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Applications of the Dar Zarrouk parameters in the study of aquifer protective capacity in Agbarho - Otor area, Delta State, Nigeria

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ABSTRACT: Aquifer transmissivity and protective capacity of the overlying rock materials in Agbarho Otor area, Delta State Nigeria was studied. The aim is to evaluate the potential to contaminant seepage employing the Da Zarrouk parameters. Fifteen (15) Schlumberger vertical electrical sounding stations were occupied. The results obtained show a lithology of predominantly sand of various grades with no significant delineable clay intercalations. Maps of aquifer transmissivity and longitudinal unit conductance show a high transmissivity/porosity of the aquifer and a low protective capacity of the overburden material. The low value of the protective capacities makes the aquifer system in the area highly vulnerable to surface contamination. A high transmissivity value of the aquifer materials implies that the storativity is high and this will enhance the migration and circulation of contaminants within the ground water system. It is concluded that the ground water quality may have been impaired in the area. Hence, Hydrogeochemical analysis should be carried out to ascertain the water quality in the area.

Keywords: Transmissivity, longitudinal unit conductance, contaminants, protective capacity, hydrogeochemical

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INTRODUCTION

Rapid industrialization recently witnessed by the Agbarho Otor in Ughelli North area of Delta State has resulted in population increase and urbanization of the area and satellite villages and settlements around the area. The people of the area depend solely on surface water from streams and hand dug wells for their domestic use. However, these sources of water are highly vulnerable to pollution thereby making the people to be susceptible to water borne diseases. Furthermore, rapid population growth of the area has also made these sources of water inadequate for the dwellers, and the need for good quality and readily available portable groundwater in this area forms the basis for this research.

The study area is Agbarha-Otor located in Ughelli-North Local Govenrment Area of Delta State. It lies within longitude 5°522 and 6°202 East and latitude 5°152 and 5°402 North of the equator (Figures 1 and 2). The study area is located in the western Niger-Delta. The area plays host to several industrial corporation; SPDC, Nigerian Gas, NPDC, Supabru Brewery and Delta power IV station.

Agbarha Otor falls within the tropical rain forest zone of Nigeria which subsequently gave way to very thick vegetation that is stratified with

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the much thicker vegetation occurring along river channels and this normally typifies primary vegetation while the presence of grassland with sparse trees and shrubs typifies the secondary vegetation pattern within the vegetation belt.

Generally, two major wind systems influence the climate in the area. They are the Northeast trade wind blowing cold dry air from the Sahara and the South-west trade wind blowing cold moist air from the Atlantic Ocean. The South-west winds prevails almost throughout the year that is from March – October, while the North-east trade wind is responsible for the cold dry period (Harmattan) which influences the area for about four months (November – February). This brings about two types of seasons within a year; the rainy and dry seasons respectively, (Iloeje 1981).

The high commercial and industrial activities in the area have increased environmental concern in relation to waste generation and management and ground water contamination. The uncontrolled and indiscriminate dumping of waste materials on the land surface, landfill and water bodies has placed the groundwater at the risk of being contaminated. Also, the activities of oil companies working in the area can also have negative impact of the groundwater.

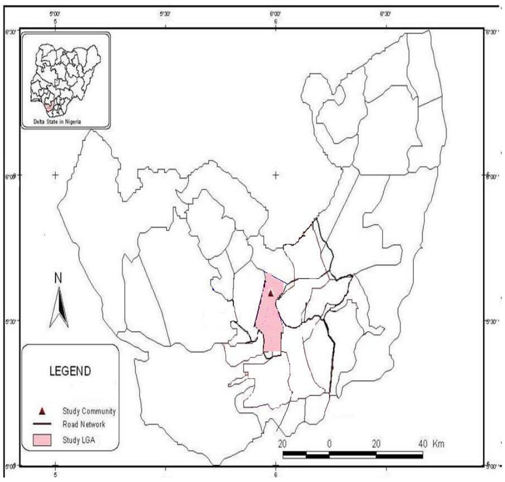

Figure 1: Map of Delta state showing the study area

Estimation of the impact of these waste materials, and oil leakage on ground water quality requires the determination of the transmissivity of the aquifer materials and protective capacity of the overburden rocks.

Transmissivity is a major property of an aquifer and aids in the characterization of rocks as water conducting media/strata. The ability of the overburden to retard and filter percolating fluid is a measure of its protective capacity (Belmonte et al, 2004). Estimating these properties from pumping tests can be very expensive and time consuming. Surface geoelectrical methods offer an alternative, rapid and cost effective approach for aquifer evaluation and groundwater quality assessment using empirical relations between hydraulic and geoelectric parameters (Hubbard and Robin, 2002).

