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Hydrogeologic and Geophysical Assessment of Groundwater Prospects and Aquifer Vulnerability in Alade Idanre, Southwestern Nigeria

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Authors' contributions

This work was carried out in collaboration between all authors. Authors OSE and SO designed the study, performed the statistical analysis, wrote the protocol, wrote the first draft of the manuscript and managed literature searches. Authors FIO, SO and OSE managed the analyses of the study and literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Geophysical survey, involving Schlumberger depth soundings, were conducted at Alade, Ondo State, Nigeria. This was aimed at delineating the water supply areas and assessment of the vulnerability of the aquifers to contaminants infiltrating from the surface. The area is underlain by the basement complex rocks of Southwestern Nigeria. A total of 56 Schlumberger Vertical Electrical Soundings were carried out along the study area. The VES curves were preliminarily interpreted by partial curve matching. The interpretation results were refined with the WinRESIST software, and used to generate geo-electric sections and maps. The HA curves constitute the highest percentage of curves in the area. The geo-electric sections show three to four geo-electric layers which include topsoil, weathered layer and fresh basement. The topsoil varies between 0.4

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and 3.6 m, and the depths to the bedrock are generally less than 7.0 m. The thickness of the vadose zones across the area ranges between 1.4 and 6.0 m. This shows that unconsolidated materials are generally not significantly thick and hence of apparently low groundwater prospect. The topsoil layer has a resistivity mostly within the range of 1 – 100 ohm-m across the area. Resistivity values within the bracket indicate clay sequence; this suggests that aquifers within the unconsolidated overburden at Alade Idanre are mostly capped by semi - pervious materials, geologically protecting the aquifer from near - surface contamination.

Keywords: Schlumberger; aquifer; groundwater; vulnerability; resistivity.

1. INTRODUCTION

The availability of safe and potable water in an environment is a veritable index of a tremendous role to the development and growth of a community. Alade Idenre has witnessed an exponential increase in population of various groups of people in recent time; this development has impacted heavy demands on potable water for domestic uses. At present, groundwater through shallow hand dug well and few borehole constructions constitutes a major source of drinking water supply in this area. The yields are somewhat not enough for the populace and some hand dug well may be vulnerable to surface or near surface contamination. In order to ease the problem of water scarcity and improve the living standard of the community this study was initiated to investigate the hydrogeological characteristics/groundwater potentials and aquifer vulnerability in the area. Geophysical methods play increasingly important roles in locating suitable and productive groundwater reservoirs. Electrical resistivity methods can be used for assessment of hydraulic conductivity of aquifer, transmissivity of aquifer, specific yield of aquifer and contamination of groundwater [1].

These geological features deform the basement rock and enhance groundwater storage and movement [2]. Aquifers in basement complex terrain sometimes occur at shallow depths and such aquifer could be vulnerable to surface or near surface contamination [3]. Animal waste, septic tanks and buried waste at landfills all have the potential to contaminate infiltrating precipitation, and ultimately groundwater. Infiltrating precipitation moves through the vadose zone (the unsaturated material above the water table) and can transport virtually any compound that dissolves in it (chemicals that are improperly stored at the surface). The speed of groundwater movement is measured in feet per year [4]. This is why contaminants that enter groundwater require many years before they are filtered out. The size of the spaces in the soil or rock and how well the spaces are connected determined the speed at which groundwater flows. Contamination usually reduces the electrical resistivity of pure water due to increase in ionic concentration [5]. Alade lies within the precambrian basement complex terrain of southwestern Nigeria [6].

1.1 Location and Geology of the Study Area

Alade Idanre is located at the central Senatorial district of Ondo State. Alade lies within latitudes 6°37’37.55”N to 7°8’24.78”N and longitudes 5°5’43.38”E to 5°37’55.58”E (Fig. 1). The study area falls within the basement complex of southwestern Nigeria and its surface topography can be described as highly undulating with high gradients. Parts of the study area have high rising mountain ranges with topographical elevation ranging from 274 to 304 m. The area experiences two major season; the rainy season which is usually between April to October and dry season between November to March, the annual rainfall ranges between 1250 mm to 2500 mm [7]. The area is situated in the rainforest type of vegetation and characterized by dense evergreen forest; the thick vegetation, farming, forest exploration and other main activities have affected the natural vegetation.

Alade area is underlain by the Precambrian basement complex of southwestern Nigeria [8]. [9] identified six major petrologic units. Mineralogically, the granite gneisses around Alade area composed of alkaline feldspar, quartz, plagioclase and biotite [10]. The structures observed on the outcrops in the study area are faults and Dykes structures. Generally, in a typical basement complex area, groundwater is usually contained in the weathered column and fractured, sheared or jointed/faulted basement column. These geological processes alter rock units to reduce resistivity and hence increase the porosity and permeability of such units for groundwater accumulation.

