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ORIGINAL ARTICLE

EVALUATION OF GROUNDWATER POTENTIAL OF CHANCHAGA AREA, MINNA, NORTH-CENTRAL NIGERIA

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ABSTRACT

Background: Inadequate potable water supply remains one of the challenges of residents of Minna Metropolis, Niger State, Nigeria owing to the basement complex terrain underlying the area. The rapid increase in population in the area, which is due to its proximity to the nation's capital city (Abuja) among others, has led to a corresponding increase in the demand for potable water for domestic, irrigational and industrial uses which public water by government could not meet. Consequently, the inhabitants resort to seeking alternative arrangements for water through hand dug wells and surface water sources which are often of uncertain quality. **Objectives**: Thus, this study investigates the groundwater potential of Chanchaga area, Minna, North-central Nigeria with a view to delineating the suitable aquifer for groundwater development. **Material and Methods**: The technique employed for this study was Vertical Electrical Sounding (VES) of the Electrical Resistivity (ER) method. A total number of twenty-three (23) Vertical Electrical Sounding (VES) points were investigated using Schlumberger array configuration and the data obtained were analyzed using partial curve matching and computer iteration techniques. The data were interpreted to reveal various geoeletric layers that characterize the area. **Results**: The results revealed predominantly H-type curve typical of the basement complex system with three geoelectric layers: the top soil, weathered/fractured basement and fresh basement. The apparent resistivity of the first layer ranged from 25 Ωm – 928 Ωm with a corresponding thickness of 0.5 m – 3.1 m, second layer has apparent resistivity values of 8.3 Ωm – 41.3 Ωm with a corresponding thickness of 2.1 m – 33.0 m and the third geoelectric layer has apparent resistivity values ranging from 74 Ωm – 4173.5 Ωm with an infinite thickness. A careful examination and integration of the isopach map with the isoresistivity maps (at 30 and 40 metres depths) indicated that the central and northern parts of the study area have very low to low apparent resistivity values and shallow overburden which is capable of constituting shallow aquifer units. **Conclusions:** It is concluded that the central and northern parts of the study area have poor to marginal groundwater potential, and this is supported by the occurrences and concentration of fractures which can constitute weathered/fractured aquifers around these regions. It is recommended that water wells be drilled to an effective depth of 40 to 50 m for optimum groundwater yields, and that pumping test be carried out on the drilled wells in order to further determine the aquifer efficiency and productivity in the area.

Keywords: *Geophysical Investigation, Schlumberger Array, Groundwater Potential, Basement Complex Terrain, Aquifer, Nigeria.*

1. INTRODUCTION

Niger state is one of the 36 federating states in Nigeria with the state capital located in Minna, it has immensely witnessed all round infrastructural developments and a corresponding population growth with an annual population growth rate of 3.4% which is higher than the overall national growth rate of 3.2%. The area has witnessed a high increase in population as a result of its proximity to the nation's capital city, Abuja among others [1]. The increased population has led to rapid increase in the demand for potable water for domestic, irrigational and industrial uses which public water by government could not meet. The consequential effect of the situation is that some inhabitants making alternative arrangements for water through wells and boreholes and others that could not afford that get water of uncertain quality from water vendors in carts and tankers and also from surface water sources. However, available bodies of water on the Earth's surface which include streams, rivers, oceans and lakes are often not very safe for direct consumption due to their exposure to atmospheric pollutants (from natural and anthropogenic sources) and pathogenic organisms that make these water sources not as clean as the groundwater, and this has necessitated subjecting them to chemical treatments before consumption or industrial use. Groundwater, the water held in porous and permeable rocks deep within the earth called aquifers, is relatively pure and grossly protected from surface pollutants perhaps due to their depth of storage and natural filtration through different subsurface layers (soil horizons). Groundwater is enormous and therefore its development is essential to supplement the expensive surface water to relieve stress which population growth often places on water availability and supply.

Many researchers have worked on the groundwater potential of Minna and its environs. Mohammed et al. (2007), in their regional study and investigation for groundwater potential in Minna area, identified Chanchaga as one of the locations in the area with less than the average aquifer's thickness of 24 m [1]. Amadi et al. (2009) worked on the hydrogeology and water quality of southwestern part of Minna and concluded that the water is of good quality and occurs in the regolith and fractured bedrock [2]. Idris-Nda et al. (2013) also conducted a study on the occurrence and chemical composition of groundwater in Minna Metropolis and found that weathering in the granitic bedrock ranges from 3 – 25 m and constitutes the main source of water for shallow dug wells, chemically the water shows a gradual enrichment in manganese, arsenic and lead [3]. The present study therefore investigates the groundwater potential of Chanchaga area in Minna Metropolis, Niger State, using Vertical Electrical Sounding (VES) of the Electrical Resistivity (ER) method. This present study is more detailed than the work of previous workers, and adds to the existing geophysical database for groundwater development activities in Minna area.

