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Geoelectrical evaluation of groundwater potentials of Bwari basement area, Central Nigeria

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An investigation has been made of the groundwater potentials of Bwari basement area using solely geoelectric surveys. Twenty vertical electrical soundings along different transverses were conducted with maximum electrode spacing of 300 m. The results revealed that the area is characterized with 3 to 6 geoelectric subsurface layers with variability in resistivities and thicknesses of the different layers. The overburden thickness ranged from 6.9 to 72.9 m, with thinnest and thickest overburden observed at the central and western areas respectively. Dar Zarouk parameters (transverse resistance and coefficient of anisotropy), reflection coefficient, resistivity contrast, weathered layer thickness and overburden thickness were used as indices for evaluation of groundwater potentials. The area's groundwater productivity potential was hence, classified into two zones namely; high and low. This study has revealed that no single factor (index) determines the groundwater productivity potential but a combination of two or more factors. For example, not all the areas with thick overburden or high weathered layer thickness correspond to high groundwater potential.

Key words: Groundwater potential, electrical resistivity, transverse resistance, coefficient of anisotropy, Bwari.

INTRODUCTION

Water is essential to the continuous existence of man. Sources of water supply in Bwari range from pipe borne water (tap water), borehole, open hand dug well and stream. Tap water and borehole which constitute 9 and 23% of total water supply in the area are known to be the only sources of potable water for drinking and domestic purposes (MDG, 2012). Access to potable water supply over the years has been declining due to influx of people into the area without a corresponding expansion in the pipe borne water supply and borehole drilling programmes. Most of the water supply facilities (pipe borne water and boreholes) are fairly functional to non-functional, and this could be attributed to the use of substandard materials and wrong sitting of boreholes (MDG, 2012).

Electrical resistivity survey, a geophysical survey technique has proved to be an effective and a reliable tool in locating viable aquifers for continuous and regular water supply (Todd and Mays, 2005). This method has the advantage of non-destructive effect on the environment, cost effective, rapid and quick survey time and less ambiguity interpretations of results when compared to other geophysical survey methods (Todd, 1980). Twenty vertical electrical resistivity soundings along different transverses have therefore been carried out with the aim of delineating areas or zones of high and low groundwater potentials which is intended to aid in the groundwater planning and development of the area.

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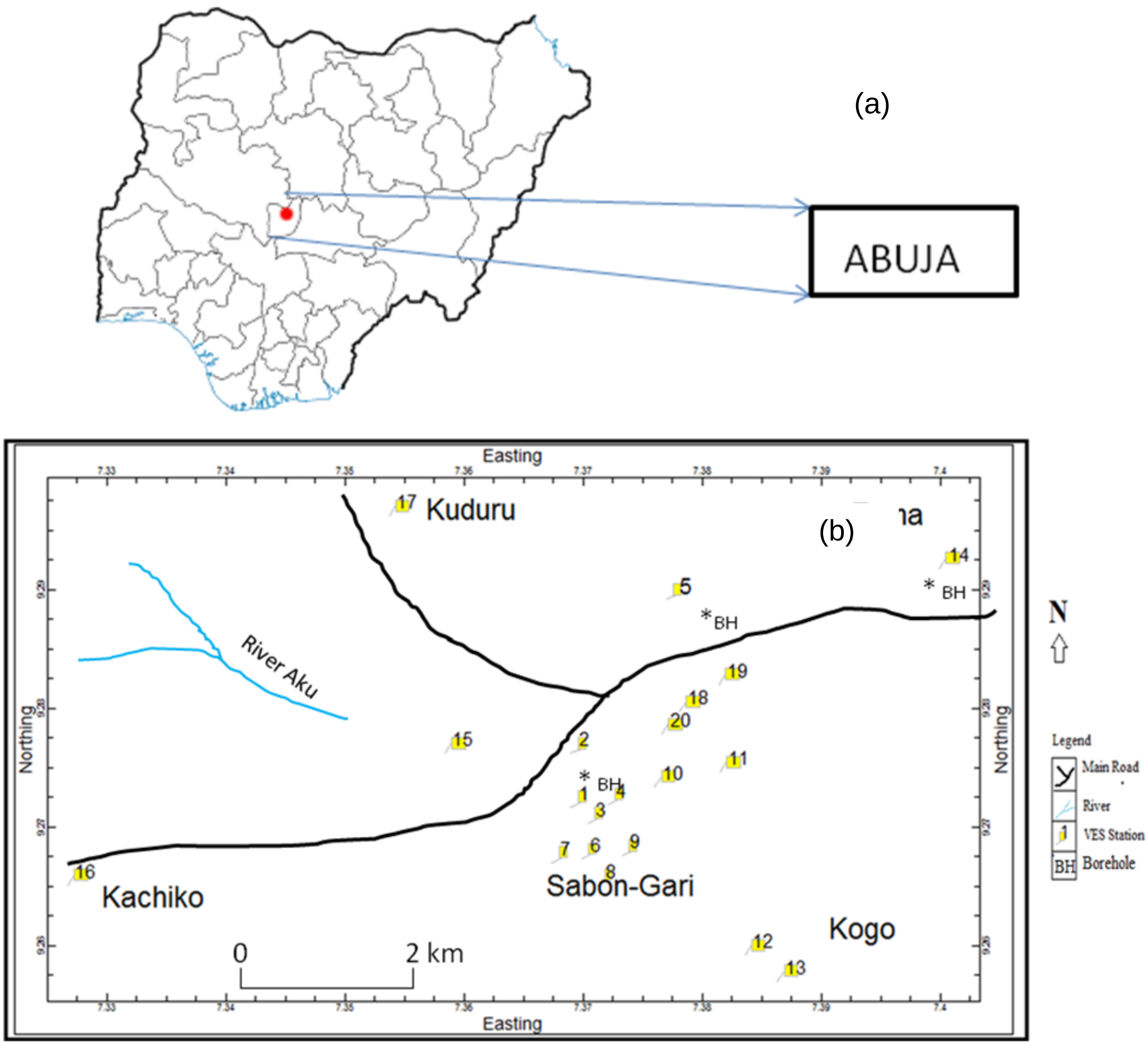

Figure 1. (a) Shows the map of Nigeria in which the study area is located. (b) Location and VES station map of the study area.

Study area

The study area is Bwari located in Abuja, Nigeria between latitudes 9° 15'N and 9° 18'N and longitudes 7° 19'E and 7° 25'E (Figure 1). It covers an approximate area of about 40 km^2. It is bounded in the north by Kaduna state, in the south by the FCT municipal town, in the East by Nassarawa state and in the west by Niger state. The general elevation of the study area varies considerably; it ranges from 535 to 597 m above mean sea level. The climate of the area is made up of two distinct seasons; the dry and rainy seasons. The dry season usually lasts from November to February with warm sunshine and hazy harmattan around December to January. The rainy season lasts from April to October. Mean annual rainfall ranges from 1500 to 2099 mm while the mean annual temperature varied from 27 to 30°C. The area falls under the Guinea savannah vegetation and is drained mainly by River Iku and its tributaries.

