Hydro-Geoelectrical Study for Groundwater Potential of Lassa And Environ, North Eastern Nigeria

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ABSTRACT

Twenty-two Vertical Electrical Sounding (VES) were carried out to evaluate groundwater potential and aquifer protective capacity of the overburden units using Schlumberger configuration. It was observed that H-curve is the dominant curve type in the study area. The Geo-electro stratigraphic section revealed that the geologic sequence beneath the study area is composed of topsoil, highly weathered basement, partly fractured basement and fresh basement. The first layer has an average thickness and resistivity of 1 m and 130 Ωm, respectively. The second layer has an average thickness of 14 m and an average resistivity of 53 Ωm. The third layer is partly fracture basement with an average resistivity of 747 Ωm while at some VES point represents fresh basement. The highly weathered basement and partly fracture basement layer make up the water bearing formation of the area. Dar-Zarrouk parameter revealed that the area under study has protective capacity range from weak to good capacity of the overburden material. Areas that are classified as poor and weak are indicative areas are thus vulnerable to infiltration of leachate and other surface contaminations. The groundwater potential of the area ranges from low to moderate potential; the moderate zone constitutes 86% while the low potential constitutes 14% of the study area. The transverse resistance within the study area ranges from 119.6 to 6983.7 ohms-m² with an average value of 1024.59 ohms-m². Hydraulic conductivity values determined from geoelectrical technique range from 3.05 to 38.04 m/day with an average value of 14.86 m/day.

Keywords: Dar-Zarrouk, Geo-electrostratigraphi, Lassa, Protective Capacity, VES.

I. INTRODUCTION

The area under investigation falls within 1964 sheet of Federal Survey of Nigeria. It is situated in the North eastern part of Nigeria in Borno state located between longitudes 13° 07'-13° 13' 17'E and latitudes 10° 40'-10° 54'N. It occupies an area of 336.6sq km. The area is accessible via the Uba-Askira road (Fig. 1) in the northern part of the Borno basement region.

Water is a highly mobile and variable resource that exists on the surface of the earth and within the subsurface in the pore spaces of geologic materials of the earth. Water beneath the subsurface generally occurs within water bearing porous and permeable rocks called aquifers. Examples of such rocks include sedimentary rocks like sandstone. However, fractured basement rocks and weathered basement rocks can also be classified as aquifers. Water is an indispensable resource and the concern of many earth scientists and researchers has been on the acquisition of a reliable source. The climate of the area is sub Sudan climatic zone characterized by wet and dry seasons. Most of the rain falls during the months of May to September but small amounts fall in March, April, October, and November. The remaining months of the year are dry. It is worthy to note that the Askira plain lies partly within the rain shadow of the Biu Plateau to the west and for this reason, there is a marked increase in mean annual rainfall from North to South. Temperatures are extreme in the area; however, the coldest night of the year occurs in the months of December and January during which air is often hazy and visibility is poor due to fine particles of dust. During this period, temperatures range from 21 °C to 25 °C while at night, it could be as low as 14 °C, though at higher altitudes [3]. March to June experiences an increase in temperature as the rainy season set in the daily maximum temperature up to 44 °C. of drinking water [1].

Domestic water supply in Lassa and environs comes largely from the groundwater; much of this is taken from the overburden and fractured granite. Over the years, boreholes and water wells have been drilled with or without previous knowledge of the subsurface information due to multiple failed boreholes, research efforts grew to minimize failed wells thereby reducing the risks as well as reducing the cost of drilling abortive wells. The use of geoelectrical data can give the approximate depth to aquifer [2].

Information concerning the lithology, stratigraphic sequence and hydro-geological characteristics of the subsurface material can be provided through the aid of electrical resistivity prospecting method. This geophysical method determines the variation in the subsurface...
distribution of electrical properties within the homogenous entity of the earth. This study, therefore, involves the use of the resistivity geophysical method, specifically the Schlumberger array to assess the average thickness of the aquifers within the study area so that apart from investigating the locations of these water bearing formations, it will show how they occur beneath the subsurface in Lassa and environs, hence contributing to a better understanding of the geological characteristics of the areas.

II. GENERAL GEOLOGY OF THE AREA

The area is located within the eastern province of the basement complex of north-eastern Nigeria, and most rocks belong to the older granites of the Pan African Orogeny. The granitic rocks have undergone complete weathering leading to unconsolidated weathered overburden consisting of sands, clays, and laterite. The basement complex of the eastern province is divided into the Mandara Mountain, Alantika Mountain, Shebshi Mountain, and the Adamawa Massif according to Carter et al. [4].

