Research Article

Geophysical Assessment of Aquifer Vulnerability to Pollution in Parts of Umuahia, Southeastern Nigeria

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Received 23 February 2023; Acceptance 15 March 2023; Published 19 April 2023

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How to cite this article: Ibenche *et al.,* (2023). Geophysical Assessment of Aquifer Vulnerability to Pollution in Parts of Umuahia, Southeastern Nigeria *Scholar J*, **1**:4 https://scholarj.com/ojs

Abstract
In this study, the geophysical assessment of aquifer vulnerability to pollution in parts of Umuahia southerneastern Nigeria was undertaken. This study adopted Vertical Electrical Sounding (VES) using the Schlumberger array. A total of twenty (20) resistivity sounding were carried out across the study area. The results of the interpreted electrical resistivity data helped to delineate the aquiferous horizons within the study area. The aquifer protective capacity (APC) rating obtained from second order parameter of the VES revealed the rating less than 0.1Mhos across the study area; indicating aquiferous zone with poor protective capacity to contamination migration. The APC values tend to increase towards the extreme south of the area (Ntigha Ngwa) which has an APC value 0.0932 close to 0.1(weak) protective capacity. Based on these findings, the study recommends that the citing of facilitates like an automobile mechanic settlement and abattoir/meat processing factory in the study area should be discouraged.
Keywords: Geophysical, Assessment, Aquifer, Vulnerability, Pollution.

Introduction

Geophysical techniques, especially gravity, magnetic, seismic and electrical methods, detect difference or anomalies of physical properties within the earth's crust [1]. Density, magnetism, elasticity and electrical resistivity are properties most common measured.
The increased interest in recent years in underground sources of water has led to a need for more intensive studies of the geometry and properties of aquifers.
Geophysics has played a useful part in such investigation for many years and improvements in instruments and the development of better methods is resulting in a widening of its applications. It is still used mainly to determine structure but there is a considerable interest in the possibilities of estimating aquifer properties such as permeability and porosity from the measurements of geophysical properties.
Recently, resistivity imaging surveys have been used to map groundwater contamination and it is widely used for environmental surveys [1,2]. It has also been successfully used in Engineering and hydrogeological applications.
The author in [3] carried out mapping of groundwater contamination using DC resistivity. The studies [4-5] demonstrated that resistivity imaging has application in hydrogeology in basement areas and mapping of strong faulted areas even where the weathered layer is so deep and laterally variable such that other electrical and electromagnetic methods prove ineffective. It has been proved to be useful for mapping saline

intrusion into aquifer [6]. It can be used to map rock quality for quarrying purpose and where tunneling is required [7].
The demand for groundwater is increasing very fast the rapid urbanization and industrialization programs of the developing and the developed countries and the urgency to increase food production. Finding potential sources of groundwater by wildcat drilling is proving to be very expensive when the cost benefit ratio is taken into account.
Many geophysical methods have been used to locate and delineate subsurface water resources. They are inexpensive and can rapidly provide information about the geological structure and lithology's of a large region under investigation compared to an extensive drilling program.
The most important objective of any geophysical survey for groundwater prospecting and study is to translate the result of geophysical interpretation in terms of the subsurface hydrogeology [2]. For this purpose of fence diagram, a water table map, geological cross-section, geological correlation and location map of potential sites for drilling to groundwater are prepared.
Petroleum, mineral exploration and geotechnical and groundwater geophysicists have routinely used geophysical reconnaissance surveys [8]. Further detailed geophysical survey can in many cases accurately identify geological structures or environments suitable for a particular target of interest. In this way the geological survey results are used to determine the locations of the minimum number of exploratory boreholes required for both selecting potential sites of groundwater aquifer and to provide controls for the geophysical interpretation.
Different studies exist in the literature on aquifer vulnerability of pollutions. The author [3] carried out mapping of groundwater contamination using DC resistivity. The authors [4-5] demonstrated that resistivity imaging has application in hydrogeology in basement areas and mapping of strong faulted areas even where the weathered layer is so deep and laterally variable such that other electrical and electromagnetic methods prove ineffective. It has been proved to be useful for mapping saline intrusion into aquifer [3]. It can be used to map rock quality for quarrying purpose and where tunneling is required [7].

