

Geo-electrical delineations within Kubanni basin, north-central Nigeria

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Received: 14 December 2011 / Accepted: 5 October 2012
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Abstract The research site is the whole landmass of the Federal College of Education, Zaria, seated on basement complex of north-central Nigeria. Direct current resistivity geophysical method was employed to characterise parameters such as the basement depth and topography, aquifer depth and thickness, weathered basement distribution as well as mapping of orientations of fractures and faults present in the premises using radial sounding technique. The conventional vertical electrical sounding (VES) Schlumberger array was carried out at 40 stations, and eight of which were radial stations. Radial sounding was used to establish resistivity anisotropy which gives clue for the choice of consistent VES profile direction used throughout the fieldwork. Results from the resistivity interpretation suggest three layers in most parts of the premises with some minor occurrence of two and four layers. The first layer (topsoil) has its thickness ranging between 3.5 and 14.0 m; second layer (weathered basement) thickness ranges between 9.0 and 36.5 m, while the third layer (fresh basement) is deepest (40.1 m) towards the eastern corner of the area. The aquifer depth ranges from 1.5 to 4.0 m with a thickness range of 5.0 to 14.0 m. The thickest aquifer occurs around the centre to the west in the area. Results from radial sounding show presence of resistivity anisotropy, an insight to fracturing and faulting; this is more pronounced around the west-central part of the premises.

Keywords Geometrical factor · Radial sounding · Aquifer depth · Fracturing and faulting · Basement and resistivity anisotropy

Introduction

The demand for sub-surface structural information is immense in a developing organisation such as the present study site. In fact, with the recent federal government emphasis on upgrading federal colleges to universities of education, the search for sub-surface information on those campuses becomes imperative. This will be of immense use during constructions of physical structures to accommodate the expected larger population (Bactaves Geo-Technical Services Nigeria Limited 1992; Harold 1970).

The premises lack detailed geophysical investigation as all previous geophysical works around the area are regional in nature, though the college site falls within the scope of some of them. Identification of the strategic and potential positions for the location of boreholes and high-rise buildings and determination of suitable depth of sewage system, among others, are the needs which the outcomes of this study provide.

Location and brief geology

Located around the north-east of Zaria local government area in Kaduna state of Nigeria, the survey area is bounded approximately by longitudes 7°43'21" E and 7°43'49" E and latitudes 11°05'10" N and 11°5'28" N within the Zaria topographic map sheet 102 SW (Fig. 1) The area is located at the extreme south-eastern end of Kubanni River basin and within the semi-arid zone of Nigeria (Harold 1970).

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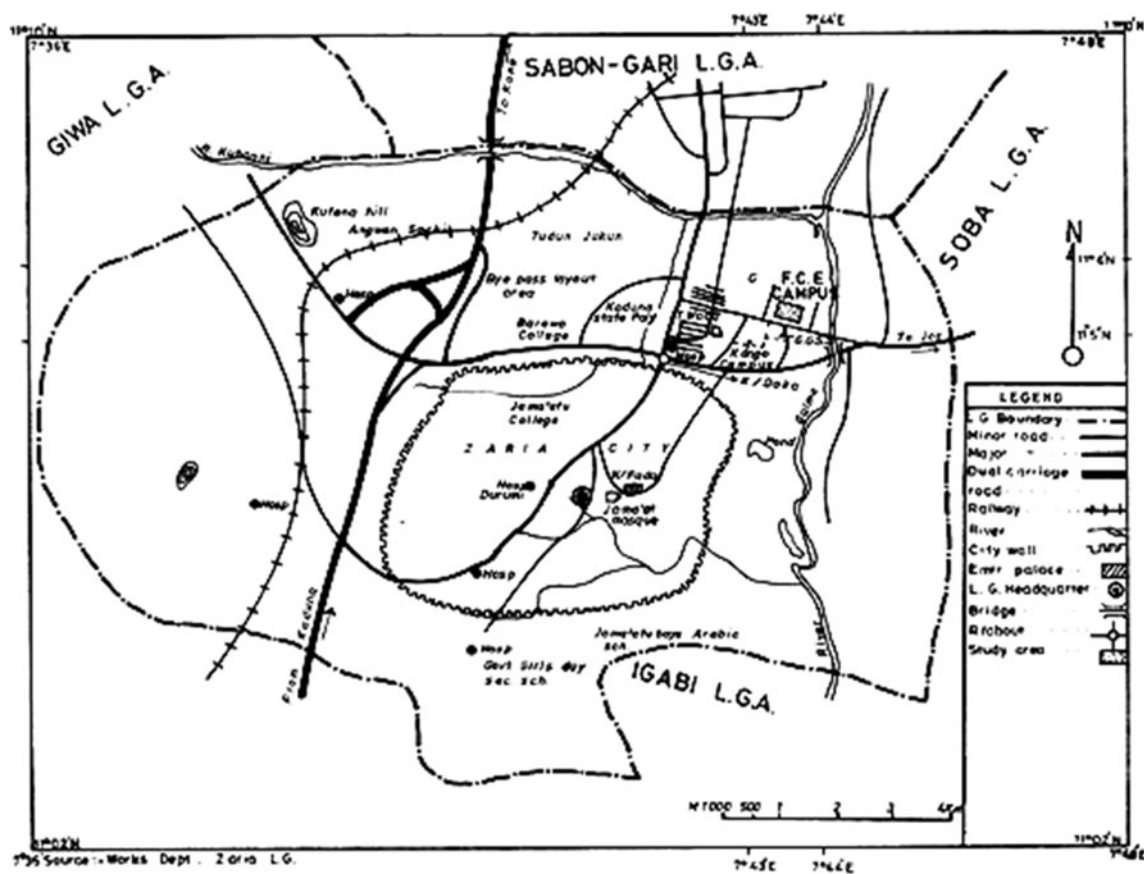
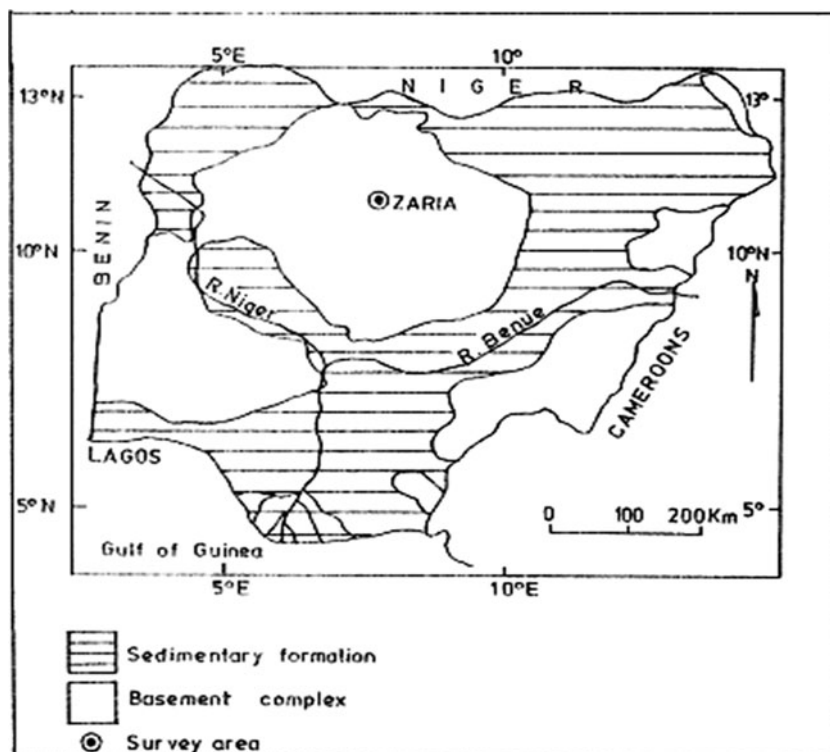


