Use of vertical electrical geophysical method for spatial characterisation of groundwater potential of crystalline crust of Igboora area, southwestern Nigeria

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Abstract- Due to non-availability of records of essential pre-drilling investigations and drilling data of Boreholes' installations at Igboora Town and its environs, it is difficult to manage and develop the groundwater resource which is the main water supply for the entire inhabitants. The present investigation used the conventional electrical resistivity geophysical method to characterise the weathering and bedrock fracturing, and to reveal the water conductance potential of the Basement crust of Igboora areas of southwestern Nigeria.

The results showed that the dominant geo-electric sequence is the three-layer H type curve that is characterised by subsurface system of conductive middle saprolite unit that terminates on more resistive bedrock units. The resistivity of the middle-saprolite layer ranged from 9.10 to 225.2 (average of 53.1)Ωm, and that of the bedrock from 105.7 to 5472.7 (average of 1515.6)Ωm. The total regolith thickness ranged from 4.4 to 39.4m with an average of 18.08m, while the measurements of the potential for groundwater conductance ranged from 0.02 to 1.42 (average of 0.45) mhos across the study area. More so, the extent of rock weathering decreases with depth and about 44% of the surveyed points terminated on fractured basement.

Across the study area; rock decomposition, bedrock fracturing, and by extension potential for water conductance are more intensive at the western side, and due to the fine grained nature of the regoliths that developed in locations with fractured basement, the siting of artesian (or prolific) wells is higher along the western axis than any other parts of the study area. This is due to the fact that the largely fine grained middle regolith (weathered) layer can function as the aquiclude (or confining units) for the probably water-bearing fractured bedrocks.

Index Terms- crystalline, weathered, fractured, groundwater, prolific

I. Introduction

Groundwater occurrence in areas underlain by Basement crusts is normally characterised by shallow water-table conditions, associated with seasonal and disconnected water occurrence. Hence, successful groundwater exploitation in respect to well yield will require a proper understanding of the hydrological attributes of the soil cover, otherwise called the weathered layer and the underlying bedrock. The use of appropriate geophysical methods such as the vertical electrical sounding (VES) techniques are applicable to reveal the groundwater potential of the weathered-fractured concepts in Basement areas (Olorunfemi and Okhue, 1992; Murali and Patangay, 2006). Consequently, constructions of boreholes with good water yield are now feasible in Basement areas (Offodile, 2002).

The present study area is located in Ibarapa region of SW Nigeria (Fig. 1) and it is entirely underlain by the Basement rocks. Human population was almost 117,000 as at the last census in 2006. The area is entirely underlain by intrusive crystalline rocks of Precambrian age (Jones and Hockey, 1964; Dada 1998) which are inherently characterized by negligible low porosity and permeability (Singhal and Gupta, 1999; Tijani and Abimbola, 2003). The inhabitants of Igboora and adjoining communities rely entirely on groundwater supply from the water bearing zones found within the Basement rock units for domestic water supply all year round, since there is no functioning piped water supply across these communities. However, in the course of the field work, the yields of the various boreholes projects sponsored by international agency and Oyo state government in these communities were notably erratic, divergent and largely influenced by seasonal climatic variations. Records of pre-drilling investigations, and well/borehole data such as lithologic logging are not available; hence there are no background data for further groundwater development and management across the study area.

Consequently, this study aims at evaluating the degree of rock weathering and bedrock fracture for characterising the groundwater recharge potential of the study area using vertical electrical resistivity method. This study will be helpful for future water prospecting at Igboora and the adjoining communities.

