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Full Length Research Paper

Aquifer vulnerability assessment at Oke-Ila area, Southwestern Nigeria

Aweto, K. E.

Department of Geology, Delta State University, Abraka, Nigeria. E-mail: kizaweto@yahoo.com.

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Twenty Five Schlumberger depth sounding data from Oke-Ila and environments, Southwestern Nigeria was interpreted to delineate the aquifers. The geoelectric parameters of the uppermost layer across the area were used to assess the vulnerability of the underlying aquifers to the surface and near-surface contaminants. The aquifer in the area is located mostly within the weathered layer above the basement rock and occurs at a shallow depth ranging from 3.9 to 15.7 m, where depths less than 8 m constitute 52% of the study area. The average depth to the aquifer is 8.6 m. The protective capacity of the overburden showed that 60% of the study area has poor protective capacity, 12% weak protective capacity and 28% moderate protective capacity. This suggests that aquifers within the weathered basement rock are prone to surface and near-surface contaminants.

Key words: Intrinsic, aquifer, vulnerability, saprolite.

INTRODUCTION

Domestic water supply in Oke-Ila area, Southwestern Nigeria comes majorly from groundwater. Oke-Ila lies within the basement complex terrain of Southwestern Nigeria (Rahaman et al., 1983; Rahaman, 1988). In the basement complex area, groundwater occurs in either the weathered basement or in the joints/fractured zones of the unweathered basement rock (Clark, 1985; Jones, 1985; Acworth, 1987; Olasehinde and Raji, 2007; Adelusi et al., 2000; Abdullahi, 2005). The intrinsic value of resistivity of the unweathered basement rocks differs by several orders of magnitude from those of the weathered overburden. Hence, electrical resistivity method is suitable to delineate the thickness and extent of the overburden (Koefoed, 1979).

The people around Oke-Ila area abstracts water from the weathered material overlying the crystalline basement rock through hand dug wells. Aquifers in the Precambrain Basement Complex usually occur at shallow depths and hence are vulnerable to surface or near-surface contaminants. The protection of groundwater reservoir is given by the covering layers, also called protective layers. An effective groundwater protection is given by protective layers with sufficient thickness and low hydraulic conductivity.

Some geophysical techniques currently being applied to assess aquifer vulnerability include spontenous potential methods and ground penetrating radar. These methods identify leakages in reservoirs and membrane-lined sites (U.S. Environmental Protection Agency, 1993). Vulnerability of aquifers can also be assessed using the aquifer vulnerability index which quantifies vulnerability by hydraulic resistance to vertical flow of water through the protective layers (Van Stempvoort et al., 1992). The present study involves the use of electrical resistivity method to assess the vulnerability of aquifers using geoelectric parameters of the near-surface materials overlying the aquifer. This method is much easier, because it is a well established method, equipment is inexpensive, mobile, easy to operate, provides relatively rapid areal coverage and depth of penetration is limited only by the ability to extend electrode spacing (U.S. Environmental Protection Agency, 1993).

Location and geology

The study area is situated between latitude 8°00'N and 8°04'N and longitude 4°56'E and 4°58'E. The geology of

