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GEOELECTRIC EVALUATION OF AQUIFER VULNERABILITY IN IGBANKE, ORHIONMWON LOCAL GOVERNMENT AREA OF EDO STATE, NIGERIA

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Abstract: The electrical resistivity survey has been used in the determination of the overburden protective capacity in Igbanke area of Orhionwhonm Local Government Area of Edo State, Nigeria. Ten Schlumberger vertical electrical soundings (VES) were carried out with maximum electrode separation of 350m. The data were presented as VES curves interpreted quantitatively by computer iteration using the WinResist Software to obtain the first order geoelectric model parameters. The results of the geoelectric investigation revealed six geoelectric layers namely the topsoil, laterite clayey sand, fine to medium sand, medium sand, medium to coarse sand and coarse sand which are in agreement with the driller's log obtained from the borehole. The overburden protective capacity in an area was evaluated using the total longitudinal unit conductance values. The values obtained show poor and weak protective capacity rating in almost all parts of the study area. The aquifer of the study area is not protected since the protective capacity rating is poor (< 0.1).

Keywords: Geoelectric, borehole, aquifer, Igbanke, protective capacity rating.

INTRODUCTION

Aquifer protection is essential for a sustainable use of the groundwater resources, protection of the dependent ecosystems, and a central part of spatial planning and action plans. Although buried valley aquifers are often covered by thick clayey tills, they can be sensitive to contaminants due to their limited extent and to missing Tertiary clay layers. In some areas they may actually create virtual pollutant highways, where they cut through clayey layers that protect deep lying aquifers. In such areas even the deeper parts of the valleys may be vulnerable, and may also render deep lying aquifers vulnerable to surface pollution. It is therefore of great importance to be able to locate such high risk areas.

The key expression for a quantification of aquifer protection is vulnerability. Vulnerability of an aquifer is defined as the sensitivity of groundwater quality to an imposed contaminant load, which is determined by the intrinsic characteristics of the aquifer (Lobo-Ferreira, 1999).

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Aquifer vulnerability solely indicates whether the physical and biochemical characteristics of the subsurface prevent or favour the transport of pollutants in and into aquifers. It does not take into account the actual pollutant loading in an area. An area without polluting activities may therefore be very vulnerable to pollution, if for instance the water table is close to the surface and the soil and subsoil is very permeable. Likewise, areas with polluting activities may have low or moderate vulnerability to pollution, if the geological and hydrological settings prevent migration of pollutants. Potentially polluting activities should of course be located in areas with low vulnerability, while areas with high vulnerability should have a higher protection level against pollution.

Apart from a few boreholes providing potable water, the communities rely mostly on water from septic tank domestic and agricultural purposes. However, there is an increased demand for portable water in the study area as a result of increase in population to cater for agricultural and domestic needs. An evaluation of the aquifer protective capacity is very important in such communities to ascertain the portability of the water.

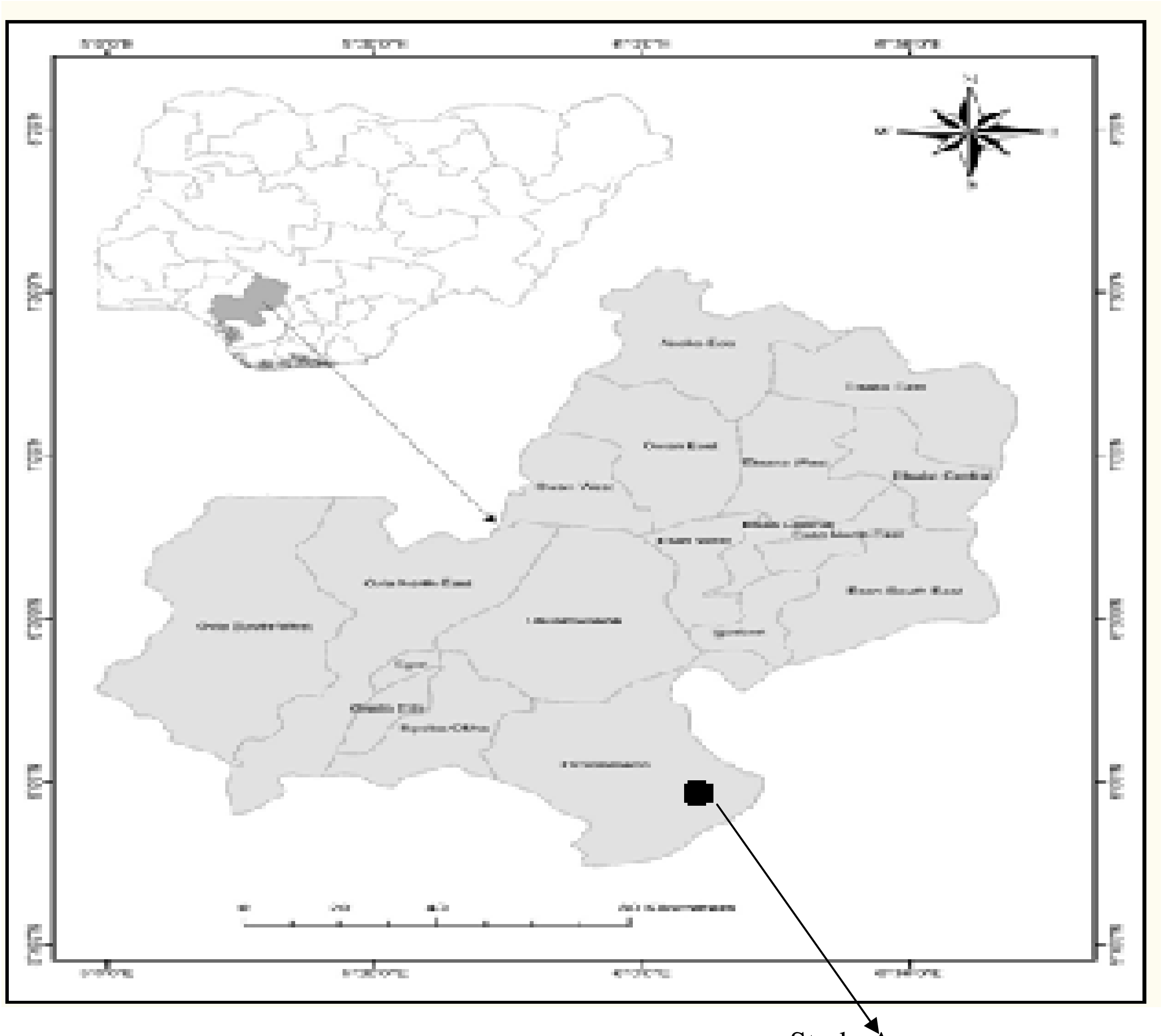
Thus, the main objectives of the study is to carry out detailed geological and hydrogeological mapping of Igbanke area, conduct geophysical study to determine the geoelectric parameters (resistivity, ρ_i and thickness, h_i) and delineate the depth to the aquifer and its lateral extent and determine the aquifer protective capacity. Henriet (1976) showed that the combination of layer resistivity and thickness in the Dar Zarrouk parameters S (longitudinal conductance) and T (transverse resistance) may be of direct use in aquifer protection studies and for the evaluation of hydrologic properties of aquifer.

