IOSR Journal of Applied Geology and Geophysics (IOSR-JAGG)
e-ISSN: 2321–0990, p-ISSN: 2321–0982.Volume 2, Issue 2 Ver. I. (Mar-Apr. 2014), PP 44-54
www.iosrjournals.org

Surface Resistivity Survey for Siting Shallow Boreholes within The 1000 Housing Estate, Maiduguri, Northeast Nigeria.

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Abstract: *Twenty five resistivity data points were sounded in the study area with an ABEM Terrameter. Maximum electric current half spacing attained for each point was 100 m. The raw data were interpreted with IX1D software. The X, Y, Z data file was imported into Surfer9 software for resistivity mapping and contouring using kriging interpolation algorithm. Isopach closures of the surface layer trend along NNE – SSW and NE – SW directions. The iso-ohmic map of the layer depicts compositions of sands, sands/gravels, and gravels. Thickness of the second layer ranges from 1 - 21 m and its resistivity values suggest sediments of argillaceous and arenaceous composition. The third layer isopach map indicates that sediments of intermediate values are sandwiched and partly sandwiched by thinner ones. Iso-ohmic map of the layer has clay lenses within sandy constituents. Isopach map of the fourth layer shows majority of the thinner sediments occurring along the west to the south directions. Thicker sediments are located at the northeast. Clayey fractions are situated at the western and north easternmost parts, while sandy ones occur from the south to the north. Iso-ohmic map of the fifth layer indicates patches of arenaceous sediments within argillaceous types. The significance of the surface layer sediments is that they aid infiltration of rainwater into the underlying layers. Percentage of clay matrix in the second resistivity sequence and its proximity to the surface may hamper accumulation of groundwater. By virtue of their stratigraphic positions, thicknesses, lateral continuity and compositions the third and fourth layers are suitable targets for shallow aquifer boreholes' location.*

Keywords*: Aquifer, borehole, isopach map, iso-ohmic map, lithology*

I. Introduction

One of the world's most essential resources is water. It is vital for plants and animal alike and plays significant roles in advancing civilization. Where it is readily available one hardly notices its importance until the day it disappears. Depending on environment water could be renewed through precipitation, melting, infiltration and percolation. It occurs on the surface and the subsurface. Surface water though diverse, may be absent in certain areas due to geological peculiarities and, when and where present, may be of limited use due to pollution. As a result of pollution, complicated by problems of industrialization and burgeoning world population, the pressure on surface water resources has necessitated the search and exploration of groundwater resources. The occurrence, movement and storage of groundwater are influence by the lithology, thickness and structure of rock units.

The search for groundwater is being conducted using high accuracy equipments and techniques that provide indirect indication of groundwater, so that underground hydrologic data could be inferred from the subsurface data. Resistivity sounding technique is one of such methods which furnish information on water bearing structures by determining the vertical variation of the subsurface electrical properties which is related to the geology of the area.

II. Study area

The area is situated in Maiduguri metropolitan area in north eastern Nigeria between latitudes 11°48' - 11°55' N and longitudes 13°04' E - 13°14' E (Fig. 1).

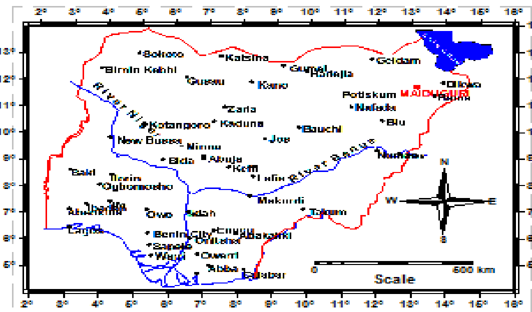


Fig. 1 Map of Nigeria showing location of the study area

Maiduguri area lies in a semi arid zone of long dry season from October to April and short rainy season that lasts from May to September. Rainfall is generally low, averaging 405 mm. The temperature ranges from 24° - 40° C and more during the months of April to June. The temperature may drop below 27° C on cloudless nights. Dry dusty harmattan blows off the desert during the months of December to February. Evaporation is about 1600 mm. Maximum precipitation is from 650 - 700 mm. Effective precipitation is appreciably preceded by high rate of evaporation.

The area is characterized by Sahel Savannah vegetation which consists of short grasses and shrubs. The trees are few and scattered; the grasses often dry up and the trees shed off their leaves during dry seasons. The estate area is relatively flat and is situated on the Chad Basin sediments. The soil is brownish in colour and consists of clay, sand and gravels. In recent time the area has not experience any major geologic event.

The present work is aimed at determining optimal drilling sites for shallow (upper) aquifer boreholes using the vertical resistivity sounding (VES) technique. It is conceived that the maximum current electric separation of 100 m adopted during the survey should be adequate to achieve the desired depths of the boreholes.

III. Geology of the study area

The area is underlain by sediments of the Chad Formation (Fig. 2). The Chad Formation overlies the Kerri Kerri Formation of Tertiary period and it is overlain by recent alluvial deposits [1]. These sediments were deposited during the end of the Cretaceous period and the beginning of the Tertiary period. The formation covers an area of about 23,000 km^2 in parts of Bauchi, Borno, Jigawa, Kano and Yobe States in Nigeria.