Moreover, there has been a continuous and steady increase in the demand for portable water due to rapid urbanization, population explosion as well as industrial activities within and around the study area. This has resulted to a large threat on the groundwater resources of the area. Similarly, information regarding hydraulic characteristics of the aquifer systems and quality of few groundwater bodies in the areas that will give rise to economic exploitation of the groundwater resources are scarcely unavailable. To the end, this study aims to assess geophysical vulnerability of pollution in parts of Umuahia southeastern Nigeria.

Materials and method

Location and Physiography of the Study Area

Geographically, the study area is located within Lat. $5^0$34' - $5^0$38'and Long. $7^0$22' – 733'E within the rain forest belt. The area is characterized by high temperatures of about 29^0-31^0C and has double maxima rainfall peaks in July and September.

Geologically, the area is underlain by the Benin Formation (Miocene-Recent), Ogwashi-Asaba (Oligocene-Miocene) formation and the Ameki formation (Eocene-Oligocene) as shown in Fig.1. The sediments of the Benin formation consists of lenticular, unconsolidated coarse grained sands and clayey shales. The sands are generally moderately sorted, poorly cemented and angular to sub-angular in shape. The Benin formation overlies the Ogwashi-Asaba formation and the youngest in the area. The Ogwashi-Asaba formation overlies the Ameki formation, it is mostly coarse-grained, pebbly poorly sorted and contains pods and lenses of fine grained sands, sandy-clays and clays. The Ameki formation consists of medium to coarse grained white sandstone, bluish calcerous silt with mottled clay, thin limestone beds and abundant calcareous shale.

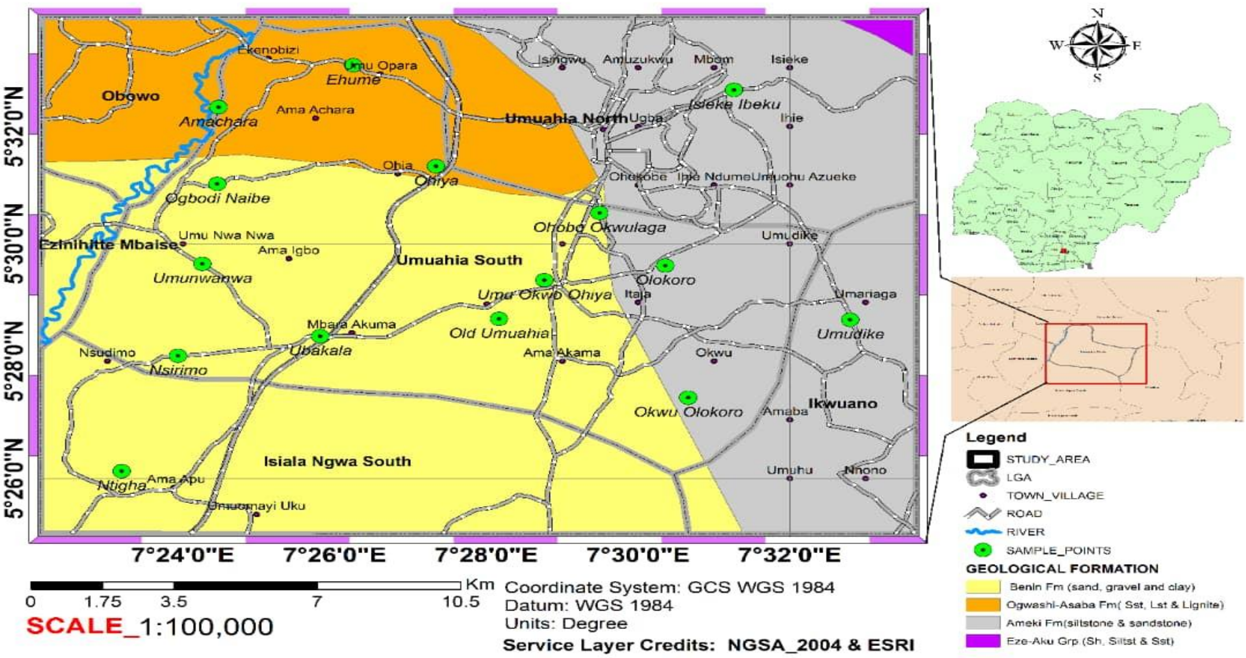

Figure 1. The Geological Map of the Study Area

Data Acquisition and Processing

Acquisition

This study adopted Vertical Electrical Sounding (VES) using the Schlumberger array. A total of twenty (20) resistivity sounding were carried out across the local government area using the following;

