Aquifer characterization of some parts of Ijebu Igbo using electrical resistivity methods

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Abstract. Groundwater aquifer mapping is a scientific process, where-in a combination of geologic, geophysical and hydrologic analyses are applied to characterize the quantity, quality and sustainability of groundwater in aquifers. A total of ten (10) Vertical Electrical Sounding (VES) and six (6) two dimensional (2-D) Electrical Resistivity Tomography (ERT) lines were achieved. The 2-D ERT lines were carried out on a length of about 240 m – 320 m using Dipole-dipole electrode configuration. Acquired 2-D and VES data was processed using RES2DINV and WINRESIST software respectively. The VES results obtained showed that the study area has 3 to 4 geoelectric layers with the following lithology namely; the topsoil, partially weathered, fractured layer and the fresh bedrock. The topsoil has a resistivity value of about 609 Ωm. The thickness and the depth representation of weathered basement and fractured basement vary from one another. They have a resistivity value of about 128 Ωm and 1089 Ωm respectively. The 2-D inverse models obtained from the area showed the presence of vertical contacts and fractured zones that can serve as an aquifer for the surveyed area. The pseudosection of the inversion results unravel the two profiles with saturated fractured basement where adequate groundwater can be obtained. The Iso-Pach map showed high contour closures which are good signature for good to moderate groundwater potential zones on profiles four, five and six (VES 7, 8 and 9). In contrast, profiles one, two, three (VES 2 and 6) displayed low closures which depicts low overburden thickness and categorically means poor groundwater potential zones.

Keywords: Groundwater, Aquifer, Two-Dimensional (2-D), Resistivity, VES

1. INTRODUCTION

Water is important for the well-being of humans. It plays a very vital role in the development and growth of humans, animals and plants. Quality drinking water can be obtained from tap
water distributed by the government or through ground water. High population growth rate in Nigeria has led to increase demands for water resources [1].

Groundwater has been defined by many researchers as the water units that lies beneath the Earth’s subsurface, present in the pore spaceof sedimentary rock grains and filling cracks and crevices of crystalline rocks [2]. Among the source of groundwater is rain and snow which percolates down into the ground upon their falling [3]. Groundwater is seldom free from surface pollution because the Earth media is believed to compose of some surface layers which filter any potential harmful materials. Though, some cases of leachate infiltration do occur, but the weak layer can be easily identified and groundwater in such place can be appraised accordingly[4].Jayeoba and Oladunjoye [5]explained that exploration of groundwater in crystalline hard rock is a very challenging task especially when the high yield of potable water is associated with fracture of the rock. However, the size and location of the fractures, interconnection of the fractures, and amount of the material that may be clogging the fractures and recharging sources determine how much water one can get out of hard rock [5].

Geophysical survey involving electrical resistivity method constitutes one of the most reliable means, outside direct mechanical drilling, through which basement structures such as ancient river channels, basement depressions and fractured zones that are of hydrogeological significance can be mapped [6, 7, 8].Electrical resistivity technique involves the propagation of electrical currents within the Earth. The varying electrical property of the subsurface, results in the buildup of variations in the potential distribution as a result of presence or absence of conducting materials in the Earth. The potential distribution generated is then measured at the surface to provide information on the form and electrical properties of the subsurface. Electrical resistivity imaging has been used for imaging fractures in hard rock terrain. This has revealed that where fractures are present, the bedrock is expected to be more strongly weathered to a greater depth than where it is not fractured. For this reason it is best to drill at points where the bedrock reaches its greatest depth for thick reservoir of water in the overburden and the likelihood of the reservoir being underlain by bedrock that is fractured [9]. Analysis of the resistivity measurements can reveal how the physical properties of the earth’s interior vary vertically and laterally and reflecting the subsurface geology. Two Dimensional (2-D) electrical imaging has been found to be new
technology deployed in mapping areas with moderate geology [10]. This method has showed high efficacy in identifying the fractured and weathered zones in the surveyed areas. This efficiency has increase the success rate of drilling of borehole towards groundwater exploration [11]. Therefore, the use of such technique for groundwater exploration has earned an important place in recent years despite some interpretive limitations [12, 11, 3].

The previous results obtained from the anisotropic study of Ijebu-Igbo [13] revealed the flow direction of Groundwater but failed to give details of the depth and fracture pattern. However, this research work is aimed at evaluating the efficacy of Vertical Electrical Sounding (VES) and Two-Dimensional (2-D) Electrical Resistivity in groundwater aquifer imaging with the objectives of characterizing the subsurface of the study area into geoelectric sections, determining the depth to the basement, delineating possible zones that can serve as aquifer from the various anomalous zones in the study area. Hence, the study will solve the problem of non-availability of portable water supply whose deficiency can lead to outbreak of diseases by delineating possible zones that can serve as aquifer.

