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Research Paper

Geoelectrical Study for Groundwater Prospect in a Typical Physiographic Basement Area, Southwestern Nigeria

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ABSTRACT: *A geoelectrical study for groundwater prospect in a physiographic area of Oke – Igbede in Ikare – Akoko, southwestern Nigeria was undertaken, with specific objective of evaluating the weathered – fractured basement components. Thirty five (35) Schlumberger soundings were acquired with ABEM SAS 1000 Resistivity Meter. The electrode spacing (AB/2) was varied from 1 – 75 m with maximum spread length of 150 m. Results revealed three to four distinct subsurface geologic/geoelectric layers, comprising clayey / sandy topsoil, weathered basement/fractured basement and fresh basement, with resistivity and thickness values of 33 - 410 Ωm ohm-m and 0 - 2.5 m; 17 - 961 Ωm and 0 - 32.8 m and; infinity ohm-m and thickness respectively. The depth to bedrock varied from 0.1 - 33.5 m indicating a series of uneven basement topography constituting varying thicknesses of the heterogeneous regoliths. The weathered - fractured column is generally sandy with average resistivity of 252 ohm-m, thin with average value of 11.0 m across the area. Fairly thick columns of pockets of basement depressions found particularly towards the northwestern part constituted the aquifer unit(s) with tendencies to yield appreciable quantity of groundwater to wells and boreholes. The diminishing groundwater prospect in the area may be attributed to the general thin nature of the regoliths and limited fractures at deeper depth beyond 30 m. The weathered - fractured components with thicknesses not less than 30 m may be considered as first order priority sites, while others with thicknesses less 30 m are outside choices. It can, therefore, be concluded that the groundwater potential of the study area is feasible with the weathered - fractured components of the basement being considered the targets for groundwater prospect for sustainable domestic water supplies in the area.*

KEYNOTE: *Basement, fractures, groundwater prospect, overburden, resistivity, water supply*

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I. INTRODUCTION

Over the geologic time scale, the basement complex of southwestern Nigeria has undergone intense tectonic and polycyclic deformations associated with Pan African orogenic events. These deformations have resulted in various degrees of fracturing and folding styles [1], [2], and complete obliteration of primary structures [1] and compositional differentiation in places. The magnitude and patterns of folding are indication of different episodes of deformation of rocks [2], of which the study area may not have been an exception. The physiographic factors associated with the physical nature of the area include slope gradient, slope aspect and altitude. These factors are among the most important factors affecting spatial distribution pattern of groundwater flow, reservoir and catchment areas. The need to appraise and update the geologic profile and/or hydrogeology of the weathered – fractured components of the tectonized basement terrain of Oke - Igbede area of Ikare Akoko, hitherto had dominated by hills of crystalline rocks that made groundwater resource exploration difficult, has brought about the recognition of geoelectric sounding technique as an effective tool in prospecting for this earthly mantle resource.

Several utilities such as civil engineering, solid minerals, environmental and groundwater resources are important areas of applications of the technique. The technique, is therefore significant in the evaluation of the hydrogeological characteristics of the basement terrain. The relative resistivity contrast between the water bearing zone and non water bearing or host rocks informed the use of the technique. Delineation of of

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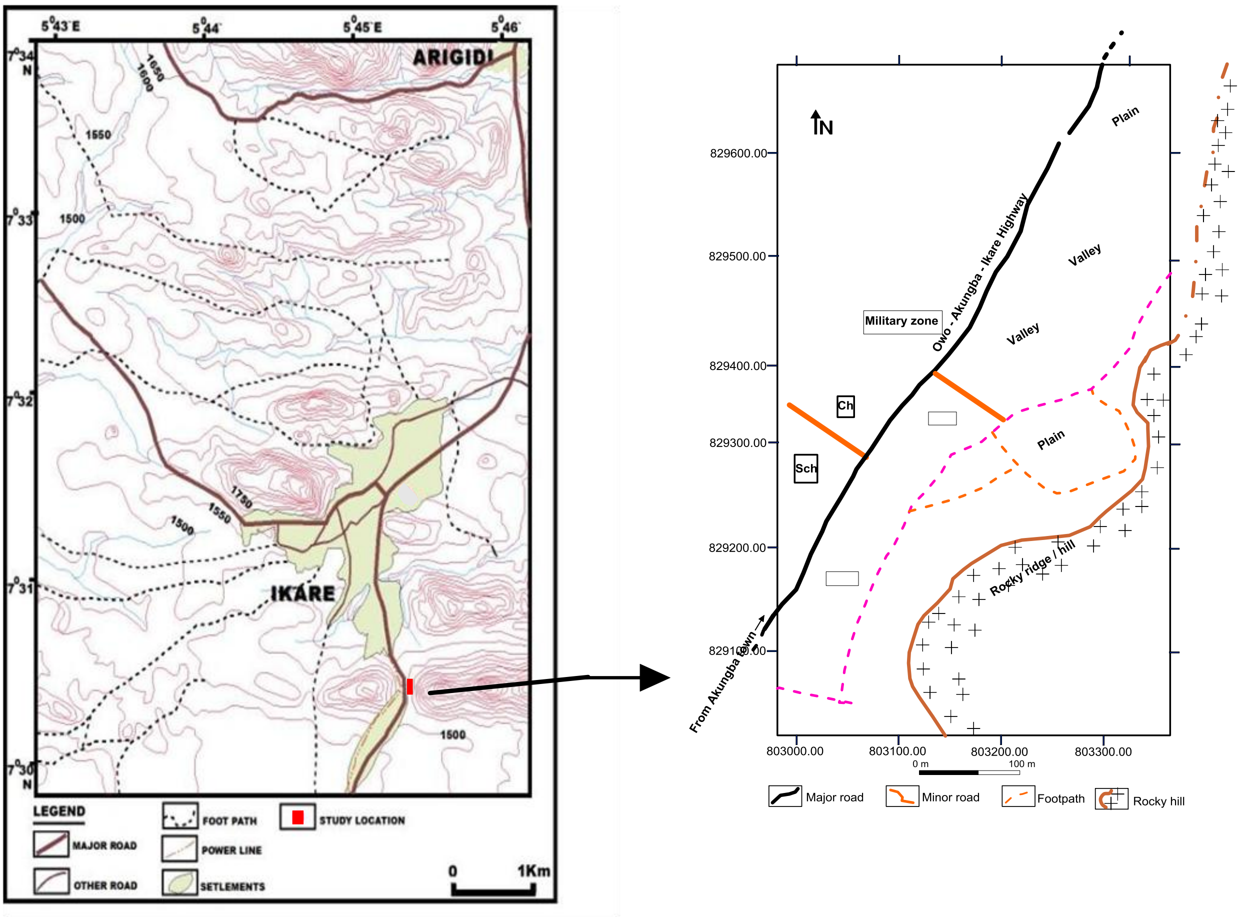
subsurface geological layers and aquifer units, mapping of water table and basement structures, water table, depth to rock-head, bedrock topography, groundwater flow direction, saline water zones and fresh/saline water interface in coastal areas are other areas of application of the technique[2]. Such above and geological structures as faults, network of joints/fracture provide the basis for groundwater potential rating and development in a typical basement terrain.