i. ABEM Terameter SAS 300B
ii. Two current electrodes
iii. Two potential electrodes
iv. A power source (12 Volts car battery)
v. Electrical cables
vi. Hammer
vii. Measuring Tapes

Instrumentation

The ABEM SAS 300B model consists of a basic unit called the Terameter SAS 300B.

Signal Averaging System is a system whereby series of readings are taken automatically and the results are averaged continuously.

The Terameter SAS 300B can operate in two modes. First, in the resistivity survey mode, it comprises of a battery powered deep penetration resistivity meter with an output sufficient for a current electrode separation of 2000 meters under good surveying conditions. Secondly in the voltage measuring mode, the SAS 300B comprises of a self-potential instrument that measures natural DC potentials. The result is displayed in Volts or millivolts (Mv). The overall range from 0.01Mv to 500V.

The transmitter, receiver and microprocessor- the three main units of the Terameter SAS 300B are all housed in a single casing. The electrically insulated transmitter sends in well-defined and regulated signal currents. The receiver discriminates noise and measures voltage correlated with transmitted signal current and also measures uncorrected DC potential with the same discrimination and noise rejection. The microprocessor monitors and controls operation and calculates the final resistivity result of interest. The equipment permits natural or induced signal to be measured at extremely low levels with excellent penetration and low power consumption. Moreover, it can be used in a wide variety of application where effective signal/noise discrimination is needed.

Field Procedure

Direct current resistivity sounding was made at various locations with a maximum electrode spread of 1000m. The ABEM Terameter SAS 300B gave a direct readout of resistance. The interval between the potentials and current electrode were increased at appropriate steps in order to obtain potential differences large enough to be measured with satisfactory precession. Readings were taken at different electrode spacing and the resulting values for each distance recorded. The data obtained was plotted as a graph of apparent resistivity against current electrode spacing (AB/2) on a log-log graph scale. The electrode spacing at which inflection occurs on the graph provides an idea of the depth of the interface. A useful approximation is that the depth of the interface is equal to two-third (2/3) of the electrode spacing at which the point of inflection occurs [8]. The approximation has found useful application in iterative modelling.

Data Processing

The observed field data were converted to apparent resistivity values by multiplying with the Schlumberger geometric factor K given as:

$$k = \pi\left(\frac{a2}{\mathrm{b}} - \frac{b}{4}\right) \qquad (1)$$

The sounding curve for each point was obtained by plotting the apparent resistivity on the ordinate against the half current electrode spacing on the abscissa on a bi-logarithmic paper. The parameters such as apparent resistivity and thickness obtained from partial curve matching and the method of asymptotes were used as input data for computer iterative modelling [9]. Hence the computer program allowed the reading obtained from the field to be converted to apparent resistivity values and to be stored for the detailed interpretation using the OFFIX software.

Qualitative Curve Description

The interpretation of the apparent resistivity curve began by the entering of a model represented by the apparent resistivity and thickness of each layer of the curve. Theoretically curve is drawn automatically with these two parameters. The theoretical curve may not match the field curve and the other models are tried until the curves match.

Generally, the apparent resistivity curve for a three-layer structure has one of four typical shapes determined by the vertical sequences of the resistivity of the layers. Theoretically, these curves include type A, type H, type K, and type Q curves (Fig.2)

K-type curve: this curve type rises to a maximum and then decreases, indicating that the intermediate layer has higher resistivity than the top and bottom layer

A-type VES curve: This curve shows a continuous increase in resistivity down the passing layer.

Q-type curve: This curve shows direct opposite of A-type curve with continuous decrease in resistivity down.