The geology is made up of the Precambrian basement complex rocks which are considered to be undifferentiated basement complex mainly gneisses, migmatite, and granites. The gneiss-migmatite complex is the most widespread and occupies more than half of the area and is the oldest rock in the area. They are heterogeneous rock group, which is composed gneiss migmatite of various origin and series of metamorphosed basic and ultra-basic rocks. Most of the basement complex of the area is dominated by biotitic granite, which is light gray, very coarse grained and occasionally pegmatitic and aplitic. Porphoric feldspar is occasionally present, and some places show a generally parallel alignment. The vegetation consists of large isolated trees and shrubs of savannah type which tend to thicken along the drainage line and at the foot of the hills. Reference [3] reported that Mylonite occupies a narrow shear zone trending north-south.

During field work the rocks identified in the study area are crystalline rocks as the basement complex which makes up the African shield composed of Alluvium, medium to coarse grained granite, fine grained granite and porphyritic granite (Fig. 2). The fine grained granite occurs at the South-western part of the study area around Mumtal as intrusive bodies characterized by numerous bodies of mafic minerals, there are also thick deposits of alluvium as exposed along a stream channels.

III. METHODOLOGY

The application of the resistivity methods has proved effective and a rapid tool for investigation and exploration for borehole location in basement terrain and also had some success in sedimentary rocks for lithologic variations and location of fracture zones [5]. The use of the resistivity method gives a better understanding of the hydrogeology of the basement area. It can furnish information on the subsurface geology that cannot be obtained by other methods in geophysics. The electrical properties of rocks depend on the amount of water, conducting minerals and the resistivity varies with salinity and temperature. Reference [5] adopted the electrical resistivity method to investigate the geo-electrical parameters and hydro-geologic characteristics of parts of the basement complex terrain of Nigeria and identified five aquifer units. Other researchers [6]-[9] have utilized resistivity methods as a tool for groundwater

Fig. 1. Topographic Map of the Study Area (USA Geological Survey Agency (2010)).

Fig. 2. Geologic Map of the Study Area (Field work).
exploration in basement terrain where the occurrences of groundwater is due largely to the development of secondary porosity and permeability of the weathering and/or fracturing of the parent basement rocks.

Terrameter SAS 300 system was used in the field for the purpose of the survey; the electrodes were arranged along a straight line and systematically disposed of with respect to the centre of configuration. Geophysical technique of the electrical resistivity method of Schlumberger array method was conducted in 22 different locations within the area. The resistance from each sounding was multiplied by the geometric factor (k) corresponding to each electrode spacing to obtain the apparent resistivity ($\rho_a$) values needed in plotting the Vertical Electrical Sounding (VES) curves.

IV. RESULTS AND DISCUSSION

The results obtained from the computed output of twenty-two VES in Lassa town and environs North Eastern Nigeria is presented in Table I. The curve types obtained were predominantly H types which include VES1, VES2, VES3, VES4, VES5, VES6, VES7, VES8, VES9, VES10, VES11, VES12, VES13, VES14, VES16, VES18, VES19, VES20, VES21 and VES22 constituting 90.9% of the study area with one A type at VES 15 representing 4.55% and one K type at VES 17 representing 4.55% of the study area. First-order geometric parameters (resistivity and thickness) of all sounded points which contain details of layer thicknesses, resistivity, longitudinal conductance, transverse resistivity, and fitting error for all the points sounded in the area are shown in (Table I). Iso-Resistivity map and Geo-electric sections have been drawn on the basis of interpreted VES data.

A. Iso-Resistivity Maps

Iso –resistivity maps were prepared using surfer software by plotting the resistivity obtained from sounding curves at a given electrode spacing common to all the sounding points for AB/2=40 m and AB/2=100 m (Fig. 3 a and 3 b) in the area and the points of equal resistivity were contoured. High resistivity values were observed at the western part of the maps whereas the northern, southern eastern parts were characterized by low resistivity values. This means that there is high conductivity in the southern parts of the area as opposed to the western part.

