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Delineation of potential groundwater zones using geo-electrical sounding data at Awka in Anambra State, South-eastern Nigeria

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Abstract
Vertical Electrical Sounding (VES) technique was used to map Awka municipal groundwater potential zones. Sixteen VES were carried out across the area using the schlumberger electrode array configuration. The geoelectric sections obtained from the sounding curves revealed 4-layer earth models respectively.

2-D surface map of the anisotropic coefficient map layer, hydraulic conductivity map layer, isoresistivity map layer, and isothickness map layer were overlay to produce the final groundwater potential layer. Three potential groundwater zones were delineated: the high groundwater potential zone, the medium groundwater potential zone and the low groundwater potential zone. The final groundwater potential map revealed that the Northern parts of the study area are the most promising region for groundwater potential/borehole development, while the Western and Southern parts can also be considered as fair for groundwater potential/borehole development. The Eastern part of the study area has the lowest groundwater potential/borehole development. The various contour maps and final overlay for the potential groundwater zone mapping will serve as a useful guide for groundwater exploration in the study area.

Keywords: Groundwater potential, vertical electrical sounding, geo-electric section, isoresistivity, hydraulic conductivity, isothickness, anisotropic coefficient.

1. Introduction

In Nigeria, a staggering proportion of wells and boreholes fail. Failure can occur for a number of reasons – inadequate maintenance and community involvement, poor engineering or lack of water. Often it can be difficult to work out the exact reason after the event. However, in many geological environments the impacts of poorly sited and designed boreholes and wells are a major concern to funding agencies, implementing institutions and local communities. In such areas, good supplies of groundwater cannot be found everywhere, and boreholes and wells must be sited and designed carefully to make use of the available groundwater.

The ground resistivity is related to various geological parameters such as the mineral and fluid content, porosity, nature and degree of water saturation in the rock. Electrical resistivity surveying is a geophysical operation in which measurements of earth resistivity are made from the ground surface (Michael, 1978). Electrical resistivity surveys have been used for many decades in hydro-geology, mining and geotechnical investigations. More recently, it has been used for environmental surveys. The purpose of groundwater exploration is to delineate the water bearing formation, estimate their hydrological characteristics and determine the quality of water present in these formations. Geophysical methods are used to provide an indirect evidence of the subsurface formation that indicate whether the formations may possibly be aquifers (Michael, 1978). A number of geophysical exploration techniques are available which enables an insight to be obtained rapidly in the nature of water bearing layers and include geoelectric, electromagnetic, seismic and geophysical borehole logging (Alile, *et al.* 2008). These methods measure properties of formation materials, which determine whether such formation may be sufficiently porous and permeable to serve as an aquifer. The electrical resistivity method and seismic refraction method are the surface geophysical methods commonly used for groundwater exploration (Asawa, 2009). Ishola *et al.*, (2013) used areas of thick overburden (materials above the bedrock) and the iso-resistivity maps showing the resistivity distribution of the aquifer layers in mapping promising areas for groundwater abstraction. Groundwater potential zones also were delineated based on aquifer transmissivity classifications alone by Okonkwo and Ujam (2013). Anudu *et al.,* (2011) used hydro-resistivity maps produced from the geoelectric sounding data interpretation which include total transverse resistance map; 3-D surface total transverse resistance map; total longitudinal conductance map; 3-D surface total longitudinal conductance map; basement relief map and 1-Grid Vector basement relief map for groundwater prospecting. A number of times these maps tends to contradict each other in drawing conclusion on prospective groundwater zones because of the complex inter-relationship that exist between the geology, post emplacement tectonic history (fractures), weathering processes and depth, nature of the weathered layer, groundwater flow pattern, recharge and discharge processes (Eze 2012). Hence, there is need to delineate groundwater zones using map overlay, since a composite map will as in suitability map overlay analysis, provide a more accurate information. The aim of this paper is to delineate groundwater potential zones in Awka municipality using 2-D surface map of the anisotropic coefficient map layer, hydraulic conductivity map layer, isoresistivity map layer, and isothickness map layer.

2. Materials and Methods

2.1 Study Area

The study area (Awka in Anambra State of Nigeria) is located between Latitude 6º12'-6º16' N and Longitude 7º04' - 7º07' E, it lies within the tropical wet climate zone having two distinct seasons: wet season (April- October) and dry season (November – March). The mean temperature which prevails over this region varies between 27 ºC - 28ºC which most times peak to 35ºC between January and April. Annual rainfall of about 2000 mm is witnessed within this region with maximum monthly rainfall during the peaks ranging from 270 mm – 360 mm (Odumodu and Ekenta, 2012).

