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The Nature of Aquifers in the Crystalline Basement Rocks of Ado-Ekiti, Igede-Ekiti and Igbara-Odo Areas, Southwestern Nigeria

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Abstract. Geoelectrical investigations (vertical electric sounding, VES) for groundwater in the basement rocks of Ado-Ekiti, Igede-Ekiti and Igbara-Odo areas, Southwestern Nigeria were carried out. Geophysical data revealed the area as the one that has undergone an irregular weathering front. The geoelectric curves at VES 1, VES 2 and VES 3 at Igbara-Odo were classified as HA, HAA and KH, respectively, while the two VES stations at Ado-Ekiti produced Q and KQH type curve. At Igede-Ekiti, the geoelectric curves obtained for the three VES stations were KH, KQHK and KHKH types. The VES stations were located in a migmatite-gneissic terrain at Igede-Ekiti, gneissic charnockite at Ado-Ekiti and in a granite-gneiss migmatite country rock at Igbara-Odo. Geoelectric layers varied from 3 at Ado-Ekiti to 6 at Igede-Ekiti, with probed thicknesses of between 0.7 m to 151.9 m. The results of the processed data suggested that aquifers occurred both in the regolith and the fractured bedrock. In places, a regolith and the underlying saturated fractured bedrock might constitute the aquifers, having the promise of siting high yielding boreholes, such as at Igede-Ekiti and Igbara-Odo. However, thickness and recharge problems made siting a borehole at Ado-Ekiti VES stations undersirable.

Keywords: aquifer, regolith, groundwater, water recharge, geoelectrical method, Southwestern Nigeria, vertical electric sounding

Introduction

Three prominent towns in Southwestern Nigeria, Ado-Ekiti, Igede-Ekiti and Igbara-Odo were investigated geophysically for their underground water potential. These towns lie within the basement complex terrain in Southwestern Nigeria. This study area is a part of the extensive Yorubaland Plateau which stretches from the Niger Trough in the North to the Yoruba lowlands of the Southwestern Nigeria in the South. The elevation varies between 200 m and 500 m above mean sea level. Prominent hilly features include inselbergs, whalebacks and other categories of residual hills which are commonly associated with massive granite bodies (Olarewaju, 1981). The area of study was within latitudes 7°20′ N and 7°41′ N and longitudes 5°6′ E and 5°20′ E (Fig. 1), which receives tropical rainfall from March to November with a short spell of dry season in December to February. There may occur sporadic rainfall during the short dry season. The study area has a tropical climate with a mean annual rainfall of 1,500 mm. Major rivers which drain the area include Rivers Elemi, Ureje and Ogbese, which together with their tributaries act as sources of recharge, apart from the direct infiltration of rain into the ground. The mean groundwater recharge from the rivers is about 250 mm, while rainfall infiltration accounts for a much higher amount of about 1,000 mm (DMS, 1999). The heavy rainfall is responsible for myriads of seasonal streams which drain the area of study giving a somewhat dendritic drainage pattern. Tropical weathering and erosion affect the basement rocks of the Southwestern Nigeria. The rocks in the area studied, similar to other rocks in the basement complex of Southwestern Nigeria, have undergone polycyclic metamorphic deformation leading to folding, foliation, faulting and fracturing. In the basement complex of the study area, both the regolith and fractured bedrocks have been described as the aquifers for groundwater from where it has been described as being structurally controlled (Clark, 1985). Other workers have described aquifers that are situated in the non-transported weathered overburden of crystalline rocks in the basement complex (Ajayi and Abegunrin, 1990; Alagbe and Raji, 1990). Jones (1985) concluded that the regolith overlying the fractured bedrock often provides the aquifer for groundwater in the basement complex terrain.

Despite the abundant and regular rainfall, associated with consequent surface water abundance in the area of study, the potable water supply is grossly inadequate constituting a recurring social problem. Surprisingly, the problem of shortage of potable water supply is not restricted to the developing world alone. Recently, Falconer (2003) described water as one of the world's most precious resources, concluding that urbanisation presents increasing challenges of how to ensure adequate water supplies and a suitable water environment for future generations worldwide. In the present study,