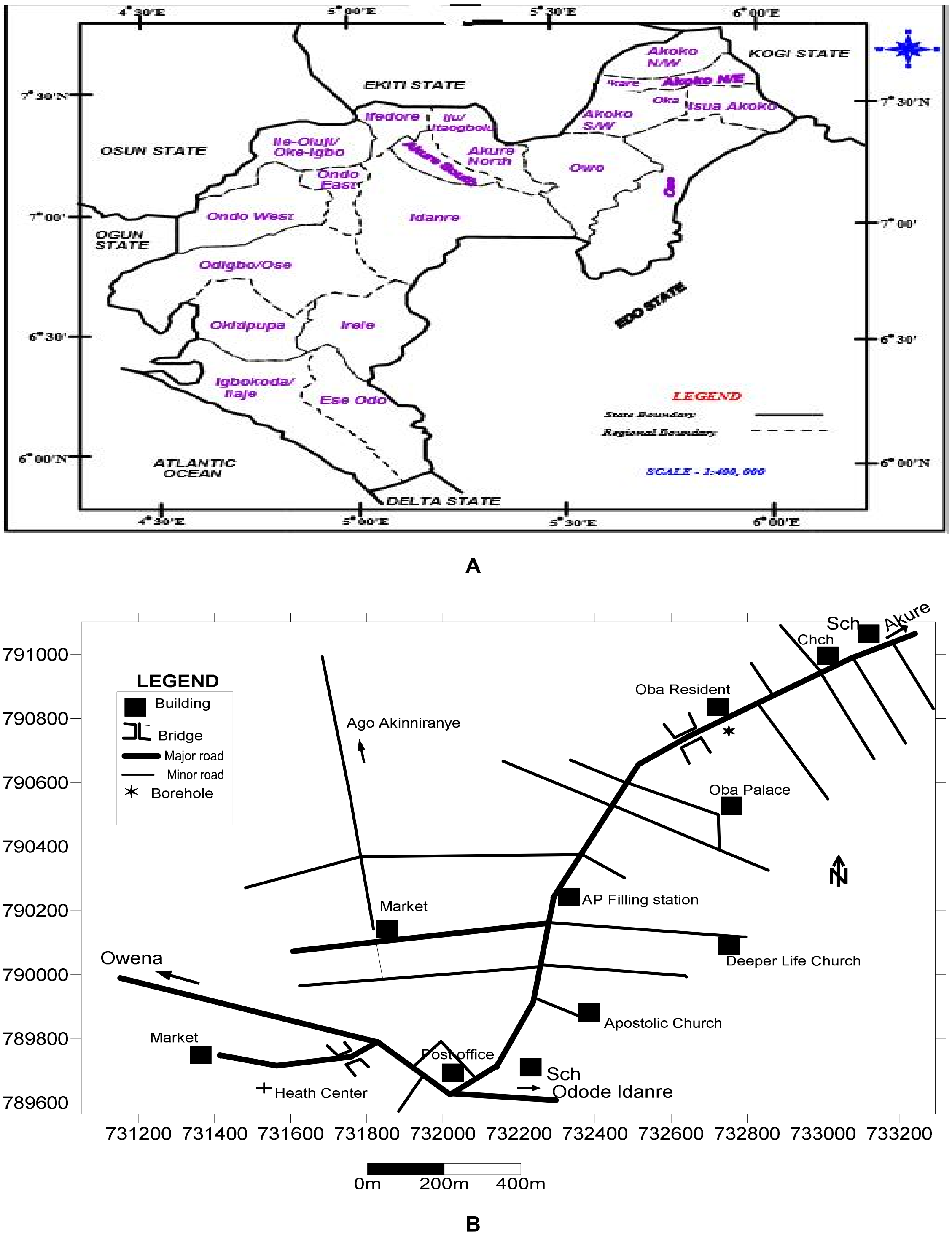

Fig. 1. Map of the study area. A: Map of Ondo State; B: Location map of Alade Idanre

2. METHODOLOGY

2.1 Geophysical Survey

Schlumberger electrical resistivity method (ERM) was utilized in this work, The instrument used are cable, steel electrodes, hammers, ABEM SAS 1000 Terrameter, D.C battery, G.P.S, measuring tapes. It involved moving the current electrodes and having the potential electrodes fixed with reference to the center point. Sixty electrical soundings were carried out in the study area with maximum current electrode spacing (AB) = 130 m, (AB/2) = 65m on each VES points. Vertical Electrical Soundings (VES) were performed continuously and the resistivity along a profile was measured.

