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CHARACTERIZATION OF GROUNDWATER POTENTIAL IN PARTS OF ASABA, DELTA STATE, NIGERIA USING VERTICAL ELECTRICAL SOUNDING TECHNIQUE

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Abstract
The characterization of groundwater potential in parts of Asaba, Delta State, Nigeria, was carried out using the vertical electrical sounding technique. During the geophysical survey, twelve vertical electrical soundings (VES) were conducted using the Schlumberger Array. The processed resistivity data were interpreted using conventional curve matching and computer iteration methods with the aid of a resistivity software named Interpex-1-dimensional (IX1D) software. The VES results depict four different curve types, namely, HK, K, KHK, and HA-curve types. The result also reveals that 58% of all the sounding curves belong to K-types, whereas the remaining 42% belong to the other three curve types within the study area. Four to five geo-electric layers comprising the top soil, clayey sandstone, dry sandstone, saturated sandstone, and shale were delineated, with the latter usually occurring as the last layer. The third and fourth layers underlying dry sandstone formed the aquiferous unit. This unit was found to have an average resistivity value range of 1258.39 Ωm and an average aquifer thickness of 137.52 m. The water-saturated unit is deeply seated in some areas, with an average depth of 53.69 m. The watertable map shows a southeast groundwater flow pattern in the area. The result also shows that the hydraulic conductivity obtained ranges from 0.1427 to 0.9918 m/day with an average of 0.3917 m/day, while the transmissivity range is from 27.3327 m^2/day to 79.1576 m^2/day with an average of 41.0090 m^2/day within the study area. The study concludes that there is huge groundwater potential within the study area, which can yield sufficient water to serve the immediate environs.
Keywords: *Asaba, Aquifer, VES Curve Type, Hydraulic Conductivity and Transmissivity.*

Introduction
Water, a major source of life is required by all and sundry either in small or large quantity. The quality of water required for domestic and industrial use also needs to be taken into consideration. Underground water exploration using vertical electrical sounding (VES) technique in a sedimentary environment has been done by various workers (Anakwuba *et al.*, 2022; Udo *et al.*, 2021; Osele *et al.*, 2016; Chinwuko *et al.*, 2015; Anizoba *et al.*, 2015; Anakwuba *et al.*, 2014; Anudu *et al.*, 2008; Onwuemesi and Egboka, 2006). The VES technique uses direct current or low frequency alternating current for subsurface investigation (Telford *et al.*, 1998). Probing involves the adoption of the current and the potential electrode spread is used to delineate the apparent resistivities and it follows that the deeper the probing, the farther away from the current source is the measurement of the potential difference regardless of the electrode array utilized (Onwuemesi and Egboka, 2006).

In homogeneous layer the depth of current penetration increases with increasing separation of current electrodes. In view of this, the vertical electrical sounding is expected to be carried out in order to study the horizontal and near horizontal interfaces. In effect, this helps to determine the horizontal zones of porous strata. The area being a developing residential area with good surface sandy soil and considerable distance to the main road needs all the amenities and infrastructure required to make habitation conducive. Unfortunately, water supply by the water corporation might not be readily available within Asaba and its Environs; it can also sometimes be inaccessible since settlers have to walk long distances to get good potable water.

Since the area is developing and human habitation is springing up, the study therefore, seeks to provide good potable water for human and industrial use, hence knowing the best possible location for sinking borehole in order to access the quantity and quality of ground water supply becomes very necessary. Another inherent issue that prompted this study is to determine the subsurface lithology which will help us delineate the depth to which boreholes can be sunk to obtain potable water and thus determining the depth to each layer.

Consequently, the occurrence of groundwater in the study area is mainly in medium- to coarse sands. Subsurface information inferred from a geophysical survey gives a more realistic picture of the groundwater potential of an area. This study attempts to characterize the groundwater potential in parts of Asaba, Delta State, Nigeria, using the vertical electrical sounding technique in order to determine the depth of the aquifer, the aquifer characteristics, and the groundwater flow pattern of the study area.

