APPLICATION OF ELECTRICAL RESISTIVITY METHOD FOR ROUNDWATER EXPLORATION AT INKIL AREA OF BAUCHI, NORTHEASTERN NIGERIA.

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ABSTRACT
Geoelectrical resistivity sounding using the Schlumberger array was carried out at Inkil area in Bauchi, northeastern Nigeria. The aim of this study is to investigate the hydrogeological conditions of the study area. Fifteen Vertical Electrical Soundings (VES) were carried out, from which geoelectric sections - composed of four subsurface layers – were inferred. The first layer has resistivity ranging from 58 to 2029 ohm-m and thicknesses from 0.46 to 10.7 m and is inferred to be lateritic topsoil. The second geoelectric layer has resistivity values ranging between 188 and 518 ohm-m with thicknesses varying between 14.7 and 25.8 m, this layer is interpreted to represent a highly weathered to completely decomposed crystalline rock. The third geoelectric layer is considered to be the dominant aquifer in the area under investigation and is inferred to be weathered and/or fractured crystalline rock. This layer has moderate electrical resistivity values (80–396 ohm-m), and could be recognised sometimes as the most extreme depth of current penetration. At the maximum depth of current penetration, the lower layer (fourth layer) was recognised to have the highest electrical resistivity values (451–8935 ohm. m) that depicts fresh crystalline basement. Recommended points for borehole drilling are VES 2,3,4,5,6,7,8,9,11.12.13 and 15 as they contain probable aquifers. The depth of drilling should be between 60m and 70m to take advantage of the basement fractures. In general, the area can be said to be poorly weathered and this cannot support substantial water abstraction of industrial scale when drilled.

Keywords: Electrical resistivity, VES, aquifer, groundwater, Inkil

INTRODUCTION

Bauchi area lies in the eastern margin of Northern Nigerian Basement complex within longitudes 9^0 45' and 9^0 59' East and latitudes 10^0 08' and 10^0 23' North. The study area (Inkil) lies to the east of Bauchi town, (Figure 1). It has shortage of portable water supply due to inadequate surface water source and insufficient rainfall. Previous studies on groundwater potential in this area tend to be scanty and undocumented (Bain, 1926; Offodile, 1992). These are mostly sparse sampled VES points employed with the aim to delineate aquifers for residential water wells. The inadequate knowledge of the hydrogeology of this area necessitates the need for detail study to delineate groundwater viability of the study area.

The electrical resistivity technique is one of the most widely applied geophysical methods for groundwater investigation in crystalline basement terrane (Martinelli, 1978; Olorunfemi and Olorunniwo, 1985; Dike et al., 1994). This technique estimates the distribution of rock resistivity in the subsurface, which among others can vary with moisture content and lithology. The relevance of this method is based on the noticeable resistivity contrast between water bearing zones (usually weathered and or fractured zones) and very resistive non-water bearing fresh rocks. The extent and nature of the weathered layer and the degree of fracturing of fresh rocks are dependent on the subsurface geology (Martinelli, 1978; Keary and Brooks, 1991). The method has proven to be rapid and effective in providing useful information about hydrogeological conditions and is relatively cheaper when compared to other geophysical techniques.

Water boreholes in the basement terranes are drilled to different depths depending among others on the aquifer thickness or depth to fresh non-fractured bedrock.

Therefore, the basic aim of this study is to determine the thickness and depth of the water-bearing layer(s) (aquiferous layer) in the area. The study also aimed to give an insight into the hydrogeological relationship between different parts of the study area. This knowledge may help in future groundwater development of the study area. In this paper, we focus on the presentation of the highest-quality resistivity measurements from Vertical Electrical Soundings (VES's) in order to present a first-order picture of the hydrogeological condition of the study area.