1.1 Location of the Study Area

The study area, which covers an area of about 8 square kilometres, is part of Chanchaga Local Government Area of Niger State, North-central Nigeria. It is located between latitudes 9°31'18'' to 9° 34'39''N and longitudes 6° 33'25'' to 6° 35'10''E (Fig. 1). The study area is accessible through the Minna – Paiko road and other unpaved roads that network movement in and out of the city.
The relief of the study area is relatively flat and rocky at the river channel drained by River Chanchaga. Chanchaga area falls within the Guinea Savanna Belt, it is covered with grassland which is basically used for agricultural purposes. The area is also characterized by two climatic seasons, each season lasting for about six months, the total annual rainfall of the area is between 1200 mm in the north to 1600 mm in the south, the dry season begins in November and usually ends in March, the dry season is characterized by the N – E trade wind that blows across the Sahara desert [4]. The mean maximum temperature remains high throughout the year, hovering about 32°C, particularly between March and June, while the lowest temperatures occur usually between the months of December and January during the harmattan period.

1.2 Geology and Hydrogeology of the Study Area

Minna is underlain by rocks belonging to the Basement Complex system of Nigeria, these comprises the migmatite-gneiss complex, the Older Granite and schist belt. The migmatite-gneiss complex is composed of migmatites of various structures and composition but predominantly with tonalitic or amphibolitic paleosome and granitic, pegmatitic or aplitic leucosme [5]. The Older Granite comprises rocks whose texture varies from medium-grained to coarsely-porphyritic; and composition varies from granite to tonalite [5], they form rugged topography and inselbergs. Grant (1978) identified four generations of structures for Kushaka and Birnin Gwari Schist Formation and the Zungeru Mylonite [6]. The field relation shows that the schist belts are intruded and separated by the rocks of migmatite-gneiss complex and granitic rocks [7].
Chanchaga area consists predominantly of granite and schist [8], the granitic unit outcropped in the central and northern parts of the area while the schist is confined to the southern part (Fig. 2). Chanchaga area falls within the crystalline hydrogeological province which is made up of two interconnected aquifers: the weathered overburden aquifer and the fractured basement aquifer. The average thickness of the soft overburden in Minna and its environs is about 15 m [3] and the average yield of borehole in the aquifer is about 0.5 litre per second [9]. The fractured basement formation is the secondary aquifer and the more reliable aquifer in Minna area. An average yield of 1.5 litres per second of borehole yield can be obtained when carefully sited in the fractured zone [1], while optimal yields of up to 5 litres per second can be obtained when a borehole taps water from both aquifers.
The groundwater in the area is primarily recharged by the surface precipitation and by the lateral groundwater movement. The average static water level is between 3 m and 15 m [9].

2. MATERIALS AND METHODS

A total number of twenty three (23) Vertical Electrical Sounding (VES) points were carried out along a grid in the area using the Swedish "Abem" Terrameter SAS 4000. The electrical resistivity configuration employed in the field was Schlumberger array with a maximum half electrode spread AB/2 of 60 m and with a maximum electrode potential separation MN/2 which was maintained between 0.5 m, 2.5 m and 7.5 m for the first, second and third layers respectively.
Electrical current (10 mA – 20 mA) 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, to give the apparent resistivity values (Ωm) which are the resistivity values in homogenous earth. 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 complete/partial curve matching and computer iteration technique, a computer programme based on linear filter theory [10], with the aid of the windows compatible WinResist software.

