RESISTIVITY METHODS IN HYDRO-GEOPHYSICAL INVESTIGATION FOR GROUNDWATER IN AGHALOKPE, WESTERN NIGER DELTA

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ABSTRACT

A combined surface and subsurface resistivity investigation was conducted in Aghalokpe with a view to providing adequate information about the subsurface layers, groundwater potential and quality of the area. Twelve (12) Schlumberger depth soundings and one (1) single-point resistance logging were carried out in the study area. Four subsurface layers were delineated from the investigation. The first layer is the top soil and has resistivity values ranging from 92-1009.1 ohm-m and thickness between 0.8-1.6m. The second layer composed of clay and sand has resistivity values varying from 61.9-1571.2 ohm-m and thickness ranging from 1.3-16.1m. The third and fourth geoelectric layers with resistivity values ranging from 414.8-4091.1 ohm-m diagnostic of fine and medium to coarse grained sands constitute the aquifer unit and occur at an average depth of 10.8m and extend beyond 63.8m. The result of the water quality based on total dissolved solids computed from the single-point resistance log showed that the groundwater in the upper part of the aquifer may not be potable because of TDS concentration above the lower limits of general acceptability of 500 ppm. But at the depth of 18-50m, the quality of the groundwater seems to be potable.

KEY WORDS: Potable Water, Geoelectric, Resistivity, Formation Factor, Electrical Conductivity

INTRODUCTION

Although groundwater cannot be seen on the earth's surface, a variety of surface investigation techniques can provide information about its occurrence. Though there are various geophysical techniques employed in assessing groundwater source, the electrical resistivity method remains the most useful and cost-effective techniques in groundwater studies (Koefoed, 1979; Rubin and Hubbard, 2005). The electrical resistivity contrasts that exist across interfaces of lithologic units in the subsurface are used to delineate discrete geoelectric layers and identify aquiferous or non-aquiferous layers (Schwarz, 1988). The aquifer in the study area are shallow and exploited by shallow (<30m) boreholes and dug wells. Various studies (Akpoborie *et al*., 2000, Olobaniyi *et al*., 2007) have indicated that these shallow aquifers are vulnerable to contamination from surface and non-surface sources.

A detailed study of groundwater and conditions under which it occurs can be made by supplementing surface investigation with well log data which gives a clearer picture of groundwater occurrence. It is now generally accepted that the quality of water is just as important as its quantity. Quality of groundwater can be assessed based on total dissolved solids as dissolved solids in groundwater can pose hazards if their presence goes undetected.

The present work is an integration of surface and subsurface resistivity methods in investigation of groundwater in Aghalokpe. The surface resistivity was used to locate potential aquifer(s) while the subsurface resistivity was used to evaluate groundwater quality based on total dissolved solids.

Location and Geology

Aghalokpe is about 22km Southeast of Sapele and it is bordered by latitudes $5^0$45'N, 5^0 47'N and longitudes $5^0$50'E, 5^o53'E (Figure 1). The study area is underlain by the Sombreiro-Warri Deltaic Plain (Oomkens, 1974) which overlies the Benin Formation within the Niger Delta basin. The geology of the Niger Delta has been described by Short and Stauble (1965); Asseez (1976).

The Niger Delta consists of three stratigraphic units; the base of the Delta is the Akata Formation (Paleocene-Eocene) which consists of marine shales and silts. The Agbada Formation (Eocene-Oligocene) overlies the Akata Formation and is made up of paralic sequence consisting of sands and shales. Their lateral equivalents at the surface are the Ogwashi-Asaba Formation and Ameki Formation of Eocene-Oligocene age (Short and Stauble, 1967; Asseez, 1989). Above the Agbada Formation is the Benin Formation (Oligocene-Recent) which comprises of continental/fluvial sands and gravels. The Benin Formation is however overlain by the Quatenary Sombreiro-Warri Deltaic Plain Deposits which are 40 - 150 m thick, an unconfined aquifer sequence comprising rapidly alternating sequences of sand and silt/clay, with the latter becoming increasingly prominent seawards are thought to have been laid down during the Quaternary interglacial marine transgression (Oomkens, 1974; Durotoye, 1989; Etu-Efeotor and Akpokodje, 1990). The hydraulic conductivity of the sands varies from 3.8 x 10^{-3} m/s to 9x10^{-2} m/s which indicates potentially productive aquifer (Akpoborie *et al*., 2000).

