Continental J. Earth Sciences 7 (1): 29 - 39, 2012 ISSN: 2141 – 4076
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Printed in Nigeria doi:10.5707/cjearthsci.2012.7.1.29.39

RELATIONSHIPS BETWEEN GEOELECTRICAL AND GROUNDWATER PARAMETERS IN PARTS OF OGBIA, BAYELSA SATE, CENTRAL NIGER DELTA

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ABSTRACT

The aim of this study is to evaluate the groundwater potential in Ogbia and environs, Bayelsa State using the vertical electrical sounding (VES) technique. Groundwater analysis was also carried out to investigate the water quality for both dry and wet seasons in the study area. The VES data were acquired using the Schlumberger electrode configuration. The interpreted geoelectric model results shows that the subsurface units in the area are dominated by sands of various grades with minor intercalating clay layers and has resistivity values of 50 to 395Ωm at the top of the unsaturated layer, between 13 and 352Ωm in the intermediate layers and 43 to 416Ωm in the aquiferous zones. In terms of the Dar-Zarouk parameters, the aquifers are characterized by high transverse resistance ranging from 1.2 X 10^3Ωm^2 to 1.56 X 10^4Ωm^2 and low to moderate longitudinal conductance. This implies the aquifers are highly permeable with significant specific yield and storativity. Based on the total dissolved solids (TDS), electrical conductivity (EC) and chloride concentration from the physiochemical analysis, the water facies are classified as fresh to slightly brackish. The empirical relationship developed between the bulk resistivity from the VES interpretation and $(EC)^{-1}$ from the groundwater samples using regression analysis shows variation in the benchmark for freshwater aquifer zones with respect to the season in which investigation was carried out.

KEYWORDS: Groundwater quality, geoelectrical model, aquifers, resistivity, regression analysis, Bayelsa State.

INTRODUCTION

Ground water has been a preferred source of drinking water because of the general perception that it is of higher quality, less vulnerable to contamination and requires less treatment. Groundwater provides a reasonably constant supply that is not likely to dry up under natural conditions, as surface sources may do (Nwankwoala, 2011). Geophysical methods have been successfully used in groundwater exploration, since they are usually non-invasive and relatively cheap. The resistivity methods and especially the vertical electrical sounding (VES) method has been used for investigating groundwater quality in different lithological settings because the instrumentation is simple, field logistics are easy and the analysis of data is straight forward compared to other methods (Zohdy et al., 1974). The VES survey technique has been used effectively for the study of groundwater conditions and to assess the subsurface geoelectrical layers. This survey technique can also be employed to establish the thickness and depth of water bearing formation (Oseji et al., 2006). Generally, the electrical properties of the subsurface materials is not only useful in predicting the aquiferous zones but also assists in cost reduction and provide a much more reliable platform in determining borehole drilling site for productive borehole construction and installation (Ushie and Nwankwoala, 2011).

The resistivity of a geological structure can vary significantly, depending on the porosity, water content and the concentration of salts in *groundwater. This enables both a quantification of the water content and an estimation of the groundwater quality.* The resistivity of fresh groundwater varies usually from 7 to 100Ωm, depending on the degree of dissolved solids and seawater or highly saline water has resistivities down to 0.2 Ωm (Palacky 1987), which makes resistivity method the ideal technique to distinguish the interface between saline and fresh water. However, the resistivity of different earth materials is not exclusive, e.g., clay overlaps with both freshwater and brackish water. *Because of these confusing effects, the lithology and groundwater quality effects cannot be differentiated* by the geoelectric resistivity survey alone (Choudhury and Saha 2004). For an effective use of VES survey, correlation with the chemistry of groundwater is required.

The study area is part of the numerous island communities that exist in the tidal zones of the Niger Delta. The Niger Delta is a large and ecologically sensitive region, in which various water species including surface and subsurface (fresh and saline) waters exist in a state of dynamic equilibrium Abam (1999). Most of these localities are rural to semi-urban with increasing population growth. Owing to inadequate central water supply management, majority of the water supply wells and boreholes are owned by individuals. These wells are generally located without proper geophysical and hydrogeological considerations. The result is exploiting water with objectionable quality and the encroachment of saline water into freshwater aquifer due to proximity to the brackish creeks and uncontrolled pumping. A systematic and scientific approach to the problem is therefore essential in order to overcome these challenges. This present investigation therefore involves geological, geophysical and hydrochemical studies of the groundwater resources in order to provide a guide for groundwater development and management in the study area.