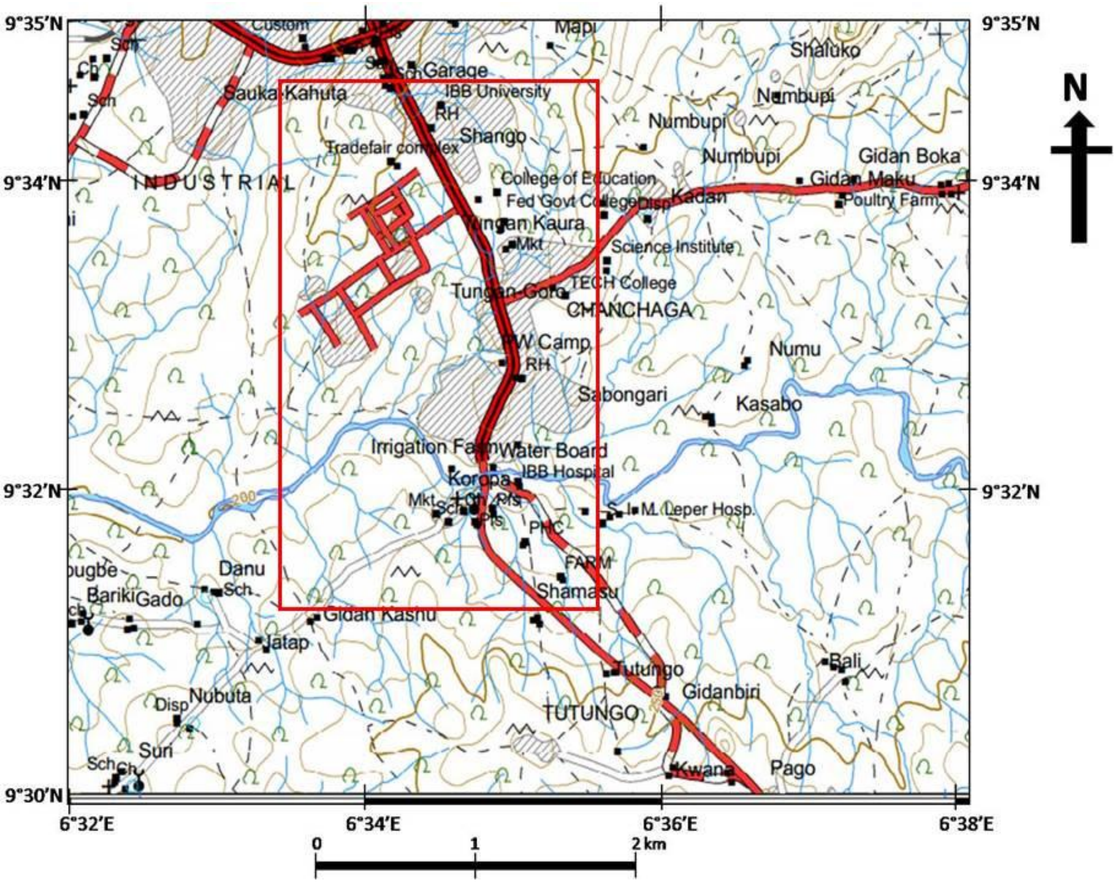

Figure 1: The figure presents the topographic map of Chanchaga area (Modified from South-west of Minna Sheet 164).