The study area is underlain by PreCambrian crystalline rocks of the Basement Complex. Rahaman (1989) classified the Basement Complex rocks of Nigeria into five groups namely; (i) Migmatite-Gneiss-Quarzite Complex which comprises of migmatite, gneisses, quartzite and quartz schist and small lenses of calcilicate rocks, (ii) Slightly migmatised to unmigmatised paraschist and meta-igneous rocks. (iii) Charnockitic rocks, (iv) Older granites which comprises of rock varying in composition from granodiorite to granite and potassic syenite, (v) Unmetamorphosed doleritc dykes. The Bwari is underlain by rocks of the Precambrian basement complex of north central Nigeria. The lithological units include the migmatite-gneiss complex and granitoids, (Mabogunje, 1977). The migmatite-gneiss complexes form generally the ridges and the icebergs while the granitiods form lowland outcrops with coarse texture. The study area can be divided into two hydro-geological units namely: the aquiferous zone within the weathered overburden overlying the basement rocks and the aquiferous zone within the intense fracture joint system in the partially weathered basement.

MATERIALS AND METHODS

This work has utilized the electrical resistivity survey method in delineating the groundwater potential of the study area, twenty vertical electrical soundings were carried out and the ALLIED OHMEGA SAS 300B model Terrameter and its accessories were used. The conventional Schlumberger array pattern, with half electrode spacing (AB/2) varying from 1 m to a maximum of 150 m was adopted. The apparent resistivity was computed using equation:

$$\rho_a = \frac{\pi L^2}{2l} R = GR \ , \qquad (1)$$

where

ρ_a is apparent resistivity

π is $\frac{22}{7}$

$G = \frac{\pi L^2}{2l}$ is geometrical factor

$R = \frac{\Delta V}{I}$. is the resistance

$L = \frac{AB}{2}$ is the half the current electrodes separation, and

$l = \frac{MN}{2}$ is the half the potential electrode separation.

The apparent resistivity values obtained from Equation (1) were plotted on bi-log graph against the half current electrode separation spacing. From these plots, qualitative deductions such as the resistivity of the first or top layer, the depth of each layer and the curve signatures or types were made. The initial quantitative interpretations were made using partial curve matching technique in which the field curves produced or generated were matched segment by segment with the appropriate master curves and auxiliary curves.

The resistivities and thicknesses of the various layers were improved upon by employing an automatic iterative computer program following the main ideas of Zohdy and Martin (1993). The WINRESIST computer software was employed for carrying out the iteration and inversion processes. Each iteration process was conducted for each sounding station until the root mean square (RMS) error of lower than 5% was obtained. The secondary parameters (longitudinal conductance (S_i), transverse resistance (T_i), longitudinal resistivity (ρ_L), transverse resistivity (ρ_l) and coefficient of anisotropy (λ)) were determined from the layers' resistivities and thicknesses using the mathematical relations (Zohdy et al., 1974):

$$S_i = \sum_{i=1} \frac{h_i}{\rho_i} \qquad (2)$$

$$T_i = \sum_{i=1} h_i \rho_i \qquad (3)$$

$$\rho_L = \sum_{i=1} \frac{h_i}{S_i} \qquad (4)$$

$$\rho_l = \sum_{i=1} \frac{T_i}{h_i} \qquad (5)$$

$$\lambda = \sqrt{\frac{\rho_l}{\rho_L}} \qquad (6)$$

The reflection coefficients (R_C) and fracture contrast (F_C) of the fresh basement rock of the study area were calculated using the method of Olayinka (1996); Bhattacharya and Patra (1968) and Loke (1999):

$$R_C = \frac{\rho_n - \rho_{n-1}}{\rho_n + \rho_{n-1}} \qquad (7)$$

$$F_C = \frac{\rho_n}{\rho_{n-1}} \qquad (8)$$

Where, ρ_n is the layer resistivity of the nth layer and ρ_{n-1} is the layer resistivity overlying the nth layer.

RESULTS AND DISCUSSION

Geoelectrical characteristics

The summary of the interpreted electrical resistivity survey is presented in Table 1. The geoelectric section (Figure 2a and b) reveals that the area is characterized by 3- to 6-geoelectric subsurface layers. Eight transverses connecting the twenty VES points were covered and their subsurface geo-electric sections are presented in figure 2. From the figure, the geo-electric subsurface section ranged from 3 to 6 layers with 4-layer type occurring more. The 3-layer geoelectric section is characterized by H curve type (Figure 3) and is generally made up of top loose soil, laterite/clay and fresh basement rock from top to bottom with variable

Table 1. Layers' resistivity, thicknesses and curve types.

VES station		Layer	Resistivity	(ohms)*				Layer	thickness	(m)+		Curve type
	ρ_1	ρ_2	ρ_3	ρ_4	ρ_5	ρ_6	h_1	h_2	h_3	h_4	h_5	
1	442	5078	1982	62	234	21063	2.6	0.4	5.4	15.9	48.6	AKH
2	44	2184	35	1668			2.1	0.8	25.5			KH
3	349	18	3357				2.9	6.3				H
4	214	62	1226				5.6	52.2				H
5	1177	155	7040				6.6	37.5				H
6	479	1047	1560	10618			1.3	6.5	18.6			AA
7	251	1066	2107	134	5338		1.6	1.3	4.0	25.6		AKH
8	344	274	5117	54677			1.1	11.9	1.0			HA
9	336	43	909				1.1	5.8				H
10	207	64	5941				1.0	9.3				H
11	110	59	3257	16	1232		1.5	1.5	1.0	6.2		HKH
12	455	482	111	6391			4.8	3.9	30.5			KH
13	438	11908	575	25454			1.5	0.7	63.7			KH
14	1109	357	6830	92805			1.4	22.6	1.9			HA
15	278	588	75	7075			1.6	1.4	54.9			KH
16	387	562	97	413			2.2	0.8	11.0			KH
17	212	314	77	17627			1.7	0.6	6.2			KH
18	95	101	13242				3.5	4.1				H
19	495	772	305	1391			3.5	0.9	15.9			KH
20	496	942	207	756			6.1	0.2	26.5			KH

VES-vertical electrical sounding; ρ -layer resistivity; h-layer thickness, m-meter.

thicknesses and resistivities. The 4-layer geoelectric section is characterized by KH and HA curve types (Figures 4, 5 and 6). The 5-layer geoelectric section is characterized by AKH and HKH curve types (Figures 7 and 8) and the six layer characterized by AKH curve types (Figure 8). Vertical electrical sounding (VES) stations 2, 5 and 14 were carried out in the vicinity of existing boreholes. The inferred lithologies and thicknesses of the various layers from the subsurface geoelectric sections of these VES stations were compared with the lithologic logs of the boreholes located very close to them and it was revealed that they are very well correlated (Figure 9). The topsoil layer is made up of loose sand, sandy clay, clay and lateritic soil and its thickness and resistivity varied from 1.0 to 6.6 m, with a mean of 2.78636m and from 44.0 to 1177 Ωm, with a mean of 415.4091 Ωm respectively. Underlying the topsoil layer is the weathered layer. The weathered layer thickness and resistivity range between 1.0 and 63.7 m with a mean of 20.675 m and from 35 to 13242 Ωm, with a mean of 3060.318 Ωm respectively. The partially weathered/fractured layer where found underlies the weathered layer and resistivity of this layer range from 16 to 92805 Ωm, with a mean of 19494.25 Ωm and where it occurs as the last layer from the surface, it has an infinite thickness. This layer together with the weathered layer constitutes the aquiferous units where they have appreciable thicknesses in the basement area. Overburden thickness measured varies from 6.9 to 72.9 m, with a mean of 21.5 m.