Fig. 1 Location map of the study area (Ministry of Urban and Regional Planning, Kaduna State, Nigeria)

Fig. 2 Generalised geology of Nigeria showing the study area (Geological Survey of Nigeria 1984)



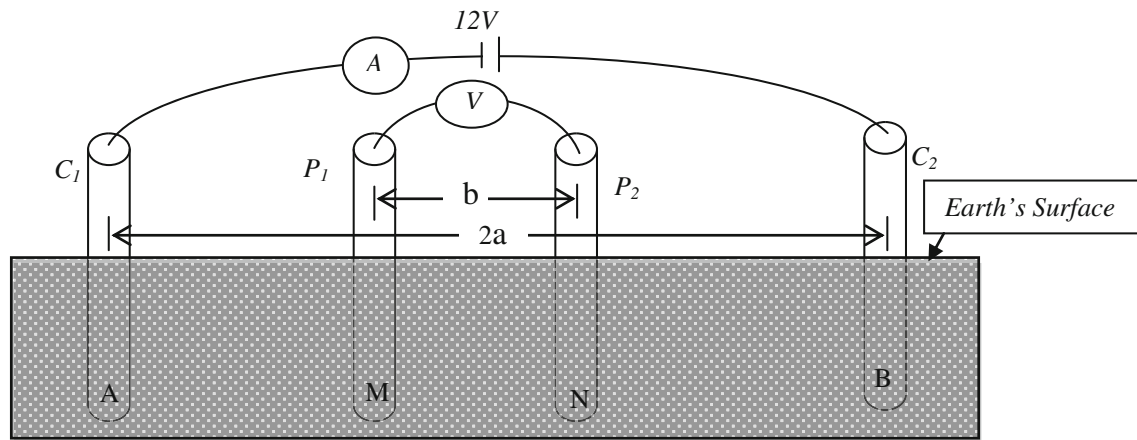


Fig. 3 Derivative of geometric factor from Schlumberger array

The area is on the northern sector of the Nigeria basement complex (Fig. 2). The basement complex (Oyawoye 1964) is divided broadly into the following:

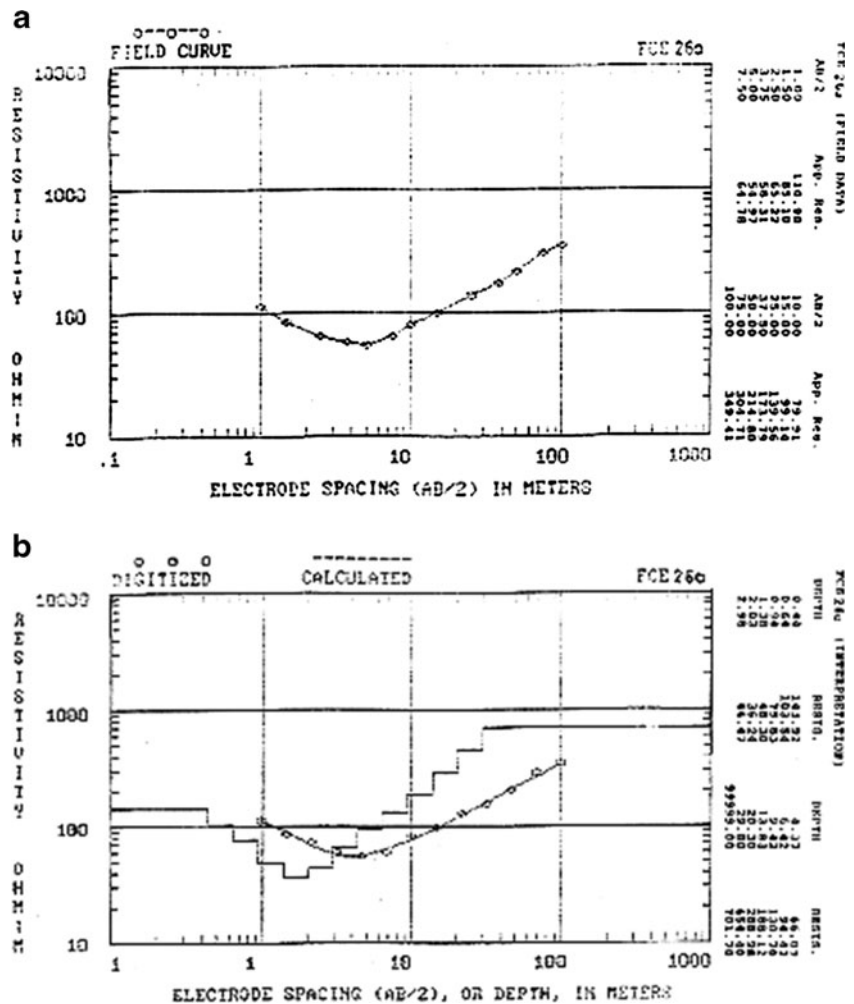
1. Older metasediment,
2. Younger metasediment,

3. Older granite and

4. Younger granite, both metavolcanics and volcanics or basement gneiss and migmatite.

The comprehensive map of rock units in Northern Nigeria, which was presented by McCurry (1970) and

Fig. 4 **a** VES curve at station 26. **b** Model interpretation of the VES 26



reviewed by Webb (1972), shows that the study area lies on the older granite of the basement complex (Fig. 2). The different basement rocks of Kubanni basin include the following:

1. Coarse porphyritic biotite granites,
2. Medium-coarse-grained biotite granite gneiss,
3. Aplite and granite; pegmatite and quartz veins intrude most of the bodies and
4. Weathered basement (Eigbefo 1978).

