British Journal of Applied Science & Technology
6(4): 364-377, 2015, Article no.BJAST.2015.095
ISSN: 2231-0843

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Groundwater Potential Assessment of Iwaro-Oka, SW Nigeria Using Geoelectric Parameters

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Author's contribution

The sole author designed, analyzed and interpreted and prepared the manuscript.

Article Information

DOI: 10.9734/BJAST/2015/14584
Editor(s):
(1) Vyacheslav O Vakhnenko, Division of Geodynamics of Explosion, Subbotin Institute of Geophysics, National Academy of Sciences of Ukrainian, Ukraine.
Reviewers:
(1) Anonymous, Nigeria.
(2) Mahmoud M. Elwaheidi, Department of Geology & Geophysics, King Saud University, Kingdom of Saudi Arabia.
Complete Peer review History: http://www.sciencedomain.org/review-history.php?iid=767&id=5&aid=7476

Original Research Article

Received 7th October 2014
Accepted 6th November 2014
Published 26th December 2014

ABSTRACT

Geoelectric investigation of Iwaro-Oka, SW Nigeria was carried out with the aim of evaluating its groundwater potential for future groundwater development. The area is underlain by Precambrian Basement Complex of southwestern Nigeria with local geology essentially made up migmatite gneiss. Thirty-nine (39) Vertical Electrical Soundings (VES) using Schlumberger configuration were acquired. The VES curves were interpreted quantitatively using partial curve matching and computer assisted 1-D forward modeling. Three distinct geologic layers were delineated within the area. These are topsoil, weathered layer and basement rock. The topsoil is generally thin with no hydrogeologic significant. The weathered layer constitutes the major aquifer unit with thicknesses generally less than 10 m. This layer is predominantly composed of clayey material with resistivity values generally <100 ohm-m. The permeability is low with tendency for low groundwater yielding capacity. The overburden thicknesses vary from 1.1 to 23.5 m but are generally less than 10 m. The fracture density in the area is very low. Out of the thirty-nine VES stations occupied within the area, none show evidence of a fractured basement. The groundwater potential rating of the study area is classified as of low based on relatively thin and clayey aquifer unit.

Keywords: Geoeletric; groundwater; hydrogeologic; aquifer; overburden.

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1. INTRODUCTION

Iwaro-Akoko is an important town in Akoko area of Ondo State, Southwestern Nigeria, but yet to be connected to a municipal water supply scheme. Recent growth in population has imposed significant stress on the existing water scheme which based solely on groundwater abstraction from hand-dug wells many of which dry up during the dry season and several boreholes drilled in the area by private individual or public enterprise were not productive.

Groundwater occurrence in the crystalline basement terrain can be very irregular due to abrupt discontinuity in lithology, thickness and electrical properties of the overburden and weathered bedrock [1,2]. Consequently, groundwater exploration within such geologic setting requires the analysis of geophysical data to effectively characterize the hydrogeologic zones and to enhance successful identification of well locations. Geophysical surveys provide a quick and inexpensive method for the assessment of various subsurface characteristics related to the study of aquifers. Probably the most widely-employed geophysical method in hydrogeological investigations is the electrical resistivity method which provides information on geological structures, lithologies and subsurface water condition without the large cost of an extensive programme of drilling. The application of the electrical resistivity method to groundwater exploration has been established in the basement complex rocks [3,4,5]. In this study however, Vertical Electrical Sounding (VES) data were used to evaluate groundwater potential of Iwaro-Akoko to assist its future groundwater development.

Iwaro-Akoko is located in Southwestern Nigeria. It falls between latitudes 7° 16’ 6.2’’ N and 7° 16’ 57.6’’ N and Longitude 5° 55’ 16.4 E and 5° 56’ 6.3’’ E with an areal extent of 0.6 km^2 (Fig. 1). The terrain is gently undulating with topographic elevation ranging between 350 and 353m above sea level. The area lies within the tropical rain forest belt of hot, wet equatorial climatic region characterized by alternating wet and dry season. The vegetation is of the rain forest type which consists of thick vegetation comprising multitude of evergreen trees. The area is underlain by the Precambrian Basement complex of southwestern Nigeria [6]. The local lithologic unit identified in the area is migmatite gneiss (Fig. 2).

2. DATA ACQUISITION AND ANALYSIS

Thirty nine (39) Vertical Electrical Soundings (VES) were acquired in the area, using the Schlumberger configuration with half electrode spacing (AB/2) varying from 1 to 100 m. The existing roads were used as traverses (Fig. 1). The Ohmega resistivity meter was used for the data acquisition and the positions of the occupied sounding stations were geo-referenced using the GARMIN 12 channel Geographic Positioning System (GPS) unit. The VES data were presented as field curves by plotting the apparent resistivity (ρ_a) against AB/2 or half the spread length on a bi-logarithm paper. The data were interpreted quantitatively by partial curve matching [7] to obtain initial estimates of resistivity and thickness of the various geoelectric layers at each VES station. These geoelectrical parameters were used as starting model parameters in a computer assisted 1-D forwarding modeling with WinResist software [8]. Aquifer thickness, isoresistivity and groundwater potential maps were generated with the interpreted geoelectric parameters using ‘Surfer’ software version 11.0.

3. RESULTS AND DISCUSSION

3.1 Field Curves

The interpreted results of the sounding curves were presented as geoelectric sections, maps, charts and tables. Table 1 shows the summary of the interpreted results of the VES. The curve types are the H, A, and KH with predominant H type curve (Fig. 3). Based on onIdornigie and Olorunfemi, [9] and Olayinka and Olorunfemi, [10],it was possible to classify the type curves into three distinct classes as follows:

Class 1: A
Class 2: H
Class 3: KH

A typical example of the Class 1 type curve (A) is illustrated in Fig. 4a. The class represents a subsurface condition in which there is increase in resistivity from the topsoil to the bedrock. The Class 2 type curve (H) is characteristic of the Basement Complex saprolite profile produced from insitu weathering. A typical sounding curves is shown in Fig. 4b.