VanStempvoort et al. (1992) showed that aquifer vulnerability can be quantified using the Aquifer Vulnerability Index (AVI). This method quantifies vulnerability by hydraulic resistance to vertical flow of water through the protective layers and the hydraulic resistance. The protective capacity is considered to be proportional to the longitudinal unit conductance in mhos (Olorunfemi *et al.*, 1998; Oladapo *et al.*, 2004; Ayolabi, 2005 and Atakpo and Ayolabi, 2009).

Location and Geology of Survey Area

Igbanke is an Ika town in Edo State. They are of the Ika people family stock in Delta State, Nigeria, Igbanke town is constituted by villages such as Omoluah, Obiogba, Idumuiru, Igbontor, Idumodin, Ake, Oligie and Ottah, all of which have different historical background of migration.

The study area, Igbanke is area located within Longitude 06˚ 10' 12" E to 06˚ 13' 25" E and Latitude 06˚ 20' 47" N to 06˚ 21' 19" N (Figure 1) in Orhionmwon Local Government Area of Edo State, Nigeria. The area is of equatorial climate made of two main seasons, the wet and dry season. The wet season begins from April and ends in September while dry season begins from October and ends in March. The inhabitants practice subsistence farming. The area is prone to erosion due to the highland/hill in the study area.



Study Area

Figure 1: Location map of study area

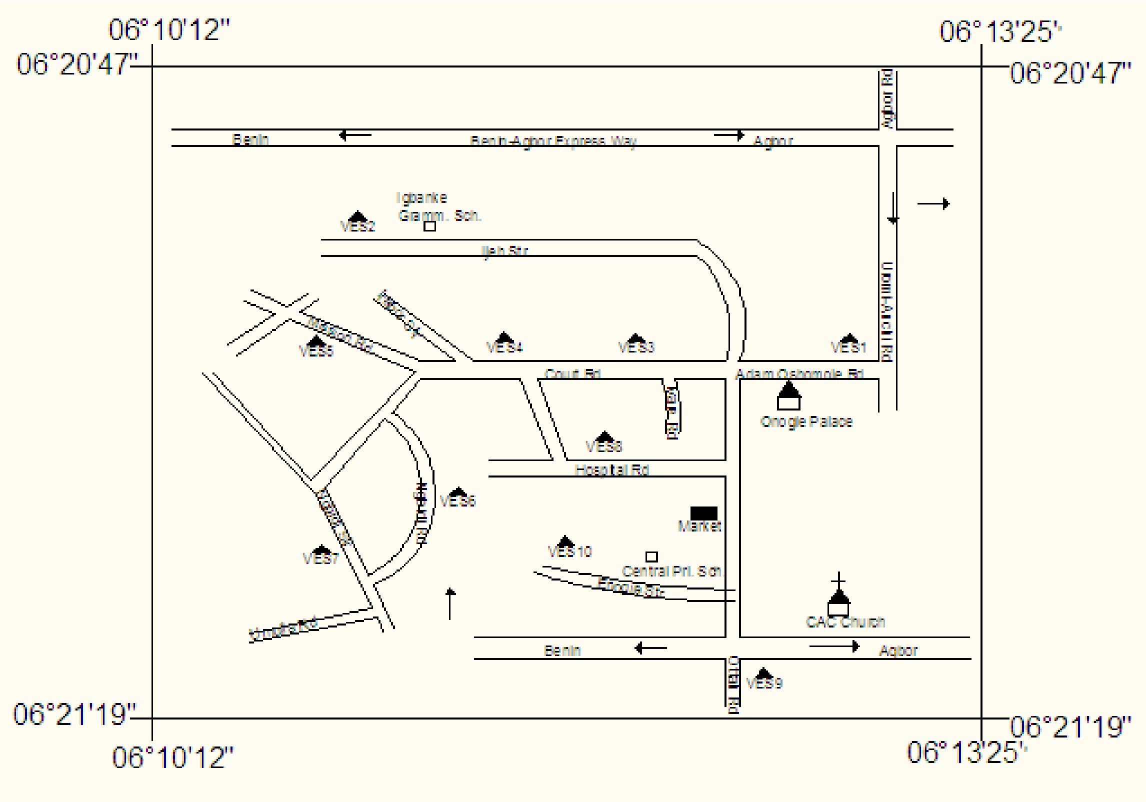


Figure 2: Data acquisition map of study area

Elevation is about 41m above sea level. The vegetation is typical of the rain forest except along drainage streams where swampy areas exist. The Niger Delta Petroleum province studied is underlain by three main stratigraphic units (Short and Stauble, 1967; Asseez, 1989). These are the basal Akata Formation of mainly marine shale and sand beds. This is overlain by the paralic sequence consisting of interbedded sands and shales of the Agbada Formation. The youngest

Benin Formation is a prolific aquifer and is penetrated everywhere in the modern Niger Delta by numerous water supply boreholes. However, the formation is masked in the Sombreiro – Deltaic plain by a sequence of silts, medium to coarse grained sands, sandy clays and clay bands which Oomkens (1974) believes as a result of interglacial marine transgressions that have occurred in the Quaternary. This sequence is indistinguishable from the underlying Benin Formation in borehole sections and is indeed the present day expression of this formation. The problem though is that the clay bands are not uniform in thickness and many boreholes have been abandoned because the entire clay sequence could not be penetrated in order to access the underlying water bearing sandy layer formation or the aquifer.