The objective of the study is to evaluate the aquifer characteristics in terms of the Dar-Zarouk parameters and hence, the transmissivity of the aquifers and the protective capacities of the overburden rocks. The results of this investigation, by inference, will give clue to the probable impairment of groundwater quality in the area.

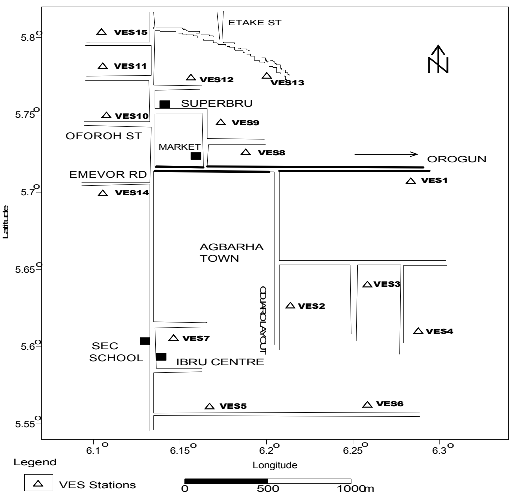

Figure 2: Location and Data acquisition map of the study area

THEORETICAL FRAMEWORK

The combination of the thickness and resistivity of the geoelectric layers into single variables; the Dar-Zarouk parameters of Transverse resistance (R) and Longitudinal conductance (S), can be used as a basis for the evaluation of aquifer properties such as transmissivity and protective capacity of the overburden rock materials (Ekwe et al, 2006). For a horizontal, homogenous and isotropic layer, the Dar-Zarouk parameters of transverse resistance and longitudinal conductance are obtained thus (Reynolds, 1977):

$$Si = \sum_{i=1}^{n} \frac{hi}{\rho i} \quad (1)$$

$$Ri = \sum_{i=1}^{n} \rho i hi \quad (2)$$

where ρi and hi are the layer resistivity and thickness of the ith layer. Also, the aquifer transmissivity T is expressed as the product of the hydraulic conductivity (k) and layer thickness (h), that is,

$$T = kh \quad (3)$$

For clean saturated aquifers whose natural fluid characteristics are fairly constant (that is, no appreciable impact on the general ground water quality by surface contaminants load), the hydraulic conductivity is proportional to the resistivity of the aquifer (Ehirim *et al.*, 2009). This implies that in the absence of a pumping test data, the aquifer hydraulic conductivity K can be approximated to the true resistivity of the aquifer derived from geoelectric investigation (Ehirim *et al.*, 2009). Therefore,

$$T = kh = \rho h \quad (4)$$

But the product of the resistivity to its thickness is the transverse resistance (R), which is numerically equal to the transmissivity (Henriet, 1976). The longitudinal conductance (S) gives a measure of the impermeability of a confining clay/shale layer. Such layers have low hydraulic conductivity (k) and low resistivity. Protective capacity (P_c) of the overburden layers is therefore proportional to its longitudinal conductance (Henriet, 1976), that is

$$P_c = S = \sum_{c=0}^{n} \frac{hi}{\rho_c} \quad (5)$$

METHODOLOGY

The ABEM Signal Averaging System 1000 digital Terrameter was used for the resistivity data acquisition. The Schlumberger array design was adopted for the data acquisition because of its sensitivity to surface inhomogeneities (Sharma, 1997). Fifteen vertical electrical sounding (VES) stations were occupied during the surface hydrogeophysical investigation to achieve a relatively good coverage of the area (Figure 2). The current electrodes were spread to a maximum field allowable distance of 600m from each centre point occupied.

The data obtained from the electrical resistivity survey was presented as field curves, which were interpreted through partial curve matching (Koefoed, 1979) with the help of master curves (Orellana and Mooney, 1966) and auxiliary point charts (Zohdy, 1965; Keller and Frischnecht, 1966). The thickness and resistivity values obtained from the partial curve matching were then used for a quantitative computer iteration using the Resist Software (Vandern Velpen, 1988) to obtain the first order geoelectric parameters (the layer resistivity ρi and the layer thickness

hi for the ith layer). These first order geoelectric parameters were utilized in deriving the longitudinal unit conductance (S) and transmissivity (T), thereby determining the overburden protective capacity in the area (Ehirim, 2010; Atakpo and Ayolabi, 2008; Oladapo, 2004)

RESULTS AND DISCUSSION

The longitudinal unit conductance and transmissivity values (Table 1), derived from the first order geoelectric parameters was used to generate maps which gives information on the protective capacity of the aquifer. This rating, modified according to Oladapo *et al.*, (2004), gave the longitudinal conductance/protective capacity rating as >10 (Excellent), 5-10 (Very Good), 0.7-4.9 (Good), 0.2-0.69 (Moderate), 0.1-0.19 (Weak) and <0.1 (Poor). Poor and weak protective zones are prone to leachate pollution.