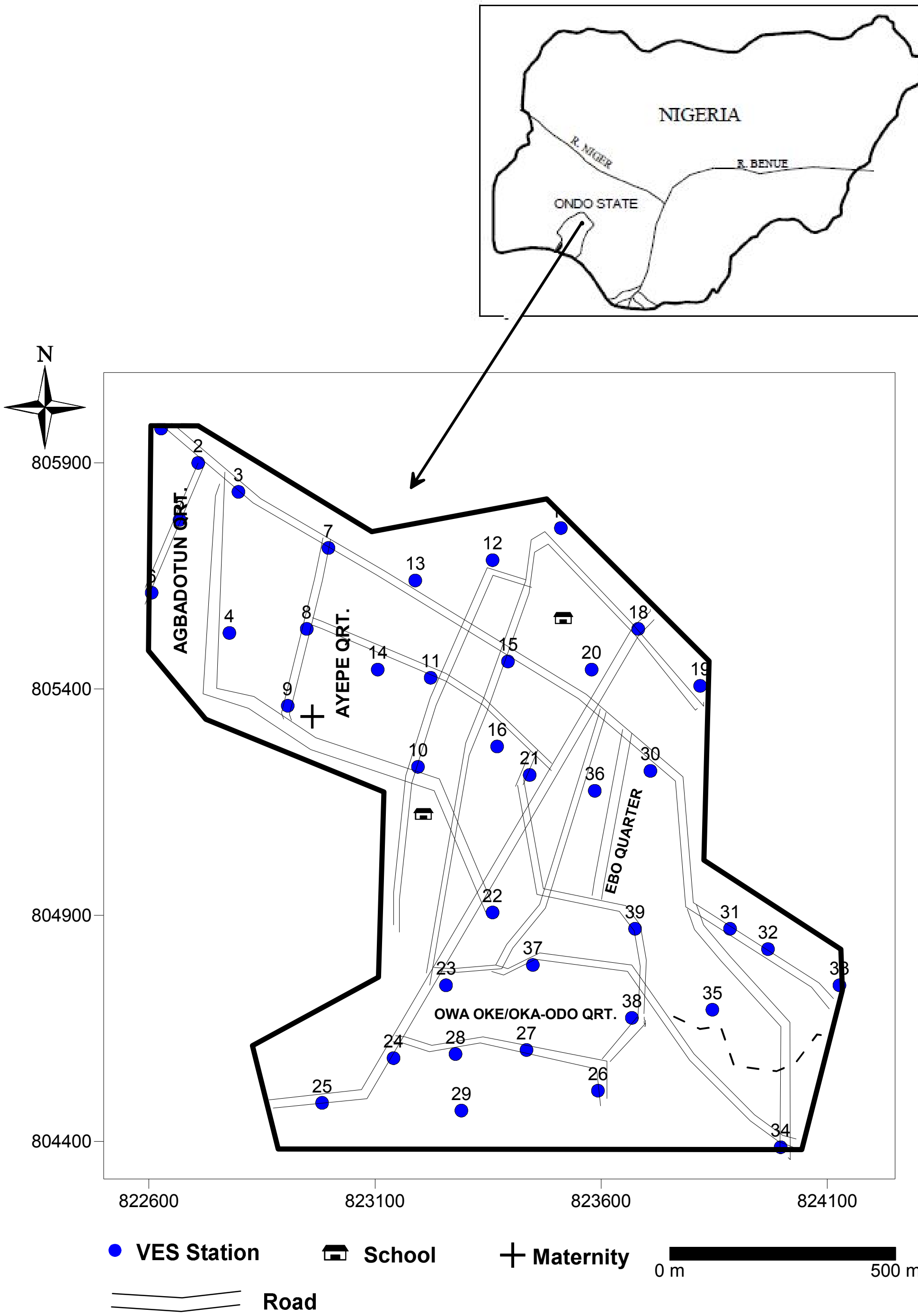

Fig. 1. Base map of the study area showing location of the vertical electrical sounding (VES) stations

In the profile, the upper horizons, when not leached, are usually clayey and the main aquifer zone is found at the base where selective mineral decomposition has produced a gravel-like material (not always). Immediately underlying the usually low resistivity, high porosity, and low permeability weathered zone is the fresh basement. The geologic model produces an H-type curve signature, which was found to be the predominant curve in the area, accounting for about 75% of the total (Fig. 3). The class 3 (KH) type curve is shown in Fig. 4c. The geologic model contains succession of relatively low and high resistivity layers. The KH four-layer setting is found where a highly resistive lateritic hard pan underlies low resistivity clayey topsoil, and a low resistivity weathered layer in turn underlies the former. The weathered layer overlies the fresh basement. The major aquifer unit in the study area is the weathered layer.

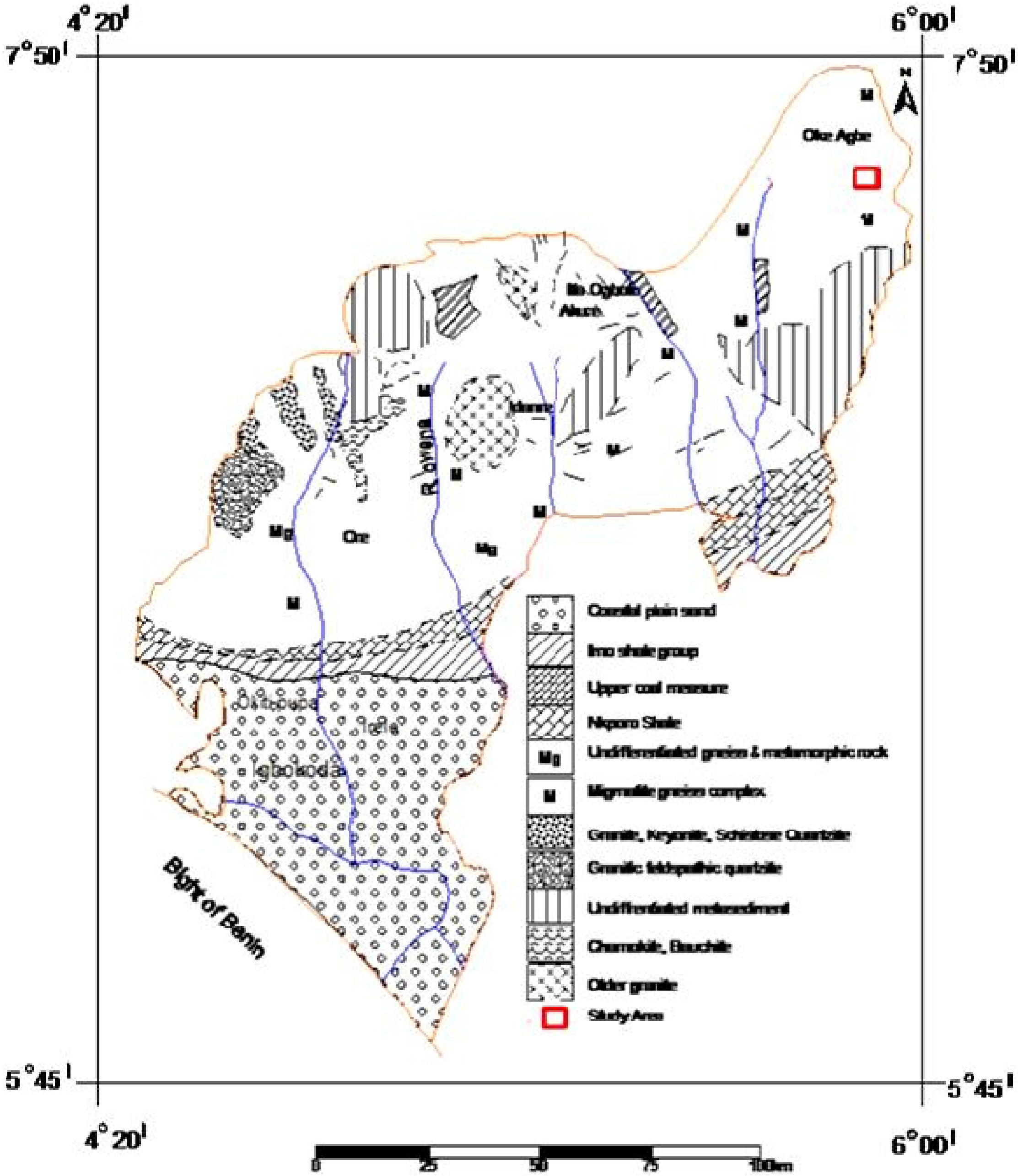

Fig. 2. Geological map of Ondo state showing the study area [11]

