Integrated Geological, Hydrogeological and Geophysical Assessment of Groundwater Potential in Tudun-Fulani area of Minna, North-Central Nigeria.

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Abstract

Groundwater is the major source of potable water for human use. An integrated approach of geological, hydrogeological and geophysical techniques has been used to investigate the potential of groundwater in part of Minna, north-central Nigeria. Granite and granite-gneiss are the two dominant rock types in the study area. Structurally, the principal joint direction in the area trend is NW-SE, which also controls the groundwater flow mechanism. A total of 50 Vertical Electrical Sounding (VES) stations were established. The major curve types encountered in the area are H, HA, A and KA. Three major lithologic units were identified from the geoelectric sections: the unsaturated top soil which is mainly lateritic clay, the weathered/fractured layer and the fresh basement layer. The lateritic clay layer as a topmost layer is a thin highly resistive layer with resistivity ranged between 41.0 Ωm to 99.0 Ωm and depth of 0.9 m to 3.2m. The weathered basement rock has resistivity value of 23 Ωm to 1820 Ωm and a thickness range of 1.6 m to 26.0 m. The fresh basement rock is characterized by high resistivity values and exceeds 1000Ωm. Static water level (SWL) measurements were collected from 80 hand dug wells in the area and the values used to plot the groundwater low map. The thickness of the layer extends to an infinite depth. Eighty (80) hydrogeological well data (SWL) were obtained from hand dug well within the study area. Isoresistivity and isopach maps were generated from the geoelectric parameters of the subsurface and used to characterize the subsurface. The results revealed that the southern portion of the study area has higher groundwater potential and the display of low resistivity value and deeper overburden thickness validates the findings. The rosset diagram confirms groundwater flow direction of NW-SE, which conforms to the regional fractures density of the area. Hand dug wells in the area can be terminated within the regoliths/weathered basement units in the area which lies within the depth range of 2.5 m to 12 m while boreholes in the area should be terminated at depth range 60 m to 100 m.

Keywords: Assessment, Geological, hydrogeological, Geophysical, Groundwater Potential, Tudun Fulani, Minna, North-Central Nigeria

Introduction

Inadequate supply of potable pipe-borne water in Minna town in general and the absence of public supply in Tudun-Fulani in particular are of great concern. The scarcity of water in Bosso and Tudun-Fulani part of Minna, Niger State especially during the dry season is worrisome. Many boreholes located in these parts of Minna fail during the dry seasons with little exception while most people living in both Bosso and Tudun-Fulani area rely heavily on water vendors for their

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daily water needs. These areas host a number of federal, state and private owned institutions and water demand especially during the dry seasons is enormous. In recent times, the relative peaceful nature of Minna town as well as its proximity to the Abuja has led to the influx of people especially from the northeastern Nigeria at the wake of insurgency, thereby putting more pressure on the irregular public water supply in the city (Amadi, 2010; Amadi and Olasehinde, 2010). The assessment of groundwater potential in Minna using multi-geoscience approach is aimed at solving the acute water scarcity currently affecting the people in the area. The present research is aimed providing geoscientific baseline information on the groundwater potentials of the area which could be maximally exploited to meet the needs of the people.

Methodology

Study Area Description

The study area is located between latitude 9°38'N and 9°41'N of the equator and longitude 6°29'E and 6°32'E of the Greenwich Meridian (Fig.1). The area is accessible through Paiko-Minna-Zungeru

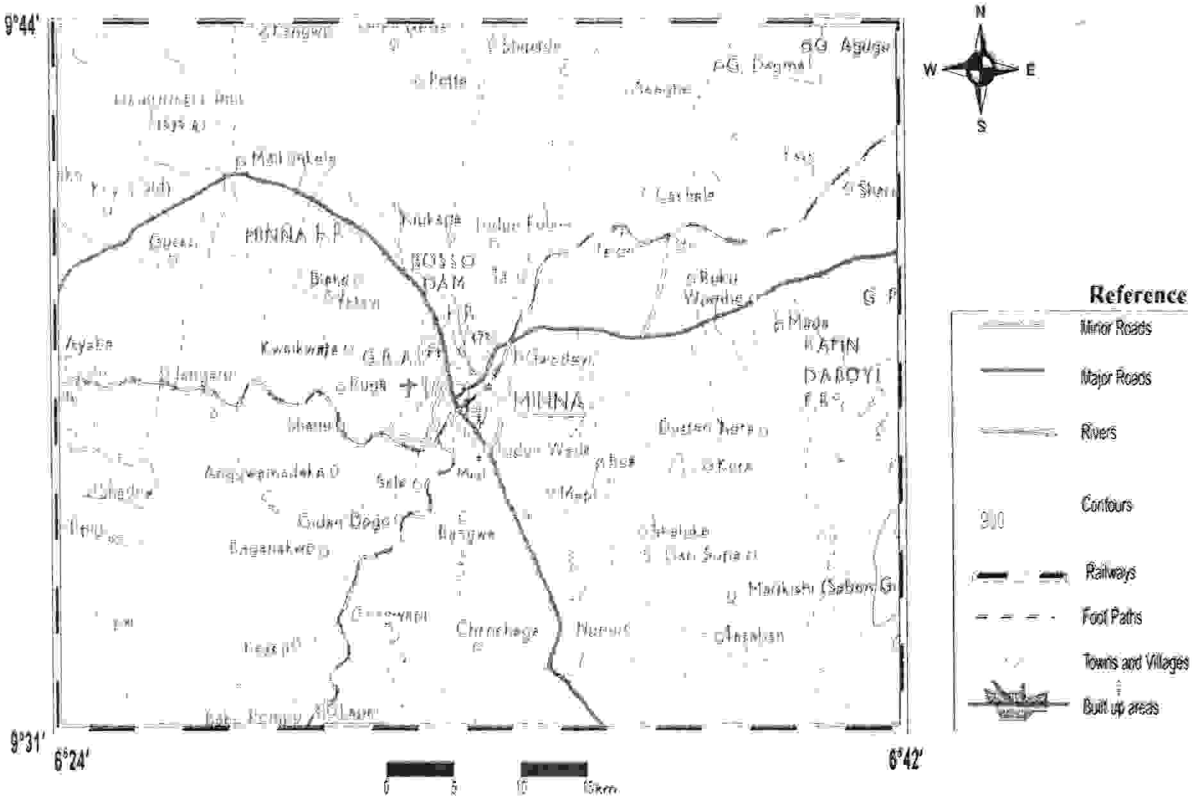

Fig. 1: Topo Map of the Study Area

Physiography of the Study Area

The climate of Minna usually alternates between dry and rainy season. The area lies within the middle belt of Nigeria with a total annual rainfall between 1270 mm and 1524 mm, spread over the month of April to October (Mc Curry, 1976). The highest amount of rainfall is observed in the month of September. Monthly temperature is highest in March at about 30°C and lowest in August at about 25°C (Ajibade, 1982). The vegetation of the area is that of the guinea savannah which comprises of various species of shrubs and high forest trees especially along the streams and depressions in the area. The vegetation also consists of short grasses of height 3 to 4.5 meters and trees of up to 15 meters high (Ajibade, 1989). The study area consists of low-lying terrains and few gentle hills of older granite suites regarded as the Minna batholiths (Olasehinde *et al.*, 2015). The southern and central parts of the site are typified of relatively flat and monotonous landscape underlain by biotite hornblende granite as evidence by petrographic analysis (Amadi *et al.*, 2012). The study area is drained by the River Chanchaga and its tributaries, following in an NE-SW direction in conformity with the structural configuration of the area.