Methodology

Location of the Study Area

The study area lies between latitude $06^{0}37^{1}$E and $06^{0}45^{1}$E and on Longitude $06^{0}09^{1}$N and $06^{0}17^{1}$N in eastern part of Nigeria (Fig. 1.0). It has an area of about 325 square kilometers. It covers parts of Asaba, Anwai, Ibusa, Okpanam and Onitsha; and can be accessed through main roads such as Onitsha-Benin expressway, with other secondary roads and main paths (Fig. 1).

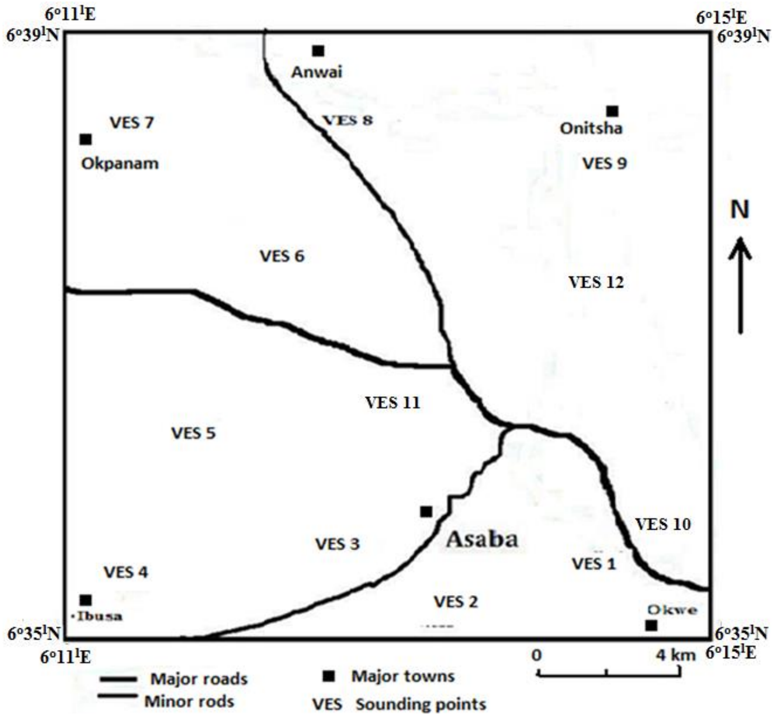

Fig. 1: Map of Nigeria Showing Delta State and the study area showing VES points

Geological Setting

The study area belongs to the Ogwashi-Asaba Formation of the Niger Delta Basin and Ameki Formation of the Anambra Basin (Fig. 2). The Ogwashi-Asaba formation is composed of alternating bands of sandstone and shale (Nwajide, 2013). The sandstone unit exhibits colours that range from yellow, whitish, red, to reddish brown. It is also mainly ferruginized and indurated, although sometimes friable. The base of the sandstone consists of poorly sorted pebbly to very coarse- grained sandy particles with mixture of some fines. Aslo, the lignite seams that characterize the Ogwashi-Asaba at depth, are normally associated with shales and clay shales.

In addition, the Ameki Formation in the far eastern part of the study area (at Onitsha) is dominantly filled with clastic sediments (Reyment, 1965). The source of the sediments into the basin is principally from the Cameroon massif and the Abakaliki synclinorium (Nwajide, 2013). The Ameki Formation consists of a top lateritic sandy layer underlain by a near monotonous sandy horizon, with occasional intercalations of thin clay and gravely beds.