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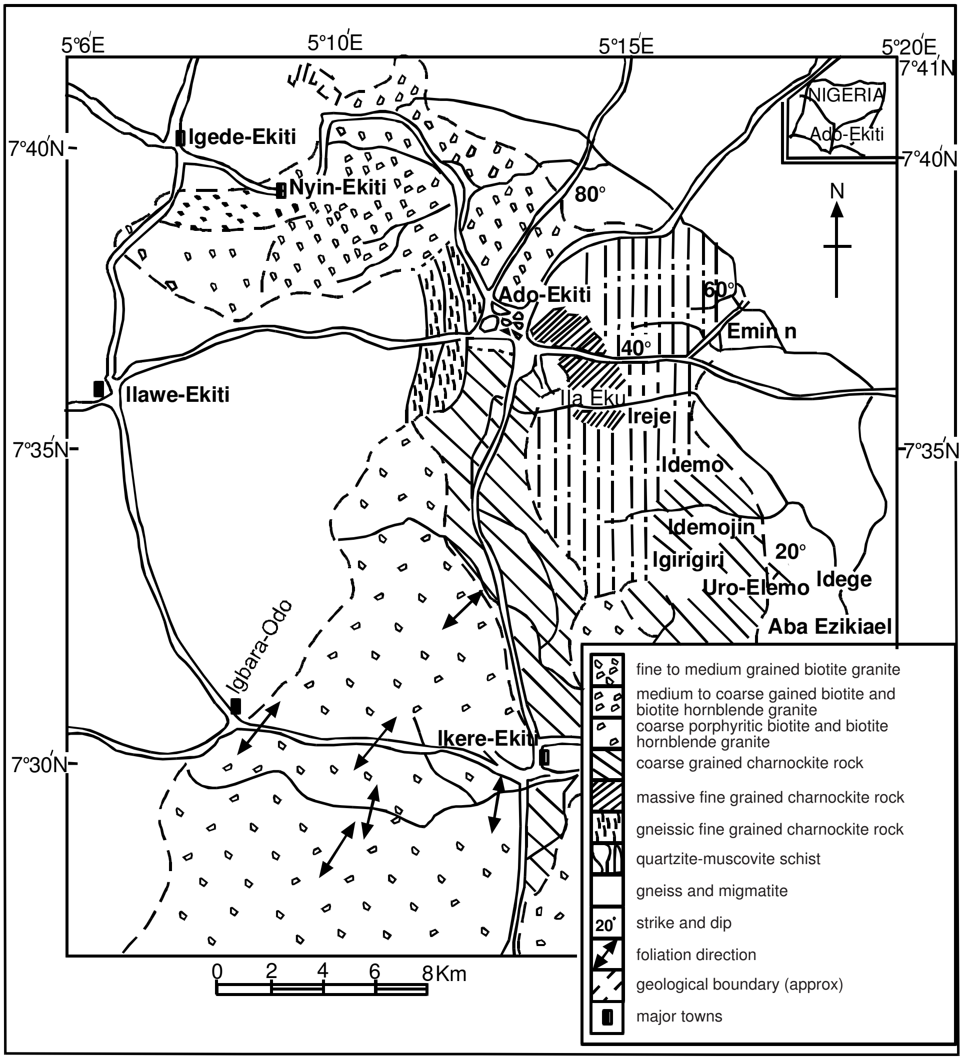

Fig. 1. Geological map of Ado-Ekiti to Ikere-Ekiti area, Southwestern Nigeria (after Olarewaju, 1987).

the geoelectrical method of resistivity was used to locate and assess the possible groundwater aquifers in the areas under investigation. According to Emenike (2001), Pulawiski and Kurth (1977), Zohdy *et al.* (1974), and Zohdy (1973), the resistivity method has superiority over others in the groundwater exploration. According to these authors, the resistivity method is capable of providing the needed information on subsurface geology, which may otherwise be impossible to obtain with other methods. Furthermore, the resistivity method has been described as a powerful tool not only in locating aquifers but also in assessing the water-yielding potential of an aquifer in the basement complex (Okwueze, 1996; van Overmeeren, 1989; Chilton and Smith-Carington, 1984). Siting high yielding water boreholes, which can produce water consistently and continuously for a long period of time in the basement complex terrain can be problematic. This may be, as proper identification of aquifers in the crystalline basement complex, based on sound scientific methods, is rarely done correctly. The present study, therefore, focused attention on the identification and assessment of the aquifers by using geoelectrical method of resistivity at Ado-Ekiti, Igede-Ekiti and Igbara-Odo areas in the basement complex of South western Nigeria.

