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Geoelectrical and Hydrogeochemical Assessment of the Groundwater Potentials of Ehandiagu, Enugu State, Southeastern Nigeria

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Abstract

Geoelectrical, hydrogeochemical investigations were carried out in order to determine the groundwater potentials of Ehandiagu in Enugu state, southeastern Nigeria. Ehandiagu is underlain by the Nkporo Shale, which is a low permeability formation. Four vertical electrical sounding (VES), employing the Schlumberger electrode configuration, was carried out in the study area, with a maximum electrode separation of 580m. The VES data were modeled with the IPI2 WIN software. The VES curves were predominantly of the QH type. The lithologic succession consists of lateritic top soil, weathered bedrock, fractured shale (the aquifer) and compact carbonaceous shale. Results show that the depth to water ranges between 6.82m and 20.7m while aquifer thicknesses range between 8.95m and 26.26m. The depth to water obtained from hand-dug wells varies between 6.20m and 15.18m. Aquifer hydraulic conductivity and transmissivity were calculated to be 2.62 x 10^{-3} m/day and 4.31 x 10^{-2} m^2/day respectively. These parameters were used to classify the aquifer as moderately good to poor aquifer. Hydrogeochemical analysis of groundwater samples collected from twelve (12) hand-dug wells in the study area reveals that weathering is the major process that controls the groundwater chemistry and the water type is Sodium-Potassium-Bicarbonate. The concentration of heavy metals (Mn, Fe, Pb) were found to be above the acceptable limits for potability and the SO_4^{2-} concentration is very low, probably due to sulphate reduction. Both sulphate reduction and high heavy metal concentration suggest a geochemical reducing environment.

Keywords: Ehandiagu, Groundwater Chemistry, Hydraulic Conductivity, Transmissivity, Vertical Electrical Sounding.

1. Introduction

Ehandiagu is located in the eastern part of the Anambra Basin, between latitudes 6°46′ and 6°50′N, and longitudes 7°32' and 7°35'E (Fig. 1). The terrain is generally flat. Few ephemeral streams exist in the area, and groundwater is not readily available due to the existence of impermeable bedrock in the area. There are several hand-dug wells in Ehandiagu, but there are no boreholes. Ehandiagu has become important lately because of the renewed interest in the exploration of oil and gas in the Nigerian inland basins. There is, therefore, a need to evaluate the potentials of the underlying formation in the area to supply groundwater as a more dependable alternative to surface water, in anticipation that development projects may quickly come up in the area. This is the reason for this work.

Relationships between aquifer characteristics and electrical parameters of geoelectric layers, as well as the chemical quality of groundwater, have been studied and reviewed by many authors. Igboekwe *et al.* (2006) delineated potential aquifer zones in Kwaibo watershed in Ikwuano and Umuchieze area, based on the high hydraulic conductivity and transmissivity values in most parts of the watershed. Ofoma *et al.* (2006) delineated 6-7 geoelectric layers in Nsukka and observed that the water table falls within the lower parts of the layers at a depth of about 110m. The primary objective of this work is to determine aquifer characteristics such as aquifer depth, thickness, hydraulic conductivity and transmissivity from both hydrogeological and geophysical data, and to assess the quality of the groundwater with a view to determining the potability.

2. Geology and Hydrogeology

Ehandiagu is located within the Anambra Basin, which flanks the Benue Trough to the east. The Anambra Basin originated in the Santonian stage by the contemporaneous subsidence of the Anambra platform and the uplift of the Abakaliki-Benue anticlinorium (Murat, 1972). This basin is funnel shaped and filled with texturally and mineralogically mature sediments of the Cretaceous age. The stratigraphic packaging of the Anambra Basin is divided into two, namely: Nkporo Group and the Coal Measures. The Nkporo Group comprises Nkporo Shale, Enugu Shale and Owelli Sandstone. Ehandiagu is directly underlain by the Nkporo Shale (Fig.1).