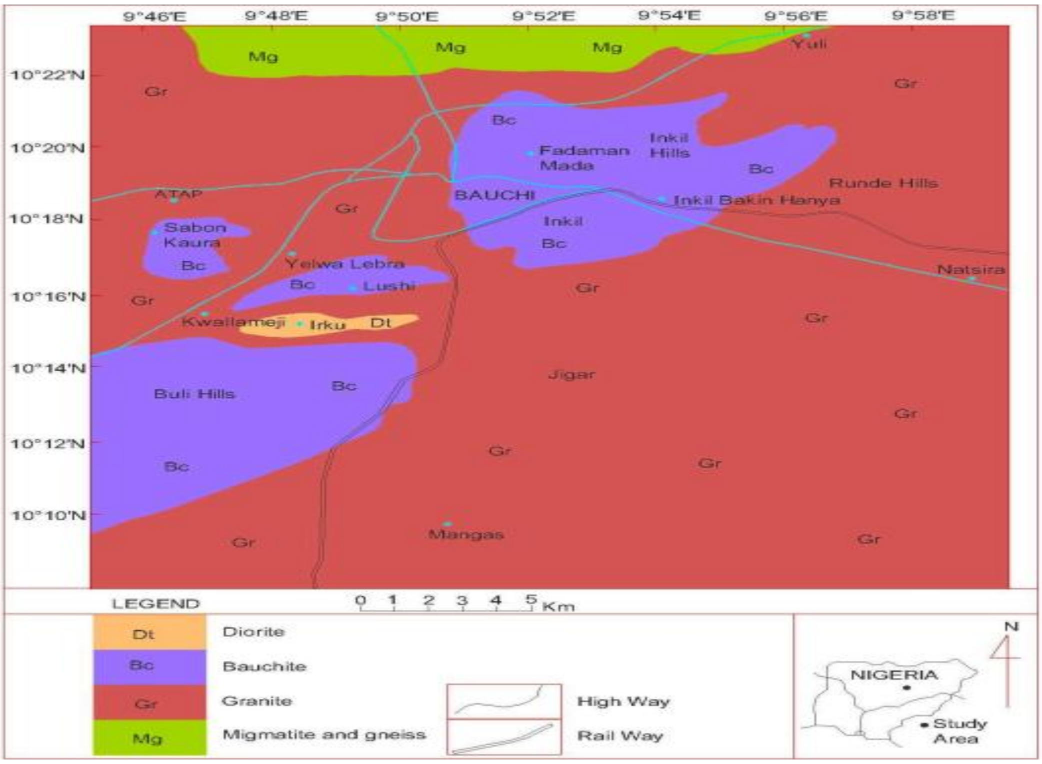

Figure 1: Location map of the study area showing its relation to major geological components (after Haruna, 2016).

REGIONAL AND LOCAL GEOLOGY OF THE STUDY AREA

Inkil is located within the Nigerian Basement Complex, which forms part of the Pan African Mobile Belt that lies between the West African Craton and the Tuareg Shield. Earlier workers have intricately linked the overall emplacement of the Nigerian Basement Complex to the earliest orogenic events that affected the African continent (Oyawoye, 1972, 1964; McCurry, 1989). These Basement Complex rocks include gneisses, migmatites and metasediments of Precambrian ages that have been intruded by a series of Pan African age rocks. These rocks have been variably metamorphosed and granitised through tectonometamorphic cycles, so that they have been largely converted to migmatites and granite-gneiss (Falconer, 1911; Oyawoye, 1964). Younger metasediments believed to be of upper Proterozoic of age were supposedly deposited on this granitised basement, and folded along with it during the Pan African Orogeny. They are low-grade metamorphic rocks that now represented as synclinal troughs among older rocks in northwestern Nigeria (Carter et al., 1963; Rahman, 1988; McCurry, 1989). Intrusives into the Basement rocks and the younger supracrustal cover are series of intermediate plutonic rocks known as the older granite suites. These are chernokites, diorites, fayalites quartz-monzonites (bauchites) and gabbroic earlier rocks. Migmatisation has differently affected all the earlier rocks as well as the large-scale conversion of basement gneisses and migmatites (Oyawoye, 1958). Locally, older granites and fayalite bearing quartz monzanite underlie the study area (Figure 1). The principal rocks outcropping comprises of highly weathered granites featuring remnants of large feldspar crystals and well-defined zones of quartz-rich veins. This type of rock practically constitutes the high elevations of the fairly rugged topography that characterises the terrain. Another major outcrop of importance is fayalite quartz-monzonites (bauchites), which is also characterised by large quartz crystal and a taint of greenish colour when fresh but turns brown upon weathering (Oyawoye, 1961, Oyawoye and Makanjuola, 1972). They have few joints and outcropping as smooth rounded boulders derived from massive unfoliated rocks by weathering. The bauchite usually appear as large intrusions into a more widely spread biotite hornblende granite. The contact between the bauchite and the granite is gradational. This transition coincided with a gradual change in colour from dark green (where bauchite is fresh) or dark brown (where it is weathered) to pink or grey in biotite hornblende granite. The change in colour is also marked with a change in the mineralogy expressed by progressive decrease in fayalite, pyroxene (clino- and ortho-pyroxenes) and increase in biotite (Haruna, 2016). This is attributed to mineralogical changes due hydration reaction caused by water migrating from the granitic outer rock to the drier bauchite (Eborall, 1974).