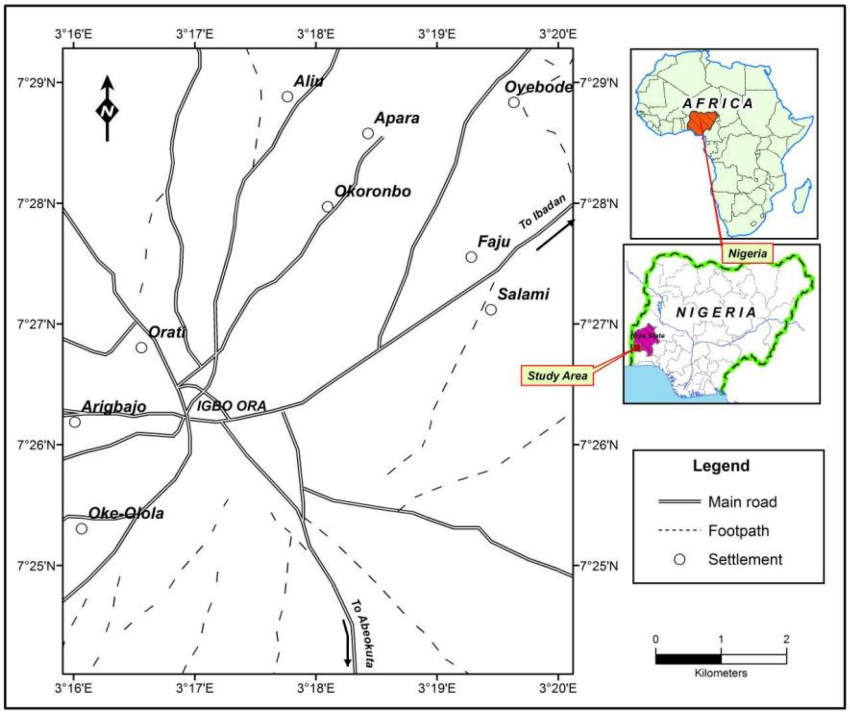


Figure 1. Location and accessibility map of the study area

Geology

The study area lies within the Basement complex of SW Nigeria underlain primarily by intrusive rocks of Precambrian age (Fig. 2). Varieties of amphibolite occasionally intercalated by quartzite and quartz veins, and augen gneiss are the main crystalline rocks that underlie Igboora communities. The amphibolites which are metamorphic rocks formed from recrystallization of amphibole rich igneous rocks were found either as schistose or massive varieties across the study area. Mineral identification of Igboora amphibolite showed that it is rich in basic minerals such as hornblende and biotite, and others like plagioclase feldspars and little quartz (Fig. 3). Other major rock types at boundary areas included of the gneiss-migmatites complex, including homogenous medium grained and porphyritic granites, augen gneiss and migmatite. (Fig. 2).