Theory

Todd (2004) stated that the resistivity of a rock material whose resistance is R and having a cross sectional area A and length L is expressed as:

$$\rho = \frac{RA}{L}$$

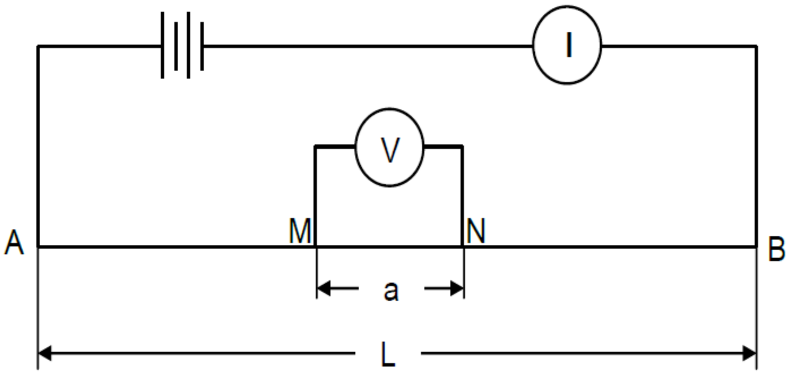


Figure 3: The Schlumberger array configuration.

In the Schlumberger array, as shown in Fig 3, A and B are current electrodes, while M and N are potential electrodes. The current entering the ground at A and returning at B as shown in Figure 1 is 'I'. Assuming the medium below the surface of the earth is homogeneous and isotropic with resistivity ρ, the potentials V_M and V_N as measured at M and N, respectively are given by:

$$V_M = \frac{\rho I}{2\pi}\left(\frac{2}{L-a}\right)$$

And

$$V_N = \frac{\rho I}{2\pi}\left(\frac{2}{L+a}\right)$$

The potential at A is

$$V_A = V_M - V_N$$

$$V_A = \frac{\rho I}{2\pi}\left(\frac{2}{L-a}\right) - \frac{\rho I}{2\pi}\left(\frac{2}{L+a}\right)$$

$$V_A = \frac{\rho I}{2\pi}\left\{\left(\frac{2}{L-a}\right) - \left(\frac{2}{L+a}\right)\right\}$$

And

$$V_B = V_N - V_M$$

$$V_B = \frac{\rho I}{2\pi}\left(\frac{2}{L+a}\right) - \frac{\rho I}{2\pi}\left(\frac{2}{L-a}\right)$$

$$V_B = \frac{\rho I}{2\pi}\left\{\left(\frac{2}{L+a}\right) - \left(\frac{2}{L-a}\right)\right\}$$

Thus, the potential difference measured by the voltmeter connected between A and B becomes:

$$V = V_A - V_B$$

$$V = \frac{4\rho I}{\pi}\left(\frac{a}{L^2 - a^2}\right)$$

The apparent resistivity is therefore given by the relation:

$$\rho_a = \frac{\pi V(L^2 - a^2)}{4I}$$

where L and a are the current and potential electrode spacing, respectively.

METHODOLOGY

The vertical electrical sounding (VES) using the Schlumberger electrode configuration was adopted. A total of 10 Soundings points were carried out. The VES stations are shown in Figure 3. The ABEM SAS 1000 portable Terrameter with an inbuilt booster for greater depth current penetration was used for the data acquisition. The maximum current electrode separation (AB) was 1000m. The data obtained from the electrical resistivity survey was interpreted quantitatively by computer iteration with the aid of the Win Resist Software based on the work of Vander Velpen, (2004) to obtain the true resistivity and thickness of the layers delineated (Table 1 and table 2).