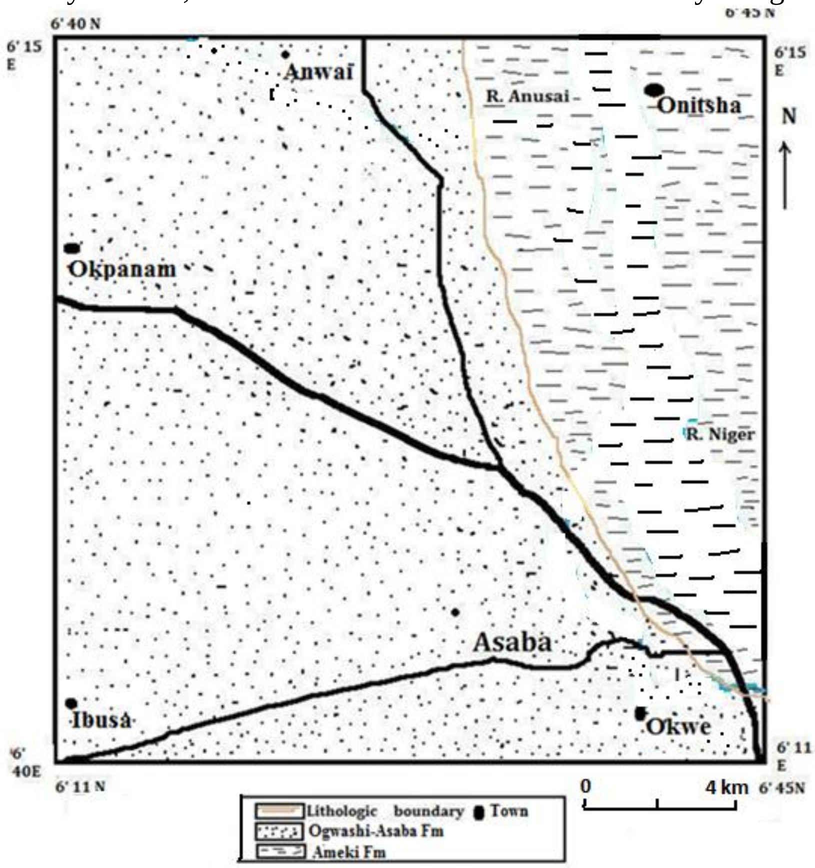

Fig. 2: Geologic map of the study area (Deduced after Nwajide, 2013)

Data Collection and Interpretation

The vertical resistivity sounding (VES) was carried out at twelve VES locations within the study area (Fig. 1) using Resistivity meter called Petro-Zenith model for groundwater investigation purposes. The coordinates of each station were taken using the global positioning system (GPS) equipment. The Schlumberger electrode configuration having a maximum current electrode spread of 500 m was used. The apparent resistivity values obtained from the measurement were plotted against half the current electrode spacing on a bi-logarithmic graph in order to determine the apparent resistivities and thicknesses of various layers penetrated. This technique has been functional in groundwater exploration by various investigators such as Anakwuba *et al.* (2022); Udoh *et al.* (2021); Anizoba *et al.* (2015); Anakwuba *et al.* (2014); Ezeh (2011); Okoro *et al.* (2010); Oseji and Ujuanbi (2009); Anudu *et al.* (2008); Nfor, *et al.* (2007); Onwuemesi and Egboka, (2006) and others. The resistivity curves were interpreted qualitatively and quantitatively by matching small segments of the field curves using two-layer model curves and the corresponding auxiliary curves. The resistivity data were also interpreted manually using partial curve matching method as well as using IXID that was developed by Interpex Limited. The software has been used in many similar research works and has proven very effective for groundwater investigations (Anakwuba *et al.*, 2022; Okeke *et al.* 2021; Chinwuko *et al.*, 2015). The hydraulic conductivity (K) of the aquifer layers across the area was estimated using equation generated by Heigold *et al.* (1979) worked on aquifer transmissivity from surficial electrical methods deduced that;

$$K = 386.40R_{rw}^{-0.93283} \quad \textbf{(1)}$$

Where, K = Hydraulic conductivity; R_{rw} = Apparent resistivity of the aquifer.

However, the aquifer transmissivity (T) of the aquifer units across the area was estimated using the relation generated by Freeze and Cherry (1979) and Okeke *et al.* 2021:

$$T = Kh \quad \textbf{(2)}$$

Where, T= Aquifer transmissivity; K= aquifer hydraulic conductivity; h= aquifer thickness.

3.0 RESULTS AND DISCUSSION

3.1 Qualitative Interpretation

Twelve VES curves obtained from the study area (Figure 4) were interpreted qualitatively. The result revealed four to six geo-electrical layers. Also, the results revealed that the study area has four (4) typical curve types namely; HK, K, KHK and HA (Telford *et. al*., 1998, Anakwuba *et. al*., 2021, Osele *et al*., 2016, Chinwuko *et al*., 2015). The most predominant among these curve types in the study area are K-curve types with 58%, whereas the remaining 42% belongs to the three other curve types within the study area (Fig. 5).

