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PIEZOMETRIC SURFACE DEDUCED FROM VERTICAL ELECTRICAL SOUNDING DATA

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ABSTRACT
In hydrogeological studies the knowledge of the water table is very essential. In this work, one hundred and eight vertical electrical soundings were carried out, with the view of unravelling the hydrogeological characteristics of Kuri River Basin, Kaduna, Nigeria. The water table for eleven hand dug wells were directly measured and a comparison was made with cumulative resistivity ($\sum\rho_a$) plots at such well sites. The apparent resistivities were obtained using the Schlumberger electrode array configuration with a spread current electrode of 300m. The data obtained was processed using the GP Resound program. It was found that all the depths to the water table for the measured wells fell within the 3rd segment of the cumulative plots with a standard deviation of 0.04. The 3rd segment or 3rd break of the plot is considered as the zone of permanent saturation. It was on the basis of these cumulative plots that the depths to water table of all other sites sounded were deduced. By this, it is now possible to infer depths to water table from vertical electrical soundings without necessarily undergoing direct well measurements.

Keywords: Water Table/Piezometric Surface, Vertical Electrical Sounding, Hydrogeology, Cumulative Resistivity Plot.

INTRODUCTION
Geophysical methods have found useful application in groundwater investigation, geological mapping and engineering site investigation. These include bedrock determination for structural mapping, aquifer delineation, saline water mapping, lithological boundary differentiation and determination of structural trends (Early and Dyer, 1964; Page, 1968; Zohdy, 1974; Olorunfemi and Mesida, 1987; Olorunfemi and Opadokun, 1987; Mbipom and Okon-Umo, 1990; Shemang etal, 1992; Dogara, 1998; Dogara, 2003). The present work has proved the usefulness of the geophysics method through the Vertical Electrical Sounding measurements in the deduction of piezometric surfaces.

The increasing demand for water, for domestic, industrial and agricultural purposes has led to widespread search in all geological formations in Nigeria for this resource. The situation has become particularly compelling because of the drought, which seems to occur in decade cycle in Kaduna State (Danladi, 1981). This occurrences has further necessitated the need for adequate knowledge of the water table before drilling of boreholes which is by far much more expensive than the geophysical survey which leads to the inference of the piezometric surface.

This drought necessitated the government becoming interested in the exploitation of groundwater to meet the shortage created and also to provide clean potable water in the rural areas primarily for domestic purposes. This led to "wildcat" drilling programme (Danladi, 1981), which attendant failure led to change of approach in the exploration and development of groundwater resources in the whole State through the use of geophysical surveys. The geophysical survey in the State recorded 72% success in boreholes drilled (Danladi, 1985). Nigeria and Kaduna State in particular, have been striving hard to solve some of her many social, economic and political problems, as part of this scientific methods are being used to approach national planning and the increasing demand for domestic water, industrial and agricultural purposes which is more compelling during the dry season. In the light of this then, a study on the deduction of piezometric surface from vertical electrical sounding was undertaken.

Maps of water table are basic tools of hydrogeological interpretation. These maps are two dimensional representations of three-dimensional surfaces, such maps can be shown as contour maps with lines of equal elevation. They can also be shown as perspective drawings representing a three – dimensional view of surface (Fetter, 2001). Ground-water contours form a 'V', pointing upstream when they cross a gaining stream and bend downstream when they cross a losing stream (Fetter, 2001). Responding to the pull of gravity, water percolates down into the ground through the soil and through cracks and pores in the rock. The rate of groundwater flow tends to decrease with depth because rock pores tend to be closed by increasing amount of weight of the overlying rock. Moreover, sedimentary rock overlies igneous and metamorphic crystalline basement rocks, which usually has very low porosity (Charles and Diane, 2008). The subsurface zone in which all rock openings are filled with water is called the saturated zone. A well drilled downward into the zone, groundwater would fill the lower part of the well. The water level inside the well marks the upper surface of the saturated zone, this surface is the water table or piezometric surface, hence, the crux of this study.