However, the surface of the older granite basement in the survey area was found to be overlain by deposits which listed as older laterite (McCurry 1970), younger laterite, older alluvium and younger alluvium. This superficial deposit finds its value in the areas acting as a recharging medium to the aquifer and as a shield to storage when it is underlain by a weathered basement.

Review of previous related studies in the survey area

In spite of the fact that their locations were not specified, the presence of prominent, steeply dipping joints in some outcrops of granite in the Kubanni basin was reported (Du-Preez 1952). He furthered that some of the joints were found to contain ground water. Danladi (1985) equally confirmed the presence of water-bearing fractures, but aquifers are isolated and located at shallow basement areas of Zaria.

Hassan (1987) reported that the bedrock is undulating, with depths of burial increasing towards the southern part of the present survey area. He estimated that the depths vary between 5 and 60 m in the north–south direction and that the area is likely to have been faulted or down thrown.

A regional study of sheet 102 SW by Olowu (1967) revealed that, with the exception of Galma River, all streams in the area are seasonal and that the depth to water table

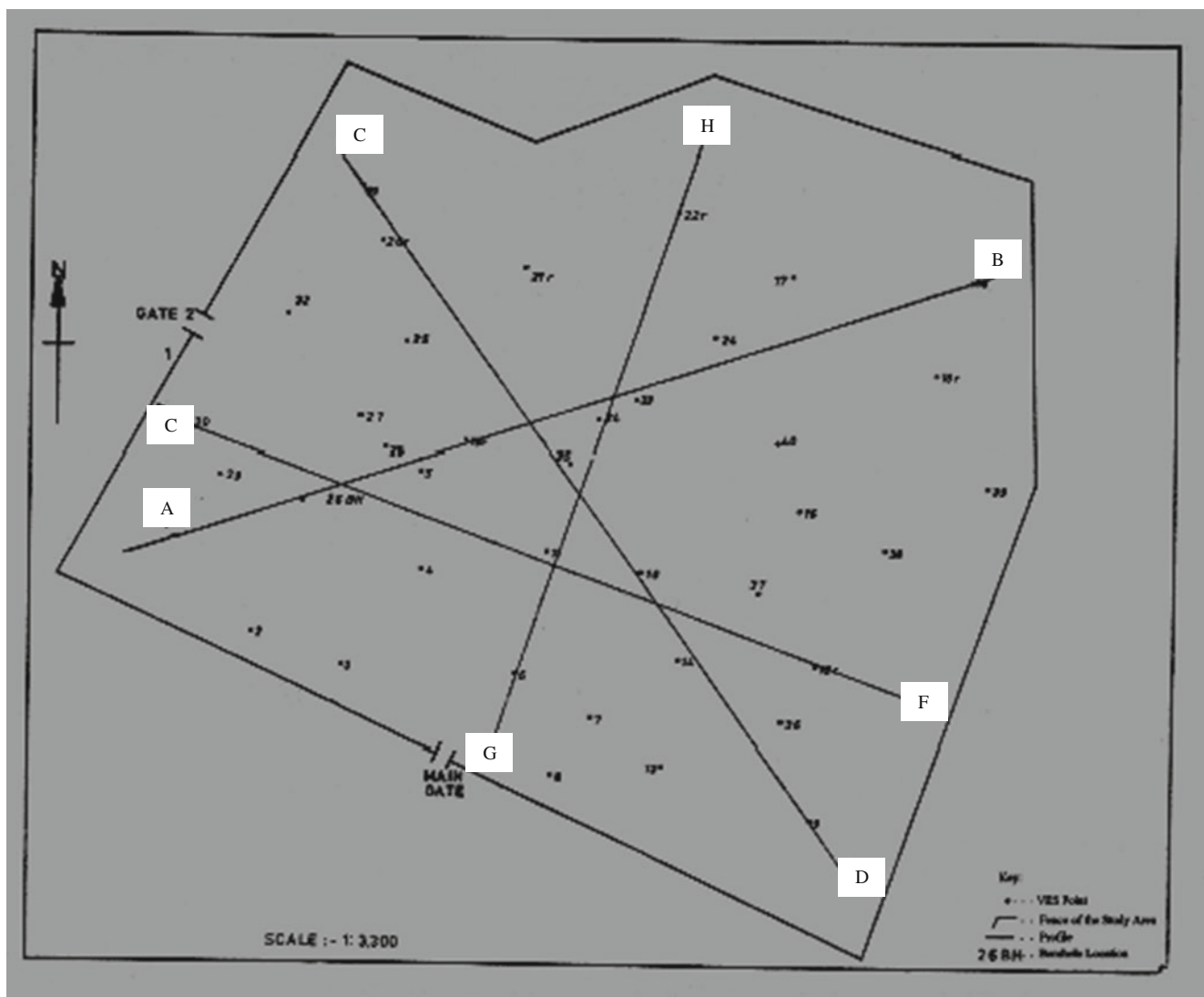


Fig. 5 VES points and the profiles used

increased progressively away from the banks of the river during dry season. He also reported the occurrence of ground water in joints, weathered portion of basement complex and in overlying alluvium. Eigbefo (1978) not only confirmed that the depths to water table at various points in Kubanni basin range between 3 and 10 m but also found out the range of thickness of weathered basement to be 1 to 30 m. McCurry (1970) studied the basement geology of Zaria and established that basement complex rock is made up of older granite and biotite granite gneiss. Klinkenbara (1970) classified soils in Zaria under leached ferruginous tropical soils. According to him, the soil is weakly developed near the inselbergs and hydromorphic soils and formed Fadama soils (i.e. subject to periodic flooding) and that the soils contain about 40 % clay at some depths.

Theory of resistivity method

The DC resistivity method is based on the superficial measurement of the electric potential variation (potential difference) caused by the sub-surface resistivity variation resulting from the various rock materials when an electric current is driven into the Earth. Thus, the ratio of the potential to the current driven into the Earth will give the electric resistance which, in turn, elicit the resistivity variations in the sub-surface rock materials (apparent resistivity) measured by the Terrameter on the Earth's surface as shown in Eq. 1 below (Lowrie 2007; Telford et al. 2004; Milson 2003). Events of thunderstorms are evident in the presence of electric field in the Earth, which act radically inward, as if the Earth is a negatively charged sphere. The downward gradient of such field

$$\ell_a = k \left(\frac{\Delta V}{I} \right) \quad (1)$$

from the Earth's surface is around 200 V/m (Lowrie 2007; Milson 2003). Atmosphere has equal and opposite net charges to that of the solid Earth.

where ℓ_a is apparent resistivity; $\frac{\Delta V}{I}$ is the resistance measured by the Terrameter, and k is called the geometrical factor (Fig. 3). For Schlumberger array, let potential electrode separation (MN)= b and current electrode separation (AB)= $2a$.