The sediments which were deposited by turbulent current are poorly sorted. They vary in grain size and colour; finer grains exhibiting fluviatile depositional patterns were deposited at low velocity.

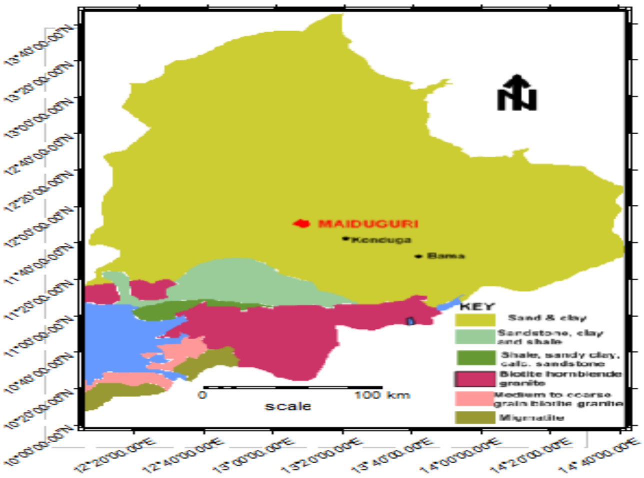


Fig. 2 Geology map of part of Borno State showing the study area

Deposition of the Chad Formation occurred after the regression of the sea southwards at the end of Cretaceous time [2]. Wells and boreholes in Maiduguri revealed three distinct zones of sandy sediments separated by clay deposits. Logs from boreholes' sediments vary both laterally and vertically. The sandy sediments were laid as Lake Margin deposits or as alluvial fans and deltas.

IV. Hydrogeology of the Chad Formation

In the Chad Formation groundwater occurs mainly within three aquifer zones. The lower aquifer is encountered at depth of 420 – 650 m. Not much is known about the recharge to this aquifer but it is assumed to be far from the study area. The middle aquifer is a widely spread and best developed confined aquifer in the Nigerian sector of the Chad Basin. It has a surface area in excess of 50,000 km^2. Its depth ranges from 200 - 350 m. It consists essentially of sands and gravels with silts and clays intercalations. Recharge to the aquifer occurs horizontally around the ridge of rocky areas fringing the Chad Basin and by vertical percolation from the Bama Ridge area. The upper aquifer consists of three zones around Maiduguri area. These zones are referred to as A, B, and C and are encountered from 10 – 40 m, 40 – 70 m and 78 – 99 m respectively below the ground surface. Recharge to this aquifer system occurs through vertical infiltration of rain water and seepage along rivers and streams.

V. Methodology

Resistivity raw data were acquired with an ABEM Terrameter SAS 300 C. A direct current I_{AB} was transmitted into the ground through two electrodes (A, B), while the difference of potential V_{MN} produced by the circulation of current into the geological layers was measured with two other electrodes (M, N). The current and the potential measurements were then used to calculate the apparent resistivity of the subsurface materials. The ground was assumed to compose of horizontal layers [3] and [4]. The transmitting A and B electrodes were successively moved away from each other at each new reading to increase the depth of investigation. As the time necessary to move from one position to the next one becomes longer and longer for deep investigations, a significant time was spent to stack the signal so as to improve the quality of the reading.

For linear symmetry array of the electrodes (AMNB), the apparent resistivity (ρ_a) was calculated using [5] formula:

$$\rho_a = \pi \frac{AMAN}{MN} \frac{V}{I} \qquad (1)$$

where,
V is the measured potential difference and I is the current.

At every stations, the maximum electric current half spacing (AB/2) attained was 100 m. Location of a particular VES point was predetermined by the space available to achieve the desire maximum separation. The numbers of stations sited were 25 (Fig. 3) which is considered adequate for detailed investigation of the area. The apparent resistivity data were plotted against electrode spacing on log-log scales. These produced smooth segmented curves.

