA', BB' and CC'.

The geoelectric section across profiles AA', BB' and CC' are shown in Figures 8, 9 and 10. The overburden thickness is generally < 20m in all the three profiles. The weathered and fractured layers are known to exhibit lower resistivity than that of the topsoil or lateritic layer (Table 1). The resistivity of the fractured layer is often lower than that of weathered and the fresh bedrock and usually occur before the fresh bedrock. A column may not compulsorily contain both fractured and weathered basement simultaneously but when they do, the potential for groundwater is improved. The three profiles drawn contained the two columns simultaneously at the central part (AA'), left hand side (BB') and at both the left- and right-hand side (CC'), all of which attest to the fact that the prospect for groundwater in the study area is good.

CONCLUSIONS

Three to five lithologic units have been delineated with VES in Ode-Omu palace area of Gbongan, Osun state within the Basement Complex terrain of southwestern Nigeria. These include: topsoil (30-1992$\Omega-\mathrm{m}$), clayey sand (23-60$\Omega-\mathrm{m}$)/laterite(213-401$\Omega-\mathrm{m}$), weathered basement(15-164$\Omega-\mathrm{m}$), fractured basement(7-121$\Omega-\mathrm{m}$) and fresh bedrock (415-13054 $\Omega-\mathrm{m}$) which are predominantly of the 'H' curve type (48.1%), followed by 'HA' type (14.8%), other curve types include: 'HKH' (7.4%), 'QH' (7.4%), 'KH' (7.4%), 'AKH' (3.7%), 'AK' (3.7%), 'AA' (3.7%) and HAA (3.7%). The weathered, partly weathered and the fractured basement constitute the main aquifer units. The aquifers are of generally low resistivity values (from 7-164 Ω-m). The depths to bedrock at the chosen VES locations vary from 2.8 to 23.4 m with a mean value of 8.81 m in the study area. The geoelectrical interpretation of data obtained in these areas have permitted the delineation of the study area into shallow north and moderately thick west, southwest, south and southeastern regions in terms of overburden thickness while the resistivity over the study area is generally low and is expected to favour groundwater prospectively (provided the low resistivity is not caused by clay content). This study shows the usefulness of VES in groundwater potential zone delineation and planning of groundwater resources.

REFERENCES

1. BAYEWU, O.O., OLORUNTOLA, M.O., MOSURO, G.O. & OSHO, A.C. (2012). The resistivity and electromagnetic survey for groundwater evaluation in part of Ago-Iwoye, Southwestern Nigeria. *International Journal of Advances in Science and Technology*, **5(1)**: 87-99.
2. ANOMOHANRAN, O. (2015). Hydrogeophysical and hydrogeological investigations of groundwater resources in Delta Central, Nigeria. *Journal of Taibah University for Science*, **9**(1): 57 – 68.
3. NAMPAK, H., PRADHAN, B. & ABD MANAP, M. (2014). Application of G.I.S based data driven evidential belief function model to predict groundwater potential zonation. *Journal of Hydrology*, **513**: 283-300.
4. KEAREY, P., BROOKS, M. & HILL, I. (2002). An introduction to geophysical exploration. Blackwell Science Ltd., Oxford, U.K.
5. OSEJI, J.O. & UJUANBI, O. (2009). Hydrogeophysical investigation of groundwater potential in Emu Kingdom, Ndokwa land of Delta State, Nigeria. *International Journal of Physical Sciences*, **4**(5): 275-284. Online: http://www.academicjournals.org/IJPS
6. AWOMESO, A. OREBIYI, O. & OYEDOKUN, O. (2008). Geophysical Investigations for Groundwater Exploration in a Crystalline Basement, Southwestern Nigeria. *New York Science Journal*, **1**(4): 19-35.
7. RAHAMAN, M.A. (1988). Recent advances in the study of the basement complex of Nigeria: In. Oluyide, P.O., Mbonu, W. C., Ogezi, A. E., Egbuniwe, I. G., Ajibade, A. C. and Umeji, A. C. (Editors): *Precambrian Geology of Nigeria. Geological Survey of Nigeria*, pp.11 – 41.
8. DADA, S.S. (2006). Proterozoic Evolution of Nigeria. In: Oshi, O., Ed., *The basement complex of Nigeria and its mineral resources* (A tribute to Prof. M.A.O. Rahaman), Akin Jinad and Co., Ibadan, Nigeria, pp. 29 - 44.
9. ADESIYAN, T.A., ADEKOYA, J.A. & ALAO-DANIEL, A.B. (2018). Distribution patterns of trace metals in soils of Gbongan-Orileowu area, Southwestern Nigeria. *Ife Journal of Science*, **20**(3): 577-599.
10. DAVIS, S.N. & DE WIEST, R.M.J. (1966). *Hydrogeology*, New York: John Willey and Sons, New York, 463p.
11. ISSA, U., ALAGBE, S.A. & GARBA, M.L. (2014). Hydrogeology and physico-chemical quality assessment of groundwater in Oke-Oyi area

and environs, Kwara State, Nigeria. *Journal of Environmental Earth Science*, **4**(18): 76-83.