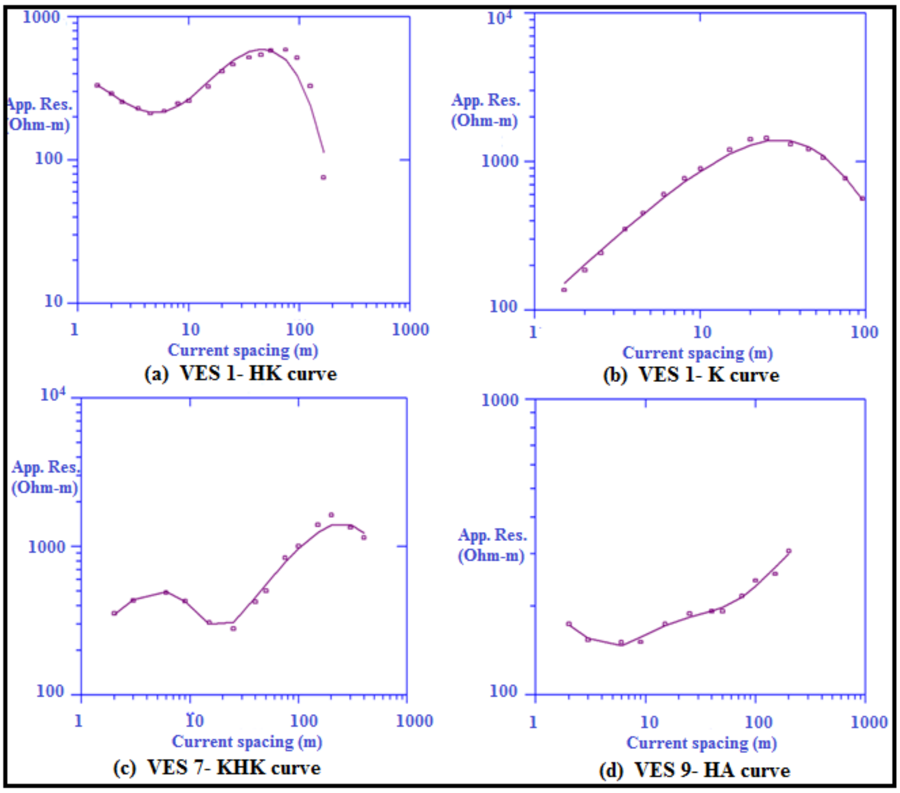

Figure 4: Representative VES curves within the study area.

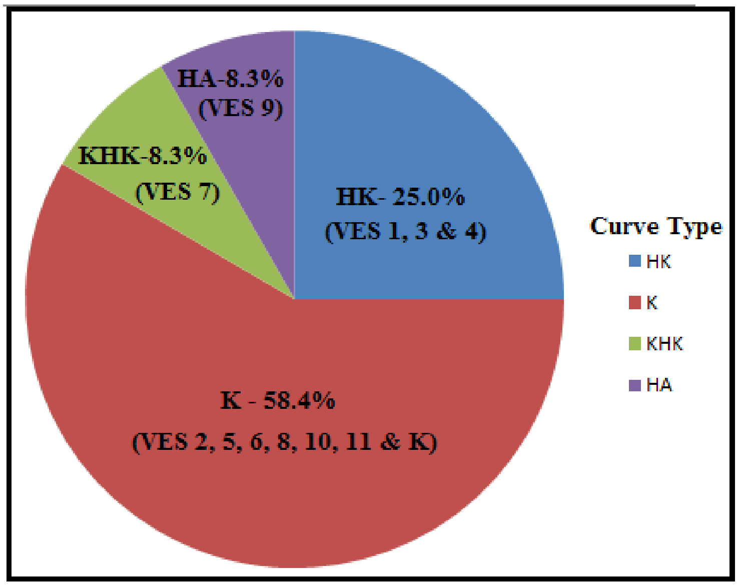

Fig. 5: Pie Chart showing the various curve types within the study area.