These first order geoelectric parameters (resistivity ρi and thickness h_i) were utilised in deriving the total longitudinal unit conductance (S), which is a second order geoelectric parameter or the Dar Zarrouk Parameter (Maillet, 1947). The total longitudinal unit conductance is

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

Hence the overburden protective capacity was evaluated using the total longitudinal unit conductance values in the equation (Henriet, 1976, Oladapo *et al*, 2004, Atakpo and Ayolabi, 2008). The longitudinal conductance (mhos)/protective capacity ratings modified by Oladapo *et al.*, (2004) as: >10 – Excellent; 5 to 10 – Very Good; 0.7 to 4.9 – good; 0.2 - 0.69 moderate; 0.1 to 0.19 Weak and <0.1 – Poor were used for the interpretation of the protective capacity.

RESULT AND DISCUSSION

Ten vertical electrical sounding were conducted in Igbanke. The electrical resistivity curves obtained show six layers HAAA, HKQH, KHAA, KHKH, HKHA type curves. The study shows that lithology of Igbanke are lateritic topsoil, clay, fine-medium grained, medium sand, medium to coarse sand and coarse sand. Table 4.3 shows the geoelectric parameters of the study area. Figure 4 to figure 13 shows the geoelctric sounding curve of the study area and figure 14 shows the geoelectric section of the study area. The topsoil is laterite with resistivity ranging from 24.2 to 989.1Ωm and thickness varying from 0.7 to 1.3m. The second layer is clay though some area displays clayey sand with resistivity ranging from 54.2 to 742.8Ωm and thickness varying from 3.4 to 6.3m. The third layer is fine to medium sand with resistivity ranging from 17.3 to 913.2Ωm and thickness varying from 9.8 to 18.9m. The fourth layer is medium sand with resistivity ranging from 28.8 to 493.6Ωm and thickness varying from 9.2 to 29.1m. The fifth layer is medium to coarse sand and it is aquifererous unit with resistivity ranging from 165.6 to 745.2Ωm and thickness varying from 14.4 to 32.0m. The sixth layer is coarse sand with resistivity ranging from 401.1 to 1025.7Ωm. The thickness of the layer cannot be determined as the current electrode terminated in this layer. The interpreted geoelectric data correlates well with the lithologic log of a borehole drilled close to VES1.

Table 2 shows the longitudinal conductance of the study area. The values obtained shows that the aquifer is not protected since the protective capacity rating is poor (< 0.1) in almost all the parts of the study area. The low value of the protective capacity is as a result of the absence of significant amount of clay as an overburden impermeable material in the study area and this may enhance the percolation of contaminants into the aquifer.

Table 1: Curve Types and Lithologic Delineation of Study Area

S/N	Layers	Lithology	Curves Types
VES1	1 2 3 4 5 6	Lateritic Topsoil Clay Fine to Medium sand Medium Sand Medium to Coarse Sand Coarse Sand	HAAA $\rho_1 > \rho_2 < \rho_3 < \rho_4 < \rho_5 < \rho_6$

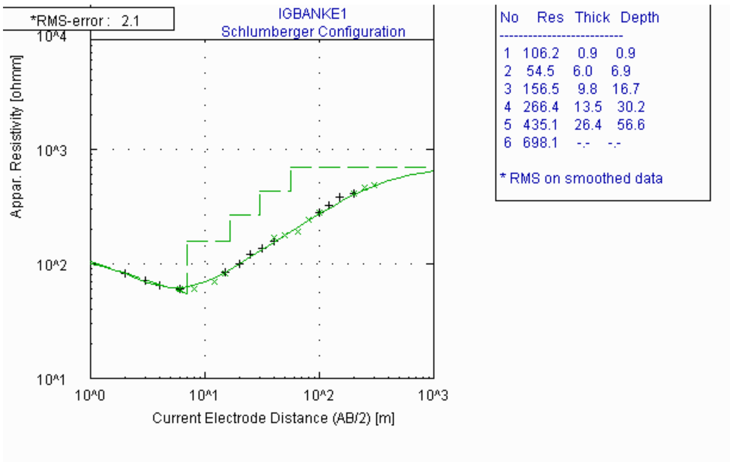
VES2	1	Lateritic Topsoil	HKQH $\rho_1 > \rho_2 < \rho_3 > \rho_4 > \rho_5 < \rho_6$
	2	Clayey Sand	
	3	Fine to Medium sand	
	4	Medium Sand	
	5	Medium to Coarse Sand	
	6	Coarse Sand	
VES3	1	Lateritic Topsoil	KHAA $\rho_1 < \rho_2 > \rho_3 < \rho_4 < \rho_5 < \rho_6$
	2	Clayey Sand	
	3	Fine to Medium sand	
	4	Medium Sand	
	5	Medium to Coarse Sand	
	6	Coarse Sand	
VES4	1	Clayey Topsoil	KHKH $\rho_1 < \rho_2 > \rho_3 < \rho_4 > \rho_5 < \rho_6$
	2	Clayey Sand	
	3	Fine to Medium sand	
	4	Medium Sand	
	5	Medium to Coarse Sand	
	6	Coarse Sand	
VES5	1	Clayey Topsoil	KHAA $\rho_1 < \rho_2 > \rho_3 < \rho_4 < \rho_5 < \rho_6$
	2	Clayey Sand	
	3	Fine to Medium sand	
	4	Medium Sand	
	5	Medium to Coarse Sand	
	6	Coarse Sand	
VES6	1	Lateritic Topsoil	KHKH $\rho_1 < \rho_2 > \rho_3 < \rho_4 > \rho_5 < \rho_6$
	2	Clayey Sand	
	3	Fine to Medium sand	
	4	Medium Sand	
	5	Medium to Coarse Sand	
	6	Coarse Sand	
VES7	1	Lateritic Topsoil	HAAA $\rho_1 > \rho_2 < \rho_3 < \rho_4 < \rho_5 < \rho_6$
	2	Clay	
	3	Fine to Medium sand	
	4	Medium Sand	
	5	Medium to Coarse Sand	
	6	Coarse Sand	
VES8	1	Lateritic Topsoil	HKHA $\rho_1 > \rho_2 < \rho_3 > \rho_4 < \rho_5 < \rho_6$
	2	Clay	
	3	Fine to Medium sand	
	4	Medium Sand	
	5	Medium to Coarse Sand	
	6	Coarse Sand	