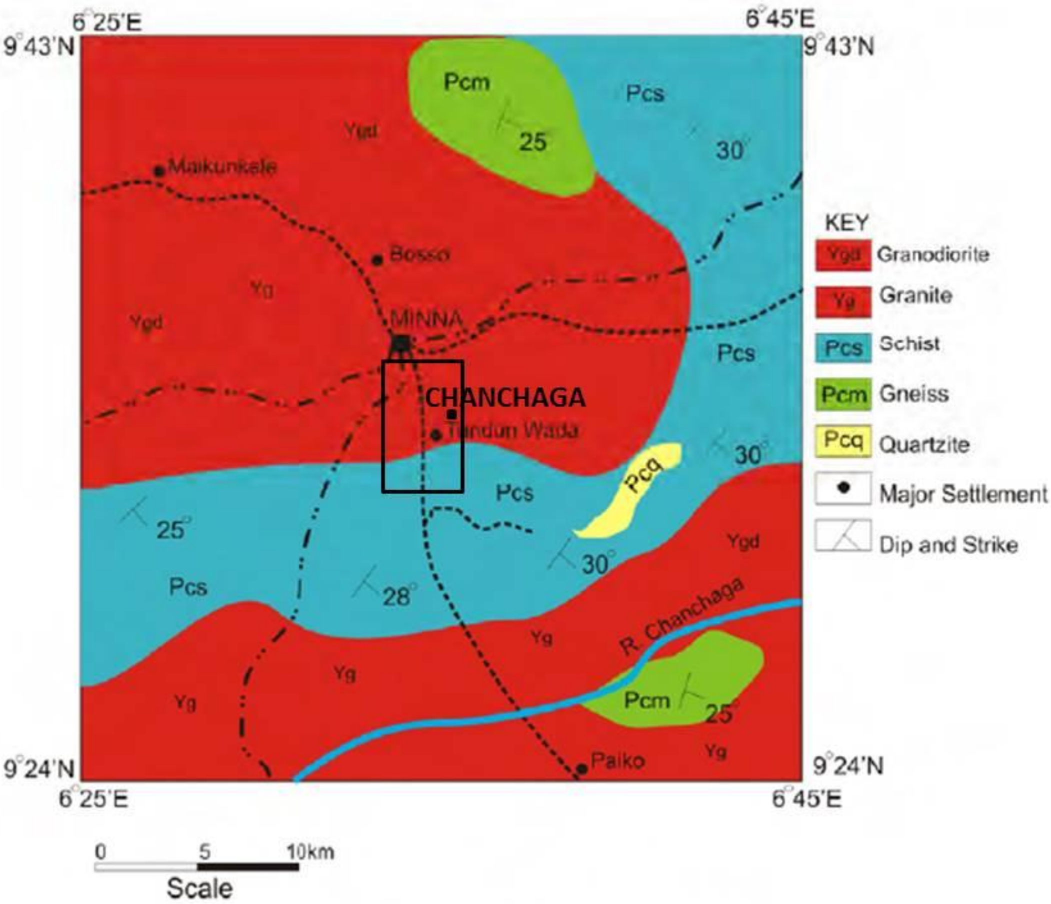

Figure 2: Figure presents the geological map of Minna area showing the study area [8].

3. RESULTS

The summary of the data obtained is shown in Table 1 while Figures 3 - 6 show a summary of the interpretations of representative curves of the VES points in the study area. The data set were contoured to produce iso-resistivity maps and isopach maps in order to show the variation of resistivity on a constant plane across the study area (iso-resistivity) and to show the thickness of the overburden (isopach) respectively. The contouring software, Surfer 10, was employed in this work to produce a series of three-dimensional depth maps at the study area such as the isopach (Figure 7), and iso-resistivity maps at 30 m and 40 m depths (Figures 8a and b).

Table 1: Table presents the data presentation for Vertical Electrical Sounding points 1 – 23.

Vertical Electrical Sounding Points	Apparent Resistivities (Ωm)	
	Range	Mean
1	16 – 439	68.4
2	31 – 370	126.63
3	13 – 272	107.06
4	22 – 97	55.27
5	30 – 144	63.06
6	90 – 206	141.44
7	31 – 370	126.63
8	13 – 272	107.06
9	24 – 89	45.94
10	25 – 154	67.13
11	23 – 91	42.69
12	12 - 224	52.81
13	17 – 91	40.56
14	23 – 101	48.31
15	44 – 128	80.63
16	16 – 116	55.6
17	35 – 188	76.13
18	17 – 72	38.13
19	21 – 122	63.53
20	20 – 138	57.4
21	16 – 116	55.6
22	28 – 422	153.69
23	35 – 928	135.13

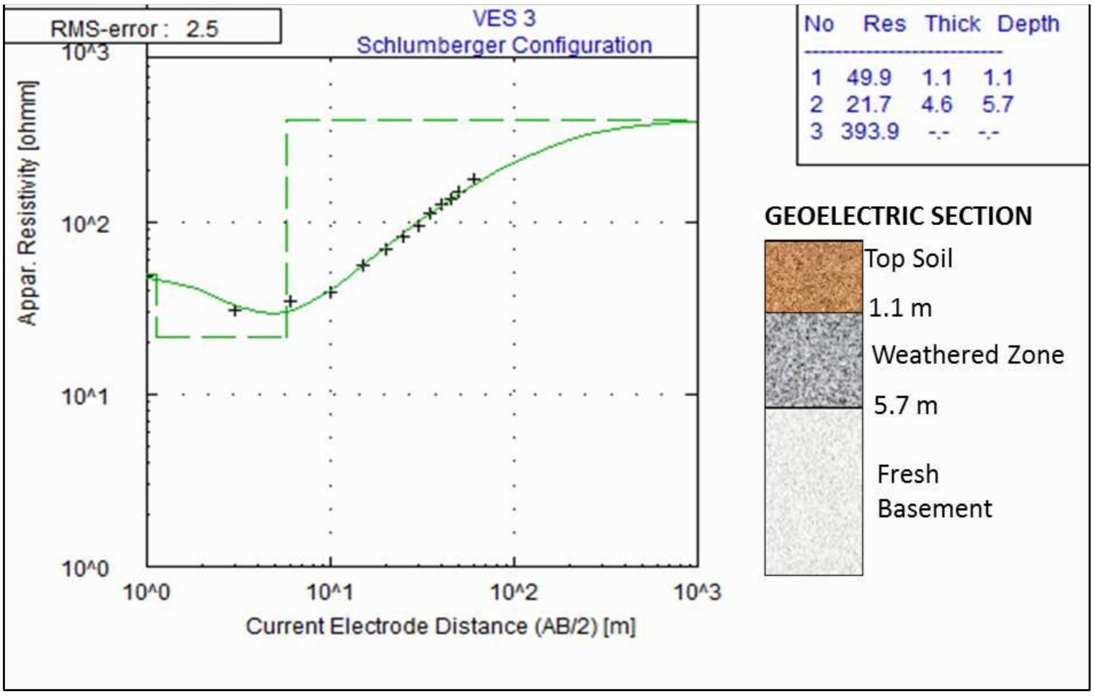

Figure 3: The figure presents the apparent resistivity curve for Vertical Electrical Sounding point 3.