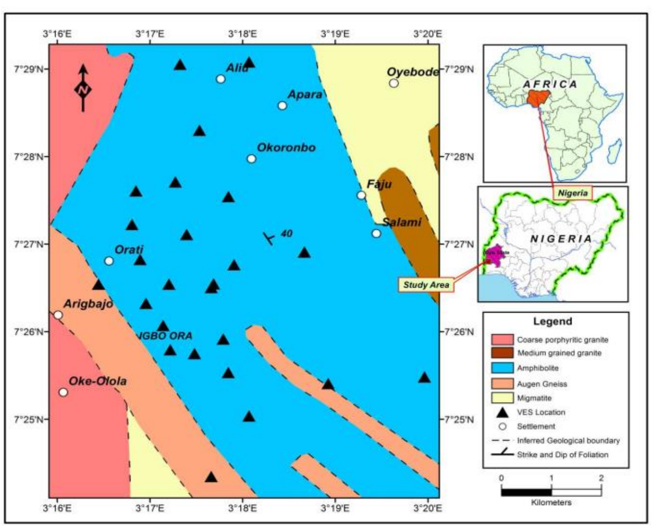


Figure 2: Geological map of the study are with VES points

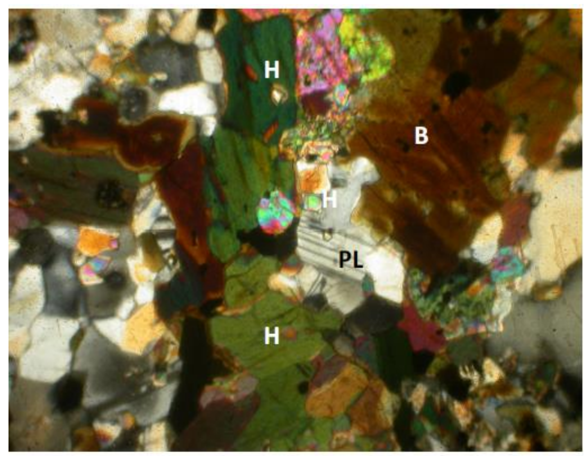


Figure 3: Photomicrograph of a section through amphibolite, showing hornblende (H), plagioclase feldspars (PL), and biotite (B) under cross polarised light and X40 magnification at location: Pako- Igboora.

Method

The vertical electrical sounding (VES) resistivity method was employed for geophysical characterisation of the Basement crust of the study area. This method has been found to be mostly applicable for hydrogeological surveys in crystalline area for studying groundwater basins and tracing potential groundwater zones in hard rocks such as saturated weathered zones and fractures (Murali and Patangay, 2006). For this present study, a total of 25 soundings was carried out using the Schlumberger configuration with the maximum AB (electrode) separation ranging between 200-266m; which is considered appropriate for groundwater investigation in basement areas where regolith development and fresh rock contacts are expected to be at shallow depths. In schlumberger, the distance *L* between the current electrodes is varied and the distance *l* between the potential electrodes are kept constant for a while over a set of AB separation. For these configurations, the apparent resistivity (ρa) which is a measure of the effects of all the layers between the maximum depth of penetration and the surface is calculated as follows.

$\rho_a = \pi\ (L^2/2l)R$

where, R is the measured resistance (in voltage/current) and *a, L* and *l* are as defined above. The electrode separations, L and l determines the depth of investigation. The electrode (AB) spacing is then increased and the corresponding apparent resistivity 'ρa' value is measured.

Partial curve matching technique was used for quantitative interpretation of the field data with the help of some auxiliary curve charts of Orellana-Mooney, 1966. The geo-electric parameters obtained were used as models for computer iteration using winresist to obtain the true layers' resistivities (ρ) in ohm.m (Ωm) and thicknesses (h) in metre, which are the primary geo-electric parameters of interest. The layer resistivities are applicable for interpreting the degree of fineness or coarseness of the weathering products and for qualifying the nature of bedrock which could either be fresh, weathered or fractured (David 1988; Olorunfemi and Olorunniwo, 1985). The layer thickness showed the vertical extent of regolith or soil development at each sounding point. Additionally, pseudo-sections were generated from apparent resistivities at AB separations of 20m, 84m, 150m and 200m across surveyed points to reveal the extent of weathering development at the corresponding depths.

The concepts of longitudinal unit conductance and transverse unit resistance which are known as the Dar Zarrouk parameters were first introduced by Maillet, 1947 and now emphasized by more recent research works (Oladapo and Akintorinwa, 2007; Abiola et. al., 2009; Aweto; 2011) and literature (Sabnavis and Patangay, 2006). Sabnavis and Patangay, 2006, highlighted the use of these parameters to quantify water transmission through the porous regolith overburden. These Dar Zarrouk parameters are derivatives of the primary geoelectric parameters which are the layer thicknesses and their corresponding true resistivities. The background concept for Dar Zarrouk parameters assumes that the earth is parallel with n layer and the flow of current through such sequence is controlled by individual layer resistivities and their respective thicknesses. Of particular interest to this present work is the longitudinal conductance (S) which is the parameter that influences current flow when the current flow is parallel to the geo-electric boundaries and when the current flow normal the geoelectric boundaries the significant parameter is the transverse resistance T. When a number of layers are involved in a geoelectric section, their total longitudinal conductance S is estimated thus:

$S = S_1 + S_2 + S_3 + ...$, where $S_1 = h1/\rho1$, $S_2 = h2/\rho2$ etc, where;
S1, S2 are the longitudinal conductance for layers 1 and 2, while h1 and ρ1 are the layer's thickness and resistivity respectively.