Aquifer Transmissivity Map

Aquifer transmissivity of the area varies from 2068 to 14081 □m^2 (Figure 3). Considering also, the transmissivity rating of Gheorghe (1978), Table 2, the values are >500 □m^2 and they correspond to zones where the thickness and resistivity of the aquifer are large. The high transmissivity values suggest that the aquifer materials are highly permeable to fluid movement within the aquifer which is a function of the porosity of the area, which possibly may enhance the migration and circulation of contaminants in the groundwater aquifer system. The fact that the aquiferous materials in the study area are highly permeable and relatively shallow, suggests that the groundwater has a high propensity of being contaminated over large area once the aquifer receives contaminant from any surface source.

Longitudinal Unit Conductance Map

The longitudinal unit conductance map gives information on the overburden protective capacity of the aquifer in the area. This is because the earth medium acts as a natural filter to percolating fluid. Its ability to retard and filter percolating ground surface polluting fluid is a measure of its protective capacity (Olorunfemi *et al.,* 1999). The highly impervious clayey overburden, which is characterized by relatively high longitudinal conductance, offers protection to the underlying aquifer. The longitudinal unit conductance (S) values obtained from the study area are generally less than 0.1mhos, ranging from 0.01208 to 0.09247 mhos (Table 1). The low values of the protective capacity is due to the absence of significant overburden impermeable rock material (clay/shale), which can impede contaminant infiltration. The implication of this is that any surface contaminant travels down at a faster rate and goes into storage in the aquifer with relative ease and with unprecedented impact on the general ground water quality over time. However, around VES 3, 4, 8 and 9 the longitudinal unit conductance has the highest values ranging from 0.5 to 0.9mhos (Figure 4), making that region fairly protected when compared to the other regions. Therefore, groundwater development in the area should be done around VES 3 and 4.

Table 1: First and second order geoelectric parameters

VES Stn.	Resistivity (Ωm)	Thickness (m)	Depth (m)	Inferred Lithology	Curve Type	Transmissivity (Ωm²)	S (mhos)
1	2318.9	0.8	0.8	Topsoil	KHK	9146	0.01727
	3022.0	3.3	4.1	Fine - Coarse Sand			
	1004.9	9.1	13.2	sand			
	2636.9	16.8	30.0	Fine - Coarse sand			
	1374.3	-	-				
2	2152.0	1.1	1.1	Topsoil	KH	13478	0.0182
	2455.3	5.7	6.8	Fine - coarse sand			
	936.0	14.4	21.2	sand			
	1136.9	-	-				
3	1159.2	0.8	0.8	Topsoil	KHK	9629	0.01208
	2285.0	3.6	4.3	Fine - coarse sand			
	1319.2	7.3	11.6	Sand			
	3734.9	16.1	27.7	Fine - coarse sand			
	1290.7	-	-				
4	2367.7	1.0	1.0	Topsoil	KHK	23836	0.01214
	2616.4	4.9	5.9	Fine- coarse sand			
	2563.2	9.3	15.2	Fine - coarse sand			
	3513.9	25.7	40.9	Fine - coarse sand			
	2096.3	-	-				
5	2760.8	1.1	1.1	Topsoil	HK	38657	0.01438
	2042.9	7.8	8.9	Fine- coarse sand			
	3071.2	31.2	40.1	Fine - coarse sand			
	1239.0	-	-				
6	1820.4	0.9	0.9	Topsoil	KH	11985	0.01723
	2122.4	7.1	8.0	Fine - coarse sand			
	1687.6	22.6	30.6	Sand			
	2222.7	-	-				
7	257.0	0.6	0.6	Topsoil	KH	3010	0.09247
	643.4	5.8	6.4	Clayey sand			
	519.1	42.1	48.5	Clayey sand			
	2488.7	-`	-				
8	994.9	0.8	0.8	Topsoil	HA	2068	0.05356
	666.8	3.1	3.8	Laterite			
	977.1	47.0	50.8	Clayey sand			
	1317.5	-	-				
9	1074.4	1.0	1.0	Topsoil	KH	7227	0.04999
	1376.1	7.3	8.3	Sand			
	989.9	43.3	51.6	sand			
	2730.8	-	-				