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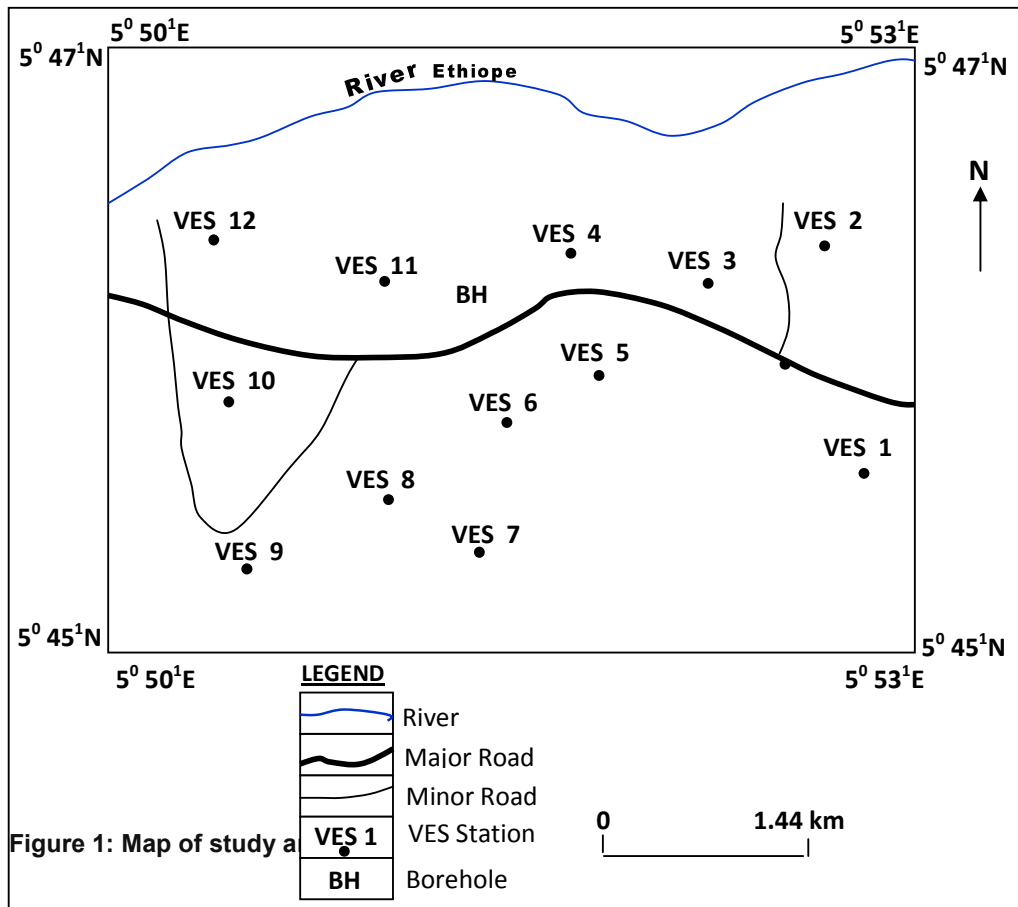
Figure 1: Map of study area

MATERIALS AND METHODS

Surface Investigation

Twelve (12) dc-resistivity vertical electrical soundings were run in Schlumberger array with an ABEM SAS 1000 model Terrameter using current electrode spacing (AB) ranging from 2-450m. The measured apparent resistivities and electrode spacing were plotted on a bi-log graph paper. The initial interpretation of the VES data was accomplished using conventional partial curve matching techniques utilizing two-layer master curves (Koefoed, 1979) and their corresponding auxiliary point diagrams (Orellana and Mooney, 1966). The resistivities and thicknesses obtained were used in a computer programme for refining the partial curve matching interpretative results which reduced errors to acceptable levels (Barker, 1989). The programme, winResist version 1.0 based on the work of Vander Velpen (2004) was used. The interpreted VES results are summarized in Table 1.