However, conventional geological mapping of part of Akoko and other areas in the basement terrain shows that the fractures mostly occur in gneisses, granites and quartzites, of which geophysics shows about 76% of the total fractures occurred within the depth range of 30 m[3], while other geophysical studies further revealed most fracture frequency at depths typically ranging between 20 – 30 and 32 - 65 metres[1], [4] are significant for sustaining groundwater yields in most basement geological settings. Studies have also shown that the resistivity sounding technique has found useful application in groundwater exploration particularly where weathered–fractured components of the basement are significantly thick, saturated and permeable for the formation of aquifers [5], [6]; [4] and [7]. In this hard rock terrain with only a veneer of weathered materials, the fractures are the targets of most groundwater exploration programmes. Arising from the high contrast in relief, complex geologic, structural and geomorphologic nature of the basement terrain in the area, the hydrogeology of weathered–fractured aquifers is highly expected to be heterogeneous with varied groundwater prospect and yields. The need to evaluate the hydrogeology and prospect of the weathered – fractured bedrock components for groundwater development is the focus of this study.

II. LOCATION, PHYSIOGRAPHY AND GEOLOGIC SETTING

The study area, with 1.5 km^2 areal extent, is located within Longitudes **5.320-6.070E and Latitudes 7.050-7.710N,** corresponding to easting and northing values of 829100 mE and 829600 mE and 803000 mN and 803300 mN of the Universal Traverse Mercator (UTM) coordinates of zone 31 respectively (Figure 1).



topographic outlook   site location

Figure 1: maps showing the study environment

It is situated 56 km from Owo town enroute and near Akungba – Akoko. It lies within the tropical rain forest belt characterized by alternating rainy and dry seasons. The peak of the rainy season spans between June and September with the mean annual rainfall of 1500 to 1600 mm, while the dry season spans through November and April.

The area is characterized by mean annual temperature between 26^0C and 28^0 C, and relative humidity above 75% [8]. The stream, which intersects the highway, streamlets and erosional run-offs at the peak of wet seasons drain the area with flow directions which appear to have been controlled by the basement outcrops and fracture pattern. The stream/streamlets meandering take their sources at the summit or foot of the highland/ridge located at the eastern end, thus indicating a downward movement of groundwater from east to the west in the area.

Oke - Igbede, forms part of the southwestern Nigeria Precambrian crystalline Basement Complex. The area, being characterized by low and high rising inselbergs features a plain, valley and hill as three distinct landforms, with a mean elevation of 700 metres above mean sea level (Figure 1). Rock types in the environment include migmatites, granite gneisses, pelitic gneisses, quartz schists, biotite gneiss, quartzo-feldspathic gneisses and some xenolithic basic rocks [9]. Older granites of hornblende and porphyritic varieties, and thin lenses of quartzite [1]. Geochronological evidences [10]; [11]; [12] have shown the polycyclic nature of the Nigerian basement complex with deformation, metamorphism and remobilisation activities over the geologic past.

III. MATERIALS AND METHOD

Thirty five (35) Schlumberger resistivity soundings were acquired at selected stations (Figure 3). The 75 m station – station interval was chosen in agreement with standard field practices, being the optimum sounding spacing interval within the basement areas. The sounding stations were located on the shoulder of the existing highway, minor roads and footpaths, thus constituting five traverses established (Figure 2). The electrode spacing (AB/2) was varied from 1 - 65 m with maximum spread length of 130 m. The ABEM SAS 1000 Resistivity Meter was used for the measurements of ground apparent resistivity as a function of electrode spacing, geometry of electrode array, subsurface layer thickness, angle of dip and anisotropic properties [13]. The product of the measured ground resistance (R) value displayed by the equipment and the geometric factor (G) of the electrode array for each set up gave the ground apparent resistivity values as shown in Equation 1.

$$\rho_a = GR \tag{1}$$

The data processing / interpretation involved partial curve matching and computer iteration techniques. The partial curve matching technique involved the matching of successive segments of the field curve by a set of two-layer theoretical Schlumberger curves [14] and the corresponding auxiliary curves. The computer iteration of the sounding data by forward and inverse modeling techniques is an interactive computer-graphic display system [15], [161]; [17]. The system which is based on Ghosh linear filter theory [15], makes use of a fast computer to calculate an apparent resistivity curve for a given layer sequence so that the validity of the results of the partial curve matching interpretation result can be checked.

Field curves were superimposed and matched segments by segments with a two-layered standard modelled/master curve and its auxiliary. The field curves were moved over the modelled curve while keeping the vertical and the horizontal axes of the two curves parallel until a fit was obtained with the first segment of the model curves at small electrode spacing. The origin of the matched the two-layer master curve was marked on the field curve. Resistivity (ρ_1) of the first layer was obtained from the horizontal co-ordinate on the field curve, while the thickness (h_1) of the first layer was found on the vertical co-ordinate. The reflection coefficient (k_1) of the matched curve was recorded. The field curve was then superimposed on the auxiliary curve and the axes were kept parallel, a symbol denoted by ($+_1$) was made at the origin of the auxiliary curves. The appropriate auxiliary curve with the reflection coefficient (k_1) was traced on the field curve. The resistivity of the second layer was determined using the formula

$$\rho_2 = \rho_{1\times} k_1 \tag{2}$$

Where, ρ_1 is resistivity of the first layer, ρ_2 is resistivity of the second layer and k_1 is the reflection coefficient at the boundary between the first and second layer. The next segment of the field curve was matched in the same way by keeping the axes parallel and ($+_1$) at the origin. The second cross point ($+_2$) was noted on the field curve and the reflection coefficient (k_2) was recorded. The vertical and horizontal co-ordinates of the second cross point give the thickness replacement (h_{2r}) and resistivity replacement (ρ_{2r}). The resistivity (ρ_3) of the third layer was obtained from the relation:

$$\rho_3 = \rho_{2r\times} k_2 \tag{3}$$

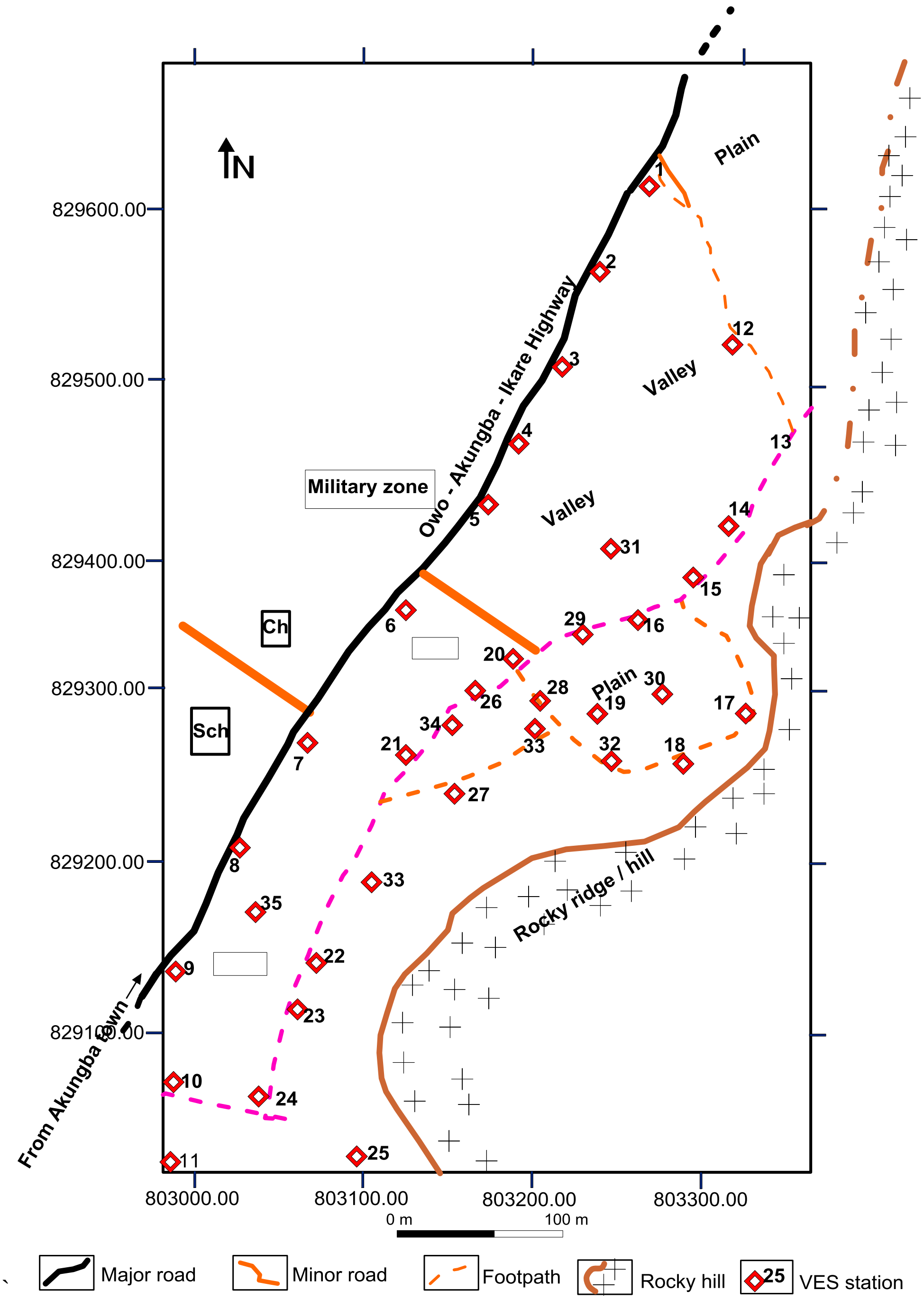


Figure 2: data acquisition map of the study area

The thickness (h_2) of the second layer, the first cross point ($+_1$) was placed at the origin of the auxiliary curves keeping the axes paralleled. The $\frac{D_n}{D_r}$ value was read off at the location of the second cross point ($+_2$) from first cross point ($+_1$). The second layer thickness was obtained from the equation:

$$h_2 = \frac{D_n}{D_n} \times h_1 \qquad (4)$$

However, the general formula for generating true resistivity in Schlumberger array is given as:

$$\rho_n = \rho(n-1)r \times (K(n-1)) \qquad (5)$$

Where, n is the number of layer. Therefore, the quantitative interpretation of depth sounding curves with more than three layers can be done by repeating the procedure described above. Computer iteration was done by feeding the layer resistivities and thicknesses obtained from curve matching into Resist software for iteration and refinement, where a root mean square error of <10 obtained, the interpretation was considered satisfactory. The refined geoelectrical parameters/results of the sounding curves are displayed on the resist graphs as shown in a typical one in Figure 3. These parameters were summarized in Table 1, and subsequently used to construct geoelectric sections along eight traverses for analysis and deductions.

IV. RESULTS AND DISCUSSION

4.1 Results

The field curves obtained are the KHKH (1), KHA (2), HA(7), KH (9), KAA (1), HAKH (1), HKH (2), AA (3), A (4), AAKH (1), AKH (1), H (1), K (1), AK (1) types with the KH- and HA- types being the dominants. The diversity in curves within a short spread, of not greater than 75 m, in the area is evident from the complex nature of geology, structure and geomorphology and/or landform. The typical sounding type-curves (Figure 3) reflect the heterogeneity of the subsurface sequences.

The geoelectric section along traverse 1 runs NW-SE direction offsetting sounding stations 28 and 19, and displays other VES stations 6, 20, 30 and 17 (Figure 4 a). The section revealed three distinct geologic layers with the first layer corresponds to the topsoil, with resistivity values of between 119 - 208 ohm-m and thickness values 1.1 - 2.0 m. The second layer has resistivity values that vary from 156 - 482 ohm-m and thickness values of the range 2.7 - 27.5 m as the weathered – fractured components. The third layer is the fresh bedrock with resistivity values that vary from 4344 - 12574 ohm-m assumed to be infinitely resistive due to high resistive members of the basal fresh basement rock.

