DELINEATION OF FRACTURE ZONES FOR INVESTIGATION OF GROUNDWATER POTENTIALS USING VERTICAL ELECTRICAL SOUNDING IN A SEDIMENTARY COMPLEX TERRAIN (A CASE STUDY OF SOUTHERN PART OF GULUMBE DISTRICT, KEBBI STATE, NORTH-WESTERN PART OF NIGERIA)

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ABSTRACT

Vertical electrical sounding (VES) method was used to investigate the groundwater potential at the southern part of Gulumbe district, Kebbi State, north-western part of Nigeria. The study was carried out with the aim of determining the subsurface layer's parameters (resistivity and thickness) and uses same to characterize the groundwater potential of the study area. The Schlumberger configuration was used for the data acquisition. A total number of thirty-three (33) sounding points (VES) were surveyed over six profiles. The software IPI2WIN was used to obtain n-layered geo-electric sections. The geo-electric section drawn from the results of the interpretation revealed that three subsurface layers could be delineated which comprise of top soil, sand, sandstone, coarse sand, limestone and gravelly sand. The results of the resistivity sounding were correlated with the lithological logs of nearby boreholes that expose cross section geologic units around the study area. We found out that, the area is dominated by three subsurface layers. The coarse sand layers constituted the aquifers zones in the majority of sounding stations. Thus, this present study concluded that the depth of any borehole in the study area should be located between the depth of 18.5 to 39 m. The study further classified the VES points penetrated based on their conductivity content as highly suitable, suitable, moderately suitable and poor zones for groundwater exploration. Hence, from this research we recommended that boreholes can be sited in high conductivity zones across VES 2, 11, 13, 16, 20, 21, 27, and 33 respectively.

Keywords: Vertical electrical sounding, Resistivity, Geo-electric, Resistivity, Aquifer and Groundwater.

INTRODUCTION

The use of Geophysical tools specifically vertical electrical sounding technique in search for groundwater potentials has gained a wider recognition due to its ability to identify a fractures zones for groundwater development. Schlumberger array configurations has been considered to be one of the most suitable mean for groundwater explorations, therefore for successful groundwater explorations in a sedimentary complex terrain, there is need to understand its hydrological and geologic characteristics.

Groundwater is water found underground in the cracks and space of soils, sand and rocks. When rain falls to the ground the water does not stop moving, some of it flows along surfaces in streams or lakes, while some are used by plant in a process known as Transpiration, some evaporate back into the atmosphere, while some sinks into the ground in a process known as Infiltration and trickles downwards into the rock becoming ground-water (Kearey *et al.,* 2002). Groundwater is the water held in the subsurface within the zone of saturation under hydrostatic pressure below water table (Telford *et al.,* 1990). It is characterized by a certain number of parameters which geophysical methods are trying to determine from surface measure-ments, mostly indirectly, but sometimes directly. The most usual parameters are the porosity, the permeability, the transmissivity and the conductivity. Practically all groundwater that is used by human beings originates from the atmosphere or has a "meteoric" origin, and the principal source of natural recharge is precipitation that falls directly on the Earth's surface.

There is an increasing demand for water resources in the study area due to rapid population growth rate, growing prosperity and agricultural activities especially during dry season due to the fact that the available sources of water which is surface water are polluted by the activities of local farmer during dry season making it unsafe for drinking and domestic uses. The needs and uses of water by man and animal cannot be overemphasized, because it plays a vital role supporting wetlands and stream flow. Groundwater is used for drinking and other domestic activities by more than 50% of the world's population including those who live in urban and rural areas, but the largest use of groundwater is to irrigate crops (Telford *et al.,* 1990).

Location and Accessibility

The study area belongs to the Sudan and Sahel Savannah region of Africa, an area that is mostly affected by the droughts and flood. It is characterized by very short grasses located in-between sand and sandstone Figure 1.2. The area so defined is characterized by broadly flat topography with gentle undulations and hill ranges. The major occupation of the community is agriculture. The area so defined can be found based on its geographical coordinates between N12^{0}23.85, E004^{0}21.293′, N12^{0}23.779′, E004^{0}21.525′, N12^{0}23.517′, E004^{0}21.624′ and N12^{0}23.583′, E004^{0}21.237′. The area covers approximately 500 by 500 m, around Birnin-Kebbi, the state capital 5-7 km North-western of Sir Ahmadu Bello international airport. The villages around the study area are Bawada, Dakala, Kardi, Dan-Hadi and kyara. They are well linked through footpath and fairly motor able roads. The roads are mainly used by the rural dwellers to access their farms and settlement; it also provided linkages to the survey traverse Figure 1.2.