HYDROGEOLOGY OF THE STUDY AREA

Hydrogeologically, the occurrence of acquiferous layer in the area is sought within the highly decomposed to partially weathered basement rocks as well as fractured basement rocks, and these are found at depth in excess of 1 meter from the ground surface (BSADP Report, 1983). However, large portion of the basement rocks are not readily exploitable owing to the poor weathering and/or fracturing on this rocks (Offodile, 1992). Hence yields have been reported to be low, typically less than 40 litres per minute and more frequently less than 25 litres per minute (Offodile, 1992). The area comprises of (2) stream channels – likely contributors for aquifer recharge –, which occupy the various depressed areas in a rather dendritic to angular drainage pattern. These channels, which are seasonally charged by rain merged into minor tributaries that ultimately feed several ponds around the study area.

METHOD

The field operation involves the use of electrical resistivity method employing the Schlumberger electrode configuration at fifteen (15) randomly selected stations (Figure 2). Electrical resistivity studies using the Schlumberger electrode configuration were known to give much insight into the vertical variation and lateral extent of subsurface geology (Telford et al., 1990; Keary and Brooks, 1991).

In practice, the electrical resistivity technique measures earth resistance (R) by inducing direct current or low frequency alternating current into the ground using a pair of metal electrodes (current electrodes). Another pair of electrodes (potential electrodes) measures the resultant potential difference. Generally, the current electrodes (C_1 and C_2) and the potential electrodes (P_1 and P_2) are arranged in a linear array. For each particular electrode configuration, a geometric factor is calculated which converts the resistance measured to an apparent resistivity (ρ_a); this is true for the Schlumberger electrode configuration employed for this study. In this technique the potential electrodes maintain a constant separation during sounding, while the current electrodes are moved outwards after each reading (Keller and Frischknecht, 1966). Resistivities are then only a function of the current electrodes separation as increasing this separation increases the subsurface exploration.

During the field operation earth resistance determinations were made using an Allied Campus Ohmega resistivity meter. This is a portable microprocessor controlled integrated receiver and transmitter which provides a direct digital readout of resistance (Kollert, 1969). Power is supplied by a re-chargeable pack with current amplitudes switch selected from 0.5-50 milli-amperes and output in the form of a square wave. The measurement system employs signal stacking, digital and analogue filtering, rejection of self-potentials and current transients enabling accurate discrimination of the signal even in high noise environments. Moreover, several self-diagnostics are in-built; error codes are displayed for instrument, cable, and electrodes faults.

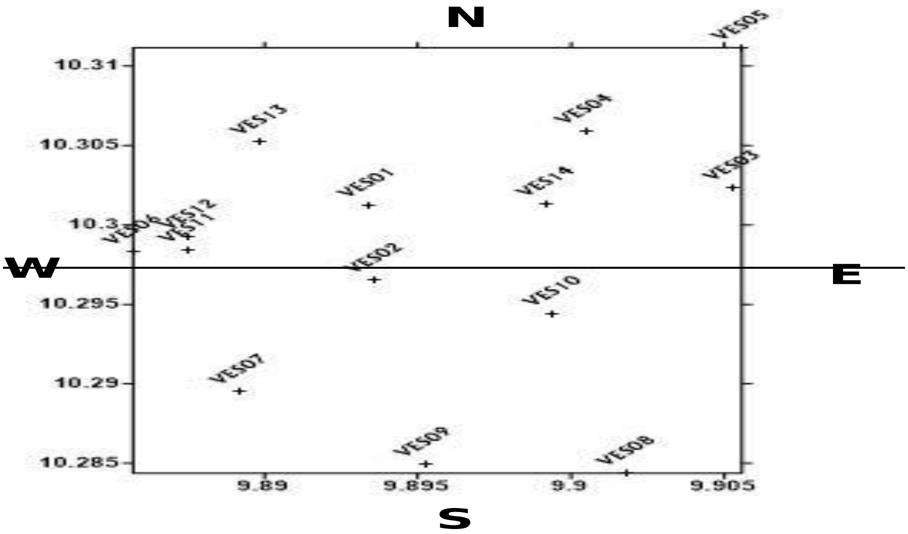

Figure 2: Distribution of the VES stations in the study area.