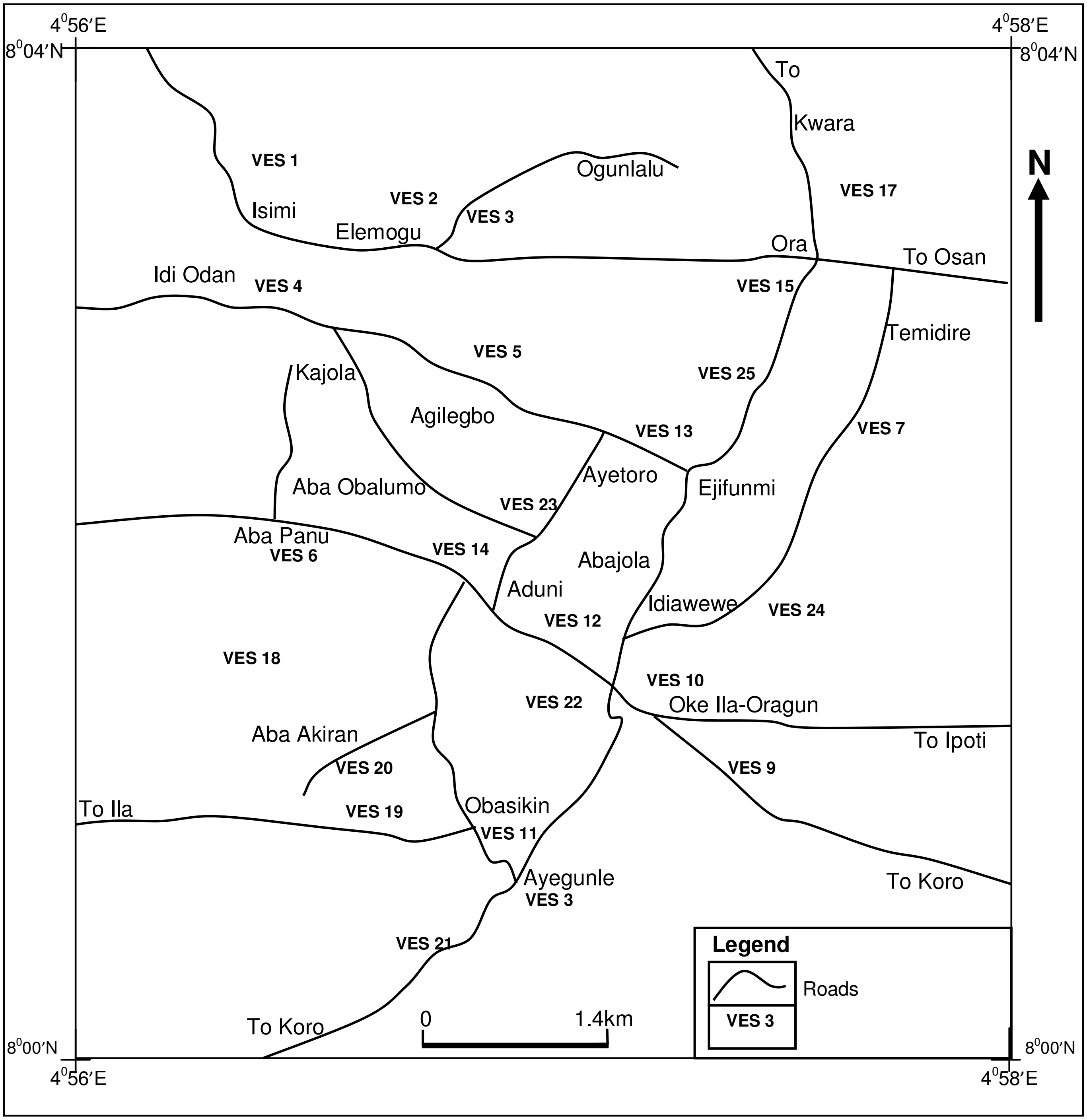


Figure 1. Map of the study area.

the study area is made up of older granites, grey gneiss, granite gneiss, mica schist and migmatites of Southwestern Nigeria. There are also minor pegmatite vein and quartz vein intrusions. The barrovian type of metamorphism has affected the area, and metamorphic grade is from green schist to amphibolite facies (Rahaman, 1989).

MATERIALS AND METHODS

Twenty five vertical electrical sounding adopting the Schlumberger configuration (Zohdy et al., 1974) was carried out in the study area (Figure 1). The ABEM SAS 1000 Terrameter was used for this study with a maximum electrode separation of 180 m.

The data acquired from the survey were plotted on a bi-log graph paper with the electrode separation (AB/2) on the abscissa and apparent resistivity (ρ_a) values on the ordinate. The field curves were interpreted by partial curve matching (Koefoed, 1979) and the corresponding auxiliary curves (Orellana and Mooney, 1966). The thickness and resistivity values obtained from the partial curve matching were then used for a quantitative computer iteration using the winResist software (Vander, 2004) which reduced the interpretation errors to acceptable levels (Barker, 1989).

The existing electrical resistivity contrasts between lithological sequences in the subsurface (Dodds and Ivic, 1988) were used in the delineation of geoelectric layers and identification of aquiferous units (Deming, 2002).

The resistivity parameters of the upper most geoelectric layer in the study area have been used to assess the vulnerability of the underlying aquifer. The combination of the resistivity and thickness in the Dar Zarrouk parameter (longitudinal conductance, S) may be of direct use in aquifer vulnerability studies (Henriet, 1976).

Total longitudinal conductance:

$$\sum_{i=1}^{n} h_i / \rho_i$$

where ρ_i is apparent resistivity of layer and h_i is the thickness of layer.

The earth medium acts as a natural filter to percolating fluid and it ability to retard and filter percolating fluid is a measure of its protective capacity (Olorunfemi et al., 1998). The longitudinal conductance/protective capacity rating was modified as >10 (excellent), 5 to 10 (very good), 0.7 to 4.9 (good), 0.2 to 0.69 (moderate), 0.10 to 0.19 (weak) and < 0.1 (poor) (Oladapo et al., 2004). The results obtained are presented in Table 1.

