Evaluation of Groundwater Potential and Subsurface Lithologies in Unilorin Quarters Using Resistivity Method

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The Schlumberger array of the electrical resistivity method was used to sound a total of six VES points within premises of the Senior Staff-Quarters of the University of Ilorin in Ilorin, Kwara State, Nigeria. The objective was to evaluate the groundwater potential and to delineate the subsurface lithology of the area. The results obtained from the sounding were then analysed to determine the aquifers in the zone. It can be deduced from the result of the interpretation that the test site has at least four major Lithologic layers with the topmost layer (topsoil) majorly laterite, the second layer being clay/sand, the third being weathered basement and the fourth layer being fractured basement. The aquifer in the area is located mostly within the fractured basement found at a depth ranging from 16.8 m to 88.6 m. The average depth to the aquifer is 50.0 m. The protective capacity of the overburden showed that 16.67% of the study area has poor protective capacity, 50% weak protective capacity and 33.33% moderate protective capacity. This suggests that the area is a fair aquifer zone but the fractured basement containing the groundwater is not prone to surface and near-surface contaminants.

1. Introduction

The evaluation of groundwater potential and subsurface lithology has become increasingly important due to the need of good drinking water sources. This becomes more necessary as a result of difficulties encountered during selection of suitable sites for drilling boreholes. University of Ilorin senior staff quarters is located south of the university of Ilorin main campus. It has an approximately 150 flats with a population over 1000 peoples. Due to this enormous increasing population, the demand for portable, reliable and consistent water supply in the area is high. Hence, the need for an independent source of groundwater in the area has become necessary. The quarter has four drilled water boreholes among these only one is functional, and the functionality of this borehole cannot even be relied upon. Although the university dam site, which is about 5km to the quarters, gives supply of water once in a week. Majority of the residents in the quarters find an alternative means of getting portable water, for example, buying of sachet water. In the past, various geophysical methods have been carried out on the basement complex of the university of Ilorin main campus [1-8]. This has contributed tremendously to fracture pattern and the geology of the area. Olasehinde [1] elucidated fracture patterns through electrical resistivity sounding and radial sounding and observed that closely stacked resistivity contours mark positions of fractures. Olasehinde [4] also studied the rock types and structures within the university of Ilorin main campus using ground magnetics and geo-electrical method. His work revealed that university of Ilorin is made up of syntectonic to late tectonic granitoids commonly refer to as older granites, intruded both the migmatite gneiss complex and the schist belts. Nwankwo et al. [6] interpreted the electrical resistivity pseudo-section, which was derived from a combination of VES and profiling along the eastwest profile and reveal that the sources of spring water and other structural formations, prominent geological structures discerned are the fractures bordering and controlling the Oyun river. Raji and Bale [8] carried out geological and geophysical studies of gravel deposits using vertical electrical drilling and horizontal profiling method of electrical resistivity at the eastern part of the campus. Their result also revealed three to four geoelectric layer namely, top soil, gravel layer, weathered rock and the fresh basement rock observed that gravel deposit occure as a laterally continuous geoelectric layer with an average thickness of 3.1m. Nwankwo [7] carried out a 2D resistivity survey for groundwater exploration in hard rock terrain at the MADAS Observatory University of Ilorin, 20 kilometres away from the study area; his results also revealed the presence of three geo-electric layer namely the top lateritic soil, weathered basement and fresh basement layer. He recommends area with low resistivity value in the

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fractured weathered rocks to be a good target for ground water tube drilling.

All of these studies have contributed tremendously towards understanding the terrain of the University of Ilorin main campus. The above summary implies that other parts of the university campus have received much attention in term of geophysical studies. However, the present study area has been ignored in this regard. Therefore a comprehensive evaluation of groundwater potential and subsurface lithology of the study area becomes necessary in order to make the area independent in its quest to provide a portable, reliable and consistent water supply for the increasing population of staff.

However, studies have shown that groundwater could be explored using electrical resistivity survey [9]. Electrical resistivity survey is more diversified, cheap, popular, and has the widest adoption for groundwater exploration than any other geophysical methods due to the simplicity and relative high diagnostic value of the technique [10-15]. More so, the Vertical Electrical Sounding (VES), using the Schlumberger array has gained wider application owing to its cost effectiveness and easy data acquisition and interpretation among numerous advantages as compared to other resistivity measurements. This method has been a veritable tool to mapping aquifer in all geologic terrains in the country and beyond [16].