Materials and Methods

For the collection of geophysical data in this study, an ABEM terrameter SAS 300B was used. The traverse lines were established along the 320^0-140^0 azimuths. The method used in collecting data was the vertical electric sounding (VES) based on Schlumberger electrode configuration arrangement. This method had the advantage of giving very good resolution of vertical variations in the apparent resistivity, thickness of the subsurface formation and saturation of the terrain of study (Bala and Ike, 2001). Eight

VES stations were established and fully penetrated in the three towns in the area of study. Electrode separations varied from 2 to 266 m, thus ensuring a reasonable depth of investigation of about 55 m on the average. The general morphological, hydrogeological and geological appraisal of the area carried out dictated the choice of the location of VES points. The data collected were interpreted using partial curve-matching technique and the direct mathematical methods. The resulting data were reinterpreted using RESIST- a computer assisted interpretation package that uses linear filter, which gave a better resolution of the number of geoelectric layers that could be of geological significance in the study area. The data obtained were finally interpreted as geoelectric curves and sections.

Results and Discussion

Geological setting. The geology of the study area has been well studied and documented in literature (Olarewaju, 1987; Tubosun *et al.,* 1984; Olarewaju, 1981; Cooray, 1975; Hubbard, 1968). In Ado-Ekiti area, the basement crystalline rocks include migmatite-gneissic complex, intruded by the contemporaneous charnockite and older granite and metasediments, which are quartzite-muscovite schists (Fig. 1). The granite gneiss migmatite and the metasediments have been affected by repeated metamorphic episodes, which reached a climax in the Pan-African thermotectonic period (Dada, 1998; Oyinloye, 1995). The charnockite in Ado-Ekiti area occurs as coarse grained, fine grained and gneissic varieties. Other late intrusive rocks are porphyritic biotite-hornblende, older granite and fine to medium grained granite. The gneissic charnockite shows some gneissic banding, fracturing and jointing. In Igede-Ekiti area, the geology is dominated by migmatite and granite gneisses with pegmatite and older granite intrusions. These migmatite and gneisses form low and high hills and may be juxtaposed in places with metasediments, which are dominantly quartzitic. The migmatite and granite gneisses are foliated, folded, fractured and faulted. Erosional surfaces (ex-foliation) are commonplace phenomena on these rocks. The migmatite-gneissic terrain extends from Igede-Ekiti to Ilawe-ekiti and to Igbara-Odo (Fig. 1). The structure, texture and mineralogy of the gneisses and migmatite at Igbara-Odo are similar to those observed on the Igede-Ekiti migmatite-gneissic complex. In all these three zones, weathering is very deep. It is not uncommon to observe sediments and lateritic soil derived from the basement rocks covering-up rock outcrops. Geophysical data indicate that the area of study has an irregular weathering front, that is, depth to the fresh bedrock varies rapidly within a short interval of space.

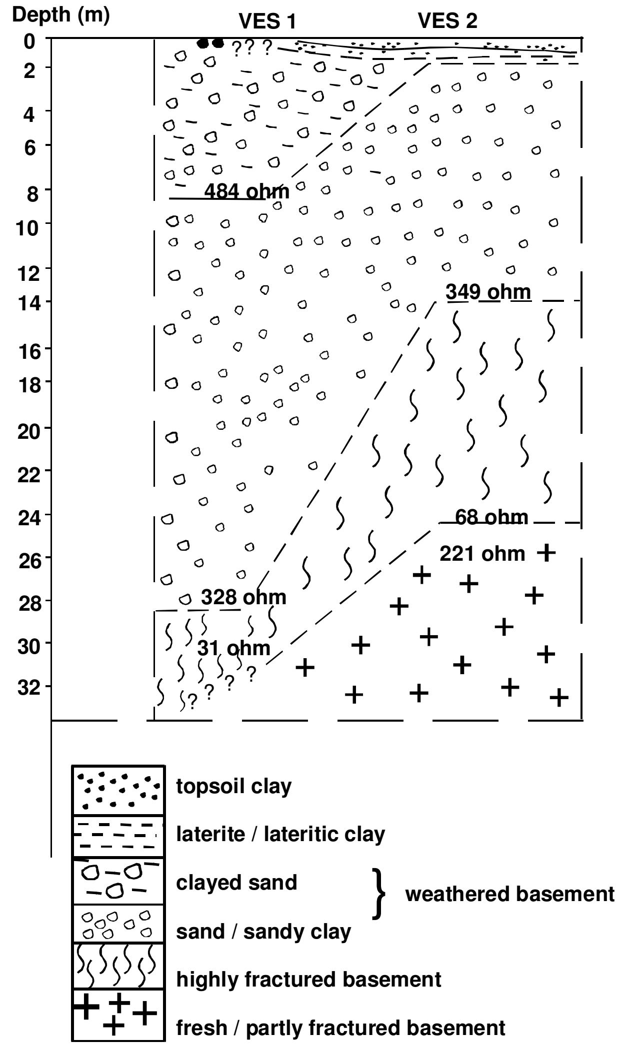

Fig. 2. Geoelectric section across vertical electric sounding (VES) station at Ado-Ekiti.