The data obtained were plotted on a bi-log graph and the best smooth curve taken through the set of data from the traditional method using master curves and auxiliary charts [11]. The VES data were refined by computer iteration technique as curves, on plots of apparent resistivity against electrode spread (AB/2) on a bilog-paper [12]. The model signature indicates low and high resistivity in the different layers encountered. This method was interpreted qualitatively and quantitatively. Qualitative interpretation involves inspection of profiles, maps and pseudo-sections for anomaly patterns that are characteristics of a particular target. Quantitative interpretation involves partial curve matching techniques which require model curves [13].

2.2 Static Water Level Determination

With the aid of meter rule and tape, the depth to the water levels and total depth in the hand-dug wells within Alade were measured and recorded. The global positioning system (GPS) was used to measure the longitude, latitude and the surface elevation with respect to the mean sea level at point within Alade. The mean sea level is the lowest surface within the earth.

Forty two hang dug wells were logged to reveal estimation of depth to the water level, depth to the bedrock and water table elevation. The surface elevation at different points vary due to topographic variation, the true water level were obtained by subtracting the measured depth to the water level in the hand-dug wells from the surface elevation to get uniform water levels otherwise known as the elevation of the water level [14].

2.3 Hydro-Geological Measurements

Measurements were done from hand dug well to reveal the depth of unsaturated zone (Vadose zone) and the water column.

3. RESULTS AND DISCUSSION

The geo-electric section displays mostly three distinct geo-electric layers which is defined by topsoil comprising of clay/sandy, clay/laterite, (thickness ranging from 0.4-4.0 m and resistivity value between 29 and 854ohm-m), weathered layer (thickness ranges from 0.3-14 m, resistivity value between 3.4 and 489ohm-m) and partially weathered/fresh bedrock (resistivity value between 470 and 8843ohm-m). The groundwater flow direction is towards the southern part of the area. Geo-electric section along E-W in the study area revealed thick weathered layers at VES 16, 36, and 40 indicating good aquifer units for groundwater prospects. The geo-electric section revealed thick overburden zones beneath VES 5, 11, 32 and 41 indicating good aquifer units for groundwater prospects.

3.1 Aquifer Vulnerability Study

Aquifers in crystalline basement terrains are often exposed to environmental risks, due to shallow depth of occurrence. The resistivity parameter of the topsoil geo-electric layer in the study area was used to assess the vulnerability of the underlying aquifer. Fig. 5 is a contour map of resistivity of the layers. About 70% of the resistivity values of the topsoil layer fall within 1 – 100 ohm-m range. In Nigeria, geologically this suggests clayey or silt sequence, which can constitute impervious/semi-impervious barriers.

The unsaturated zone (Vadose) is the geologic materials between the earth's surface and the water table and can also be referred to as zone of aeration. The thickness of this zone determines the transit time, therefore the thicker the vadose zone, the lesser the groundwater vulnerability to contaminants. The contour map (Fig. 5) shows the thickness of the vadose zones in the study area.

Longitudinal unit conductance (S) was used to determine how aquifers are being protected from any infiltrating contaminants. The study revealed that, the higher the value of (S), the more protected the aquifer is (Table 3). Therefore the aquifers at the central flank/Northeastern part of the study area are more protected and not vulnerable to contaminants.