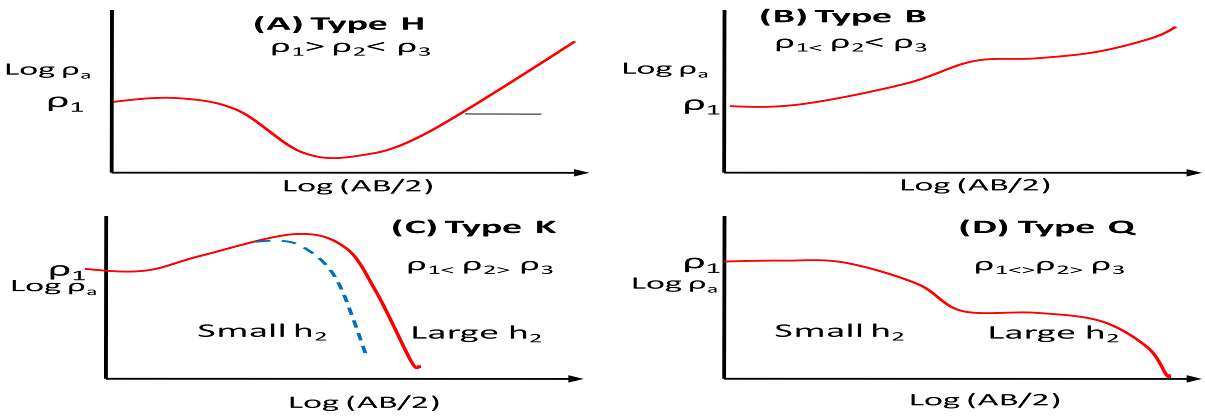

Figure 2. Typical VES types curves

Results and discussion

Geophysical Field Data Results

Results of the curve matching obtained by the analysis of the field data were studied. The type curve for each sounding gave an insight on the character of the beds or layers between the surface and the maximum depth of penetration. This is because the shape of a VES curve depends on the number of layers in the subsurface; the thickness of each layer, and the ratio of the resistivity of the layers [10]. Considering the quantitative curve description shown earlier, the types identified in this work ranges from K, Q, HK, KH, KKH, KK and HKH.
Groundwater takes the chemistry of the surrounding rocks; the amount of dissolved inorganic and organic ions present in aquifer affects the electrical conductivity of the aquifer [11]. Electrical conductivity is the inverse of electrical resistivity hence, once the electrical resistivity is obtained from the interpreted VES sounding, the electrical conductivity is obtained by taking the inverse of the resistivity value.
The amount of the total dissolved solids (TDS) present in the underground water determines the electrical conductivity of the underground water. When TDS value is higher beyond the acceptable value, the underground water quality is reduced and unsafe for domestic use. When the TDS value falls within the WHO acceptable range, the underground water is assumed safe and qualitative [12].

Electrical Conductivity of the Study Area

The values of Electrical conductivity of the study area obtained from the inverse of the resistivity shows varying electrical conductivity across the entire study area with exceptional value in Ogbodinibe whose value is unusually very high. The value of the electrical conductivity in this community is attributed to higher ions content. The high value of electrical conductivity obtained from the VES in Ogbodi is in corroboration with the known geological history of the community which is known for its high ions content within its aquifer. The high ions content in the aquifer is responsible for the increase in the electrical conductivity in the area and this has adverse effect in water quality within this community.

Aquifer Thickness

The physical properties of an aquifer such as thickness, rock or sediment type and location, play a large part in determining whether the contaminants from the land surface will reach the ground water. The risk of contamination is greater for unconfined aquifers than confined aquifers because they usually are nearer to the land surface and lack an overlying confining layer to impede the movement of contaminants.

From the result of the interpreted VES data from the study area, the average aquifer thickness of the entire study area is 71.47m. The ratio of aquifer thickness to the aquifer resistivity is proportional to the protective overburden of the aquifer against contamination by movement of polluted water down the aquifer.

Interpretative Profiles

For the purpose of lithological correlation and classification, five profiles were taken across the study area as shown in the Figures 3-7. The profiles revealed about six distinct geo-electric units; the ranges in the aquifer thickness and aquifer resistivity across the entire area were identified as shown below.

