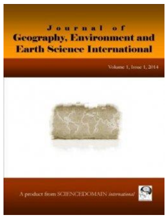

Journal of Geography, Environment and Earth Science International
3(1): 1-12, 2015; Article no.JGEESI.17832

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Application of Vertical Electrical Sounding to Investigate the Groundwater Potential in Abak Local Government Area, Akwa Ibom State, Nigeria

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Authors' contributions

This work was carried out in collaboration between all authors. Authors AES and EST carried out the field work, analysis and interpretation. Author JEO prepared the manuscript and majorly the literature review. All authors agreed as to where to publish the article.

Article Information

DOI: 10.9734/JGEESI/2015/17832
Editor(s):
(1) Nagendra Pratap Singh, Department of Geophysics, Banaras Hindu University, India.
Reviewers:
(1) Andy Anderson Bery, School of Physics, Universiti Sains Malaysia, Malaysia.
(2) Anonymous, University of Benin, Benin City, Nigeria.
(3) Anonymous, Manonmaniam Sundaranar University, India.
Complete Peer review History: http://sciencedomain.org/review-history/9796

Original Research Article

Received 27th March 2015
Accepted 20th May 2015
Published 16th June 2015

ABSTRACT

The vertical electrical sounding (VES) method has been used to characterize the aquifer in part of Abak Local Government Area, Akwa Ibom State, Nigeria. Thirteen (13) electrical sounding were taken in three transect using ABEM Terrameter (SAS1000). The maximum current electrode spread ranged between 1000 m and 2000 m. The VES field data obtained were interpreted using the WinResist programme to generate the final model for layer resistivity and thickness. Dar Zorrouk parameters, transmissivities and kσ values were also determined.

Apart from the topsoil, the underlain layers have sizeable thicknesses that can host groundwater. The transverse resistance ranges from 31725.72 – 387732.5 Ωm^2 and the average value is 119750.46 Ωm^2. The longitudinal conductance ranges from 0.0053864 – 0.049078 Ω^{-1} and the average value is 0.05215 Ω^{-1}. The transmisivity ranges from 394.848 to 728.852 m^2/day and the

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average value of 548.82 m^2/day was obtained. The Kσ - value ranges from 0.0010 to 0.0128 $(\Omega day)^{-1}$ and the average value was 6.43 x 10^{-3} $(\Omega day)^{-1}$. The Kσ values show that the area studied has fresh water that is in abundance in fine-coarse grained sands. The water table map shows the pattern of water flow in the study area and this can be used for groundwater contamination study.

Keywords: Abak; vertical electrical sounding; transmisivity dar zarrouk parameters; groundwater.

1. INTRODUCTION

Groundwater study implies a study of subsurface water extending into a zone of saturation where all the interstices are filled with water and where, as a result, the retention and movement of water are governed by the laws of saturated flow [1]. The source of groundwater is chiefly from precipitated atmospheric moisture which has percolated down into the soil and subsoil layers [2]. The geophysical aspect of groundwater studies is always centered on adequate definition and understanding of the properties concerning the zone of saturation. The occurrence of groundwater in a given locality is determined by the interconnection of pores existing in the rock, the size, shape, and distribution of such pores both in depth and area through the zone of saturation. The importance of groundwater exploration cannot be overemphasized, especially when development of surface water sources in some countries such as Great Britain, is difficult [3] while in some developing countries like Sudan, scarcity and safety of surface sources remain issues yet to be fully tackled [4].

Groundwater is indeed a social and an industrial need: where it recharges into a lake, it can influence social and commercial activities such as fishing and tourism [5,6]. The use of electrical resistivity method to investigate geoelectric parameters, Dar-Zarouk parameters, hydraulic characteristics and assessment of vulnerability of aquifers is gaining more recognition recently [7-13].

In this study vertical electrical sounding (VES) was carried out at a number of points fairly distributed over the area on an approximate grid –like pattern and dense enough to enable the following information related to the aquifer characteristics to be determined: Depth to water table and aquifer thickness; Geologic formation(s) within the survey area; The Dar Zarrouk parameters and the aquifer transmissivity and direction of groundwater recharge and discharge. It is expected that by this information, explanation to the seasonal variation in yield of wells in the area will be evolved and recommendation made towards effective groundwater management.

2. LOCATION AND GEOLOGY OF STUDY AREA

The survey area is located between Longitudes 7° 40′E and 7° 50 E and Latitude 4° 50′N and 4° 10′N with the total area of about 50km^2. This expanse cut across Midim, Afaha-Obong, and Otoro which are three of the four clans existing in the Local Government Area (Fig.1). The area considered here includes some villages within the Abak Local Government Area Headquarters and other neighbouring villages. The Local Government Area is accessible through a network of trunk roads and is bordered by Essien Udim, Ikono, Uyo, and Uyo Local Government Areas on the northern side, and Oruk Anam and Ukanafun Local Government Areas on the southern side. The area generally has a land surface of very little or no significant reliefs over many kilometers. Surface water found in the area are mainly seasonal ponds and a few streams that run across in some segments of the Local Government Area. Geologically, Abak belongs to the area classified as coastal plain-sands also called the Benin formation [14]. The coastal sediments of the Benin formation develop frequent anticlinoid – fault structures at depths of practical importance in the search for oil trays [14,15]. Abak Local Government is one of the local Governments in Akwa Ibom State, Nigeria (Fig. 2).