Table 1. Summary of VES results from the study area

S/N (VES)	Layers	Resistivity (ohm-m) $\rho_1/\rho_2 \ldots \rho_{n-1}$	Thickness(m) $t1/t2/\ldots t_{n-1}/t_n$	depth(m) $d1/d2/\ldots d_{n-1}/d_n$	Curve type
1	4	98.6/75.8/53.4/486.4	1.1/0.5/2.8	1.1/1.6/4.4	HA
2	5	74.3/153.9./1705.7/1820.6/705.9	0.6/0.6/1.6/3.4	0.6/1.2/2.8/6.2	A
3	4	232.5/1472/2395.3/4470.3	0.6/0.8/3.4	0.6/1.4/4.9	A
4	5	146.3/100.5/83/1356.9/1130.8	1/0.5/2.1/5.2	1/1.5/3.6/8.3	HA
5	3	164.4/466.9/3090	0.8/5.6	0.8/6.4	A
6	4	115/61.6/52.6/1522.3	0.9/0.4/1.8	0.9/1.4/3.2	HA
7	4	55/34.5/23/2348.3	0.9/0.6/2.3	0.9/1.4/3.7	HA
8	4	33.5/21.8/14.9/1296	1/0.5/2.4	1/1.6/4	HA
9	4	29.4/28/22.7/1429.7	1.2/0.6/2.1	1.2/1.7/3.8	HA
10	3	52.7/32.5/1659.1	1.4/1.1	1.4/2.6	HA
11	4	210.4/102.1/40.4/587.5	1.1/0.8/4.6	1.1/1.9/6.4	HA
12	3	99/49.9/753.8	3.6/1.7	3.6/5.4	HA
13	4	56/32.9/37.8/1936.6	1/0.5/1.7	1/1.4/3.2	HA
14	4	55.1/28.3/26.5/1568.8	0.8/0.6/1.6	0.8/1.4/3	HA
15	4	72.9/69.1/31.9/3692.6	1.1/1/4.6	1.1/2/1/6.7	HA
16	4	88.5/166.6/77.1/2361.1	1.6/1.1/6.6	1.6/2.7/9.4	KHA
17	4	59.4/251.4/38.7/834.6	0.8/1.3/4.4	0.9/2.1/6.5	KHA
18	4	93.5/59.6/38.7/3163.1	1/0.5/3.4	1/1.5/4.9	HA
19	4	44.9/14.5/219.6/4543.2	0.9/1/2.5	0.9/1.9/4.4	HA
20	4	59.4/3.4/292.3/3434.3	1.1/0.3/1.6	1.1/1.5/3	HA
21	5	677/149.1/116.3/47.6/1417.3	0.7/0.4/1/5.7	0.7/1.1/2.1/7.8	KHA
22	3	38.8/39.2/2455.6	1/2.8	1/3.8	A
23	4	217.2/16.8/38.8/1009.1	0.4/0.5/3.4	0.4/0.9/4.3	HA
24	4	96/72.1/252/4211.2	0.9/3.4/2.4	0.9/4.3/6.7	HA
25	5	42.8/110.4/64.1/32.3/1908.2	0.7/0.6/1.7/4	0.7/1.2/2.9/6.9	KHA
26	4	280.7/128.2/17.3/909	1.5/0.6/3.7	1.5/2.1/5.8	HA
27	4	187.8/82.8/43.4/613.4	0.8/0.5/4.1	0.8/1.2/5.3	HA
28	4	145.8/54/35/913	0.6/0.4/2	0.6/1/3	HA
29	5	552.9/252.8/355.2/708.5/790.2	0.7/0.4/1/9	0.7/1.1/2.1/11	HA
30	4	217.8/79.3/119.5/944.2	0.7/0.9/2.6	0.7/1.7/4.2	HA
31	4	127.8/30.4/60.6/6140.2	1.2/1.4/1.9	1.2/2.6/4.4	HA
32	4	464.7/137.1/126/661	0.7/1.6/11	0.7/2.3/13.3	HA
33	3	79.8/488.5/6643.5	0.5/9	0.5/9.5	A
34	4	182.9/65/90.6/8843	0.7/1/3.7	0.7/1.6/5.3	HA
35	4	333.5/74.2/54.8/3587	1/1.3/4.9	1/2.4/7.3	HA
36	4	91/39.5/41.4/906.2	0.5/0.9/4.8	0.5/1.4/6.2	HA
37	4	71.1/18.4/45.9/1342	0.7/0.9/1.8	0.7/1.6/3.4	HA
38	4	67.8/11.8/21.4/2142.3	0.8/1.1/2	0.8/1.9/3.9	HA
39	4	368/74.1/35.9/3938.4	0.8/0.6/2.4	0.8/1.4/3.8	HA
40	4	176.6/39.6/55.4/469.5	0.9/1.5/3.6	0.9/2.5/6.1	HA
41	5	150.8/199.2/100.7/111.4/1722	0.9/0.8/1.9/4.3	0.9/1.7/3.6/8	KHA
42	4	853.5/119.9/131.7/1396	0.7/1.1/4.1	0.7/1.8/5.9	HA
43	4	461.7/70.1/74.3/5349.4	0.4/2.2/4.2	0.4/2.5/6.7	HA
44	4	68.8/86.2/82.3/3130.2	0.9/2.5/3.2	0.9/3.4/6.6	A
45	5	386.8/176/287/317.5/2751.2	0.8/1/4.6/11.2	0.8/1.8/6.4/17.6	HA
46	4	408/58.3/31.9/5685.1	0.6/0.9/3	0.6/1.4/4.5	HA
47	5	383.8/47.9/86.2/134.9/1246.2	0.5/1/2.5/13.7	0.6/1.6/4/17.7	HA
48	4	270.6/56.9/45.4/2449.5	0.5/1.1/5.7	0.5/1.6/7.3	HA
49	4	659.3/177.6/73.5/3252.5	1.3/1.2/4.8	1.3/2.5/7.3	HA
50	5	164.8/228.5/164.1/280.9/3095.8	0.9/0.8/1.8/3.3	0.9/1.7/3.5/6.8	A
51	4	313.4/496.1/377.2/2604	1/1.6/4.7	1/2.6/7.4	A
52	4	163.7/4637.7/1099.3/3034.8	0.6/3.1/6.8	0.6/3.7/10.5	A
53	3	72.3/57/705.4	3.9/3.6	3.9/7.5	HA
54	5	130.2/188.7/22.7/77.3/4067.7	0.8/0.8/2/2.4	0.8/1.5/3.5/5.9	KHA
55	4	627.9/201.8/79.7/2713.2	0.7/2.1/7.3	0.7/2.8/10	H
56	4	234.3/98.2/163.7/868.6	1.5/2.7/6.1	1.5/4.2/10.3	HA

