Geo-electric assessment for groundwater potential at permanent site of Waziri Umaru Federal Polytechnic, Birnin Kebbi, Kebbi State North Western, Nigeria

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ABSTRACT: Vertical Electrical Soundings (VES) afford fast and economical measurements used in geophysical exploration. VES was used for groundwater exploration at the permanent site of Waziri Umaru Federal Polytechnic, Birnin Kebbi. Eighteen (18) Vertical Electrical Sounding (Schlumberger array, maximum AB/2 distance 100 m) were performed, data were acquired using ABEM terrameter (SAS 300c), to determine the geoelectric units in the subsurface stratigraphy as well as to delineate groundwater potential in the area via electrical resistivity soundings. Field data collected was analyzed using computer software (IPI2win) which gives an automatic interpretation of the apparent resistivity in ohm-meter. Data was interpreted in terms of the resistivity and thickness of subsurface layers. Results indicates that three to five (3-5) distinct layers in the study area namely; top soil which is mainly sand, clayey sand/loose sand, sandy clay/fine sand and clay unit were delineated. The result also revealed that water bearing formation exists in the third layer in some identified VES locations i.e VES 3, VES 5, VES 13 and VES 14 with very good aquifers, with thickness and corresponding resistivity values of 40.5, 37.5, 45.8, 60 m and 173, 148, 222 and 432 Ωm respectively. The electrical resistivity data, therefore gives reasonable accurate results that can be used to understand stratigraphy and sedimentary configuration in ground water exploration.

Keywords: Exploration, geophysical, resistivity, thickness, vertical electrical sounding.

INTRODUCTION

Electrical resistivity method in geophysical exploration for groundwater in a sedimentary environment has proven reliable (Alile et al., 2011). In the sedimentary terrain, permeable and porous rock masks such as sandstone and loose sands are good indicators of aquifer and these are often characterized by relatively low resistivity (Odunaike et al., 2013). There are various techniques employed in groundwater exploration (gravity, magnetics, seismic, electrical and electromagnetic methods), electrical resistivity method is reliable in delineating zones of relatively low resistivity which might be a signatory of saturated strata in various geophysical terrain (Oyedele and Olayinka, 2012; Olasehinde et al., 2015).

Groundwater is the largest available reservoir of fresh water (Adepelumi et al., 2013). Groundwater is of significant importance to northern Nigeria where the amount of rainfall is limited to very few months of the year with annual rainfall of 1000 to 1500 mm and surface water sources are usually inadequate (Olasehinde et al., 2015). Water is of significant importance not only for human survival, but also for every development. It is used for various purposes which include domestic, irrigation, industrial, power generation and recreation. The amount of surface water available for domestic, industrial and agricultural use is insufficient to fulfill the current demand in the world (Abdullahi and Iheakanwa, 2013). The
The study area lies within the sedimentary region of northern Nigeria between latitudes 12°27.454’N to 12°28.239’N and longitudes 004°13.624’E to 004°14.874’E in Birnin Kebbi metropolis between latitude 12°27.13’N and longitude 4°12.01’E of Kebbi State between latitude 10°N to 13°N and longitude 3°E to 6°E in north-western Nigeria. The Kebbi State belongs to the savanna climate, and the rainy season and the dry season are clear. The rainy season is from May to October, and the dry season is from November to April. Between December and March, it hardly rains with mean monthly precipitation of almost 0 mm, though the annual mean precipitation is 835 mm. The annual average minimum temperature is 22.2°C, and the annual average maximum temperature is 34.7°C (JICA, 2011).

The study area Birnin Kebbi (Figure 1) is dominated by two formations; Precambrian Basement Complex in the southern and south east and young sedimentary rocks in the north. In the Basement Complex, gneiss is distributed in large area and the schist and granite is distributed in narrow area. In the Cretaceous, the argillaceous strata with intercalated sandstone layers are predominant in the lower part of the Cretaceous, and sandstone strata become thick in the upper part of the Cretaceous. In the Tertiary, the argillaceous strata are predominant in the lower part of the Tertiary, and the sandstone layers are intercalated in the upper part of the Tertiary. The alluvial deposit of Quaternary is distributed over the lowlands along big rivers such as Niger River and Sokoto River, with the small thickness of the deposit. It is presumed that the aquifer consists of (i) the weathered and fractured part of the Basement Complex, (ii) the sandstone and the fractured part of the Cretaceous, and (iii) the sandstone layers of the Tertiary (JICA, 2011).