2.1 Current Groundwater Supply Situation in Abak

The creation of new local government areas following Governments interest in developing the rural areas has resulted in sudden concentration of human population within the areas of the local government headquarters. The consequences are the overstretching of facilities, and the urgent need for the development and expansion of infrastructure to meet both present and future demands. This has turned out to be the situation faced in Abak Local Government Area in respect of water supply. The problem is compounded by the paucity of reliable sources of water prior to the creation of the local Government headquarters. Ponds, streams and open wells have been relied upon for a long time until recent attempt to site a few boreholes at strategic places.

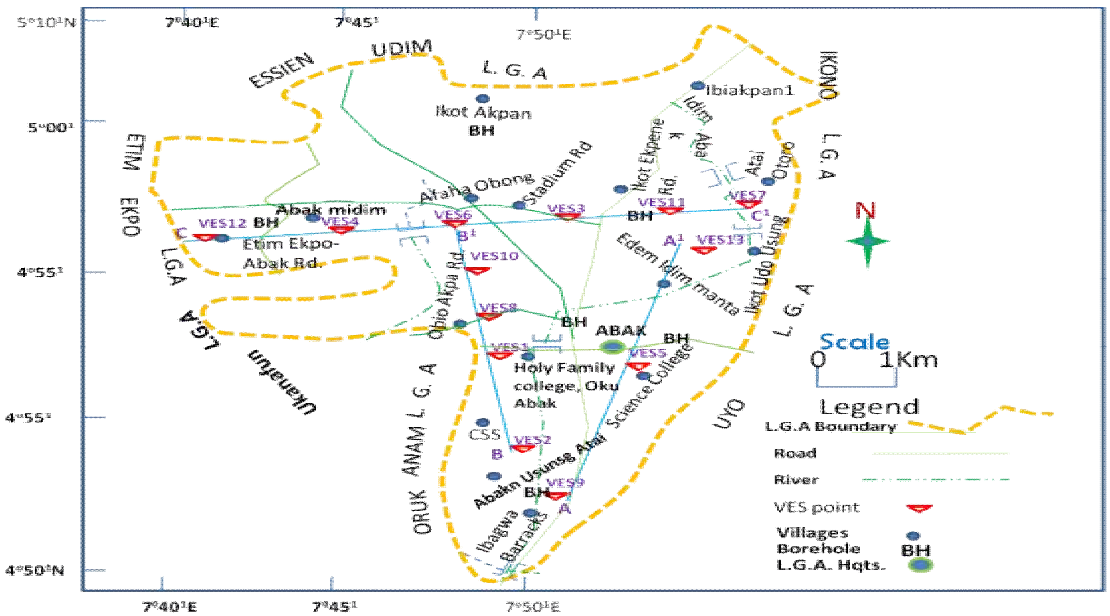

Fig. 1. Location map showing the villages, VES transects, VES station and some boreholes

Fig. 2. Akwa Ibom state – the study area (source: [16])

3. THEORY

3.1 Schlumberger Electrode Array

This array is the most widely used in electrical prospecting especially in quantitative interpretation of VES, [17,18]. The basic arrangement of the electrodes is as shown in Fig. 3.

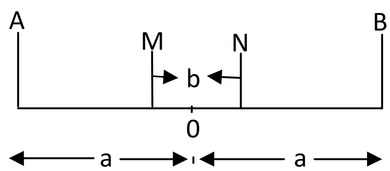

Fig. 3. The schlumberger electrode array

0 is the centre of the array; A and B are the current electrodes, while M and N are the potential electrodes. The distance, b, between M and N is usually very small compared to a.
Let,

$$V = \frac{I\rho}{2\pi}\left(\frac{1}{r_1} - \frac{1}{r_2}\right) \qquad (1)$$

The potential difference ∇V between M and N can be written in terms of notations in Fig. 2 (in the case of two potential electrodes being used instead of one as assumed in equation (1) as follows:

$$\Delta V = \frac{I\rho_{as}}{2\pi}\left(\frac{1}{\left(a-\frac{b}{2}\right)} - \frac{1}{\left(a+\frac{b}{2}\right)} - \frac{1}{\left(a+\frac{b}{2}\right)} + \frac{1}{\left(a-\frac{b}{2}\right)}\right) \qquad (2)$$

The terms in bracket can be represented by G and simplified to the form:

$$G = \frac{2b}{a^2 - \frac{b^2}{4}} \qquad (3)$$

Considering that b is very small for the schlumberger array,

$$G = \frac{2b}{h^2} \qquad (4)$$

Substituting equation (A4) in (A2) gives a relationship between the potential ΔV and the apparent resistivity measured in the Schlumberger array (ρ_{as})

$$\Delta V = \frac{Ip_{as}}{2\pi}\left(\frac{2b}{a^2}\right) \qquad (5)$$

$$\frac{I\rho_{as}}{\pi}\frac{b}{a^2}$$

Or

$$\rho_{as} = \frac{\pi a^2}{b}\left(\frac{\Delta V}{I}\right) \qquad (6)$$

$\frac{\pi a^2}{b}$ can be represented by a single symbol, k, called the geometric factor for the Schlumberger array.