From the total longitudinal conductance the groundwater recharge potential of the regolith unit was inferred.

Iso-resistivities and isopach maps of the soil layer or the regolith were plotted for characterising groundwater potential, while the latter provided the lithology of the weathering layer or the saprolite, the isopach maps showed the spread of the soil cover or the variation of weathering development across the study area. Aside the subsurface fractures, the attributes of weathering or the nature of soil development as interpreted from the geo-electric parameters are crucial factors guiding the groundwater occurrence and movement in the subsurface environment. The weathered layer otherwise called the saprolite units and the top soil are collectively known as the regolith or the soil cover.

II. RESULTS AND DISCUSSION

VES CURVES

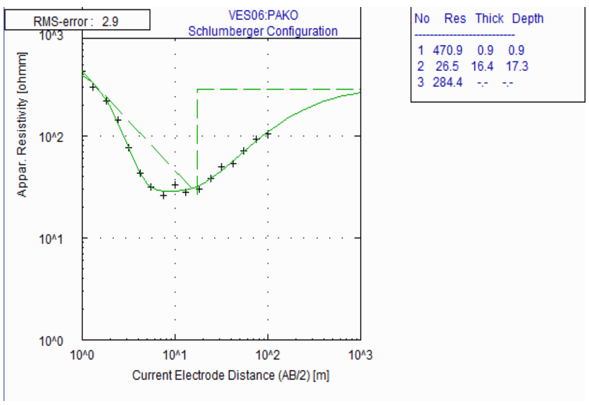
The dominant geo-electric curve is the 3-layer H type that represents three geo-electric layer, characterised by a topsoil, relatively more conductive middle layer that terminates on more resistive infinite layer. The middle layer is otherwise called the saprolite. The infinite layer is the bedrock that can either be fresh, weathered or fractured bedrock depending on the resistivity. Continuous water flow is likely favoured when the bedrock is fractured and there are good connections between the fractures and the weathered layer. Only three VES points on VES 2, 12, and 14 were characterised by more than 3-layer curves. VES curves representatives are presented in figure 4.

Weathering and fracture development

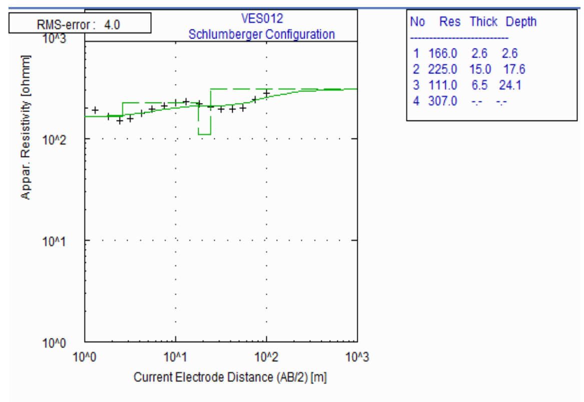
The pseudo-sections for four AB separations presented in figure 5 revealed that the extent of rock decomposition decreases with depth. The spread of areas with apparent resistivities below 100Ωm regarded as highly weathered horizon thins out as current electrodes separation increases from 20m to 200m. This zone is almost completely absent at AB separation of 200m but soil development still persists to larger electrodes separations even to AB separation of 200m, but the larger parts are regarded as being moderately weathered. This is an indication of a fairly deep weathering across the study area.