Ado-Ekiti: VES 1 and VES 2. The summary of curve characteristics, types and description of each geoelectric layer in all the three areas investigated is shown in Table 1. Two stations were investigated at Ado-Ekiti. The geoelectric section across the vertical electric sounding (VES) of the two stations is given in Fig. 2. The VES 1 station showed a system of dry top soil underlain by a layer of plastic clay (Table 1). The curve characteristics ($\rho_1 > \rho_2 > \rho_3$) gave a Q type curve (Fig. 3, Table 1). Only three geoelectric layers were distinctly penetrated here to about a thickness of 32 m. This station, which was somewhat saturated, held no promise for siting a water borehole because the aquifer was too thin (Fig. 2, 3). The VES 2 station at Ado-Ekiti consisted of five geoelectric layers. The first layer (1.1 m thick) formed the dry top soil. This was underlain by weathered clayey soil (2.6 m thick). The third layer was a saturated sandy-clayey soil (8.7 m thick). A sec-

Table 1. Summary of geoelectric observations in the areas of study

Location	Curve characteristics	Curve type	Number of layers	Description
Ado-Ekiti				
VES 1	$\rho_1 > \rho_2 > \rho_3$	Q	3	Clayey sand underlain by sand/sandy clay on top of fractured bedrock
VES 2	$\rho_1 < \rho_2 > \rho_3 > \rho_4 < \rho_5$	KQH	5	Dry top soil, sand/sandy plastic clay, fractured bedrock on top of fresh/partly fractured bedrock
Igede-Ekiti				
VES 1	$\rho_1 < \rho_2 > \rho_3 < \rho_4$	KH	4	Dry top soil, weathered basement clayey, clayey sand on top of undeterminable fractured basement
VES 2	$\rho_1 < \rho_2 > \rho_3 > \rho_4 < \rho_5 > \rho_6$	KQHK	6	Dry top soil, fractured basement, fresh basement on top of fractured basement
VES 3	$\rho_1 < \rho_2 > \rho_3 < \rho_4 > \rho_5 < \rho_6$	KHKH	6	Dry top soil, thin weathered basement, sand/sandy clay, clayey sand, fractured basement and fresh basement rock
Igbara-Odo				
VES 1	$\rho_1 > \rho_2 < \rho_3 < \rho_4$	HA	4	Dry top soil, followed by sandy clay on top of sand/clayey sand, resting on fractured basement
VES 2	$\rho_1 > \rho_2 < \rho_3 < \rho_4 < \rho_5$	HAA	5	Dry top soil on top of sandy clay, followed by sand/clayey sand, underlain by fresh basement rock over a fractured basement
VES 3	$\rho_1 < \rho_2 > \rho_3 < \rho_4$	KH	4	Dry top soil on top of sandy clay, underlain by thick column of sand/sandy clay, resting over the fresh basement complex

tion of highly fractured weathered bedrock in the fourth layer underlies the third layer. The fifth layer was a partly fractured fresh gneissic bedrock (Fig. 2, Table 1). The curve type at VES 2 station at Ado-Ekiti ($\rho_1 < \rho_2 > \rho_3 > \rho_4 < \rho_5$), which was classified as a KQH (Fig. 4), indicated that this station could be promising for groundwater yield if a borehole was sited there.