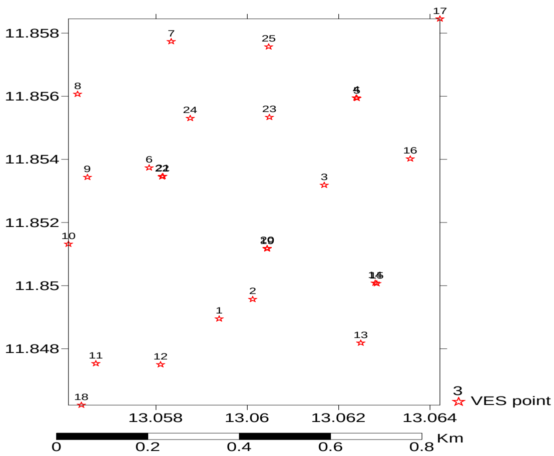


Fig. 3 VES points in the study area

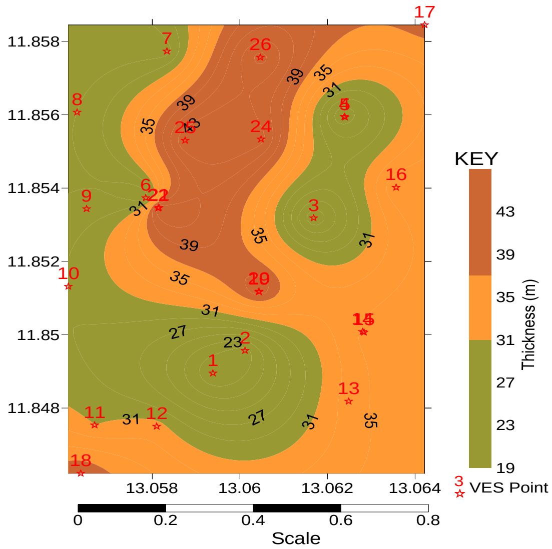
A computer software [6] developed by Interpex Limited was used to properly interpret the field curves. The software allows for forward and inverse modeling of resistivity data. While entering the field data, the AB/2 values were entered first and the apparent resistivity values next. The AB/2 values were entered in ascending order; one segment following another. Each segment is a set of AB/2 values used with constant MN/2 values, which are constant for each segment. When the interpretation was completed, plots of the calculated layers thickness and resistivity values, error closure statistics and geoelectrical parameters and geoelectrical sections were displayed.

The X, Y, Z irregularly spaced data file was imported into [7] software for resistivity mapping and contouring using simple kriging interpolation algorithm.

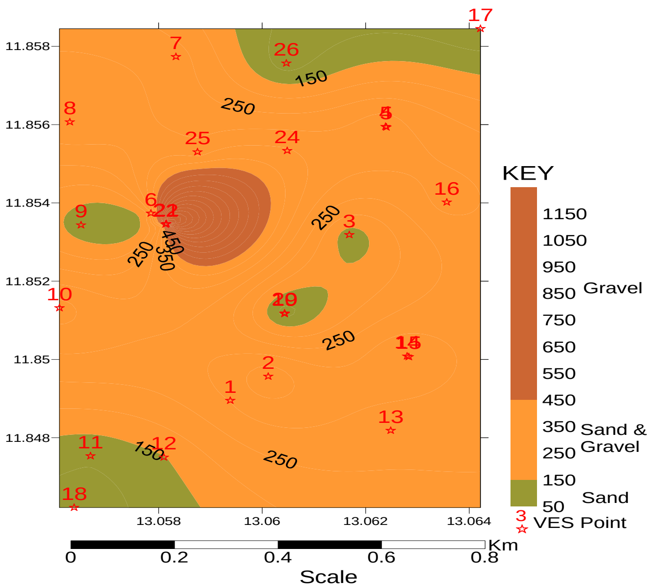
VI. Description of the resistivity maps

6.1 Surface layer resistivity maps

Thickness of the surface layer shown in Fig. 4a varies between 1.9 and 4.8 m. Thinner sediments are located at the west and part of the northeast along VES points 3 and 6 and trends more or less along the NNE – SSW direction. Sediments of intermediate thickness occupy three quarter of the area. These sediments partly enclosed those of higher values from the north to the centre and sandwiched those with lower values at the northeast. Thicker sediments are observed at the northern to the central parts and trend along the NE – SW direction. Iso-ohmic map of the surface resistivity layer in Fig. 4b shows the superficial sediments to consisting of sand, sand/gravel, and gravel. Sand occurs at the northeast, west, centre and southwest. Sand/gravel occupies more than ninety five percent of the area. Gravel constituents are located at the central region around the VES point 25.