Any anomalous body at depth within AB would influence the potential field. Such influencing structures make for the inhomogeneity of the Earth's materials. Thus, the varying resistivity measured when electrode array position is varied in an inhomogeneous medium is termed apparent resistivity. Considering A and B as point electrodes on the surface, the equipotential surface is semisphere downward into the ground. So, the surface area of the equipotential

surface is $2\pi L^2$; L being the radius of the equipotential surface. Now, by Ohm's law, potential $V = \frac{I\ell}{A}$.

$$V = \frac{I\ell}{2\pi L} \quad (2)$$

By induction, potentials at M and N due to currents from A and B are as follows:

$$V_M = \frac{I\ell}{2\pi} \left(\frac{2}{a-b} - \frac{2}{a+b} \right) \quad (3)$$

and

$$V_N = \frac{I\ell}{2\pi} \left(\frac{2}{a+b} - \frac{2}{a-b} \right) \quad (4)$$

Potential difference $\Delta V = V_M - V_N$. So, for inhomogeneous body, apparent resistivity

$$\ell_a = \lambda \left(\frac{a^2}{b} - \frac{b}{4} \right) \left(\frac{\Delta V}{I} \right) \quad (5)$$

$$\ell_a = k R \quad (6)$$

That is, in Eq. 1, $k = \lambda \left(\frac{a^2}{b} - \frac{b}{4} \right)$.

Thus, k are determined prior to the survey works from a and b which are predetermined by Dobrin and Savit (1988).

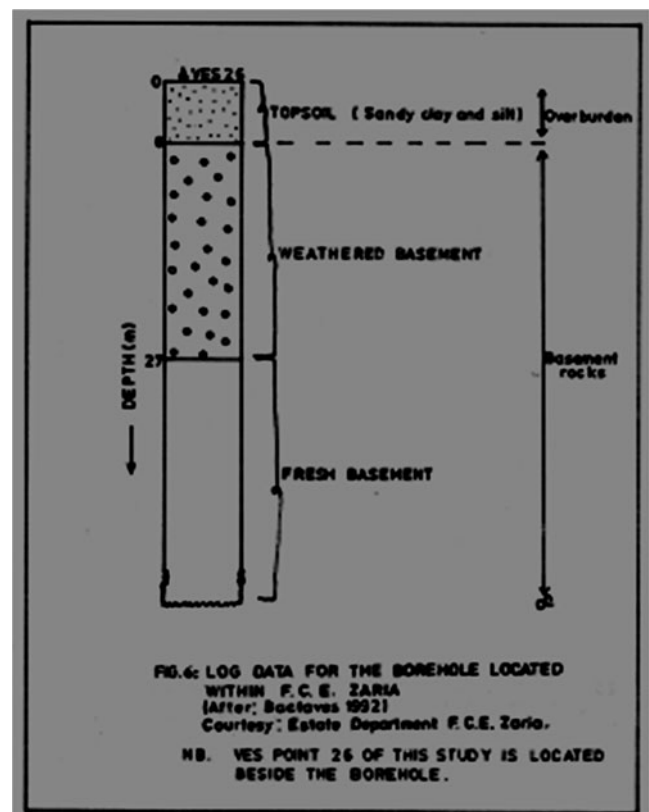


Fig. 6 Log data for the borehole located within FCE Zaria

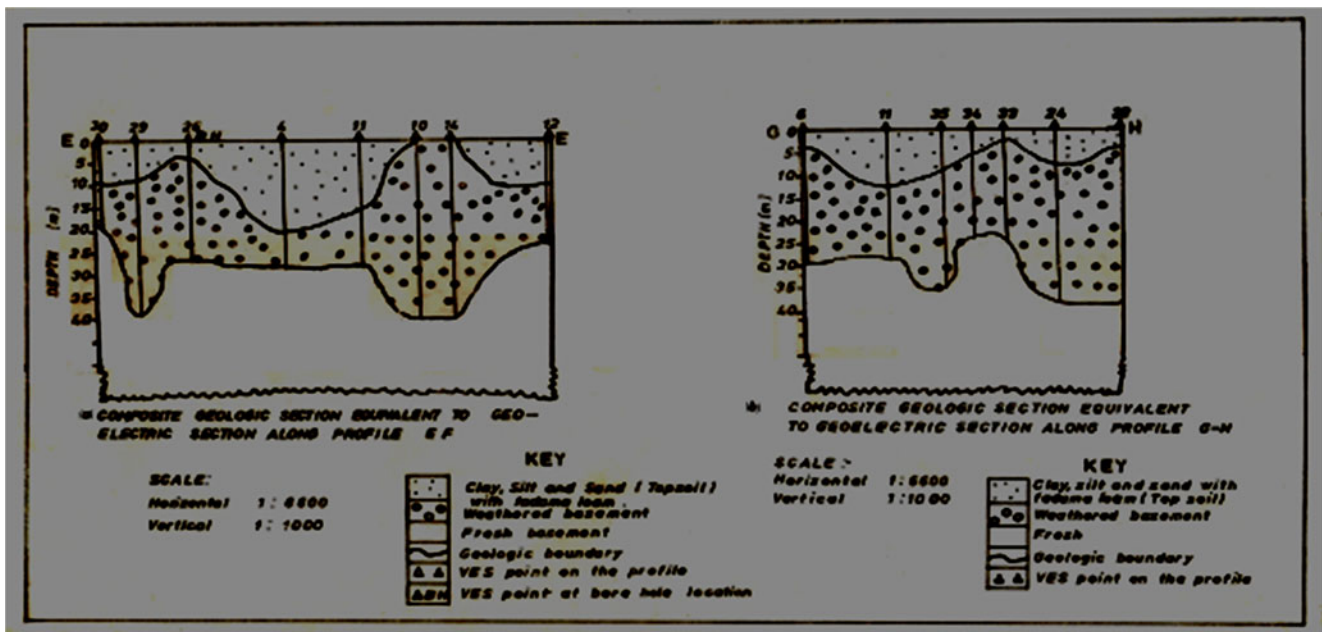


Fig. 7 a Composite geologic section equivalent to geo-electric section along profile EF. b Composite geologic section equivalent to geo-electric section along profile GH

Materials and methods

Schlumberger electrode configuration with total current spread of 200 m was employed to carry out vertical electrical sounding (VES) in 40 stations with ABEM SAS 300 Terrameter suitable for the area in question. Meanwhile, eight out of the 40 stations were sounded radially with four profiles per point. This is aimed at detecting sub-surface resistivity anisotropies and directions.