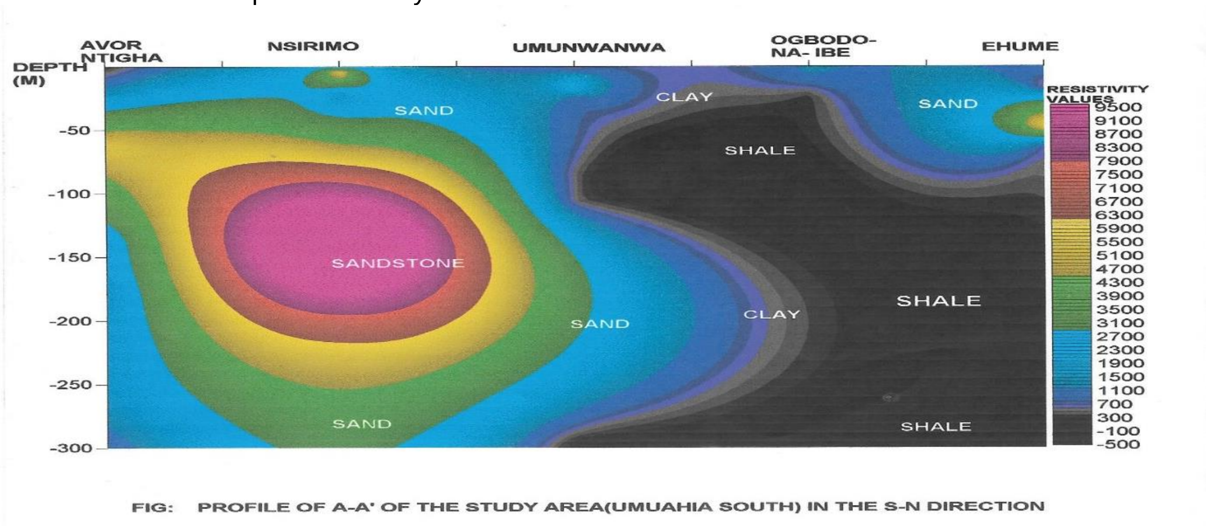

Figure 3. Map showing the geo-electric layer along profile A-A^l

The communities in the North-South direction of the study area comprises Avor Ntigha, Nsirimo, Umunwanwa,Ogbodinaibe and Ehume. The aquifer thickness in this direction ranges between 8.5m-162.9m and the resistivity ranges between 786 Ωm-5120Ωm. The lithological units in this direction are mostly sand, sandstone with interaction of clay/shale within Umunwanwa and Ogbodinaibe.