Evaluation of groundwater potentials

The groundwater potentials of the area are evaluated based on the following indices; weathered layer thickness and resisitivity, overburden thickness, transverse resistance, coefficient of anisotropy, reflection coefficient and resistivity contrast. The weathered/or weathered fractured layer constitute the water saturation zone or aquifereous units. Areas where weathered layer thickness is greater than 25 m (Table 2) and of low clay content as indicated by the resistivity (> 150 Ωm) value is categorized to be area of high groundwater potentials. The spatial distribution of the weathered layer is presented in Figure 10. From the figure, area around VES stations 12, 13 and 15 have very high (in the range of 40 to 65 m) weathered layer thickness while area around VES stations 8, 9, 11 14, 16, 17 and19 have very low (in the range of 5 to 15 m) weathered layer thickness. Zones that have thick overburden and low percentage of

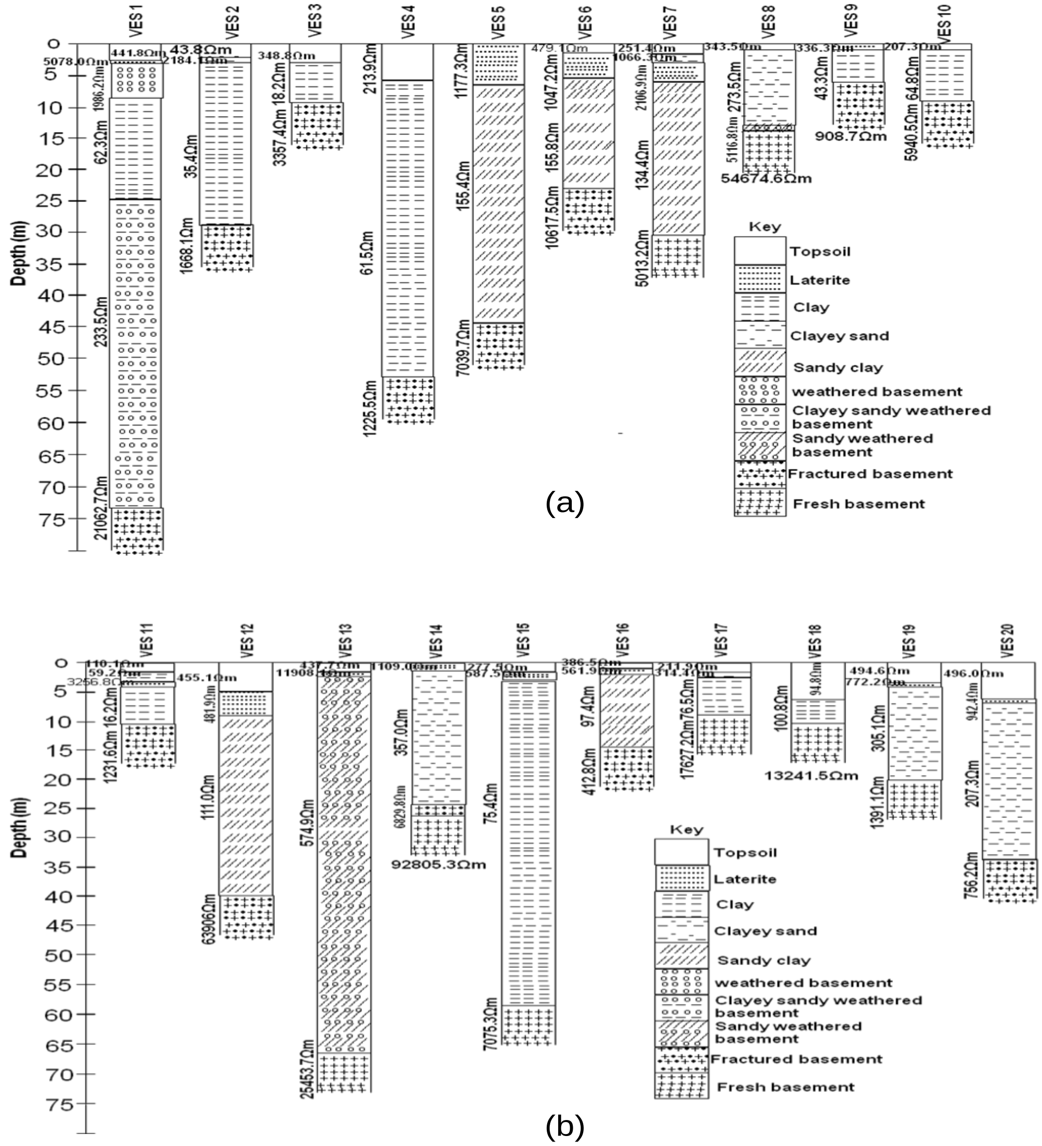

Figure 2. (a) 1-D geoelectrical models for VES 1 – 10, (b) 1-D geoelectrical models for VES 11 – 20.

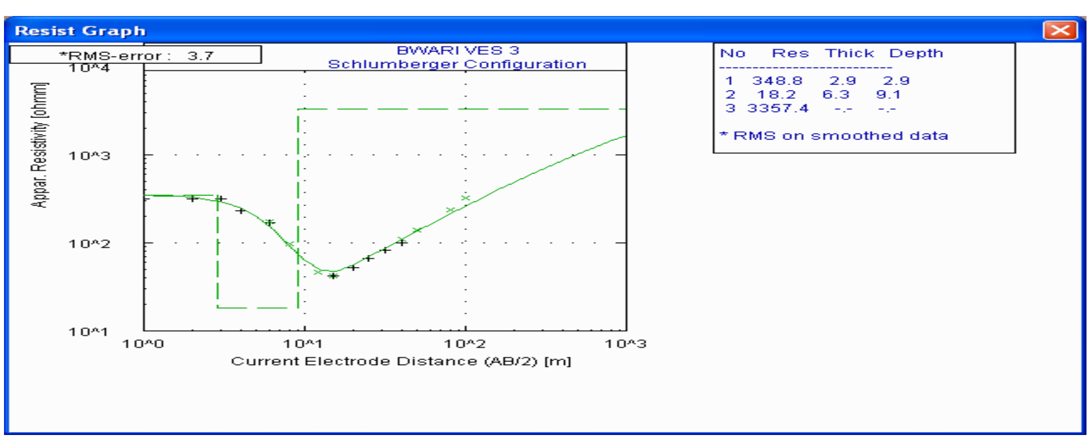

Figure 3. Typical H curve type.

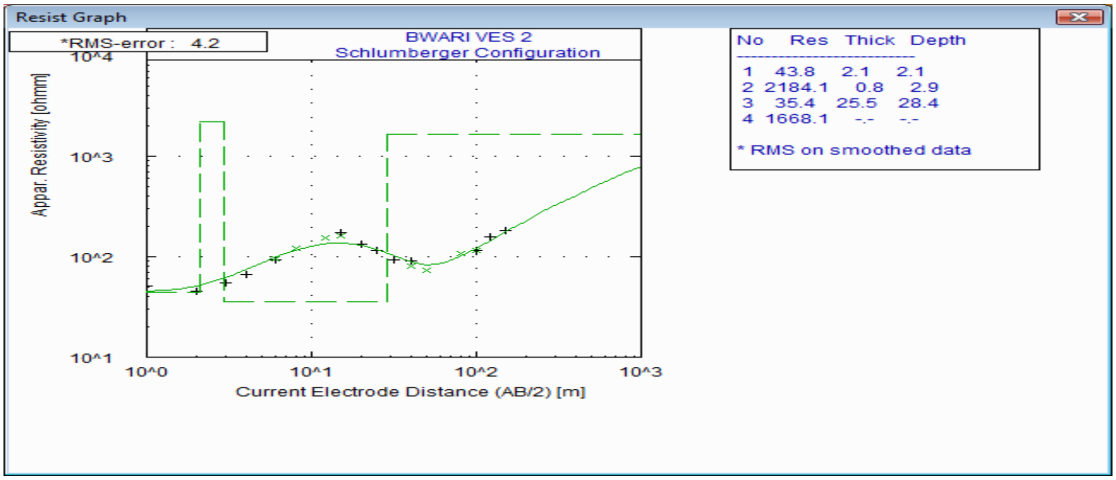

Figure 4. Typical KH curve type.