Having obtained geometric factors k for all the current electrode spacings used, the apparent resistivity values were calculated using Eq. 6 above in conjunction with the field data from Terrameter. These data were then analysed using Zohdy's method which gives the automatic interpretation of the Schlumberger sounding curves to obtain the equivalent n -layer model from the resistivity curve of each sounding. The software further generates depth equivalent apparent resistivity values for each VES point. These values were

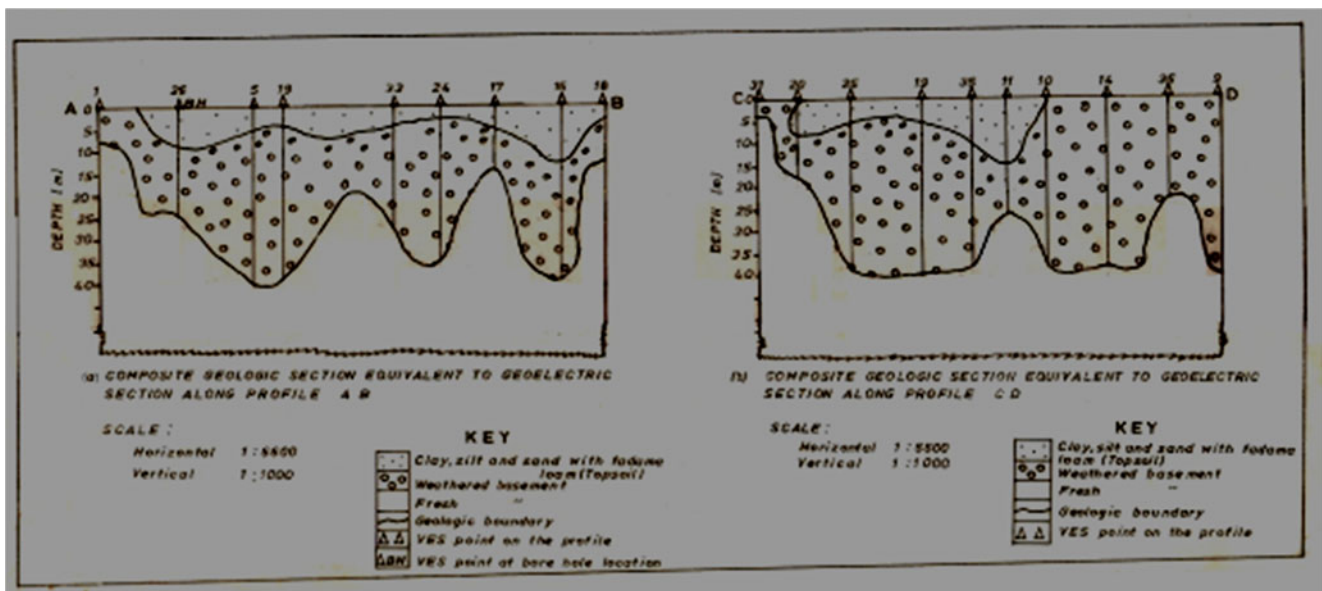


Fig. 8 Equivalent geology of the geo-electric data along profiles EF and GH

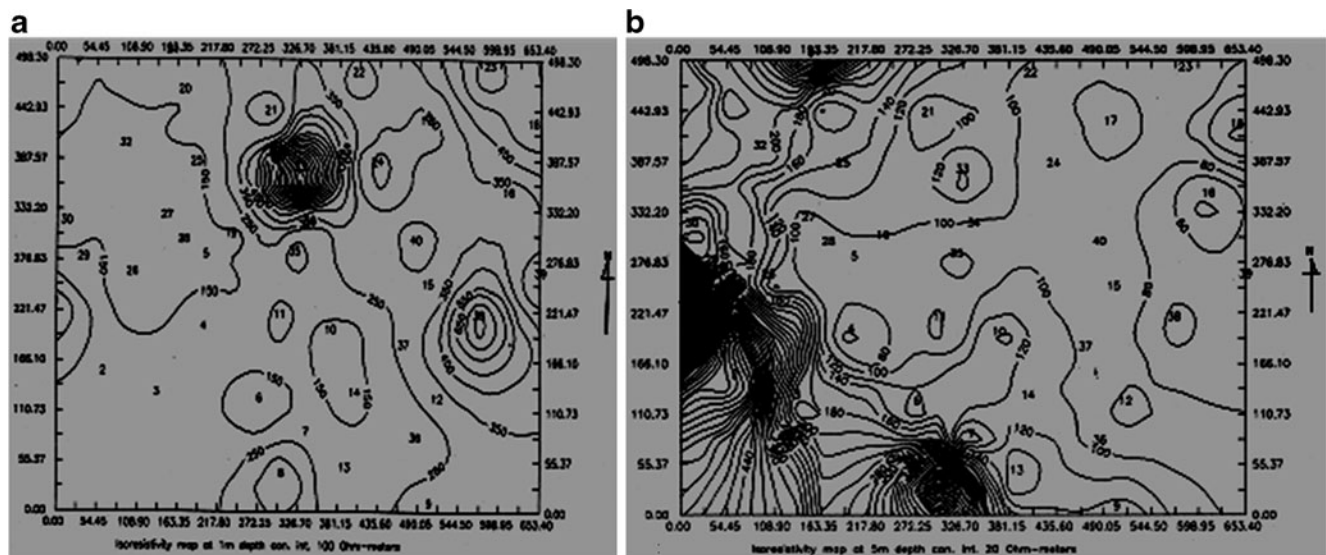


Fig. 9 **a** Isoresistivity map at 1 m depth, contour interval 100Ωm. **b** Isoresistivity map at 5 m depth, contour interval 20Ωm

then used to obtain various contour maps and geologic equivalence of geo-electric sections for two-dimensional interpretations.

Linear plots, on Cartesian plane, of apparent resistivity and current electrode spacing along each of the four profiles at each radial VES point were accomplished. Thus, resistivity anisotropy probably resulting from geologic deformation was observed from the later plots.

Results and discussion

Typical field and the equivalent n -layer-interpreted model curves from apparent resistivity data at all stations generated

by Zohdy's method (Zohdy 1989) are shown in Fig. 4a, b on a 3×4 log-log graph. Similar plot and interpreted model were obtained for each of the 40 VES points. The interpretation of these curves is based on the principle that all points of maxima and minima and points of inflection are indicators of existence of boundaries of different lithologies. Where the values tend to infinity is an indication of fresh basement rock (Zohdy 1989; Oyawoye 1964).