3. Experimental Field Procedure

The field procedure involves measuring the apparent resistivity as the mid-point of the array is kept fixed while the distance between the current is progressively increased. The Schlumberger configuration was adopted for this study. After data acquisition, the apparent resistivity values are plotted against half the current electrode spacing on bi-logarithmic graph paper.

Terrameter SAS 1000C was used for this study, it transmits a well- defined and regulated square wave, which minimizes induction effects and attenuation. The current was introduced into the ground by a pair of steel stakes driven into the ground. The electrode separation allows for the calculation of apparent resistivity of the earth. Measurements were taken manually using the above mentioned Terrameter that normally provides a direct readout of resistance. In order to convert the resistance reading to an apparent ground resistivity, a geometric factor was applied to the data, based on the Schlumberger configuration used in this study. The sounding data were interpreted using computer software (1X1D Interpex).

Sixteen (16) vertical electrical sounding (VES) points were conducted at various locations within the study area in order to study the variations in the resistivity distribution of the soil with depth. The spatial location of the VES points in the study area is as shown below:

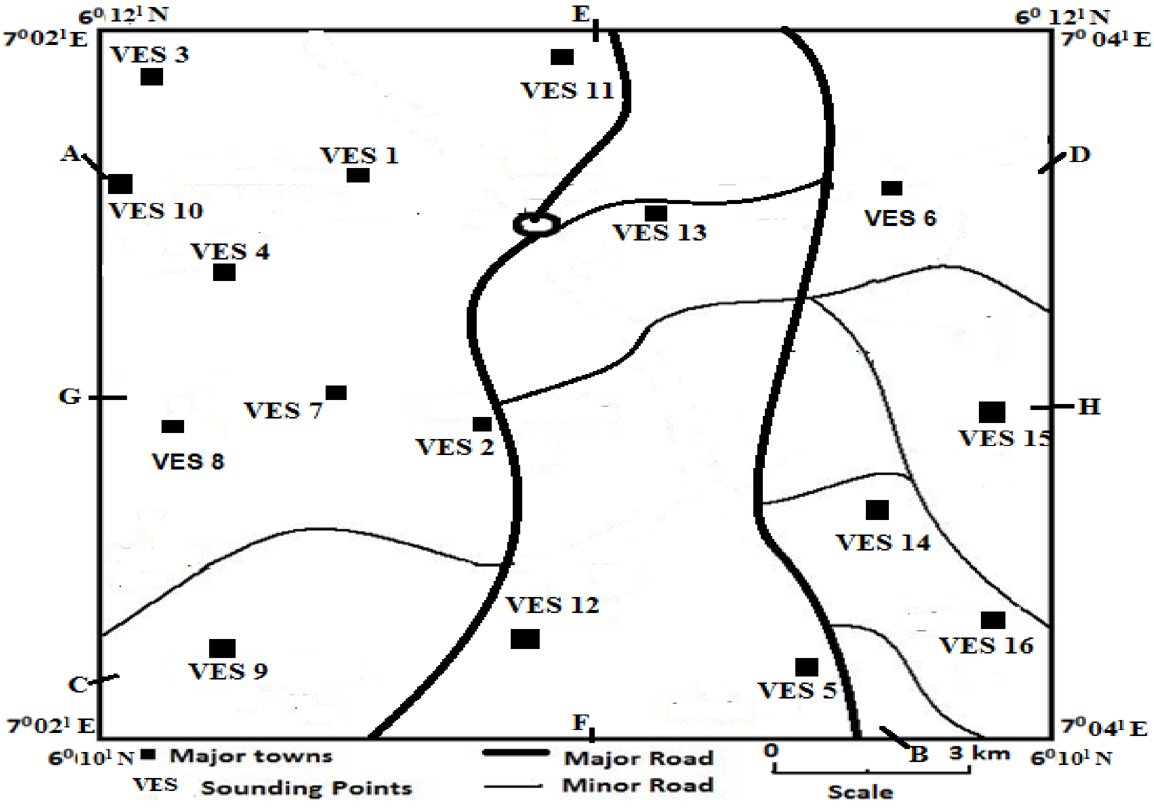

Fig 1: Map of the study area showing location, access roads and VES points.