VES9	1	Clayey Topsoil	KHAA
	2	Clayey Sand	$\rho_1 < \rho_2 > \rho_3 < \rho_4 < \rho_5 < \rho_6$
	3	Fine to Medium sand	
	4	Medium Sand	
	5	Medium to Coarse Sand	
	6	Coarse Sand	
VES10	1	Clayey Topsoil	KHAA
	2	Clayey Sand	$\rho_1 < \rho_2 > \rho_3 < \rho_4 < \rho_5 < \rho_6$
	3	Fine to Medium sand	
	4	Medium Sand	
	5	Medium to Coarse Sand	
	6	Coarse Sand	

Table 2: Geoelectric parameter of the study area

S/N	Layers	Resistivity	Thickness	$S = \sum_{i=1}^{n} \frac{h_i}{\rho_i}$	Longitudinal Conductivity of Protecting Layers	Protective Capacity Rating
VES1	1	106.2	0.9	0.00485	0.28892	Poor
	2	54.5	6.0	0.11009		
	3	156.5	9.8	0.06262		
	4	266.4	13.5	0.05068		
	5	435.1	26.4	0.06068		
	6	698.1	---	---		
VES2	1	898.1	1.0	0.00111	0.07338	Weak
	2	470.3	5.4	0.01148		
	3	913.2	14.9	0.01632		
	4	238.0	22.9	0.09622		
	5	191.8	32.0	0.16684		
	6	536	---	---		
VES3	1	413.1	1.0	0.00241	0.03378	Weak
	2	742.8	6.3	0.00848		
	3	364.3	15.9	0.04365		
	4	493.6	21.4	0.04335		
	5	745.2	27.7	0.03712		
	6	843	---	---		
VES4	1	24.2	0.8	0.03333	0.22257	Moderate
	2	257.0	3.4	0.01323		
	3	17.3	10.6	0.61272		
	4	58.3	9.2	0.15780		
	5	196.7	14.4	0.07321		
	6	986.7	---	---		

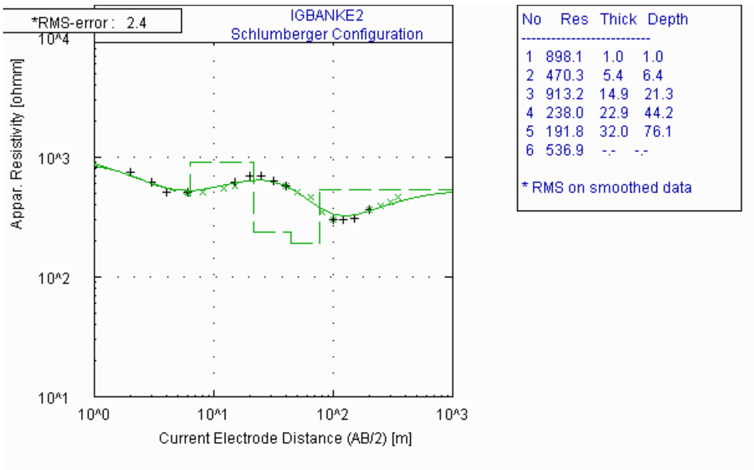
VES5	1	41.4	0.9	0.02174	0.12005	Weak
	2	120.9	4.3	0.03557		
	3	33.9	10.4	0.30678		
	4	174.4	11.4	0.06537		
	5	389.1	20.2	0.05074		
	6	1025.7	---	---		
VES6	1	129.8	0.9	0.00693	0.07083	Poor
	2	215.2	5.9	0.02649		
	3	126.4	12.6	0.09968		
	4	242.4	19.9	0.08201		
	5	385.7	26.3	0.06819		
	6	492.8	---	---		
VES7	1	108.2	1.0	0.00924	0.10904	Weak
	2	54.8	4.4	0.08029		
	3	95.1	18.9	0.19874		
	4	252.1	18.5	0.07338		
	5	442.9	22.3	0.05053		
	6	677.8	---	---		
VES8	1	129.1	1.3	0.01007	0.32945	Moderate
	2	56.5	4.4	0.07788		
	3	224.4	11.2	0.04991		
	4	28.8	29.1	1.01042		
	5	165.6	24.1	0.14553		
	6	910.4	---	---		
VES9	1	95.6	1.0	0.01046	0.08915	Poor
	2	168.6	6.2	0.03677		
	3	95.8	13.6	0.14196		
	4	198.0	16.3	0.08232		
	5	286.8	24.4	0.08508		
	6	401.1	---	---		
VES10	1	41.0	0.7	0.01707	0.11708	Weak
	2	181.8	4.4	0.02420		
	3	56.4	12.9	0.22872		
	4	284.2	20.6	0.07213		
	5	375.1	25.4	0.06772		
	6	426.4	---	---		