Subsurface Investigation

The conventional single-point resistance logs measure the resistivity in ohm-m between an electrode as it is lowered down a well and another electrode on the land surface (Keys, 1990). A digital ABEM SAS 1000 model Terrameter was used for logging the well and total of twenty two (22) readings were recorded from bottom of the well (50m) to the top (8m) of the well at a regular interval of 2m. The bulk resistivity of the formation measured is given by

$$\rho_b = KR \ldots \ldots (1)$$

Where K is geometric factor and R is resistance in ohms.

The resistivity of the pore water ρ_w, can be related to the bulk resistivity through Archie's law for sandy materials (Archie, 1942).

$$\rho_b = F \text{ x } \rho_w \ldots \ldots (2)$$

where F is the formation factor and is given by

$$F = a / \phi^m \ldots \ldots (3)$$

Where a, is a constant taken as 0.62 for soft deposits (Repsold, 1989).

ϕ is the porosity (taken as 0.34 for the sands of the Sombreiro-Warri Deltaic Plain Deposits) and m, a cementation index taken as 2.15 for soft deposits (Repsold, 1989). The formation factor depends on the lithology and usually consistent for a given sedimentary unit. Using a formation factor value of 5.4 determined from equation (3) in equation (2), the resistivity of the pore water (formation water) ρ_w is obtained. The resistivity of the pore water was plotted as the abscissa while the corresponding depths plotted as the ordinate as shown in Figure 5.

Turcan (1966) method for estimating water quality from electronic logs utilized mathematical expression which relates the following parameters.

  i.   Formation resistivity factors and fluid resistivity

  ii. Pore water resistivity and electrical conductivity

iii.   Electrical conductivity (EC) and total dissolved solids (TDS).

TDS = 0.64   x EC

= 0.64   x $\underline{10,000}$ . . . . (4)

$$\rho_w$$

The resistivity of the pore water was used for estimating the total dissolved solids (TDS) in ppm of groundwater using

equation (4). The results of water quality based on TDS are presented in Table 2.

Table 1: Results of interpretation of VES curves at Aghalokpe

VES Stations	Resistivity (ohm-m) $\rho_1/\rho_2/\rho_3/----\rho_n$	Thickness (m) $h_1/h_2/h_3/----h_n$	Type curves
1	1009.1/494.5/445.7/1210.2/4091.1	1.3/1.3/7.8/53.4	QHA
2	1310.0/76.0/1854.4/188.6	3.1/5.5/20.1	HK
3	92.0/61.9/937.5/1206.0	0.8/12.5/21.1	HA
4	392.6/508.3/653.0/1011.8/1246.1	0.8/2.6/71/18.3	AAA
5	588.0/73.5/861.2/1570.0	1.1/8.2/26.4	HA
6	68.0/240.0/414.8/1370.8	1.0/2.7/11.5	AA
7	271.2/494.3/717.1/958.5	1.0/8.8/18/4	AA
8	245.0/361.3/682.6/1214.1	0.9/12/16.5	AA
9	512.3/449.0/658.1/1341.6	1.3/16.1/14.5	HA
10	581.2/419/737.4/1128.6/1524.8	1.2/3.1/2.5/17.9	HAA
11	538.0/101.3/827.1/1632.0	1.2/7.5/21.6	HA
12	713.3/1629.4/2107.1/1325.0	1.0/2.8/19.9	AK

Table 2: Bulk resistivity, pore water resistivity and total dissolved solid values