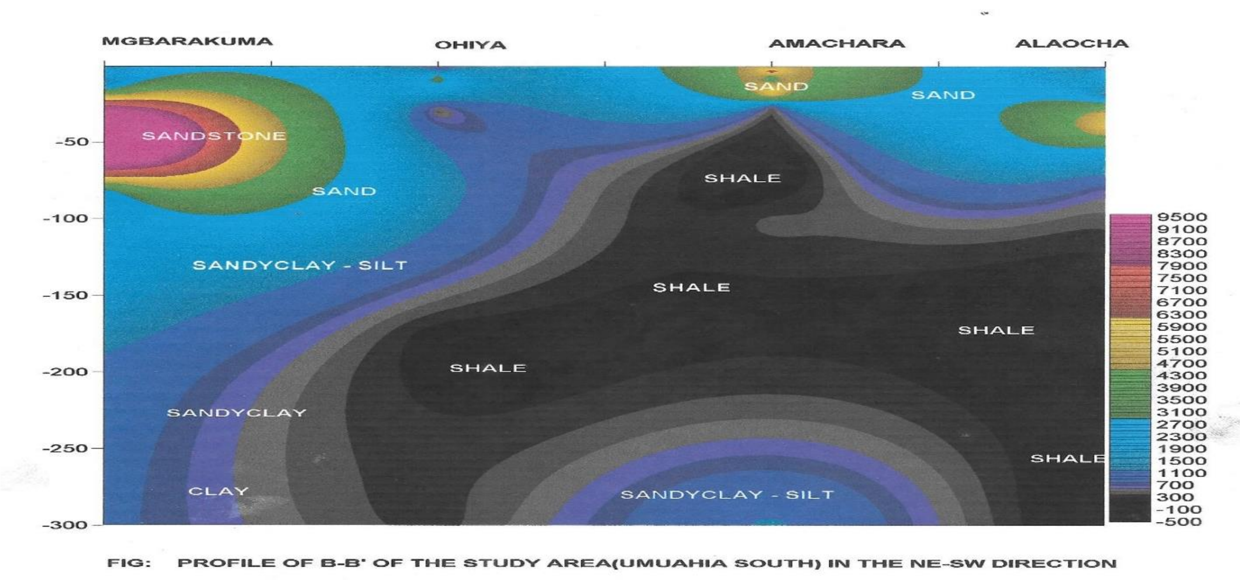

Figure 4. Map showing the geo-electric layer along profile B-B^l

The communities in the North East- South West direction in the main study area are Mgbarakuma(Ubakala), Ohiya, Amachara and Alaocha. The aquifer thickness in this direction is between 15m-178.6m while the resistivity is between 1270Ωm-5785Ωm. The lithological units in this direction are mainly sand, sandstone, sandy clay, sandy-silt, clay and shale.

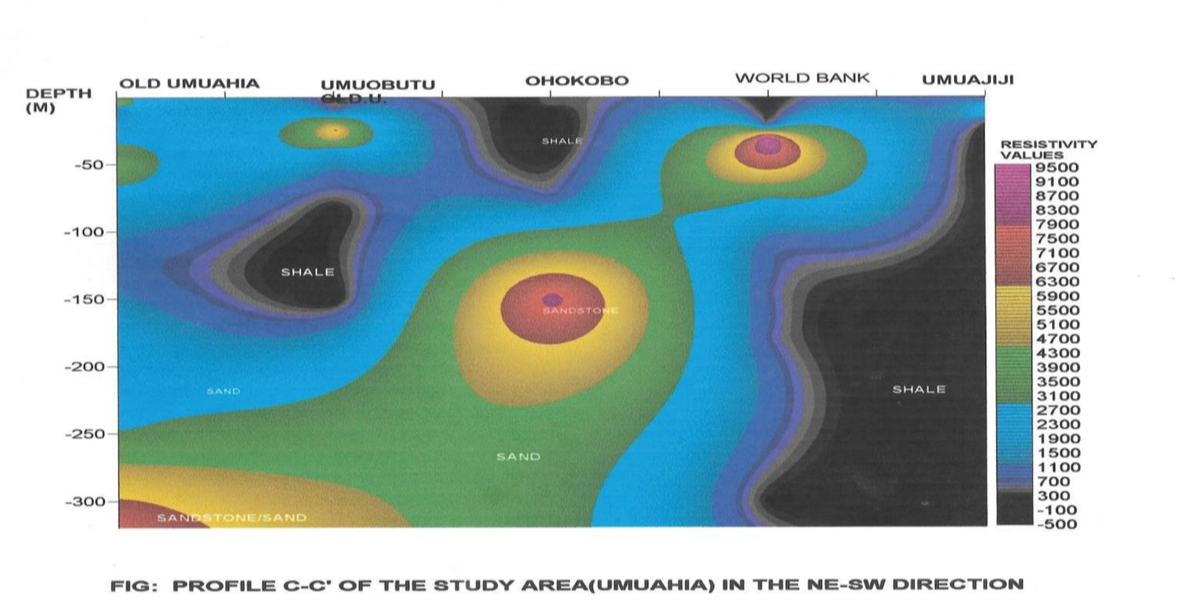

Figure 5. Map showing the geo-electric layer along profile C-C[I]

The communities along this direction include Old Umuahia, Umuobutu, Ohokobo, World bank Housing Estate and Umuajija. The aquifer thickness along this direction is between 11.85m -59m and the aquifer resistivity along the profile is between 2121.5Ωm-8400Ωm. The lithological units along this direction are mainly sand, sandstone and shale.