No	Res	Thick	Depth
1	106.2	0.9	0.9
2	54.5	6.0	6.9
3	156.5	9.8	16.7
4	266.4	13.5	30.2
5	435.1	26.4	56.6
6	698.1	-.-	-.-

* RMS on smoothed data

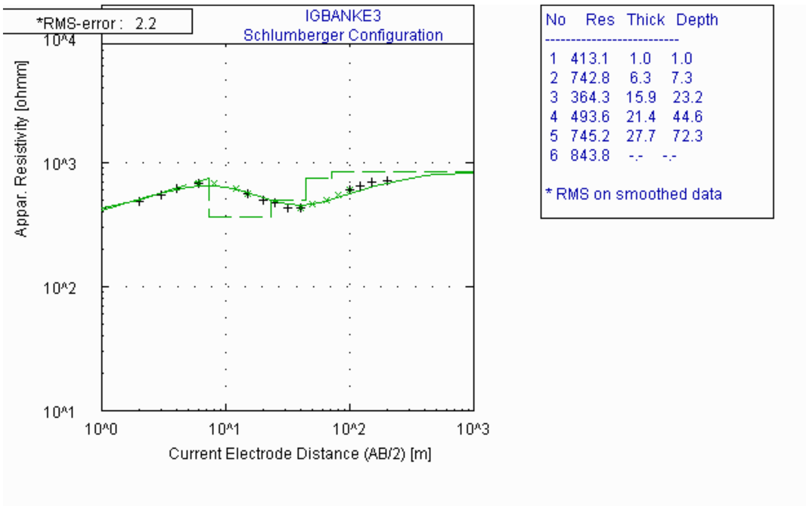
Figure 4: Typical Sounding curves for Igbanke Geophysical Investigation VES1



No	Res	Thick	Depth
1	898.1	1.0	1.0
2	470.3	5.4	6.4
3	913.2	14.9	21.3
4	238.0	22.9	44.2
5	191.8	32.0	76.1
6	536.9	-.-	-.-

* RMS on smoothed data

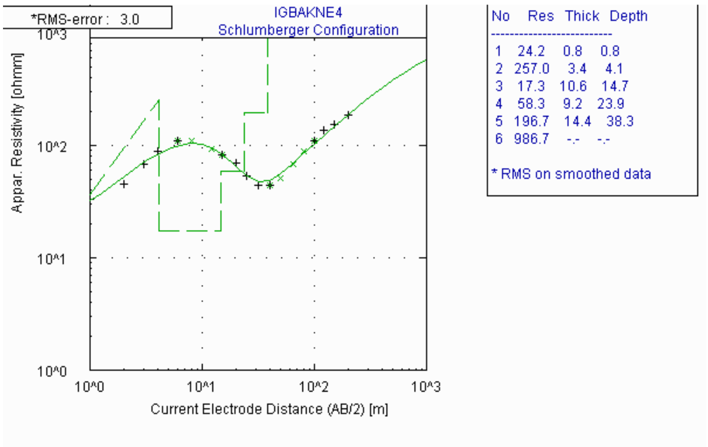
Figure 5: Typical Sounding curves for Igbanke Geophysical Investigation VES2



No	Res	Thick	Depth
1	413.1	1.0	1.0
2	742.8	6.3	7.3
3	364.3	15.9	23.2
4	493.6	21.4	44.6
5	745.2	27.7	72.3
6	843.8	-.-	-.-

* RMS on smoothed data

Figure 6: Typical Sounding curves for Igbanke Geophysical Investigation VES3



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No   Res   Thick  Depth
-------------------------
1   24.2   0.8    0.8
2  257.0   3.4    4.1
3   17.3  10.6   14.7
4   58.3   9.2   23.9
5  196.7  14.4   38.3
6  986.7   -.-    -.-