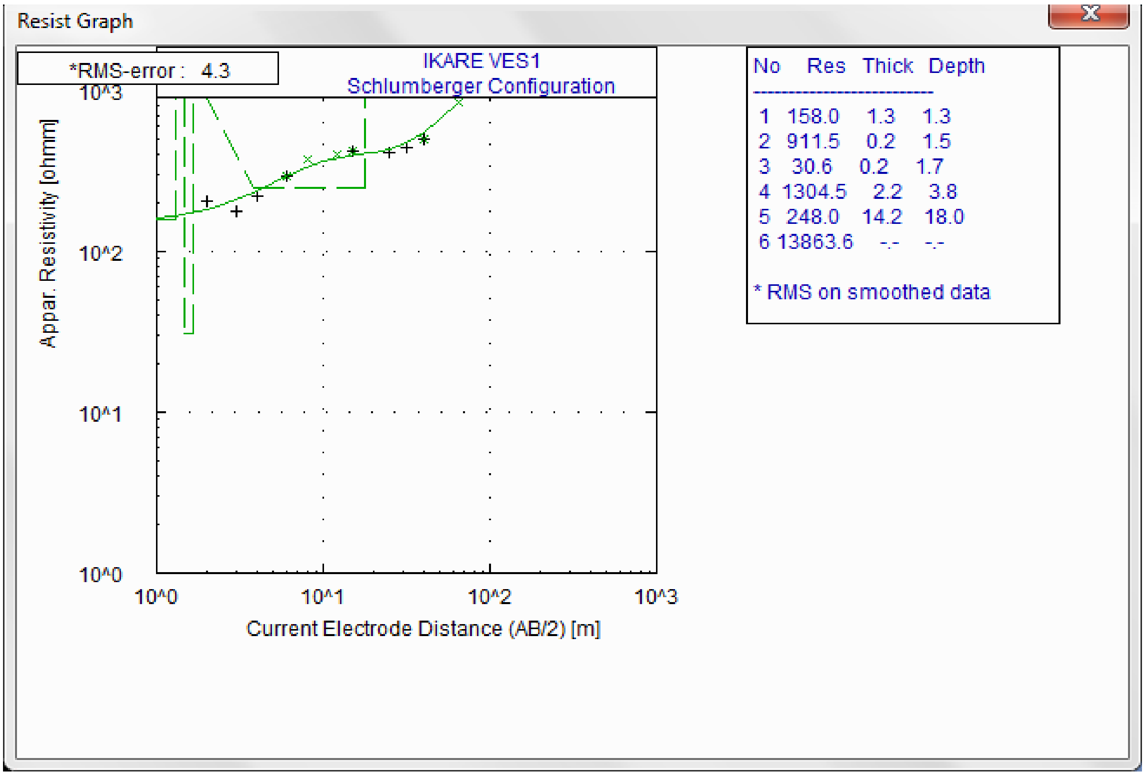
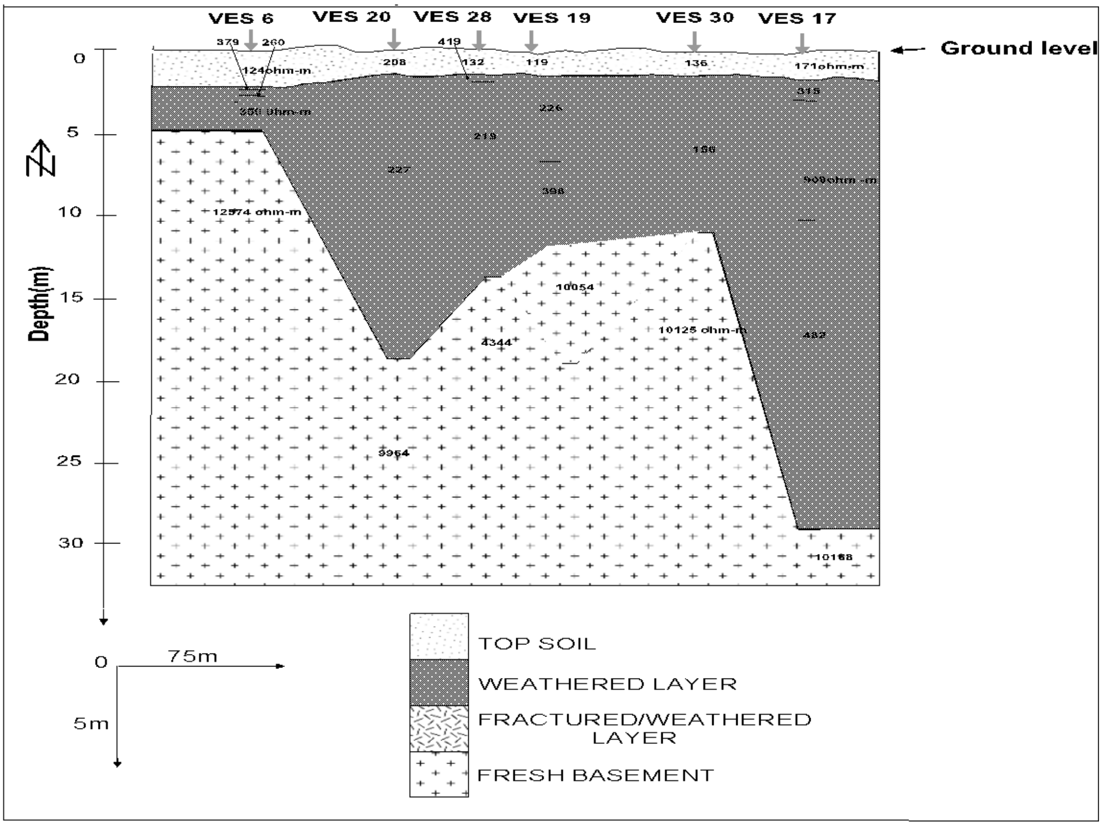