Principle of Electrical Resistivity Method

The principle of electrical resistivity is generally based on the famous Ohm's law (R= V/I). Measurements are normally made on the ground by sending current into the ground surface through pairs of current electrodes (C1 and C2). The resulting voltage (V) difference is measured between another pairs of potential electrodes (P1 and P2) as illustrated in Fig. 2. Vertical Electrical Sounding (VES) points were carried out along a grid in the area using the Abem Terrameter SAS 4000. The electrical resistivity configuration employed in the field was Schlumberger array with a maximum half electrode spread AB/2 of 80 m. Electrical current was passed into the ground through the two outer current electrodes and the resulting potential difference was measured across the two inner potential electrodes that were arranged in a straight line, systematically about a centre point. The electrode spacing was progressively increased, keeping the centre point of the electrode fixed, the potential difference to the current ratio was displayed by the terrameter as resistance, measured in ohms (Ω). The resistance values were taken from the terrameter and multiplied by the standard geometric factor (k), which is calculated as a function of the electrode spacing. The apparent resistivity values were plotted against the distance (AB/2 in m) on the log-log graph for interpretations. The VES curves were quantitatively interpreted by partial curve matching and computer iteration technique with the aid of the windows compatible WinResist software.

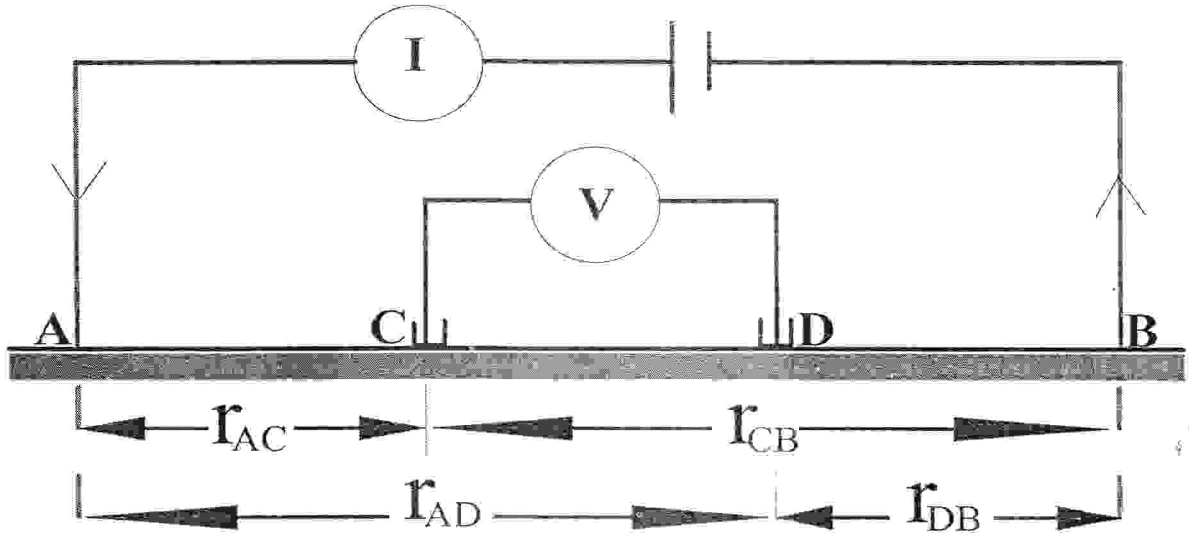

Fig. 2: Schlumberger Array for Vertical Electrical Sounding

Results

The geological map generated from the field mapping is shown in Fig. 3 while the rosset diagram obtained by the computation of measured joint direction is illustrated in Fig, 4. A total of 80 static water level (SWL) values measured from existing hand-dug wells within the study area were used to construct the groundwater flow direction of the area (Fig. 5). The SWL values were obtained with the aid of a measuring tape and GPS coordinate values. The results of the vertical electrical sounding (VES) field data for VES 1-10 and VES 11-20 are summarized in Tables 1 and 2 while the corresponding geo-electric sections are contained in Figs. 6 and 7 respectively. The various computer modeled curves type for the area are shown in Figs. 8 to

11 respectively. Also, the VES field data were used to generate iso-resistivity map of the regolith aquifer in the area (Fig. 12), iso-resistivity of fractured basement in the study area (Fig. 13) and iso-pach map of the study area (Fig. 14).