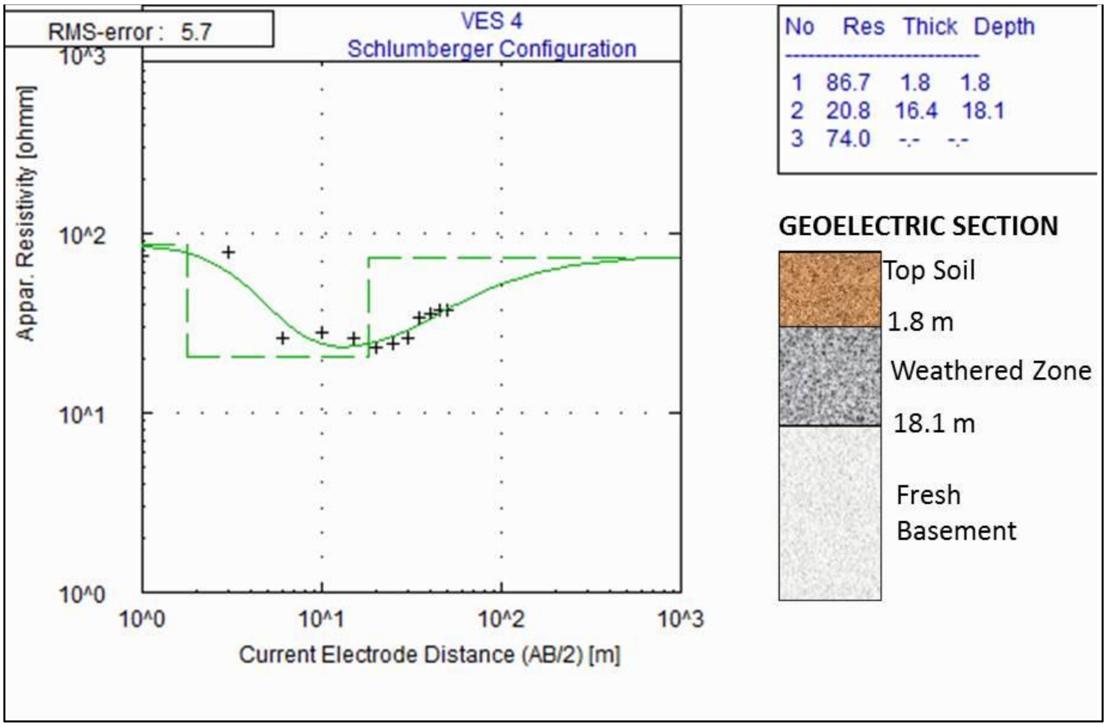

Figure 4: The figure presents the apparent resistivity curve for Vertical Electrical Sounding point 4.