Figure 3: typical sounding type – curve

Table 1: Summary of the geoelectrical sounding results

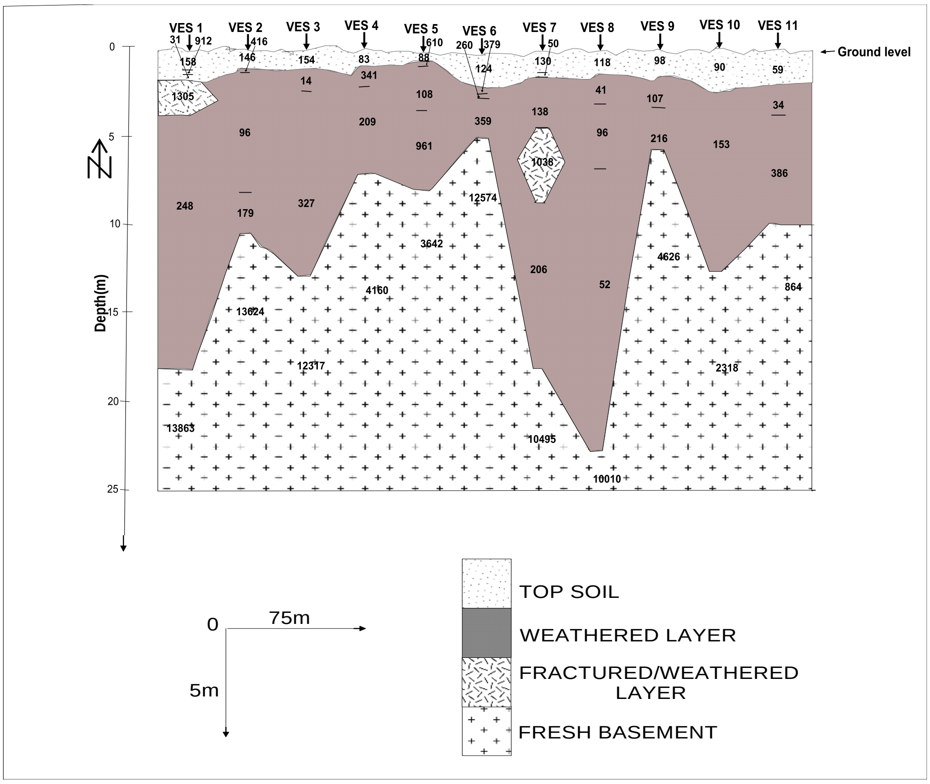
Sounding VES No	Topsoil Resistivity (ohm-m)	Topsoil Thickness (m)	Weathered - Fractured Resistivity (ohm-m)	Weathered - Fractured Thickness (m)	Overburden Thickness (m)
1	158	1.3	248	16.8	18.1
2	146	1.0	96	9.5	10.5
3	154	1.0	327	11.7	12.7
4	83	0.9	209	6.0	6.9
5	88	0.5	961	7.1	7.6
6	124	2.0	359	2.7	4.7
7	130	1.4	206	16.4	17.8
8	118	1.1	52	20.9	22.0
9	98	1.1	216	4.0	5.1
10	90	1.7	153	10.4	12.1
11	59	1.4	386	8.0	9.4
12	33	1.4	145	14.9	16.3
13	274	1.0	148	2.0	3.0
14	127	1.0	17	1.4	2.4
15	158	0.9	102	11.9	12.8
16	91	1.5	295	16.4	17.9
17	171	1.6	482	27.5	29.1
18	131	0.7	543	32.8	33.5
19	119	1.1	396	17.8	18.9
20	208	1.1	227	17.4	18.5
21	174	1.8	116	4.3	6.1
22	0	0	0	0	0
23	79	0.1	0	0	0.1
24	410	1.9	0	0	1.9
25	175	2.4	0	0	2.4
26	214	0.7	313	14.4	15.1
27	129	1.6	146	4.1	5.7
28	132	1.2	219	12.3	13.5
29	179	1.1	413	4.4	5.5
30	136	1.4	156	9.4	10.8
31	116	0.3	125	14.9	15.2
32	126	0.8	0	0	0.8
33	154	1.1	132	1.3	2.4
34	151	1.2	106	4.5	5.7
35	100	2.5	260	5.7	8.2

The geoelectric section along traverse 2 runs across the whole length of the area, along the shoulder of the highway in NE–SW direction. It contains sounding stations 1, 2, 3, 4, 5, 6, 7, 8, 9, 10 and 11 (Figure 4 b). Three geoelectric layers were delineated to include the topsoil with resistivity values that vary from 59 - 158 ohm-m and thickness values that vary from 0.5 - 2.0 m. The second layer has resistivity range of 52 - 961 ohm-m and thickness range of 2.7 - 20.9 m as the weathered - fractured layer/component. The third layer is the basal fresh basement with resistivity range of 864 - 13863 ohm-m. The geoelectric section along traverse 3 runs NW – SE and NE – SW azimuths. Sounding stations 1 and 12 are in NW –SE, while others which include stations 13, 14, 15, 30, 32 and 18 are in NE – SW direction to offset station 18 (Figure 4 c). The section reveals the first layer corresponding to the topsoil with resistivity values that vary from 33 - 158 ohm-m and thickness values 0.7 - 1.4 m. The second layer has resistivity of the range 0 - 543 ohm-m and thickness values 1.4 - 32.8 m as the weathered – fractured component. The third layer is the fresh bedrock with infinite resistivity.



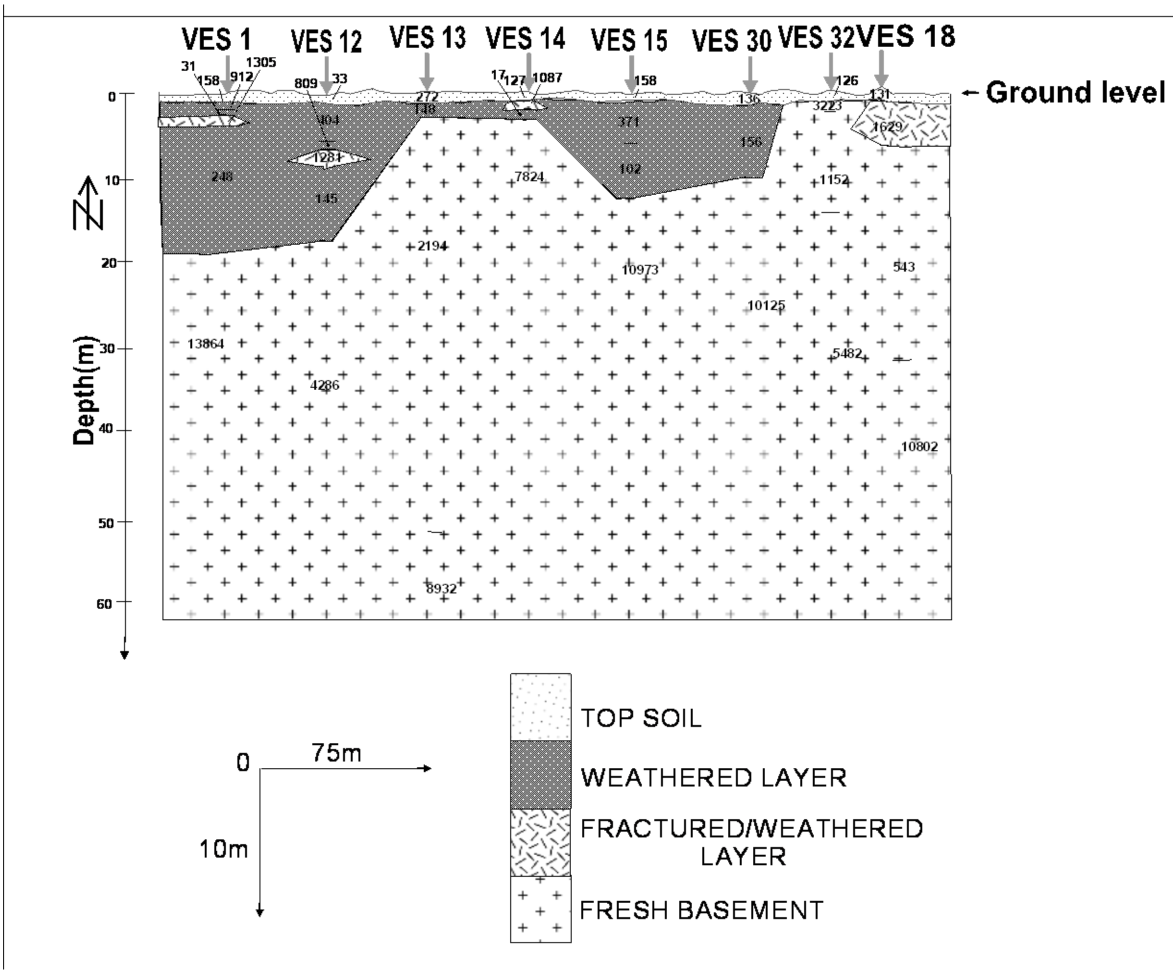
(resistivity values in Ωm and thicknesses in m)