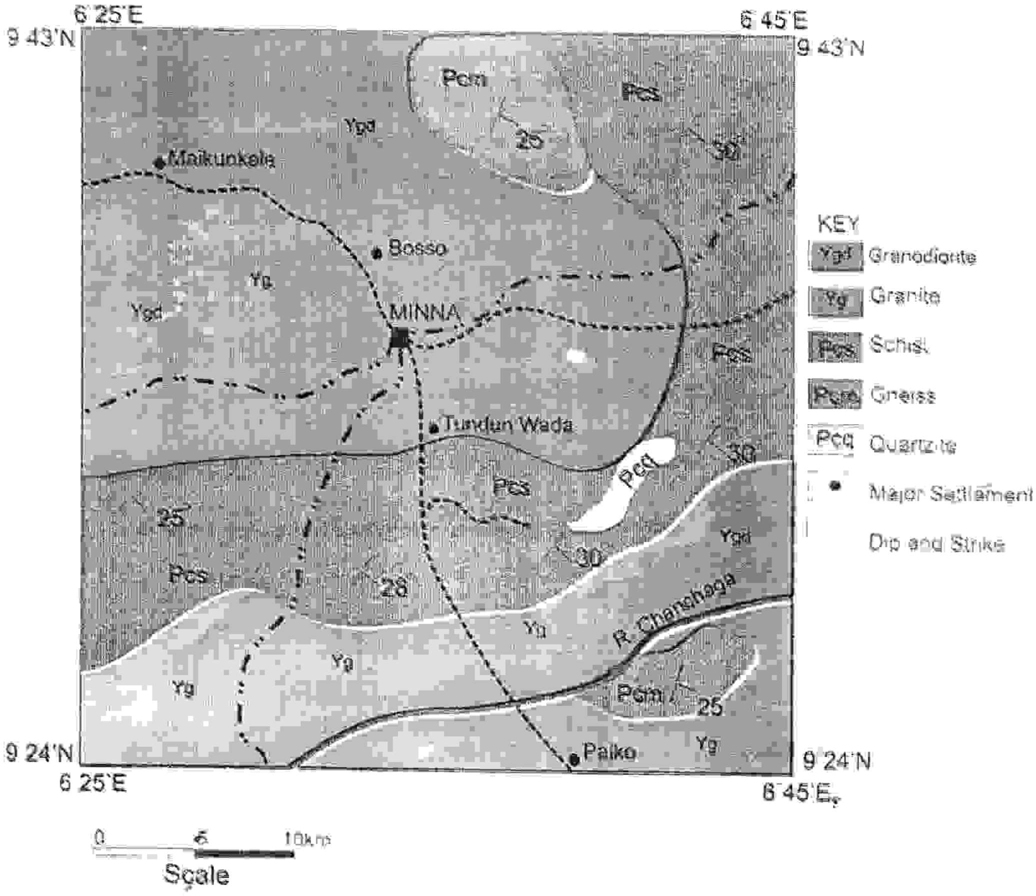

Fig. 3: Geology map of Minna and Environs

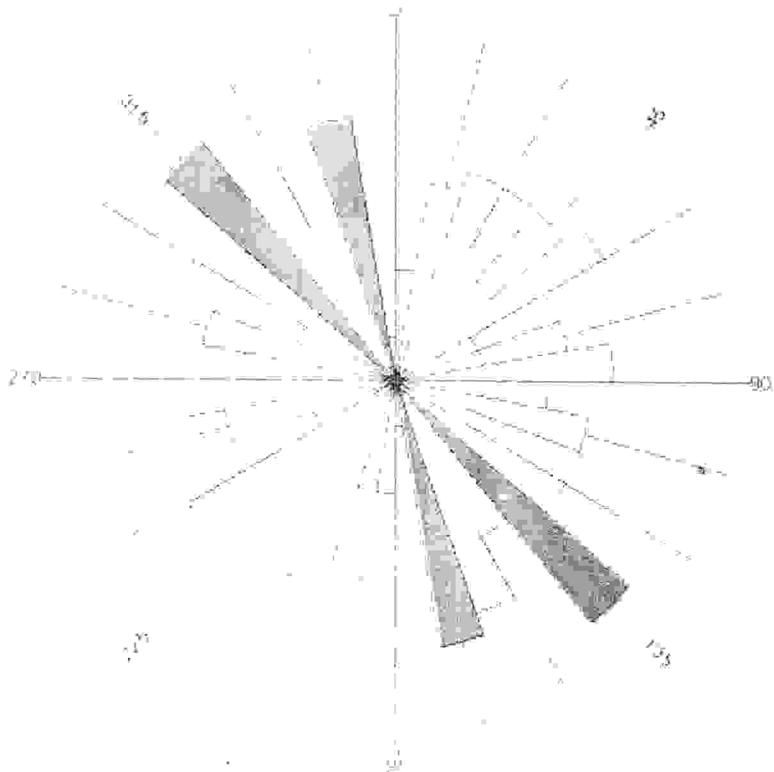

Fig. 4: Rosset diagram of the Study Area

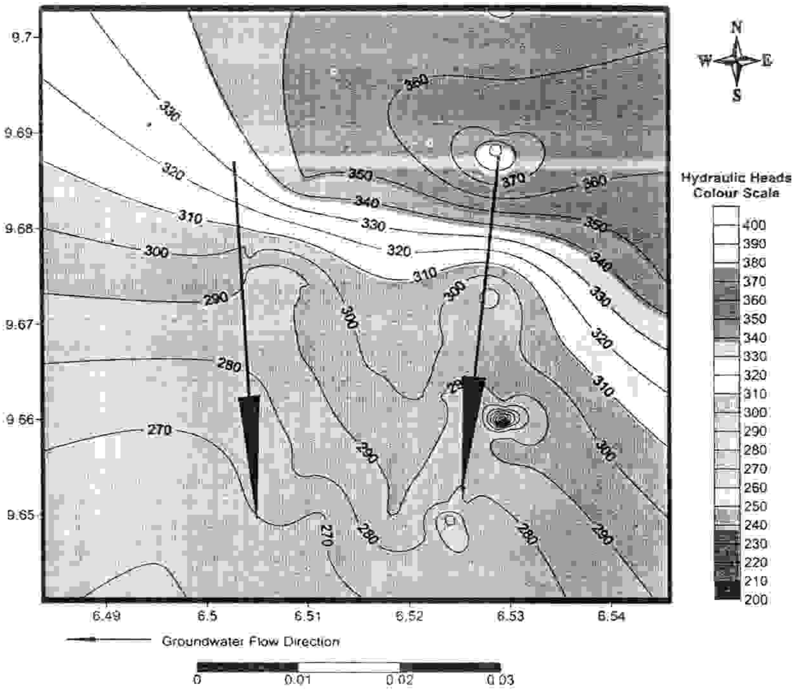

Fig. 5: Groundwater flow direction of the Study Area.

Table 1: Results of Vertical Electrical Sounding obtained in the Study Area (VES 1-10)

LAYER	RESISTIVITY ℓ (Ωm) / THICKNESS T (m) / DEPTH d (m)									
	First Quadrant									
	VES 1	VES 2	VES 3	VES 4	VES 5	VES 6	VES 7	VES 8	VES 9	VES 10
Layer1 ℓ1/T1/d1	230/1.2/1.2	99/1.0/1.0	119/1.4/1.4	76/1.3/1.3	691/0.4/0.4	130/0.9/0.9	604/0.7/0.7	89/1.1/1.1	69/1.2/1.2	2188/1.0/1.0
Layer 2 ℓ2/T2/d2	186/5.9/7.1	35/3.9/4.02	209/5.6/6.92	11/5.8/7.2	186/8.2/8.6	61/3.3/4.2	89/6.7/7.3	45/5.4/6.5	6/3.0/4.2	88/5.3/6.3
Layer 3 ℓ3/∞	55698/∞	2016/∞	1326/∞	554/∞	6285/∞	8756/∞	5337/∞	1973/∞	7297/∞	8955/∞
CURVE TYPE →	A	HA	A	HA	HA	HA	HA	HA	HA	HA

Table 2: Results of Vertical Electrical Sounding from the Study Area (VES 11-20)

LAYER	RESISTIVITY ℓ (Ωm) / THICKNESS T (m) / DEPTH d (m)									
	Second Quadrant									
	VES 11	VES 12	VES 13	VES 14	VES 15	VES 16	VES 17	VES 18	VES 19	VES 20
Layer1 ℓ1/T1/d1	41/0.6/0.6	1563/0.7/0.7	1377/1.0/1.0	924/1.1/1.1	268/0.9/0.9	522/1.0/1.0	293/1.7/1.7	572/2.0/2		161/0.9/0.9
Layer 2 ℓ2/T2/d2	202/2.2/2.5	174/8.4/9.1	265/14.4/15.6	374/11.6/12.6	130/5.1/6.0	223/4.4/5.5	163/6.8/8.4	324/6.5/8.4		40/5.2/6.1
Layer 3 ℓ3/∞	26/7.1/9.6	2181/∞	2081/∞	2383/∞	1168/∞	2380/∞	2365/∞	12985/∞		1324/∞
CURVE TYPE →	KA	H	H	H	HA	HA	HA	K		KA