MATERIALS AND METHOD

The materials used for the Vertical Electrical Sounding (VES) includes: the Global Positioning System (GPS), ABEM Terrameter (SAS 300c), connecting cables, four electrodes (steel rods), measuring tapes and hammers. The IP2Win software was used for analyzing geo-electrical data. Vertical Electrical Sounding (VES) was carried out at eighteen (18) different points using Schlumberger configuration with electrode spread at maximum AB/2 = 100 m. The fixed point was chosen and an iron rod was driven into the ground with the aid of hammer. This marks the VES station which was used as a mid-point from where half current electrodes spacing (AB/2) and half potential electrodes spacing (MN/2) were measured in opposite directions using the marked mid-point and measuring tape. Two current electrodes (C1 and C2) of equal distance on the opposite sides of the VES station were measured and driven into the ground with the aid of hammer for proper contact to be made with the ground. Similarly, two potential electrodes (P1 and P2) of equal distance and between the current electrodes were measured and driven into the ground. The measurements were repeated and recorded with MN/2 fixed at its initial distance and AB/2 was symmetrically increased. Whenever the resistance measured becomes low, then MN/2 was also increased symmetrically. The arrangements of the current and potential electrodes were made in such a way as to maintain a straight line. These pairs of electrodes were connected to the Terrameter through points AB and MN (Figure 2a), which referred to as Schlumberger configuration, in which the inner potential electrodes have a spacing 2l which is a small proportion of that of the outer, currents electrodes (2L). In a case where the current sink is a finite distance from the source (Figure 2). The potential VC at an internal electrode C is the sum of the potential contributions Vc and VB from the current source at A and the sink at B.

\[ V_C = V_A + V_B \]

\[ V_C = \frac{I}{2\pi} \left( \frac{1}{r_A} - \frac{1}{r_B} \right) \]

Similarly,
Thus

\[ \rho = \frac{2\pi V_D}{2\pi (\frac{I}{R_A} - \frac{I}{R_B})} \]

Substitution of this condition into equation (3)

\[ \rho_a = \frac{\pi (l^2 - x^2) \Delta V}{2l (l^2 - x^2) I} \]

Where \( \rho_a \) = apparent resistivity.

**RESULTS AND DISCUSSION**

The results of the geoelectrical survey were presented in Tables 1, 2 and 3. The 2D view of the geo-electric parameters (resistivity and thickness) obtained from the analysis of the electrical resistivity data obtained (Figure 3 and Appendix Figure 1) were used to adjudge the aquiferous or non aquiferous layers and expected geologic formations. The resistivity variations exist across lithologic interfaces or geo-electric boundaries in the subsurface. The interpreted result revealed three to five geoelectric
Table 1. Geoelectric parameters of VES 1 to 6.

| Coordinates | VESno. | Layer no. | Resistivity (Ωm) | Thickness (m) | Depth (m) | Curve Types |
|-------------|--------|-----------|------------------|---------------|-----------|-------------|
| 12°27.904'N | 1      |           | 884              | 0.7           | 0.7       |             |
| 00°04.392'E |        | 2         | 9172             | 1.6           | 2.3       |             |
|             | 3      |           | 1441             | 14.6          | 16.9      | KH          |
| Elevation: 744 | 4    |           | 18               | 22.1          | 39        |             |
|             | 5      |           | 3593             | ...           | ...       |             |
| 12°27.952'N | 1      |           | 1738             | 0.9           | 0.9       |             |
| 00°04.365'E |        | 2         | 6595             | 8.2           | 9.1       | KH          |
| Elevation: 734 | 3    |           | 60               | 13.2          | 22.3      |             |
|             | 4      |           | 1362             | ...           | ...       |             |
| 12°28.005'N | 1      |           | 496              | 0.8           | 0.8       |             |
| 00°04.351'E |        | 2         | 14876            | 3.7           | 4.6       | KQ          |
| Elevation: 734 | 3    |           | 173              | 40.4          | 45        |             |
|             | 4      |           | 4.18             | ...           | ...       |             |
| 12°28.058'N | 1      |           | 994.7            | 0.3           | 0.3       |             |
| 00°04.351'E |        | 2         | 2638             | 13.4          | 13.8      | K           |
| Elevation: 726 | 3    |           | 128.9            | ...           | ...       |             |
|             | 4      |           | 13389            | ...           | ...       |             |
| 12°28.112'N | 1      |           | 782              | 0.5           | 0.5       |             |
| 00°04.335'E |        | 2         | 2868             | 9.5           | 10        | KH          |
| Elevation: 704 | 3    |           | 148              | 37.5          | 47.5      |             |
|             | 4      |           | 13389            | ...           | ...       |             |
| 12°28.167'N | 1      |           | 412              | 0.4           | 0.4       |             |
| 00°04.337'E |        | 2         | 9867             | 0.5           | 0.9       |             |
| Elevation: 716 | 3    |           | 1247             | 9.6           | 10.4      | HKH         |
|             | 4      |           | 289              | 31.7          | 42.2      |             |
|             | 5      |           | 0.69             | ...           | ...       |             |