2. DESCRIPTION AND GEOLOGY OF THE STUDY AREA

The study area lies within Latitude of $6^057'N$ and $7^000'N$ and Longitude $3^058'E$ and $4^002'$ with an area extent of approximately 27.4 square kilometers. Ijebu Igbo (as shown in Fig. 1) is easily accessed through series of interconnecting minor roads, footpaths and few major roads from neighbouring towns such as Ago - Iwoye, Oru- Ijebu, Ijebu-Ode[13]. The study area has the same climate as shared by other towns in Ogun State. It has a typical tropical climate consisting of alternating wet and dry seasons. The wet season which typically lasts from March/April to October/November and the dry season last for the rest of the year starting from October /November to March/April. The study area is characterized with a mean annual rainfall of 750-1000mm and the peak being June and September. The temperature ranges between 21°C in July to 32°C in February. The vegetation within the study area is typical rainforest with dendritic pattern of drainage [14, 13]

The study area falls within the Basement Complex of Nigeria. It comprises of both the migmatite gneiss complex and the older granite, which shows structural disposition [15] (Figure 2). The main lithologies include the amphibolites, migmatite gneisses, granites and
pegmatites. Other important rock units are the schists, made up of biotite schist, quartzite schist talk-tremolite schist, and the muscovite schists [16]

![Location Map of the Study Area](image)

**Fig. 1: Location Map of the Study Area**

3. METHODOLOGY
The Vertical Electrical Sounding (VES) and two-dimensional (2-D) electrical resistivity imaging techniques were employed in this study so as to measure the change in Earth’s resistivity both vertically and horizontally because of the complex geology of the study area. Electrical resistivity is a function of porosity, fluid saturation, resistivity of the pore fluid and the solid, and the material texture among others. A conductive body concentrates electric current flow lines towards itself while a resistive body causes the current to flow
around itself. The electrical resistivity imaging is a survey technique recently developed for the investigation of areas of complex geology where the use of resistivity sounding and other technique is unsuitable [10]. In this study, field resistivity data were obtained at ten (10) vertical electrical sounding points which were situated along six (6) 2-D traverses. The six traverses cut across populated areas in the study area such that traverse 1 and 2 are oriented Northwest – Southeast direction, traverse 4 and 5 Northeast - Southwest direction, traverse 3 South – North direction and traverse 6 Northeast and Southwest as shown in the base map figure 3 below. The dipole-dipole configuration was used with the traverse length ranging from 240 m to 324 m and electrode spacing of 3m and 4m respectively were used based on the availability of space. The Schlumberger array was used for the Vertical Electrical Sounding with a maximum spread of about 120m.

Fig 2: The Geologic Map of the Study Area
Fig. 3: Base map of the Study area showing the 2-D traverse Lines
4. RESULTS AND DISCUSSION

4.1. The VES data is presented as a graph of Current electrode separation (AB/2) and the corresponding resistivity value (ρ). The curve and also the geological equivalent of the plot with the parameters were deduced from the iterated curve generated by WINRESIST software. The geological equivalent of the plot shows that structure of the layers with respect to their resistivity value and the thickness of the strata. This provide 1-D representation of each sounding VES point.

The curve types identified within the study area from the VES data includes HA-Curve $\rho_1 > \rho_2 < \rho_3 < \rho_4$ and H-Curve type $\rho_1 > \rho_2 < \rho_3$ with the latter being the predominant curve type. The summary of the VES Interpretation is given in Table 1 below.

From the result, VES point 1, 2, 4, 5, 6, 7, 9 and 10 are curve type H (Fig. 4) and VES points 3 and 7 are curve type HA (Fig. 5) model. The interpreted result showed 3-4 inferred geoelectric layers. The inferred geoelectric layers are topsoil, weathered basement, fractured basement and fresh basement. For VES 1, 4, 5, 8, 9, and 10 the resistivity value ranges from 551Ωm–828Ωm with thickness ranging from 1.3m – 3.3m. The resistivity of the second layer which is inferred to be the weathered basement has resistivity value ranging from 103Ωm–357Ωm with thickness ranging from 3.7m-7.8m and the third layer which is the fresh basement has resistivity value over 10000Ωm. At VES 2 and 6, the resistivity for the topsoil which is the first layer has resistivity value between 698Ωm and 721Ωm with thickness from 1.7m -4.1m, the second layer has resistivity value ranging from 524Ωm - 691Ωm with thickness between 16.3m and 39.8m, this layer is inferred to be an unsaturated fractured basement. VES 5 and 7 has resistivity of its first layer to be around 650 Ωm with thickness ranging from 2.0m-2.3m and this is inferred to be the topsoil. The second layer is with resistivity ranging from 103Ωm–121Ωm and thickness from 3.7m- 4.6m. The third layer has resistivity ranging from 1038 Ωm-1868 Ωm with thickness of between 6.9m-12.9m and it is inferred to be fractured basement.
Table 4.1 SUMMARY OF INTERPRETATION OF VES