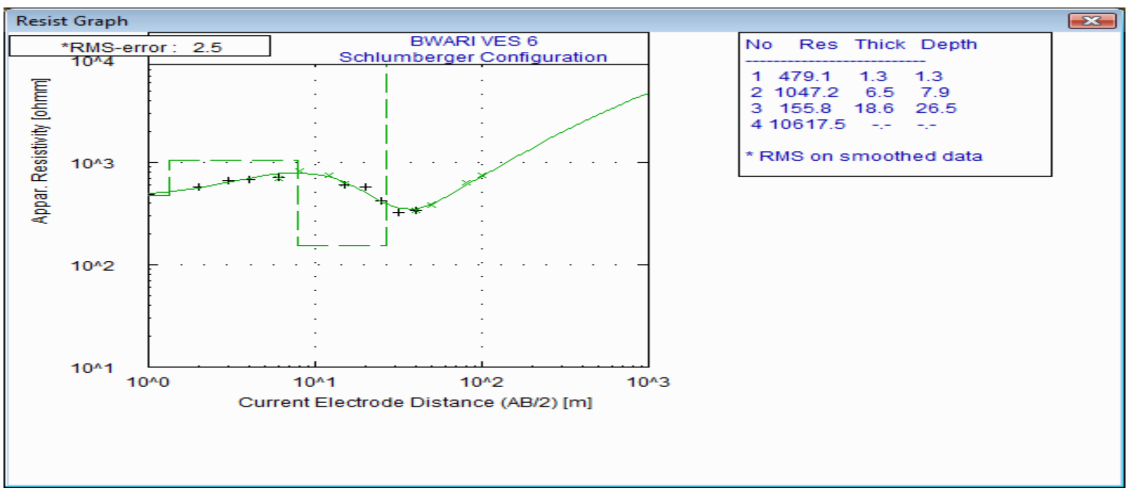

Figure 5. Typical KH curve type.

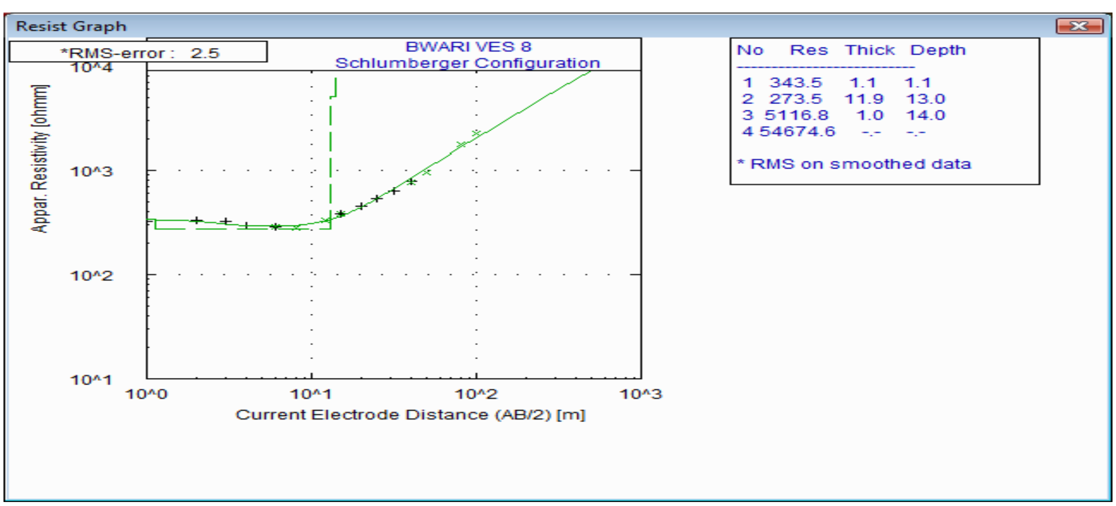

Figure 6. Typical HA curve type.

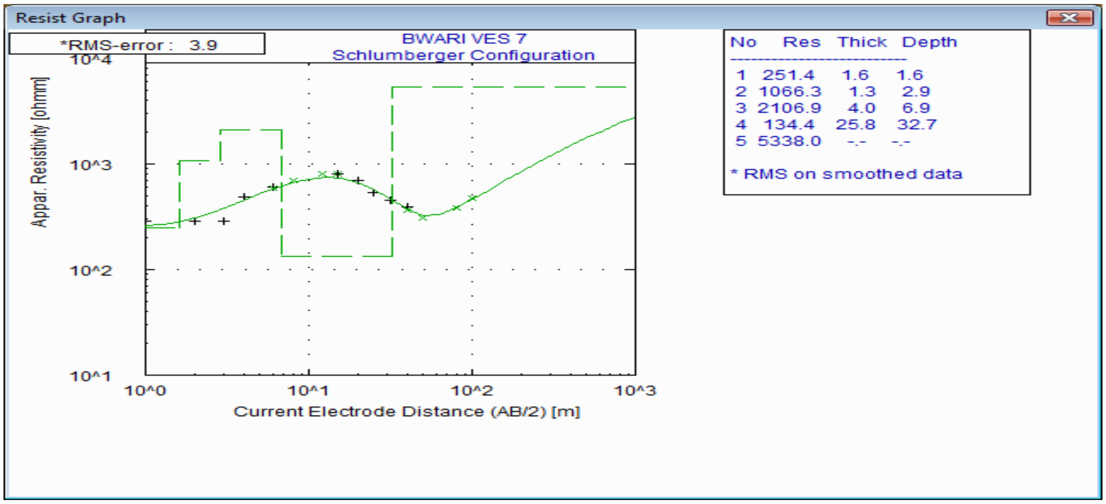

Figure 7. Typical AKH curve type.

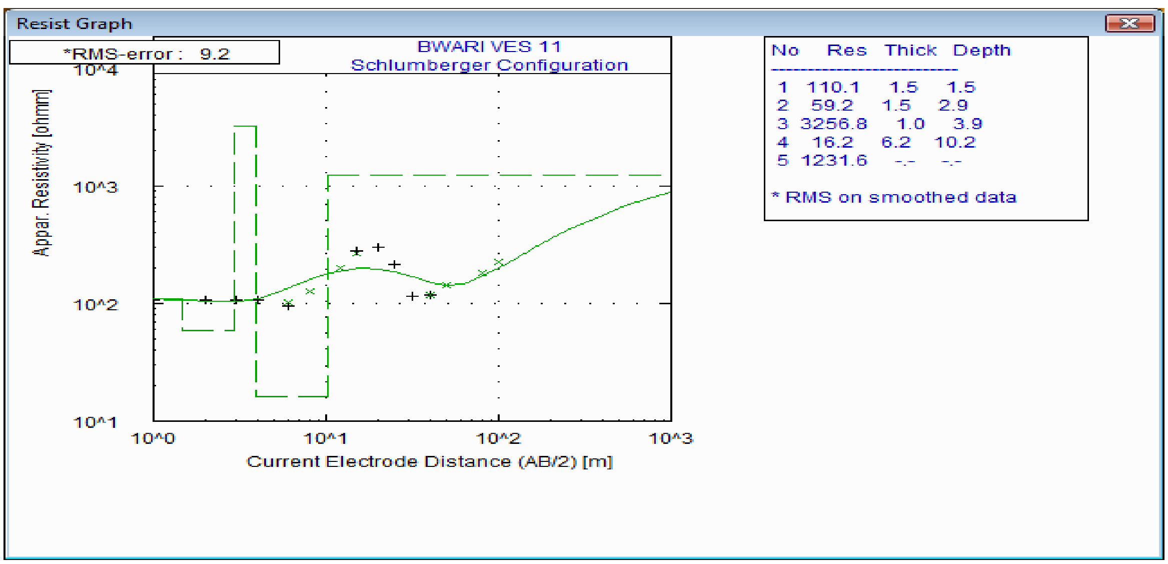

Figure 8. Typical HKH curve type.