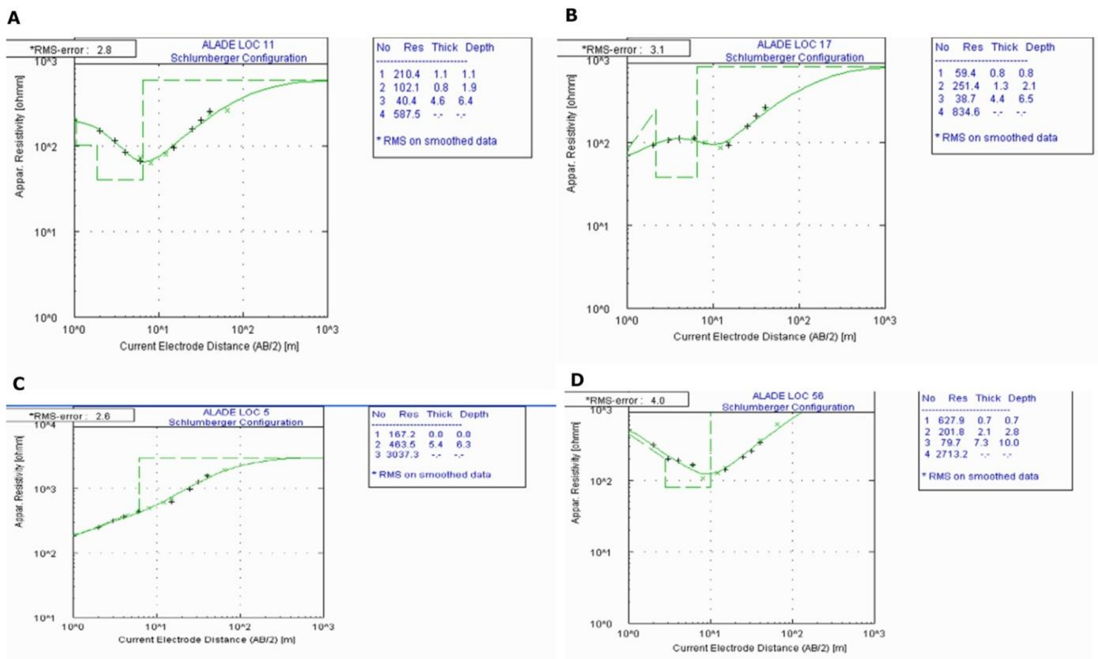

Fig. 2. Typical vertical electrical sounding curves from the study area
A: HA curve type, B: KHA curve type, C: A curve type, D: H curve type

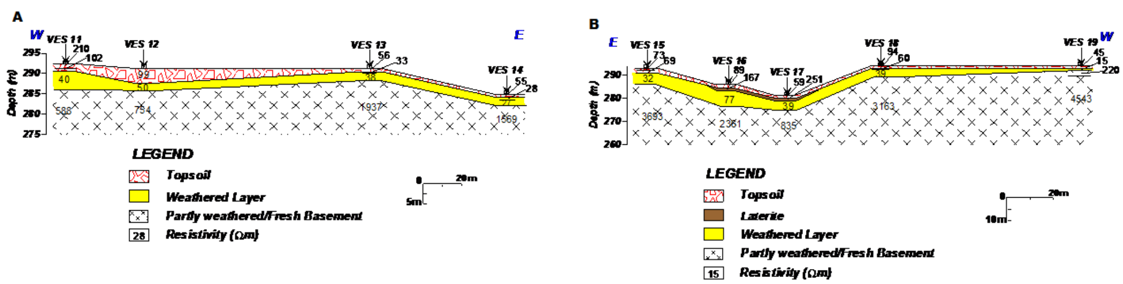

Fig. 3. Geo-electric sections of interpreted resisitivity data from the study area
A: Geo-electric section along W – E direction; B: Geo-electric section along E – W direction