The geometric factor is dependent only on the spatial arrangement of the electrodes. Similar equations can also be obtained for other electrode arrays. Some cases involving the use of the Schlumberger-VES in groundwater exploration have been reported by [6,19-23].

4. MATERIALS AND METHODS

Thirteen (13) VES points in three transacts were occupied using ABEM Terrameter (SAS1000). Practically, as the distance between the current electrodes is increased about a centre, the total volume of the earth included in the measurement also increases both vertically and laterally. The maximum current electrode spread ranged between 1000m and 2000m. The VES field data obtained were interpreted using the WinResist programme to generate the final model for layer resistivity, thickness and depth to basement. The Aquifer Transmissivity were determined using the analytical relationship established by [15,24] and recently by [25], between aquifer transmissivity (Tr) and transverse resistance (T) on one hand and aquifer transmissivity and longitudinal conductance (S) on the other hand. The values of $K\sigma$ (product of hydraulic conductivity and electrical conductivity)were also determined.

5. RESULTS AND DISCUSSION

The typically dominated groups of curves which are represented in Figs. 4-8, are H, K, AA, KH and AK. In general three to four layers were identified in the study area. The WinResist inversion programme generated the final models for resistivity, thickness and depth.

Below the top lithology lies a thick mass of medium grained sand whose depth is about 40m near VES 13. The effect of the resistive surface condition is considered to have enhanced the current penetration and increase the chances of detecting deeper layers that are undulating across the profile. The unsaturated topsoil runs horizontally while the saturated fine coarse grained sand seems undulating at the depth of about 60 m to 90 m and infinitely thick in VES 10. This layer is sizeably thick and can be a good aquifer in the study area. Below 60 m to 90 m in VES 8, the saturated gravelly sand is infinitely thick. This layer can as well act as a good aquifer. The resistivity and thickness of the aquifer for the different VES locations, the Dar zarrouk parameters, the transmissivity values and the value obtained with the use of average hydraulic conductivity of 8.64 m/day determined by [26] for the study area.

he isoresistivity and isopach maps shown in Figs. 9 and 10 for 2 - D and 3 – D drawn to show the distributions of resistivity and thickness within the study area. For isoresistivity, the prograding of the contour values in the 2 – D diagram indicates that aquifer resistivity is high within VES 8, 9 and 10. The value peaks at VES 10 with the highest value of 8484.3Ωm at Obio Akpa – Ikot Okoro road. The high values at these locations indicate that the aquifer is highly devoid of brackish water. In terms of the isopach maps, the 3-D diagram in Fig. 10 indicate that aquifers in the study area generally have high thicknesses. The peak of the thickness is at VES 9 (Ibagwa Barracks) with 83.0 m. The least value of aquifer thickness according to the maps occur at VES 10 (Ikot Okoro road) with thickness of 45.7 m. Characteristically, the aquifer resistivity and the thickness distributions suggest that the study area is highly endowed with prolific aquifers.