* RMS on smoothed data
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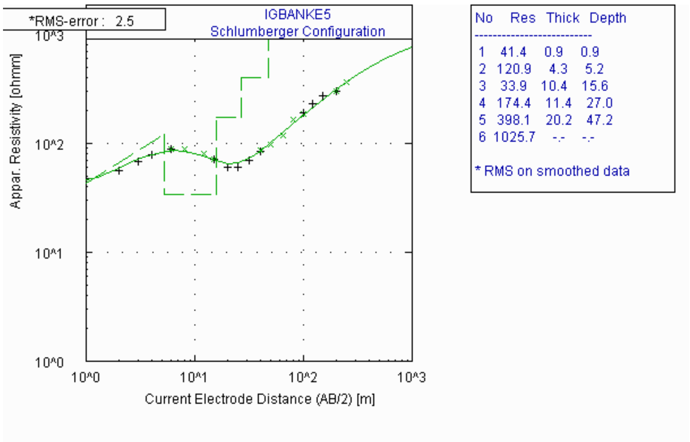
Figure 7: Typical Sounding curves for Igbanke Geophysical Investigation VES4



```
No   Res   Thick  Depth
-------------------------
1   41.4   0.9    0.9
2  120.9   4.3    5.2
3   33.9  10.4   15.6
4  174.4  11.4   27.0
5  398.1  20.2   47.2
6 1025.7   -.-    -.-

* RMS on smoothed data
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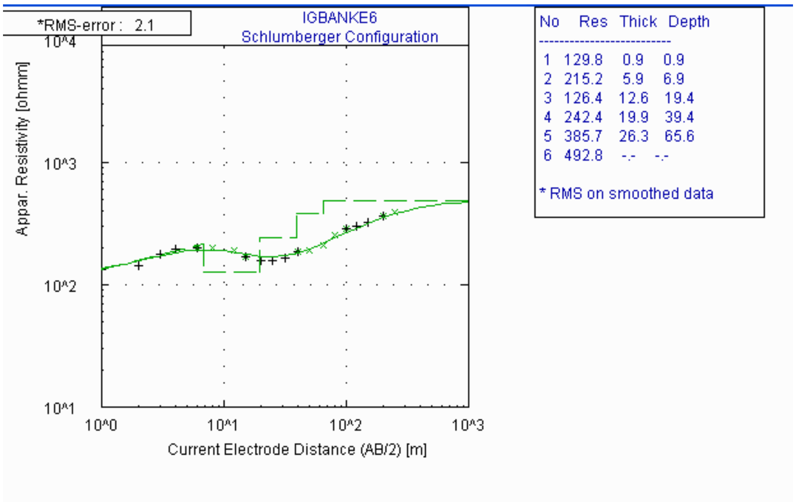
Figure 8: Typical Sounding curves for Igbanke Geophysical Investigation VES5



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No   Res   Thick  Depth
-------------------------
1  129.8   0.9    0.9
2  215.2   5.9    6.9
3  126.4  12.6   19.4
4  242.4  19.9   39.4
5  385.7  26.3   65.6
6  492.8   -.-    -.-

* RMS on smoothed data
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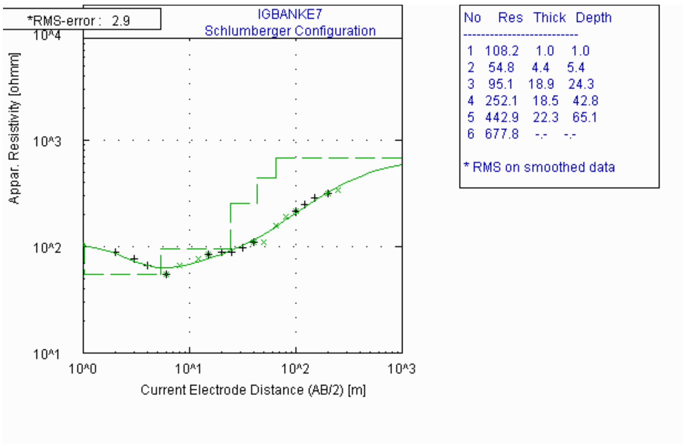
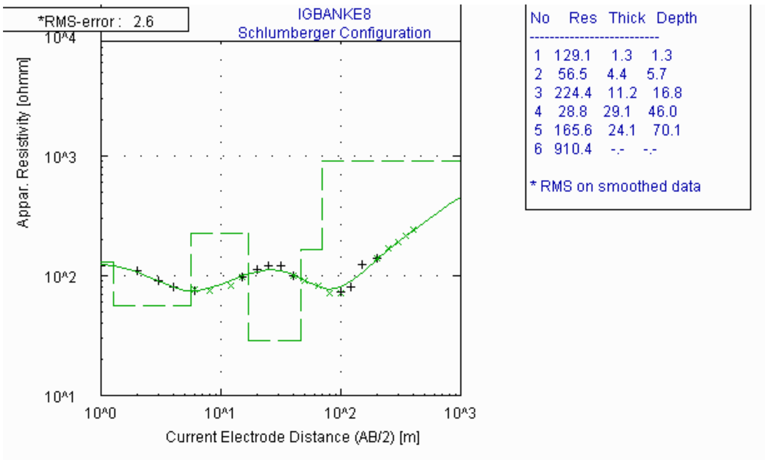
Figure 9: Typical Sounding curves for Igbanke Geophysical Investigation VES6



No	Res	Thick	Depth
1	108.2	1.0	1.0
2	54.8	4.4	5.4
3	95.1	18.9	24.3
4	252.1	18.5	42.8
5	442.9	22.3	65.1
6	677.8	-.-	-.-

* RMS on smoothed data

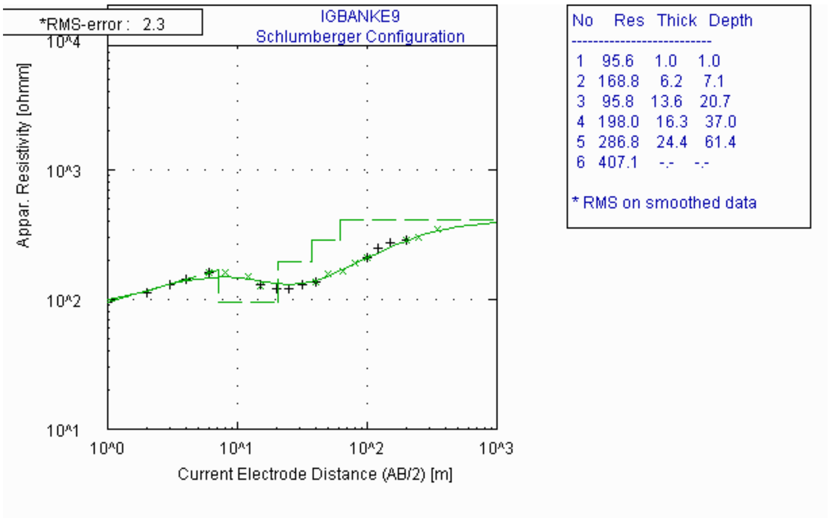
Figure 10: Typical Sounding curves for Igbanke Geophysical Investigation VES7



No	Res	Thick	Depth
1	129.1	1.3	1.3
2	56.5	4.4	5.7
3	224.4	11.2	16.8