Quantitative Interpretation

VES correlations within the study area

A VES correlation interpretation along a cross section drawn through VES locations 7, 6 and 1 in the northwest to south east (NW-SE) direction (Fig. 6a). The top soil, which is relatively thin, is characterized by resistivity values between 131.72 Ohm-m to 441.45 Ohm-m and thickness values between 1.69 m to 2.39 m. Based on the resistivity values, the top soil is diagnosed to be lateritic (Chinwuko *et al.*, 2015). The top soil is diagnosed to be clay towards the eastern end at location of VES 1 and clay at the western end at VES 7. Beneath the top soil layer, the VES section reflects a layer identified as the dry sandstone at VES 7 which is characterized by resistivity value range of 1238.27 Ohm-m to 2344.3 Ohm-m and thickness value of 16.01 m to 129.25 m. The next layer, recognized as the aquifer layer with unit resistivity values between 498.29 Ohm-m to 1603.57 Ohm-m and thickness range of 42.82 to 168.79m is the water saturated sandstone. The water bearing sandstone depth varies from one region to the other. The bases of the last layers were not reached.

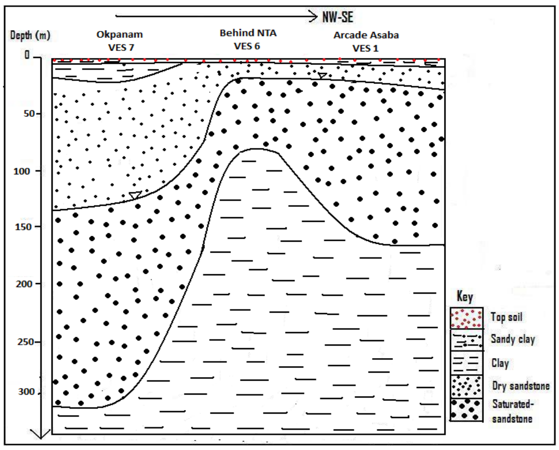

Fig. 6a: Geo-electric correlation along NW-SE

More so, the interpretation of VES cross section in the northeast-southwest direction within the study area (Fig. 6b) shows that the topsoil is categorized as lateritic soil and the resistivity values vary from 544.32 to 1232.4 Ohm-m and thickness ranging from 1.26 to 2.84m, which are very thin. Beneath the topsoil at VES 4, the second layer resistivity value is diagnostic of the clayey sandstone with resistivity value of 802.42 Ohm-m. The next layer is the dry sandstone which has high resistivity values ranging from 4881.2 Ohm-m to 5670 Ohm-m and indicating low conductivity. Its thickness ranges from 83.15 m to 120.24 m, having the highest thickness at DELSU, Anwai. Also, the depth to water saturated units along this section varies from 83.15 m to 120.24 with resistivity values ranging from 1138.38 Ohm-m – 2526.03 Ohm-m which are variable and continuous within this region. This layer is suitable for siting borehole in the area. The basal units are the impermeable layer which are recognized as clay, which has resistivity values of 84.08 Ohm-m to 195.34 Ohm-m.