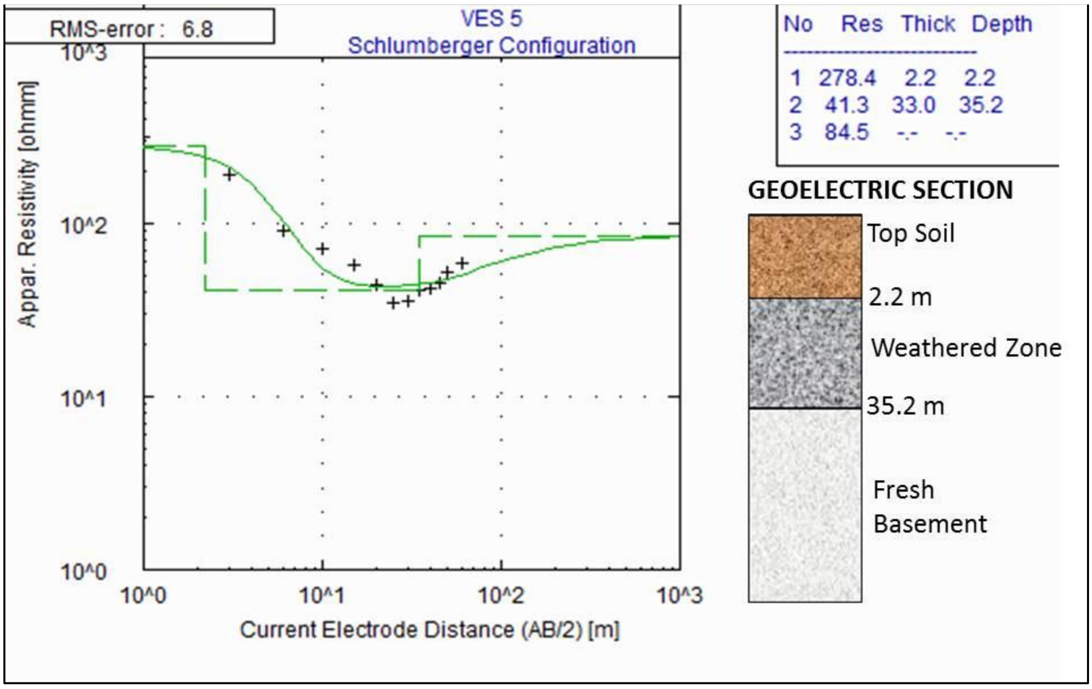

Figure 5: The table presents the apparent resistivity curve for Vertical Electrical Sounding point 5.

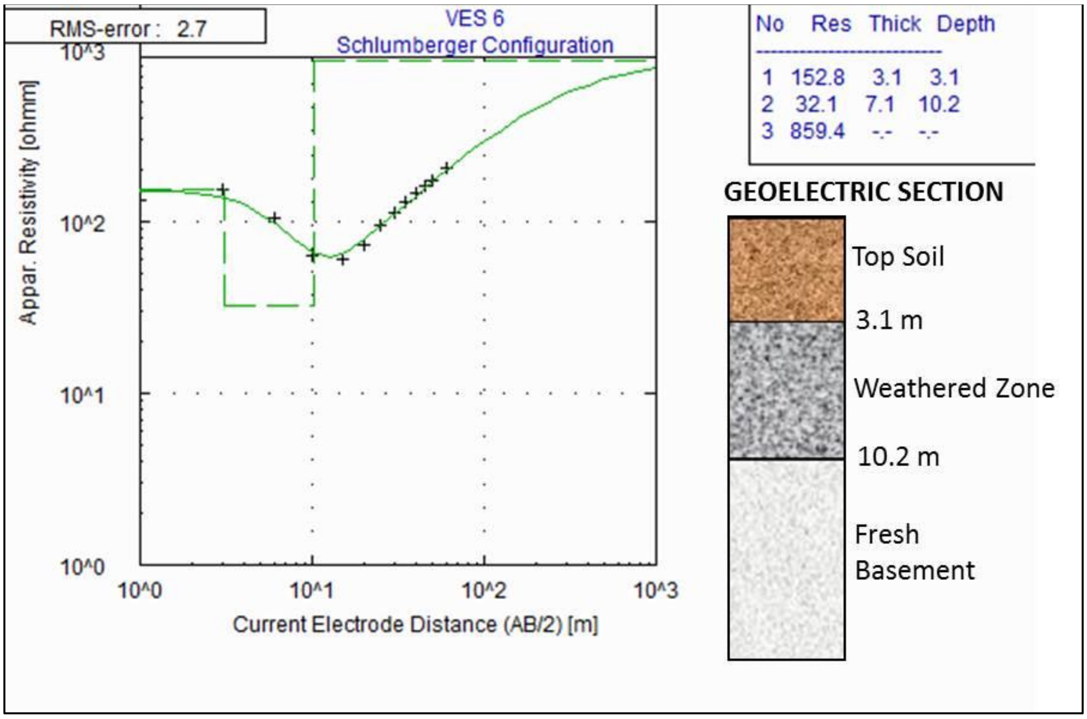

Figure 6: The figure presents the apparent resistivity curve for Vertical Electrical Sounding point 6.

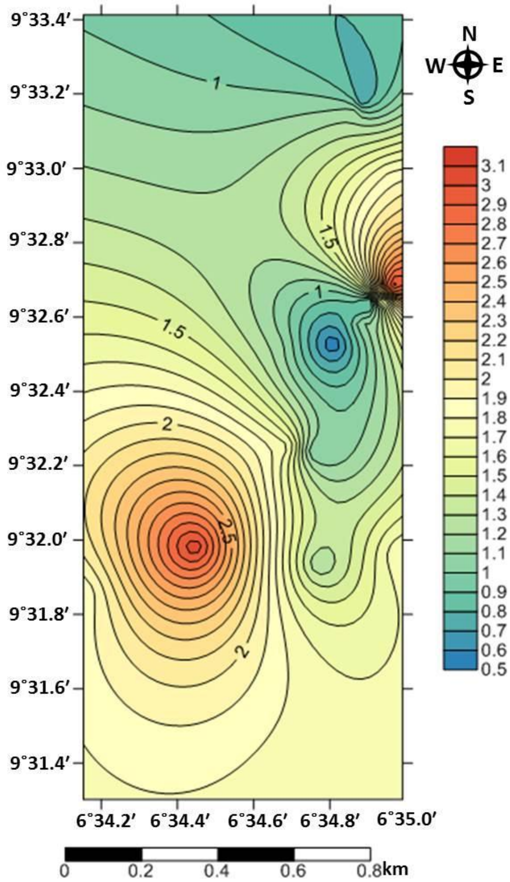

Figure 7: The figure presents the Iso-patch map for Vertical Electrical Sounding points 1-23.