In all, the study site is mostly three layers, as 75 % of the VES results gave three-layer curves. On average, 22.5 % of the study site is two layers, while just 2.5 % are four layers. The first layer (topsoil) composed of sand, silt and clay with *Fadama* loam mixed; the second layer appears to be mostly weathered basement, while the third layer is mainly fresh basement rock.

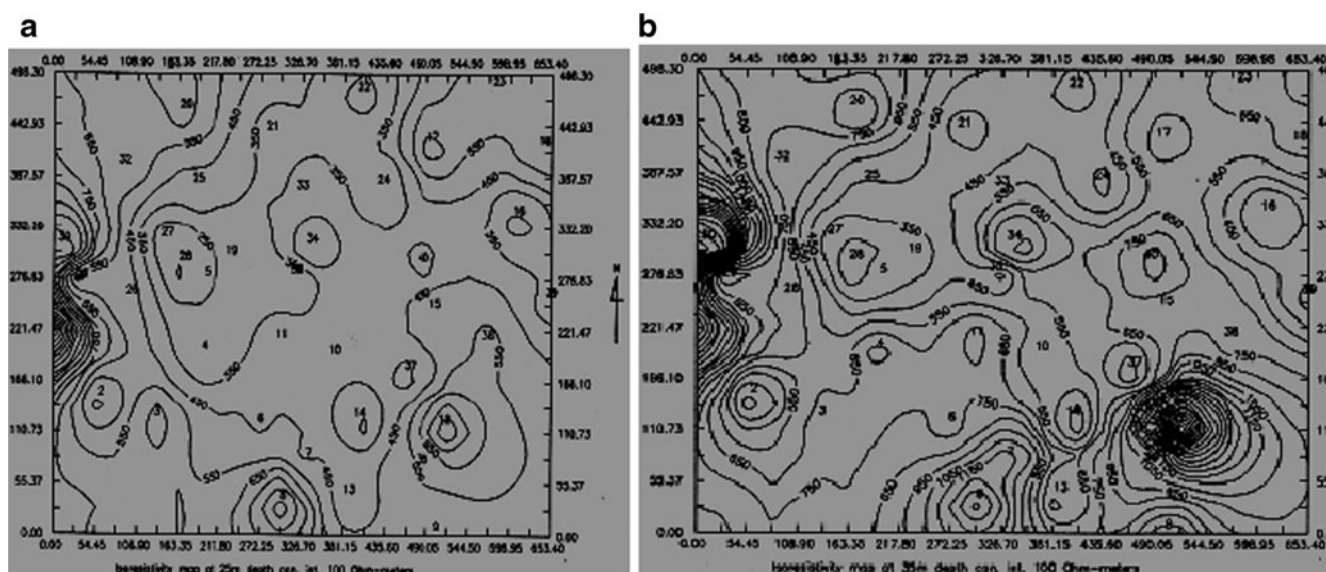


Fig. 10 **a** Isoresistivity map at 25 m depth, contour interval 100Ωm. **b** Isoresistivity map at 25 m depth, contour interval 100Ωm

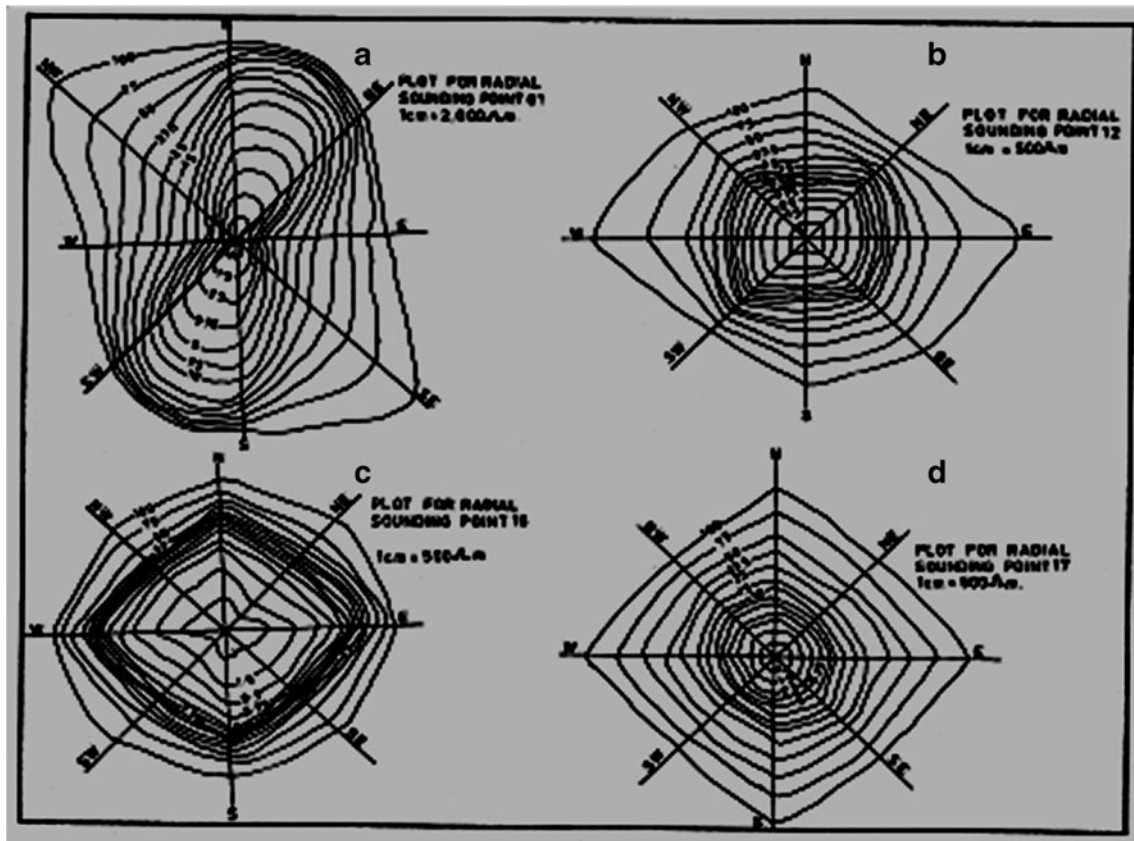


Fig. 11 Linear radial plots

Four profiles were taken (Fig. 5) to obtain two-dimensional vertical cross-section for geologic equivalence of collected geo-electric sounding data. The geologic sections were drawn based on (1) the borehole log data for the

only one existing on the site at the time of the survey (Fig. 6), (2) typical resistivity values from previous works around the area and (3) the result of the rock samples collected from the outcrops in the survey area. Each profile