12. WOAKES, M., RAHAMAN, M.A. & AJIBADE, A.C. (1987). Some metallogenetic features of the Nigerian basement. *Journal of African Earth Sciences*, **6**(5): 655-664.

13. ABOYEJI, O.S., MOGAJI, K. & OYINLOYE, R. (2012). Structural interpretation of remotely sensed data sets, its hydrogeological implication over Ile-ife and environs. *Ozean Journal of Applied Sciences*, **5**(1): 43-54.

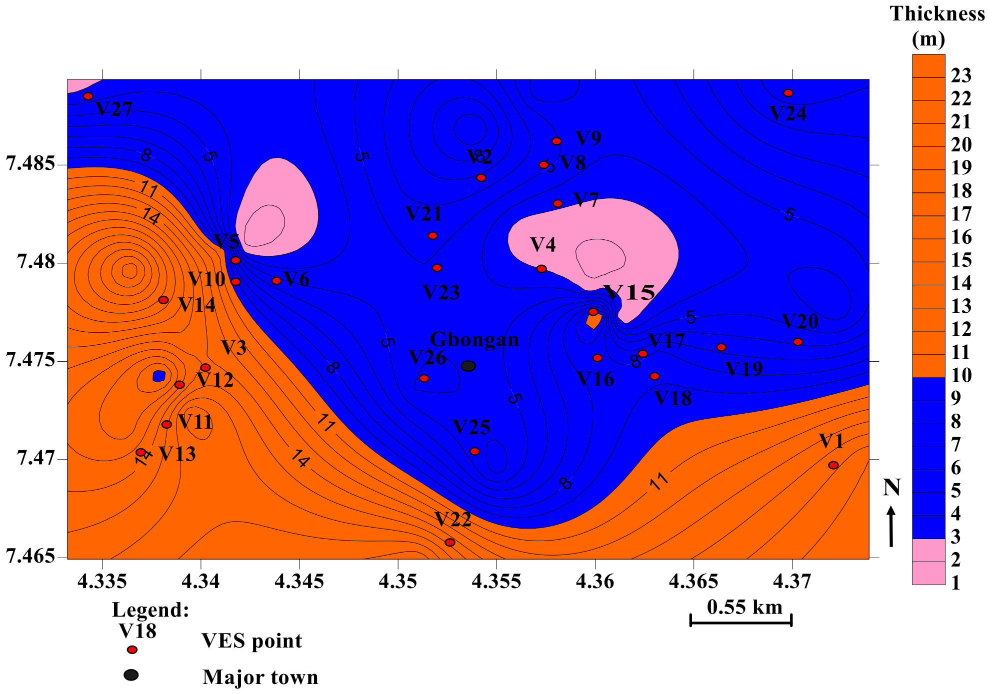

Figure 7: Contour map of aquifer thickness

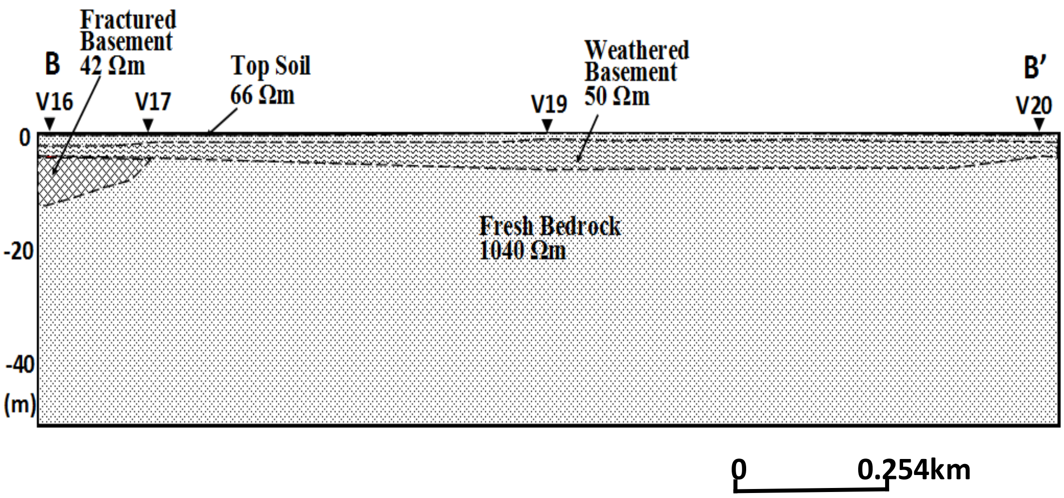

Figure 8: Geoelectric section along profile AA'