Igede-Ekiti: VES 1, VES 2 and VES 3. Stations at Igede-Ekiti consisted of four, six and six geoelectric layers, respectively, at VES 1, VES 2 and VES 3 (Fig. 5-8, Table 1). In all the three stations, the top soil was clay/lateritic sand, which varied from 0.6 m to 1.2 m in thickness. The second geoelectric layer at VES 1 was about 7.8 m thick, which thinned out to about 4.8 m at VES 2 and further reduced to 1.1 m at VES 3 (Fig. 5). This second layer was a weathered clayey section of the bedrock. The third layer was absent in VES 1 and VES 2, but present as sand/sandy clay at VES 3 with a thickness of 3.3 m. This section was followed by a layer of saturated clayed sand, which was relatively thin at VES 1, increasing in thickness from VES 2 to VES 3 (14.3 m and 23.1 m), respectively (Fig. 5). Following the geoelectric layer four was a system of fractured and partly weathered bedrock (layer five), the thickness of which was undeterminable at VES 1, but varied from 39.1 m in VES 2 and up to 151.9 m at VES 3. The geoelectric layer number four overlies this saturated fractured bedrock. The sixth layer was the fresh basement rock, which appeared at VES 2 and VES 3. At VES 1, the characteristic curve, $\rho_1 < \rho_2 > \rho_3 < \rho_4$, was a KH type curve (Fig. 6, Table 1), while at VES 2, the characteristic curve, $\rho_1 < \rho_2 > \rho_3 > \rho_4 < \rho_5 > \rho_6$, was KQHK type curve (Fig. 7, Table 1). At the VES 3 station, the curve, $\rho_1 < \rho_2 > \rho_3 < \rho_4 > \rho_5 < \rho_6$, was a KHKH type curve (Fig. 8, Table1). This curve type, which was usually diagnostic of a system of combined weathered and fractured layer aquifers, is indicative of a promising groundwater accumulation and possible high yield, given the adequate saturation of such acquifer systems.

Igbara-Odo: VES 1, VES 2 and VES 3. The resistivity data obtained for these stations revealed four and five geoelectric

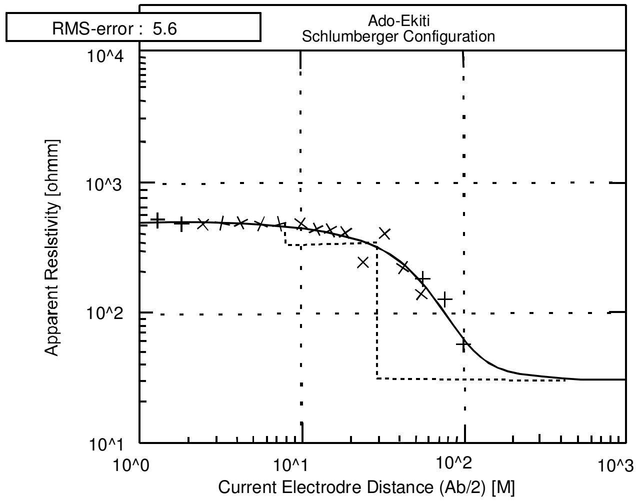

Fig. 3. Geoelectric curve for vertical electric sounding VES 1 station at Ado-Ekiti.

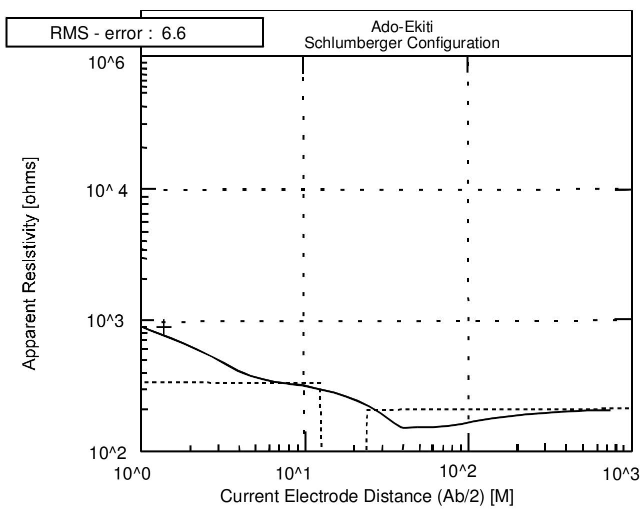

Fig. 4. Geoelectric curve for vertical electric sounding VES 2 station at Ado-Ekiti.