| Table I: Result obtained from Computed output of Twenty-two (22) VES Point within Lassa Town and Environs |
|---|---|---|---|---|---|---|---|
| S/No | VES Point | Coordinates | Thickness of Layers (m) | Resistivity ($\Omega$m) | Longitudinal Conductance (Siemens) | Transverse Conductance (Qm²) | Fitting Error | Curve Type |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 1 | VES 1 | E13°14´ N10°50´ | 1.0 13.0 100 48 64 | 0.0001 0.270 500 623 | 2.24 | H |
| 2 | VES 2 | E13°14´ N10°50´ | 1.0 6.0 63 12 346 | 0.013 0.474 519 677 | 2.44 | H |
| 3 | VES 3 | E13°12´ N10°42´ | 1.0 14.2 85 36 425 | 0.011 0.394 79.7 512 | 2.24 | H |
| 4 | VES 4 | E13°08´ N10°41´ | 1.1 7.6 134 38 222 | 0.008 0.198 147 290 | 2.47 | H |
| 5 | VES 5 | E13°09´ N10°42´ | 1.0 5.4 70 55 313 | 0.011 0.099 55.9 295 | 2.30 | H |
| 6 | VES 6 | E13°09´ N10°43´ | 1.0 16.0 204 73 340 | 0.004 0.216 175 1167 | 2.96 | H |
| 7 | VES 7 | E13°08´ N10°43´ | 1.0 13.0 39 12 246 | 0.024 1.080 36.9 153.8 | 2.66 | H |
| 8 | VES 8 | E13°10´ N10°44´ | 1.3 18.0 91 41 158 | 0.015 0.434 121 715.0 | 2.27 | H |
| 9 | VES 9 | E13°44´ N10°45´ | 1.0 6.40 34 25 203 | 0.028 0.257 32.3 161.0 | 2.45 | H |
| 10 | VES 10 | E13°12´ N10°46´ | 1.4 11.0 233 109 351 | 0.006 0.100 330 1190 | 2.05 | H |
| 11 | VES 11 | E13°16´ N10°47´ | 1.0 14.0 578 170 6599 | 0.002 0.080 539 2321 | 2.99 | H |
| 12 | VES 12 | E13°16´ N10°47´ | 1.0 15.0 86 36 526 | 0.011 0.401 78.9 532 | 2.51 | H |
| 13 | VES 13 | E13°10´ N10°53´ | 1.3 13.3 116 30.4 3264 | 0.011 0.438 145 404 | 4.48 | H |
| 14 | VES 14 | E13°12´ N10°50´ | 1.0 12.4 30 14 63 | 0.029 0.887 26.8 174 | 1.92 | H |
| 15 | VES 15 | E13°09´ N10°51´ | 1.1 10.0 21 30 53 | 0.052 0.322 22.1 290 | 2.51 | A |
| 16 | VES 16 | E13°16´ N10°51´ | 1.0 8.2 220 44 550 | 0.003 0.186 156 356 | 3.81 | H |
| 17 | VES 17 | E13°14´ N10°52´ | 1.3 39.0 30 179 95 | 0.045 0.215 39.7 6944 | 3.70 | K |
| 18 | VES 18 | E13°16´ N10°53´ | 1.0 11.1 73 38 813 | 0.001 0.295 56.9 421 | 3.36 | H |
| 19 | VES 19 | E13°15´ N10°53´ | 1.0 8.5 31.4 22.3 446 | 0.029 0.383 28.5 190 | 2.71 | H |
| 20 | VES 20 | E13°10´ N10°52´ | 1.0 29.0 169 34 923 | 0.006 0.833 165 984 | 3.04 | H |
| 21 | VES 21 | E13°09´ N10°53´ | 1.0 15.0 177 51 261 | 0.005 0.283 150 744 | 3.60 | H |
| 22 | VES 22 | E13°07´ N10°53´ | 1.0 15.0 271 73 166 | 0.003 0.201 201 1068 | 3.44 | H |

The topsoil is generally thin (about 1 m thick). The resistivity ranges between 21 Ωm at VES 15 to 578 Ωm at VES 11 which corresponds to topsoil composed of Clayed to lateritic sand. The Highly weathered / fractured layer has a varying thickness ranging from 6.4 m thick at VES 9 to 29 m at VES 20 with resistivity values of 12 Ωm at VES 7 to 170 Ωm at VES 11, the third layer has resistivity ranging from 203 Ωm at VES 9 to 659 Ωm at VES 11 with thickness tend to infinity. The third layer at VES 7, 9 and 21 represent partly weather basement while at VES 11, VES 13, and VES 20 depicting the fresh basement zone.

B. Geo-Electric Section along Profile A-A’

Geo-electric section was drawn along profile A-A’ in South to North direction and made up of six (6) Vertical electrical soundings (VES) points. These points are VES 7, VES 9, VES 11, VES 13, VES 20, and VES 21 (Fig. 4 a). The section was constructed by plotting the resistivity obtained as observed along vertical probing surface at each sounding point on a chosen profile and the result was plotted and correlated. These represent subsurface variation in resistivity and depths of different layers along with the profile.
C. Geo-Electric Section along Profile B-B’

These represent sub-surface variation in resistivity and depths of different layers along with profile B-B’ which consist of five Vertical electrical sounding (VES) points. These points are VES 3, VES 10, VES 12, VES 16, and VES 18 (Fig. 4 b). The topsoil is generally thin about 1m thick. The resistivity range between 85 Ωm at VES 3 to 233 Ωm at VES 10. The Highly weathered/fractured layer has a varying thickness ranging from 8.2 m thick at VES 16 to 15 m thick at VES 12 with varying resistivity of 36 Ωm at VES 3 to 109 Ωm at VES 10. While the third layer at representing partly fractured granite with a resistivity of 351 Ωm to 813 Ωm.