clay in which intergranular flow is dominant are known to have high groundwater potential particularly in basement complex terrain (Okhue and Olorunfemi, 1991). In this study, areas with overburden thickness greater than 30 m such as areas around VES stations 2, 12, 13 and 15 (Figure 11) are classified as high groundwater potential zones. Transverse resistance (T_i) has a direct relation with transmissivity (T) and the highest T_i values reflect most likely the highest T values of the aquifers or aquiferous units and vice-versa (Anudu et al., 2011; Kumar et al., 2001). Vertical electrical sounding stations such as 6, 9, 12, 13 and 14 with computed transverse resistance greater than 5000 Ωm^2 (Figure 12) are defined as areas of high groundwater potentials.

Generally, the co-efficient of the anisotropy is 1 and does not exceed 2 in most of the geological conditions (Zohdy et al., 1974). Compact rock at shallow depth increases the coefficient of the anisotropy (Keller and Frischknecht, 1966). Hence, these areas can be associated with low porosity and permeability. The areas with 1.0 and less than 1.5 anisotropy (VES stations 2, 12, and 16; Figure 13) values (high porosity and permeability) are considered as high groundwater potential zones (Rao et al., 2003). The reflection coefficient and resisitivity contrast at fresh basement rock interface can provide some insight into the aquiferous nature of the basement rocks. According to Olayinka (1996), he observed that area of lower reflection

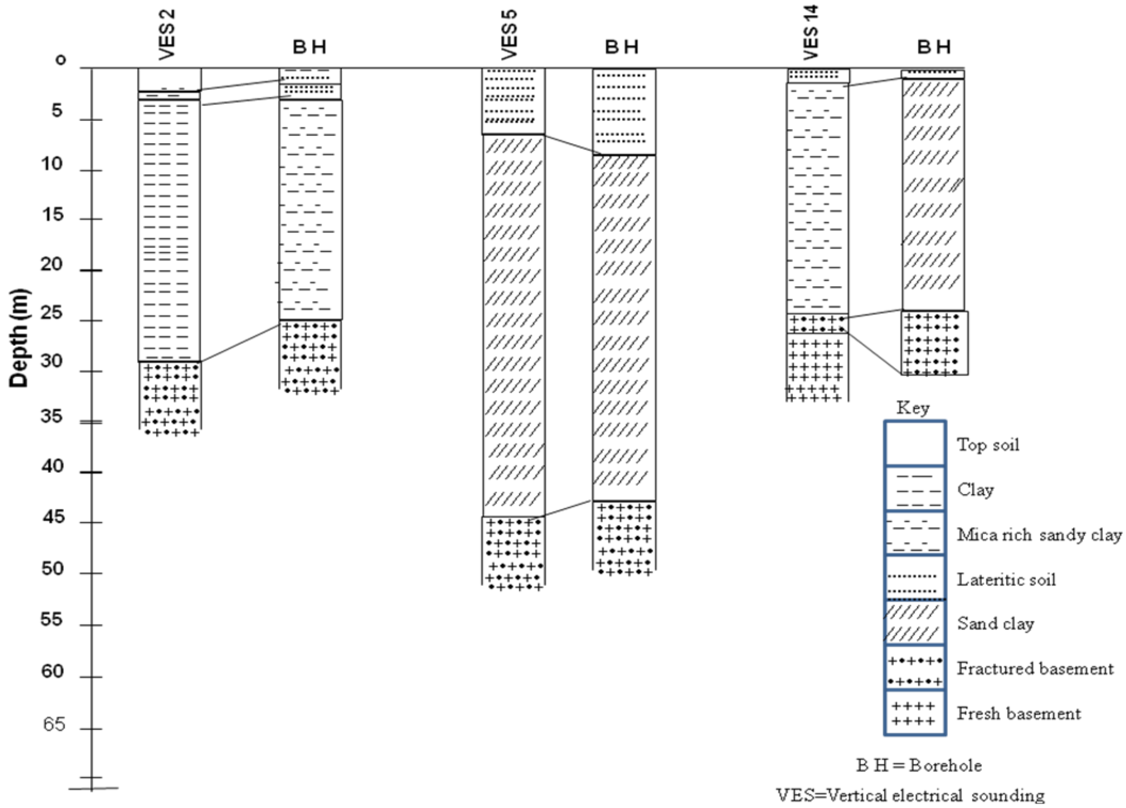

Figure 9. Correlation between geoelectric section and lithological logs.

Table 2. Groundwater potential indices

VES station	Weathered layer thickness (m)	Overburden thickness(m)	Transverse Resistance (Ωm^2)	Coefficient of Anisotropy	Reflection coefficient	Resistivity contrast
1	48.6	72.9	25095.35	0.8159	0.97	90.65
2	25.5	28.4	2741.96	0.6186	0.96	46.66
3	6.3	9.2	1126.18	1.421	0.99	186.50
4	46.6	57.8	4063.74	0.8755	0.90	19.77
5	37.5	44.1	13597.68	1.0558	0.96	45.42
6	25.1	26.4	10327.51	0.7280	0.74	6.80
7	25.8	32.5	8134.96	0.8108	0.95	39.88
8	1.0	14.0	8749.3	0.6911	0.83	10.69
9	5.8	6.9	620.74	0.7476	0.91	21.14
10	9.3	10.3	809.94	0.9397	0.98	92.82
11	7.2	10.2	3611.19	0.2613	0.97	77.00
12	30.5	39.2	7449.39	1.3469	0.97	57.58
13	63.7	65.9	45613.35	1.2117	0.96	44.27
14	1.9	25.9	22597.42	0.4973	0.86	13.59
15	54.9	57.9	5405.96	2.7006	0.98	94.33
16	12.3	14.0	2202.61	1.0102	0.62	4.26
17	6.2	8.5	1023.17	0.9419	0.99	228.90
18	4.1	7.6	745.08	0.9995	0.98	131.11
19	15.7	20.3	7216.15	0.9678	0.64	4.56
20	26.7	32.8	8707.53	0.9383	0.57	3.65