INTERPRETATION

The interpretation of the sounding curves (Figures 2 and 3) shows the following curve types: A, QH, HA, KH, QQH and HKH. Cross section of the interpreted resistivity data from the area (Figure 4) show three major geoelectric layers: the top soil, weathered layer (saprolite) and the fractured /fresh bedrock. Different approach has emerged as major focus for groundwater resources development in a basement terrain. The fractured zones in crystalline rocks are important sources of water for communities in such area (Meju et al., 1999) and also the thickest weathered layer above the basement rock constitute the major water-bearing layer (Lenkey et al., 2005). However, the most promising sites for groundwater development may not necessarily coincide with the thickest development of the saprolite; this becomes evident after considering other geoelectric parameters which may impact on the aquifer characteristics, such as the resistivity of the saprolite as well as that of the bedrock (Olayinka et al., 1997). Optimum aquifer potentials are attained in the mid-range of saprolite resistivity (20 to 100 Ωm), while resistivity values less than 20 Ωm indicate clays (Wright, 1992). Also, if the bedrock has relatively low resistivity (< 750 Ωm) this could indicate fracturing and a high aquifer potential (Olayinka et al., 1997).

The aquifer in Oke-Ila area occur within the weathered basement at a depth range of 3.9 to 15.7 m (Figures 3 and 4), where depths of less than 8 m constitute 52% of the study area. The average depth to the weathered rock is 8.6 m. The thickness of the aquifer ranges 3.6 to 49.0 m, and has an average thickness of 18.68 m. The fractured and jointed basement rock are also water bearing in areas characterized by resistivity lows (< 750 Ωm) within the resistivity highs of the basement rock (Figure 5) around VES 9, VES 13, VES 15 and VES 17 where the average depth to the aquifer at the locations is 41.8 m.

Assessment of Aquifer Vulnerability

Due to the shallow depth of aquifer in the basement complex terrains, they are often exposed to surface and near-surface contamination. Groundwater is given protection by protective geologic barriers having sufficient thickness (Mundel et al., 2003) and low hydraulic conductivity. Silts and clays are suitable aquitards which often constitute protective geologic barriers and when they are found above an aquifer they constitute a protective cover (Lenkey et al., 2005) and they protect the aquifer from surface and near-surface contamination, because their low hydraulic conductivity leads to high residence time of percolating water.

The results of the assessment of aquifer vulnerability (Table 1) showed that the protective capacity at VES 6, 7, 8, 10, 11, 12, 13, 15, 18, 19, 20, 23 and 25 ranges between 0.013 and 0.084 mhos. This indicate that the aquifer in these area have poor protective capacity, this is because the overburden above the aquifer are mostly sandy except at VES 10, 11 and 12 where there are lenses of clay but are not thick enough to give adequate protection. The protective capacity at VES 1, 2, 3, 17 and 24 ranges between 0.101 and 0.134 mhos, this indicates a weak protective capacity, which also results from absence of suitable aquitards (silts and clays). The protective capacity at VES 4, 5, 9, 14, 16, 21 and 22 varies between 0.22 and 0.42 mhos, this indicate that the overburden above the aquifer have a moderate protective capacity. At VES 5, 16, 21 and 22, the aquifer is protected by silts and clays with thickness ranging from 3.7 to 7.5 m while the overburden at VES 4, 9 and 14 is sand, the aquifer are given moderately protection and this is probably due to the presence of silts and clays in the sandy overburden. The poor and weak protective zones are prone to surface and near-surface contamination, while in the moderately protected zones, the aquifer is protected from contaminated percolating fluids. The moderate protective capacity tallies with the thick silt and clay overburden.

The topmost layers are mostly sandy and where silts and clays which protect the aquifer are found, they are usually very thin and hence provide little or no protection for the aquifer beneath them. This indicates that the overburden above the aquifer in Oke-Ila area, generally have poor protective capacity and where present it is weak or moderate.

Table 1. Geoelectric parameters, lithological delineation and protective capacity of the study area.