(4a) Isopach map of the surface resistivity layer

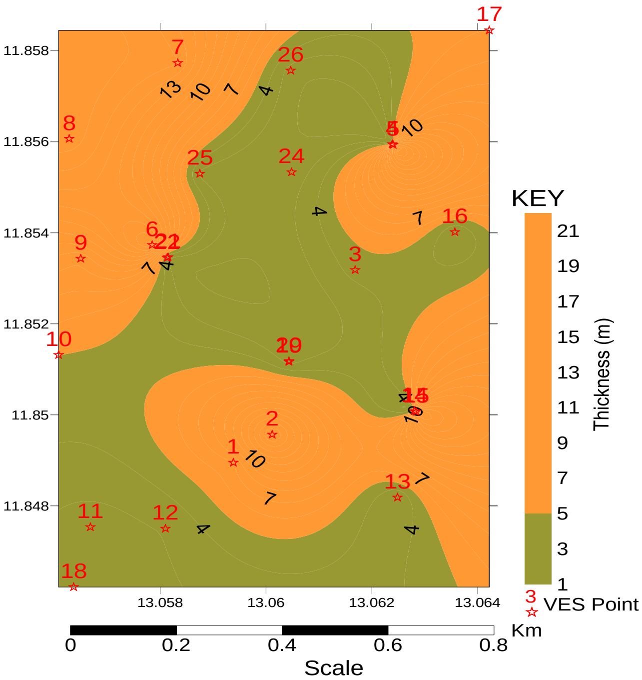


(4b) Iso-ohmic map of the surface resistivity layer

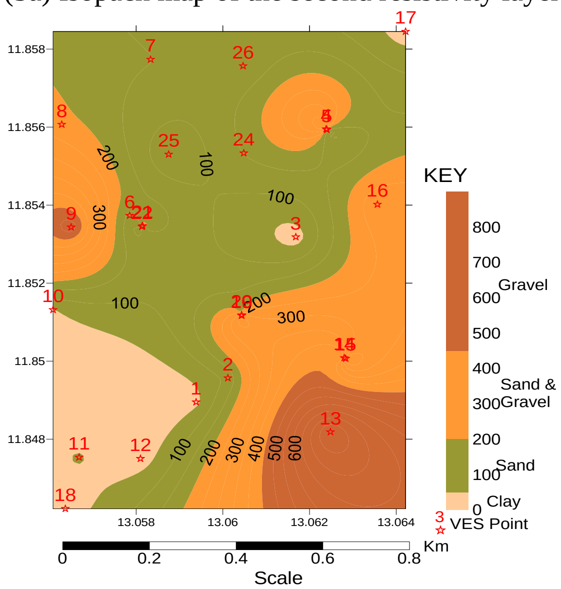
Fig. 4 Surface layer resistivity maps

6.2 Second layer resistivity maps

Thickness of the second resistivity layer is shown in Fig. 5a. The thickness of the unit ranges from 1 – 21 m. Sediments lower than 5 m thick occur in isolation at the northwest, northeast and southeast. These closures are separated by the sediments that exceed 5 m thick. Iso-ohmic map in Fig. 5b gives range of resistivity values from approximately 0 - 1000 ohm-m, which depict that the layer consists of argillaceous and arenaceous materials. Lower resistivity values that constitute clayey materials occupy the southwest and smaller portions of the central and extreme northeastern regions. Sand/gravel materials occur in patches within sandy fractions at the northeast. The same sediments partly engulfed gravels along the NW – SE direction at the northwest and partly sandwiched gravelly constituents at the east to the southeast. Gravels are bounded to a small portion of the northwest and a greater part of the southeast.



(5a) Isopach map of the second resistivity layer

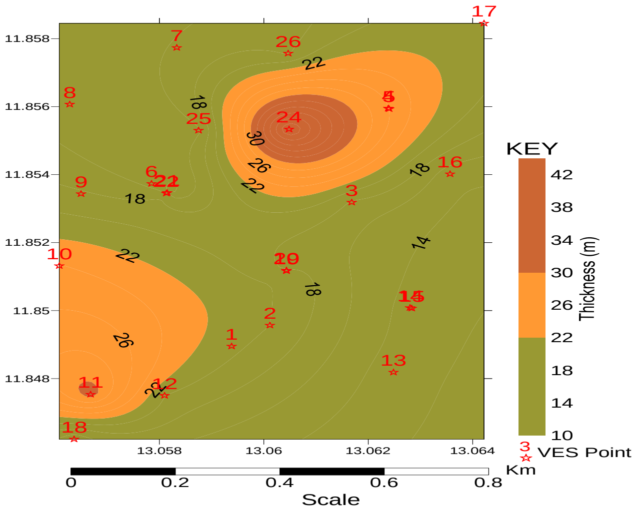


(5b) Iso-ohmic map of the second resistivity layer

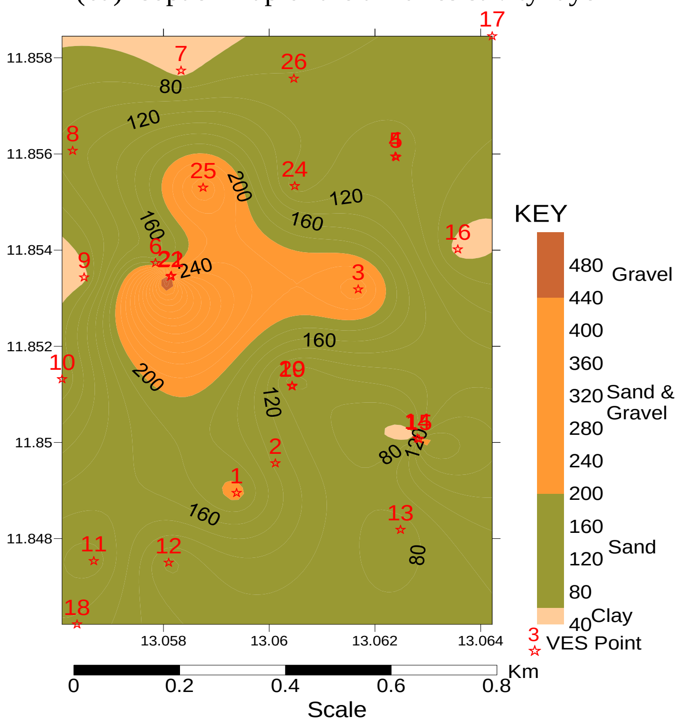
Fig.5 Second layer resistivity maps

6.3 Third layer resistivity maps

Fig. 6a is an isopach map of the third resistivity layer. The thickness ranges from 10 – 43 m. Sediments thickness of 10 – 22 m occupy about ninety percent of the area. Such sediments enclosed other sediments with lesser thicknesses at the northeast and southwest. Sediments of intermediate thickness (22 - 30 m) are sandwiched by thinner ones at the northeast and are partly sandwiched by the same sediments at the southwest. Sediments with thickness of 30 m and above are limited only to the north central part and are engulfed by thinner and intermediate thickness sediments. Within this layer clay fractions occur in patches in the northwest, west and east around VES point 4. Iso-ohmic map of the layer shows its resistivity values ranging from 40 – 400 m (Fig. 6b). Clay, sand, sand/gravel and gravel materials make up the unit. Clay occurs in smaller patches within sandy sequence. Sands cover more than ninety five percent of the area. Gravel materials are negligibly present as only a small pocket is observed at the south central area.