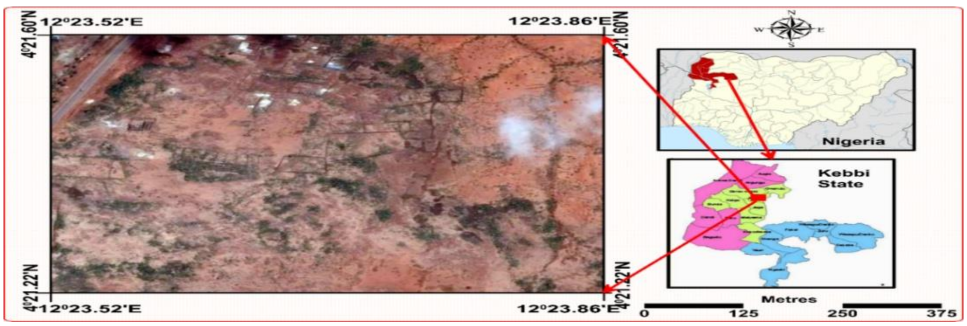

Figure 1.1: Google earth's map of the study area

Geology and Hydrological Setting of the Study Area

The study area is generally underlain by Sedimentary Complex Terrain of the Gwandu Formation. It contains a number of prominent ridges and group of flat topped steep-sided hills capped by ironstone. The sediments consist of massive white clays interbedded with coarse and medium-grained red stones and mud-stones with occasional peat bands. beneath the lateritic capping is a hard ferruginous sandstone layer which is easily eroded into a network of gullies. These are underlain by red sandy clays and white massive mudstones, which are invariably stained pale brown or pink. The mudstone with sandstone intercalations extends monotonously throughout the sections. Similar, section of Gwandu formations occurs on the slopes of the Gwandu outliers within the Kalambaina formation. The sand at the surface are quite red in colour, often showing colour banding and poor stratification, the mudstones often show a nodular structure with nodules suggestive of local turbulence in the depositional environment. The study area does not have any major river that passes through it. However, there exists a seasonal river and swamp/depression that surrounds the eastern part of the study area. This swamp functions only during the rainy season where it drains and collects all the excess runoff water from the surrounding scarps and hills. The swamp serves as a major source of domestic water supply as well as for irrigation activity for the community during the dry season.

MATERIAL AND METHOD

Electrical resistivity method using Schlumberger array was used along the six (6) profiles, Figure 1.3. Terrameter SAS 300C was used for data acquisition, the current and potential electrodes are progressively expanded about a fixed central point. Therefore, by progressively expanding the current electrodes readings of the potential difference are taken as current reaches to a greater depth, (Omosuyi, 2010). This gives the information on the resistivities and thicknesses of the underlying horizontal strata. The apparent resistivities are subject to interpretation techniques including the curve matching and/or computer interpretation.

Resistivity Method

D.C. resistivity technique is used to measures earth resistivity by injecting a direct current signal into the ground and measuring on the earth's surface the resulting potentials (voltages) created. For D.C. current flowing in a subsurface homogeneous isotropic medium, the potential at a single point electrode can be obtained using Ohm's law.

$$E = \rho J \quad (1.1)$$

where, E = is the magnitude of the electric field intensity (N/C).

ρ = is the resistivity of the medium, and (Ωm)

J = is the magnitude of the current density (A/m^2)

Now for a point current electrode at the surface of a homogeneous isotropic medium the current flows through a hemispherical surface in the lower medium then,

$$I = 2\pi r^2 J \quad (1.2)$$

Thus, $I = -2\pi\sigma a = -\frac{2\pi a}{\rho}$ therefore,

$a = -\frac{I\rho}{2\pi}$ hence, from equation (1.8)

$$u = \frac{I\rho}{2\pi r} \quad (1.11)$$

This imply that $\rho = 2\pi r\left(\frac{u}{I}\right)$ (1.12)

In a case of several point current sources the total potential U at an observation point M is the algebraic sum of potential distribution from each source considered independently.

Thus, for n point current sources equation (1.11) becomes:

$$U_m = \frac{\rho}{2\pi}\left(\frac{I_1}{r_1} + \frac{I_2}{r_2} + \frac{I_3}{r_3} + \ldots + \frac{I_n}{r_n}\right) \quad (1.13)$$

where I is the current.