Table 1. Summary of the interpreted result of the sounding curves

VES	Resistivity (Ωm)					Thickness (m)				Curve type
	ρ_1	ρ_2	ρ_3	ρ_4	ρ_5	h_1	h_2	h_3	h_4	
1	59	88	1210			2.4	4.5			A
2	146	90	780			1.4	4.4			H
3	145	74	4178			0.7	1.5			H
4	213	86	331			2.9	20.6			H
5	126	211	1081			1.9	8.6			A
6	307	452	40	9457		1.2	7.0	6.2		KH
7	314	96	1999			0.6	4.1			H
8	180	103	2993			1.8	7.4			H
9	263	52	1311			1.1	5.4			H
10	122	454	100	2083		0.7	0.8	6.4		KH
11	236	41	6841			0.9	12.3			H
12	349	155	5960			3.4	6.7			H
13	227	118	5230			1.3	11.0			H
14	80	35	1175			0.8	4.1			H
15	62	285	873			2.1	8.9			A
16	73	59	355			1.2	2.5			H
17	311	52	1185			1.5	11.5			H
18	76	57	207			1.0	13.0			H
19	83	19	1122			0.8	2.3			H
20	87	21	309			1.2	5.2			H
21	233	39	1208			1.1	7.6			H
22	189	46	545			0.8	12.9			H
23	107	36	460			1.8	10.7			H
24	127	30	1675			0.8	6.0			H
25	446	275	5379			1.4	4.0			H
26	405	64	1038			0.9	8.4			H
27	238	40	∞			0.7	1.6			H
28	51	188	∞			1.6	0.7			A
29	564	116	1127			1.0	4.5			H
30	107	45	824			1.1	9.4			H
31	67	91	618			1.3	3.7			A
32	42	129	585			1.1	10.8			A
33	223	445	2307			2.0	3.5			A
34	423	94	8990			2.8	13.7			H
35	216	25	1409			1.4	5.4			H
36	141	18	1029			0.5	2.0			H
37	296	79	3857			0.6	5.3			H
38	373	806	5551			1.6	0.4			A
39	793	370	4070			0.5	3.7			H

3.2 Geoelectric Characterization and Hydrogeologic Significant

The electrical resistivity method measures variation in ground resistivity. The electrical resistivity contrasts between discrete geoelectric layers, or lithological sequences in the subsurface are generally adequate to enable the characterization of geoelectric layers. This further assists the delineation and identification of aquiferous or non-aquiferous layers and enables reliable geological deductions. Figs. 5a and b show typical geoelectric sections along North – South and East-West direction respectively. Three distinct geoelectric/geologic sequences were delineated along the north - south profile. The first layer (Topsoil) has resistivity values ranging from 51 to 564 ohm-m, representing clay, sandy clay, clayey sand, and laterite. It has thickness values that range between 0.7 and 1.8 m. The topsoil is underlain by clay/sandy clay layer (weathered layer), with resistivity value ranging from 36 to 118 ohm-m and thickness varies between 0.7 and 12.3 m. The geoelectric basement rock is at depth ranging from 1.6 m to 13.2 m, with resistivity values >460 ohm-m.