4. Groundwater Parameter Calculations

Hydraulic conductivity is symbolically represented as *K*, which depends on the intrinsic permeability of the material and on the degree of saturation. Saturated hydraulic conductivity, K_{sat}, describes water movement through saturated media.

$K_c = 1/p$ (1)

Where Kc is the calculated hydraulic conductivity and *p* is the resistivity of the saturated layer.

Transverse Resistance, T_r (Ohm-m^2) and Longitudinal Conductance, L_c (Ohm^{-1}) are parameters used to define target areas of good groundwater.

$T_r = hp$ and $L_c = h/p$ (2)

Where h is aquifer thickness and *p* resistivity value of the aquifer.

The apparent resistivity and thickness of aquifer values estimated from the VES results are presented in Table 2.

The overburden's coefficient of anisotropy was calculated for each VES station using the transverse resistance and longitudinal conductance (Sunmonu *et al.,* 2012).

$$C_a = \sqrt{\frac{T_r}{l_c}} \qquad (3)$$

5. Results and Discussions

The vertical electrical sounding curve types identified in the study area includes K, H, QH, HK, KH, QK, KQ and KHK (Table 1). Approximately, 31.25% of all the sounding curves are HK-type whereas the remaining 68.75% belongs to the seven curve types within the study area. Therefore, HK type is the most dominant sounding curve type in the study area.

Table 1: The vertical electrical sounding curve types

VES Curve type	VES N0	VES curve characteristic	Frequency	Percentage
K	4, 7,	ρ1< ρ2> ρ3	2	12.5
H	10	ρ1> ρ2< ρ3	1	6.25
QH	1, 8,	ρ1> ρ2> ρ3<ρ4	2	12.5
HK	2, 6, 9, 13, 14,	ρ1> ρ2< ρ3> ρ4	5	31.25
KH	12	ρ1< ρ2> ρ3< ρ4	1	6.25
QK	3, 5	ρ1> ρ2> ρ3<ρ4>ρ5	2	12.5
KQ	11	ρ1< ρ2> ρ3> ρ4	1	6.25
KHK	15, 16	ρ1< ρ2> ρ3< ρ4> ρ5	2	12.5
Total			16	100

Table 2: Apparent Resistivity and Aquifer Thickness

	Layer 1	Layer 2	Layer 3	Layer 4	Layer 1	Layer 2	Layer 3	Layer 4
	App. Resistivity (Ω-m)	App. Resistivity (Ω-m)	App. Resistivity (Ω-m)	App. Resistivity (Ω-m)	Thickness (m)	Thickness (m)	Thickness (m)	Thickness (m)
VES 1	182.7	219	158	13.2	2.7	3.7	5.1	180.7
VES 2	3103.12	1220.19	4650.16	3813.22	3.5	6.2	90.7	49.6
VES 3	125.70	8.54	82.01	6.27	2.5	10.3	8.9	165.7
VES 4	640.41	2320.17	1894	124.98	2.3	38.4	65.2	-
VES 5	425.23	3.41	38.14	532.52	2.2	23.6	24.6	55.8
VES 6	393.01	144.16	2050.22	1235.37	2.4	2.3	45.3	106.1
VES 7	232.92	875.54	4090.16	1004.04	2.7	6.7	36.9	59.5
VES 8	597.02	858.21	10.22	139.14	2.2	6.3	29.7	66.8
VES 9	235.21	42.54	1986.1	893.2	2.8	2.4	98.1	92.9
VES 10	682.1	13.85	122.11	564.28	1.96	10.67	15.64	14.91
VES 11	366.12	2268.19	29.50	32.40	2.41	12.79	128.6	20.5
VES 12	389.18	151.05	635.23	8.19	2.3	4.3	13.3	57.9
VES 13	910.05	47.81	6080.11	1274.08	2.7	6.6	91.4	93.51
VES 14	411.09	83.24	1439.75	947.05	2.6	3.9	31.7	158.9
VES 15	300.22	504.03	78.11	970.41	2.1	4.1	9.5	39.6
VES 16	92.08	687.01	46.11	893.21	2.8	3.6	20.9	19.2

6. Groundwater Potential Evaluation

The groundwater potential of an area is determined by a complex inter-relationship between the geology, physiography, post emplacement tectonic history (fractures), weathering processes and depth, nature of the weathered layer, groundwater flow pattern, recharge and discharge processes (Ezeh 2012). The groundwater potential of the study area was evaluated based on maps. Maps of anisotopic coeffiecient layer, Isoresistivity layer, hydraulic conductivity layer and Isothickness layer were overlayed to obtain the composite map layer for the final groundwater potential

7. Coefficient of Anisotropy Map Layer

The overburden's coefficient of anisotropy is a function of transverse resistance and longitudinal resistance. Transverse resistance and longitudinal transverse resistance is correlated with aquifer transmissivity and is one of the parameters used to define target areas of good groundwater potential. Higher values of transverse resistance indicate aquiferous zones with high transmissivity.