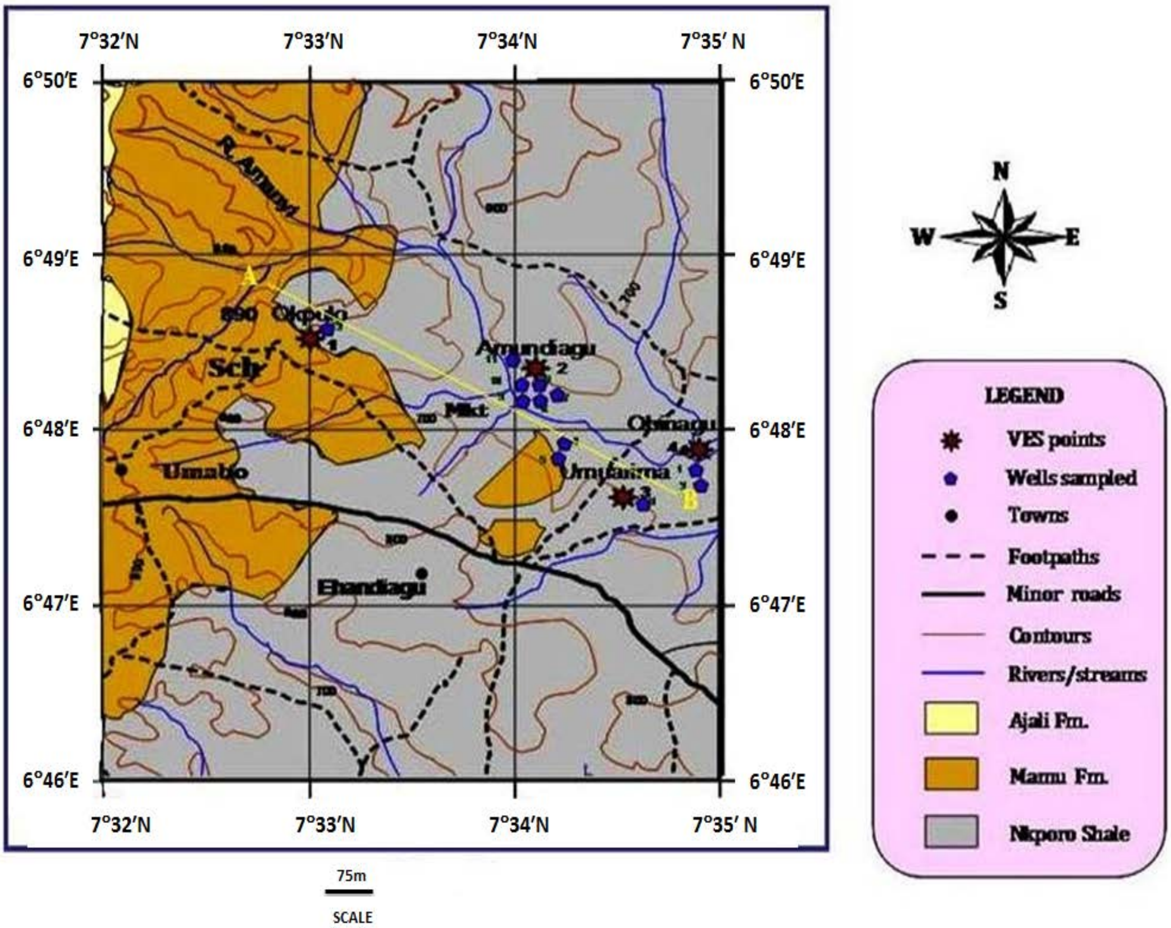


Figure 1. Location and geologic map of the study area**.**

The Nkporo Shale and the Enugu Shale are known to be aquicludes (Offodile, 2002). Outcrops of the Nkporo Shale are scarce but cored samples from boreholes show that the formation consists of dark shales and mudstones, with sparse intercalations of sandstones. The shales have weathered to lateritic clay regolith that overlies fractured and fresh bedrock in Ehandiagu. The regolith and the fractured bedrock constitute the only known aquifer in the study area. The impermeable bedrock underlying the study area favors the existence of ephemeral springs and streams. This condition underscores the importance of groundwater in Ehandiagu. The geologic and groundwater situations in Ehandiagu compares positively with those of Enugu town (Onwuka et al., 2009). Enugu town is directly underlain by the Enugu Shale, a lateral equivalent of the Nkporo Shale.