Water table maps enable us to know the direction of groundwater flow (Mahajan, 2011). The depth to water table map is of special use in delimitating the extent of areas in need of drainage. For this reason, depth to water table maps are drawn for some chosen typical dates for example when the highest water table occurs or when the lowest water table occurs, preferably before the rainy season or after the rainy season (Mahajan, 2011). The data collection in this work was carried out before the beginning of the rainy season.

THEORY

The theoretical study of the earth resistivity methods is to consider the case of completely homogenous isotropic medium. The equation which gives the potential due to a single point source of current at surface can be deduced from two basic equations; ohm's law and divergence condition. And the ohm's law is given by:

$$\Delta . J = 0 \quad (1)$$

The potential due to a single point source of current at earth surface is given as:

$$U = \rho I / 2\pi r \quad (2)$$

Where ρ = earth resistivity, I = Current, 2π = Constant, r = Resistance. The current I, is passed through current electrodes.
The potential difference at a point m is

$$U_m = \frac{I\rho}{2\pi}\left[\frac{1}{r_1} - \frac{1}{r_2}\right] \quad (3)$$

The potential difference at a point n is

$$U_n = \frac{I\rho}{2\pi}\left[\frac{1}{r_3} - \frac{1}{r_4}\right] \quad (4)$$

The difference in potential at m and n is given as:

$$\Delta U = U_m - U_n$$

$$U_n = \frac{I\rho}{2\pi}\left[\frac{1}{r_3} - \frac{1}{r_4} - \frac{1}{r_3} + \frac{1}{r_4}\right] \quad (5)$$

Hence, the resistivity is given by:

$$\rho_a = \frac{\Delta U}{I}\left[2\pi\left\{\frac{1}{r_3} - \frac{1}{r_4} - \frac{1}{r_3} + \frac{1}{r_4}\right\}\right] \quad (6)$$

Let $K = 2\pi\left\{\frac{1}{r_3} - \frac{1}{r_4} - \frac{1}{r_3} + \frac{1}{r_4}\right\}$

Therefore

$$\rho_a = KR \quad (7)$$

Where, K is a Geometric factor and $R = \frac{\Delta u}{I}$.

The velocity of ground water flow is entirely laminar and is given by Darcy's law, which states that the velocity of flow in a porous medium is proportional to the hydraulic gradient

$$V = Ki \quad (8)$$

where

K = Coefficient of Permeability
i = hydraulic gradient = Δh/L,
Δh = contour interval and
L = length.

$$Groundwater\ flow = Q = AV = KAi = \frac{KA\Delta h}{L} \quad (9)$$

In water table maps, areas with uniform ground water flow, the portions having wide water table, contour spacing having flat gradients and higher permeabilities are more promising site for a well. In many areas it is not possible to obtain sufficient data from existing wells to construct water table and/or piezometric surface maps (Raghunath, 2007) hence the importance of this study

DATA COLLECTION

The Vertical Electrical Sounding data were collected in 108 stations. The stations were separated from each other at an average interval of 2km (Figure1). The longitudes and latitudes of each sounding was determined from the topographical maps of Lere and Geshare (1:100,000). The maximum current electrode separation used for each sounding was 300m.The ABEM Terrameter Model SAS 300 of the Department of Physics, Ahmadu Bello University, Zaria was used for the data collection. For a better study of the piezometric surfaces based on the geoelectrical data, direct measurements of water table from eleven open wells where electrical soundings were made were undertaken primarily aimed at comparing with the cumulative resistivity plots at such well sites.