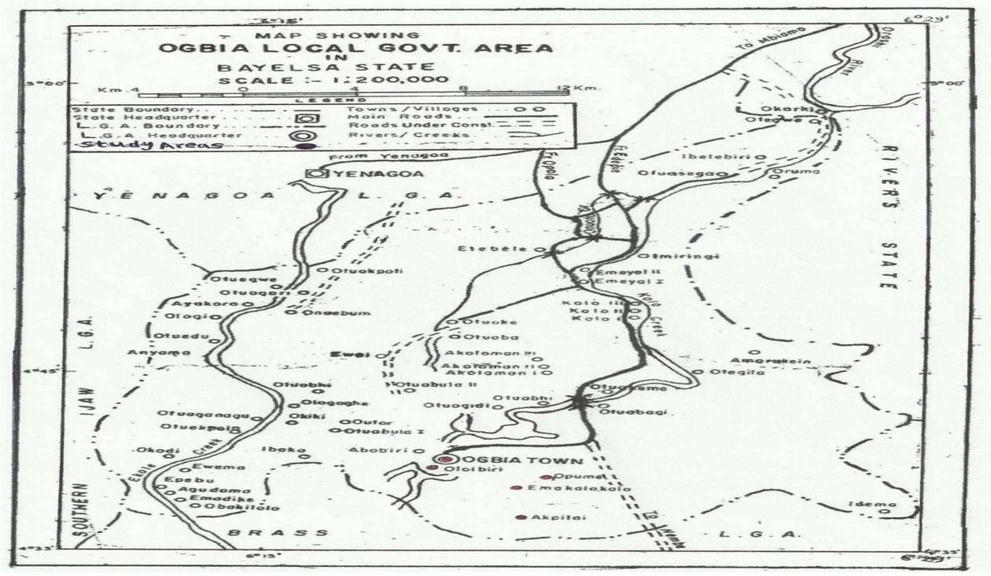


Fig1: Map of Ogbia L.G.A, Bayelsa State Showing Study Areas

Location of Study Area

The study area is approximately situated between latitudeN4^{0}33’ and N4^{0}45’ and longitude E6^{0}15’and E6^{0}29’ (Fig 1). Physiographically, it lies within the saltwater and freshwater swamp geomorphic units of the Niger Delta.

The communities investigated in this study include Ogbia town to Akeplai in Ogbia L.G.A. of Bayelsa state, Nigeria The area is accessible by road and water transport.

Geology and Hydrogeology

The geology of the Niger Delta has been extensively documented by various workers, including Reyment (1965) and Short and Stauble (1967). The formation of the present delta started during Early Paleocene and it resulted mainly from a build-up of fine grained sediments eroded and transported by the River Niger and its tributaries. The subsurface geology of the Niger delta consists of three lithostratigraphic units (Akata, Agbada and Benin Formations) which are in turn overlain by various types of Quaternary deposits. The Benin Formation (2100m) is made up of over 90% massive, porous, coarse sands with localized clay/shale interbeds (Allen 1965). The Cenozoic delta basin is said to have developed during Cretaceous times from the RRR triple junction (Burke et al, 1971). It is bounded by the Benin Flank to the North-west, the Calabar Flank to the East and the Anambra basin to the north. The Quaternary deposits (40-150m thick) generally consist of rapidly alternating sequences of sand and silt/clay with the latter becoming increasingly more prominent seawards. *The Akata Formation is of marine origin, while the Agbada Formation is transitional between the upper continental Benin Formation and the underlying marine Akata Formation.* The dominant freshwater aquifer is found within the Benin Formation which consists mostly of continental sand with clay and silt. These materials are believed to have been deposited in a continental fluviatile to deltaic environment. The clay units have variable thickness ranging from 1m to as much as 15m in some places.

The sand and clay intercalations constitute a system of aquifers separated by aquitard giving rise to a multi-aquifer system which characterize the Niger Delta (Etu-Efeotor and Odigi, 1983).

Indiscriminate abstraction of groundwater has resulted in saltwater intrusion in several coastal wells especially in Bonny, Nembe, Buguma and Degema areas (Akpokodje et al, 1998).