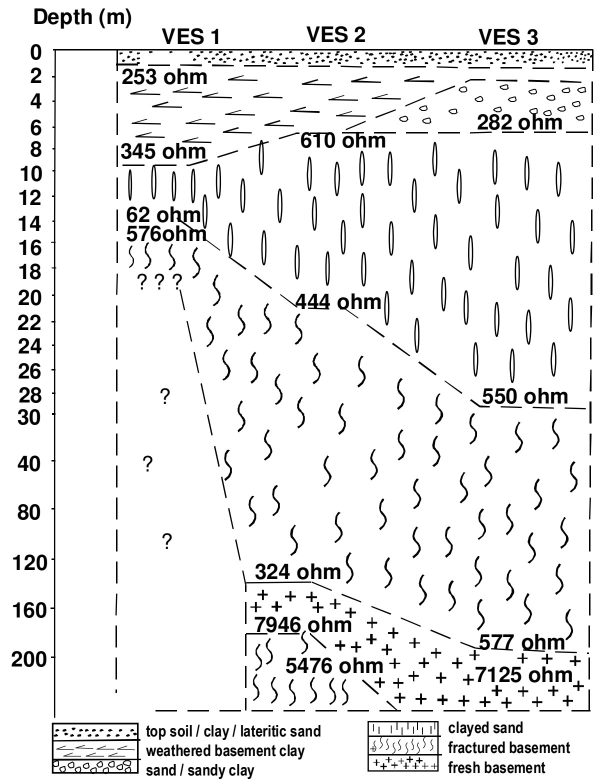

Fig. 5. Geoelectric section across vertical electric sounding (VES) stations at Igede-Ekiti.

layered sections in which a relatively thin top soil covered a sandy clay soil which formed the second geoelectric layer. This second geoelectric layer was relatively thick (3.8 m) at VES 3 (Fig. 9). The third geoelectric layer was a system of saturated sand/clayey sand derived from the weathering of the bedrock. This section was relatively thin at VES 1 (7.4 m), but increased in thickness at VES 2 and VES 3, 10.7 m and 21.1 m, respectively. At VES 1, the third geoelectric layer was underlain by a fractured saturated basement rock. At VES 2, this fractured bedrock only appeared after the fresh basement rock, which was penetrated. The same situation was obtained at VES 3 (Fig. 9). Here, the regolith laid directly on the fresh basement rock at VES 2 and VES 3, whereas the regolith was lying on fractured basement rock at VES 1. The characteristic curve at VES 1, $\rho_1 > \rho_2 < \rho_3 < \rho_4$, was an HA type curve (Fig. 10, Table 1), whereas $\rho_1 > \rho_2 < \rho_3 < \rho_4 < \rho_5$, was an HAA type curve at VES 2 (Fig. 11, Table 1). VES 3 produced $\rho_1 < \rho_2 > \rho_3 < \rho_4$, which was a KH type curve (Fig. 12, Table 1).

From the foregoing discussion it may be observed that the aquifers at Ado-Ekiti VES stations were in the regolith, which was a system of clayey sand and sandy clay (weathered products of the basement rock) that laid on the fractured bedrock. At VES 2 only the clayey sand was saturated, but it was too thin (8.7 m) to support a high yielding borehole. This problem was further compounded by the underlying layer of sandy clay which was plastic and, therefore, limited the recharge potential of the aquifer. The recharge here was through the annual rainfall and water stored in fractures of the bedrock. At Igbara-Odo, the aquifers were in both the regolith and fractured bedrock at VES 1 and in the regolith at VES 2 and VES 3. At Igede-Ekiti the aquifers were located in the regolith and fractured bedrock at VES 2 and VES 3. In all these stations, recharge was through rainfall. At VES 2 and VES 3, the water accumulated in the fractured bedrock might serve as a recharge source for the overlying aquifer in the dry season, which made the VES stations at Igede-Ekiti highly promising groundwater acquifers.

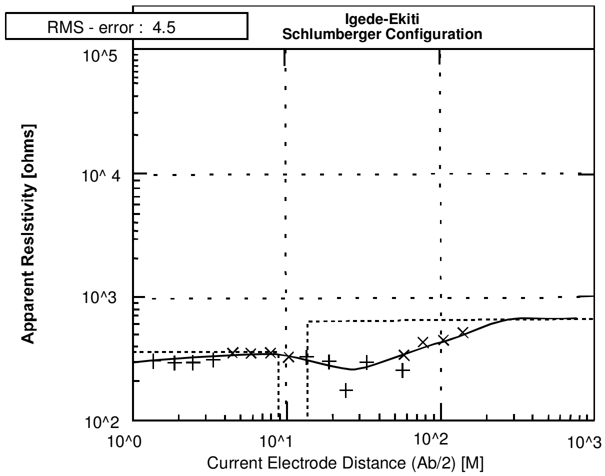

Fig. 6. Geoelectric curve for vertical electric sounding VES 1 station at Igede-Ekiti.