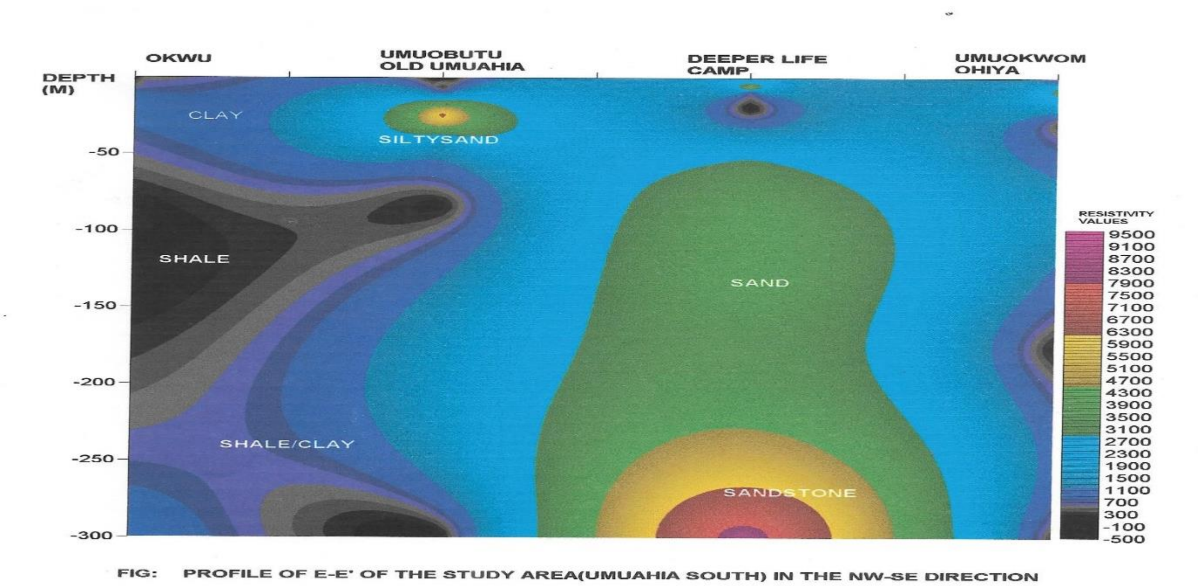

Figure 6. Map showing the profile along the profile E-E[I]

The communities along this direction include Okwu, Umuobutu Old Umuahia, Deeper Life Camp Ohiya and Umuokwom Ohiya. The aquifer thickness along the profile is between 39.5m-151.3m and the resistivity along the profile is between 1,130Ωm -4,406.5Ωm. The lithological units revealed along the profile are mainly sand, sandstone, shale/clay and shale.