METHODS OF STUDY

The study involves field sampling, laboratory analysis and development of quantitative relationships between geoelectric measurements and water chemistry analysis. The scope of study entails determining the groundwater resource potential of the study area and the hydrogeological and geophysical challenges associated with exploiting its groundwater. The approach to tackling the groundwater problems of the communities under investigation is to study their geoelectric and hydrochemical characteristics. Surface geophysical study is designed to delineate the subsurface layers, determine depth to fresh water aquifer and to locate zones for productive boreholes. The hydrochemical investigation is carried out to determine the dominant cations, anions and other physiochemical parameters that serve as indices of ground water quality. The geoelectric and hydrochemical studies were carried out in two phases; the wet and dry seasons. The essence of sampling twice was to investigate the effect of saturation in the aquifers and the chemistry of the contained water.

Field Studies

Sixteen (16) groundwater samples were collected from eight (8) locations in the research area with each location sampled twice (ie for dry and wet seasons). The samples were collected from boreholes at depths ranging from approximately 15 to 100 metres. A total of sixteen (16) vertical electrical soundings (VES) were also carried out in the area for the wet and dry seasons in close proximity to the groundwater sample locations. The ABEM Terrameter SAS 1000, a self-averaging digital device was used for the field operation. A computer aided modelling technique using IP2Win software was employed for the data interpretation. The instantaneous values obtained from the laboratory analysis of the groundwater from discrete locations in the study area are limited in time and space. Therefore to predict the quality of groundwater in the entire study area, the electrical conductivity of the groundwater samples was chosen, converted to electrical resistivity and correlated with the bulk resistivity measurement obtained from the VES using regression analysis. *For reasons of analytical convenience, a practical index of salinity and TDS is electrical conductivity, expressed in deci Siemens per meter (Pervaiz et al, 2010)*

A regression is a statistical analysis assessing the association between two variables. For linear regression, e.g. between water resistivity and bulk resistivity,

$$Y = a + bx \dots\dots\dots (1)$$

Where

$$intercept\ a = \frac{(\Sigma Y - b(\Sigma X)}{N} \dots\dots\dots (2)$$

and

$$slope\ b = \frac{N\Sigma XY - (\Sigma X)(\Sigma Y)}{(N\Sigma X^2 - (\Sigma X)^2} \dots\dots\dots (3)$$

In this study the objective of this approach is an attempt to use the surface electrical measurements to fix a benchmark for freshwater aquifers and delineate contaminated zones.

THEORETICAL BASIS

A geoelectric unit is characterised by two basic parameters: the layer resistivity and the layer thickness. The combination of the thickness and resistivity of the geoelectric layers into single variables known as the Dar-Zarouk parameters which are 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.

The Dar-Zarouk parameters of transverse resistance R and longitudinal conductance S are obtained as:

$$\varsigma i \, \_ \quad \backslash^{\,''} \quad .... (4)$$

$$Ri = \sum_{i=1}^{n} \rho i \, hi \ldots \ldots \ldots (5)$$

where p_i *and* h_i *are the layer resistivity and thickness of the ith layer. The aquifer transmissivity T is expressed as the product of the hydraulic conductivity (k) and layer thickness (h),*

$T = k h \quad ..... (6)$

For aquifers whose fluid characteristics are fairly constant, the hydraulic conductivity is proportional to the resistivity of the aquifer. 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.

Therefore,
$T = kh = ph ...... (7)$

But the product of the resistivity of a layer and its thickness is the transverse resistance (R), which isnumerically equal to the transmissivity (T) (Ehirim and Nwankwo, 2010).

$T = R ..... \quad (8)$

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 (Pc) of the overburden layers is proportional to its longitudinal conductance S.