Table 2: Standard for Transmissivity (T) (after Gheorghe, 1978)

Transmissivity Range	Transmissivity Potentials
Greater than 500m^2/dy (5.79 x 10^{-3}m^2/s)	High Potential
Between 50 and 50 m^2/dy (5.58 x10^{-3}and 7.39x10^{-3}m^2/s)	Moderate Potential
Between 5 and 50 m2/dy (9.06 x 10^{-3} and 5.50 x 10^{-3} m^2/s)	Low Potential
Between 0.5 are 5 m^2/dy (5.01x10^{-3} and 5.58 10^{-3}m^2/s)	Very low potential
Below 0.5m^2/dy (5.01 x 10^{-3} m^2/s)	Negligible flat

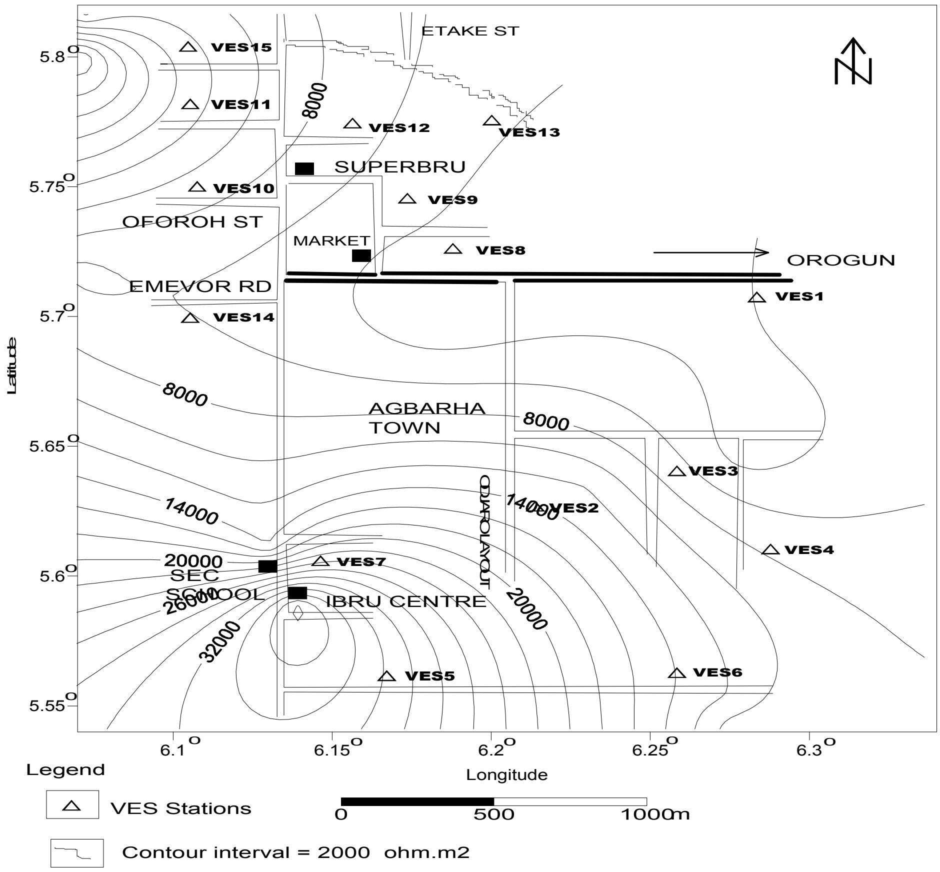

Figure 3: Aquifer Transmissivity map

CONCLUSION

Determination of the first and second order geoelectric parameters using the vertical electrical sounding has helped to delineate aquiferous zones and also to study the protective capacity of the overburden materials in the area. A total of 15 VES stations distributed evenly in the study area was occupied. The general lithology is mainly sands of various grades with no delineable intercalating clay impermeable bed. The area is characterised by low longitudinal unit conductance values, giving rise to low protective capacity of the overburden materials which are mainly sands of different grades, which makes the aquifer vulnerable to contamination in the event of pollution in the area. Also, the high aquifer transmissivity values recorded implies an enhancement of the migration of contaminant within the groundwater system.

With the results of this study, there is the likelihood that the groundwater quality in the area may have been impaired and therefore it is advised that groundwater monitoring wells should be provided for contaminant loads and water quality analysis.

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