From the map of anisotropic layer map (See figure 2), the Northern Zones shows higher coefficient of anisotropy, it tends to decrease towards the Eastern Zones where VES 9, VES 12, VES 5 are located, the Southern zones shows gradual increase from what is obtainable from the Eastern zones, the Western parts (VES 8. VES 7, VES 4 and VES 10) of the study area also recorded gradual increase in comparison to the Southern parts.

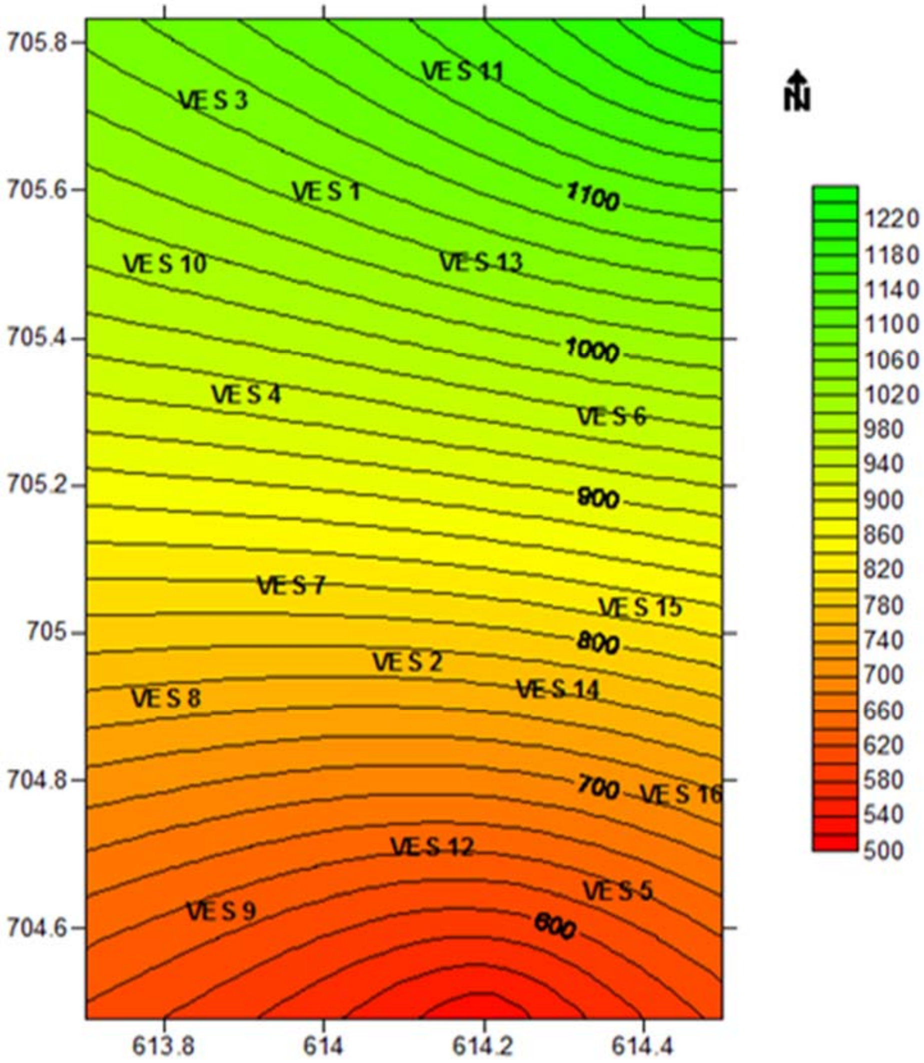

Fig 2: Anisotropy Coefficient Map Layer

8. Hydraulic Conductivity Layer Map

Hydraulic Conductivity characteristics of aquifers are important properties for both groundwater and contaminated land assessments and also for safe construction of engineering structures (Singh, 2005).