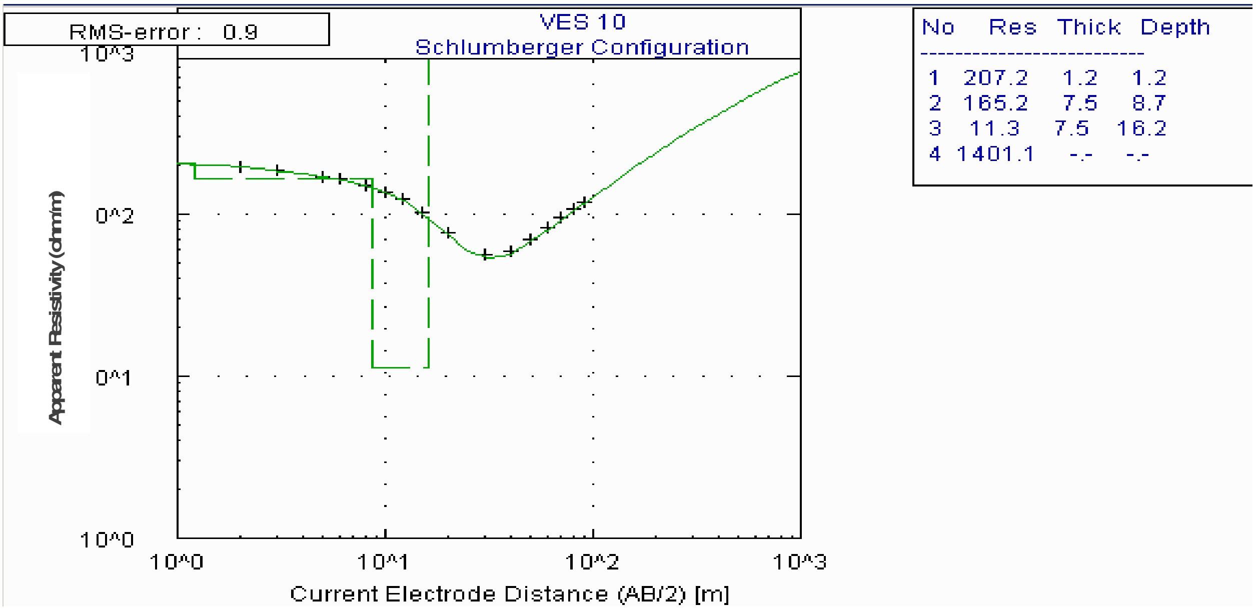
VES	Layer	Resistivity (Ωm)	Thickness (m)	Lithology	Longitudinal conductance	Protective capacity
1	1	224.8	1.1	Top soil	0.00489	0.108
	2	88.6	9.2	Sandy	0.103	
	3	109.1	11.3	Sandy	0.104	(weak)
	4	1224.7		Basement		
2	1	603.5	1.2	Top soil	0.00199	0.101
	2	51.3	5.1	Sandy	0.0994	
	3	114.6	9.7	Sandy	0.0846	(weak)
	4	1008.2		Basement		
3	1	388.3	0.6	Top soil	0.00155	0.04
	2	32.8	1.4	Silty	0.0427	
	3	84.2	18.5	Sandy	0.151	(poor)
	4	123.3		Fractured Basement		
4	1	192.4	0.8	Top soil	0.00416	0.28
	2	41.7	11.6	Sandy	0.278	
	3	303.8	28.3	Sandy	0.0932	(moderate)
	4	1586.4		Basement		
5	1	184.2	1.5	Top soil	0.00814	0.22
	2	31.6	6.6	Silty	0.2089	
	3	73.5	3.6	Sandy	0.049	(moderate)
	4	1837.3		Basement		
6	1	806.9	1.2	Top soil	0.00149	0.016
	2	580.6	2.8	Sandy	0.00482	
	3	326.2	3.0	Sandy	0.0092	
	4	81.4	9.3	Sandy	0.1143	(poor)
	5	1916.4		Basement		
7	1	184.8	0.9	Top soil	0.00487	0.022
	2	621.6	10.4	Sandy	0.0167	
	3	48.1	8.6	Sandy	0.179	(poor)
	4	2014.7		Basement		
8	1	336.2	1.4	Top soil	0.00416	0.013
	2	553.9	5.1	Sandy	0.00921	
	3	214.8	13.1	Sandy	0.061	(poor)
	4	1735.1		Basement		
9	1	308.6	0.9	Top soil	0.00292	0.24
	2	67.2	15.1	Sandy	0.225	
	3	215.0	32.5	Sandy	0.151	(moderate)
	4	616.9		Fractured Basement		
10	1	207.2	1.2	Top soil	0.00579	0.05
	2	165.2	7.5	Sandy	0.0454	

Table 1. Contd.