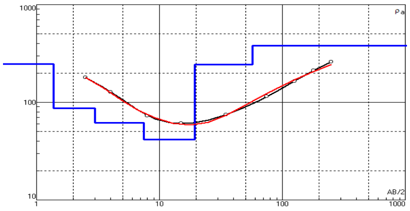
RESULTS AND DISCUSSION

The apparent resistivity data from the field measurements were inverted using IP12WIN resistivity sounding interpretation software to determine the true resistivity and depths of the subsurface formations. The model curves have RMS errors of <10% and exhibit KH and QH type curves with 4-6 geoelecttic layers (Fig 2)

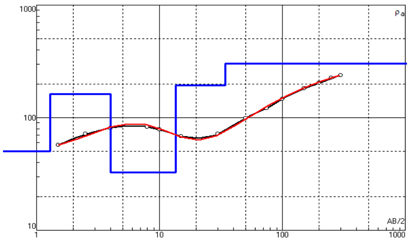
The results were interpreted in terms of the resistivity of the subsurface units with the aid of the lithologic log of a borehole penetrated to the depth of about 70m in Ogbia. The model interpretation based on the above correlation show that the geoelectric sections consists of fine to coarse sands, clayey sands with occasional clay units (Fig 3).

Fig 2a: Interpreted Geoelectric Curves (Dry Season)

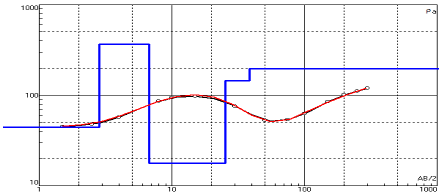
VES 1



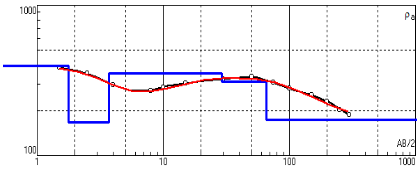
VES 2



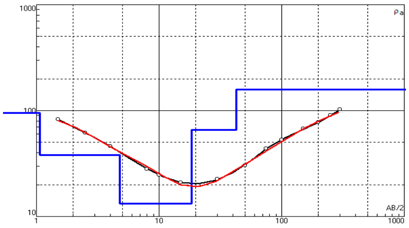
VES 3



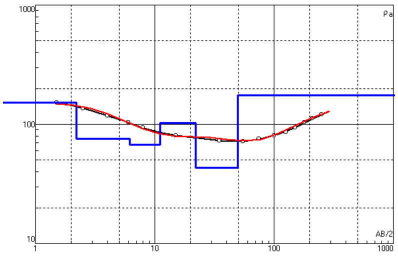
VES 4



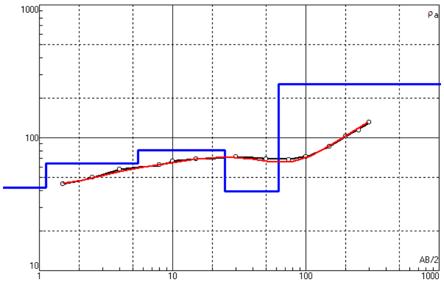
VES 5



VES 6



VES 7



VES 8

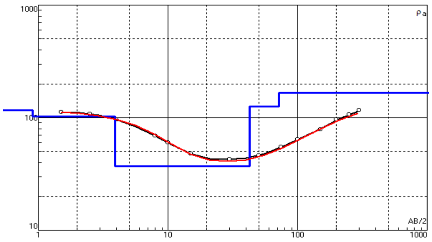
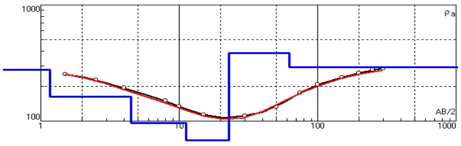
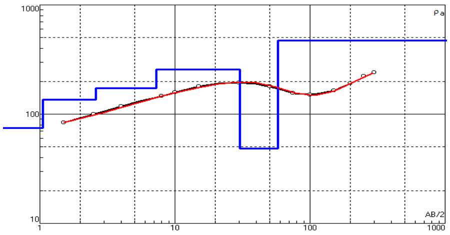


Fig 2b: Interpreted Geoelectric Model Curves (Wet Season)