3. Methods of Study

Vertical electrical sounding survey and hydrogeochemical studies were employed in this work.

3.1. Vertical Electrical Sounding (VES)

VES is a method of resistivity survey that provides information on the variation of the resistivity of subsurface materials with depth. The instrumentation of VES is simple; field logistics are easy and straightforward while the analysis of data is less tedious and economical (Zhody et al., 1974; Ekine and Osobonye, 1996; Ako and Olorunfemi, 1989). Resistivity measurements are normally made by injecting current into the ground through two current electrodes and measuring the resulting potential difference at two potential electrodes. From the current (I) and voltage (V) values, an apparent resistivity (ρa) value is calculated using the formula:

where K is the geometric factor, which depends on the arrangement of the four electrodes (Loke, 1999).

The electrode arrangement used in this study was the Schlumberger method because fieldwork is easier while master curves and software for result analysis are more readily available. In the Schlumberger configuration, all the four electrodes are arranged collinearly and symmetrically placed with respect to the centre (Fig. 2).

$$\rho_a = K\frac{V}{I}$$

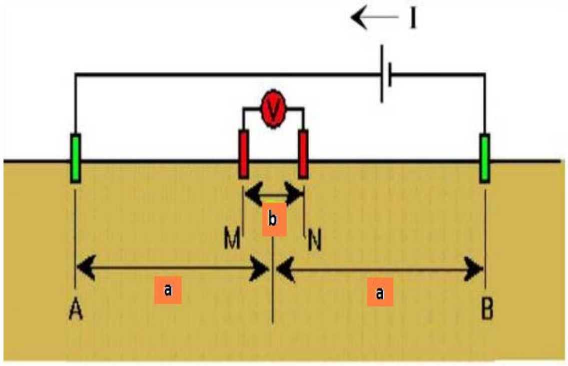


Figure 2. Sketch diagram of the Schlumberger array

In the present study, four vertical electrical sounding results were acquired. The maximum current electrode (AB) spacing ranged from 300 to 580meters. All the soundings were carried out near existing hand-dug wells for comparative purposes to explore the interrelation between lithological sequences with geo-electrical layer sequences (Fig.1). The apparent resistivity (ρa) for the Schlumberger array was calculated using the formula

$$\rho a = \pi R \left(\frac{a^2}{b} - \frac{b}{4} \right)$$ (Keller and Frischnechk, 1979)

Where R= resistance in ohms,

a= half current electrode separation

b= potential electrode spacing

The field data were used to generate sounding curves with the aid of the IPI2Win interpretation software (Fig. 3). Geoelectric sections were drawn using the information obtained from the sounding curves while aquifer thickness was estimated from the geoelectric sections. The hydraulic conductivity (K) of the aquifer was calculated from a simple hydraulic conductivity test (Auger hole test) carried out in the field. The calculated K and the aquifer thickness, derived from the interpretation of resistivity sounding data, were used to calculate aquifer transmissivity (T), using the relation:

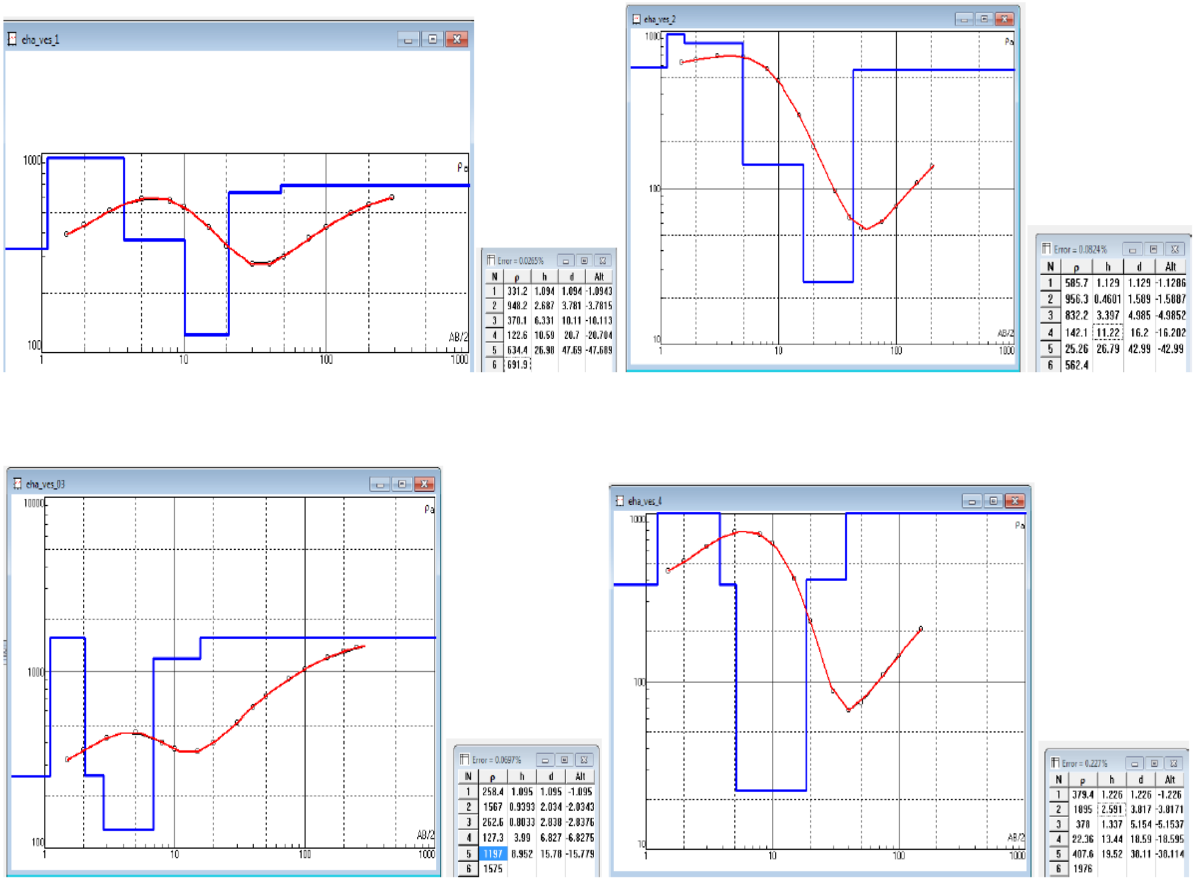
T=Kh where h is the aquifer thickness.

3.2. Hydrogeochemical Investigation

Groundwater samples were collected from twelve (12) hand-dug wells in the dry season (February, 2009). The electrical conductivity and temperature of the samples were measured in the field. Total dissolved solids (TDS) were measured using EDTA (ethylenediaminetetraacetate titrimetric method) complexometric method. Cations (Na^+, k^+, Mg^{2+}, Ca^{2+}, Mn^{2+}, Fe^{2+}, Pb^{2+}, Cu^{2+}, Ti) were analyzed using the atomic absorption spectrophotometer (model 210 VGP). Anions (NO_3^-, SO_4^{2-}, Cl^- and HCO_3^-) were analyzed using different methods. NO_3^- and SO_4^{2-} were determined by turbidometric titration, using a spectrophotometer (model Genesys 20). HCO_3 was analyzed by titration with sulphuric acid. pH was determined using a Pye Unican 290MK pH metre. The reliability of the water quality data was determined using the ionic balance or electric neutrality formula:

$$\frac{\sum Cations + \sum Anions}{\sum cations - \sum Anions} x100 \leq 5\%$$ (Hounslow, 1995)

From the computation of ionic balance, the water quality data was found to be 86% reliable.



Error = 0.0265%

N	ρ	h	d	Alt
1	331.2	1.094	1.094	-1.0943
2	948.2	2.687	3.781	-3.7815
3	370.1	6.331	10.11	-10.113
4	122.6	10.59	20.7	-20.704
5	634.4	26.98	47.69	-47.689
6	691.9			

Error = 0.0824%

N	ρ	h	d	Alt
1	585.7	1.129	1.129	-1.1286
2	956.3	0.4601	1.589	-1.5887
3	832.2	3.397	4.985	-4.9852
4	142.1	11.22	16.2	-16.202
5	25.26	26.79	42.99	-42.99
6	562.4			