Table 2. Geoelectric parameters of VES 7 to 12.

| Coordinates | VESno. | Layer no. | Resistivity (Ωm) | Thickness (m) | Depth (m) | Curve types |
|-------------|--------|-----------|------------------|---------------|-----------|-------------|
| 12°27.920'N | 1      |           | 513              | 0.7           | 0.7       |             |
| 00°04.445'E |        | 2         | 8505             | 1.1           | 1.8       | KQ          |
| Elevation: 726 | 3    |           | 950              | 27.1          | 28.8      |             |
|             | 4      |           | 1.23             |               |           |             |
| 12°27.971'N | 1      |           | 884.7            | 0.5           | 0.5       |             |
| 00°04.428'E |        | 2         | 12292            | 0.6           | 1.1       |             |
| Elevation: 731 | 3    |           | 1296             | 13.7          | 14.9      | HKH         |
|             | 4      |           | 351.9            | 25.9          | 40.8      |             |
|             | 5      |           | 1.31             |               |           |             |
| 12°28.024'N | 1      |           | 382              | 0.5           | 0.5       |             |
| 00°04.409'E |        | 2         | 1781             | 5.4           | 5.9       | KQ          |
| Elevation: 730 | 3    |           | 962              | 19.6          | 25.5      |             |
|             | 4      |           | 13               |               |           |             |
Table 2 Contd. Geoelectric parameters of VES 7 to 12.

| Coordinates       | VESNo | Layer no. | Resistivity (Ωm) | Thickness (m) | Depth (m) | Curve Types |
|-------------------|-------|-----------|------------------|--------------|-----------|-------------|
| 12°28.075'E       | 10    | 1         | 445              | 0.5          | 0.5       | KQ          |
| Elevation: 727    |       | 2         | 2725             | 2.9          | 3.4       |             |
|                   |       | 3         | 1194             | 18.7         | 22.1      |             |
|                   |       | 4         | 33.3             |              |           |             |
| 12°28.132'E       | 11    | 1         | 775              | 1.1          | 1.1       |             |
| Elevation: 720    |       | 2         | 8312             | 1.5          | 2.5       | HKH         |
|                   |       | 3         | 1080             | 8.0          | 10.6      |             |
|                   |       | 4         | 308              | 37.9         | 48.4      |             |
|                   |       | 5         | 1.99             |              |           |             |
| 12°28.186'E       | 12    | 1         | 1307             | 1.0          | 1.0       |             |
| Elevation: 670    |       | 2         | 5633             | 0.5          | 1.4       |             |
|                   |       | 3         | 1269             | 11.4         | 12.8      | HKH         |
|                   |       | 4         | 265              | 38.1         | 50.9      |             |
|                   |       | 5         | 0.78             |              |           |             |

Table 3. Geoelectric parameters of VES 13 to 18.