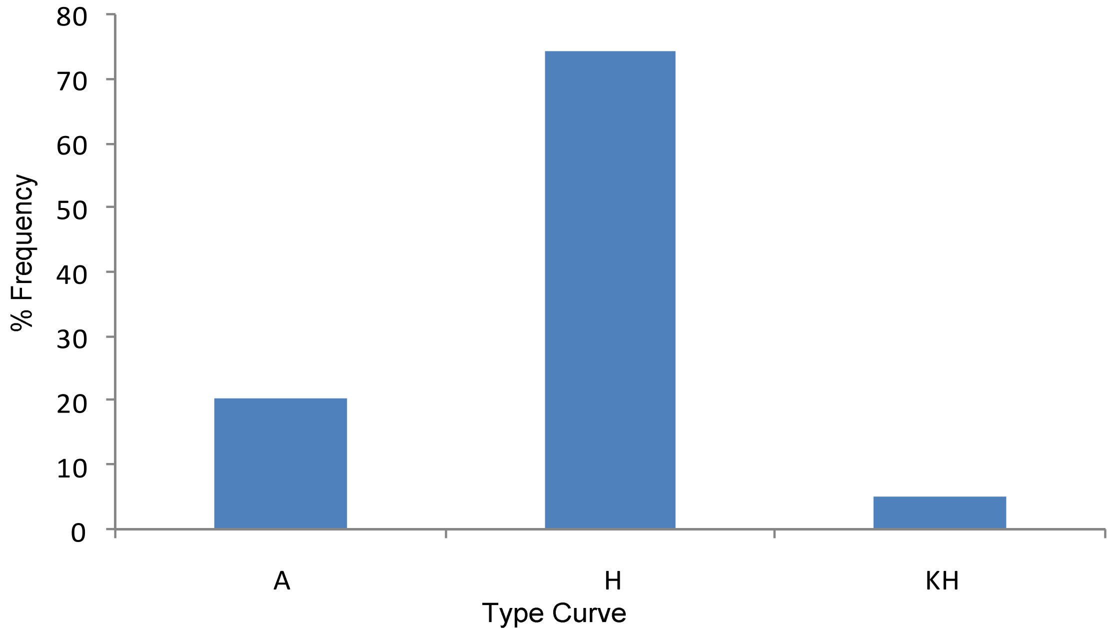

Fig. 3. Bar chart of the type curves

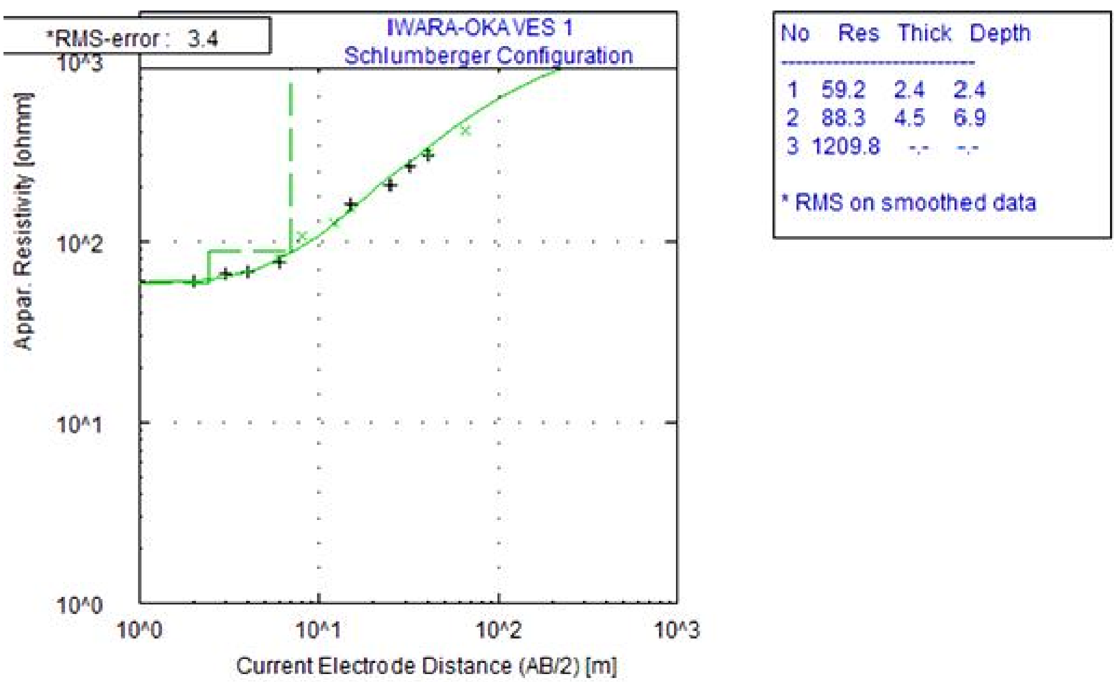

Fig. 4a. Typical class 1 type curve

Fig. 5b shows interpreted geological section along the West – East profile. This section reveals three geoelectric/geologic layers: the topsoil, with resistivity values ranging from 73 to 454 ohm-m and thickness varying from 0.5 to 1.5 m; the weathered layer, with resistivity of 18 to 100 ohm-m and thickness ranges from 1.6 to 9.4 m and predominantly made up of clayey materials and the basement, with resistivity values ranging from 355 to ∞ ohm-m and depth to basement rock ranging from 2.3 to 10.5 m. The thickness and resistivity parameters of unconsolidated materials (overburden) overlying the basement rock is important factor in the evaluation of groundwater potential in the crystalline basement area. The delineated topsoil in this area is very thin, hence it has no hydrogeologic significant. The weathered layer constitutes the major aquifer unit within the study area but predominantly composed of clayey material, which has low permeability with tendency for low groundwater yielding capacity. The fracture density in the area is very low; none of the VES stations occupied show an evident of a fractured basement.

3.3 Isopach and Isoresistivity Maps of the Major Aquifer Unit in the Area

Figs. 6a and 6b show the isopach and isoresistivity maps of the aquifer unit (weathered layer) respectively. The thickness varies from 1.1 to 20.5 m but generally less than 10 m (Fig. 6a) and the resistivity values vary from 18 to 373 ohm-m but are generally less than 100 ohm-m, hence predominantly composed of clayey materials.

3.4 Isopach Map of Overburden and Hydrogeological Zoning of the Study Area

The map of overburden thickness (unconsolidated regolith overlying the consolidated bedrock) is as shown in Fig. 7. The overburden thickness in the study area varies from 1.1 to 23.5 m but is generally less than 10 m. Generally, areas with thick overburden and low percentage of clay in which intergranular flow is dominant are known to have high groundwater potential particularly in basement complex terrain.