Depth (m)	Bulk Resistivity ρ_b (ohm-m)	Pore water Resistivity ρ_w (ohm-m)	TDS (ppm)
8	6.2559000	1.158500	5524.0
10	12.360600	2.289000	2795.0
12	21.965000	4.067600	1573.0
14	40.678700	7.533100	850.00
16	64.945800	12.02700	532.00
18	88.608600	16.40900	390.00
20	123.14380	22.80440	281.00
22	158.02880	29.26460	219.00
24	184.55580	34.17700	187.00
26	169.27220	31.34670	204.00
28	252.80860	46.81640	137.00
30	260.30000	48.20370	133.00
32	425.90020	78.87040	81.000
34	489.35290	90.62090	70.100
36	746.14120	138.1743	46.300
38	980.23550	181.5251	32.300
40	3142.2848	581.9046	11.000
42	2032.5600	376.4000	17.000
44	2196.8820	406.8300	15.700
46	4002.4800	741.2000	8.6000
48	3091.5000	572.5000	11.200
50	3290.4360	609.3400	10.500
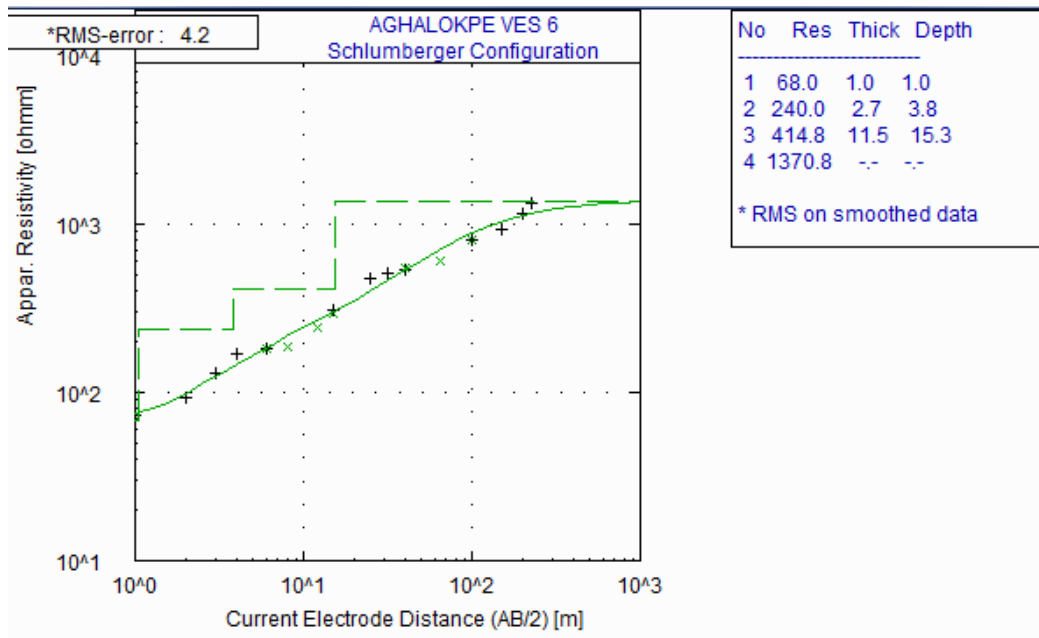
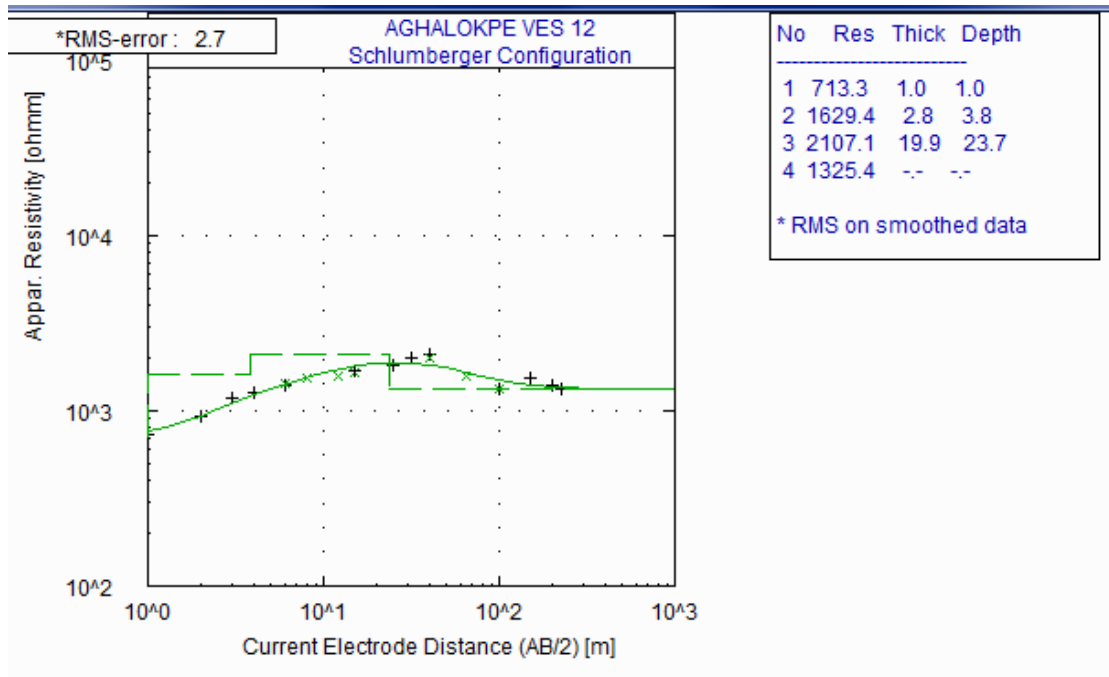**Figure 2:** Typical VES Curves for Aghalokpe