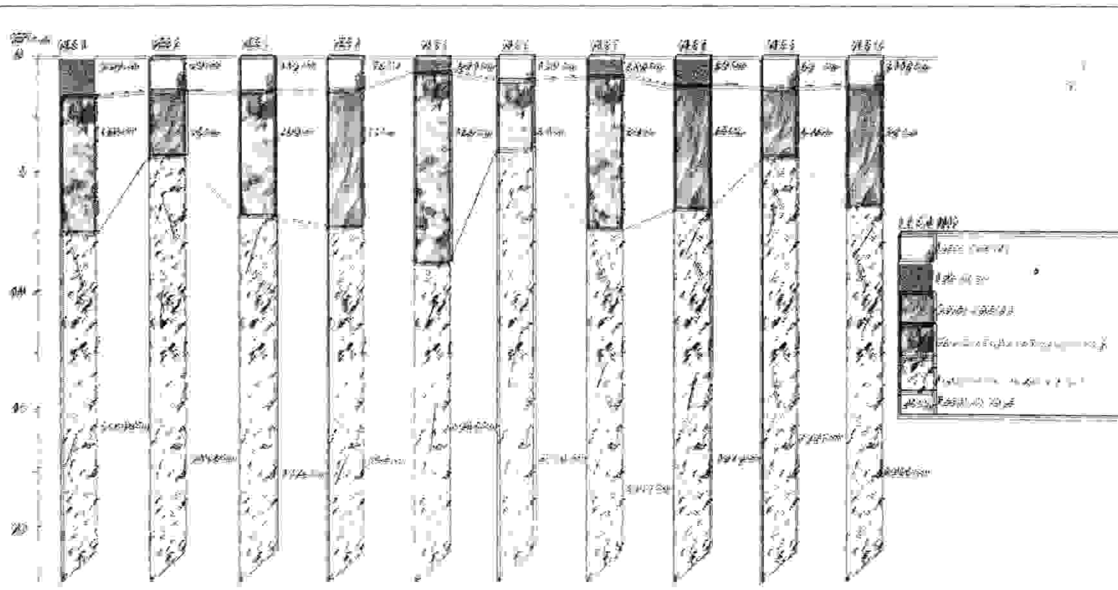

Fig. 6: Geoelectric section of VES 1-10

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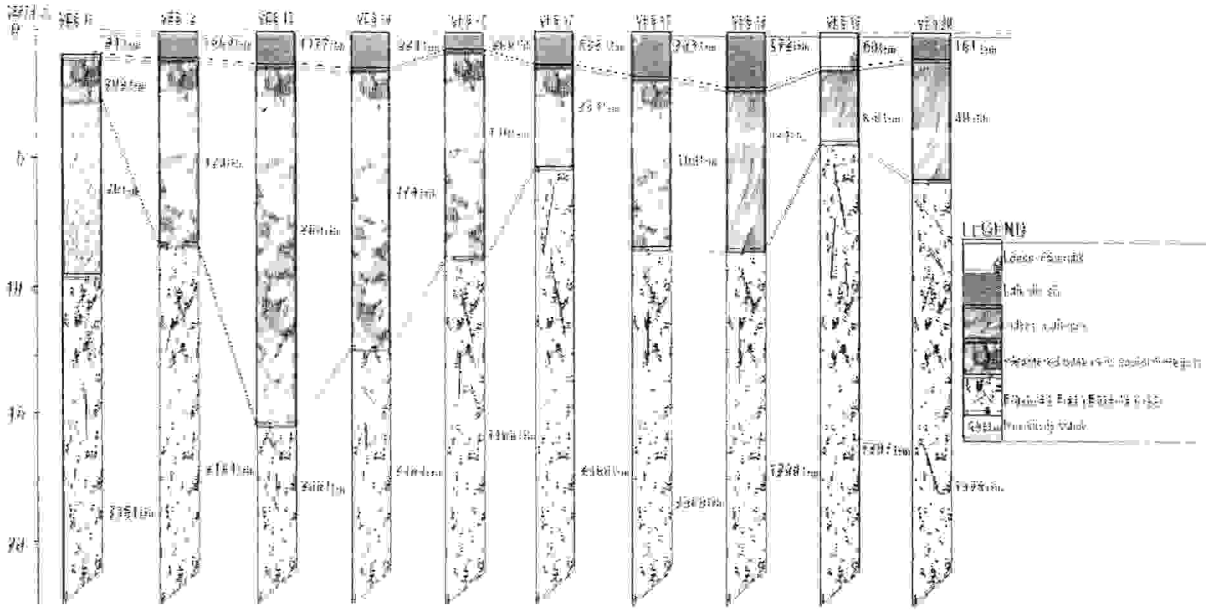