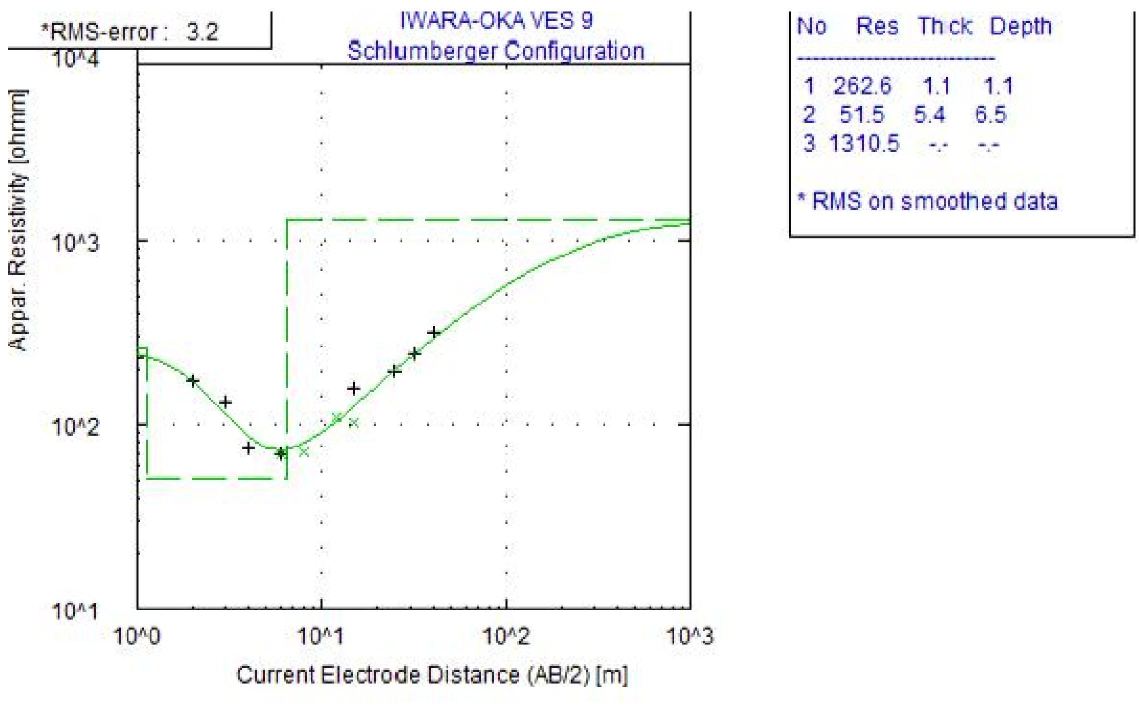

Fig. 4b. Typical class 2 type curve

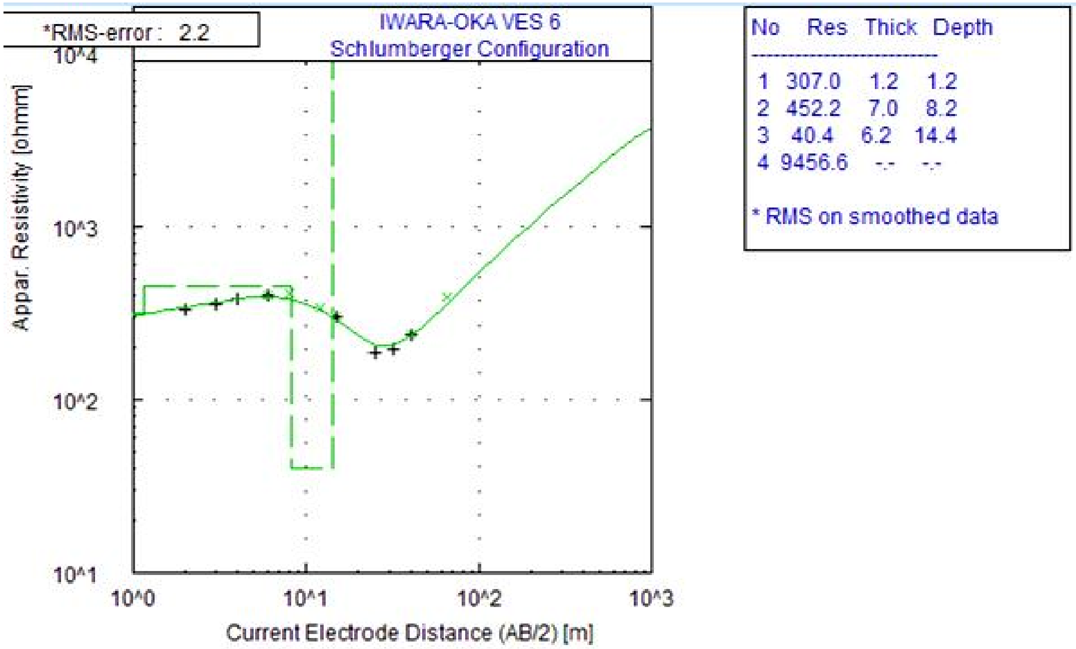

Fig. 4c. Typical class 3 type curve

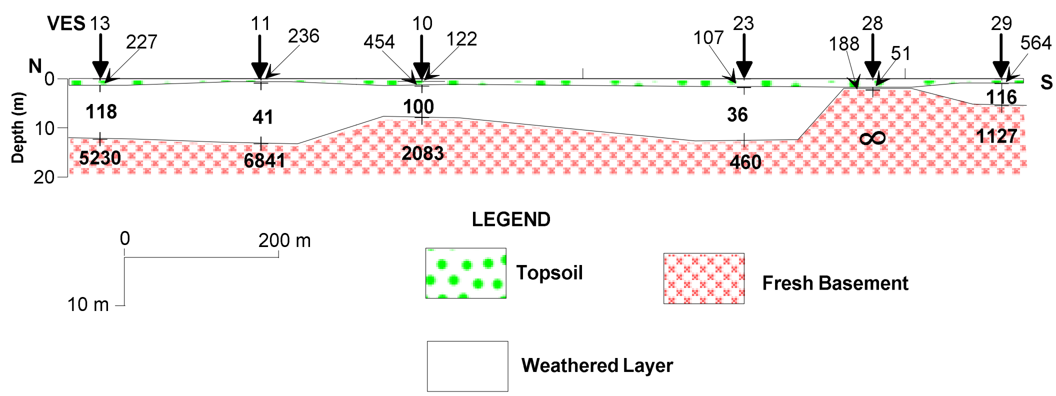

Fig. 5a. Geoelectric section along North – South (N – S) direction

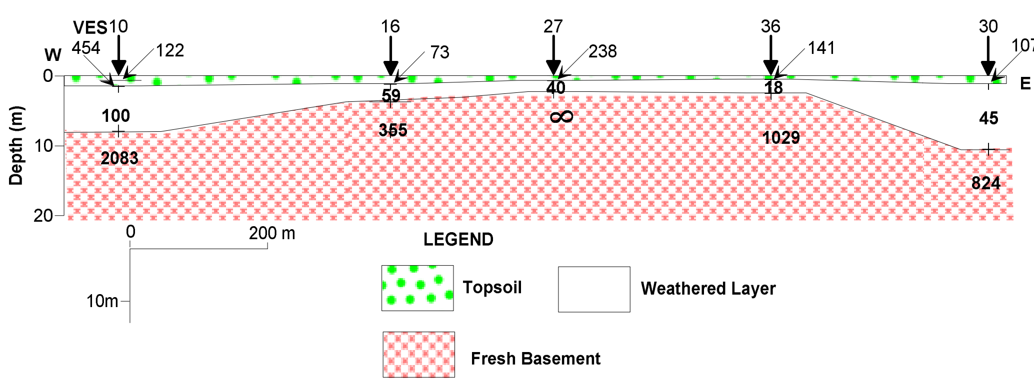

Fig. 5b. Geoelectric section along West – East (W – E) direction

In crystalline basement terrain, aquifers may occur within the overburden and/or the bedrock as fracture. The thickness, the lateral extent and the resistivity parameters of any of these aquifer units are important in groundwater prospect evaluation of an area [1,2]. Due to the heterogeneous nature of the basement terrain, the above geological parameters constantly vary. Figs. 8a and b are the maps derived from the thickness and resistivity of the aquifer units delineated at each VES stations respectively. Areas with thick aquifer units with resistivity >250 ohm-m are considered priority areas for groundwater development [12].

The hydrogeologic zoning of the area is majorly based on the aquifer thickness and it composition. Using [3], Table 2, the groundwater potential of an area based on aquifer thickness could be zoned into high, medium, low and very low potential. Zones where the aquifer thickness is <10 m are considered to be of very low groundwater potential (Fig. 8a). Zone where the aquifer thickness is range from 10 to 20 m is classified as of low groundwater potential. The zones, which have aquifer thickness ranging from 20 to 40 m are classified as medium groundwater potential and area with aquifer thickness >40 m is classified high groundwater potential (Fig. 8a).

Based on aquifer composition (Table 3) the groundwater potential could also be zoned into high, medium and low potential. Zones where resistivity is <100 ohm-m is classified as low groundwater potential (Fig. 8b), zone where resistivity ranges from 100 to 250 ohm-m is classified as medium groundwater potential while zones with resistivity > 250 ohm-m are classified as high groundwater potential (Fig. 8b).