Fig. 12 Depth to weathered basement map, contour interval 1 m

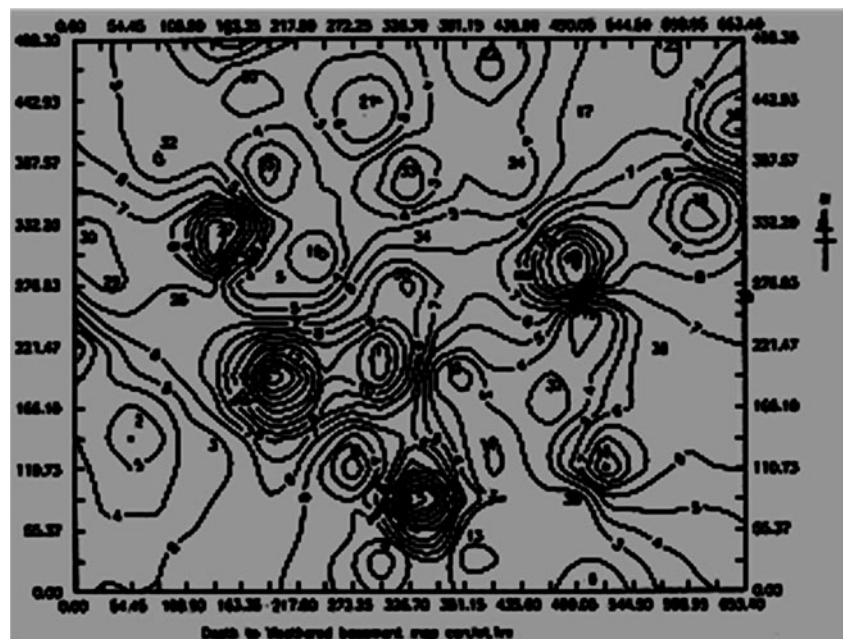
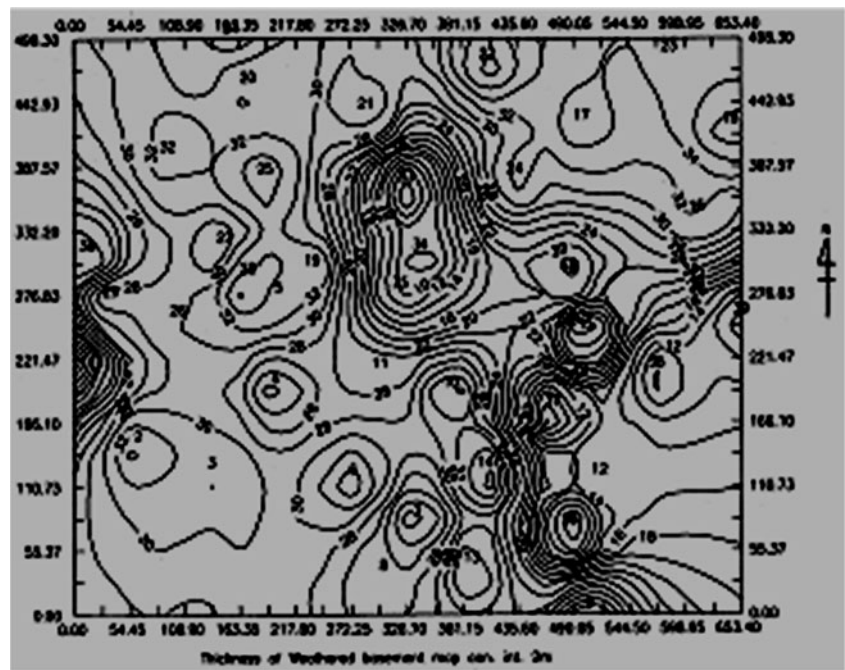


Fig. 13 Depth to weathered basement map, contour interval 2 m



was drawn across several VES points in order to see the inter-connections of occurrences of rock types along the profiles on a vertical cross-section. Hence, the proposed rock matrices are shown in Figs. 7 and 8.

Most models of the profiles revealed three-layer cases (Figs. 7 and 8) with few two-layer occurrences (Figs. 7a, b and 8a). Topsoil is thickest, about 16.5 m, around VES 4 (Fig. 8a), and fresh basement is deepest (about 40 m) around VES 5, 10, 16, 19 and 29 (Figs. 7 and 8). Weathered basement is thickest, about 36.5 m, around VES 5 and 19.

Horizontal iso-resistivity value maps at various selected depth all over the site showed some interesting trends; pictorial evidences are shown in Figs. 9 and 10, drawn at depths 1, 5, 25 and 35 m. Aside from an isolated resistive structure that appears close to the surface, at 1 m depth in Fig. 9a, a progressive downward resistivity increase to depth of 35 m (Figs. 9b and 10a, b) is showed around the south-western corner of the area. The only granite outcrop in the premises is located in this area. Furthermore, low resistivity values were noticed, trending in this area.