During the data acquisition a maximum current electrode separation (AB) of 300 m was achieved in most VES locations. Thus information to a depth of about 100 m could be achieved (Martinelli and Hubert, 1985). The apparent resistivity data obtained from VES sites were plotted against half the current electrode spacing (AB/2) on log-log axes using *Winresist* software (Figure 3), which interprets resistivity-sounding curves using curve-matching techniques. This involves matching small segments of a field curve with an approximate theoretical curve to determine both the thickness and apparent resistivity of particular layers in a half space. The resulting set of layer parameters were interpreted in terms of their lithologic equivalent.

RESULTS AND DISCUSSION

After applying the curve matching procedure described above, a four-layered model consisting of the topsoil/laterite, decomposed crystalline rock, weathered/fractured crystalline rock and fresh crystalline rock was produced from the field data (Figure 3). Values of thickness and apparent resistivities (volume average resistivity of a heterogeneous half-space) were varied until the field and theoretical curves had the least possible misfit. An example result from Figure 3 suggests that the resistivity model whose calculated apparent resistivity best fit the measurements, with a RMS error of 2.3, is characterized by a top layer with a thickness of 0.9 m and apparent resistivities of 178.2 ohm-m, a value characteristic of lateritic topsoil. The second layer is approximately 3.4 m thick, has an apparent resistivity of 56.9 ohm-m. The range of apparent resistivity values and thickness of the second layer is interpreted as the decomposed crystalline rock depicting overburden saturated with pore water for such, as suggested in Martinelli and Hubert (1985). The third layer has a thickness of 8.5 and an apparent resistivity of 65.1 ohm-m and is presumed to be the decomposed to weathered crystalline bedrock. The fourth layer has an apparent resistivity of 459 ohm-m and is presumed to be the weathered/fractured to fresh crystalline rock. Martinelli and Hubert (1985) suggested that such thickness of the weathered overburden (i.e. > 10 m) is associated with a borehole success rate of around 25% and thus the groundwater potential in this particular region may be low.

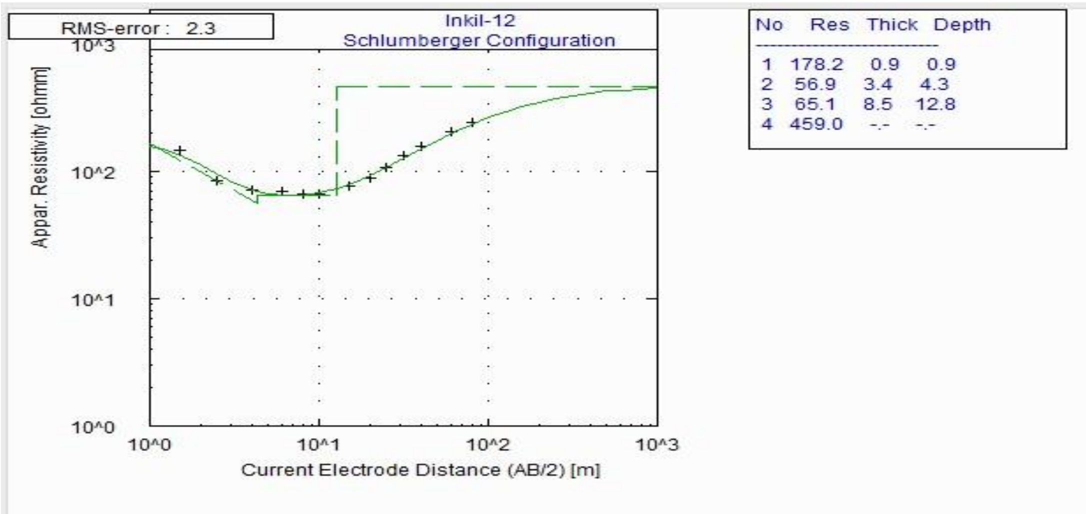

Figure 3: Resistivity model at station 12 (VES 12

As stated earlier, the objective of this study is to evaluate the groundwater potential and investigate its distribution in the study area using VES. The extent of weathering or fracturing inferred by this survey can be used to indicate groundwater potential zones in the study area.