Fig. 7: Geoelectric section of VES 11-20

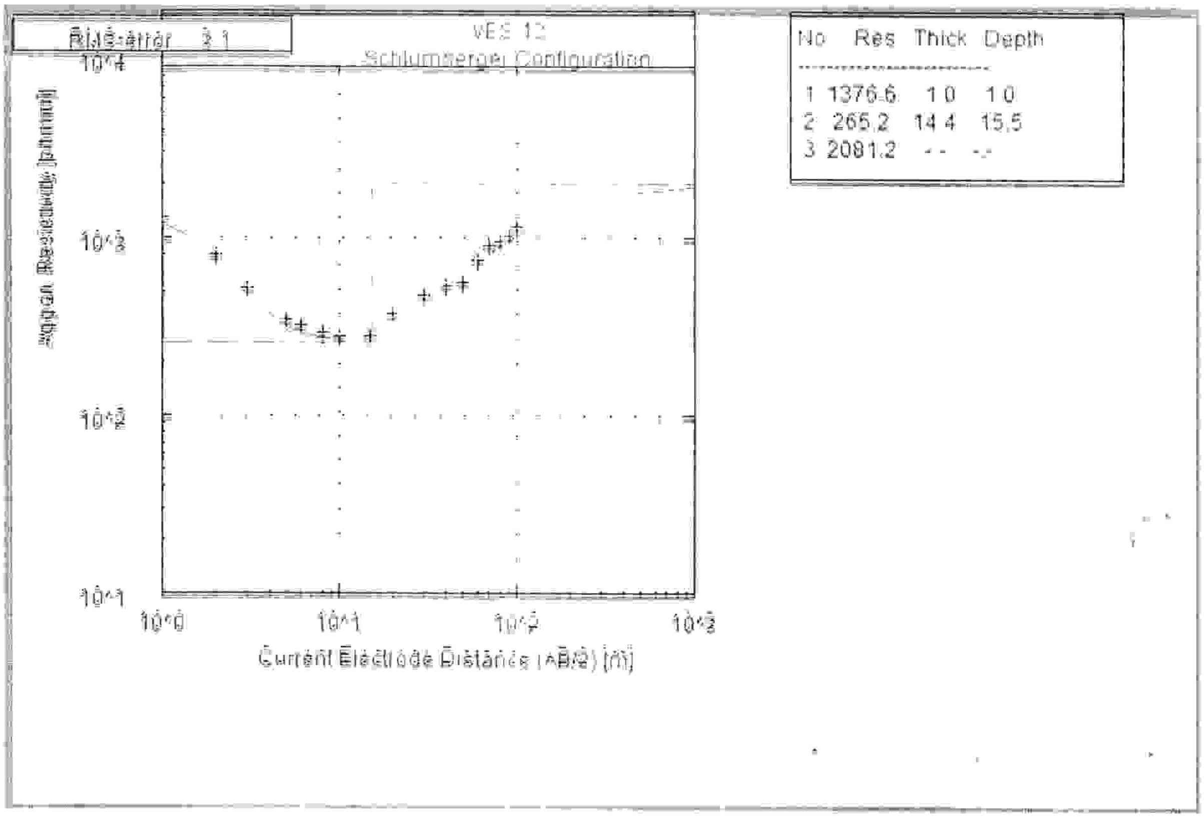

Fig. 8: H-Type modeled curve

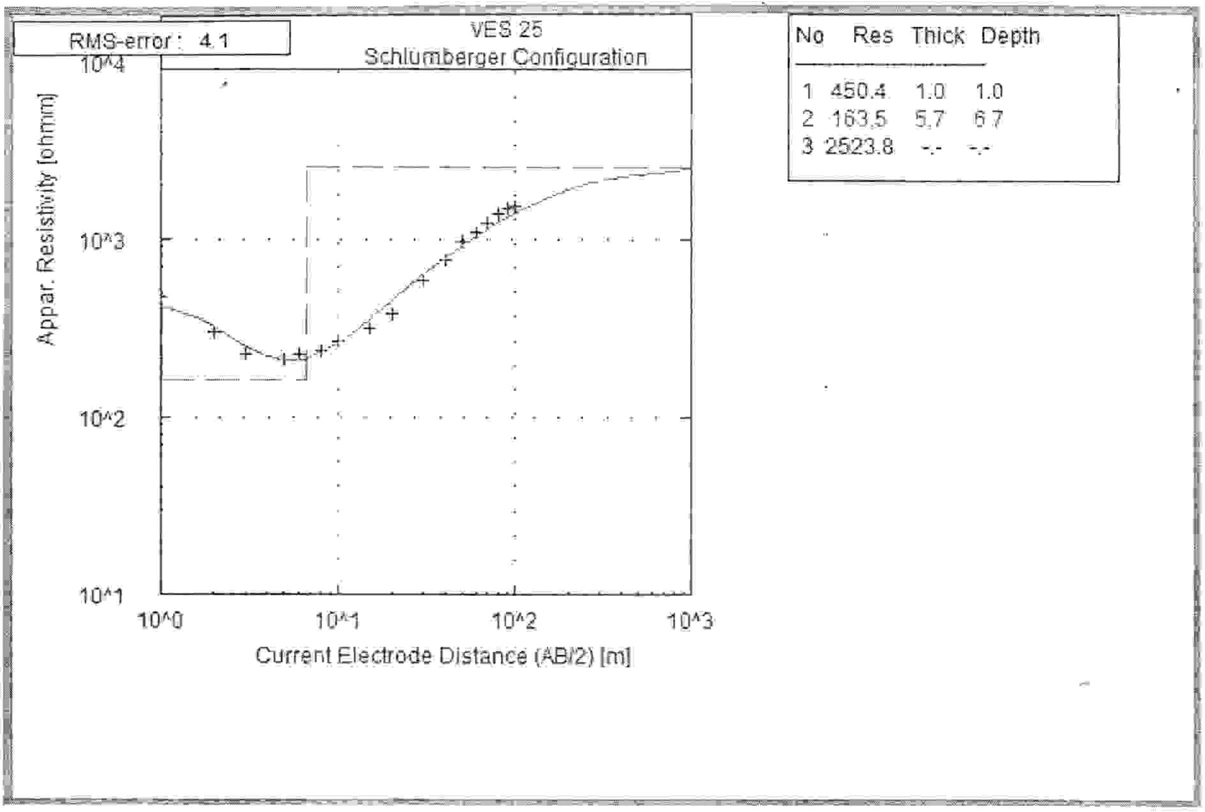

Fig. 9: HA-Type modeled curve

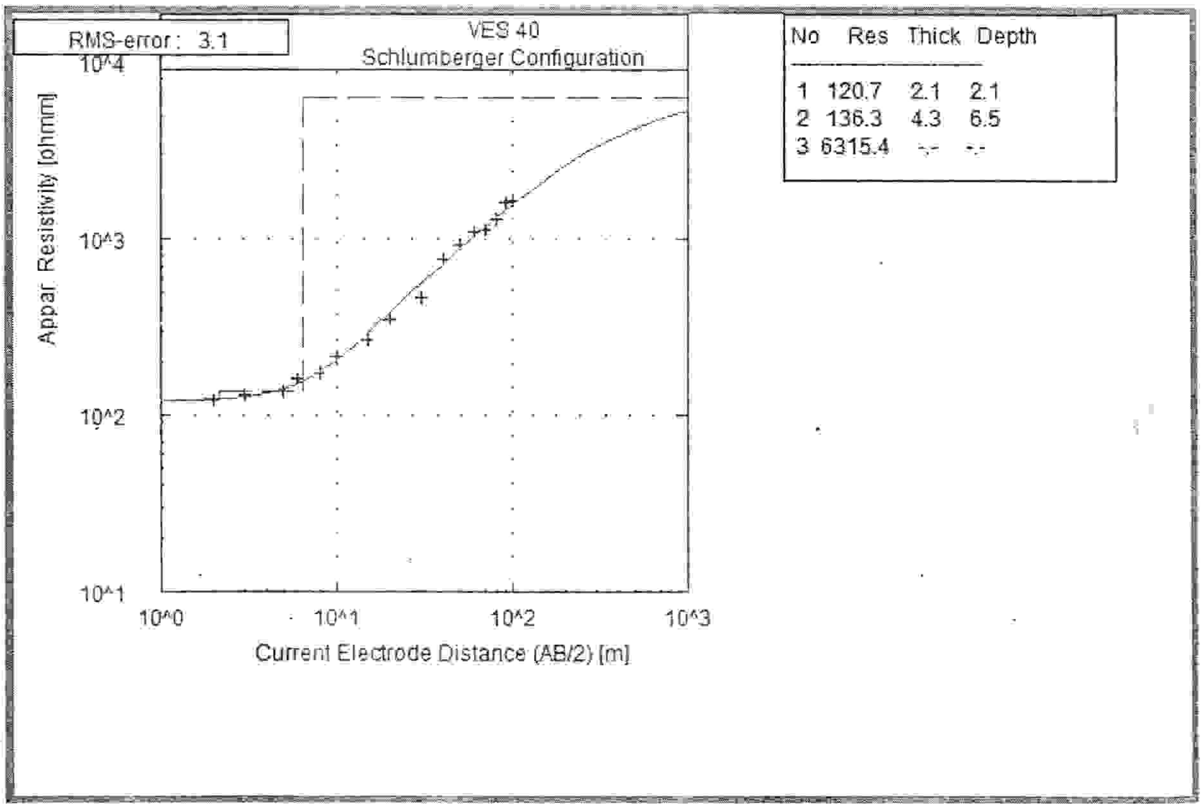

Fig. 10: A-Type modeled curve