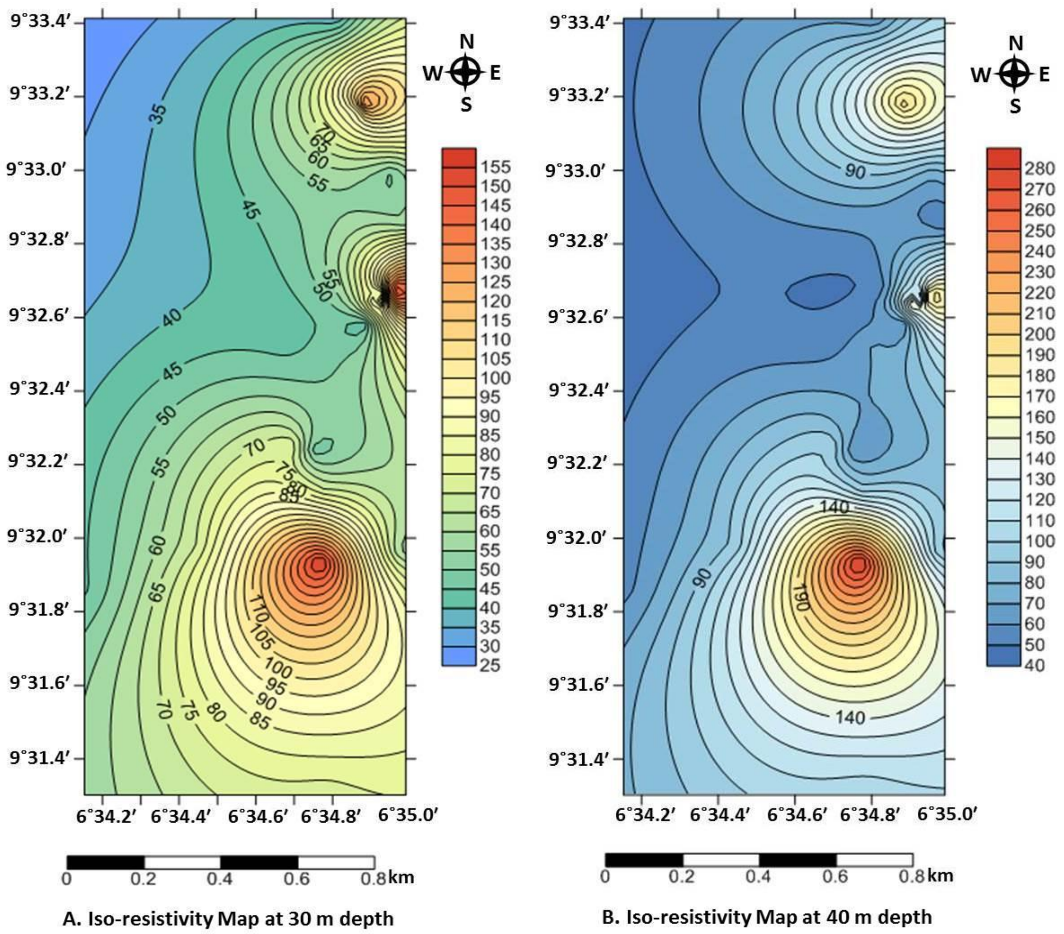

Figure 8: Iso-Resistivity for Vertical Electrical Sounding points 1 – 23 at: **A.** 30 m depth, and **B.** 40 m depth.

4. DISCUSSION

Most of the VES curves correspond to the H-type curve, which is a three – layer system, consisting of the topsoil as the first layer, the weathered/fractured basement as the second layer and the fresh or resistant basement as the third lithologic layer. The H-type curve is a characteristic of the basement complex environment [11,12]. The first layer (top soil) has apparent resistivity range of 25 – 928 Ωm with a corresponding thickness range of 0.5 – 3.1 m, second layer (weathered/fractured zone) has apparent resistivity values of 8.3 – 41.3 Ωm with a corresponding thickness of 2.1 – 33.0 m and the third layer has an apparent resistivity range of 74 – 4173.5 Ωm with an infinite thickness. The overburden depths of the VES points vary from 2.8 to 35.2 m while the depths to fresh/competent basement range from these values to infinity (∞). The fractures were observed to occur from within the weathered basement to the fresh or competent basement (Figures 3 – 6), this indicates a hydraulic connection between the weathered and fractured basement which is responsible for groundwater recharge to the fracture system.