	3	11.3	7.5	Clayey	0.664	(poor)
	4	1401.1		Basement		
11	1	123.6	0.8	Top soil	0.00647	0.084
	2	19.8	1.1	Clayey	0.056	
	3	224.2	4.8	Sandy	0.0214	(poor)
	4	42.9	29.3	Sandy	0.683	
	5	1220.7		Basement		
12	1	741.6	0.6	Top soil	0.0008	0.069
	2	17.0	1.0	Clayey	0.0588	
	3	746.0	7.0	Sandy	0.0094	(poor)
	4	238.6	25.0	Sandy	0.105	
	5	1359.1		Basement		
13	1	810.2	0.6	Top soil	0.00074	0.022
	2	158.4	3.3	Sandy	0.0208	
	3	127.8	20.8	Sandy	0.163	(poor)
	4	581.8		Fractured Basement		
14	1	186.4	1.2	Top soil	0.00644	0.42
	2	15.3	6.3	Clayey	0.4118	
	3	96.7	14.5	Sandy	0.15	(moderate)
	4	1635.6		Basement		
15	1	851.9	1.3	Top soil	0.0015	0.03
	2	234.1	6.8	Sandy	0.029	
	3	41.6	49.0	Sandy	1.178	(Poor)
	4	349.2		Fractured Basement		
16	1	89.1	1.3	Top soil	0.0146	0.42
	2	21.1	3.7	Clayey	0.1754	
	3	37.3	8.7	Silty	0.2332	(moderate)
	4	1938.1		Basement		
17	1	108.4	0.7	Top soil	0.0065	0.134
	2	41.1	5.2	Sandy	0.127	
	3	45.9	31.0	Sandy	0.675	(weak)
	4	124.4		Fractured Basement		
18	1	511.3	1.3	Top soil	0.0025	0.081
	2	137.5	10.8	Sandy	0.0785	
	3	156.4	20.6	Sandy	0.132	(poor)
	4	1008.1		Fractured Basement		
19	1	426.7	1.0	Top soil	0.0023	0.053
	2	168.1	8.5	Sandy	0.051	
	3	83.3	30.5	Sandy	0.366	(poor)
	4	1462.4		Basement		

Table 1. Contd.

20	1	131.4	0.9	Top soil	0.0068	0.045
	2	375.2	14.4	Sandy	0.0384	
	3	63.8	8.8	Sandy	0.138	(poor)
	4	1608.1		Basement		
21	1	239.7	1.0	Top soil	0.0042	0.29
	2	15.3	4.4	Clayey	0.2876	
	3	375.6	28.1	Sandy	0.0748	(moderate)
	4	1279.4		Basement		
22	1	184.1	1.6	Top soil	0.0087	0.28
	2	27.3	7.5	Silty	0.2747	
	3	413.7	21.4	Sandy	0.052	(moderate)
	4	1362.8		Basement		
23	1	209.8	0.5	Top soil	0.0024	0.022
	2	762.3	152	Sandy	0.02	
	3	286.2	5.8	Sandy	0.02	(poor)
	4	1663.5		Basement		
24	1	121.8	1.2	Top soil	0.0099	0.155
	2	61.5	8.9	Sandy	0.1447	
	3	172.3	17.6	Sandy	0.102	(weak)
	4	1307.1		Basement		
25	1	117.2	4.5	Top soil	0.038	0.038
	2	521.3	13.8	Sandy	0.026	(poor)
	3	1257.1		Basement		