The calculated hydraulic conductivity (Kc) values estimated from the VES results ranges from 0.08 to about 0.194cm/s (See Fig. 3). Hydraulic conductivity depends on the intrinsic permeability of the material and on the degree of saturation. From the hydraulic conductivity layer map, maximum hydraulic conductivity values are observed at the extreme East while the minimum hydraulic conductivity values are observed in the Northern portion of the study area.

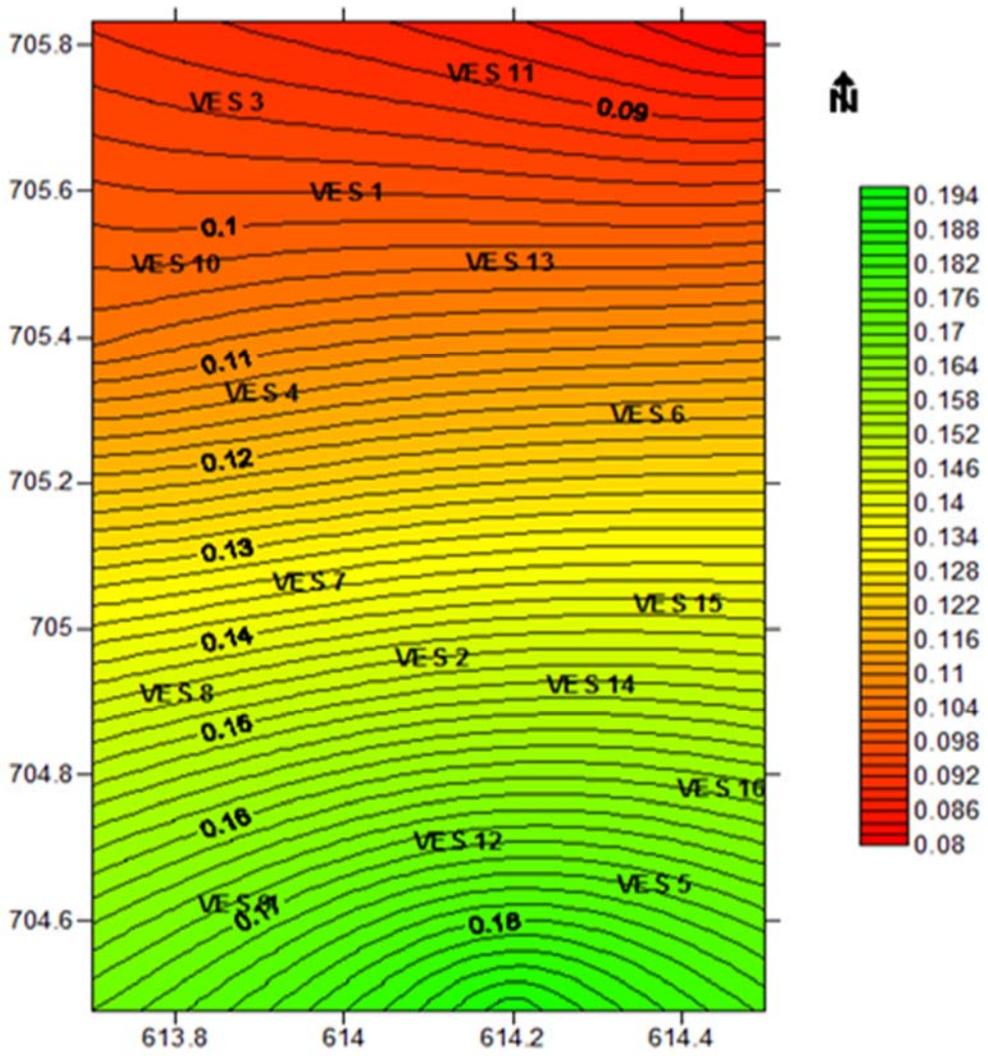

Fig 3: Hydraulic Conductivity Layer Map

9. Isoresistivity Layer Map

Also, the iso-resistivity map showing the resistivity distribution of the aquifer layers had been proven useful in mapping promising areas for groundwater abstraction. The resistivity contour map representing a low resistivity region could be potential ground water zones due to increase in the thickness of the aquifer (Ishola *et al.,* 2013). The Southern parts shows low resistivity (see figure 4). The Northern parts (VES 3. VES 1, VES 11 and VES 13) generally indicates higher resistivity.