From the aquifer isoresistivity contour map (Figure 4), a high resistivity zone along the central region of the study area suggests the possibility of fresh crystalline rick at shallow depth which could be explained by the occurrence of low lying granitic outcrop around VES 10. A low resistivity zone along the northern and western margin of the study area suggests the possibility of groundwater saturation, hence a weathered or fractured zone. This was also reported by Shehu et al., (Verb. Statement, 2020) who stated that the few residential boreholes drilled around these regions of the study area showed higher frequency of fractures in the upper 20 m of the bedrock, just below the overburden. The low resistivity region along the southern part of the study area may also suggest the presence of a fracture zone in this region. This also agrees with earlier studies by BSADP Report, 1983 which suggested that the geological features of this area consist of weathered and fractured basement in which groundwater tends to occur within residual overburden (regolith) and the fractured zone. The presence of fractures, as interpreted from the VES, is also consistent with the hydro-geophysical study conducted by Shehu et al., (Verb. Statement, 2020) who suggested that the occurrence of groundwater in the study area is solely controlled by secondary porosity due to presence of fractures in the underlying bedrock.

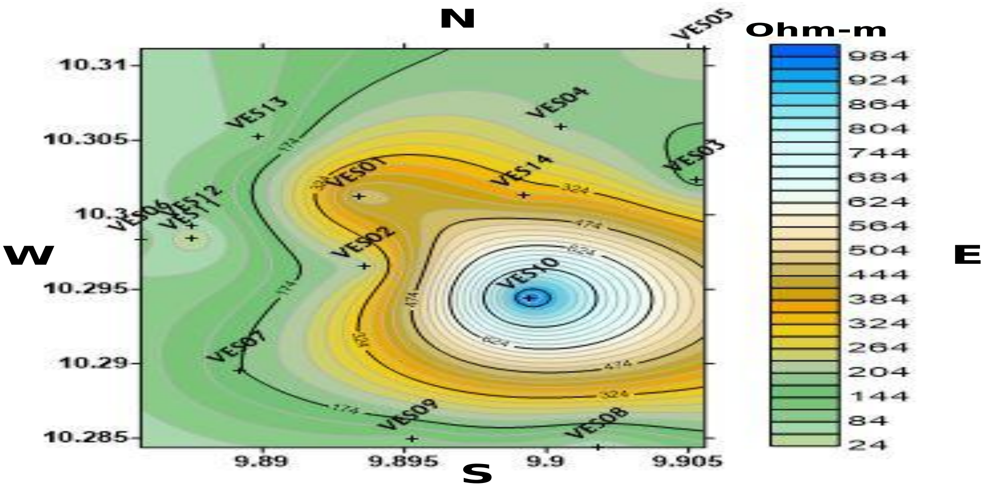

Figure 4: Isoresistivity contour map of the inferred aquiferous zone.

CONCLUSIONS

New results from electrical resistivity data presented here provided an insight into groundwater potential of the study area. The study was able to delineate four-geoelectrical layers underneath the study area. The aquiferous layer has an average resistivity of 272.4 Ωm and a thickness of ~10.67 m. The southwest part of the study area appears to have more potential for groundwater development in view of the low resistivity and thicker section of the aquiferous zone as compared to other parts of the study area. However, northeastern and southeastern part of the study area tends to have a complex geology where we tend to have some pockets that have potential for groundwater development. Overall, a partially weathered and fractured basement with a relatively thin overburden underlies the area surveyed. This suggests that the surveyed points will be predominantly low yielding in terms of groundwater extraction. Therefore, drilling is recommended on VES 2,3,4,5,6,7,8,9,11.12.13 and 15 as they contain probable aquifers. The recommended depth of drilling should be between 60m and 70m to take advantage of the deep seated basement fractures. Finally, this study demonstrated the efficiency of using electrical resistivity in imaging the subsurface from which structures and extent of fractures and weathering that influence the occurrence of groundwater in crystalline rocks may be interpreted.

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