4	28.8	29.1	46.0
5	165.6	24.1	70.1
6	910.4	-.-	-.-

* RMS on smoothed data

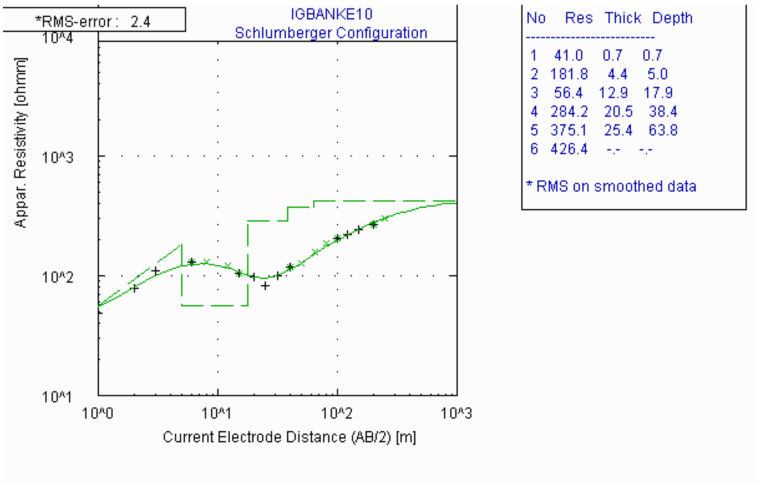
Figure 11: Typical Sounding curves for Igbanke Geophysical Investigation VES8



No	Res	Thick	Depth
1	95.6	1.0	1.0
2	168.8	6.2	7.1
3	95.8	13.6	20.7
4	198.0	16.3	37.0
5	286.8	24.4	61.4
6	407.1	-.-	-.-

* RMS on smoothed data

Fig. 4.12 Typical Sounding curves for Igbanke Geophysical Investigation VES9



No	Res	Thick	Depth
1	41.0	0.7	0.7
2	181.8	4.4	5.0
3	56.4	12.9	17.9
4	284.2	20.5	38.4
5	375.1	25.4	63.8
6	426.4	-.-	-.-

* RMS on smoothed data

Figure13: Typical Sounding curves for Igbanke Geophysical Investigation VES10

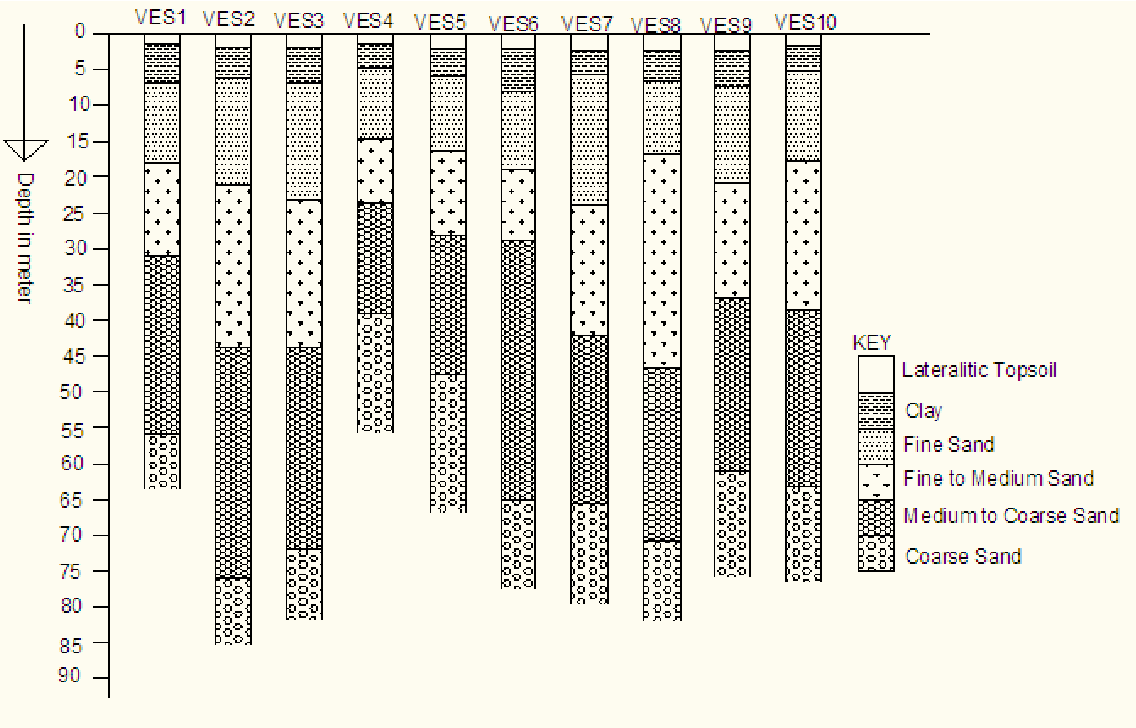


Figure 14: Geoelectric Section of Igbanke

Conclusion

The overburden protective capacity in the area was evaluated using the total longitudinal unit conductance values. The values obtained for VES locations show poor and weak protective capacity rating in almost all parts of the study area. The aquifer of the study area is not protected. Awareness should be created by encouraging the inhabitants to drink potable water from deep boreholes and discourage them from drinking water from septic tank which can be easily polluted. Groundwater monitoring wells should be provided in the community and regular water quality analysis conducted.

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