Let assume that the potential gradient associated with this current is measured across two electrodes M and N on the surface, Figure (1.1) then the potential at M will be:

$$U_m = \frac{I\rho}{2\pi}\left(\frac{1}{r_1} - \frac{1}{r_2}\right) \quad (1.14)$$

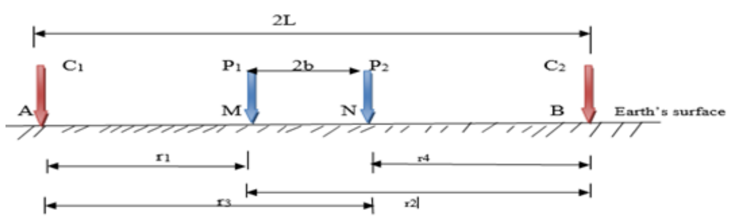

Figure 1.2: Geometric diagram of Schlumberger Array showing electrodes arrangement

$$U_N = \frac{I\rho}{2\pi}\left(\frac{1}{r_3} - \frac{1}{r_4}\right) \quad (1.15)$$

Therefore, the potential difference ΔU measured across M and N electrodes is

$\Delta U = Um - Un$

That is $\Delta U = \frac{I\rho}{2\pi}\left\{\left(\frac{1}{r_1} - \frac{1}{r_2}\right) - \left(\frac{1}{r_3} - \frac{1}{r_4}\right)\right\}$ (1.16)

From the above equation the apparent resistivity for non – uniform earth can be expressed as,

$$\rho_a = \frac{\Delta U}{I}$$

$$\left[\frac{2\pi}{\left(\frac{1}{r_1} - \frac{1}{r_2}\right) - \left(\frac{1}{r_3} - \frac{1}{r_4}\right)}\right] \quad (1.17)$$

the term inside the square bracket is called the geometric factor denoted by letter K.

Based on the resistivities and the thicknesses of the underlying formations and the available geology of the area, the depth to water bearing rocks (aquifer) can be estimated (SARDA, 1988). The survey area was grouped into six profiles P_1, P_2, P_3, P_4, P_5 and P_6 respectively Figure1.3, and are not necessarily parallel to each other, each profile was divided into six VES soundings points with grid distance of 100 m the first profile has VES 1, 2, 3 and 4 with a survey orientation W-E, the second profile for the survey has five VES points 5, 6, 7, 8 and 9 with survey traversing from E-W, with an inter profile spacing of 100 m. Similarly, the same patterns were employed across profiles 3, 4, 5 and 6 respectively. The data acquisition was carried out using Schlumberger and modified Half Shlumberger array of configurations. Measurements were taken along each profiles following the technique outlined by Telford *et al.,* (1990). A station interval of 100 m was established and measurement were taken at each VES point by expanding the current electrodes symmetrically about the centre of the spread. Measurements was continue to next AB/2, and then to the next, until to a distance of 100 m, then the equipment will be moved to the next VES point and the same procedure was repeated until all VES points were surveyed in a particular profile Figure 1.3.

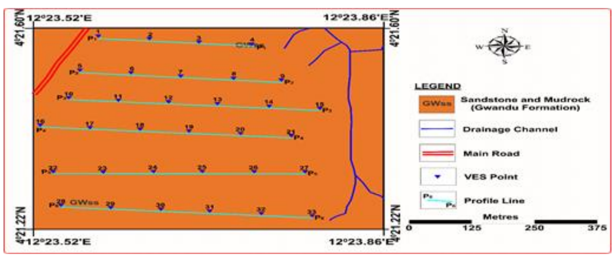

Figure 1.3: Profile lay out in the study area showing VES positions

RESULT AND DISCUSSION

The interpretation of the geo-electric parameters (resistivity and thickness) in terms of subsurface geology and groundwater conditions of the study area were carried out on the basis of the supplementary lithological information obtained near the study area Figure 1.4. The results analyses across six profiles revealed that three geo-electric sections could be delineated with the subsurface formations of the study area shows the existence of three subsurface geologic units across sounding points surveyed Figure 1.4. The maximum depth of penetration was obtained at around VES 2, 11, 13, 16, 20, 21, 27 and 33 respectively and these values are well correlated with the borehole lithological formation drilled near the study area. The lithological formation across six profiles surveyed revealed that the study area was underlain by sand, sandstone, clay/silt, coarse-sand, gravelly-sand and limestone.

Figure 1.4: Geologic section from borehole log data near the study area

0-15m pink clay, ironstone and browns clay
15-30m ironstone, fine sand, sandstone white clay and coarse sand
30m and above weathered/fracture basement.