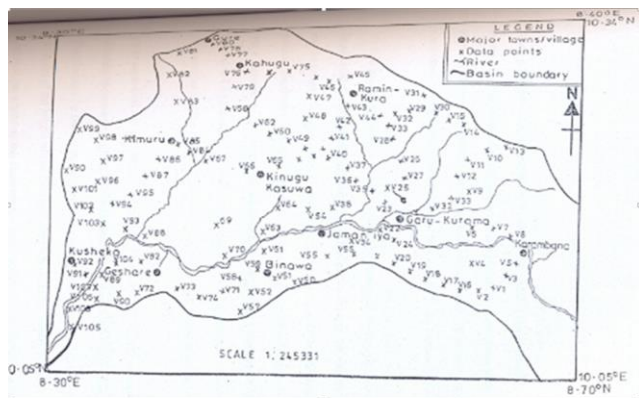

Figure 1: The Map Showing The Electrical Resistivitydata Points

RESULTS AND DISCUSSION

The deduction of piezometric surface, or water table from Vertical Electrical Sounding was possible through estimating the depth to interfaces from the cumulative (∑ρ_a) plot. The resistivity values for each sounding were summed up and plotted against the respective electrode spacing. From the plot, attempt was then made to draw segments of straight lines through as many points as possible. The breaks in the segments indicate depths to interfaces corresponding to the zones of non-saturation (first break), intermittent saturation (second break) and permanent saturation (third break). A typical cumulative plot is shown in Figure 2.

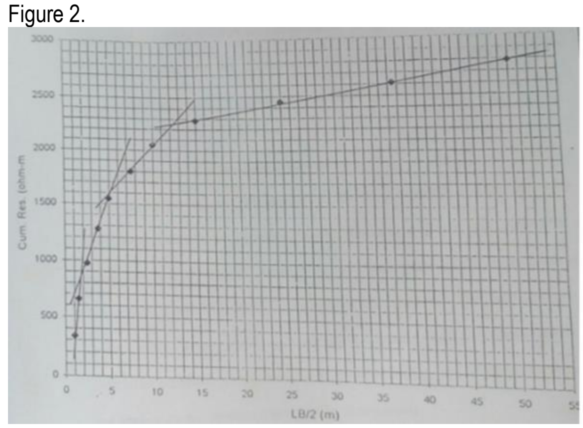

Figure 2: A Typical Cumulative Plot for VES Point VO32

The use of cumulative plot became necessary because geophysical methods for determining groundwater level are based on the fact that certain physical properties of rocks change considerably depending on their water content. Thus, a physical boundary is created between the under saturated zone of aeration and the saturated zone below it (Ogilvy, 1975). Ogilvy (1975) also pointed out that though electrical geophysical methods provide the basis for a reliable indication of the water saturated surface however, it should be bored in mind that the best method determines not the water table proper but the depth to the capillary fringe. In preliminary geophysical interpretation, the cumulative plot is known to give reasonable estimates for shallow depths and also shows the presence of several contrasting beds (Dogara, 2003) which is typical of the basement complex. In this work, it was found that all the depths to the water table fell within the 3rd segment of the cumulative resistivity plots with a standard deviation of 0.04. It was on this basis that the depths of the water table of all other sites sounded were deduced and produced on a map form as shown in Figure 3.

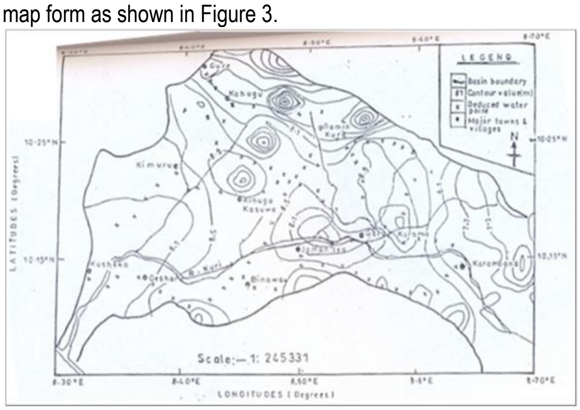

Figure.3: Deduced Water Table Map of Kuri River Basin Superimposed on the Drainage Pattern (VES points see Figure.2)

Conclusion

The increasing demand for water, for domestic, industrial and agricultural purpose in all geological formations has become extremely necessary as such the scientific search and knowledge of this essential commodity has become particularly compelling in underground water studies, information on the water table is fundamentally important. This work has revealed that piezometric surfaces can be known even without direct measurement from wells or drilled boreholes. It has been shown that the depth to water table falls within the 3rd segment of the cumulative resistivity plot, with a standard deviation of 0.04. Also, the third segment corresponds with the zone of permanent saturation. Thus, this study has elucidated that the vertical electrical sounding data carefully interpreted can infer with good accuracy the depths to water table of any geological formation.

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