| VES | Layer | Resistivity \( \rho_a (\Omega m) \) | Thickness (m) | Depth (m) | Inferred Lithology       |
|-----|-------|----------------------------------|---------------|-----------|--------------------------|
| 1   | 1     | 741.4                            | 4.1           | 4.1       | Topsoil                  |
|     | 2     | 177.6                            | 13.3          | 17.4      | Weathered Basement       |
|     | 3     | 8378.0                           |               |           | Fresh Basement           |
| 2   | 1     | 698.0                            | 1.9           | 1.9       | Topsoil                  |
|     | 2     | 524.2                            | 16.3          | 18.2      | Weathered Basement       |
|     | 3     | 15998.2                          |               |           | Fresh Basement           |
| 3   | 1     | 645.5                            | 2.3           | 2.3       | Topsoil                  |
|     | 2     | 103.8                            | 3.7           | 6.0       | Weathered Basement       |
|     | 3     | 1868.4                           | 6.9           | 12.9      | Fractured Basement       |
|     | 4     | 29278.9                          |               |           | Fresh Basement           |
| 4   | 1     | 828.6                            | 1.7           | 1.7       | Topsoil                  |
|     | 2     | 117.4                            | 7.5           | 9.5       | Weathered Basement       |
|     | 3     | 100000.0                         |               |           | Fresh Basement           |
| 5   | 1     | 551.6                            | 1.3           | 1.3       | Topsoil                  |
|     | 2     | 357.2                            | 7.5           | 8.8       | Weathered Basement       |
|     | 3     | 4842.6                           |               |           | Fresh Basement           |
| 6   | 1     | 721.7                            | 4.1           | 4.1       | Topsoil                  |
|     | 2     | 691.1                            | 39.8          | 43.9      | Weathered Basement       |
|     | 3     | 3629.4                           |               |           | Fresh Basement           |
| 7   | 1     | 659.2                            | 2.0           | 2.0       | Topsoil                  |
|     | 2     | 121.0                            | 4.6           | 6.6       | Weathered Basement       |
|     | 3     | 1038.1                           | 12.9          | 19.5      | Fractured Basement       |
|     | 4     | 14095.0                          |               |           | Fresh Basement           |
| 8   | 1     | 706.7                            | 4.4           | 4.4       | Topsoil                  |
|     | 2     | 128.0                            | 6.5           | 10.9      | Weathered Basement       |
|     | 3     | 31648.0                          |               |           | Fresh Basement           |
| 9   | 1     | 609.7                            | 4.1           | 4.1       | Topsoil                  |
|     | 2     | 123.0                            | 7.8           | 11.9      | Weathered Basement       |
|     | 3     | 3103.4                           |               |           | Fresh Basement           |
| 10  | 1     | 777.0                            | 3.3           | 3.3       | Topsoil                  |
|     | 2     | 234.4                            | 8.6           | 11.9      | Weathered Basement       |
|     | 3     | 2477.7                           |               |           | Fresh Basement           |
4.2. 2-D Image lines

4.2.1. Image line 1: The inverted section (Fig. 6A) clearly shows a layer of materials with resistivity values between 150Ωm and 800Ωm and thickness ranging from 1 – 14m as the
topsoil. The thickness of this layer varies from position to position which is a consequence of the inhomogeneity of the subsurface. Below this unit is a conductive layer with thickness ranging from 11m where the basement is high to about 35 m thick where the basement is low. This layer is depicted to be the weathered basement. The weathered basement in the north eastern part shows resistivity less than 200 Ωm indicates it is saturated. Towards the southern part of the line, the weathering is also deeper and saturated as indicated by the low resistivity at depth. This is a clear indication that the degree of weathering is not uniform along the image line. The last layer is depicted to be the fresh basement with resistivity range between 1000 Ωm and 2000Ωm.

4.2.2. Image line two: The inverted section (Fig. 6B) clearly shows a layer of materials with resistivity values between 170Ωm and 600Ωm and thickness ranging from 1 – 10m as the topsoil/overburden. Underlying this layer is the weathered basement from depth 8m to 35m towards the Northwestern part of the image line and at 15m – 35m towards the southeastern part of the image line with resistivity value ranging from about 20Ωm – 350Ωm. This layer is partly weathered and partly fractured and saturated with water which is indicated in the resistivity value. The resistivity value of fractured basement ranges between 280Ωm and 350Ωm and encountered at a depth of 22m towards the south eastern part of the image line and around the northwestern part of the image line the crystalline basement has a high resistivity value of about 4000Ωm occurring at 45m depth.