(6a) Isopach map of the third resistivity layer

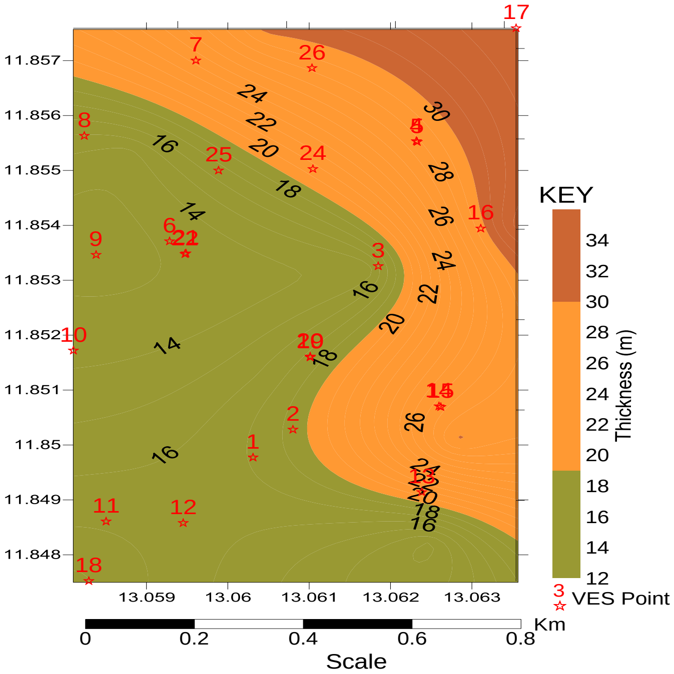


(6b) Iso-ohmic map of the third resistivity layer

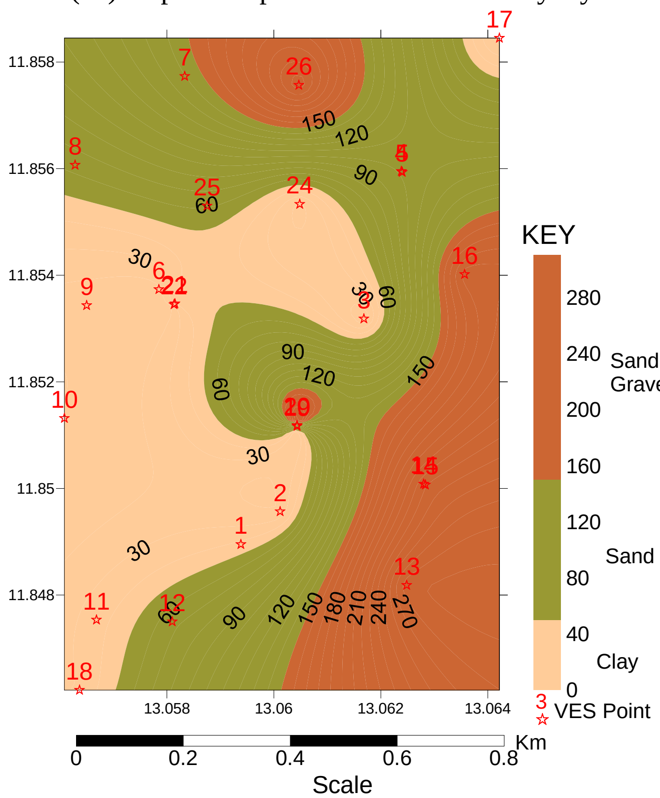
Fig. 6 Third layer resistivity maps

6.4 Fourth layer resistivity maps

Fig. 7a shows the isopach map of the fourth resistivity layer. The layer is generally thick, ranging from 12 – 35 m. Majority of thinner sediments is found along the west towards the south. Towards the north of the thinner sediments are those of intermediate values that range from 1 – 30 m. Thicker sediments are located at the northeast and occupy a small area. Iso-resistivity map of the horizon is given in Fig. 7b. The layer consists of clayey, sandy and sandy/gravelly constituents. Clay materials are located at the western and extreme northeastern parts. Sands occur along the south towards the north. At the northernmost part of the map, the sands partly sandwiched sands/gravels in the sequence. The sands/gravels are located at the north and southeast edges.



(7a) Isopach map of the fourth resistivity layer



(7b) Iso-ohmic map of the fourth resistivity layer

Fig. 7 Fourth layer resistivity maps

6.5 Fifth layer resistivity map

Iso-ohmic map of the fifth resistivity layer given in Fig. 8 may not give a clear situation of the subsurface sediments as only few VES points penetrated into it. The unit is characterized by argillaceous and arenaceous sediments. Argillaceous sediments are predominant in the stratigraphy. Their resistivity values range from 10 – 40 ohm-m. Arenaceous sediments occur in patches within argillaceous ones in the east and northwest. The resistivity values of the arenaceous deposit vary from 40 – 52 ohm-m.