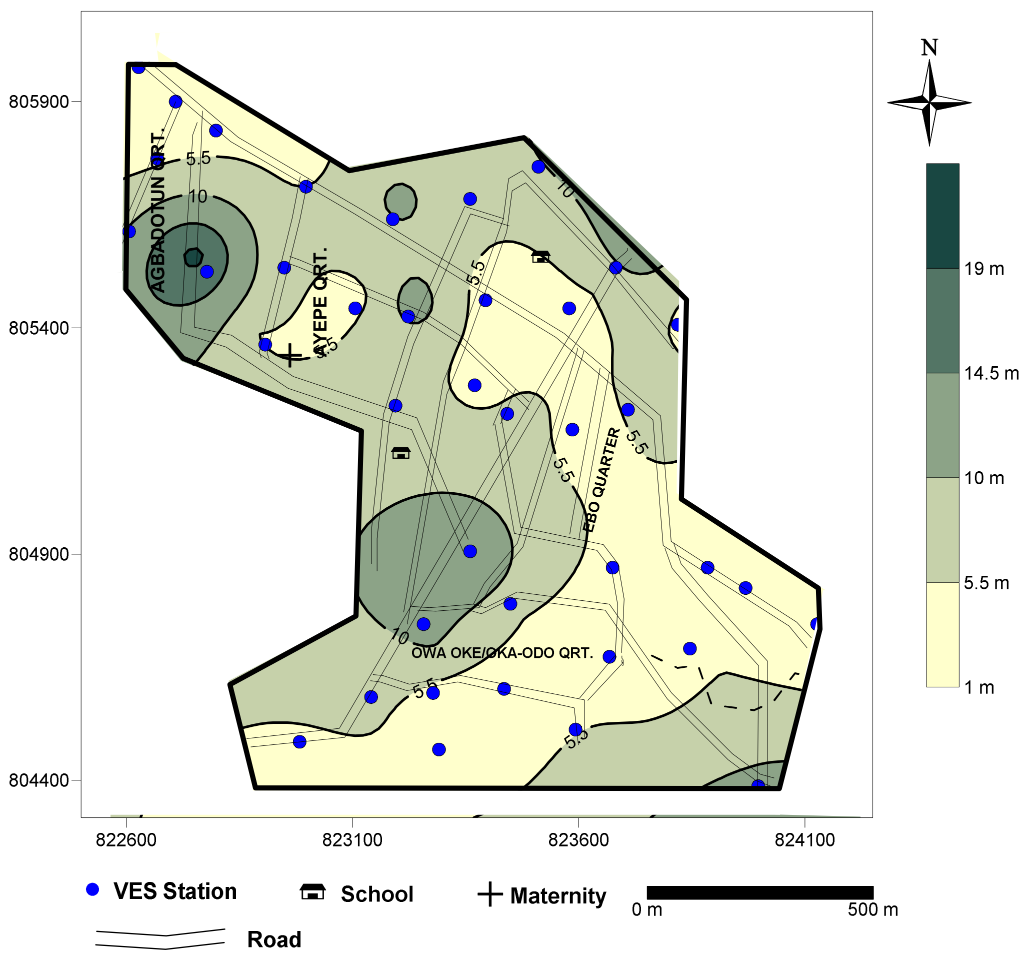

Fig. 6a. Isopach map of the weathered layer aquifer unit in the study area

Table 2. Parameter threshold for groundwater potential rating based on aquifer thickness [4]

Overburden thickness (m)	Groundwater potential rating
>40	High
20 – 40	Medium
10 – 20	Low
<10	Very Low

By correlating the groundwater potential zoning based on aquifer thickness and composition (Figs. 8a and 8b), most parts of the study area falls within very low/low groundwater potential. The medium groundwater potential zoned based on aquifer thickness (Fig. 8a) falls within the low groundwater potential zone classified based on aquifer composition (Fig. 8b), while the medium/high groundwater potential zone classified base on aquifer composition falls within very low/low groundwater potential based on aquifer thickness classification (Figs. 8a and b). The overall groundwater potential rating of the area (Table 4) shows that, the area is of low groundwater potential.

Table 3. Parameter threshold for groundwater potential rating based on aquifer unit composition [4]

Resistivity (ohm-m)	Groundwater potential rating
> 250	High
100 -250	Medium
<100	Low

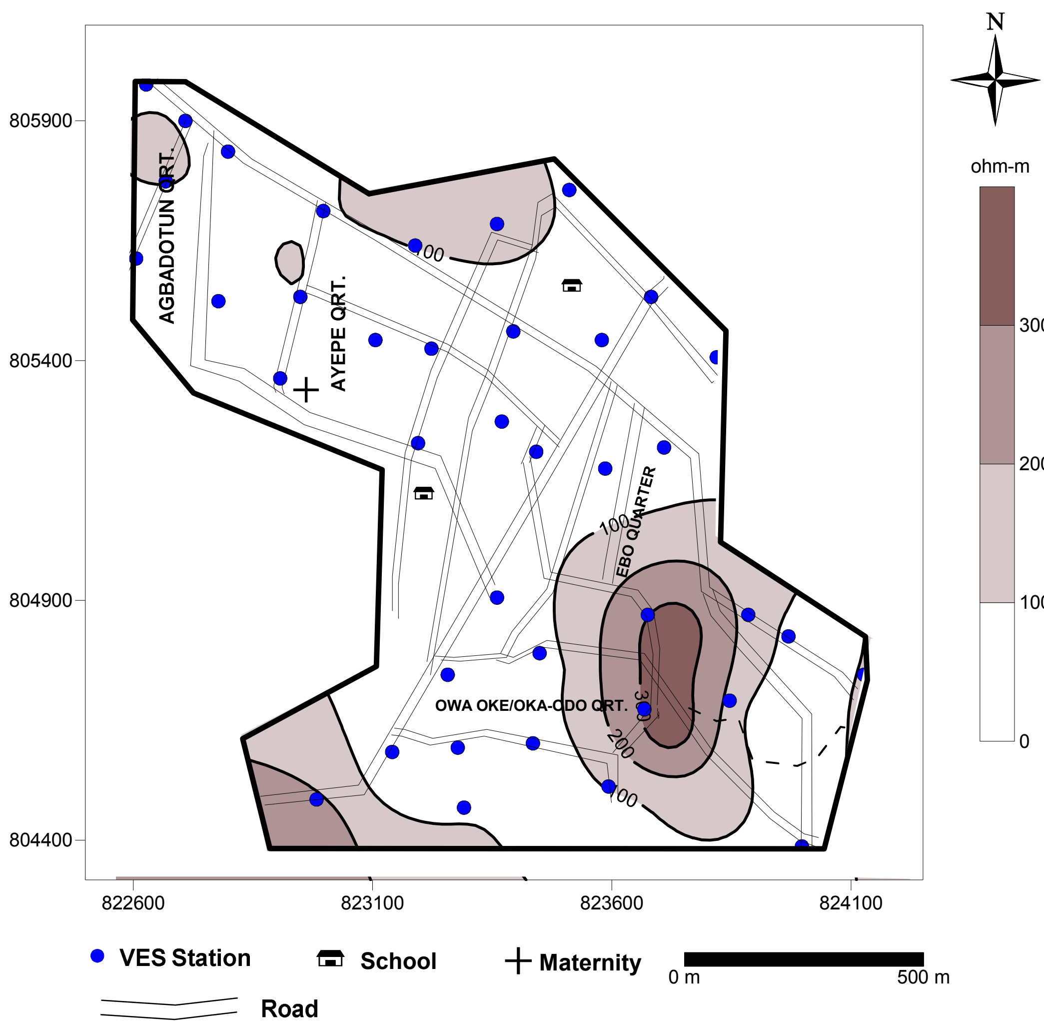

Fig. 6b. Isoresistivity map of the weathered layer aquifer unit in the study area