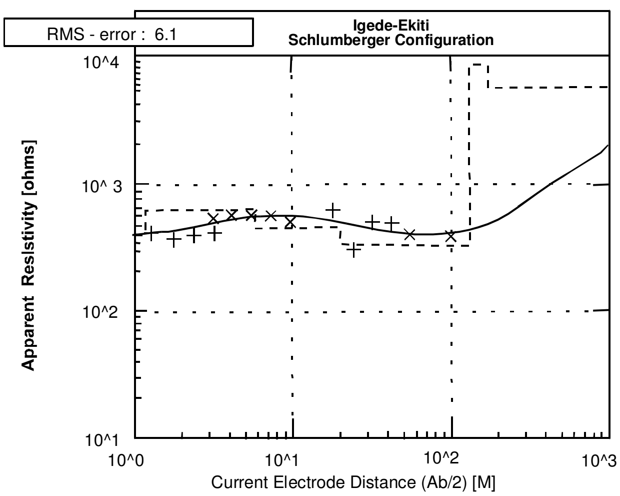

Fig. 7. Geoelectric curve for vertical electric sounding VES 2 station at Igede-Ekiti.

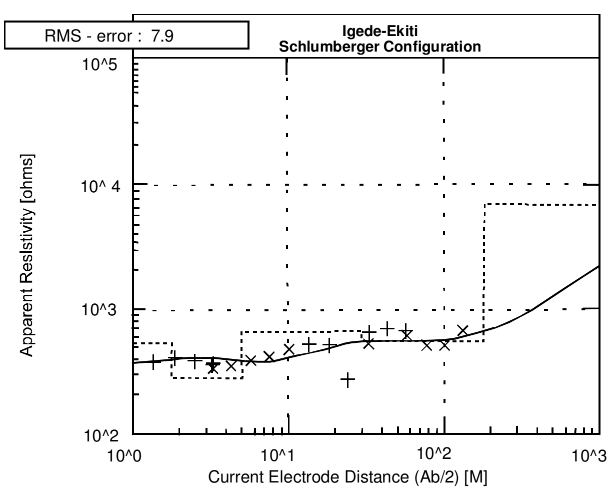

Fig. 8. Geoelectric curve for vertical electric sounding VES 3 station at Igede-Ekiti.

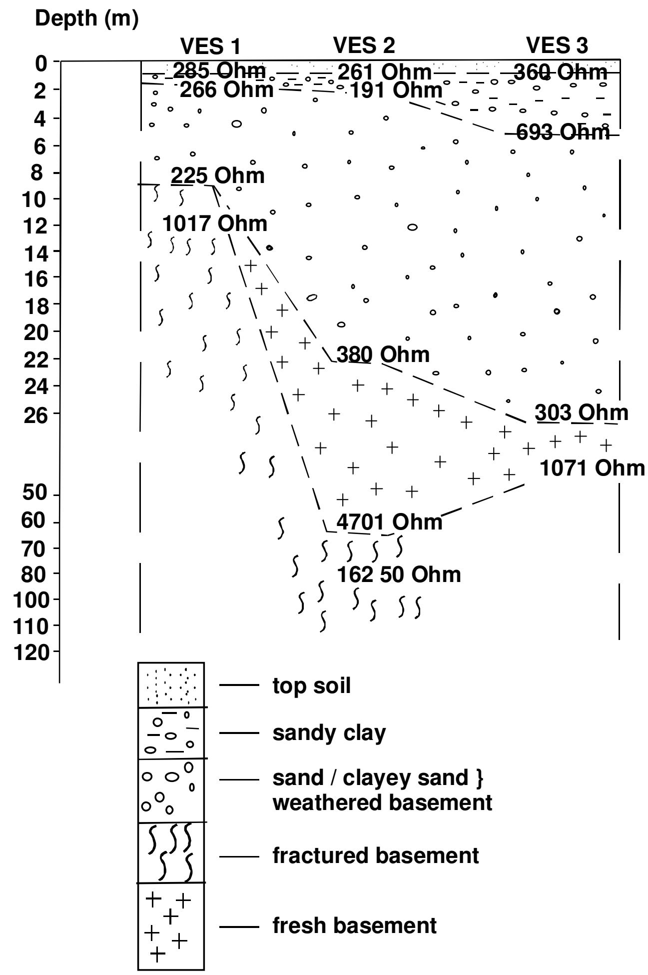

Fig. 9. Geoelectric section across vertical electric sounding (VES) stations at Igbara-Odo.