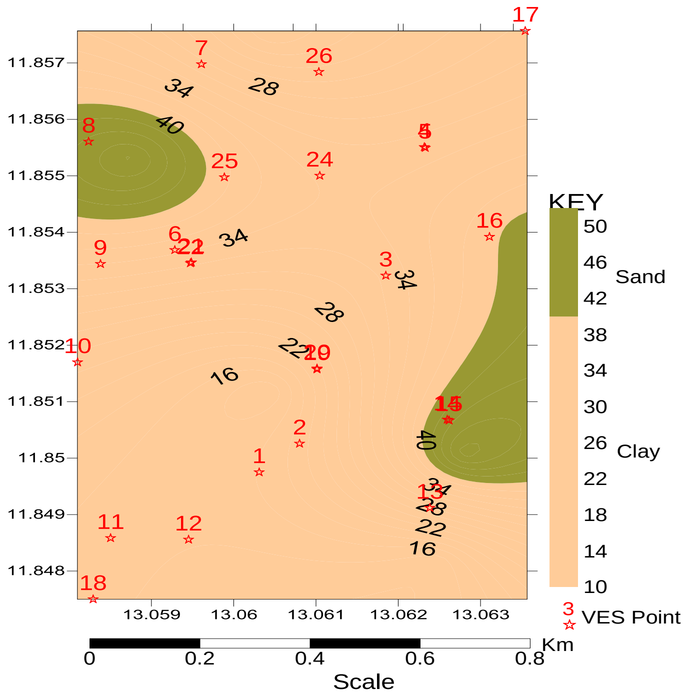


Fig. 8 Fifth layer resistivity map

VII. Resistivity profiles

Three resistivity profiles were drawn along AA', BB' and CC" (Fig. 9) so as to provide a clear understanding on the vertical variation of the resistivity layers in the study area.

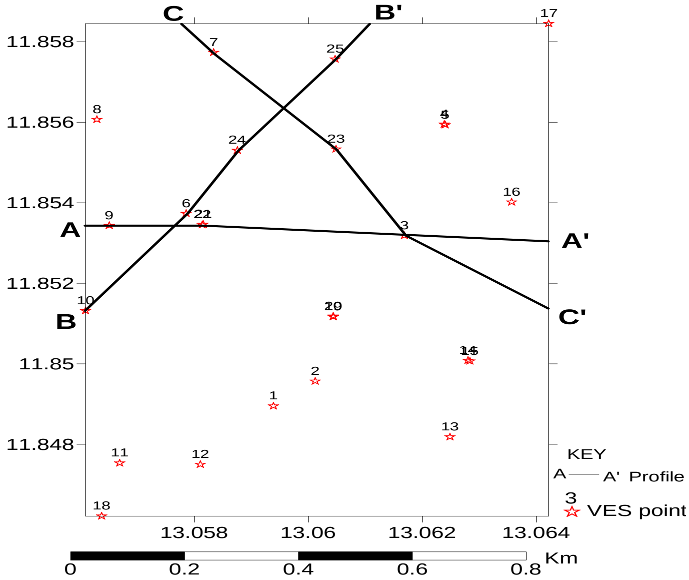


Fig. 9 Geologic profiles along AA', BB' and CC'

7.1 Resistivity profile along AA'

Resistivity profile AA' shown in Fig. 10 runs from West – East through three VES points at the central region of the area. The first, second and third resistivity units were encountered along the three VES points. The fourth resistivity unit is however absent along VES point 9. The surface layer is thin. Its resistivity values depict those of arenaceous materials. Layer two is thicker along VES point 9 but thinner along VES point 22. Along VES point 3, the resistivity unit consists mainly of gravels. The third resistivity layer is laterally continuous along the three VES points. It has a thickness of about 14 m. Its compositions vary from those of clay sands along VES point 22 to coarse sands and gravels along VES points 9 and 3 respectively. The complete thickness of the unit was not penetrated along VES point 9. The fourth resistivity unit was observed along VES points 22 and 3 only. Argillaceous materials constitute the main sediments of the unit. These materials act as barriers to groundwater losses into the underlying unit. Limiting boreholes to this horizon especially along VES points 22 and 3 should be discouraged as the available water in the sequence is likely to affect the yield of the borehole during dry seasons.

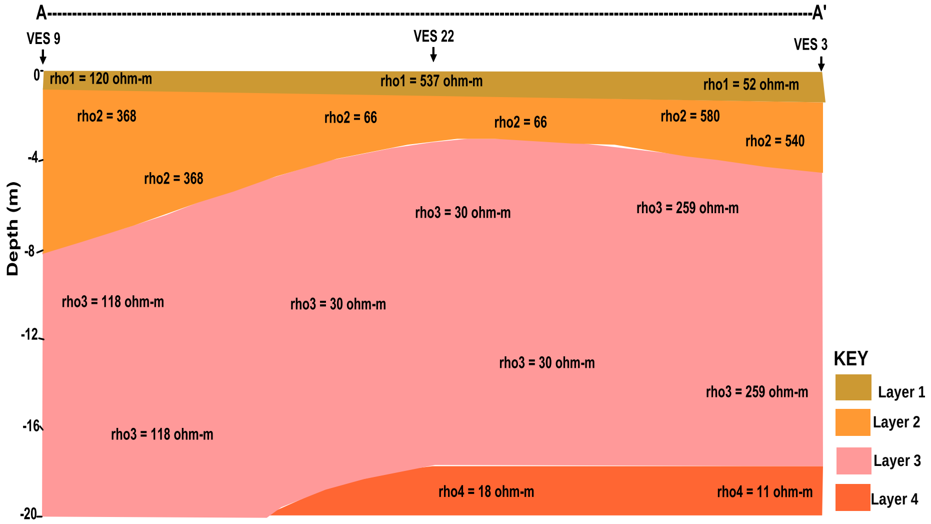


Fig. 10 Resistivity profile along AA'