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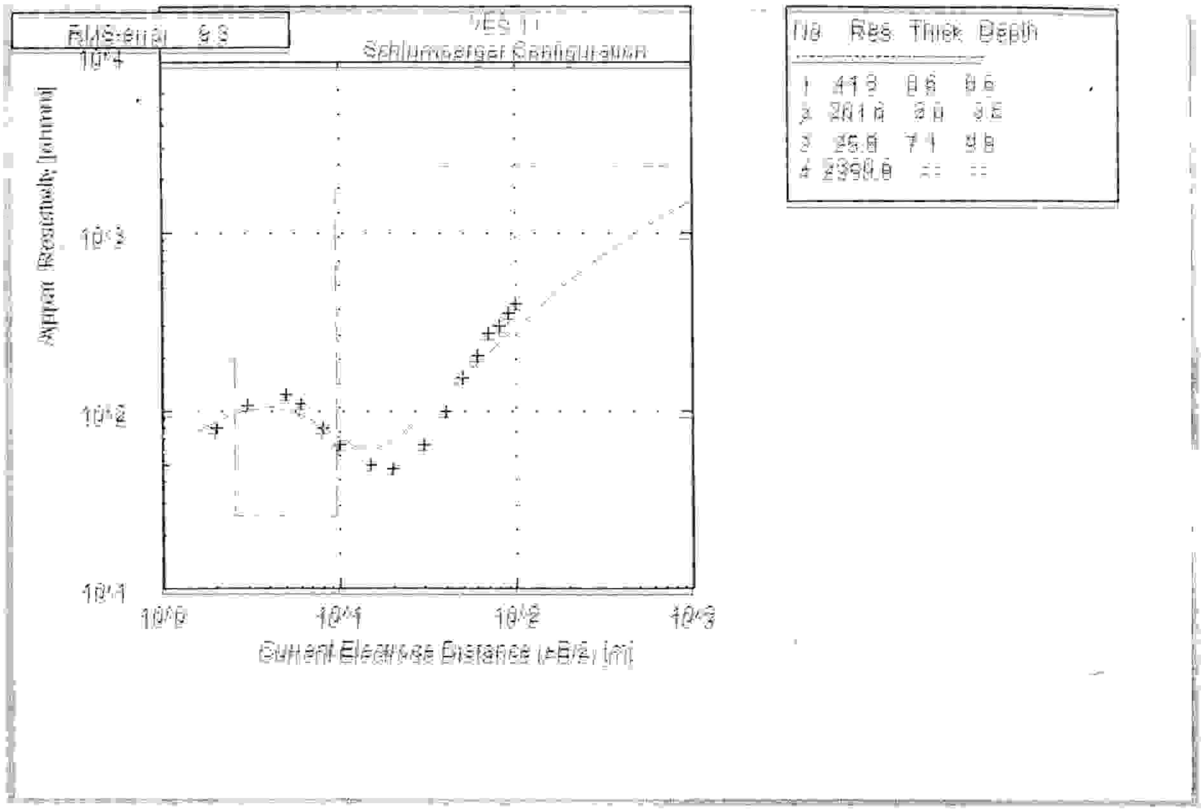

Fig. 11: KA-Type model curve

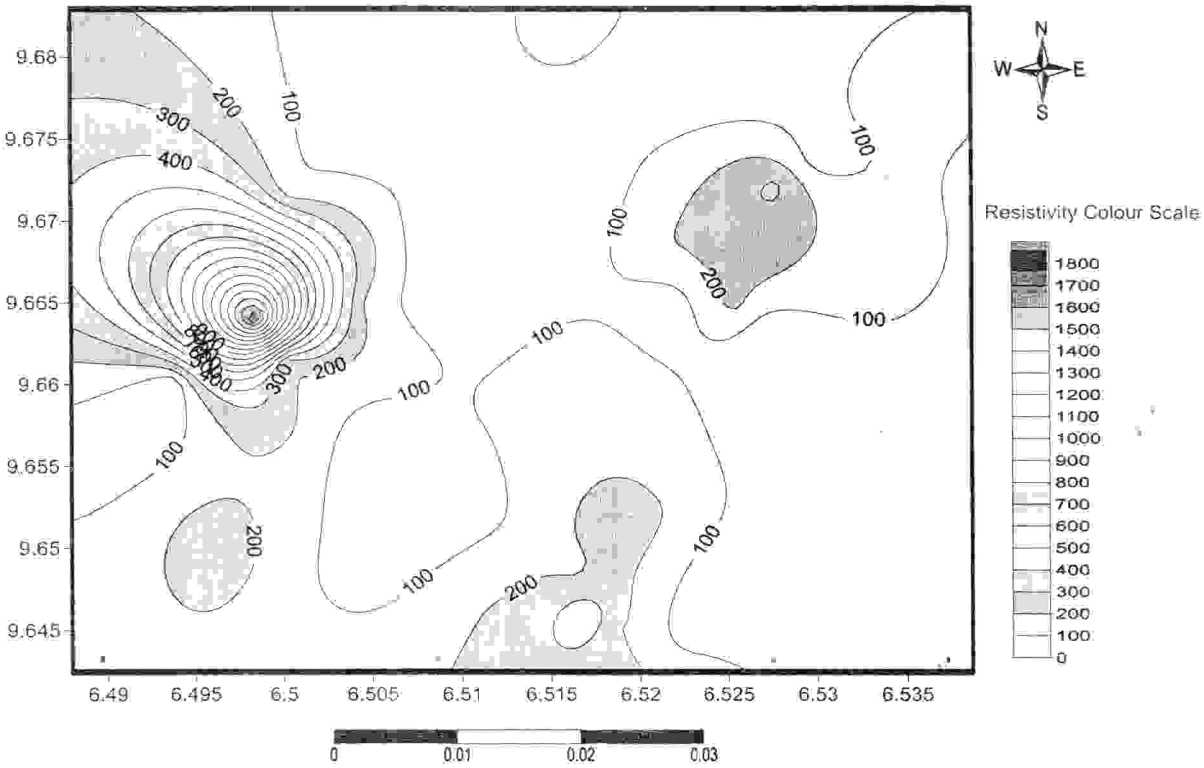

Fig. 12: Isoresistivity of the Regolith Aquifer in the Area

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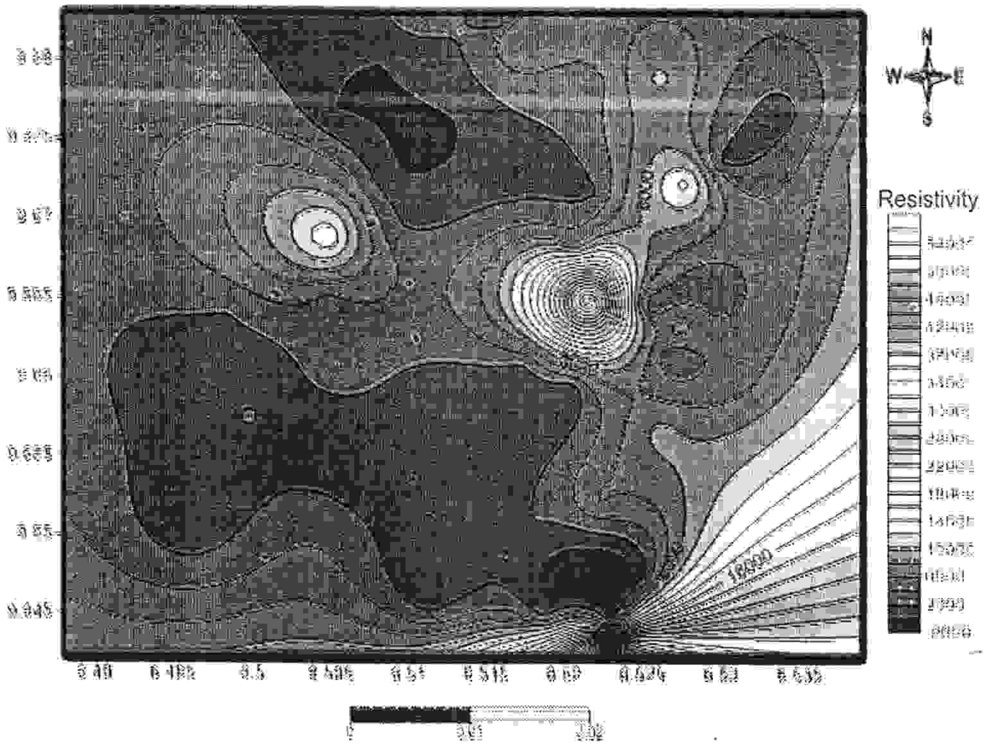