Summary of the statistics of the primary geo-electric parameters is presented in Table 1. The general spread of the saprolite resistivity is between 9.1 and 225.2 Ωm. The resistivity of the saprolite is important parameters from which the textural attributes of the constituent matrix could be inferred. With a mean value of 53.1Ωm, the weathering products of the saprolite layer is fine grained and this widespread lithology is illustrated in the isoresistivity map in figure 6. The decomposition of the bedrocks to fine grained soils is linked to the mineralogical composition of the amphibolites which are made up of reasonable amount of ferromagnesian minerals such as biotite, hornblende and plagioclase feldspars as evidence from the petrography studies of the thin section (fig. 3). Rocks rich in ferromagnesian minerals are more readily decomposed when exposed to ground surface processes such weathering than acid rocks. Sand and coarser grained saprolite lithology are also fairly represented. The textural character of the saprolite is a determinant factor for storage and transmission within the sub-surface environment. The last layer or bedrock resistivity ranged from 105 to over 5000 Ωm. The most promising fracture zones lies below 500 Ωm and bedrock fractures occurred at 11 locations across the area. The bedrock fracture zones occurred at different depth ranges between 7.9 to 29.9m at an average of 18.3m. The state of the infinite layer is a strong determinant of the sustainability of water.

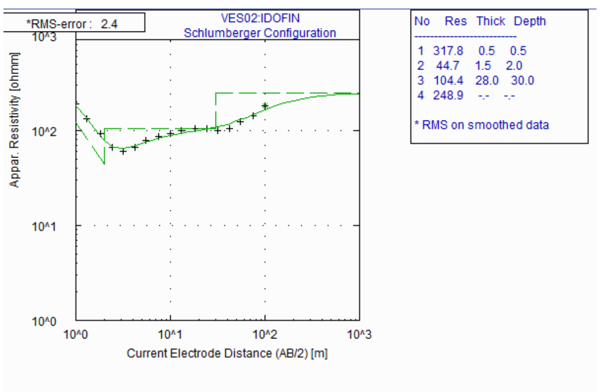
The thickness of the top soil ranged from 0.40 to 5.80m with an average of 1.68m. The topsoil confines the lower layers or zones that are commonly exploited for groundwater. Furthermore, the thickness of the saprolite varies from 3.8 to 38.7m and the average was 16.56m. The spread of regolith thickness of less than 10m was restricted to the eastern half of the study area, whereas the larger part across the western end was associated with richer soil development having regolith thickness ranging from 10m to 25m, with occurrences of few localised much deeper weathered zones exceeding 25m (fig. 7).