Error = 0.0697%

N	ρ	h	d	Alt
1	258.4	1.095	1.095	-1.095
2	1567	0.9393	2.034	-2.0343
3	262.6	0.8033	2.838	-2.8376
4	127.3	3.99	6.827	-6.8275
5	1197	8.952	15.78	-15.779
6	1575			

Error = 0.227%

N	ρ	h	d	Alt
1	379.4	1.226	1.226	-1.226
2	1895	2.591	3.817	-3.8171
3	378	1.337	5.154	-5.1537
4	22.36	13.44	18.59	-18.595
5	407.6	19.52	38.11	-38.114
6	1976			

Figure 3. Sounding curves from the study area.

3.3. Auger Hole Tests

Simple auger test was carried out at two locations in the study area in order to estimate the hydraulic conductivity of soils. A known volume of water was introduced into a hole of known depth and diameter. The time taken for the water to permeate completely into the soil was noted. The hydraulic conductivity, K, was calculated by the application of Darcy's law, as given in the equation below:

$$K = \frac{Q_L x \mu_L x L x 1000}{A(P_2 - P_1)} \text{ (the Darcy equation)}$$

where

$$Q_L = \text{flow rate} = \frac{height \quad of \quad water(h)}{time \quad of \quad water \quad to \quad dry(t)} = (ms^{-1})$$

μ_L = viscosity of water (centipoise)

A = Cross-sectional area (m^2)

$P_2 - P_1 = P_{atm} - P_w = \wp g\Delta h$

$\therefore P_w = P_{atm} - \wp g\Delta h$

$\therefore P_2 - P_1 = \wp g\Delta h$ (atmosphere)

$\wp$ = Density of water

L = height of section (m)

h = height of water (m)

$P_2 - P_1 = \Delta P = \wp g\Delta h$

$P_2 = P_{atm}$ (Atmospheric pressure) (known)

$P_1 = P_w$ (Water pressure) (unknown)

4. Results and Interpretation

We adopted the following procedures in interpreting the results:

- Interpretation of the vertical electrical sounding curves using the IP12WIN Software.
- Generation of geoelectric sections and the inferred lithologies as observed from the hand dug wells.
- Determination of Aquifer thickness and the depth to water from the sounding curves

The sounding curves generated are shown in Figure 3.

4.1. Generation of geoelectric sections and the inferred lithologies as observed from the hand- dug Wells.

4.1.1. VES 1 AT OKPULO EHANDIAGU

The first geoelectric layer with a resistivity of 331Ωm corresponds to the top soil. The second layer consists of lateritic soil with a resistivity value of 948Ωm. The lateritic layer is underlain by a layer of weathered bedrock, which overlies a fractured shale layer (aquiferous layer) with a resistivity of 123Ωm. The fifth geoelectric layer was interpreted as carbonaceous shale because of the recorded high resistivity and the degree of organic richness as observed from scooped samples from a hand –dug well in the area (Fig.4)

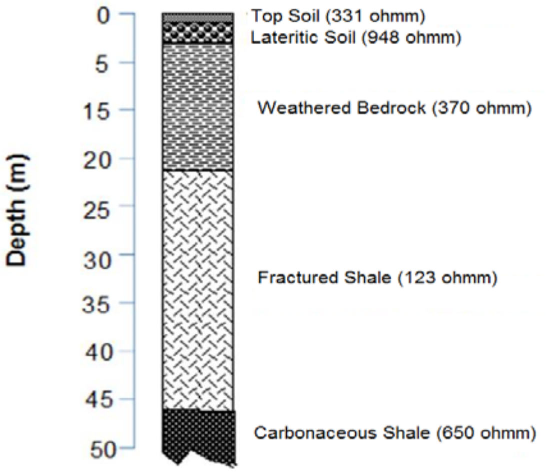


Figure 4. Geo-electric section of VES 1 showing the layer parameters.

4.1.2. VES 2 AT AMUNDIAGU EHANDIAGU

The dry reddish topsoil is underlain by a lateritic soil with resistivities ranging from 832 – 956Ωm. The third geoelectric layer consists of weathered bedrock while the aquiferous layer (fractured shale) has a resistivity of 25Ωm (Fig.5).