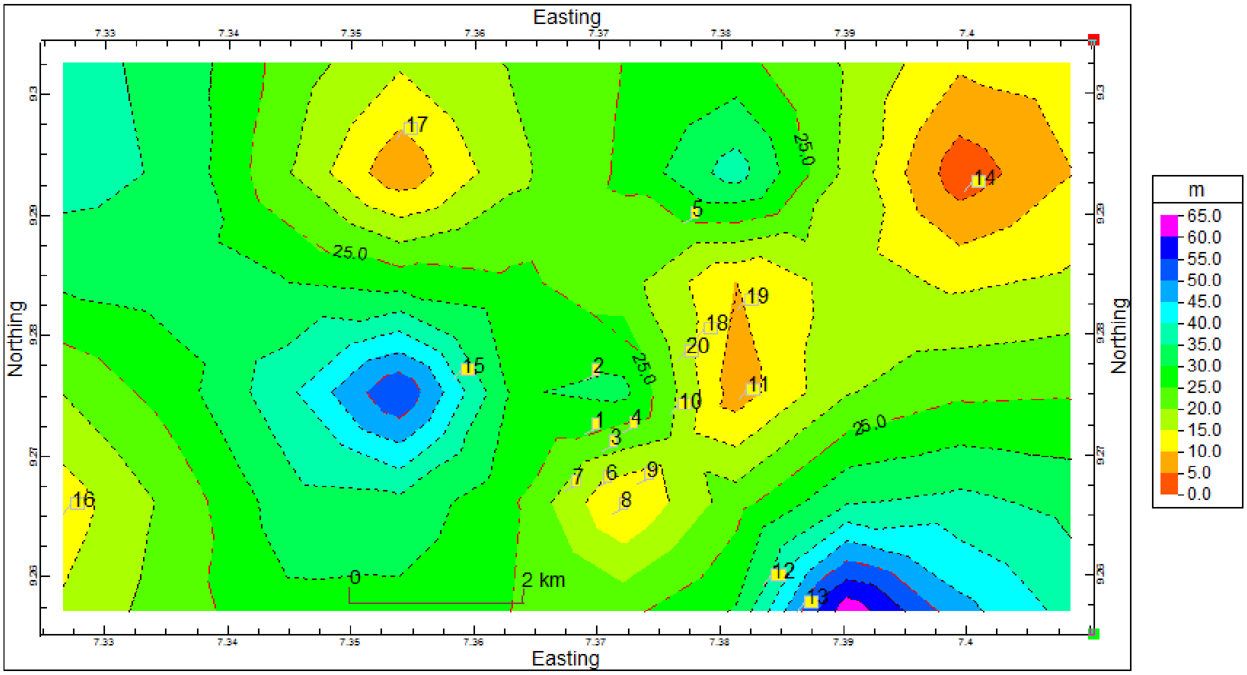

Figure 10. Spatial distribution of weathered layer thickness of the study area.

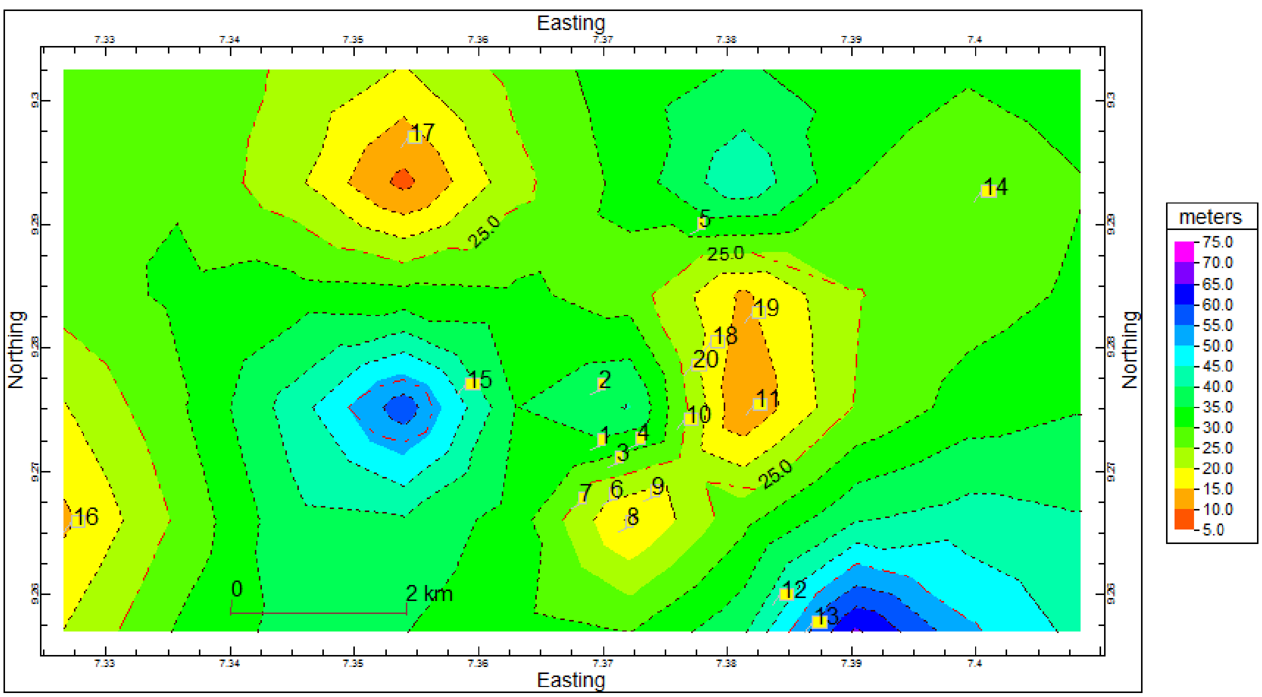

Figure 11. Spatial distribution of overburden thickness of the study area.

coefficient value exhibits a fracture of the basement rock, and hence, has a higher water potential. In the present study, reflection coefficient and resistivity contrast values less than 0.9 and 19 (VES stations such as 14 and 16; Figures 14 and 15) respectively may be indicative of high density water filled fracture (Anudu et al., 2011; Olayinka et al., 2000). The groundwater potentials map of the area is presented in Figure 16.

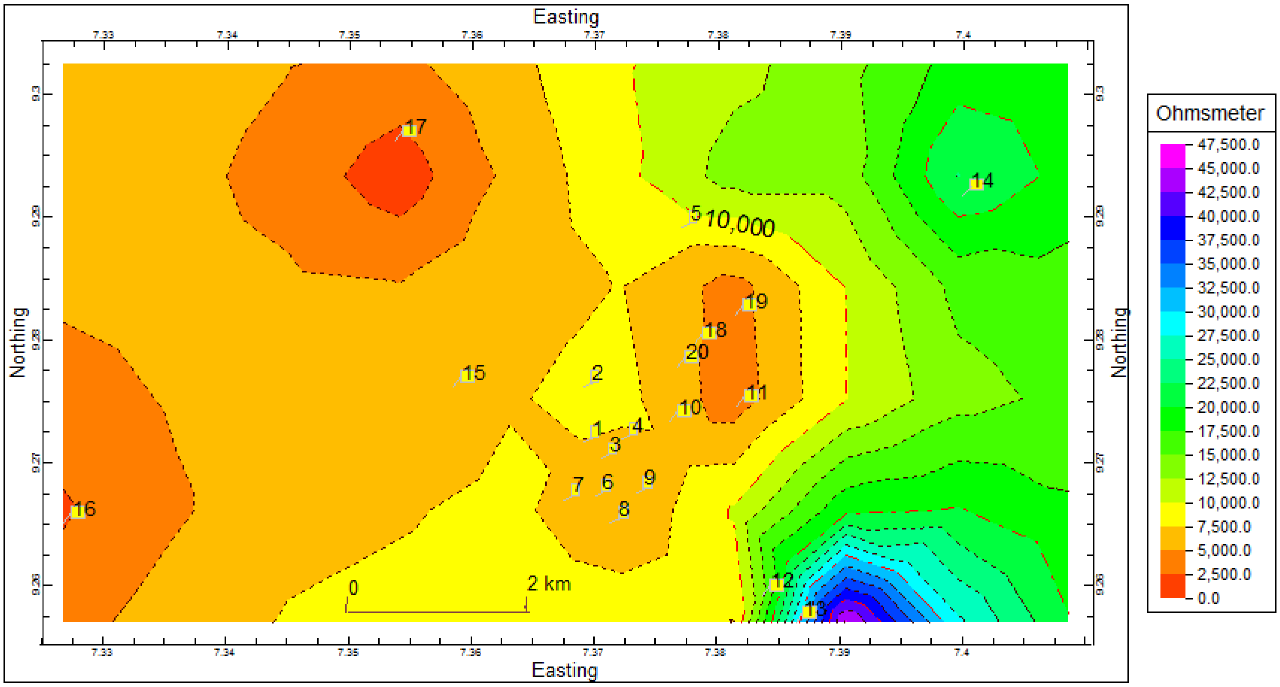

Figure 12. Spatial distribution of transverse resistance of the study area.