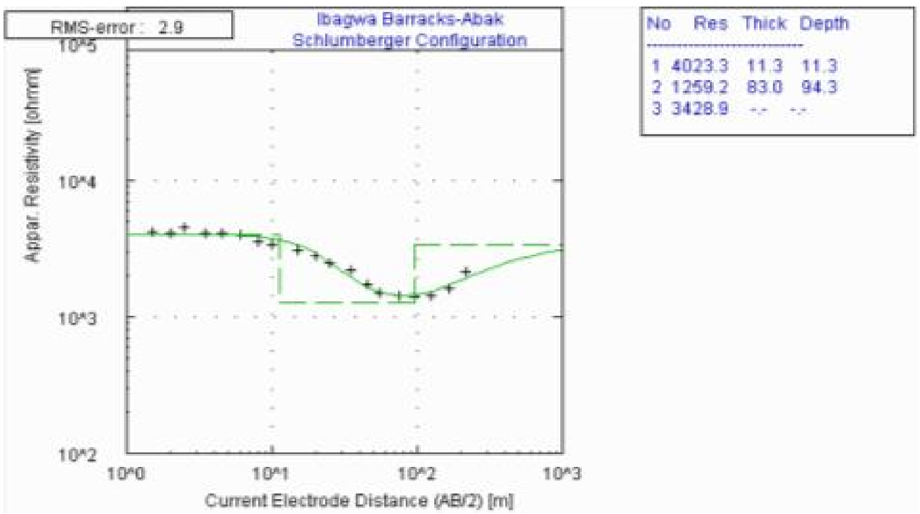

Fig. 4. VES curve corresponding to h curve type at Ibagwa barracks

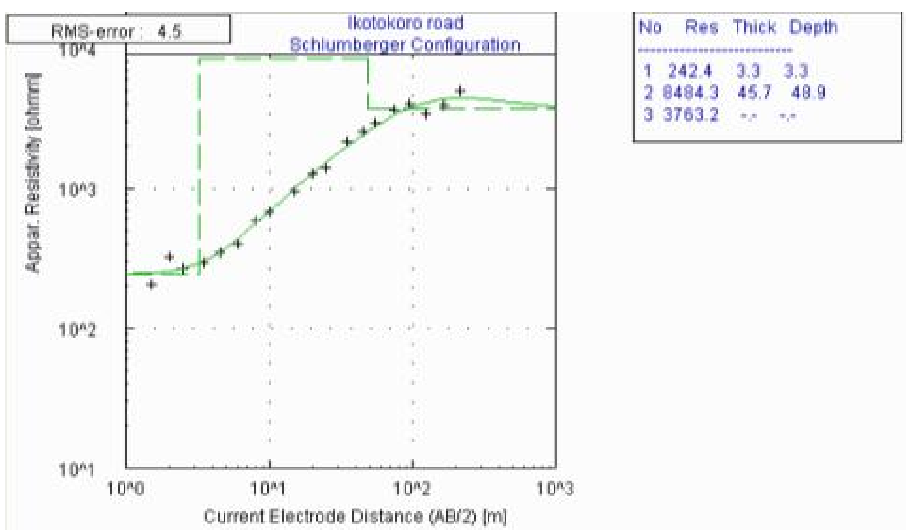

Fig. 5. VES curve corresponding to K curve type at Ikot Okoro road

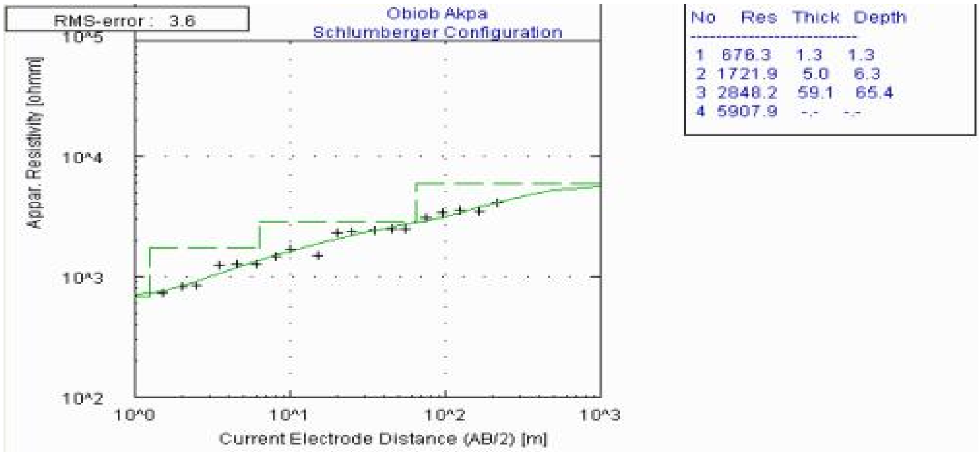

Fig. 6. VES curve type corresponding to AA curve type at Obio Akpa

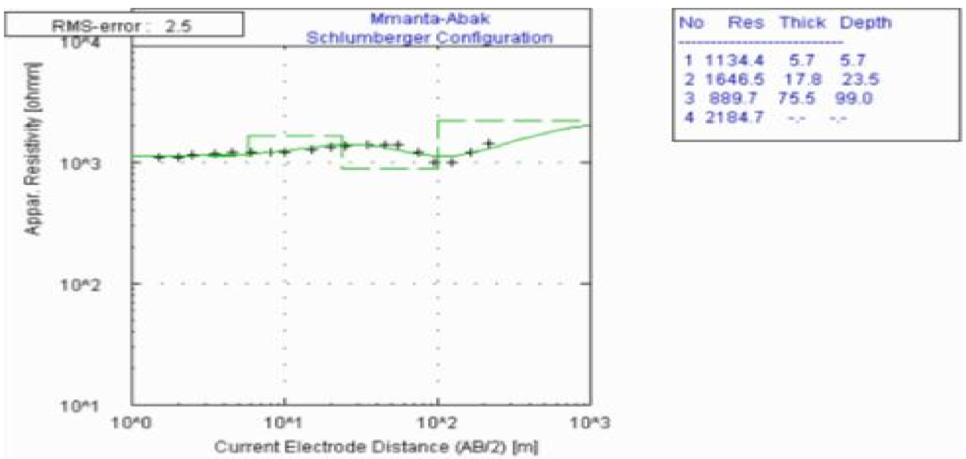

Fig. 7. VES curve corresponding to KH curve type at Manata – Abak

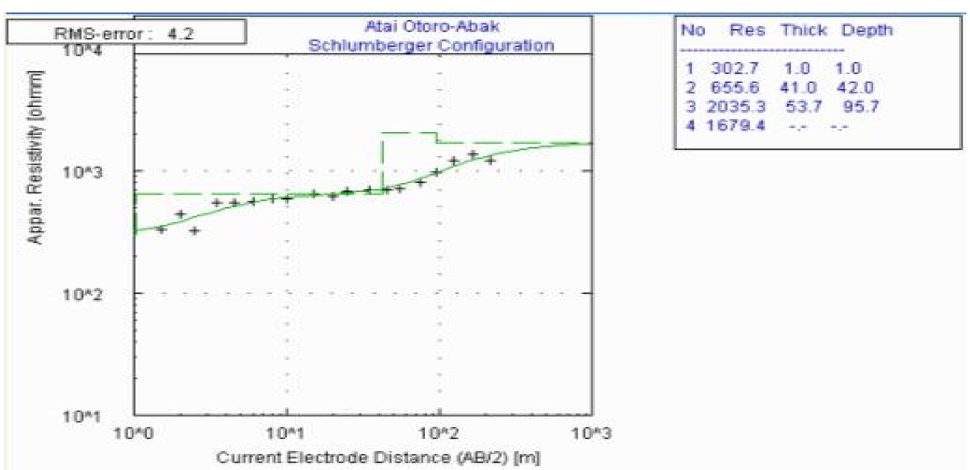

Fig. 8. VES curve type corresponding to AK curve type at Atai Otoro

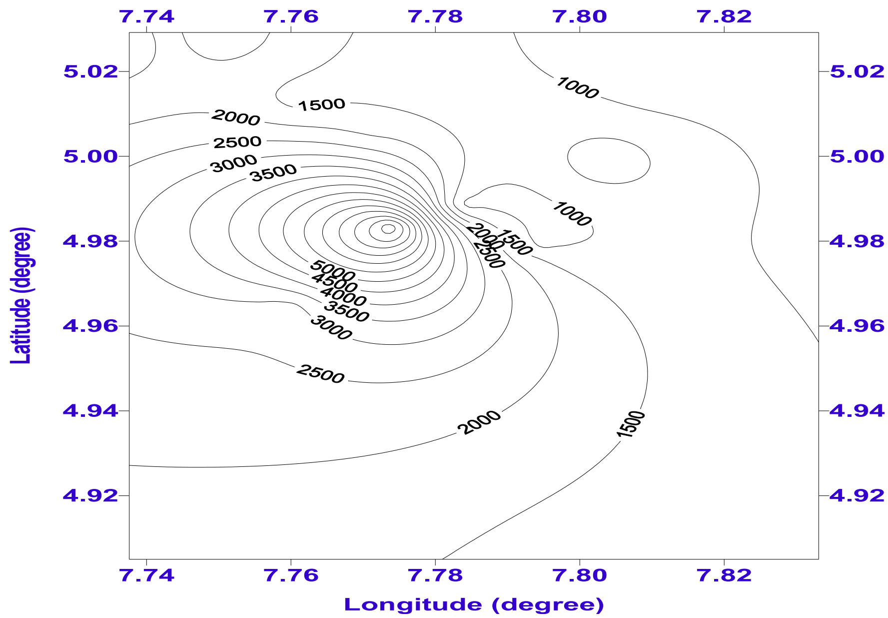

Fig. 9. 2-D isoresitivity map in the study area

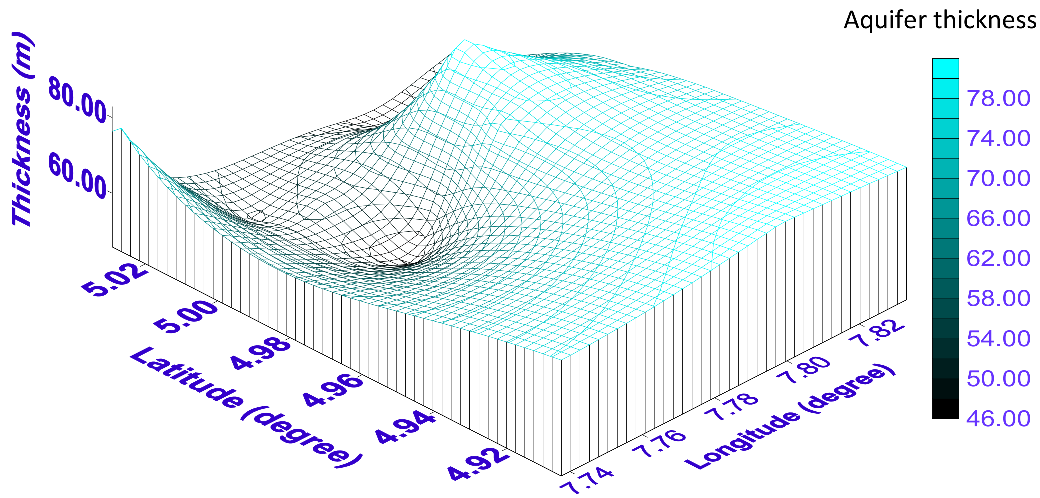

Fig. 10. 3-D aquifer isopach of the study area

The contour map showing the distribution of aquifer transmissivity is in Fig. 11. The values of the transmissivity increase on the average towards the western part of the study area. The development of hard-rock aquifers as a reliable source of rural water supply is notoriously complicated, transmissivities are spatially highly variable [27]. Transmissivity data describe the general ability of an aquifer to transmit water and is vital for developing an understanding of the controls on groundwater occurrence. In many instances the magnitude of transmissivity (aquifer permeability) affords a notion about the water-bearing characteristics of hydrogeological bodies and is a decisive factor for groundwater-abstraction possibilities. The most significant correlation between transmissivity and proximity to lineaments is found in the study area where the average and (geometric) mean transmissivity within 150 m of a lineament exceeds the average transmissivity values. It can be generally accepted that the lineaments have a positive influence on the borehole productivity in the area.

The contour maps describing the Dar Zarrouk parameter distribution in the study area are shown in Fig. 12 and Fig. 13 for transverse resistance and longitudinal conductance respectively. The orientation of increase in the transverse resistance is from northeast to northwest on the average.