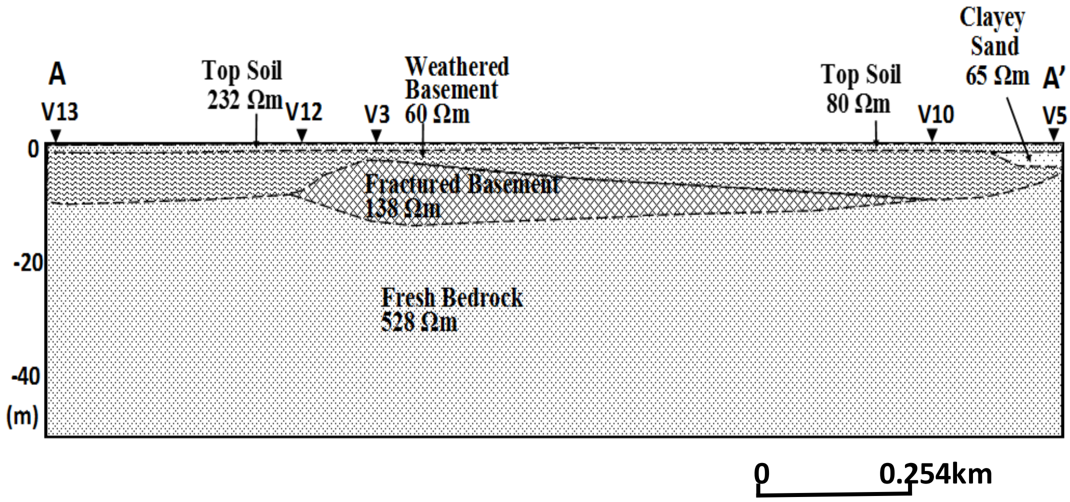

Figure 9: Geoelectric section along profile BB'

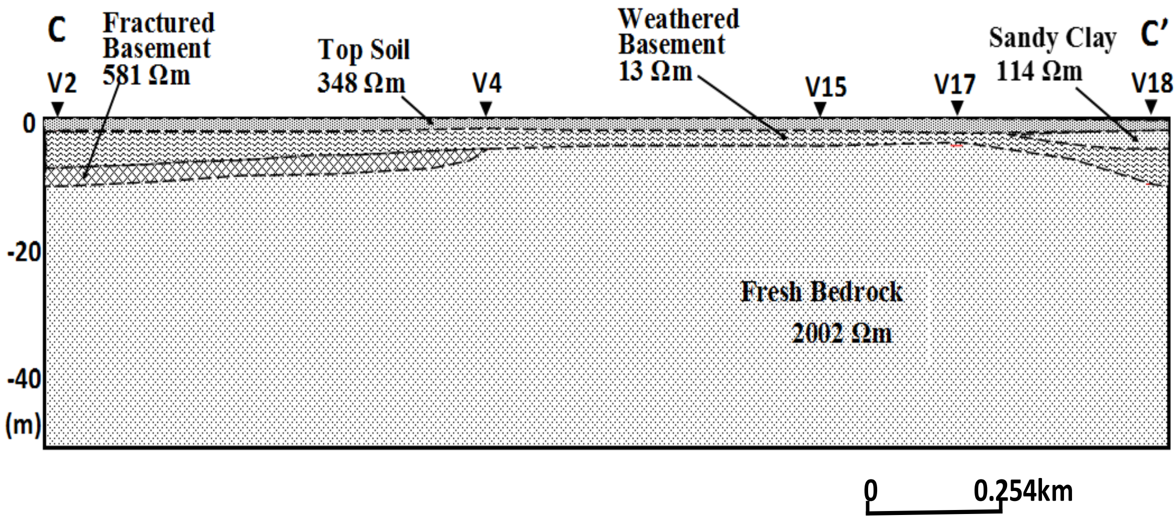

Figure 10: Geoelectric section along profile CC'