7.2 Resistivity profile along BB'

Along all the VES points of BB' profile shown in Fig. 11, four resistivity layers were encountered. The surface layer is thin. Its resistivity values portray those of sands and gravels, except along VES point 21 where it is mainly argillaceous. The second resistivity unit is also thin, however, depression along VES point 6, makes the thickness suitable for groundwater reservoir. The sediments along VES point 25 are argillaceous in character. Thickening of the second layer along VES point 6 affects the thickness of the third layer that underlies it directly. The constituents of the third horizon are those of sands and gravels. The unit along VES points 10, 24 and 25 is moderately thick. Complete thickness of the fourth resistivity layer was not defined along the four VES points; however, it is envisaged to be higher than 10 m. Arenaceous materials form the main constituents of the horizon.

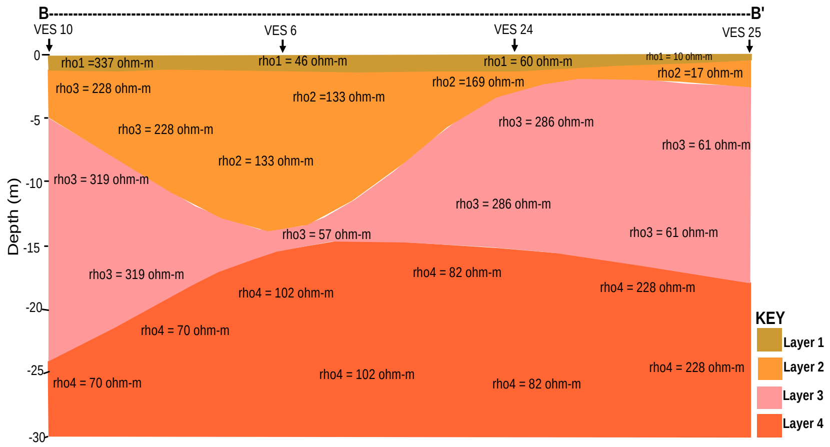


Fig. 11 Resistivity profile along BB'

7.3 Resistivity profile along CC'

The first layer of this profile is thin. Composition of the layer is essentially areanaceous except along VES point 13 where argillaceous sediments prevail (Fig. 12). The second layer is also thin, except along VES point 13, where it attains thickness of over 14 m. Its composition is dominantly argillaceous. Gravelly materials are the chief constituents of the third resistivity layer. These materials attain thickness of over 40 m. The fourth resistivity layer was not observed along VES point 13, but occurs along other VES points. The horizon is made up of sandy and gravelly materials whose complete thickness was not revealed along VES points 3, 23 and 7.

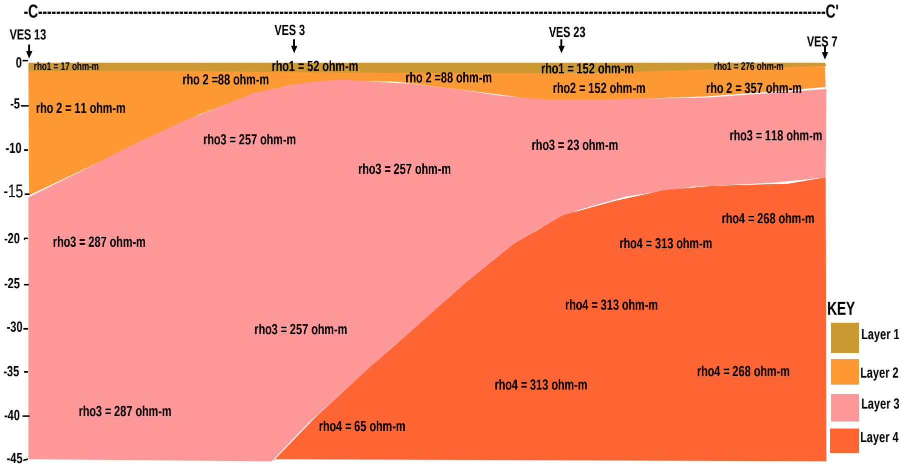


Fig. 12 Resistivity profile along CC'

VIII. Hydrogeological importance of the resistivity layers and profiles

The significance of the surface layer is that it aids infiltration of rainwater into the underlying sediments. High percentage of clay material in the second resistivity sequence and its nearness to the surface may negate groundwater accumulation [8] and [9] within it. Composition, depth of occurrence and position of the third resistivity layer are favourable for shallow aquifer borehole development. The depth to this unit probably correlates with that of the "A zone" of the upper aquifer system of the Chad Formation given by [10] and [11, 12]. By virtue of the position of the fourth resistivity layer and arenaceous composition of its sediments, the unit can serve as a shallow aquifer zone for groundwater accumulation. The layer probably forms part of the "B zone" of the upper aquifer system of the Chad Formation. The fifth resistivity unit may be correlated to the lower part of the "B zone" of the same formation. Arenaceous parts of the unit may serve as recharge windows to the "C zone" of the same aquifer.