Figure 4 a: geoelectric section along traverse 1



(resistivity values in Ωm and thicknesses in m)

Figure 4 b: geoelectric section along traverse 2



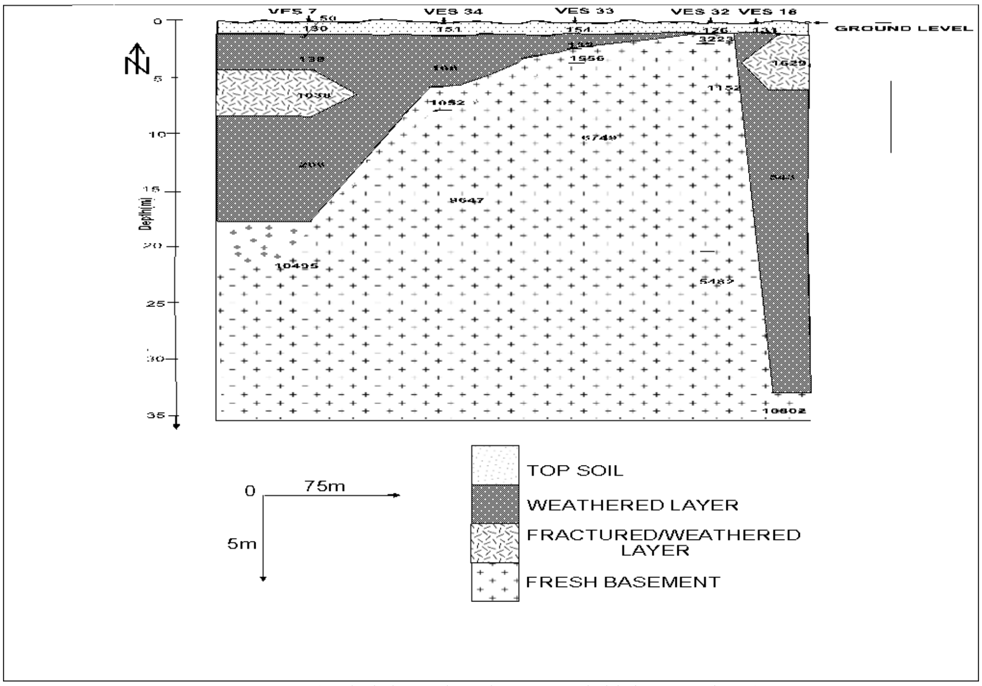
(resistivity values in Ωm and thicknesses in m)

Figure 4 c: geoelectric section along traverse 3

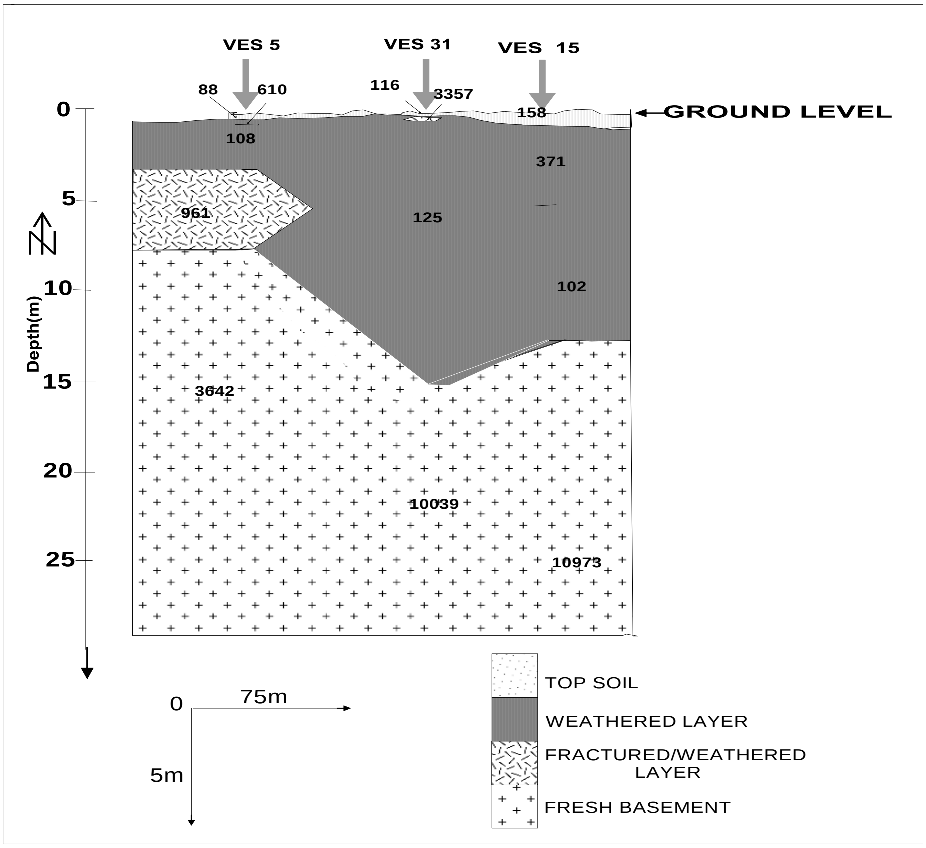
The geoelectric section along traverse 4 runs NE - SW and contains VES stations 7, 34, 33, 32 and 18 with station 7 as offset (Figure 4 d). Three geoelectric layers were delineated comprising the topsoil with resistivity values that vary from 126 - 154 ohm-m and thickness values that range from 0.7 - 1.2 m. The second layer has resistivity values that vary from 106 - 543 ohm-m and thickness values that vary from 0 - 32.5 m as the weathered - fractured component. The third layer is the fresh bedrock with resistivity range of 1052 - 10802 ohm-m.