2. Location and Geology of the Study Area

The study area is located within the basement rocks in the North central part of Nigeria. It lies between the latitudes $8^{\circ}27.810$ 'N and $8^{\circ}28.230$ 'N, and longitudes 4°38.920'E and 4°39.971'E, respectively. The study area is approximately $32,500 \text{ Km}^2$ while the geophysical profiles area is the staff quarters of the main campus of University of Ilorin. The area has a typical guinea savannah type with shrubs and undergrowth. It has a distinct climate condition of wet and dry seasons: a dry season usually lasting from October to February and a rainy season lasting from March to September. The temperature variation is between 25°C around November/December and 35°C in February/March. The elevation of the study area is between 320-335 metres and the average ambient pressure is 975.11mb (millibars).

The area lies within the crystalline basement rocks of eastern part of north central Nigeria (Fig. 1). The rocks of Nigeria are mainly the migmatitegneiss complex, which are the oldest basement rocks believed to have been of sedimentary origin, but which have profoundly undergone many processes of metamorphism and magmatic intrusions. The rocks comprise of mainly sedimentary type. It also contains both primary and secondary laterites, and alluvial. The study area falls within the category of hard rock terrain where aquifers possess distinct features from the porous and permeability and are product of secondary processes. This type of rock deposits are weak and therefore readily yield to agents of erosion [17]. No visible outcrops exist on the site of the survey (Unilorin staff quarters), but outcrops exist in the adjoining areas Unilorin-Okeoyi and Unilorin-Amoyo roads. The site is accessible and motorable, mainly through the school gate.



Fig.1: Geological map of Nigeria showing the location of the study area.

3. Data Acquisition

A total of six vertical electrical soundings were carried out along profiles AA'(vertical) and BB'(horizontal) within the study area using the DDR1 resistivity meter and accessories. The electrode arrangement was Schlumberger with maximum electrode separation of 100m. One of the VES locations was chosen very close to an existing borehole.



Fig.2: 3D Topographic map of University of Ilorin showing the position (latitude and longitude) and elevations (valleys and hills) on the large expanse of land. The university earth dam being the lowest point can be seen vividly on the topographic map and other hilly points at the outskirt of the school can also be seen. The study area is North-East of the dam.



Fig.3: Descriptive map of the study area.

The resistivity measurement is usually taken by introducing small portion of electricity through two current electrodes (A and B) and measuring the resultant voltage drop between a pair of potential electrodes (M and N). A simple calculated value of apparent resistivity ρ_a is the parameter bearing the information for the characteristics of the subsoil [9].

From the foundation of electrical resistivity theory is the ohm's law [18,19]

$$\rho = \frac{RL}{A} \tag{1}$$

Where, ρ is the resistivity, R is the resistance, L is the length of the conducting cylinder, and A is the cross sectional area.

For the solid earth, whose material is predominantly made up of silicates and basically non-conductors, the presence of water in the pore space of the soil and in the rocks fractures enhances the conductivity of the earth when an electrical current I is passed through it, thus making the rocks a semiconductor. Since the earth is not like a straight wire and it is not an anisotropic, therefore Eqn. (1) can be customized as

$$\Delta V = \frac{\rho_{IL}}{A} \tag{2}$$

Where, ΔV change in voltage and r is the radius of current electrodes' hemisphere. Since the earth is not homogeneous, Eqn. (2) is used to define an apparent resistivity ρ_a , which is computed as the

product of the geometric factor and the resistance recorded in the electrical resistivity meter and resistivity the earth would have if it were homogeneous [18,20,21]

$$\rho = \frac{\Delta V}{I} \cdot 2\pi r \tag{3}$$

Where, $2\pi r$ is then define as the geometric factor (G) fixed for a given electrode configuration and is dependent on the electrode arrangement.

The Schlumberger electrode configuration was used for this study. The geometric factor is thus given as

$$G = \pi \left\{ \frac{\left(\frac{AB}{2}\right)^2 - \left(\frac{MN}{2}\right)^2}{2\left(\frac{MN}{2}\right)} \right\}$$
(4)

Where, AB is the distance between two current electrodes, MN is the distance between two potential electrodes.

4. Results and Discussion

The field data consisting of the apparent resistivity (ρ_a) and the electrode spacing (AB/2) were partially curve matched and plotted against each other on a bi-logarithmic scale (log-log scale) with the apparent resistivity (ρ_a) on the ordinate and electrode spacing (AB/2) on the abscissa using a computer software known as DC INVERSE. The result of the partial curve matching gave the layers of the VES points, the apparent resistivity (ρ_a) of each layers, the thicknesses (h) of each layer and

the total depth of overburden to the aquiferous layers/zones. These parameters were again iterated with WINRESIST computer software with a minimised root mean square error to get the sounding curves, the true resistivity (ρ) of the layers, the real saturated aquifer thicknesses (h), and the true depth of overburden on the aquiferous zones. The site is underlain by four layers of varying lithologies. The plotted curves are exclusively of the HK type ($\rho_1 > \rho_2 < \rho_3 > \rho_4$).