The highest value is obtained at VES 10 along Ikot Okoro road. The average value of transverse resistance is 119,750.46 Ωm^2. The longitudinal conductance according to the 2 – D map (Fig. 13) increases from west to east, almost in the reverse direction of the transverse resistance. The highest value is at VES 13 located at Mmanta Abak. The average value of longitudinal conductance is 0.05215Ω^{-1}. The orientation and distributions of Dar Zarrouk parameters show regions of high aquifer thickness and of course low aquifer thickness. High transverse resistance suggests, highly prolific aquifer and high longitudinal conductance indicates regions of low aquifer thickness. The values of $K\sigma$ (product of hydraulic conductivity and electrical conductivity) were contoured as shown in Fig. 14. The $K\sigma$ - values increase from southwest to north east of the maps. The least value is found at VES 10 with the average value of 6.43 x $10^{-3}(\Omega m)^{-1}$. The average value suggests that the water in the area is not brackish as the value on the average is low. This shows that the aquifer has good quality water as the high resistivity values also suggest.

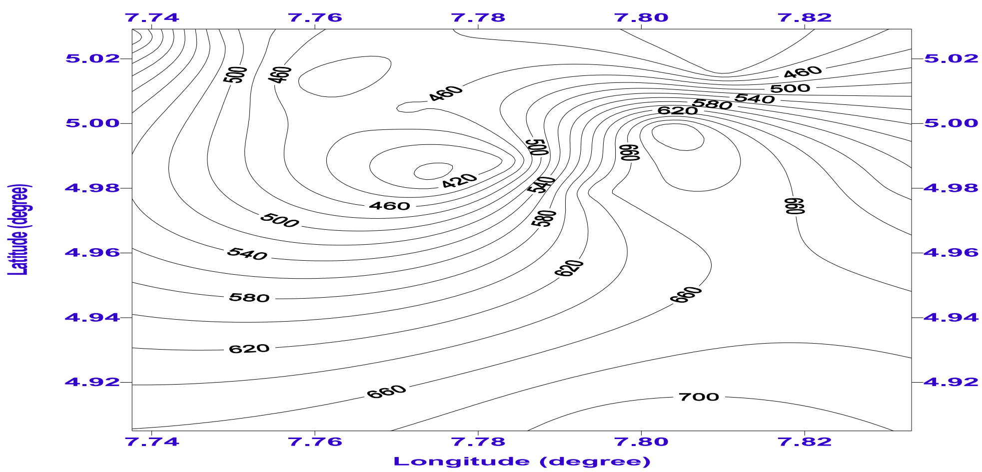

Fig. 11. 2-D aquifer transmissivity of the study area

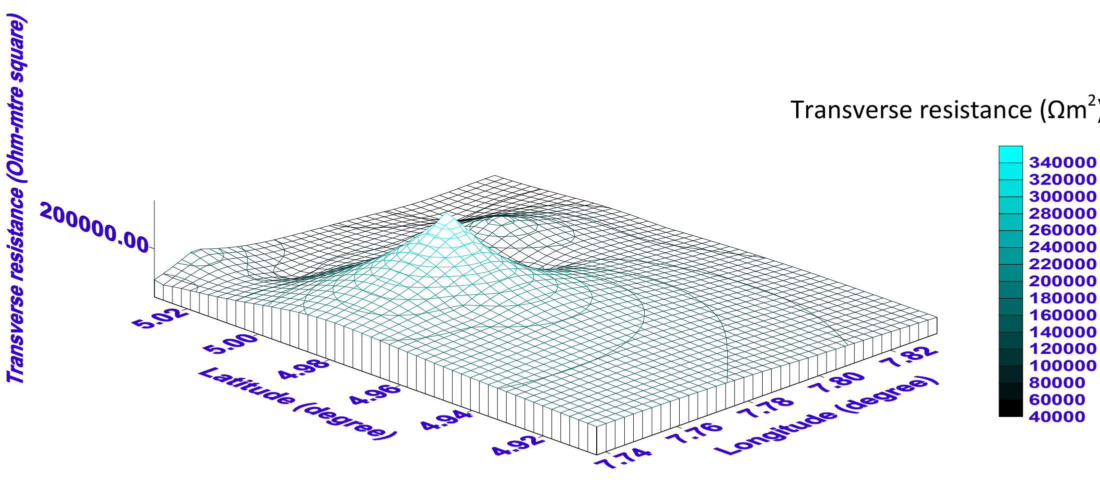

Fig. 12. 3-D Aquifer transverse resistance distribution in the study area

To assess the flow pattern of the aquifers, the water table read from VES curves were contoured for the study area Fig. 15. The orientation of the vector shows the different direction of water flow within the aquifer. In the eastern region of the map the water seems to flow towards the east on the average near the eastern part. Within the southwest, the flow direction is towards the southwest. At the northwest the flow pattern is also northwest on the average and northwest in the northwest direction within the coordinates 4.98 – 5.00°N and 7.76 – 7.78°E. The deepest water table was delineated and water seems to be flown into this zone as indicated in the arrows around the long reddish arrow at the north central portion of the vector map.