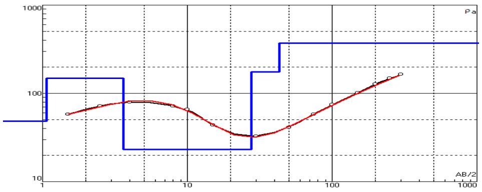
VES 1



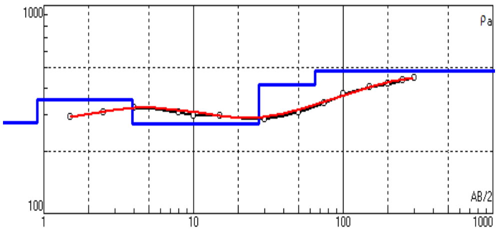
VES 2



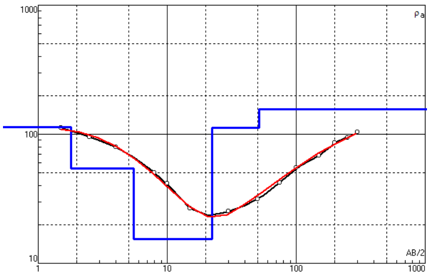
VES 3



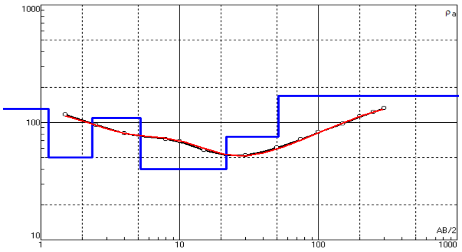
VES 4



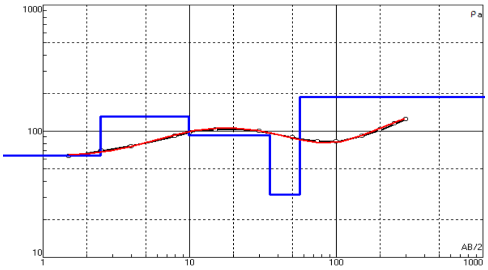
VES 5



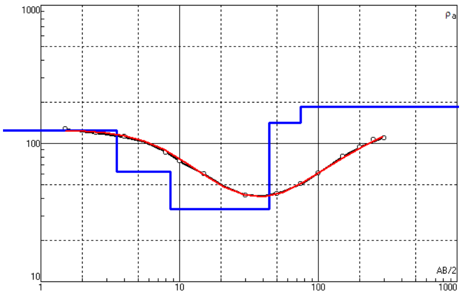
VES 6



VES 7



VES 8



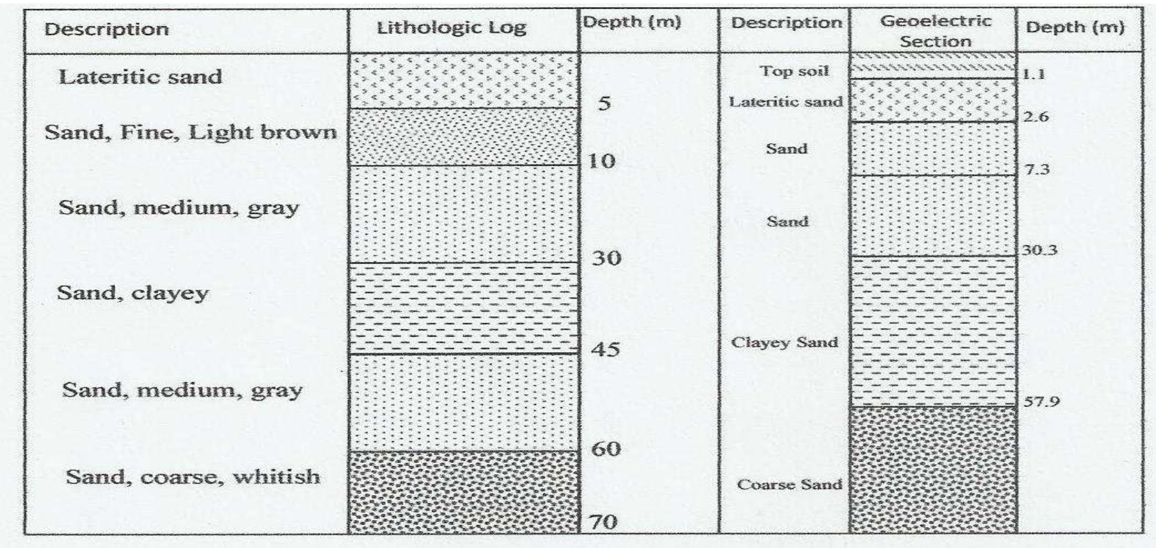


Fig. 3 Lithologic Log and Geoelectric Section

The aquifer and Dar-Zarouk parameters of the geoelectric sections are presented in (table 1 and 2). The aquiferous zones occur between the 3rd and 5th geoelectric layers with resistivity range of 43Ωm to 309Ωm and 76Ωm to 416Ωm for the dry and wet seasons respectively at depths of 24.8m to 74.6m and thickness ranging from 13.2m to 39.6m. The transverse resistance (R) and hence the transmissivity (T) of the aquiferous zones vary from 1.2 X 10^3 Ωm^2 to 1.13 X $10^4 \Omega m^2$ in the dry season and 2.27 X 10^3 Ωm^2 to 1.56 X 10^4 Ωm^2 in the wet season. These values which are greater than 400Ωm^2 correspond to aquifer zones where the thickness and resistivities are appreciably large. The high transmissivities suggest that the aquifer materials are porous highly permeable to fluid movement. (Ehirim and Nwankwo, 2010).

The longitudinal conductance (S) and hence, the protective capacity (P_C) of overburden layers range from 9.5 X 10^{-2} to 1.14 X 10^0 Siemens and 9.5 X 10^{-2} to1.18 X 10^0 for dry and wet seasons respectively. Pc values less than 1.0 Siemens are classified as low and are characteristic of sedimentary successions of overburden layers with no significant impermeable clay/shale overlying strata. Such subsurface model is an indication of high infiltration rates from precipitation as well as surface contaminants into the aquifer. In this study, 63%of the areas sampled have $P_C<1$, however, VES stations 3, 5 and 8 have P_C values >1 which implies that these locations have considerable layers of clay separating the subsurface aquifer zones. In addition to