Interpretation was also done using the "Dar-Zarrouk Parameters", particularly, the total longitudinal conductance (S). This parameter was used to classify each VES points into poor, weak, moderate, good, and excellent aquifers depending on the numerical values assigned to each point.

The Longitudinal Conductance (S) is given by

$$S = \sum_{i=1}^{n} \frac{h_i}{\rho_i} = \frac{h_1}{\rho_1} + \frac{h_2}{\rho_2} + \dots + \frac{h_n}{\rho_n}$$
(i)

Where. h_i is the saturated thickness of each layers and ρ_i is their true resistivities.

The earth medium acts as a natural filter to percolating fluid and its ability to retard or accelerate and filter percolating fluid is a measure of its protective capacity [11,22]. The total longitudinal conductance (S) is a parameter used to define the target areas of groundwater potential. High S values usually indicate relatively thick succession and should be accorded the highest priority in terms of groundwater potential and viceversa [22].



Fig.4: Diagram of Geoelectric Section and Lithologic delineation (Profile AA').



Fig.5: Diagram of Geoelectric Section and Lithologic delineation (Profile BB').

Range of S	Indication
S > 10	Excellent
5 < S < 10	Very good
0.7 < S < 4.9	Good
0.2 < S < 0.69	Moderate
0.1 < S < 0.19	Weak
S < 0.1	Poor

Table 1: Ratings of longitudinal conductance.

It can be deduced from the result that the test site has at least four major Lithologic layers with the topmost layer (topsoil) majorly laterite, the second layer being clay/sand, the third being weathered basement, and the fourth layer being fractured basement. The range of the values of thicknesses of each layers for the all VES points are given as: Topsoil ranges between 0.7m to 1.8m, second layer between 2.3m to 17.6m, weathered basement between 13.0m to 88.6m, and the average depth of overburden or aquifer depth is 50.0m. The unusually high resistivity value of the topsoil and weathered basement imply that the test site has been left untouched for quite a while making the topsoil hard and caked. As for the third layer, its high resistivity indicates a consolidated (closely packed) weathered basement. The extremely low resistivity of the fourth layer (fractured basement) shows that the layer is the aquifer zone with highly mineralized water.

VES	LAYER	RESISTIVITY	THICKNESS	LITHOLOGY	LONGITUDINAL	REMARK
		(32111)	(111)		(S)	
MEG	1	2200.0	1.6			
VES	1	3298.9	1.6	Lateritic Topsoil(caked)		
1	2	24.3	2.3	Clay		
	3	1010.5	13.0	Weathered Basement	0.11	WEAK
	4	9.4		Fractured Basement		
VES	1	928.9	0.7	Lateritic Topsoil		
2	2	131.3	17.6	Sandy clay		
	3	3903.1	70.1	Weathered Basement	0.15	WEAK
	4	11.8		Fractured Basement		
VES	1	213.0	1.8	Lateritic Topsoil		
3	2	17.1	2.9	Clay		MODERATE
	3	514.3	21.1	Weathered Basement	0.22	
	4	13.4		Fractured Basement		
VES	1	1127.0	0.7	Lateritic Topsoil(caked)		
4	2	49.3	9.9	Clay		
	3	2714.7	64.0	Weathered Basement	0.23	MODERATE
	4	11.8		Fractured Basement		
VES	1	699.5	0.8	Lateritic Topsoil		
5	2	145.8	9.3	Sandy clay		
	3	1096.1	21.5	Weathered Basement	0.08	POOR
	4	10.7		Fractured Basement		
VES	1	1007.7	1.0	Lateritic Topsoil(caked)		
6	2	92.9	9.0	Sandy clay		
	3	6928.8	78.6	Weathered Basement	0.11	WEAK
	4	11.2		Fractured Basement		

Table 2. Geoelectrical parameters, Lithologic delineation and Protective capacity of the area.

5. Conclusion and Recommendation

The pie-chart below is a summary of the results obtained in this study. It shows the percentage distribution of the aquifer zone.



Fig.6: Pie chart showing the percentage aquifer potential of the test site.

The green segment signifies weak aquifer, the red segment signifies moderate aquifer and the blue segment signifies poor aquifer. About half of the test site has weak groundwater potential, with longitudinal conductance/protective capacity less than 0.20.

It can therefore be concluded that the study area is generally not a very good aquifer zone (but fair) with 50% of the area being weak aquifer, 16.67% poor and 33.33% moderate aquifer. The aquifer is located in the fourth layer (fractured basement). The average depth of overburden to the aquifer and the highly resistive topsoil and weathered basement indicates that the aquifer zone can be free from surface and near-surface contaminations. Though the site is generally a fair wet zone, it is therefore highly recommended that borehole should be drilled in VES 3 (25.8m) and VES 4 (74.5). For economic reasons VES 3 might be preferred to VES 4 because its depth of overburden is lower compared to VES 4, which is also classified moderate aquifer.

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