Fig.13: Isoresistivity of fractured basement unit in the Study Area

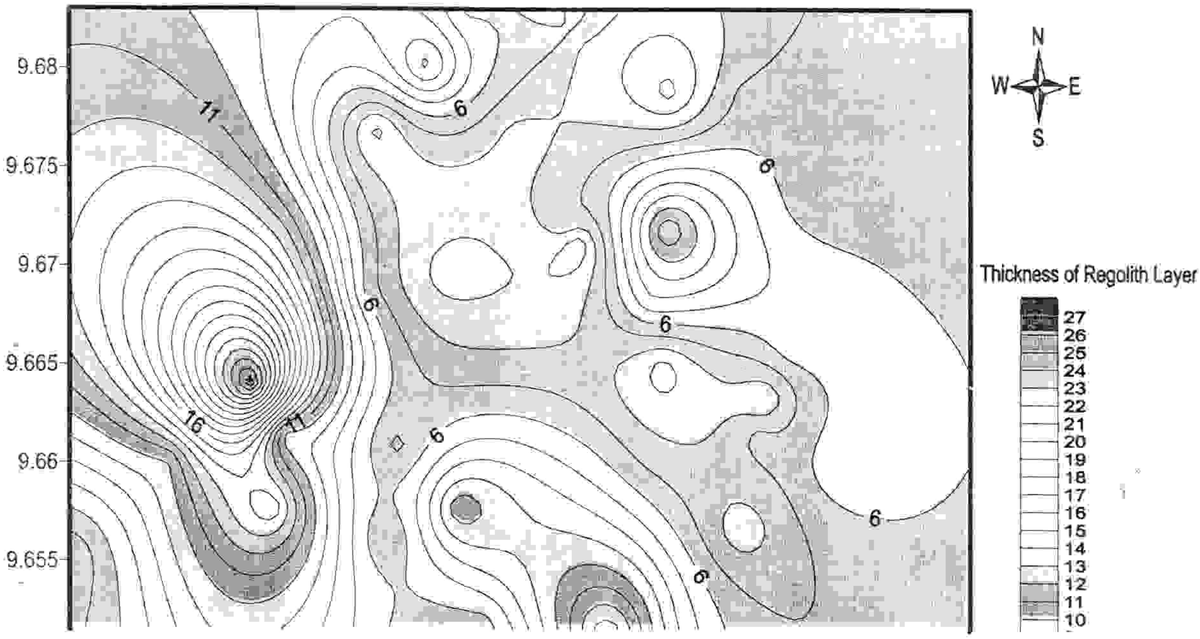

Fig. 14: Isopach Map of the Study Area

Discussion

Geology and Hydrogeology of the Minna

The study area lies within the Nigerian Basement Complex terrain. This terrain is characterized by three litho facies: gneiss, schist and granites (Ofodile, 2002; Obaje, 2009). In the local geology mapped, granite and granodiorite occupies about 70% of the study area with various degrees of fractures and weathering while schist covers about 25% of the study area with gneiss having the remaining 5% (Fig. 3). Foliations were observable on the schist and gneiss facies in the area. Quartzite intrusions were observed more on the schist facies and are believed to be the potential sites of gold area.

Groundwater flow direction

Eighty (80) static water level (SWL) data were collected from the existing hand dug well within the study area with the aid of a measuring tape and location of the wells were determined using the global positioning system (GPS). The well inventory data obtained was used to construct the groundwater flow direction of the area (Fig. 5). Groundwater in the area flows from north in accordance with Darcy's Law of groundwater movement. It states that groundwater flows laterally (horizontally) from areas of high hydraulic head (recharge area) to zones of low hydraulic head (discharge area).

Geophysical Investigation

The Schlumberger array of electrical resistivity method was employed for the investigation with a maximum AB/2 of 100 m. The electrical method was employed in this study because it is very efficient, economical and effective in delineating aquifer potentials (Mohammed and Olorunfemi, 2008; Olasehinde and Awojobi, 2004; Muraina *et al.*, 2012; Alao *et al.*, 2013; Osumeje *et al.*, 2014). The sounding model curves show three to four layers earth models. The three layer curves in the area are characterized by H and A curves while the four layer systems are reflected in HA and KA curve types as shown (Figs. 8-11). There exists a variation in the regoliths subsurface materials that overlay the basement rock from place to place in the study area. The geo-electric sections were obtained from the geo-electric parameter derived from the iteration of the model curves as shown in Tables 1 and 2 respectively. The subsurface lithology as revealed in the geo-electric sections (Figs. 6-7) derived from the VES data on Tables 1 and 2 indicate a three/four layer system typical of a basement aquifer. It include the unsaturated top soil which is made up of lateritic clay soil, the weathered/fractured basement layer and the fresh basement rock unit (Lowrie, 2007; Akintorinwa and Adenusi, 2009; Aweto, 2012; Anudu *et al.*, 2011; Amadi *et al.*, 2014).

The lateritic clay layer as a topmost layer is a thin highly resistive layer with resistivity ranged between 41.0 Ωm to 99.0 Ωm and depth of 0.9 m to 3.2m. The weathered/fractured basement rock has resistivity value of 23 Ωm to 1820 Ωm and a thickness range of 1.6 m to 26.0 m. The fresh basement rock is characterized by high resistivity values and exceeds 1000Ωm. The thickness of the layer extends to an infinite depth. The weathered basement in this case is given a wide range of interpretation by different authors depending on the characteristic nature of the soil and the degree of weathering (Amadi *et al.*, 2015). The weathered basement as referred to as regolith. It may be also regarded as saprolith.

It is also referred to as overburden materials, which is considered as any geological material overlying the fresh basement rock. Most times this layer is saturated and permeable and the permeability depends on the interconnected spores within the weathered materials, which gives it its low resistivity characteristic. Most of the wells in the area tap their water from the weathered/regolith aquifer. The final layer is the fresh basement unit. The fractured units are imbedded in contrasting resistivity, which deviates from the resistivity of the unfractured rock unit. These fractures are most times noticed on the resistivity model curves as anomalies at shallow depths of 40 m to 50 m and at advance depth of 70 m to 90 m. The fresh basement rock is characterized by high resistivity values are distinguished from the fractured basement by their high values, which in most cases exceed 1000 Ωm. The thickness of the unweathered and unfractured layer extends to an infinite depth.

The resistivity distribution of the regolith layer in the study area seems to be uniformly distributed with the exception of the western portion of the study area (Figs. 12 and 13). Most hand dug wells within the area are believed to be recharged via this weathered/regolith layer by direct infiltration

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from rainfall. From the contour map it shows that the regolith layers located down stream of Bosso dam display lower resistance range of 0 to 100 Ωm. The portions at the foot of the estates are also indicative of low resistance values. Areas within lower resistivity correspond to high conductivity and are good indicators of high groundwater potential.