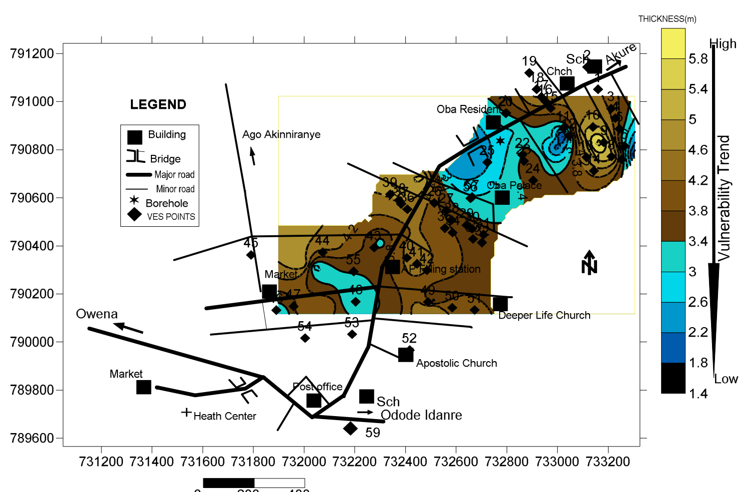

Fig. 4. Thickness map showing unconsolidated materials overlying the basement at Alade

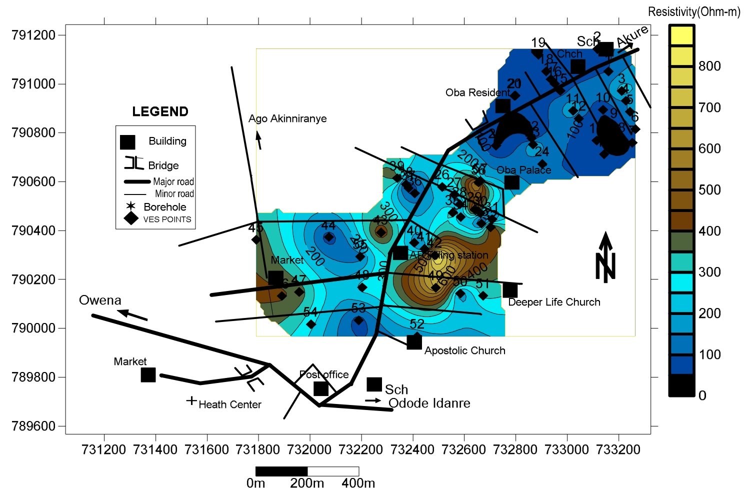

Fig. 5. Contour map showing the resistivity distribution of the aquifer units

Table 2. Field data acquired for the static water level and elevations within the study area