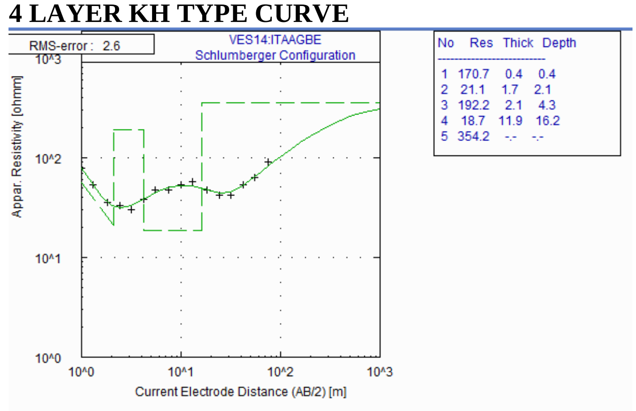
3 LAYER H TYPE CURVE



4 LAYER KH TYPE CURVE



4 LAYER HA TYPE CURVE



5 LAYER HKH TYPE CURVE

Figure 4: VES curves categories across the study area

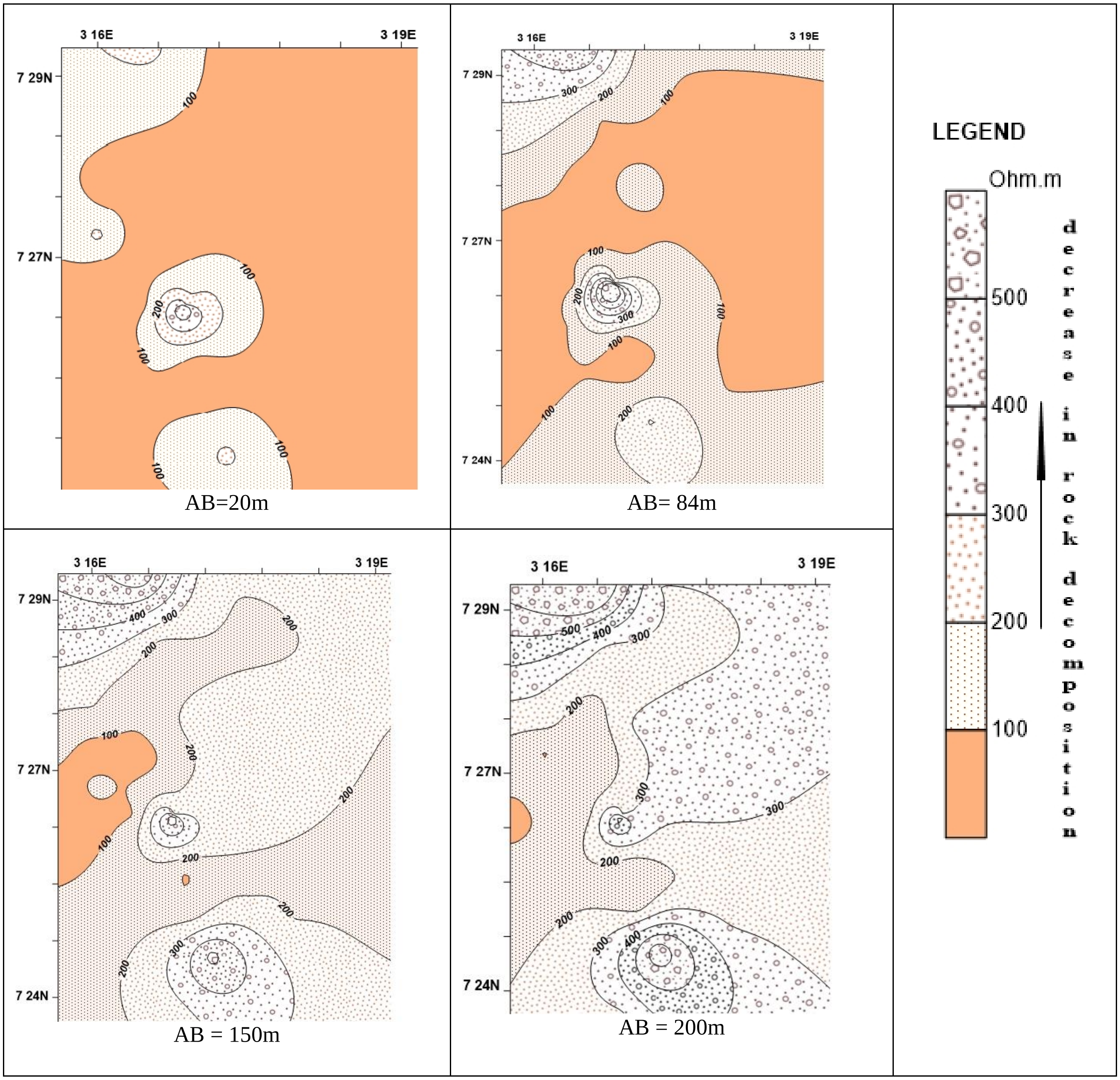


Figure 5: Pseudo-sections at different AB separations across the study area

Table 1: General statistics of the geo-electric parameters

Geo-electric parameters	Explanation	Min	Max	Mean	Median	Std dev.
ρ1 Ωm	Resistivity of the Topsoil	38.40	3478.00	658.47	407.60	779.16
ρ2 Ωm	Resistivity of saprolite layer	9.10	225.20	53.10	36.35	53.30
ρ3 Ωm	Resistivity of Infinite layer	105.70	5472.70	1515.59	927.00	1531.27
h1 (m)	Thickness of Top soil	0.40	5.80	1.68	1.45	1.22
h2 (m)	Thickness of saprolite layer	3.80	38.70	16.56	16.00	8.95
H (m)	Total regolith thickness	4.40	39.40	18.06	17.20	9.12
S	Total longitudinal conductance	0.02	1.42	0.45	0.40	0.33