Figure 3: Typical VES curves for Aghalokpe

RESULTS AND DISCUSSION

The depth sounding curves (Figures 2 & 3) were classified into different type curves: AA, AK, HK, HA, AAA, HAA and QHA. The HA-type curve is the most predominant and accounts for about 33.5% of the total type curves. The geoelectric sections (Figure 4) that was drawn from the interpreted results show four geoelectric layers. The first layer is the topsoil with resistivity values ranging from 92-1009.1 ohm-m while the thickness of the layer varied from 0.8-1.6m. The second layer which has resistivity values varying from 61.9-1571.2 ohm-m are presumably clay/fine sand/medium sand. The resistivity values of 61.9-101.1ohm-m at VES 2, VES 3, VES 5 and VES 11 with thickness ranging from 5.5m (VES 2) to 12.5m (VES 3) is characteristic of clay (Figure 4). The sandy material of the second layer has thickness that varied from 1.3-16.1m. The third and fourth layer constitutes the aquifer unit. The third layer which has resistivity values ranging from 414.8-2107.1ohm-m is diagnostic of fine sand/medium sand/coarse sand. This layer is between 2.5-53.4m thick. The fourth layer comprises of fine sand and coarse sand with resistivity values ranging from 958.5-4091.1ohm-m except at VES 2 where silt having a resistivity value of 188.6 ohm-m was delineated. The exact thickness of this layer could not be determined as the electrode current terminated within this layer.

The results of groundwater quality are presented in Table 2. For potable drinking water, USEPA (2011) proposed 500 ppm of TDS as the lower limits of general acceptability. The results of the investigation were compared with the USEPA (2011) recommended standards.