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No    Res    Thick  Depth
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 1   207.2    1.2    1.2
 2   165.2    7.5    8.7
 3    11.3    7.5   16.2
 4  1401.1    -.-    -.-
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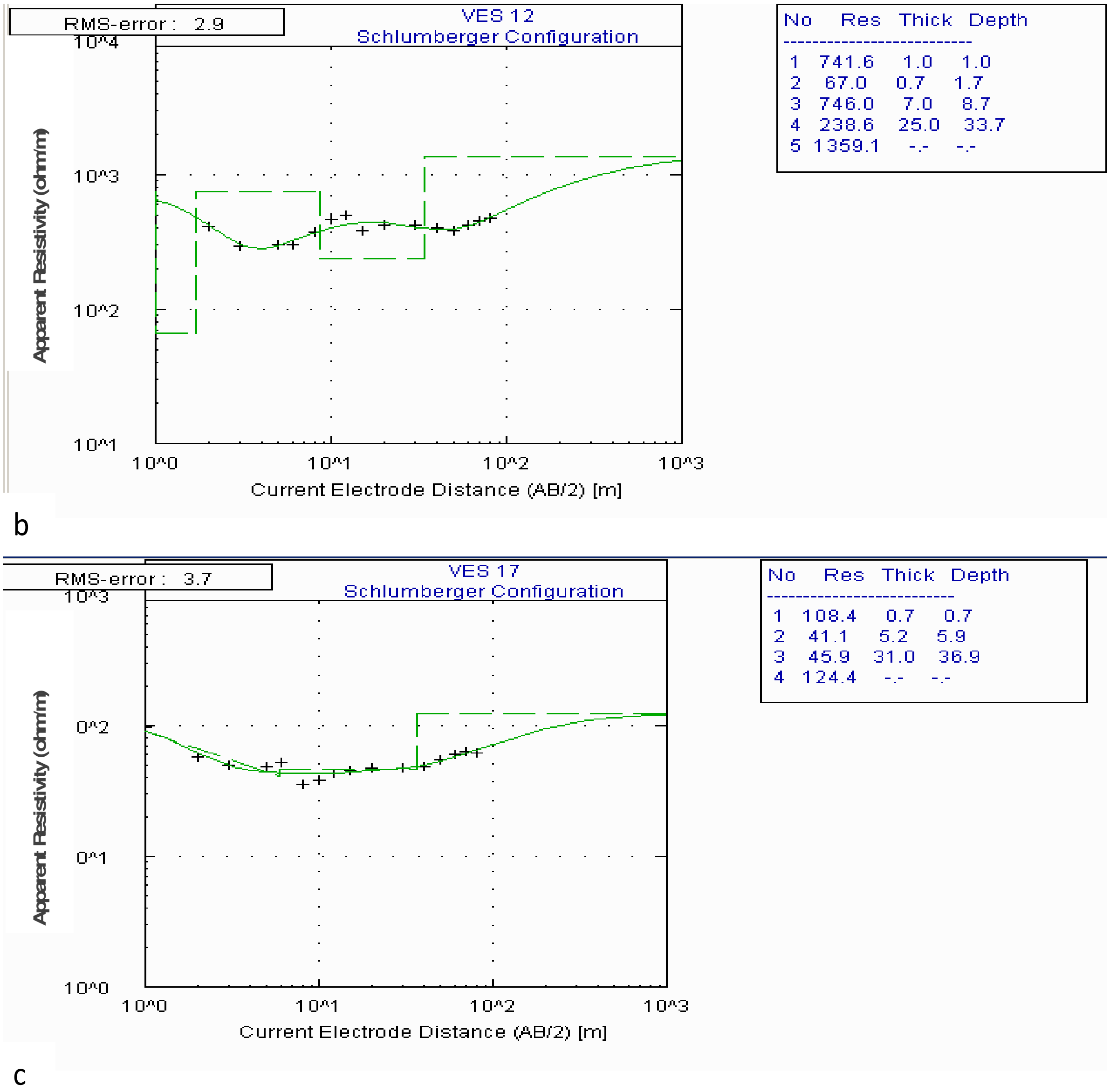
Figure 2a. Typical resistivity curve obtained from the area.



No	Res	Thick	Depth
1	741.6	1.0	1.0
2	67.0	0.7	1.7
3	746.0	7.0	8.7
4	238.6	25.0	33.7
5	1359.1	-.-	-.-

No	Res	Thick	Depth
1	108.4	0.7	0.7
2	41.1	5.2	5.9
3	45.9	31.0	36.9
4	124.4	-.-	-.-

Figure 2b and c. Typical resistivity curves obtained from the area.

CONCLUSIONS AND RECOMMENDATIONS

The weathered materials (saprolite) overlying the crystalline basement rock and fractured basement rock around Oke-Ila area constitute the major water-bearing horizon from which water for domestic use of the inhabitants of the area is abstracted.

The depth to the saprolite varies from 3.9 to 15.7 m where depth less than 8 m constitutes about 52% of the area. This indicate that the saprolite occurs at relatively shallow depth in most of the area and hence, is prone to surface and near-surface contamination.

About 60% of the study area has poor protective capacity (0.013 to 0.084), 12% weak protective capacity (0.101 to 0.134) and 28% moderate protective capacity (0.22 to 0.42). This indicates that the topmost geoelectric layers in the area are mostly pervious geologic materials through which surface and near-surface contaminants can infiltrate. Hence, the aquifer is vulnerable to surface and near-surface contaminants.

Since fractured bedrock in crystalline basement terrain can yield significant quantity of groundwater and occur in this area at greater depth which are free from surface and near-surface contamination, it is recommended that the deeper aquifer occurring at an average depth of 41.8 m should be developed, especially around location VES 9 (48.5 m), VES 13 (24.7 m), VES 15(57.1 m) and VES 17 (36.9 m).