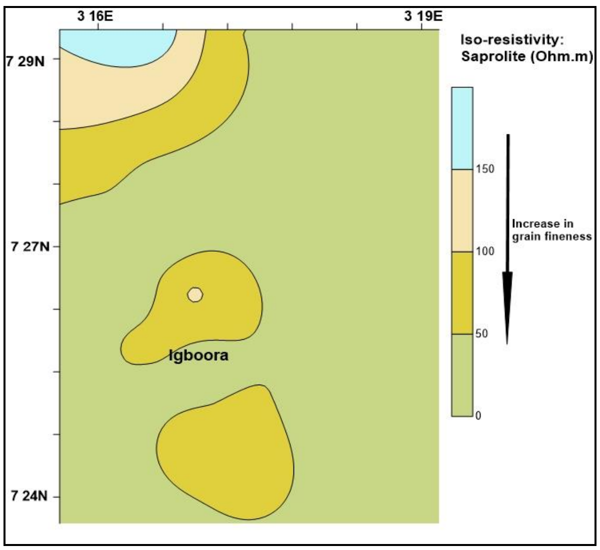


Figure 6: Isoresisitvity map of saprolite layer

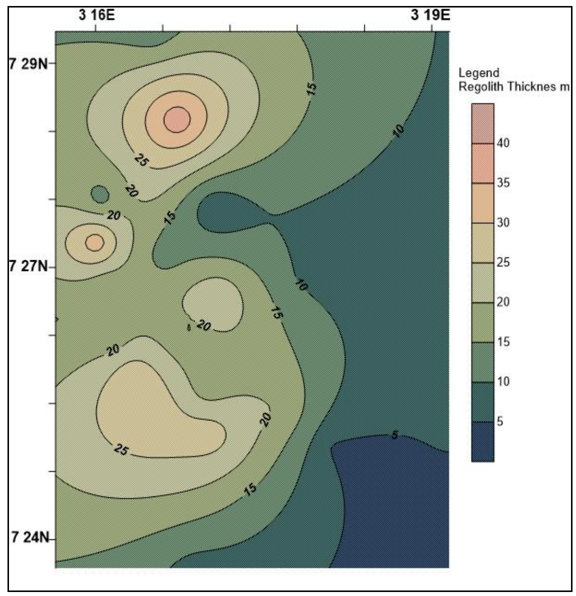


Figure 7: Isopach map of the regolith

The geo-section along west-east traverse (fig. 8) revealed that the weathered-fractured system is more developed in the western axis through the central locations than at the eastern parts of the study area. At the western end, the vertical sections were characterised by fairly deep weathering terminating on fractured bedrocks which is succeeded by reduction in soil development and much higher bedrock resistivities (which indicated fresh Basement rock units) eastward.

III. RECHARGE POTENTIAL

The potential for water conductance ranged from 0.02 to 1.42 mhos with an average of 0.45 mhos across the study area. The spatial spread of potential for water conductance is illustrated in figure 9. The western end which is notably characterised by deeper weathering and larger extent of bedrock fractures is also expected to have larger groundwater conductance as well. Conversely, coupled with the fact that the middle layer i.e. the saprolite is largely fine grained there is a strong possibility of siting more prolific (or even artesian) wells at the western sections. Such artesian wells are well confined and are mostly characterised by fairly good yield that may not be influenced by seasonal changes in weather condition all year round.