high transmissivity and low protective capacity values in most of the VES stations, the aquifers are relatively close to surface (<100m) and thus susceptible to contamination over large area once the aquifer receives a load of contaminant dose from surface or near surface sources e.g saline intrusion. Nevertheless groundwater potential in the area is high due to high transverse resistance (R) and dominantly low protective capacity values of the aquifers which is suitable for the development of boreholes of potable water supply. Results of the water analysis (Tables 3and 4) shows that the dominant anions are bicarbonate (HCO_3^-) and chloride (Cl^-) while sodium is the dominant cation followed by calcium (Ca^{2+}) and magnesium (Mg^{2+}). The electrical conductivity (EC) values range from 658 µS/cm to 2941µS/cm and 575 µS/cm to 2564µS/cm while total dissolved solids (TDS) range from 245.2mg/l to 608mg/l and 203.5mg/l to 474.6mg/l for dry and wet seasons respectively.

Table 1: Aquifer and Dar-Zarouk Parameters of Geoelectric Sections (Dry Season)

s/no.	Location	Aquifer Resistivity (Ωm)	Aquifer Depth (m)	Aquifer Thickness (m)	Transverse Resistance (Ωm^2)	Protective Capacity (Siemens)
1	VES1	246	57.1	38	9234	0.378
2	VES2	194	34.3	20.8	4035.2	0.333
3	VES3	144	38.5	13.2	1900.8	1.125
4	VES4	309	65.7	36.6	11309	0.089
5	VES5	67	42.6	24.2	1621.4	1.139
6	VES6	43	49.7	27.7	1196.6	0.371
7	VES7	81	24.8	19.2	1555.2	0.095
8	VES8	125	72.3	29.6	3700	1.083

Table 2: Aquifer and Dar-Zarouk Parameters of Geoelectric Sections (Wet Season)

VES NO.	Location	Aquifer Resistivity (Ωm)	Aquifer Depth(m)	Aquifer Thickness (m)	Transverse Resistance (Ωm^2	Protective Capacity (Ωm^2
1	VES1	385	62.5	39.6	15246	0.264
2	VES2	257	30.3	23.0	5897.2	0.053
3	VES3	175	43.2	15.5	2712.5	1.08
4	VES4	416	64.9	37.6	15630.3	0.101
5	VES5	112	51.6	29.3	3281.6	1.175
6	VES6	76	53.0	29.8	2272.4	0.472
7	VES7	93	35.2	25.4	2362.2	0.095
8	VES8	140	74.6	30.3	4242	1.176

Table 3: Analysis of Groundwater Samples (Dry Season)