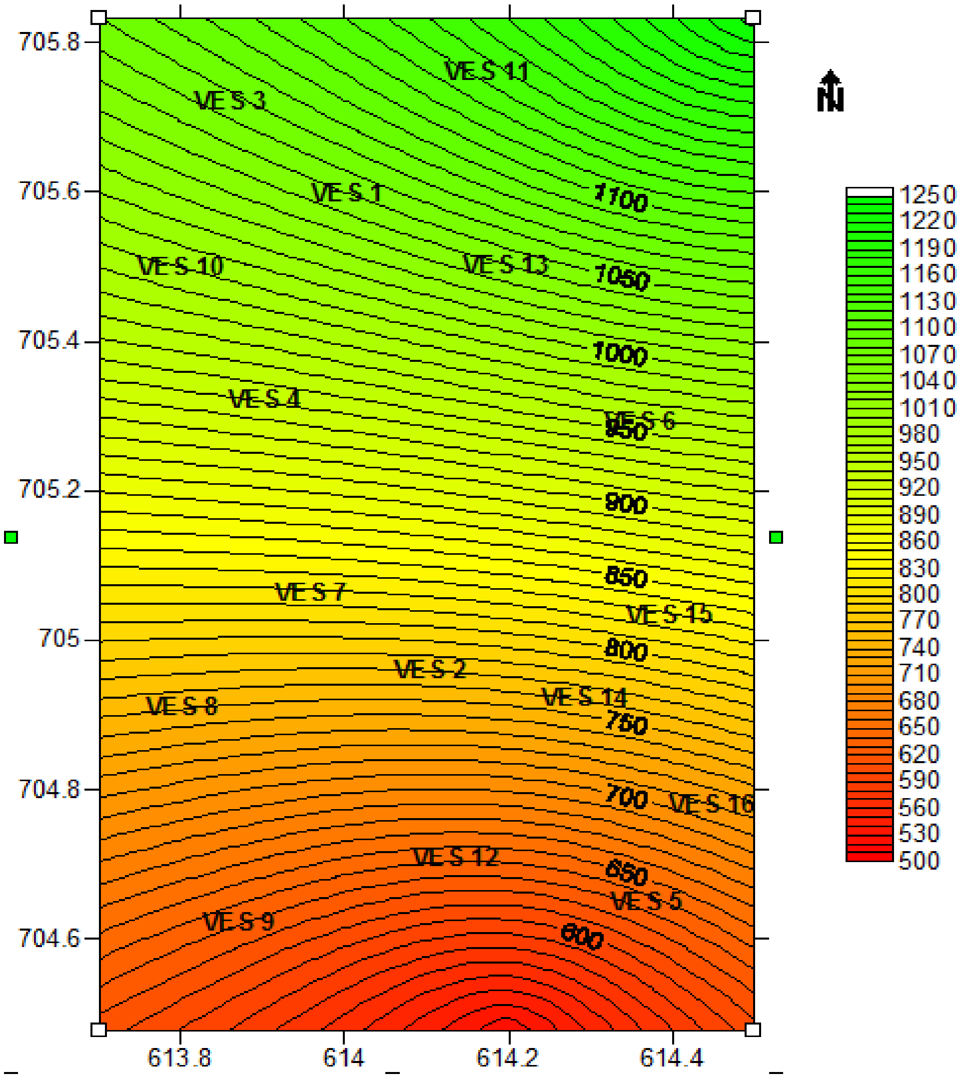

Fig 4: Isoresistivity Map Layer

10. Isothickness Layer Map

Since an aquifer is expected to yield freshwater in economically usable quantity, an important consideration in groundwater prospecting is the thickness of the overburden layer. All the subsurface layers above the weathered/ fracture fresh bedrock are considered to constitute the overburden. These include the topsoil, clayey sand/sandy clay, the areas of thick overburden (materials above the bedrock) are priority areas for possible groundwater developments. (Ishola et al., 2013). The aquifer thickness layer map (See Figure 5) revealed that the maximum aquifer thickness is at Western part of the study area (i.e VES 4, VES 8, VES 7and VES 10). The area is characterized by a thick and prolific aquiferous zone, tapped by many productive boreholes and wells. This is due to the composition of the aquifer zone, which consisted of unconsolidated medium to coarse grained sands and gravel. The Southern part of the study area has thin overburden (minimum thickness).