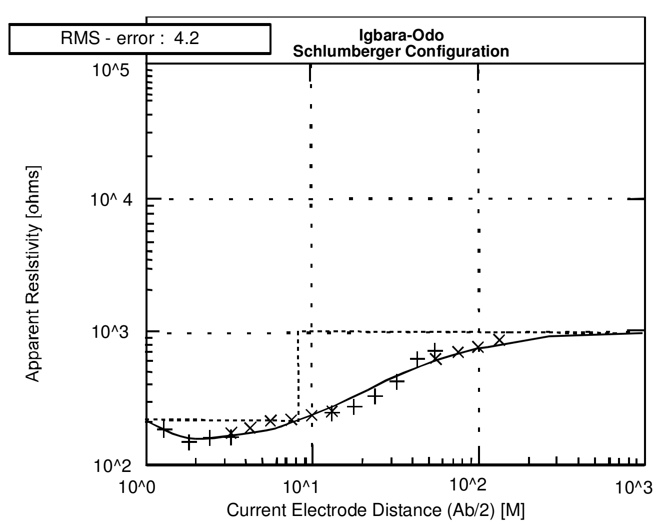

Fig. 10. Geoelectric curve for vertical electric sounding VES 1 station at Igbara-Odo.

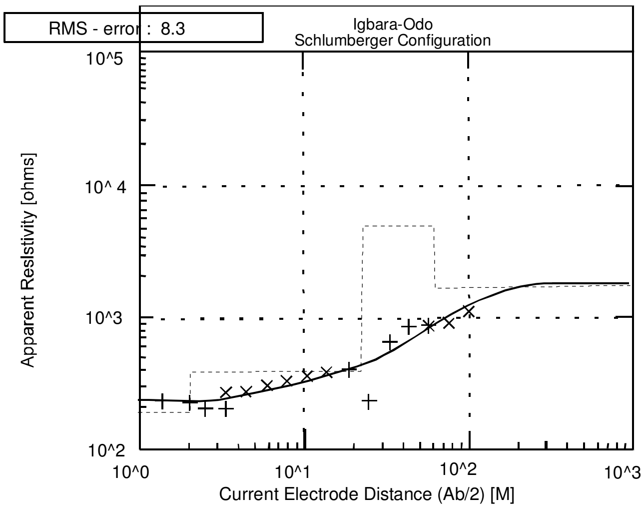

Fig. 11. Geoelectric curve for vertical electric sounding VES 2 station at Igbara-Odo.

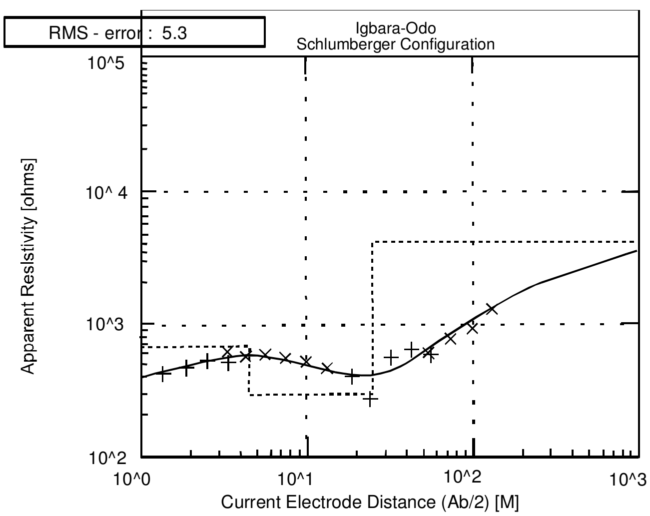

Fig. 12. Geoelectric curve for vertical electric sounding VES 3 station at Igbara-Odo.

Conclusions

The results obtained in this study showed that aquifers occurred both in the regolith and fractured basement rocks in these areas. In places, the aquifer in the regolith laid directly on saturated fractured basement rock, which might enhance recharge potential of the aquifer, especially in the dry season. From the processed data and their interpretation, the stations investigated in this study at Igede-Ekiti and Igbara-Odo held high promise for siting high yielding water boreholes in these areas, especially where both the regolith and fractured bedrock constituted the aquifers. Thickness and recharge problems might make siting a borehole at the stations investigated at Ado-Ekiti undersirable.

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