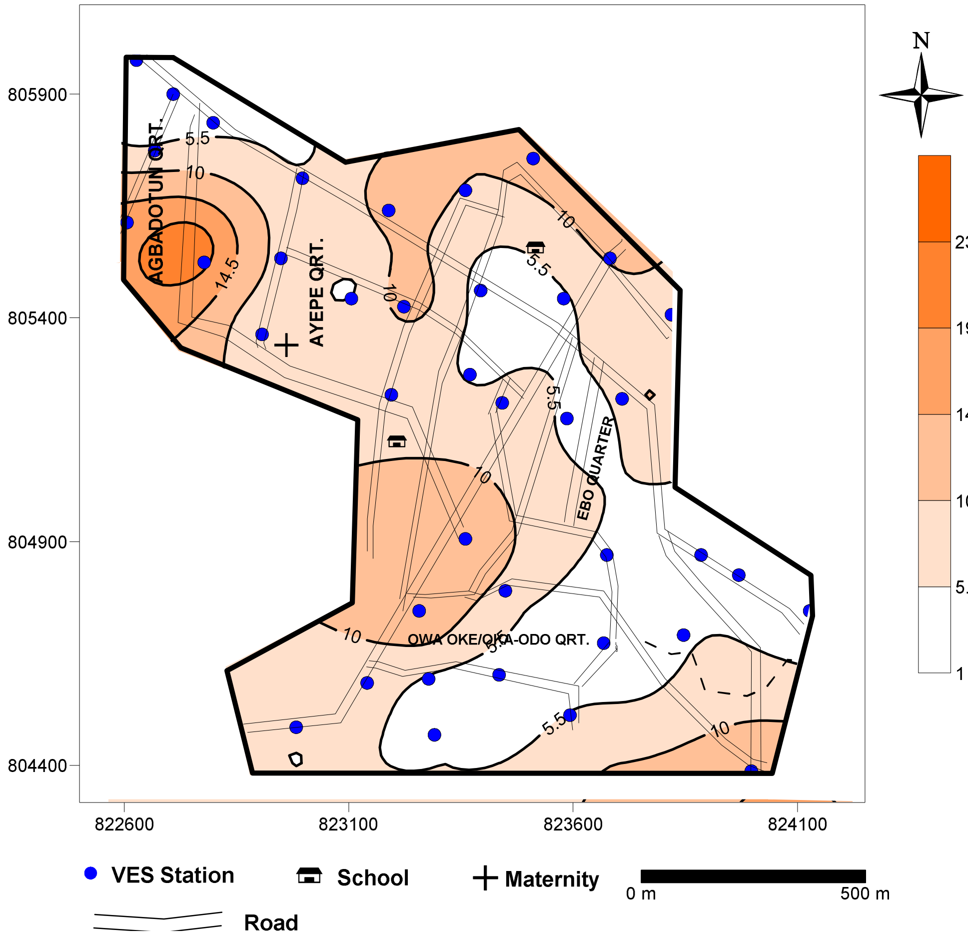

Fig. 7. Isopach map of the overburden in the study area

Table 4. Groundwater potential rating of the study area

VES	Major aquifer unit thickness (m)	Major aquifer unit composition (ohm-m)	Overburden thickness (m)	Rating based on aquifer thickness	Rating based on aquifer composition	Overall rating
1	2.4	59	2.4	VL	L	L
2	4.4	90	5.8	VL	L	L
3	1.5	74	2.2	VL	L	L
4	20.6	86	23.5	M	L	L
5	1.9	126	1.9	VL	M	L
6	7.0	40	14.4	L	L	L
7	4.1	96	4.7	VL	L	L
8	7.4	103	9.2	VL	L	L
9	5.4	52	6.5	VL	L	L
10	7.2	100	7.9	VL	L	L
11	12.3	41	13.2	L	L	L
12	6.7	155	10.1	L	M	L
13	11.0	118	12.3	L	M	L
14	4.1	35	4.9	VL	L	L
15	2.1	62	2.1	VL	L	L
16	2.5	59	3.7	VL	L	L
17	11.5	52	13.0	L	L	L
18	13.0	57	14.0	L	L	L
19	2.3	19	3.1	VL	L	L

VES	Major aquifer unit thickness (m)	Major aquifer unit composition (ohm-m)	Overburden thickness (m)	Rating based on aquifer thickness	Rating based on aquifer composition	Overall rating
20	5.2	21	6.4	VL	L	L
21	7.6	39	8.7	VL	L	L
22	12.9	46	13.7	L	L	L
23	10.7	36	12.5	L	L	L
24	6.0	30	6.8	VL	L	L
25	4.0	275	5.4	VL	H	L
26	8.4	64	9.3	VL	L	L
27	1.6	40	2.3	VL	L	L
28	1.6	51	1.6	VL	L	L
29	4.9	116	5.5	VL	M	L
30	9.4	45	10.5	L	L	L
31	1.3	91	3.7	VL	L	L
32	1.1	42	1.1	VL	L	L
33	2.0	223	2.0	VL	M	L
34	13.7	94	16.5	L	L	L
35	5.4	25	6.8	VL	L	L
36	2.0	18	2.5	VL	L	L
37	5.3	79	5.9	VL	L	L
38	1.6	373	1.6	VL	H	L
39	3.7	370	4.2	VL	H	L