At depths of 8-12m, the total dissolved solid (TDS) is very high and ranges from 1573-5524 ppm. Water from these depths is not suitable for domestic and industrial uses and as a result requires critical treatment. Groundwater from dug wells used for domestic purpose without prior treatment is abstracted from these depth zones (8-12m) and there are concerns about health implications. The high TDS levels in the shallow groundwater indicate that there is indeed cause for concern at Aghalokpe. At depths of 14-16m, the TDS concentration ranges from 532-850 ppm. The water at these depths is still not suitable for domestic and industrial purposes and requires minor-treatment. The sources of elevated TDS concentration include waste disposal and weathering of minerals in soils which can change the water chemistry (Adamson and Hornung, 1990). However, at depths of 18-50m, the TDS concentration ranged between 10.5 and 390 ppm. The quality of the groundwater at these zones is high and is suitable for domestic and industrial purposes.
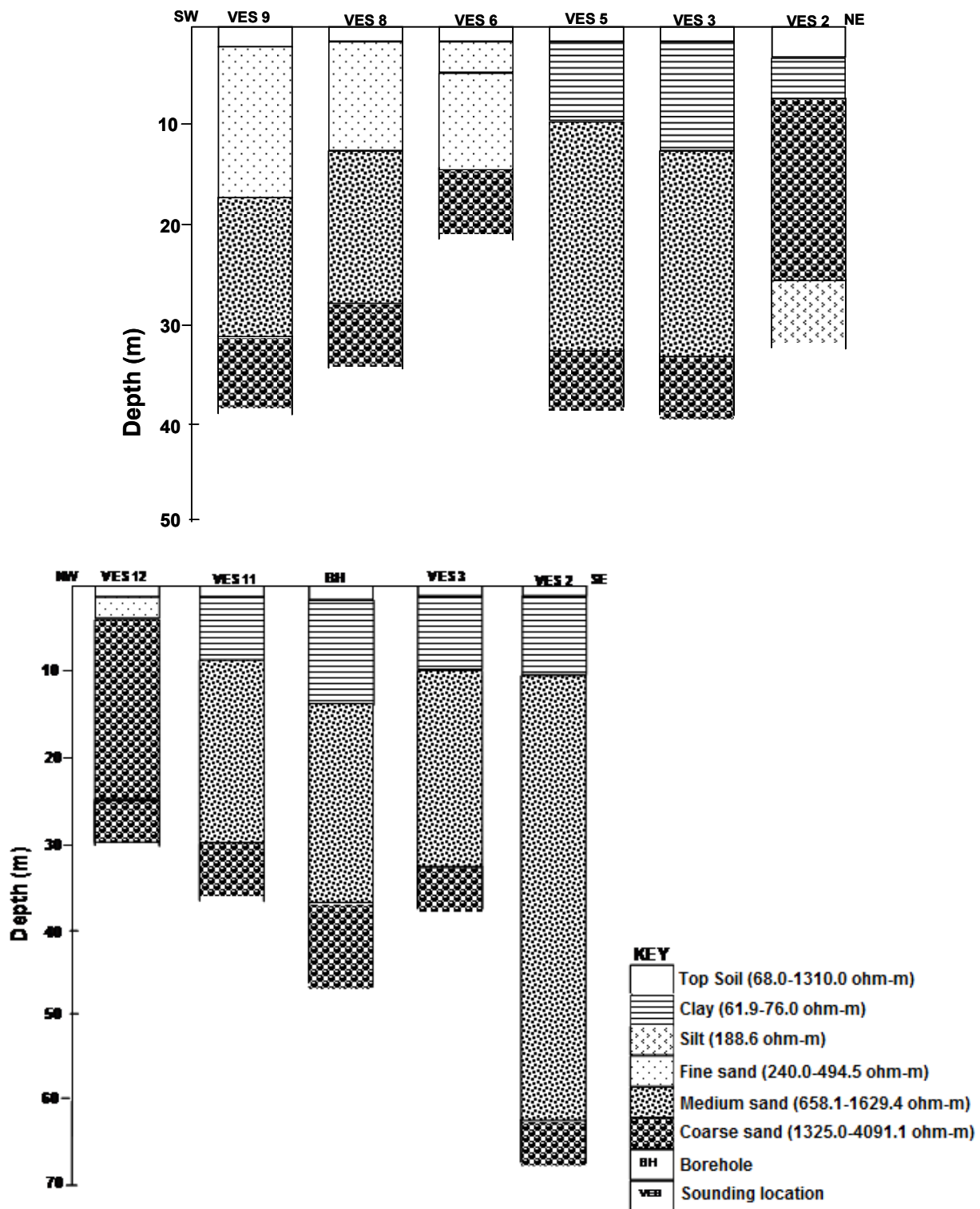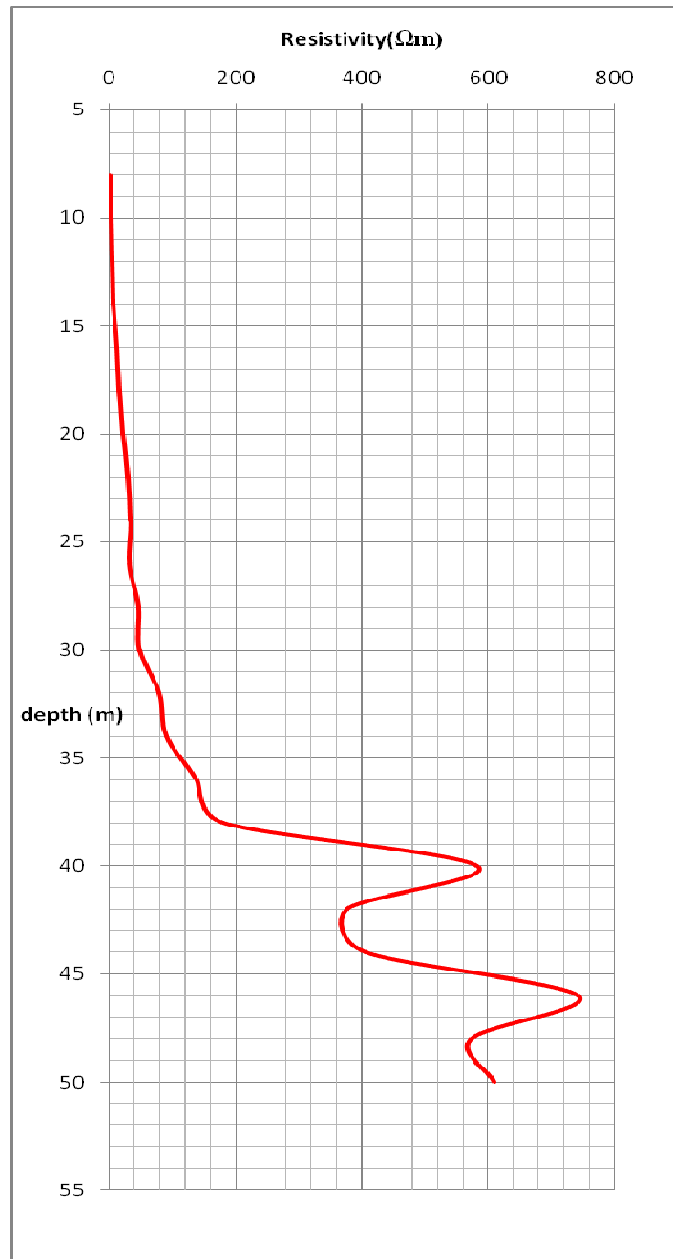
Figure 4: Geoelectric Section of Aghalokpe