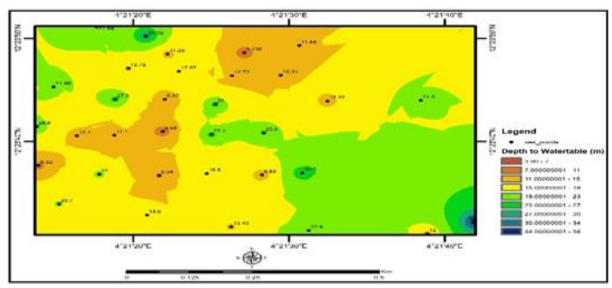

Figure 1.5: Depth to water table in the study area

Contour Map (Iso-resistivity map)

Iso-resistivity map was produced by contouring the resistivity values at thirty-three (VES) points along all the locations of the six (6) profiles within the study area. The resistivity values of the top soil ranges between 1000 to 1500 ohm-m, a contour interval of 500 Ωm was obtained. The contour map shows relatively high resistivity value at north-western part of the study area with a maximum resistivity value of 1500 Ωm and the lowest values was obtained at south-western part of the study area with 1000 Ωm respectively. The second layer or the overburden layer (aquifer layer) across all thirty-three (VES) points along the locations of the six profile within the study area Figure 1.7. The results obtained helps in locating some subsurface structural trends in the study area and also its reveal the lithological sequence of the geological formation beneath the earth. The essence of this map is to show the lateral variation of resistivity and thicknesses over a horizontal plane at certain designated depth, and also this map indicates distribution of resistivity variations and depth patterns in the study area.

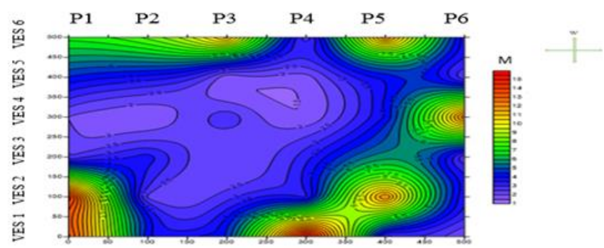

Figure 1.6: The depth contour map of the top soil with contour interval of 1.0m

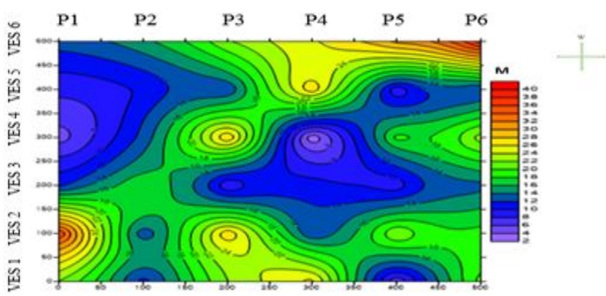

Figure 1.7: The depth contour map of the top soil with contour interval of 2.0m

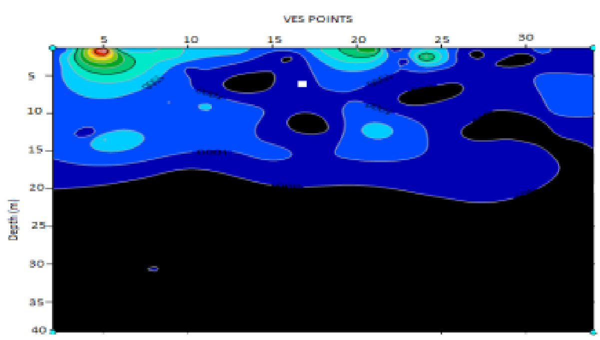

Figure 1.8: Geo-electric Section across the study area

CONCLUSION

Results from the thirty-three (33) sounding points indicates that, the area under study is underlain by three geo-electric layers within the depth penetrated, also three geologic/ lithologic units could be delineated The research revealed that the depth to water table has an aquifer thickness from 18.6 to 39 m, the sub-surface geology and lithological forma-tions of the study area shows the patterns of resistivity variation (iso-resistivity maps) with depth thus revealing its groundwater distribution as well as its potential as a substitute to the surface water resources. The study further reveal that there is strong local variation of groundwater recharge from one VES point to another and thus, concludes that the saturated water bearing zone across all the sounding points can be found within VES 1, 2, 10, 11, 13, 15, 16, 20, 21, 23, 25, 27, 28, 29, 31 and 33 respectively, with VES 2, 11, 13, 16, 20, 21, 27, and 33 respectively are the most promising area for groundwater bearing zones Figure (1.5). The study further revealed that the subsurface geo-electric sections and iso-resistivity maps showed that a thick over burden was overlaid by coarse formation zone in the north-western, north-eastern and south-eastern parts of the study area which are diagnostic of a reliable and sustainable groundwater source -suitable for borehole development at the study area. Finally, it is recommended that the drilling of boreholes should be done in the order suggested in each of the VES points.

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