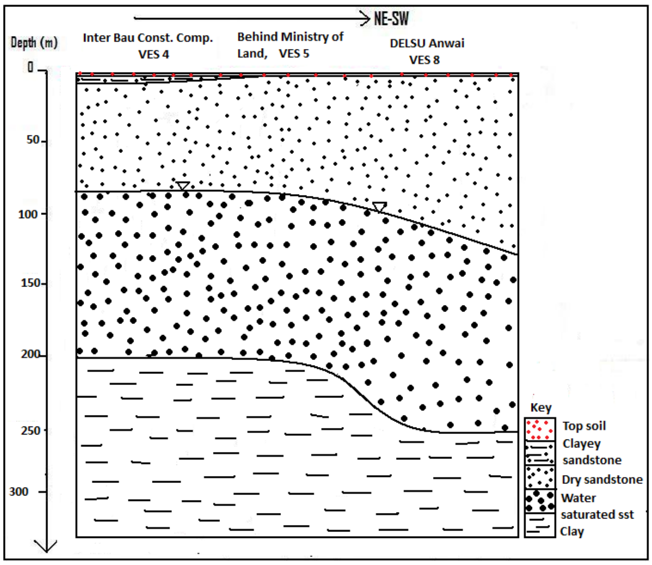

Fig. 6b: Geo-electric correlation along NE-SW

Comparison of VES section and Borehole Log

The comparison of lithologic section from the borehole located near one of the sounding stations at NTA Asaba and its interpreted geo-electric units (Fig. 7), showed that the overburden thickness in the lithologic section is 12.0m while in VES section, it is 1.24m. In the underlying layers, the geo-electric units show suppression and merging of some lithologic units from the borehole. This is due to the fact that VES units are not the same as lithologic units. A given lithologic unit with variations in resistivity will give rise to so many geo-electric units. Also, different lithologic units with similar resistivities would be merged as one geo-electric unit. Hence, the water table varies a little from the VES unit with value of depth being 16.58m in the geo-electric section and 22.00m in lithologic unit.

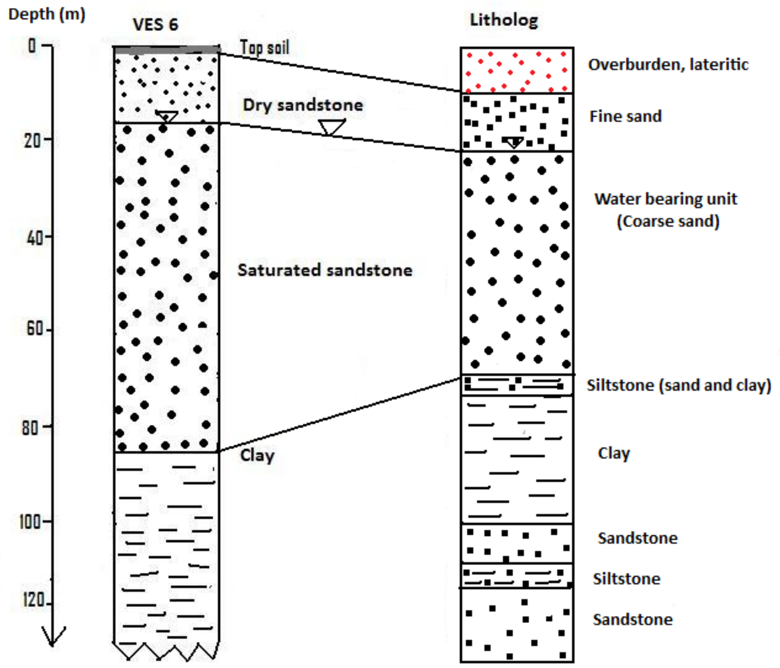

Fig.7: Correlation of geo-electric and lithologic sections at NTA, Asaba

Watertable Map

The geo-electric parameters obtained from the interpretation of the sounding data were used to construct the watertable map and cross-section which was analyzed in terms of hydro-geologic importance of the area. According to Osele *et al.* (2016) Watertable elevation values are obtained by subtracting depths to watertable deduced from the sounding curves from surface elevations obtained from the topographical map (Table 1) and contoured to produce the watertable map of the study area (Fig. 8). The cross-section was established from the map by plotting water table with respect to mean sea level on the vertical and distance on the horizontal. The water table map shows that the groundwater flows in the South-eastern directions. The flow pattern of the groundwater indicates that the groundwater flows from River Niger down to the study area.

Table 1: Watertable with reference to mean sea level within the study area

VES NO	Elevation (m)	Depth to water (m)	H2O w.r.t MSL (m)
1	24	21.01	2.99
2	45	24.01	20.99
3	91	17.91	73.09
4	76	73.534	2.47
5	45	75.52	-30.52
6	152	16.576	135.42
7	61	130.06	-69.06
8	30	114.24	-84.24
9	27	51.68	-24.68
10	47	27.32	19.68
11	46	81.06	-35.06
12	147	18.29	128.71
Average	**66**	**54.2675**	