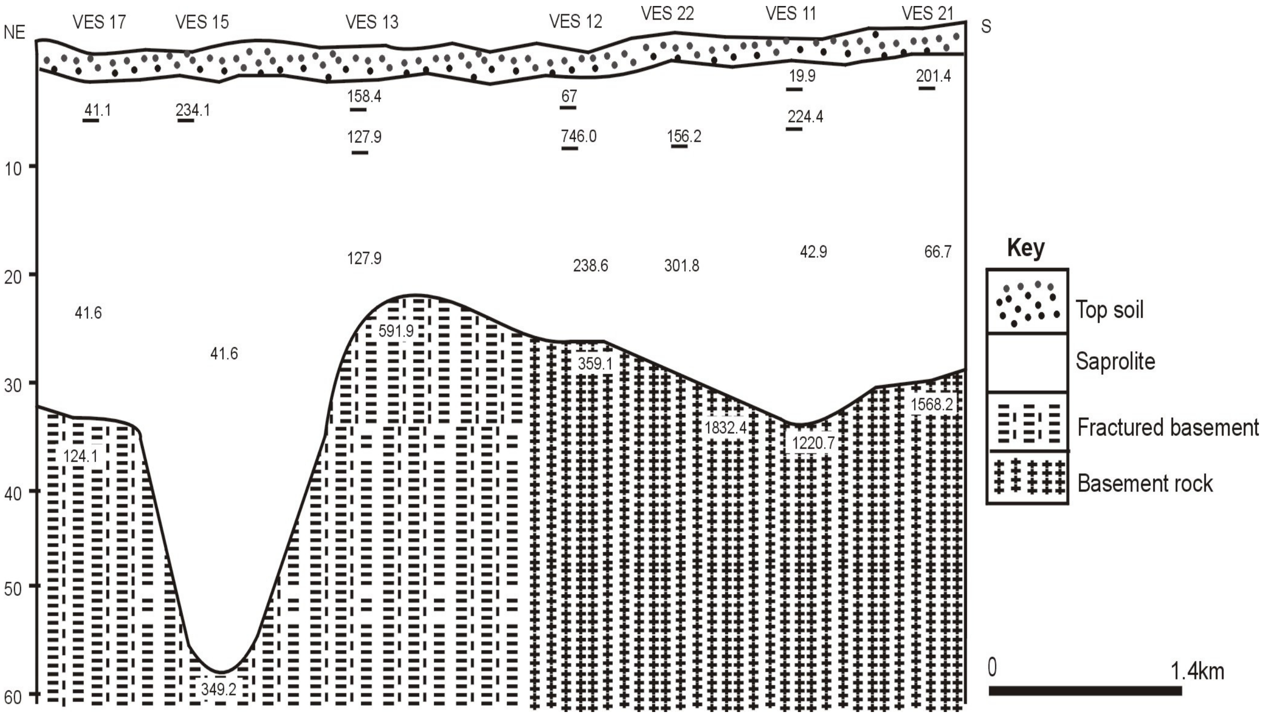


Figure 3. Geoelectric section of Oke-Ila area.