VL = Very Low L = Low M = Medium H = High

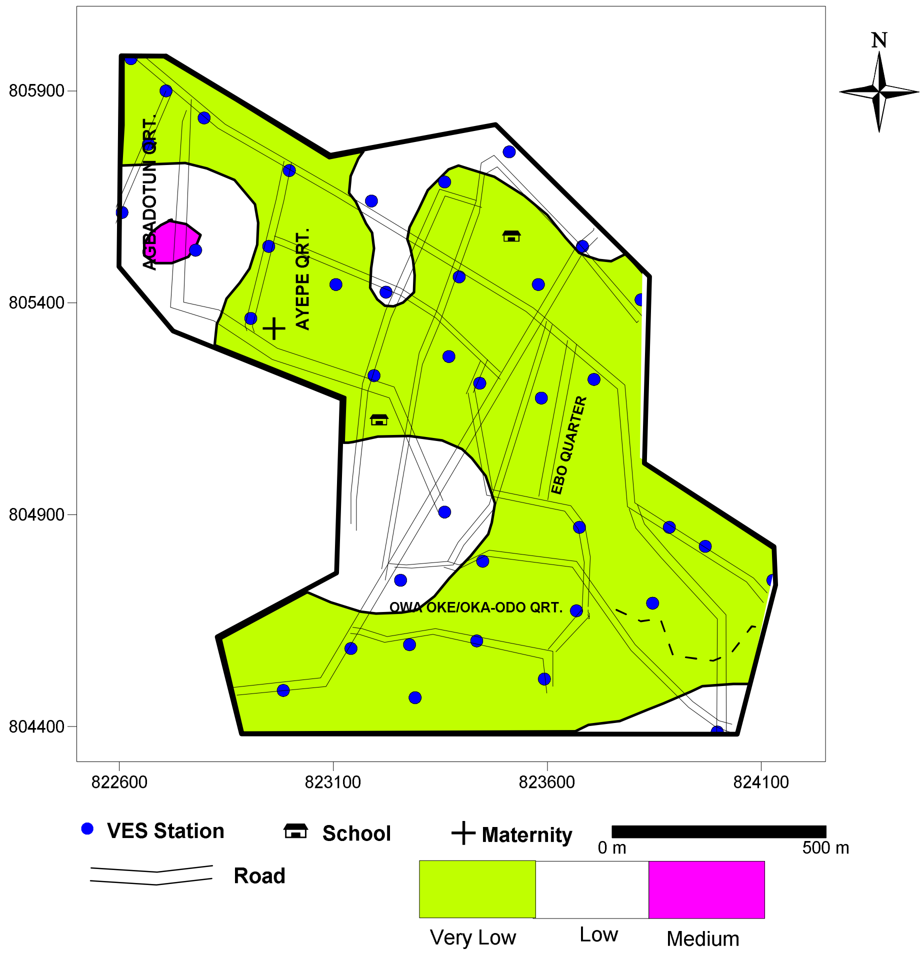

Fig. 8a. Groundwater potential map based on aquifer thickness

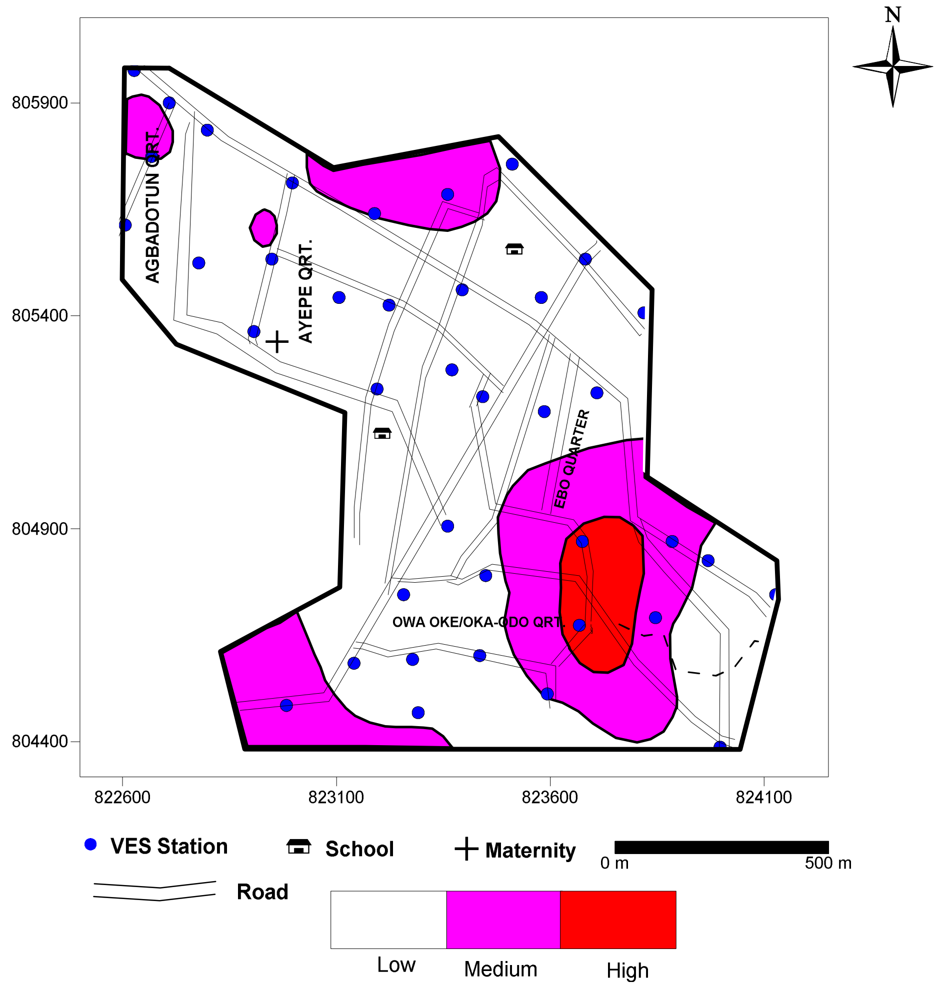

Fig. 8b. Groundwater potential map based on aquifer composition

4. CONCLUSION

The groundwater potential assessment of the Iwaro-Oka, SW Nigeria was carried out in this study. This was necessitated by the fact that, several boreholes drilled in the area were not productive and most of the hand dug wells in the area dried up during dry season and the available surface water are highly polluted. Thirty-nine (39) Vertical Electrical Soundings (VES) stations were occupied within the area using the Schlumberger configuration. This was done with a view to identify the major aquifer unit in the area as means of evaluating its groundwater potential. The field curves were interpreted quantitatively using partial curve matching and computer assisted 1-D forward modeling.

Three type curves (A, H and KH) were identified with H curve type dominating (constitutes 75%). Three distinct geoelectric layers delineated within the area: the topsoil, weathered layer and basement rock. The topsoil is generally thin with no hydrogeologic significant. The weathered layer constitutes the major aquifer unit with thickness generally <10 m. This layer is predominantly composed of clayey materials with resistivity values generally <100 ohm-m with low permeability and of low groundwater discharging capacities.

The overburden thickness in the study area varies from 1.1 to 23.5m but is generally <10 m. The fracture density of the study area is very low and hydrogeologic zoning of the area is majorly based on the aquifer thickness and its composition. It was concluded that most parts of the area falls within the very low/low groundwater potential rating.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
http://www.sciencedomain.org/review-history.php?iid=767&id=5&aid=7476