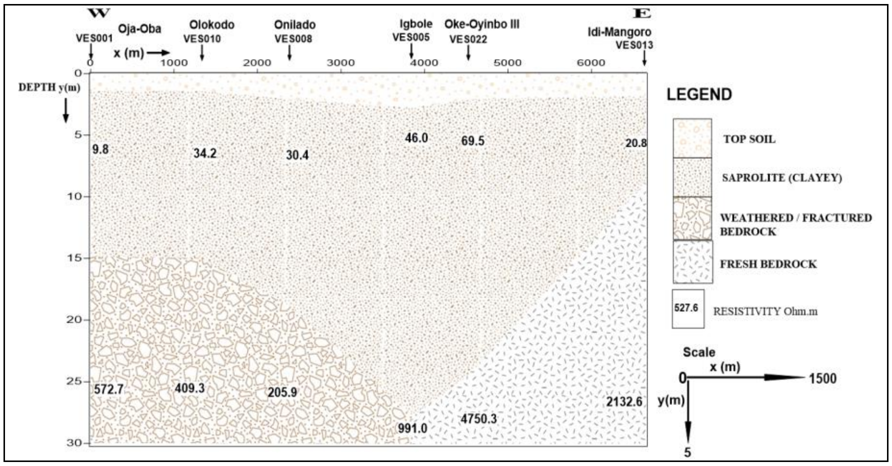


Figure 8: Geo-section along the W-E axis across the study area

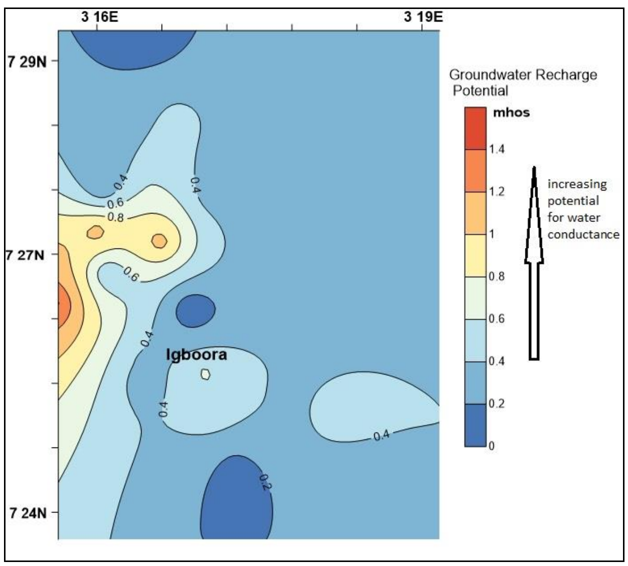


Figure 9: Recharge Potential, S Map

IV. Conclusion

It is clearly noticeable that there is disparity in the degree and extent of weathering and bedrock fracturing across the study area. Further groundwater prospect of the Basement crusts at Orati, Arigbajo and Oke-Ololа at the western section of Igboora hub is feasible. These areas were notably characterised by deeper weathering and bedrock fracturing, and they have higher groundwater recharge potential, and can further be explored for groundwater by siting more (and deeper wells) if there is need to expand the existing groundwater supply.

In respect to aquifer prospect of the sub-surface environment across the study area, the fractured Basement is expected to be more prolific, and because of the fine grained nature of the saprolite/weathered layer, artesian wells with expected continuous fairly good groundwater yield can be sited at the western section. However, the saprolite or the middle layer with an average thickness of 15.56m, can also be a prominent water bearing zones in the subsurface even in locations where the geo-sections terminate on fresh bedrocks. This is due to the more spatial distribution of thick regolith development across the area. Though, water yields of wells tapping the weathered units only are expected to be lower than those that penetrate fractured Basement and the groundwater quality may be questionable due to direct recharge from surface effluents. Notwithstanding, considering the prevailing climatic conditions of the study area, the weathered layers alone may provide an alternate groundwater supply in locations where the bedrocks are fresh provided there is continuous yearly recharge from meteoric source during rainy season in the area.

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