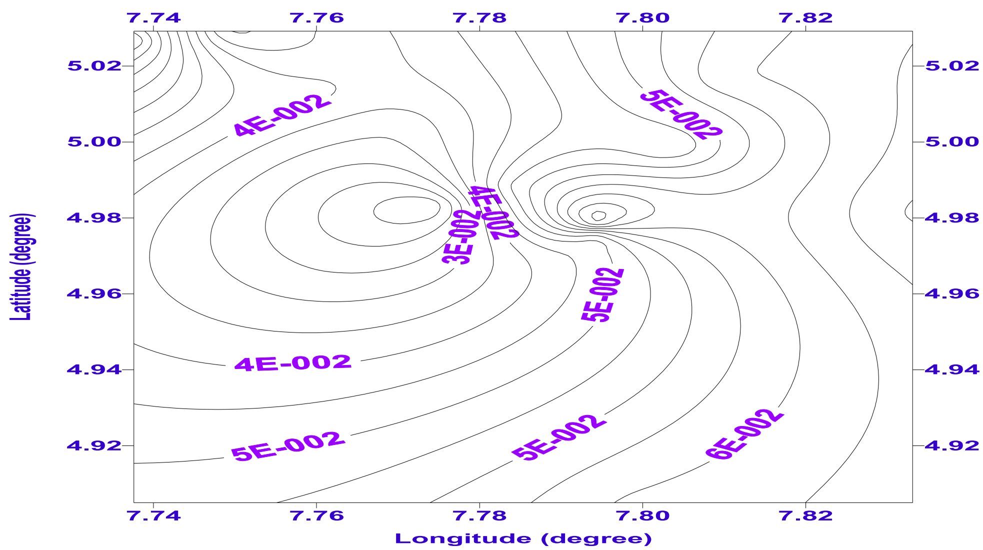

Fig. 13. 2-D Aquifer Longitudinal conductance distribution

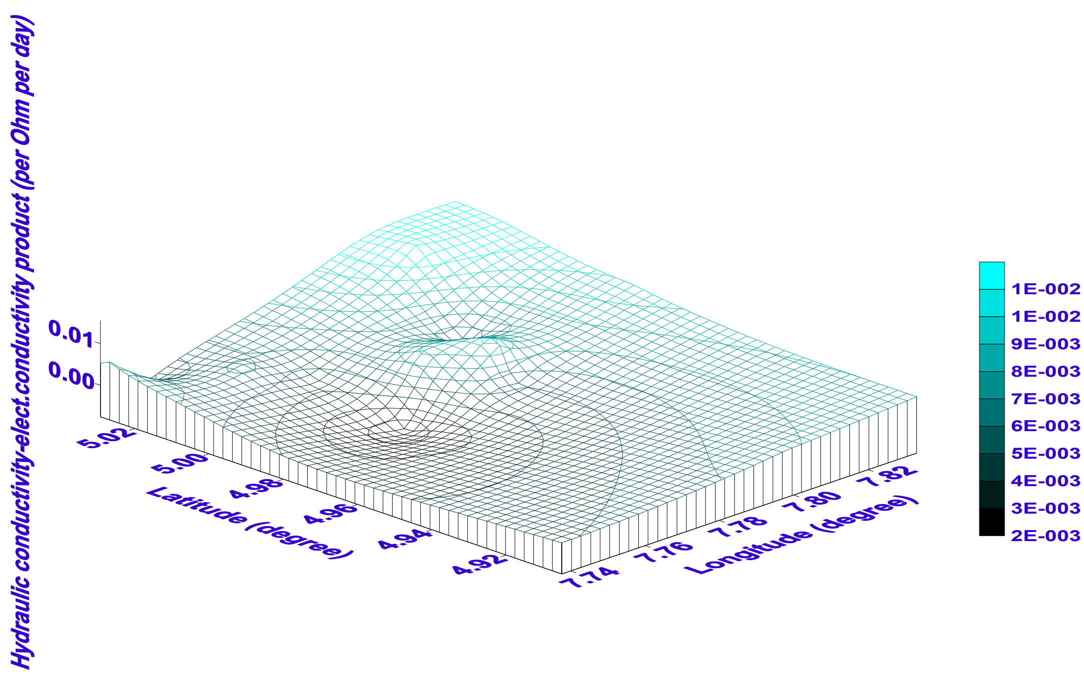

Fig. 14. 3-D Aquifer Kσ-Value distribution

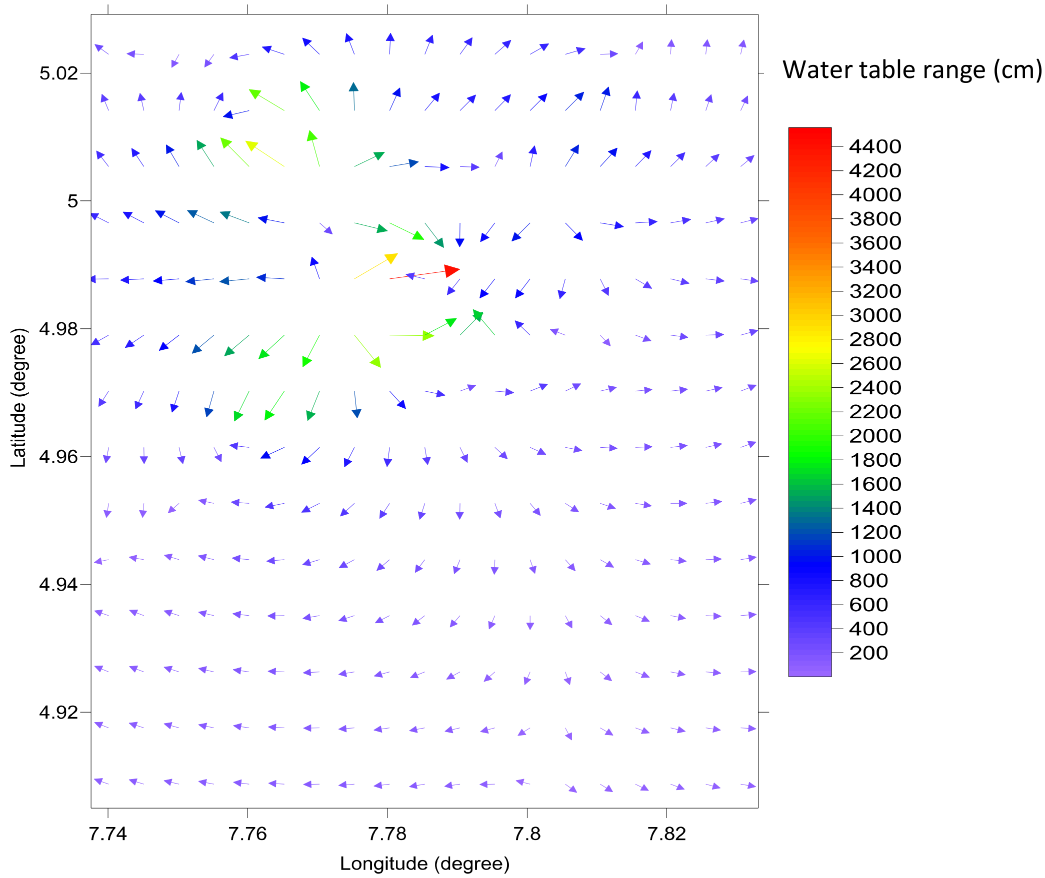

Fig. 15. Water table flow distribution map (m) in the study

This map (Fig. 15) can be used in contamination study of the area along with other hydraulic properties determined. The groundwater flow regime in the study area suggests the nature and pattern of distribution of the water table in the study area.

The major aquifer geomaterials are gravelly sand, fine sand, fine to coarse grained sand and medium-grained sand. The transmissivity, transverse resistance and longitudinal conductance distributions which are function of primary properties given on contour maps provided the means of identifying areas where the aquiferous zones are mostly prolific and safe. The $k\sigma$ - values for the aquiferous zones in the study area have been mapped. On the basis of this product, the entire study area has been found to have low values and this indicates that the area has fresh water aquifers which are also suggested by the high aquifer values of resistivities. The use of maps, 2 – D and 3 – D for presentation of aquifer hydraulic parameter distributions in this work is thoughtful because the information on the hydrogeologic conditions as well as quantitative description of geometry of the exploitable aquifer are brought to bear for effective management of groundwater resources in the study area. The contour variation of the groundwater table in the study area shows the different direction of the water flow and thus on the average is determined by the aquifer geomaterials and the water table variations.

The available borehole did not completely agree with the VES data as they have some thin layer of clays which were not picked by VES at certain depths due to the principle of suppression. The thin layer of clay therefore can render some deeper aquifer where they occur, to be semi – confined and this occurrence makes the