The geophysical survey has helped in delineating aquifer zones in the study area. From geoelectro-stratigraphic section (profile A-A’ and Profile B-B’) revealed three geologic layers beneath the subsurface; the second layer is a highly weathered basement and layer three is partly fracture basement with appreciable thickness suggesting these points are good for borehole drilling (Aquiferous Points); these points include VES 7, 9, 21 (profile A-A’) and VES 3, 10, Prof12, 16, 18 (profile B-B’). The highly weathered basement and partly fracture basement layer make up the water bearing formation of the area.

D. Aquifer Parameters Estimated from Geophysical Data

Dar Zarrouk was used to evaluate protective capacity of the area. Total overburden thickness provides protection by decreasing infiltration time of contaminant from the surface into groundwater [10]. “An aquifer protection capacity rating can be classified on the basis of the total longitudinal unit conductance (ΣS) as excellent (S > 10), very good (5 ≤ S ≤ 10), good (0.7 ≤ S < 5), moderate (0.2 ≤ S < 0.7), weak (0.1 ≤ S < 0.2) and poor (S < 0.1) protective capacity”.

VES 7, 14, and 20 showed good protective capacity with 13.6% over the study area. 72.7% have moderate capacity which comprises of VES 1, 2, 3, 4, 6, 8, 9, 11, 13, 15, 16, 17, 18, 19, 21, and 22 while VES 5, 10, and 11 (13.6%) showed weak protective capacity of the overburden materials. Areas that are classified as poor and weak are indicative areas are thus vulnerable to infiltration of leachate and other surface contaminations (Fig. 5a).

Transverse resistance is also used to define areas of groundwater potentials [11]. A resistance layer can be determined by transverse resistance. The transvers resistance within the study area ranges from 119.6 to 6983.7 ohms-m² with average value of 1024.59 ohms-m² (Fig. 5 b). High transvers resistance within the study area is in North-eastern part of the area.

The aquifer parameters calculated from geophysical data like hydraulic conductivity (K) and transmissivity (T) are important for the management and development of groundwater resources. The hydraulic conductivity was estimated using the equation as given by [12] and the summary of Aquifer Parameters estimated from Geophysical Data are presented in Table II.
Hydraulic conductivity is 0.73 and the correlation coefficient is negative. If one variable tends to increase as the other decreases, the coefficient assumes a value between −1 and +1 representing a perfect linear relationship. If both variables tend to increase or decrease together, the coefficient is positive, and the line that represents the correlation slopes upward. If one variable tends to increase as the other decreases, the coefficient is negative, and the line that represents the correlation slopes downward.

The Pearson correlation coefficient measures the degree of a linear relationship between two variables. The correlation coefficient assumes a value between −1 and +1 [13]. If one variable tends to increase as the other decreases, the correlation coefficient is negative. Conversely, if the two variables tend to increase together the correlation coefficient is positive. The larger the absolute value of the coefficient, the stronger the relationship between the variables.

For the Pearson correlation, an absolute value of 1 indicates a perfect linear relationship. A correlation close to 0 indicates no linear relationship between the variables. The sign of the coefficient indicates the direction of the relationship. If both variables tend to increase or decrease together, the coefficient is positive, and the line that represents the correlation slopes upward. If one variable tends to increase as the other decreases, the coefficient is negative, and the line that represents the correlation slopes downward.

The Pearson correlation coefficient between transmissivity and hydraulic conductivity is 0.73 and represents a positive relationship and strong correlation between the variables. As transmissivity increases, Hydraulic conductivity also increases.
Geo-electrical study of the area using the Schlumberger method has assisted in delineating groundwater potential zone of Lassa and Environ. Information gathered from an interpretation of twenty two Vertical electrical soundings in this area showed that H-type curve is the most prominent depicting three-layer earth model. Highly weathered and partly fracture basement have been identified and these constitute the aquifer zone. 13.6% showed good protective capacity, 72.7% have moderate capacity while 13.6% showed weak protective capacity of the overburden materials. High transvers resistance within the study area is in North-eastern part of the area. Hydraulic conductivity values determined from geoelectrical technique range from 3.05 to 38.04 m/day with an average value of 14.86 m/day. Transmissivity values obtained from VES method for potential aquifers range between 44.8 to 494.52 m²/day with an average of 179.13 m²/day. High transmissivity values correspond to high groundwater potential and this area corresponds to hydraulic potential zones.

CONFLICT OF INTEREST
The authors declare that they have no conflict of interest.

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