Well no	Latitude (degree, min, sec)	Longitude (degree, min, sec)	Elevation (m)	Depth to water level (m)	Total depth(m)	Water column	Static water level
1	070 08' 59.5"	0050 06' 44.9"	293	1.48	3.20	1.72	291.5
2	070 08' 59.1"	0050 06' 42.2"	294	5.00	5.40	0.40	289.1
3	070 08' 59.0"	0050 06' 42.2"	297	4.90	5.00	0.10	292.1
4	070 09' 01.2"	0050 06' 40.2"	293	6.00	6.07	0.07	287.0
5	070 09' 02.6"	0050 06' 37.7"	298	4.70	6.20	1.50	293.3
6	070 09' 02.2"	0050 06' 35.5"	293	1.50	2.60	1.10	291.5
7	070 09' 00.4?	0050 06' 34.7"	292	2.06	3.33	1.27	289.9
8	070 09' 02.0"	0050 06' 34.5"	298	3.00	4.40	1.40	295.0
9	070 09' 03.6"	0050 06' 35.8"	297	3.28	4.65	1.37	293.7
10	070 09' 07.5"	0050 06' 32.2"	306	4.68	5.10	0.42	301.3
11	070 09' 04.8"	0050 06' 27.3"	305	3.20	4.85	1.65	301.8
12	070 09' 02.8"	0050 06' 29.6"	295	3.00	3.80	0.80	292.0
13	070 09' 02.7"	0050 06' 31.2"	306	3.30	4.50	1.20	302.7
14	070 09' 00.6"	0050 06' 30.6"	297	3.40	3.80	0.40	293.6
15	070 08' 58.7"	0050 06' 30.7"	295	3.50	3.60	0.10	291.5
16	070 08' 59.0"	0050 06' 32.1"	301	3.60	3.80	0.20	297.4
17	070 08' 58.5"	0050 06' 31.0"	297	3.70	4.00	0.30	293.3
18	070 08' 59.4"	0050 06' 24.8"	291	2.30	3.80	0.50	288.9
19	070 09' 04.5"	0050 06'24 .2"	293	2.60	3.80	1.20	290.4
20	070 08' 57.9"	0050 06' 21.1"	292	2.20	3.40	1.20	289.8
21	070 08' 56.5"	0050 06' 17.5"	292	5.10	5.60	0.50	286.9
22	06037' 15.6"	0050 37' 39.6"	297	3.60	4.50	0.90	293.4
23	060 37' 15.6:	0050 37' 38.8"	298	3.80	4.30	0.50	294.2
24	060 37' 9.5"	0050 37' 34.4"	301	4.10	5.20	1.10	296.9
25	060 37' 12 0"	0050 37' 31.6"	290	4.50	5.40	0.90	285.5
26	060 37' 7.5":	0050 37' 34 8"	302	3.20	4.10	0.90	297.9
27	060 37' 5.3"	0050 37' 34.1"	294	3.80	4.90	1.10	290.2
28	060 37' 2.0"	0050 37' 33.8"	291	4.20	5.10	0.90	286.8
29	060 37' 0.7"	0050 37' 33.7"	300	4.20	5.30	1.10	295.8
30	060 36' 57.8"	0050 37' 31.8"	307	4.90	5.70	0.80	302.1
31	060 36' 59.0"	0050 37' 31.4"	302	2.80	3.90	1.10	299.2
32	060 36' 54.4"	0050 37' 25.0"	305	3.00	3.70	0.70	302.0
33	060 36' 55.1"	0050 37' 25.2"	295	3.10	4.50	1.40	291.9
34	060 36' 56.8"	0050 37' 25.4"	308	3.90	4.80	0.90	304.1
35	060 37' 1.0"	0050 37' 26.4"	304	4.10	5.10	1.00	299.9
36	060 37' 3.4"	0050 37' 26.8"	286	3.00	4.10	1.10	283.0

Well no	Latitude (degree, min, sec)	Longitude (degree, min, sec)	Elevation (m)	Depth to water level (m)	Total depth(m)	Water column	Static water level
37	006037' 3.6"	0050 37' 26.3"	277	3.20	4.50	1.30	273.8
38	060 37' 4.7"	0050 37' 26.7"	292	3.30	4.20	0.90	288.7
39	060 37' 9.6"	0050 37' 25.8"	294	3.60	4.80	1.20	290.4
40	060 37' 12.1"	0050 37' 26.1"	302	4.40	6.10	1.70	297.6
41	060 37' 14.4"	0050 37' 26.0"	301	4.60	6.30	1.70	296.4

Table 3. Longitudinal conductance on each VES point

Latitude	Longitude	VES point	Longitudinal conductance
07009'08.4"N	005006'40.2"E	1	0.0177
07009'04.5"N	005006'42.4"E	2	0.0118
07009'00.7"N	005006'43.6"E	3	0.0143
07008'58.9"N	005006'43.2"E	4	0.0335
07008'59.3"N	005006'41.9"E	5	0.0521
07009'01.2"N	005006'40.9"E	6	0.0522
07009'03.3"N	005006'39.5"E	7	0.0264
07009'03.2"N	005006'35.7"E	8	0.0130
07009'02.2"N	005006'36.4"E	9	0.0404
07008'59.2"N	005006'38.7"E	10	0.0179
07008'57.4"N	005006'39.6"E	11	0.0357
07009'05.9"N	005006'34.1"E	12	0.0296
07009'06.8"N	005006'33.4"E	13	0.0246
07009'07.4"N	005006'32.9"E	14	0.0187
07009'08.5"N	005006'32.3"E	15	0.0189
07009'10.7"N	005006'31.4"E	16	0.0200
07009'02.5"N	005006'30.2"E	17	0.0003
07009'05.3"N	005006'28.4"E	18	0.0216
07008'58.7"N	005006'30.6"E	19	0.0018
07008'56.1"N	005006'31.8"E	20	0.0094
07008'58.6"N	005006'25.9"E	21	0.0483
07008'53.1"N	005006'19.1"E	22	0.0100
07008'52.1"N	005006'20.6"E	23	0.0100
07008'50.8"N	005006'21.3"E	24	0.0120
07008'50.1"N	005006'40.7"E	25	0.0013
07008'49.6"N	005006'24.4"E	26	0.0022
07008'48.8"N	005006'25.4"E	27	0.0090
07008'47.7"N	005006'25.2"E	28	0.0132
07008'49.1"N	005006'21.4"E	29	0.0038
07008'49.7"N	005006'20.4"E	30	0.0205
07008'52.3"N	005006'15.6"E	31	0.0055
07008'53.0"N	005006'14.8"E	32	0.0098
07008'53.5"N	005006'14.5"E	33	0.1035
07008'54.3"N	005006'13.4"E	34	0.0103
07008'45.7"N	005006'15.5"E	35	0.0051
07008'44.9"N	005006'16.8"E	36	0.0100
07008'44.0"N	005006'18.1"E	37	0.0018
07008'47.1"N	005006'11.3"E	38	0.0009
07008'46.5"N	005006'04.7"E	39	0.0420
07008'46.2"N	005006'55.5"E	40	0.0021
07008'38.7"N	005006'58.7"E	41	0.0169
07008'39.2"N	005006'00.9"E	42	0.0013
07008'39.8"N	005006'08.9"E	43	0.0212
07008'39.7"N	005006'18.2"E	44	0.0087
07008'38.9"N	005006'21.3"E	45	0.0090
07008'38.6"N	005006'24.2"E	46	0.0064
07008'35.4"N	005006'08.4"E	47	0.0539
07008'43.9"N	005006'08.6"E	48	0.0103
07008'34.9"N	005006'02.4"E	49	0.0116
07008'33.2"N	005006'15.8"E	50	0.0064