The three resistivity profiles of the second resistivity layer also suggest that the surface resistivity layer aids vertical infiltration of surface water into the underlying sediments. Composition of the second resistivity layer of AA' profile makes it a recharge source only because of its closeness to the surface. Depression of the second resistivity unit along VES point 6 of profile BB', indicates suitable condition for groundwater reservoir, however, the zone is localized and therefore it is unlikely to serve as a groundwater source. Since composition of the second resistivity layer of the CC profile is dominantly argillaceous, the horizon is unsuitable for water well development. Productive shallow borehole development is brighter around VES points 13 and 3, due to their lithological characteristics and thickness which measures over 40 m.

The third resistivity layer of AA' occurs at a depth that can favour groundwater abstraction. The entire thickness of the unit was not penetrated along VES point 9, which is an additional advantage towards borehole siting. The argillceous materials that constitute the main sediments of the unit along VES point 22 serve as barriers to losses of groundwater into the underlying units. Limiting boreholes to this horizon especially along VES points 22 and 3 should be discouraged as the available water is likely to be affect during adverse periods. The thickness of the third resistivity layer of profile BB' along VES points 10, 24 and 25, offers suitable conditions for borehole siting. Gravelly materials that dominate the same unit of profile CC' can readily release water from storage. Good water well is envisaged within vicinity of the fourth resistivity layer of profile AA' due to its lithology, depth of occurrence and estimated thickness of over 10 m. Since the bases of the third and fourth resistivity layers were not determined along VES point 13 for the third layer and VES points 3, 23 and 7 for the fourth layer of profile CC', there are clear indications that they are thicker than estimated. The bottom of the fourth resistivity layer was not observed from profile AA', which is an indication of a thicker unit. By virtue of its subsurface position, lithology and thickness, boreholes located within the fourth resistivity layer along the three profiles are foreseen to be productive throughout the year.

IX. Conclusion

The occurrence of groundwater is limited to the aquiferous horizons which consist of arenaceous materials. By this groundwater may be found around such areas where these deposits occur within favourable depths. However, there must be adequate thickness and lateral continuity of the deposits to provide good groundwater reservoir. These conditions which are achieved by the depths of occurrence, lithologic compositions and thicknesses of the third and fourth resistivity successions may serve as groundwater targets in the area. Under special condition the second layer may serve as an aquifer too, but seasonal variations may have effect on the yield due to its proximity to the surface. The results revealed that shallow aquifer boreholes may be drilled to depths of 20 – 50 m. At shallower depths the groundwater in such water wells may fluctuate during the usual prolong dry season.

References

[1] W. Barber, Pressure water in the Chad Formation of Borno and Dikwa emirates, North East Nigeria. Geological Survey of Nigeria, Bulletin 35, 1965, 138 p.
[2] W. Barber and D. G.Jones, The geology and hydrogeology of Maiduguri. Geological Survey of Nigeria, Records, 1960, 20 p.
[3] B. B. Bhattacharyya and M. K. Sen, Depth of investigation of colinear electrode array over homogeneous anisotropic half - space in direct current methods, Geophysics 46, 1981, 625 - 780.
[4] J. Bernard, Short notes on the depth of penetration of electrical methods. www.iris-instruments.com . 2003.
[5] J. Gruntorad, and M. Karous, Geoelectrical methods. in M. D. Stanislav, (Ed), Introduction to applied geophysics. Reidal Publishing Company, (Dordrecht, Holland, 1984), 263 - 387.
[6] IX1D, Shareware package for windows 9x, Interpex Limited, Golden Colorado, USA, 2002.
[7] Surfer9, Surface Mapping System. Thematic Mapping System. Golden Software Inc. Golden, Colorado. www.goldensoftware.com, 2009.
[8] E. T. Okhue, and M. O. Olorunfemi, Electrical resistivity investigation of a typical basement complex area: The Obafemi Awolowo campus case study. Journal of Mining and Geology. Nigerian Mining and Geosciences Society, 27, 1991, 63 – 69.
[9] M. A. Dan-Hassan and M. O. Olorunfemi, Hydro-Geophysical investigation of a basement terrain in the North Central part of Kaduna State. Journal of Mining and Geology. Nigerian Mining and Geosciences Society, 35(2), 1999, 189 – 205
[10] J. Bumba, H. I. Kida and Z. Bunu, Exploitation of groundwater in the Chad Formation – Maiduguri as a case study, in N. M. Gadzama, F. A. Adeniji, W. S. Richards, and G. G. R. Thambyahphillay, (Eds). Arid Zone Hydrology and Water Resources, (University of Maiduguri Press, 1991), 89 – 97.
[11] S. C. Alkali, Resistivity measurement of the upper aquifer system around Lake Alau area. Water Resources Journal of the Nigerian Association of Hydrogeologists, 6 (1 & 2), 1995, 26 – 30.
[12] S. C. Alkali, Distribution of shallow sediments within the University of Maiduguri campus: Significance in hydrogeology and structural engineering. Borno Journal of Geology, 4(2), 2007, 93 -103.