Quantitatively, the representative curves as presented in Figures 3 to 6 also revealed the following specific lithology. The VES 3 (Figure 3) has depth of top soil 1.1 m, weathered/fractured zone 5.7 m. VES 4 (Figure 4) has 1.8 m thick top soil, 18.1 m thick weathered/fractured zone; VES 5 (Figure 5) has depth of top soil 2.2 m, weathered/fractured zone 35.2 m; and VES 6 (Figure 6) has depth of top soil 3.1 m, weathered/fractured zone 10.2 m; and the fracturing of the aforementioned VES points appears to occur from the second layer (weathered zone) to the fresh or competent basement as earlier noted.

4.1 Groundwater Prospectivity of the Study Area

The depth map, as presented in Figure 7, displays the variation of depths to top of bedrock across the study area by contours (depth of the overburden). The southwestern part of the study area is characterized by thick (deep) overburden. The VES points 2, 6, 7, 8, 9, 10, 13 and 23 were characterized by relatively high overburden thickness, varying from 2.8 to 13.1 m. The VES points 20 and 21 were observed to have very thick (deep) overburden of 18.2 m and 35.2 m respectively. The northern part and localized portion in the central part of the study area generally have low and very low (shallow) overburden thicknesses respectively. The average thickness of the soft overburden in Chanchaga area is about 11 m but this is much less than the average value of about 24 m found by Mohammed et al.

(2007) and 30 m found by Adeniji (1985) for Minna and its environs [1-9]. The outcome of this study is therefore an improvement to the works of these past workers.
The iso-resistivity maps depicted by Figures 8a and 8b show contours of points of equal resistivity values for the VES points at 30 and 40 metres depths respectively in the study area. The maps revealed that the western half and central portion of the study area have low to relatively low resistivity values (Figure 8a), and that the western half, central and northern parts of the Chanchaga area have very low to low resistivity values (Figure 8b). The zones with low characteristic resistivity values (high conductivity values) are known to have high groundwater yield [13,14].
Thus, by integrating the information on the isopach map with those of iso-resistivity maps, it can be deduced that the central and northern parts of Chanchaga area have low resistivity values but shallow overburden. Olorunniwo and Olorunfemi (1987) noted that low resistivity values as well as thick overburden are requirements for high groundwater yield in the basement terrain such as the study area [13]. Thus, the southwestern part of Chanchaga area which has thick overburden may be more promising for groundwater prospection. Ashaolu and Adebayo (2014) and Oladapo et al. (2009) also suggested that the area underlain by marginally thick overburden in crystalline basement hydrogeological setting are known to constitute shallow aquifer units with poor to marginal groundwater potential [15,16]. Bearing in mind the geology of the study area (Figure 2), the low resistivity in the southwestern part (Figures 8a and b) may be unrelated to groundwater. It is worth to note that the central and northern parts of the study area with very low to low resistivity values and shallow overburden shall constitute shallow aquifer units with poor to marginal groundwater potential in Chanchaga area. This interpretation is also supported by the occurrences and concentration of fractures (VES points 4, 5, 6, 9, 10, 11, 12, 15 and 17, and other subtle ones) to the central and northern parts of the study area.
A number of limitations to the electrical resistivity method employed for the study should be acknowledged. First, a considerable amount of field time and energy is required to carry out the electrical resistivity survey and this put constraints on the area covered. Another limitation was the local geology as the schist underlying the southwestern part of the study area showed low apparent resistivity response which could be mistakenly interpreted as groundwater potential.

5. CONCLUSIONS

The geophysical investigations carried out in Chanchaga area of Minna, North-central Nigeria delineated the presence of three subsurface geoeletric layers which are the top soil, weathered/fractured basement and fresh basement. These layers correspond to the H-type curve which is a characteristic of the basement complex environment. This work also revealed the presence of possible aquifers for groundwater storage in the area.
It is concluded that the central and northern parts of the study area have poor to marginal groundwater potential, and this is supported by the occurrences and concentration of fractures which can constitute weathered/fractured aquifers around these regions.
It is recommended that groundwater exploitation should be carried out most especially in the central and northern parts of the study area as they have higher concentration of fractures, and hence possibility of weathered/fractured aquifer. The wells to develop this resource should be drilled to an effective depth of 40 to 50 m for optimum yields. It is also recommended that pumping test be carried out on the drilled wells in order to further determine the aquifer efficiency and productivity in the area.

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