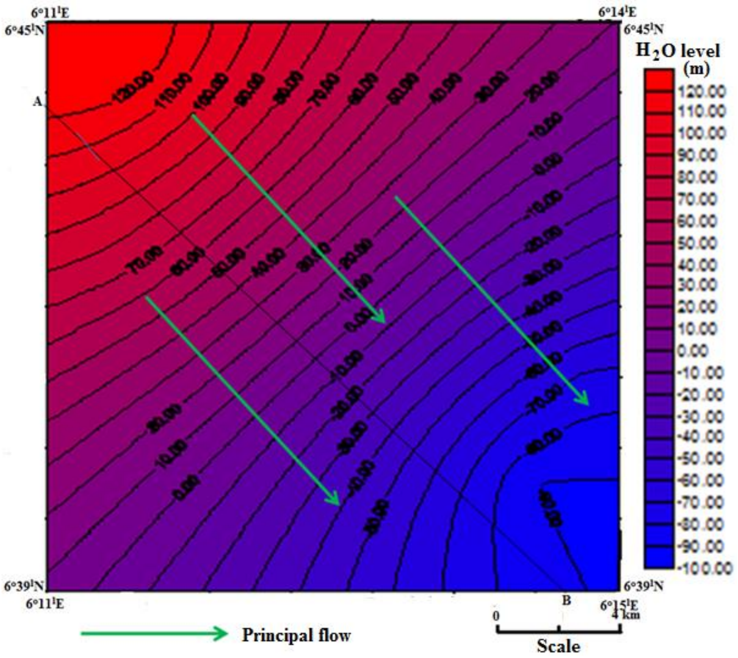

Fig. 8: Water table map with reference to mean sea level in the area (Contour interval ~10m)

Estimation of Aquifer Characteristics

The result of the calculated hydraulic conductivity according to Heigold *et al.* (1979) shows that the hydraulic conductivity obtained across the study area ranges from 0.1427 m/day to 0.9918 m/day with an average of 0.3917 m/day. Also, the calculated transmissivity values according to Freeze and Cherry (1979) range from 27.3327 m^2/day to 79.1576 m^2/day with an average of 41.0090 m^2/day within the study area. These values of aquifer characteristics obtained show that the study area has good potential for groundwater yield in line with the work done by Okeke *et al.* (2022) and Anakwuba *et al.* (2021).

Groundwater Implications

The study area is underlain by two differential geological formations namely; Ameki Formation and Ogwashi-Asaba Formation will definitely pave way for the variation of depths to aquifers within the study area (Chinwuko *et al.*, 2015). Actually, those regions with high depths to the aquifers are associated with Ameki Formation which invariably will lead to high cost of citing a borehole in northeastern part of the study area. However, drilling around those areas underlain by Ogwashi-Asaba Formation is associated with the shallower depths across the region. So, the cost of drilling in the northwestern region is very low to compare with the cost of drilling in the far northern parts of this study area (Chinwuko *et al. 2015*; Onwemesi and Egboka, 2006).

Furthermore, the results revealed the presence of four to five geo-electric layers in the area. The VES curve types encountered in the study area reveal dominate of K-type with 58.4% which signify good aquiferous region and conforms with Chinwuko *et al.* (2015) and Anizoba *et al.* (2015). The study 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, consisted of unconsolidated medium to coarse grained sands and gravel. The thickness and depth of these underground saturated sand layers varied from site to site. Asaba and its environs possess good groundwater potential and if properly managed, it would be possible to practice modern agriculture throughout the year in order produce huge agricultural products that will serve the inhabitants of the study area and the state at large.

Conclusion

Twelve vertical electrical soundings (VES) were carried out during the geophysical survey using the Schlumberger array and the processed resistivity data were interpreted using the conventional curve matching and computer iteration method with the aid of a resistivity software named Interpex-1 dimensional (IX1D) software. The VES results depict four different curve types namely; HK, K, KHK and HA-curve types. The result also reveals that 58% of all the sounding curves belong to K-types whereas the remaining 42% belongs to other three curve types within the study area. The result depicts that the third and fourth layers at different areas were interpreted to be water saturated sandstone which formed the aquiferous unit in the area. The water saturated unit is deeply seated in some areas with an average depth of 53.69 m. The watertable map shows a southeast groundwater flow pattern in the area. The result also shows that the hydraulic conductivity obtained ranges from 0.1427 to 0.9918 m/day with an average of 0.3917 m/day while the transmissivity range is from 27.3327 m^2/day to 79.1576 m^2/day with an average of 41.0090 m^2/day within the study area. The study concludes that there is huge groundwater potential within the study area as a result of that can yield sufficient water that would serve the immediate environs.

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