aquifers in some place to be multilayered. The lateral and vertical variations in the geoelectric columns which agree with lithologic log indicate that VES profiles are useful method to investigate the lateral and vertical variation of subsurface lithology as well as subsurface hydrology. This study has relevance in the following areas. The identification of Dar zarrouk parameters which depends on transmissivity and permeability are helpful for finding suitable sites for dewatering of aquifers.

6. CONCLUSION

The result of VES technique has been specifically used to characterize the aquifer in parts of Abak Local Government Area of Akwa Ibom State, Nigeria. The typically dominated groups of curves obtained are H, K, AA, KH and AK. In general three to four layers were identified in the study area. The isoresistivity map indicates that aquifer resistivity is high within VES 8, 9 and 10. The value peaks at VES 10 with the highest value of 8484.3 Ωm at Obio Akpa – Ikot Okoro road. The high values at these locations indicate that the aquifers are highly devoid of brackish water. The isopach maps indicates that aquifers in the study area generally have high thicknesses. The peak of the thickness is at VES 9 (Ibagwa Barracks) with 83.0 m. The least value of aquifer thickness according to the maps occur at VES 10 (Ikot Okoro road) with thickness of 45.7 m. Characteristically, the aquifer resistivity and the thickness distributions suggest that the study area is highly endowed with prolific aquifers. The major aquifer geomaterials are gravelly sand, fine sand, fine to coarse grained sand and medium-grained sand.

The secondary properties (Dar zarrouk parameters, transmissivity and $k\sigma$ - values) were determined. The contour variation of the groundwater table in the study area shows the different direction of the water flow. The low $K\sigma$ values obtained show that the area studied has fresh water that is in abundance in fine-coarse grained sands.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
http://sciencedomain.org/review-history/9796