| Coordinates       | VESNo | Layer no. | Resistivity (Ωm) | Thickness (m) | Depth (m) | Curve Types |
|-------------------|-------|-----------|------------------|--------------|-----------|-------------|
| 12°28.188'E       | 13    | 1         | 2089             | 2.7          | 2.7       | QQ          |
| Elevation: 718    |       | 2         | 1141             | 13.3         | 16        |             |
|                   |       | 3         | 222              | 45.8         | 61.7      |             |
|                   |       | 4         | 2.1              |              |           |             |
| 12°28.135'E       | 14    | 1         | 951              | 1.2          | 1.2       | KQ          |
| Elevation: 719    |       | 2         | 7544             | 0.9          | 2.0       |             |
|                   |       | 3         | 432              | 67           | 69        |             |
|                   |       | 4         | 4.81             |              |           |             |
| 12°28.086'E       | 15    | 1         | 616              | 0.7          | 0.7       | KQ          |
| Elevation: 719    |       | 2         | 6504             | 1.8          | 2.5       |             |
|                   |       | 3         | 907              | 22.6         | 25.1      |             |
|                   |       | 4         | 20.3             |              |           |             |
| 12°28.033'E       | 16    | 1         | 866              | 0.4          | 0.4       | KQ          |
| Elevation: 723    |       | 2         | 29558            | 0.7          | 1.1       |             |
|                   |       | 3         | 756              | 21.6         | 22.7      |             |
|                   |       | 4         | 60.9             |              |           |             |
| 12°27.979'E       | 17    | 1         | 555              | 0.8          | 0.8       | HKH         |
| Elevation: 722    |       | 2         | 3583             | 1.1          | 1.8       |             |
|                   |       | 3         | 1006             | 7.9          | 9.7       |             |
|                   |       | 4         | 411              | 24.4         | 34.2      |             |
|                   |       | 5         | 0.849            |              |           |             |
| 12°27.926'E       | 18    | 1         | 970.4            | 1.0          | 1.0       | HKH         |
| Elevation: 738    |       | 2         | 2578             | 3.4          | 4.4       |             |
|                   |       | 3         | 637.9            | 18.5         | 22.9      |             |
|                   |       | 4         | 114.4            | 39.7         | 62.5      |             |
|                   |       | 5         | 2.76             |              |           |             |
Figure 3. Model VES Curves of 4 Locations VES 1, VES 2, VES 3, and VES 4.
layers in the study area. The first layer shows the diversity of resistivity and thickness ranging from 383 to 2089 Ωm and 0.3 to 2.7 m classified as top soil. The resistivity value of the second layer ranges between 1141 to 29558 Ωm with thickness between 0.5 to 13.4 m and interpreted as clayey sand/loose sand formation. The third layer with resistivity range of 60 to 1441 Ωm and thickness varies from 7.9 m to infinity. The layer interpreted as sandy clay/fine sand. The fourth layer resistivity ranges between 1.23 to 13389 Ωm and thickness from 2.1 m to infinity, the layer interpreted as clay formation. The fifth layer exists in VES 1, VES 6, VES 8, VES 11, VES 12, VES 17 and VES 18 with infinite thickness, which indicates medium grain sand and sandstone formation. The fourth and fifth layers have a very low resistivity values in some part of the study area which attribute to the presence of saturated clay (Oyedele and Olayinka, 2012; Olasehinde et al., 2015). Due to the decrease in resistivity values in the third layer compared to the second layer in some areas, this show that third layer delineate a probable water saturation zone (Odunaike et al., 2013). The depth of the aquifer in third layer ranged between 9.1 to 69 m in some VES stations. This value is comparable to those of JICA (2011) and Usman (2019).

Iso-resistivity analysis gives the qualitative interpretation that represents the variations in resistivity at a designated depth and indicates the general lateral changes in the electrical properties around the area (Mohammed et al., 2014). Figure 5 and 6 shows the iso-resistivity and iso-depth contour maps of the aquifer layer. The depth contour maps support claim of which points may have high groundwater yield due to the appreciable values of overburden thickness. Iso-resistivity and Iso-depth contour maps of aquifer layer reveal VES 3, VES 5, VES 13 and VES 14 are rated as best locations for groundwater exploration (Figure 4 and 5).
Conclusion

Qualitative interpretation of the vertical Electrical Sounding (VES) for groundwater exploration at the permanent site of Waziri Umaru Federal Polytechnic, Birnin Kebbi, Kebbi State, North Western Nigeria, delineated a network of probable features, suspected to be groundwater occurrence as well as presence of low resistivity below 100 Ωm which serve as good indication of closeness of static water table in most of the VES stations. Different parameters, particularly resistivity and thickness of subsurface layers and their lithologic boundaries were determined and it was observed that there were variations in the levels of groundwater potential from one part of the study area to another. Good prospects therefore exist for groundwater potential within the study area where the depth to bedrock is relatively thick and has favorably low resistivity value, while those with thin depth to bedrock and high resistivity value have a lower potential for groundwater. The VES results of the entire area revealed various depth to strike the top of the water bearing zones ranged between 9.1 to 69 m. Iso-resistivity and Iso-depth contour maps of aquifer layer revealed VES 3, VES 5, VES 13 and VES 14 as best location for groundwater exploration. The geological formation in the study area consists of: top soil which is mainly sand, clayey sand/loose sand, sandy clay/fine sand and clay unit. Furthermore, the results obtained from the survey indicate the efficiency of Vertical Electrical Sounding (VES) techniques in probing groundwater potential in the sedimentary region.

Recommendation

The use of other geophysical methods, such as the seismic, magnetic and electromagnetic methods, especially
integrated geophysical investigation could be employed to prove the present outcome. The future boreholes in the study area should be drilled to a maximum depth of 69 m.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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Appendix

Appendix Figure 1. Model VES Curves of 4 Locations VES 5 - VES 8.
Appendix Figure 1 Contd. Model VES curves of 4 locations VES 9 - VES 12.
Appendix Figure 1 Contd. Model VES curves of 4 locations VES 13 - VES 16.
Appendix Figure 1 Contd. Model VES curves of 4 locations VES 17 - VES 18.