The geoelectric section along traverse 5 comprises VES stations 5, 31 and 15 (Figure 4 e). It runs ENE - WSW direction offsetting station 5. It reveals three geoelectric layers which are; the topsoil with resistivity values that vary from 88 - 158 ohm-m and thickness values that vary from 0.3 - 0.9 m. The second layer has resistivity values that vary from 102 - 961 ohm-m and thickness values 7.1 - 14.9 m constituting the weathered - fractured component. This layer is followed by fresh basement with resistivity values between 3642 - 10973 ohm-m.

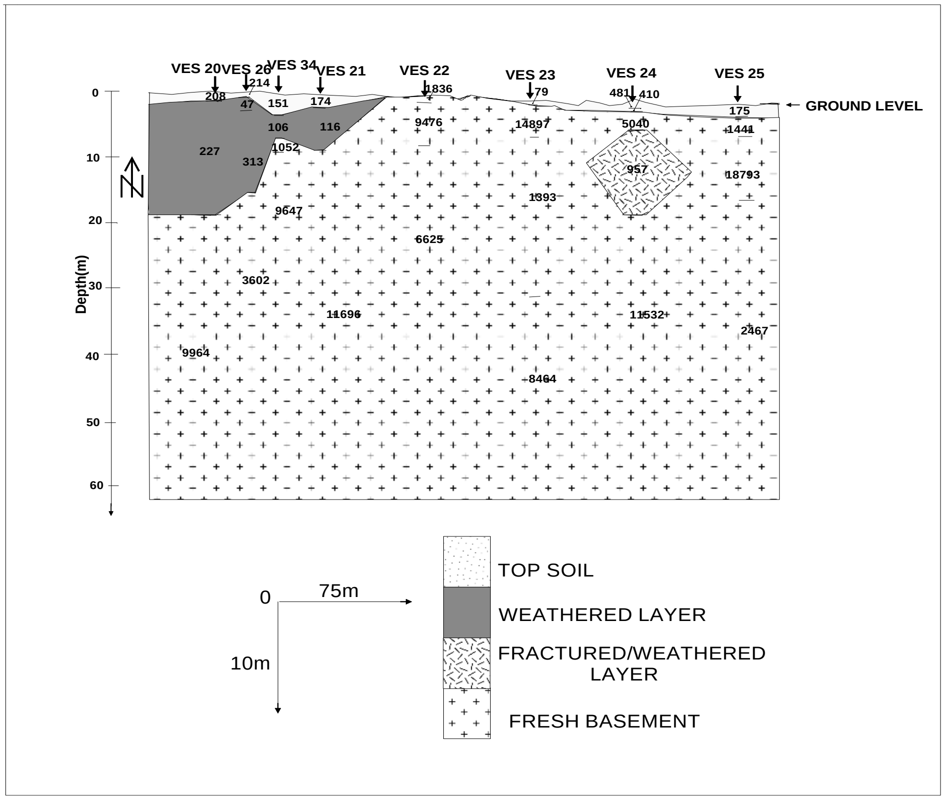
The geoelectric section along traverse 6 is in NE - SW azimuth containing sounding stations 20, 26, 34, 21, 22, 23, 24 and only station 25 being an offset (Figure 4 f). Three geoelectric layers were identified to contain topsoil (resistivity 79 - 410 ohm-m and thickness 0 - 2.4 m); weathered – fractured component (106 - 313 ohm-m and thickness values) that vary from 0 - 17.4 m as the fractured/ weathered layer. The third layer is the fresh basement with resistivity values that vary from 1052 - 14897 ohm-m. The geoelectric section along traverse 7 contains VES stations 8, 35 and 22 (Figure 4 g), made to run NW - SE azimuth. Three geoelectric layers were delineated. The first layer corresponds to the topsoil with resistivity values that vary from 100 - 118 ohm-m and thickness values that vary from 1.1 - 2.5 m. The second layer has resistivity values that vary from 52 - 260 ohm-m and thickness values that vary from 5.7 - 20.9 m as the weathered - fractured basement layer. The fresh basement is the basal unit it is assumed to be infinitely resistive due to its large resistivity.



(resistivity values in Ωm and thicknesses in m)
Figure 4 d: goelectric section along traverse 4

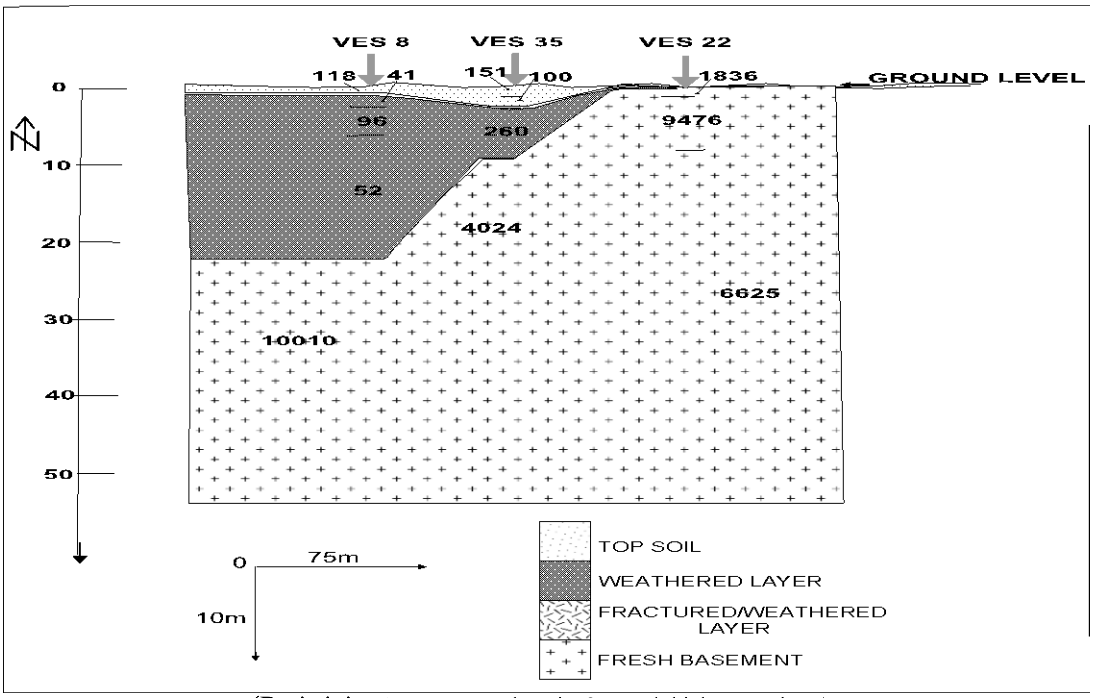


(resistivity values in Ωm and thicknesses in m)
Figure 4 e: geoelectric section along traverse 5