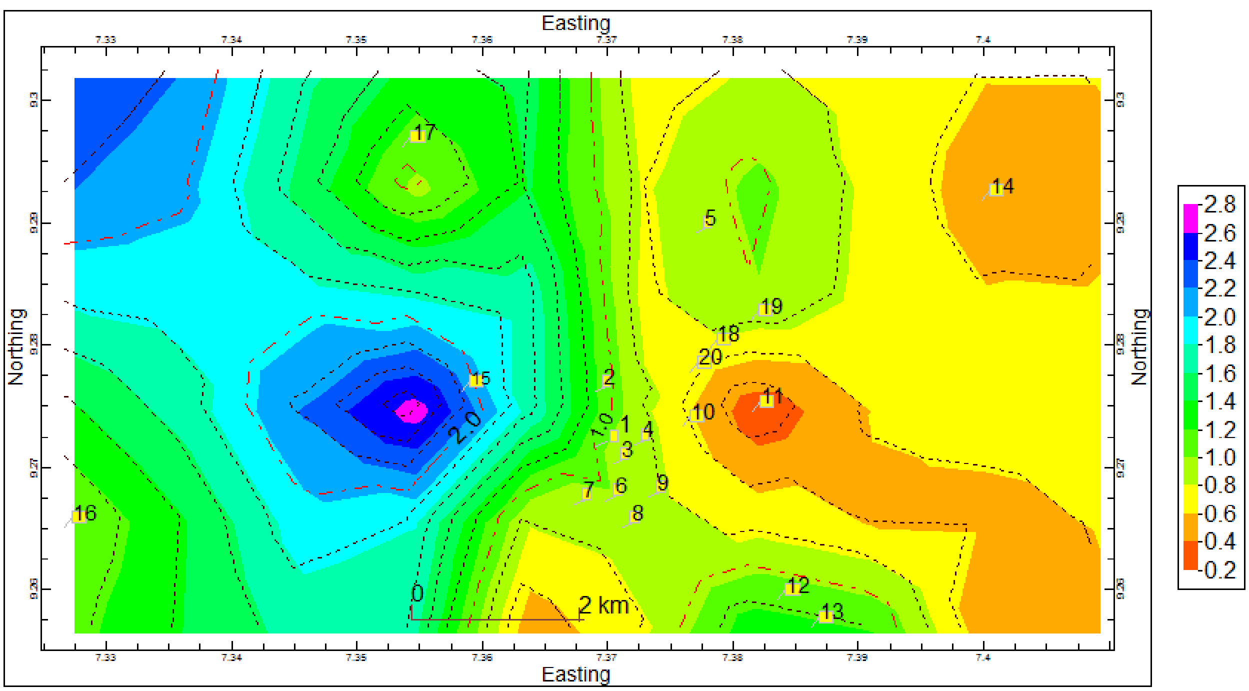

Figure 13. Spatial distribution of coefficient of anisotropy of the study area.

Conclusions

Groundwater usually occurs in discontinuous aquifers in basement complex area. Defining the potentials of the aquifers is normally a tedious exercise because of the intricate properties of the basement rocks. The integration of various electrical resistivity parameters have shown to be efficient in classifying the groundwater

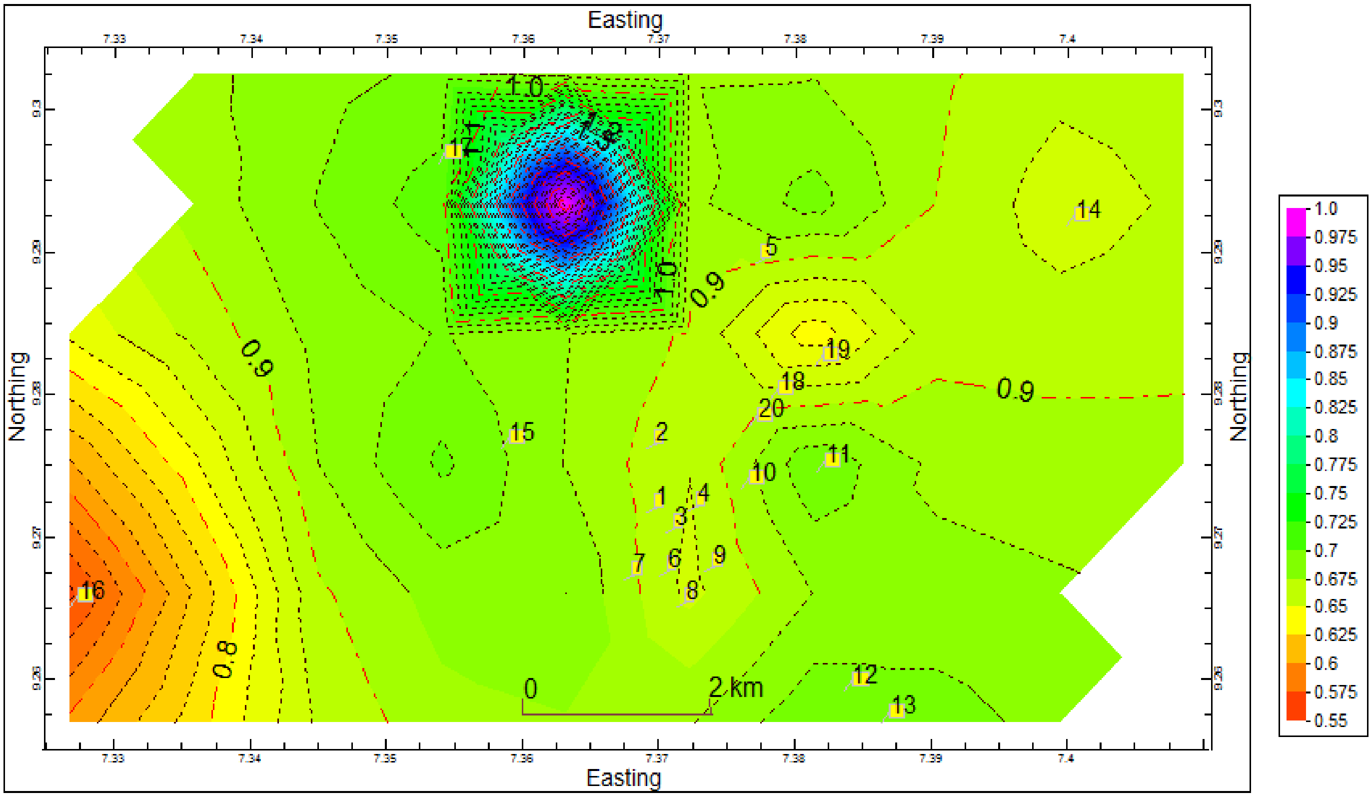

Figure 14. Spatial distribution of reflection coefficient of the study area.