Fig. 14 Depth to aquifer map, contour interval 2 m

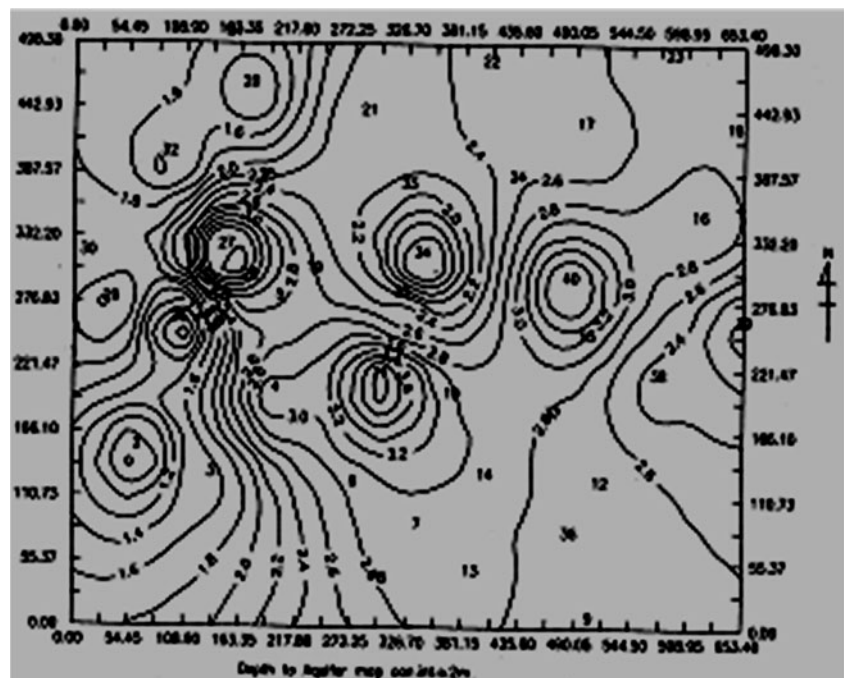
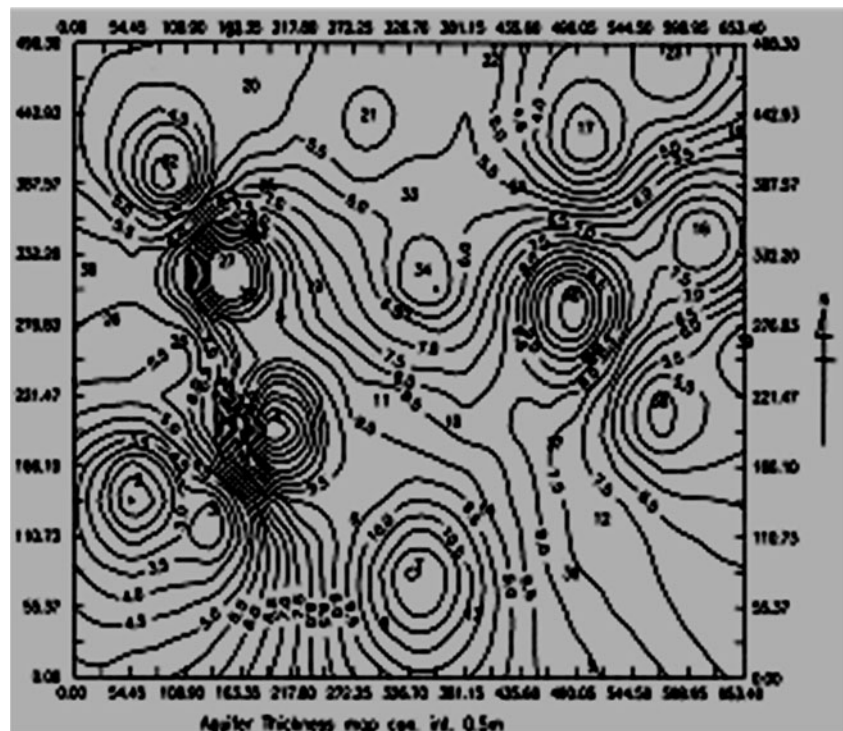


Fig. 15 Aquifer thickness map, contour interval 0.5 m

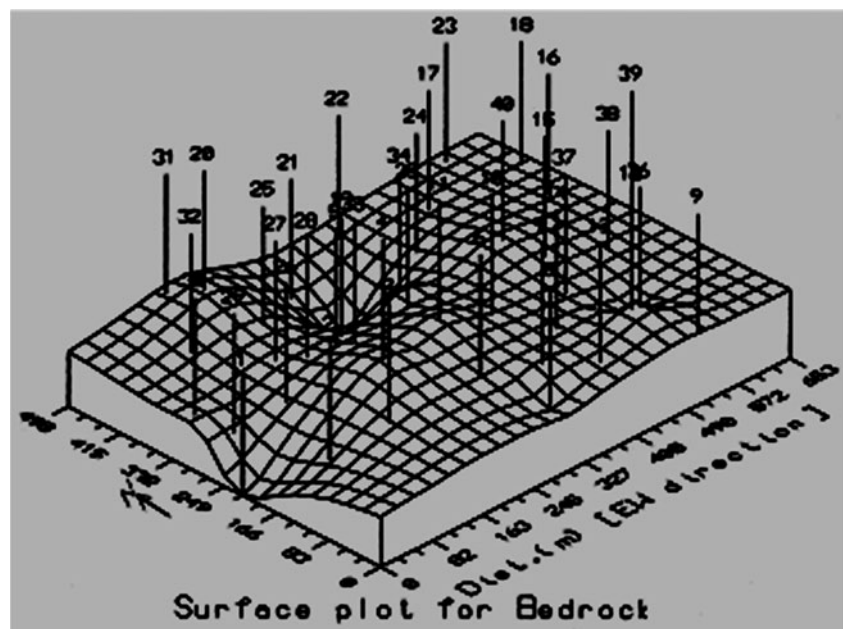


Aside from an isolated resistive structure that appears close to the surface (1 m depth, Fig. 9a), a progressive downward resistivity increase to depth of 35 m (Figs. 9b and 10a, b) is shown around the south-western corner of the area. The only granite outcrop in the premises is located in NE–SW direction; this persists to the last depth probed. This resistivity anisotropy is closely supported by the results from the radial sounding plots, typical of which Fig. 11a–d show. Therefore, the directions of anisotropies at shallow,

intermediate and great depths are NW–SE, NE–SW and E–W in some cases. The presence of anisotropy sometimes depicts occurrence of fracturing and faulting (Telford et al. 2004).

Depth/resistivity data and resistivity range for the weathered basement in the area were employed to obtain depth and thickness of weathered basement distributions shown in Figs. 12 and 13, respectively. Figure 12 shows that weathered basement is deepest at VES 4, about 15 m, which

Fig. 16 Surface plot for the bedrock of the study area



corresponds to the geologic information obtained in Fig. 8a. Figure 13 shows the thickest weathered basement, about 36 m, around VES 4, 10, 11 and 14, which also agrees with the geologic sections shown in Figs. 7b and 8a.

In the same way as above, using resistivity range of aquifer, Fig. 14 shows that aquifer is deepest around VES 11 extending towards VES 4 (about 4.0 m); this might be accounted for by the high thickness of the topsoil as shown in Fig. 14. The aquifer is shallowest around VES 2 extending towards VES 1 with a depth of about 1 m. This is not to be expected, since this is close to the only granite outcrop in the study area. The ground water there could be retained close to the surface by the shallow underlying fresh basement. Figure 15 suggested that the surrounding of VES 4, extending towards VES 5, 27 and 28, is having the thickest aquifer of about 14 m, while the thinnest portion of aquifer (1.0 m) lies around VES 2.

The surface topography of the basement surface all over the study site is shown in Fig. 16. Areas with low topography imply thick overburden, but high topography means thin overburden. The depth of basement ranges from 4 m around VES 33 to 36 m around VES 4, 10, 11 and 14 with the deepest of about 40 m around the eastern part.

Conclusion

The prominent trends of sub-surface anisotropies as obtained from the radial sounding plots are NE–SW, NW–SE and minor E–W. Thus, VES profiles were constrained to one of these directions for consistency. The premise is mostly three-layer formation viz, the topsoil (clay, silt and sand with Fadama loam), the weathered basement and fresh basement. The fresh basement is about 40 m at its deepest part which occurs at the eastern part of the premises. Also, the aquifer occurs partly in the topsoil and in the weathered

basement. It occurs almost everywhere in the area, but with varying thickness. The thickest aquifer occurs in the west-central part of the premises.

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