Figure 5: Single-Point Resistance Log of Aghalokpe

The single-point resistance log shown in Figure 5 indicated that as depth increased in the aquifer, the resistivity also increased while TDS reduced and thus, water quality improved. This showed that total dissolved solids in water are related to resistivity and quality of water. As TDS decrease, water quality increases (Turcan, 1966). Low resistivity values in the upper parts of the aquifer (8-16m) as shown in Table 1 and Figure 5 may be indication of clay layer. In water well, higher resistivity (low TDS) in a saturated zone implies higher quality water.

CONCLUSION

A surface and subsurface resistivity survey was carried out at Aghalokpe with the aim of evaluating the groundwater potential and quality. The surface study revealed four geoelectric layers. The third layer (at an average depth of 10.8m) and fourth layer (at an average depth of 31.0m) with resistivities that varied between 414.8-2107.1 ohm-m and 958.5-4091.1 ohm-m respectively constitutes the aquifer unit in the study area. The groundwater occurs in this aquifer under unconfined conditions except at VES 2, VES 3, VES 5, and VES 11 where the aquifer is confined by a clay overburden with an average thickness of 8.4m.

Water quality improved with depths as the total dissolved solids reduced. Water quality at depths between 8 and 16m is low because the TDS concentration is higher than 500 ppm proposed by USEPA (2011). However, the water quality appeared to be higher at depths between 18 and 50m because TDS concentration at these depths ranged between 10.5 and 390 ppm (below the lower limits of general acceptability of 500 ppm). Possible source of TDS in groundwater may be due to indiscriminate waste disposal.

It is evident from this study that the eastern and central parts of the study area are less susceptible to contaminants because they are protected by clay overburden having an average thickness of 8.4m. Hence, it is recommended that boreholes should be sited in these locations (around VES 2, 3, 5 and 11). Also, groundwater in the near surface parts of the aquifer may not be potable; it is therefore recommended that screens should be placed at the depth of 50m and below.

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