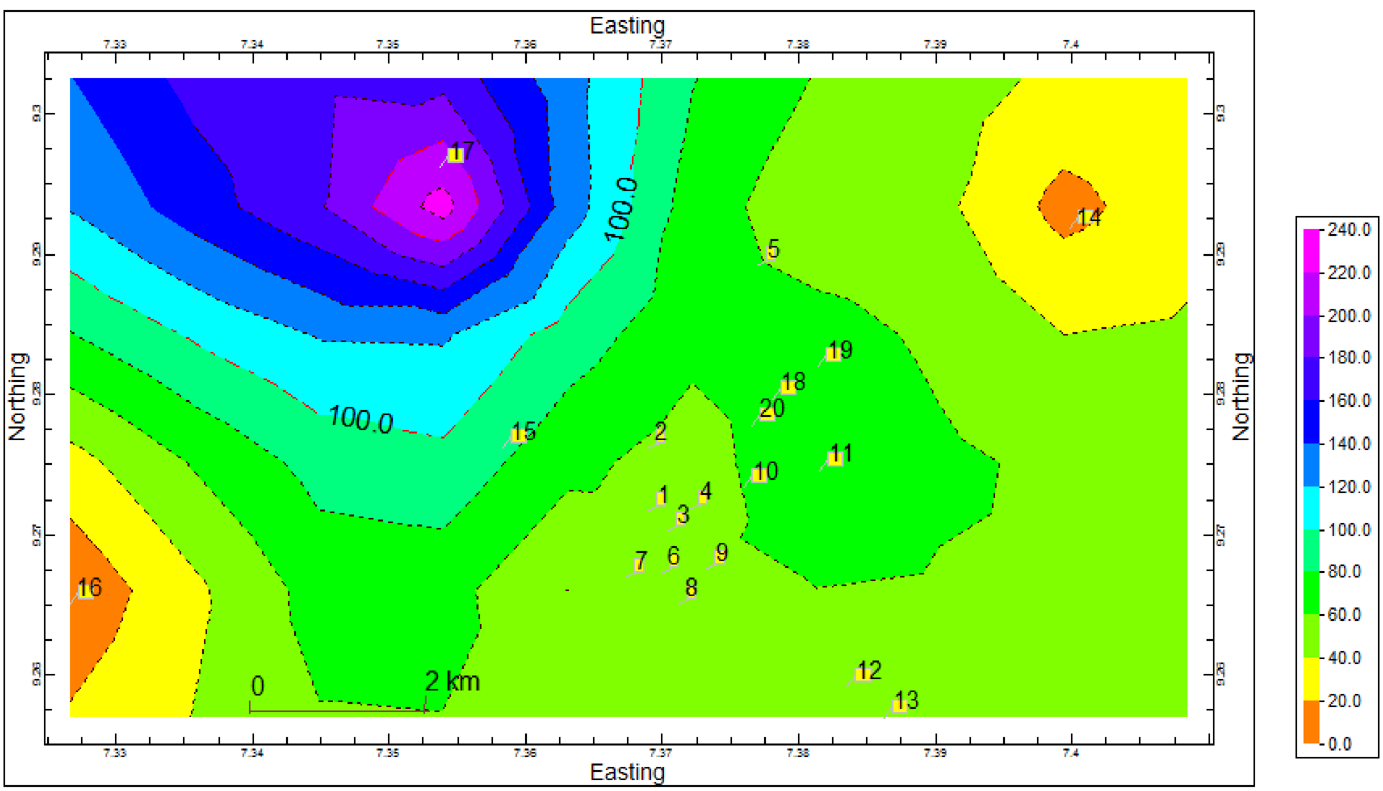

Figure 15. Spatial distribution of resistivity contrast of the study area.

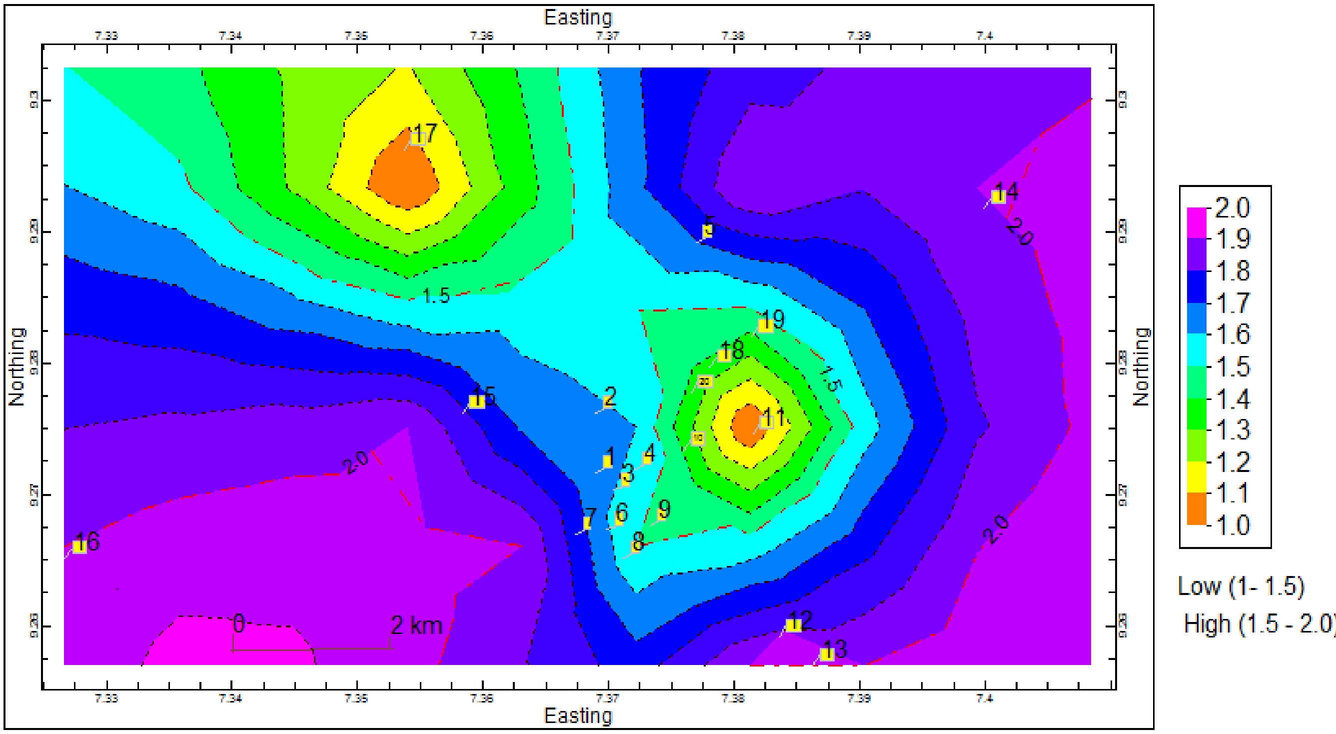

Figure 16. Groundwater potentials of the study area.

potentials of a basement terrain. Groundwater developments should be concentrated in areas of high groundwater potentials and conjunctive use of surface water should be encouraged to reduce complete dependence on groundwater.

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