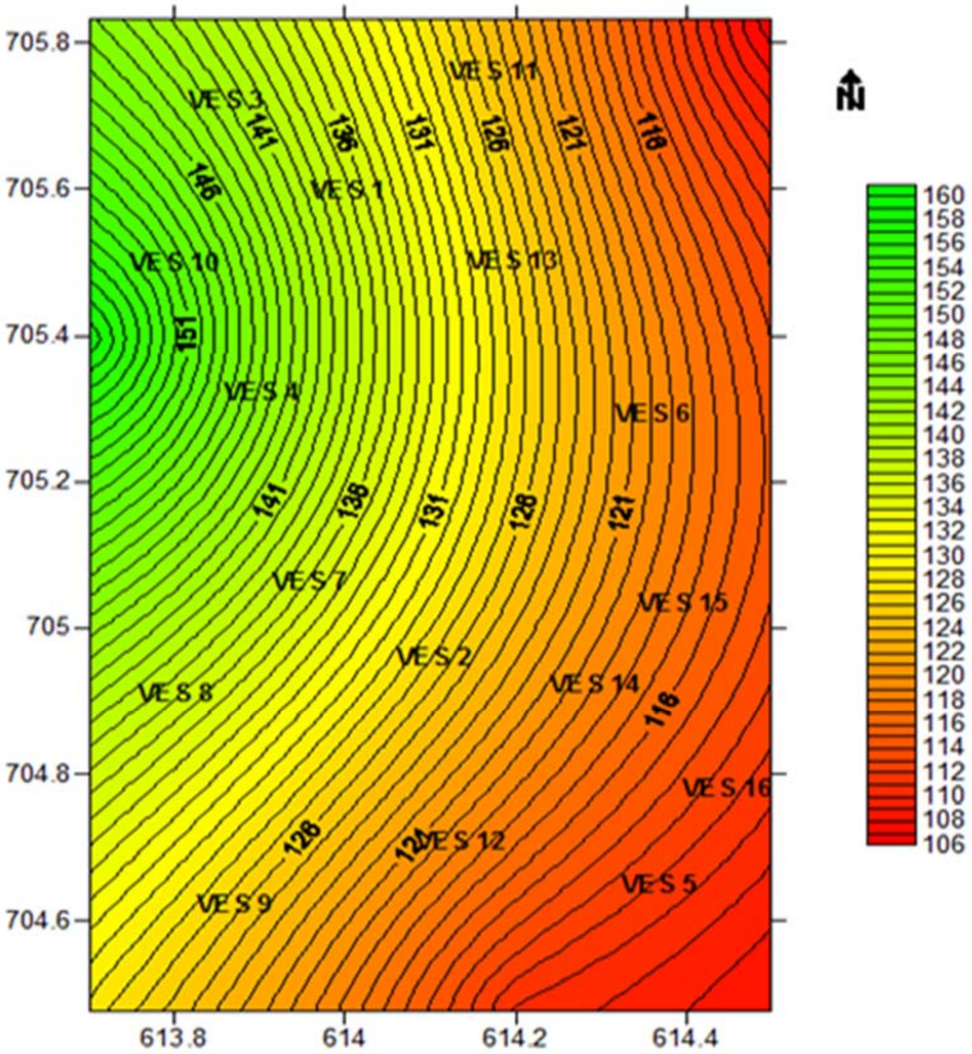

Fig 5: Isothickness Map Layer

11. Final Groundwater Potential Map of the Study Area

Final groundwater potential map of the study area was produced by overlaying the concerned maps (see figure 6) in order to draw the final conclusion from the individual maps. The map presents local groundwater prospects of the study area which is zoned in to high, medium and low groundwater potentials. Areas with red colour on the map constitute the low groundwater potential zone (i. e. VES 5, VES 16, VES 14, VES 15,and VES 6) while areas with yellow colour constitute the medium groundwater potential zone (i. e. VES 9 and VES 2, VES 11, VES 13 and VES 7), green colour represents the high groundwater potential zone, this is located at the Northwestern side of the study area (i.e. VES 3, VES 10 and VES 4). Region of high groundwater potential generally lies in the North-South and North central, while region of medium groundwater potential in the study area lies in the Western part and Southern part of the study area, the low groundwater potential region lies in the Eastern regions of the study area.