(resistivity values in Ωm and thicknesses in m)

Figure 4 f: geoelectric section along traverse 6



(Resistivity (resistivity values in Ωm and thicknesses in m)

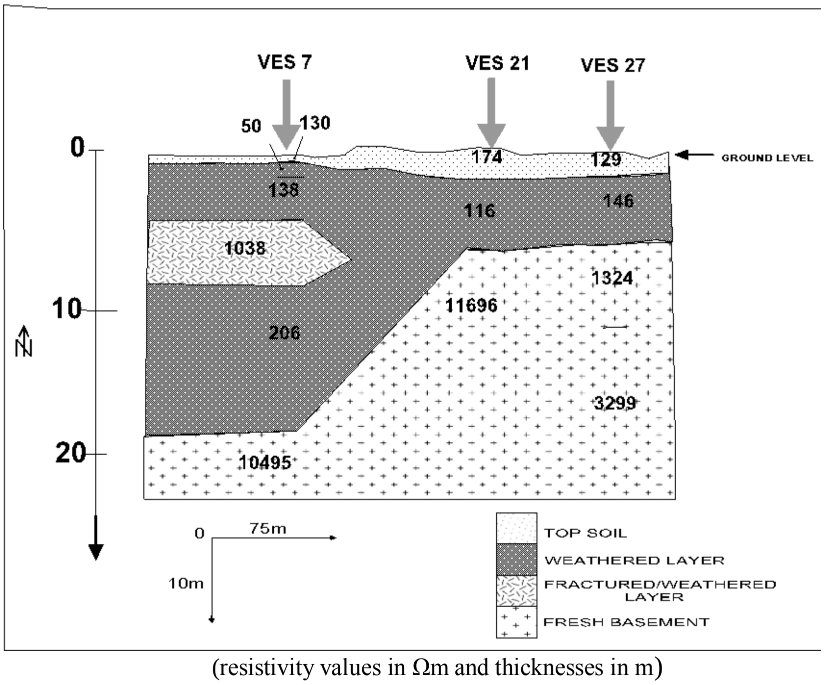
Figure 4 g: geoelectric section obtained along traverse 7

The geoelectric section along traverse 8 consists of VES stations 7, 21 (offset) and 27 (Figure 4 h). It is in NWW – SEE azimuth displaying three distinct geoelectric layers to include the topsoil with resistivity values that vary from 129 - 174 ohm-m and thickness values vary from 1.4 - 1.8 m, weathered - fractured component, with resistivity range of 116 - 146 ohm-m and thickness values of 4.1 - 16.4 m while the fresh basement has resistivity values varying between 1324 – 11690 ohm-m. The sounding station 7 has the highest basement depression and a prospective groundwater collection centre along the section.

4.2 Discussion

Discussion of results is tailored towards the evolvement of hydrogeologic significance of the geoelectrical parameters across the study area. Generally, three to four distinct geologic layers are revealed; the topsoil, weathered basement/fractured basement and fresh basement units. The topsoil has a mean resistivity and thickness of 161 ohm-m and 1.4 m respectively. The resistivity is moderately low and on the average gave a value (< 200 ohm-m) typical of silty sand materials except for sounding stations 22 - 25 and 32 that fell on low-lying outcrops. The thickness of the topsoil rarely goes beyond 1.5 m thickness except for the topographic lows at the western end where greater values are revealed and/or valley features are conspicuous. The thin topsoil and resistive fresh basement units are hydrogeologically insignificant [4] and do not support groundwater storage and prospect in the area.

The weathered basement unit is generally thin and completely absent in places especially beneath VES stations 22 - 25 and 32 positions. However, pockets of fair to relatively good thickness of the weathered layer (> 15 m) are formed beneath VES stations along traverses. Quantum of sounding stations with relatively thick weathered basement units greater than 15 m are beneath traverse two. Others are beneath sounding stations 20, 28, 17 along traverse one; stations 1, 2, 7, 8 along traverse two; stations 1, 12, 15, 30 along traverse three; stations 7 and 18 along traverse four; stations 31 and 15 along traverse five; stations 20 and 26 along traverse six; station 8 along traverse seven and; finally the sounding station 7 along traverse eight. The network of these sounding stations with column of weak unconsolidated materials reflects the contributions of the fracture columns, hitherto, identified with shallow fracture depth in the area. The fracture depth interval of 10 – 30 m plays a major role in groundwater storage and flow regime in this basement settings, and therefore, remains significant in the study. The distribution of the above weathered – fractured units is sparsed but nevertheless defines basement depressions, reliable aquifers and high groundwater potential zones in the area.



(resistivity values in Ωm and thicknesses in m)

Figure 4 h: geoelectric section along traverse 8

Previous geoelectrical studies have identified hydrogeological significance of basement depressions and ridges. Ridges are usually associated with thin overburden cover and are groundwater diverting centres, and on the contrary, basement depressions are groundwater collecting centres. The latter characteristic feature forms significant part of the plains and valleys in the area which can be explored and harnessed for consumtion.

V. CONCLUSION

Generally, the geoelectric sections delineated three to four geologic/geoelectric layers along the traverses. These layers correspond to the topsoil with resistivity values that vary from 33 - 410 Ωm and thickness range of 0.1 - 2.5 m, weathered/fractured layer with resistivity values that vary from 17 - 961 Ωm and thickness range of 0 - 32.8 m, and fresh basement with resistivity values of infinity ohm-m and infinite thickness.

The weathered - fractured column is generally sandy with average resistivity of 252 ohm-m, thin with average value of 11.0 m across the area. Fairly thick columns of pockets of basement depressions found particularly towards the northwestern part. This unit/column constitutes the aquifer unit(s) and has tendencies of yielding appreciable quantity of groundwater to wells and boreholes. The low rating of groundwater prospect in this area may be attributed to the general thin nature of the overburden and limited fractures at deeper depth beyond 30 m. Future groundwater resource development in the study area is considered feasible in few places characterized by relatively thick and sandy column of the weak unconsolidated rock units. Hence, the groundwater potential of the study area is feasible within the weathered - fractured components with thicknesses not less than 30 m as first order priority, while others with thicknesses not less than 20 m are outside choices for sustainable groundwater prospect and development at the very best.

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