4.2.3. Image line three: The inverted section (Fig. 6C) clearly shows a first layer of materials with resistivity values greater than 500Ωm and thickness of about 6m as the topsoil. However, the relatively high resistivity value indicates that the topsoil is mixed with weathered rocks as seen on the field. At some positions along the profiles line the resistivity value is very low which is inferred to be as a result of the presence of surface water. This layer overlays the weathered /fractured layer with resistivity value ranging from 10Ωm to 55Ωm with thickness ranging between 20m and 50m from the southern end to 145m position along the image line. At positions 118m – 138m this part is a fractured basement saturated with water. Underlying this layer is the fresh basement with resistivity value ranging from 4100 Ωm to 5700 Ωm at a depth of 20m at some positions along the profile line.
4.2.4. Image line four: The inverted section (Fig. 7A) inferred three geoelectric layers. The first layer which has resistivity value ranging from 300Ωm to 2000Ωm. The thickness of this layer is almost uniform along the line and has a maximum depth of about 13m from the surface. There are isolated patches of high resistivity observed on the inverted resistivity section at line positions 48m-62m, 80m-110m and at 180m. These isolated high resistivity patches is inferred to be lateritic materials present in this layer. The second layer has very low resistivity value compared to the overlying layer ranging from 2Ωm- 120Ωm. This layer occurs from a depth of 12m to a maximum depth of 35m below the surface. The thickness of this layer is almost uniform throughout the profile line. The third layer has the highest resistivity value ranging from 1000Ωm – 6000Ωm. With this resistivity contrast it can be inferred that this layer is the fresh basement. It occurred at a depth of 35m below the surface and it is almost uniform across the line.

4.2.5. Image line five: The inverted section (Fig. 7B) clearly shows a first layer of materials with resistivity value ranging from 800 Ωm-7000 Ωm. This top layer is suspected to contain lateritic materials due to the high resistivity value and as visible on the field. The depth of this layer runs to a maximum depth of 15m. This layer overlays the weathered /fractured layer with resistivity value ranging from 5Ωm to 90Ωm with thickness ranging between 20m and 30m. The third layer which is inferred to be the fresh basement from the NEE end of the profile line to 192m has a very high resistivity value ranging from 1000Ωm – 50000Ωm.
Fig. 6: 2-D Inverse Resistivity Imaging for Image line 1, 2 and 3
Fig. 7: 2-D Inverse Resistivity Imaging for Image line 4 and 5

4.3 ISO-PACH MAP (OVERBURDEN THICKNESS): The thicknesses of the overburden obtained from the interpretation results were plotted against the profile lines shown in Fig. 8, with 4m contour interval used. The map displayed the variation in overburden thickness closures across the study area. Furthermore, high contour closures which suggest possible
areas of high protective capacity and these could be found around profiles four, five and six. The low closures around profiles one, two and three depict low overburden thickness.

Fig. 8: Iso-Pach Map showing the overburden thickness in the Study Area

5. CONCLUSION

The integrated approach of VES and the 2-D Electrical Resistivity Imaging results provide detailed information necessary for the aquifer characterization of the study Area. Three geoelectric layers were delineated in some parts of the study area. These include; Top Soil, Weathered Layer and Fresh Basement. Four geoelectric layers were delineated in VES 3 and 7 within the study area. The fractured layer was found to be between the weathered layer and fresh basement. The resistivity value of the fractured layer loiters between 1038 Ωm and
1868Ωm. Groundwater aquifers delineated in the study area are characterized into good, moderate and poor aquifer. This characterization was done using the resistivity values and the thickness of the second and or third layer and the pseudosection result of the 2-D electrical resistivity imaging profile. The second layer in most of the VES is inferred to be the weathered layer and the third in other cases is inferred to be the fractured layer. The weathered layer is said to be a good aquifer when the resistivity is less than 500Ωm with an average thickness of 5m. The fractured layers are suspected to be saturated with the resistivity value range of less than 500Ωm. With all this put into consideration VES 1, 4, 5, 8, 9 are inferred to be good aquifers, VES 3, 7, and 10 are inferred to be moderate aquifers because their thickness is less than 5m hence there is possibility of them failing during the dry season from lack of water. VES 2 and 6 are considered to be poor aquifers because their resistivity is greater than 500Ωm which is an indication that the layer is not saturated. In conclusion, this study presents the characterization of the subsurface aquifer of Ijebu-Igbo Southwestern Nigeria into good aquifer, moderate aquifer and poor aquifer using the variation in resistivity values of the layer due to their constituent materials and water content.

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