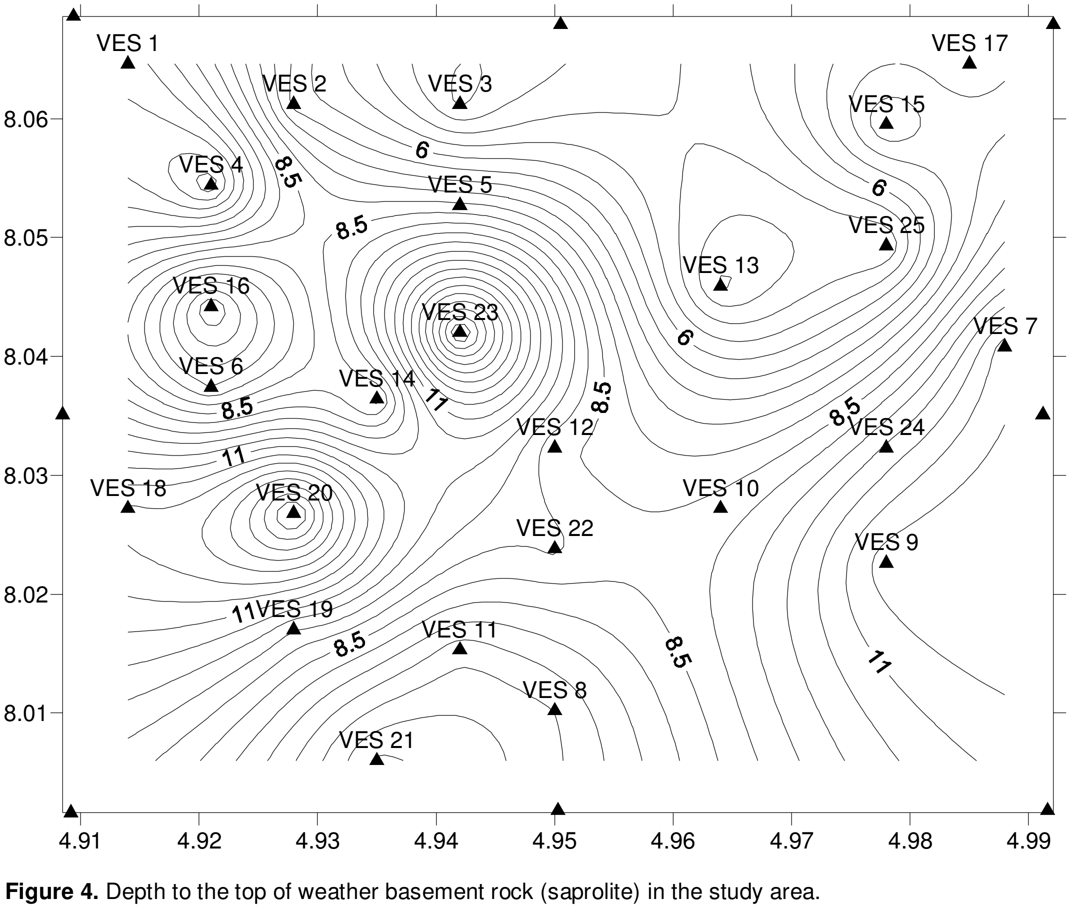


Figure 4. Depth to the top of weather basement rock (saprolite) in the study area.

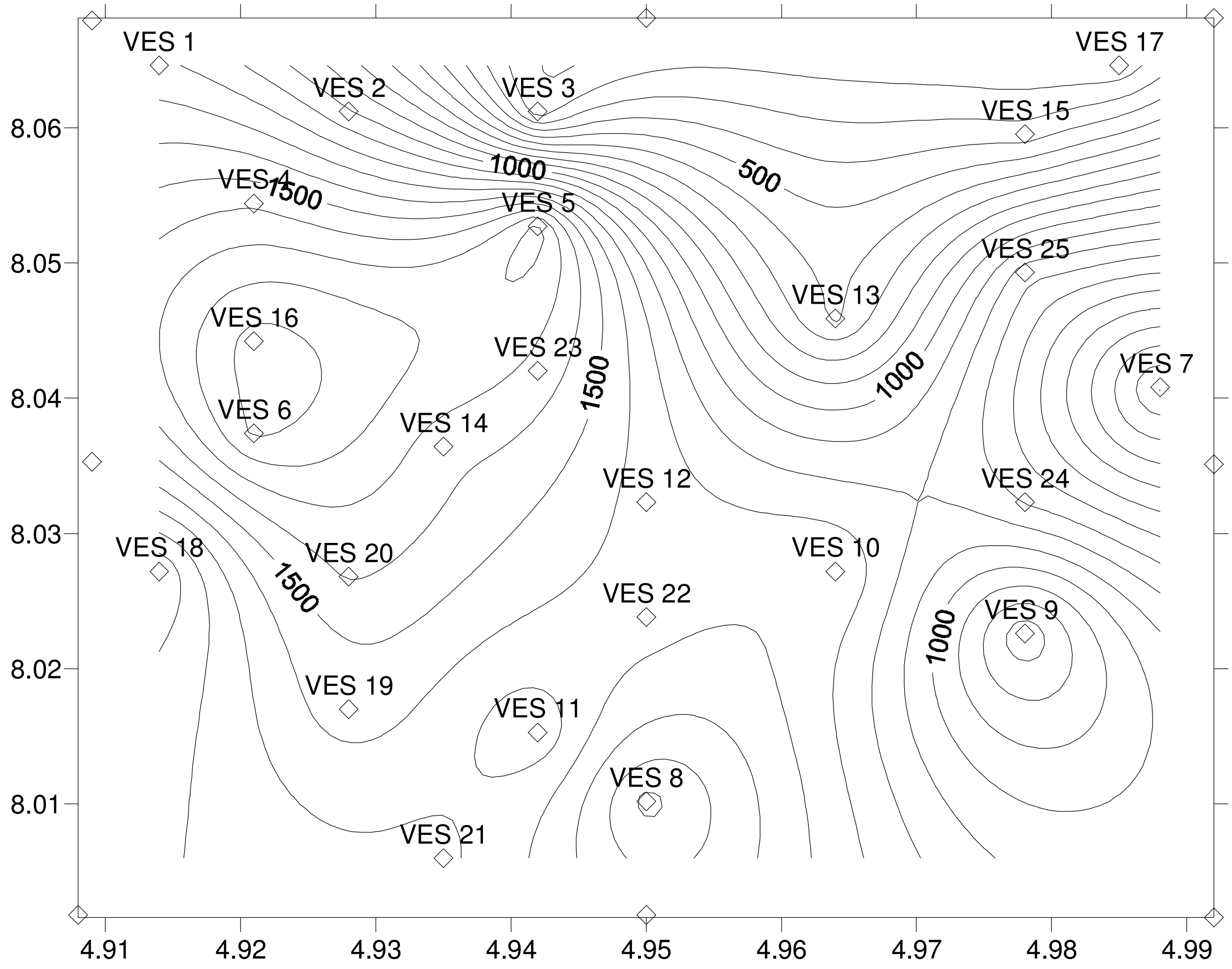


Figure 5. Isoresistivity map of the basement rocks.

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