From the isopach map of regolith thickness (Fig. 14), the thickness of the regolith layer is more pronounced at the western, northwestern and southern part of the study area. This corresponds to the isoresistivity map of the study area. Better chances for groundwater potential are attributed to areas that are indicative of thicker regoliths layer. Crystalline rocks (igneous and metamorphic) do not have primary porosity and permeability. Rather they develop secondary porosity and permeability when it undergoes weathering and fracturing. The joint directions measured during the fieldwork were used to construct a rosset diagram (Fig. 4). The principal joint direction of SE-NW was obtained which is in agreement with the regional joint direction of the area as well as isoresistivity and isopach maps obtained. It further confirms the findings that groundwater flows from the north (recharge) to the southern portion of the study area (discharge) and the display of comparatively low resistivity value and deeper overburden are signatures for good groundwater potentials.

Conclusion

Groundwater Potential evaluation using geological, hydrogeological and geophysical techniques has been carried out in part of Minna. The 1-dimensional Schlumberger array was used for the subsurface investigation. Maximum AB/2 of 100 m was established in quadrant within the mapped area and a total of fifty VES stations were established. Three major lithologic units were identified from the geoelectric sections, these include; the unsaturated top soil which comprises of lateritic-clay, the weathered/fractured layer and the fresh basement layer. The rock types in the study area are basically granite, schist and gneiss, displaying various degrees of foliation, weathering and fracturing. The principal joint direction in the area is NW-SE direction. Groundwater in the area is recharged by rainfall and flows from south to north, with the northern portion serving as recharge zones and the southern portion as discharge areas. From the isoresistivity and isopach maps, the northwest and southern portion of the study area holds high potential for groundwater storage due to the display of comparably low resistivity value and deeper overburden thickness. Static water level measurements were collected from 80 hand dug wells in the area and the values used to plot the groundwater flow map. Hand dug wells in the area are to be terminated within the regoliths/weathered basement units of the area within the depth range of 2.5 m to 12 m, while the boreholes are to be terminated between 60 m and 100 m depending on the location. Future borehole to be drilled in the area should not be less than 60 m, and the borehole should be properly monitored and developed by a certified hydrogeologist in order to avoid failure and ensure maximum yield from the deeper aquifers in the area.

References

Ajibade, A. C. (1982). The origin of the Older Granites of Nigeria: some evidence from the Zungeru region. *Nigerian Journal of Mining and Geology*, 19, 223-230.

Ajibade, A. C. (1989). Provisional Classification of the Schist Belts of North-western Nigeria. In Kogbe, C.A. (ed.) *Geology of Nigeria. 2nd Edition. Rockview International, Jos*. pp. 85-90.

Akintorinwa, O. J. & Adenusi, F. A. (2009). Integration of Geophysical and Geotechnical Investigations for a Proposed Lecture Room Complex at the Federal University of Technology, Akure, SW, Nigeria. *Ozean Journal of Applied Sciences* 2(3), 241-254.

Alao D. A., Amadi A. N., Adeoye, Yinka and Oladipo, A. V., (2013). Geo-Electric and 3D-Imaging of Groundwater

Distribution along Flood Plain Deposits of River Niger at Jebba, North-Central Nigeria. *Environment and Natural Resources Research*, 3(2), 61-68.

Amadi, A. N., (2010). Hydrogeological and geophysical study of Bosso area of Minna, North-Central Nigeria. *Bayero Journal of Physics and Mathematical Sciences*, 3(1), 66–73.

Amadi, A. N. and Olasehinde, P. I. (2010). Application of remote sensing techniques in hydrogeological mapping of parts of Bosso Area, Minna, North-Central Nigeria. *International Journal of Physical Sciences*, 5(9), 1465 – 1474.

Amadi, A. N., Nwankwoala, H. O., Olasehinde, P. I., Okoye, N. O., Okunlola, I. A. & Alkali, Y. B. (2012). Investigation of aquifer quality in Bonny Island, Eastern Niger Delta, Nigeria using geophysical and geochemical techniques. *Journal of Emerging Trends in Engineering and Applied Sciences*, (1), 180-184.

Amadi, A. N., Ameh, M. I., Idris-Nda, A., Okoye, N. O. and Ejiofor, C. I., (2013). Geological and Geophysical Investigation of Groundwater in parts of Paiko, Sheet 185, North-Central Nigeria. *International Journal of Engineering Research and Development*, 6(1), 1 – 8.

Amadi, A.N., Olasehinde, P.I. and Nwankwoala, H.O. (2014). Hydrogeochemistry and statistical analysis of Benin Formation in Eastern Niger Delta, Nigeria. *International Research Journal of Pure and Applied Chemistry*, 4(3), 327 – 338.

Amadi A.N., Olasehinde P.I., Jimoh M.O., Okoye N.O. and Aminu Tukur, (2015). Integrated Hydrogeological and Hydrogeophysical Exploration for Groundwater in parts of Gidan- Kwano and Gidan-Mangoro, North-central Nigeria. *Universal Journal of Geoscience*, 3(1), 34 – 38, doi: 10.13189/ujg.2015.030104.

Anudu, G. K., Obrike, S. E., & Onubo, L. N. (2011). Geoelectrical sounding for groundwater exploration in the crystalline basement terrain around Onupe and adjoining areas, South-western Nigeria. *International Journal of Chemical Sciences 1:296-301.*

Aweto, K. E. (2012). Delineation of fractured zones in crystalline basement rocks by direct current electrical resistivity method in Oke-Ila area southwestern Nigeria. *Indian Journal of Science and Technology*, 5(7), 53-70.

McCurry, P.(1976). The geology of the Precambrian to Lower Palaeozoic Rocks of Northern Nigeria– A Review. In: Kogbe CA (ed) Geology of Nigeria. Elizabethan Publishers, Lagos,pp 15–39.

Mohammed, M. Z. & Olorunfemi, M. O. (2008). Geoelectric investigation of the sedimentary/basement transition zone of parts of River Jama'are floodplain in the western Chad Basin, northeastern Nigeria. *Journals of Science Research Annals*, 3(2), 44-59.

Muraina, Z. M., Thompson, H. T. & Adedamola, T. F. (2012). Electrical resistivity survey for subsurface delineation and evaluation of groundwater potential of Araromi Akungba-Akoko, Ondo State southwestern Nigeria. *Journal of Environmental and Earth Sciences*, 2(7(, 28-41.

Obaje, N. G., (2009). Updates on Geology and Mineral Resources of Nigeria. Onaivi Printing and Publishing Co LTD, Abuja, Nigeria, 213p.

Offodile, M. E. (2002). Groundwater study and development in Nigeria. *Mecon Geology and Engineering Service Limited*, Jos, Nigeria, (2nd Ed.), 239-244.

Olasehinde, P. I. & Awojobi, M. O. (2004). Geological and Geophysical Evidences of a North South Fracture System, East and West of the Upper Gwiara River in Central Nigeria. *Water Resources*, 15, 33-38.

Olasehinde P. I., Amadi A. N., Idris-Nda, A., Katu, M. J., Unuevho, C. I. and Jimoh M.

O., (2015). Aquifers Characterization in Agaie, North-Central Nigeria using Electrical Resistivity Method and Borehole Lithologs, *American Journal of Environmental Protection,* 3(3), 60 – 66, doi:10.12691/env-3-3-1.

Osumeje, J. O. & Kudamnya, E. A. (2014). Hydro-geophysical investigation using seismic refraction tomography to study the groundwater potential of Ahmadu Bello University main campus, with the basement complex of northern Nigeria. *Journal of Environmental and Earth Sciences*, 4(2), 15-23.

AMADI A.N. DEPT. OF GEOLOGY