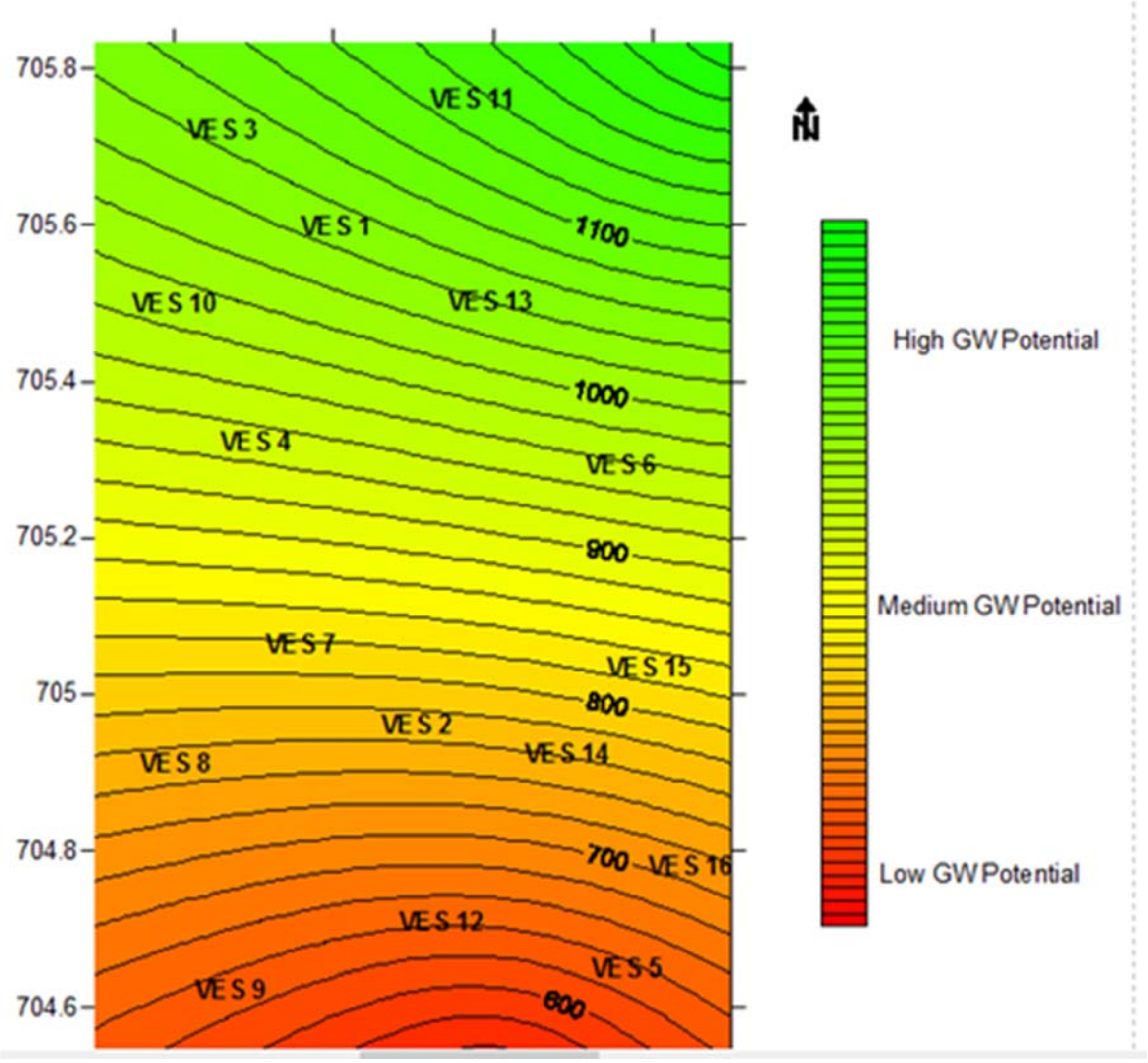

Fig 6: Final Groundwater Potential Mapping

12. Conclusion

The prospecting of potential ground zones is presented in this study. Sixteen (16) vertical electrical sounding (VES) points were conducted at various locations within the study area in order to study the variations in the resistivity distribution of the soil with depth. The vertical electrical sounding curve types identified in the study area includes K, H, QH, HK, KH, QK, KQ and KHK. Approximately, 31.25% of all the sounding curves are HK-type whereas the remaining 68.75% belongs to the seven curve types within the study area. 2-D surface map of the anisotropic coefficient layer, hydraulic conductivity map layer, isoresistivity map layer, and isothickness map layer were overlay to produce the final groundwater potential layer. Three potential groundwater zones were delineated; the high groundwater potential zone, the medium groundwater potential zone and the low groundwater potential zone. The final groundwater potential mapping revealed that the Northern parts of the study area are the most promising region for groundwater potential/borehole development, while the Western and Southern parts can also be considered as fair for groundwater potential/borehole development. The Eastern part of the study area has the lowest groundwater potential/borehole development.

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