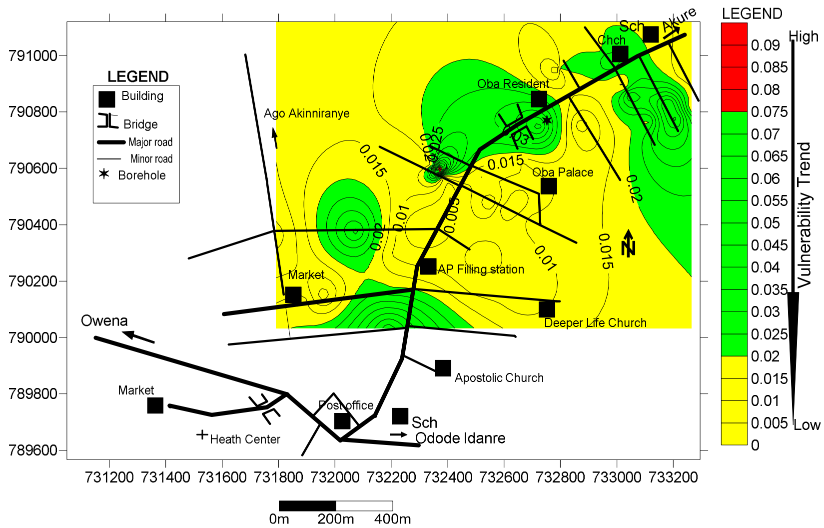

Fig. 6. Thickness map showing longitudinal conductance from the study area

3.1.1 Aquifer

The weathered unit constitutes the aquifer in the study area. The weathered layer resistivity map (Fig. 5) shows resistivity distribution ranging from about 33-900ohm-m. Low resistivity values (below 100) were observed in the central and part of the northeastern location which may be indicative of clayey materials. Also, it was observed that there are moderately weathered zones characterized with resistivity range of 100ohm-m and 450ohm-m. These zones are associated with good groundwater prospects [15]. In the absence of the fractured bedrock with resistivity range of 500-900 Ohm-m, the weathered layer is not expected to produce sufficient groundwater.

4. CONCLUSIONS

The VES results revealed that the topsoil is covered by almost 70% of clayey material. The unconsolidated layer and the weathered bedrock constitute the aquifer units in the study area. With reference to hydrological measurement of the existing wells, groundwater flow direction is towards Southern part of the area. It is also observed that considering the impermeability of the clayey topsoil which serves as the aquifer protector, the aquifer units in the study area are less vulnerable to contamination. The geo-electric sections delineated three to four subsurface geo-electric layers which include topsoil, weathered, and partially weathered/Fresh bedrock. The topsoil comprises of clay/sandy clay/laterite with thickness ranges from 0.4-3.6 m and resistivity values between 29 and 854 Ohm-m, while the weathered layer thickness range from 0.3-13.7 m, with resistivity value ranging between 30 and 489 Ohm-m. The partially weathered/fresh bedrock resistivity values ranges between 470 and 8843 Ohm-m, this indicate that the unconsolidated material in the study area is not significantly thick, thus suggesting that the groundwater potential in Alade is rating low. From the general results obtained, the study revealed that the water supply units in Alade are rated low to contamination.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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