S/N	TEMP °C	pH	TDS mg/l	EC µS/cm	HCO_3^- mg/l	Cl^- mg/l	SO_4^{2-} mg/l	Na^+ mg/l	K^+ mg/l	Ca^+ mg/l	Mg^{2+} mg/l	Fe^{2+} mg/l
1	26.0	6.3	396.2	740	52.4	9.8	6.7	36.9	12.4	26.9	15.8	0.36
2	27.0	6.5	543	952	67.5	14.6	10.5	42.4	17.1	29.5	26.1	0.15
3	26.5	6.2	340	1163	31.3	19.7	12.1	46.5	13.8	15.0	8.6	0.3
4	26.0	6.8	245.2	658	58.9	12.3	5.3	15.6	6.2	9.4	12.3	0.18
5	26.8	7.4	410.6	1818	45.2	28.0	9.6	38.3	22.0	20.3	17.0	0.23
6	26.9	6.9	608	2941	84.8	37.5	13.8	61.7	15.3	18.6	7.5	0.28
7	26.7	6.3	518.4	2380	61.0	32.3	10.2	56.3	18.2	7.8	13.8	0.32
8	27.2	6.4	395.6	1471	75.2	21.5	6.1	39.0	8.5	8.9	4.7	0.24

Table 4: Analysis of Groundwater Samples (Wet Season)

S/N	TEMP °C	pH	TDS mg/l	EC µS/cm	HCO_3^- mg/l	Cl^- mg/l	SO_4^{2-} mg/l	Na^+ mg/l	K^+ mg/l	Ca^+ mg/l	Mg^{2+} mg/l	Fe^{2+} mg/l
1	27	6.7	296.6	562	47.6	7.3	3.2	33.4	10.6	24.6	14.3	0.25
2	26	6.8	420.2	862	35.9	9.6	9.8	37.1	15.3	27.2	17.8	0.15
3	26.5	6.3	289.4	1295	39.0	16.5	6.4	44.2	12.0	12.7	6.3	0.45
4	26.2	6.8	203.5	575	45.6	10.1	8.2	10.9	4.6	19.1	8.8	0.20
5	27.5	7.2.	315.8	1639	38. 5	22.4	4.6	23.6	15.2	18.0	11.5	0.27
6	27.2	6.4	474.6	2564	60.1	31.5	7.1	48.3	11.2	16.3	9.2	0.28
7	26.5	6.5	409.5	2500	55.3	26.0	8.7	39.5	12.4	5.5	12.3	0.38
8	26.5	6.4	312.8	1563	76.7	15.8	4.9	27.4	6.7	7.6	4.9	0.34