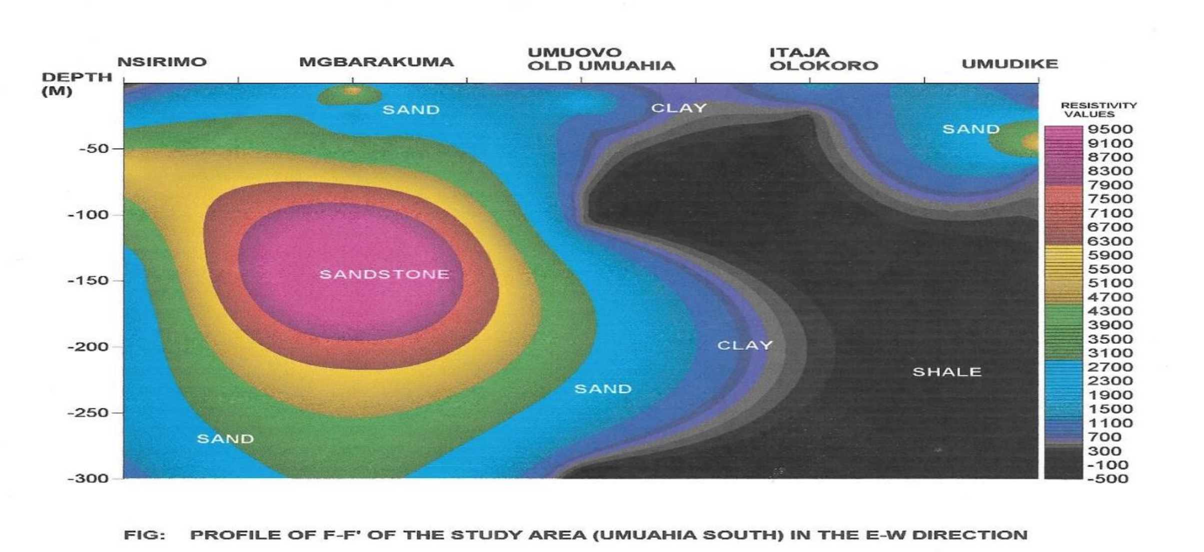

Figure 7. Map showing the profile along F-F[l]

The communities along this direction include Nsirimo, Mgbarakuma, Umuovom Old Umuahia, Itaja Olokoro and Umudike. The aquifer thickness along the profile is between 66.m-178.6m (Umudike and Mgbarakuma). The aquifer resistivity along the profile is between 1115Ωm at Umudike and 5785Ωm at Mgbarakuma. The lithological units revealed along the profile are mainly sand, sandstone, clay and shale.

Evaluation of Aquifer Protective Capacity

Aquifer Protective capacity (APC) is the ability of the overlying layers of rock (i.e the overburden) above the aquifer unit to impede, slow-down, filter and contain percolating ground surface contaminating fluids and run-offs.

The second order geoeletric parameter-Longitudinal conductance (which is a Dar Zarrouk parameter) was evaluated from the first order parameters (thickness and resistivity of the geoelectric layers which were used in the classification of the APC of the area.

Table 1. Aquifer Longitudinal Unit Conductance (S) and Overburden Protective Capacity Rating in the Study Area

LOCATION	Aquifer Thickness(m)	Aquifer resistivity ρ(Ωm)	Longitudinal-Conductance S(Mhos)	Overburden Protective Capacity Rating (After Henriet, 1976; Oladapo et al 2004)
Avor Ntigha	162.9	1747.3	0.0932	weak
Nsirimo	67.8	5120	0.0132	Poor

Umunwanwa	8.5	1119.8	0.0076	Poor
Ogbodinibe	22.4	786	0.0285	poor
Ehume	45.8	3003.7	0.0152	Poor
Mgbarakuma Ubakala	178.6	5785	0.0309	Poor
Umuokwom Ohiya	51.5	1470	0.0350	poor
Deeper Life Camp	151.3	3815	0.0397	Poor
Amachara	15 50	5080 1270	0.0423	Poor
Umuawa alaocha	53.9	3450	0.0156	poor
Umuovo Old Umuahia	72.5	2915	0.0249	Poor
Ohobo Okwulaga	3.6 50	7610 8400	0.0065	Poor
World Bank Housing	59 18.5 120.7	6000 2626.7 7110	0.0338	poor
Okwu	39.5 50	7685 1130	0.0493	Poor
Itaja Olokoro	90.9	4347.5	0.0209	Poor
Umuajiji	8.4 15.3	3870 2121.5	0.0094	poor
Amuzu-Oro	56	3585	0.0156	Poor
Umudike	66.3	1115	0.0594	Poor

Conclusion

Geophysical assessment of aquifer vulnerability to pollution in parts of Umuahia, southeastern Nigeria is presented. The increasing need for multi facets and interdisciplinary approach in underground water quality and vulnerability assessment prompted the application of VES in assessing the underground water vulnerability potential of the study area. Results obtained, revealed the area as being vulnerable and susceptible to groundwater pollution. Additionally, aquifer protective capacity (APC) values obtained from the area is less than 0.1 which depict poor protective capacity of the aquifers within the area against contamination movement. The APC values tend to increase towards the extreme south of the area (Ntigha Ngwa) which has an APC value 0.0932 close to 0.1(weak) protective capacity. Based on these findings, the study recommends that the citing of facilitates like an automobile mechanic settlement and abattoir/meat processing factory in the study area should be discouraged. The nature of the operations of these facilities has a high potential to contaminate and eventually pollute the sub-surface aquifers on the long- run.

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