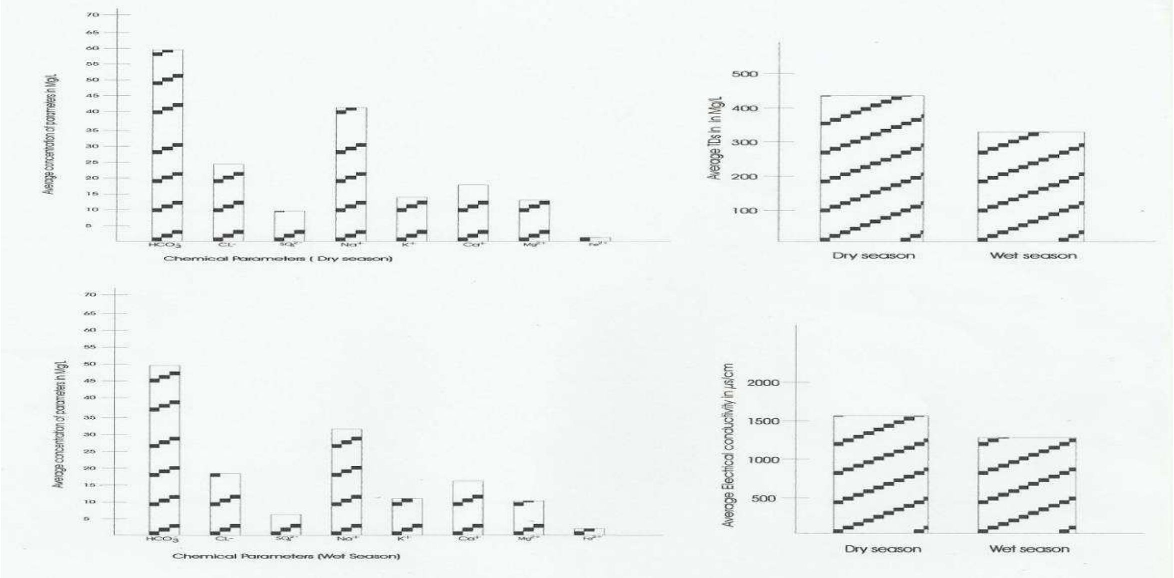


Fig. 4: Chart Showing Results of Water analysis

EC and TDS along Cl^- concentration are commonly used as indices of saline or brackish water infiltration into freshwater aquifers. Based on Abdul et al (1997) which described brackish and freshwater boundary as 1000mg/l for TDS and Bugg et al (1976) which stipulated 500-3200µS/cm as limit for brackish waters, the groundwater in the study area is classified as fresh to slightly brackish.

The results of the geoelectric models shows that resistivity values generally increased from dry to wet seasons throughout the study area with the highest increase of over 100Ωm recorded in VES stations 1 and 4. The reason for the increase is not completely clear. However, one possible explanation is that small discontinuous clay bodies in sedimentary layers develop surface charges and act as capacitors in the subsurface electrical circuit resulting in a Nernst reversal potential (Telford et al, 1990). The clay bodies when undersaturated have only minor effect on the resistivity of the facies because they make up just a small fraction of the system but when saturated, they swell and become negatively charged on their surfaces, inhibiting ionic flow through the pores. The empirical formula relating the groundwater resistivity to the aquifer resistivity using equation (2) and (3) for dry and wet seasons respectively are computed as:

$$\rho w = 1.5 + 0.046\rho e \ldots\ldots..(9)$$

$$\rho w = 0.9 + 0.041\rho e \ldots\ldots\ldots(10)$$

Adopting the lower limit value of 7 according to Parackly (1987), the above equations thus stipulates the benchmark of resistivity values for fresh groundwater aquifers as approximately 120 and 150Ωm for dry and wet seasons respectively in the study area.

CONCLUSION

The geoelectric studies have helped to delineate subsurface aquifer layers, map zones of brackish water infiltration and characterize the conditions of groundwater in terms of the transmisivities of the aquifer and the protective capacities of the overburden earth materials.

Based on the interpretation of the VES survey and the groundwater analysis conducted in the study area, the following conclusions were drawn:

(i) The effect of groundwater saturation on electrical resistivity in the study area is dependent on lithology.

(ii) The aquiferous zones occur between the 3rd and 5th geoelectric layers with resistivity range of 125 Ωm to 309Ωm in the dry season and 140 Ωm to 416Ωm in the wet season at depths approximately between 30m and 75m.

(iii) In terms of Dar-Zarouk parameters, the project area is dominated by high aquifer transmissivity values. This implies that the aquifers have appreciable hydraulic conductivity and storavity values and are highly permeable. However, groundwater flow is not continuous throughout the subsurface zones of the area as laterally discontinuous lenses of clay aquitards subdivide the aquifers into several units which may have partial hydraulic connection. Low to moderate protective capacity values characterize the overburden layers of the aquifers in the research area. Whereas the clay units indicated by higher protective capacity are poor aquifer materials, they act as barriers to migration of contaminants.

(iv) The dominant ions recorded in the groundwater analysis in the study are HCO_3 and Cl^- for anions and sodium followed by Ca^{2+} and Mg^{2+} for the cations.

(v) Based on the EC, TDS and Cl^- concentration, the groundwater in the study area is classified as fresh to slightly brackish depending on the locality.

(vi) The empirical relationship developed between the interpreted layer resistivity (ρe) and the water resistivity (ρw) using regression analysis stipulates that fresh water aquifer zones in the study area correspond to geoelectric sections with resistivity values greater than 120 and 150Ωm for dry and wet seasons respectively and are thus prospective areas for potable groundwater development.

(vii) No delineable freshwater aquifer layer was recorded within the depth probed as a result of the dominance of continuous low resistivity values considered as an indication of either high clay content or water salinity in VES stations 6 and 7. Both factors contribute to poor groundwater quality depending on the study locality.

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Received for Publication: 29/02/12
Accepted for Publication: 01/04/12

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