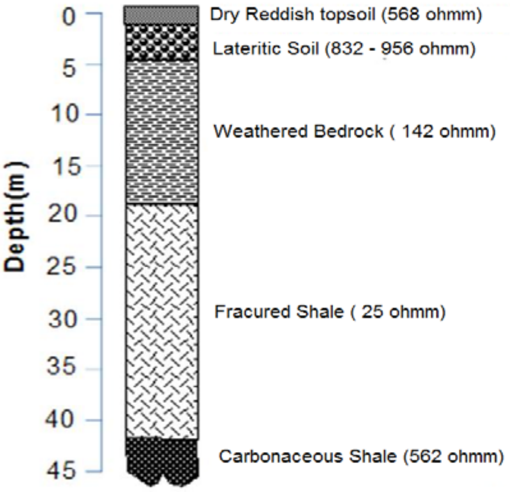


Figure 5. Geo-electric section of VES 2 showing the layer parameters.

4.1.3. VES 3 AT UMUARIMA EHANDIAGU

The first geoelectric layer with a resistivity value of 258Ωm corresponds to a reddish top soil, which is underlain by a consolidated lateritic layer with a resistivity value of 1567Ωm. The third geoelectric layer, with a resistivity value of 263 Ωm, was interpreted as the weathered bedrock, while the fourth layer, with a resistivity of 127Ωm, corresponds to the aquiferous layer. The fifth layer has a resistivity of 1575Ωm and represents carbonaceous shale (Fig. 6)

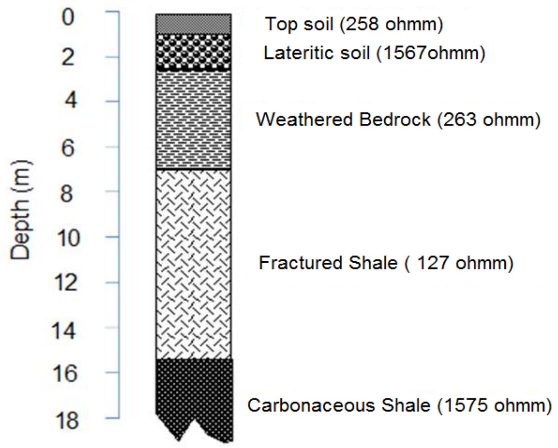


Figure 6. Geo-electric section of VES 3 showing the layer parameters.

4.1.4. VES 4 AT OBINAGU EHANDIAGU

The layered sequences consist of top soil, consolidated lateritic soil, weathered bedrock, and a fractured shaly layer, which constitutes the aquifer layer. The aquifer layer is underlain by a layer of dark carbonaceous shale with a resistivity of 1975Ωm (Fig. 7)

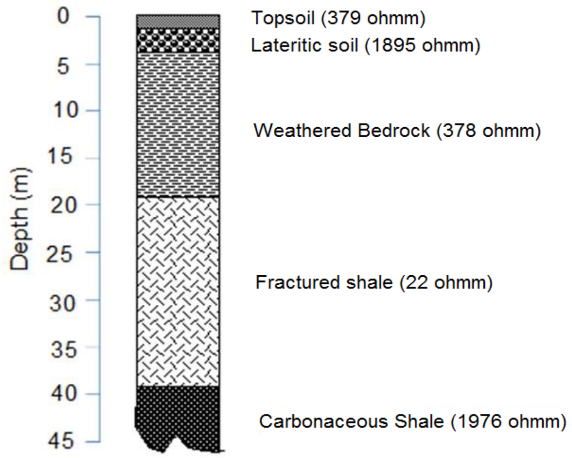


Figure 7. Geo-electric section of VES 4 showing the layer parameters

4.2. Depth to Water and Aquifer Thickness

The depths to water (Fig. 8), across the study area, were determined from the sounding results.

The deduction shows that the depth to water is generally shallow in Ehandiagu. It ranges from 6.82m at Umuarima to 20.7m at Okpulo. Aquifer thicknesses range between 8.95m at Umuarima and 26.79 m at Amundiagu (Fig. 9). The above results compare very well with those obtained from hand-dug wells in the area. The depth to water as measured from wells ranges from 6.20m and 15.18m.

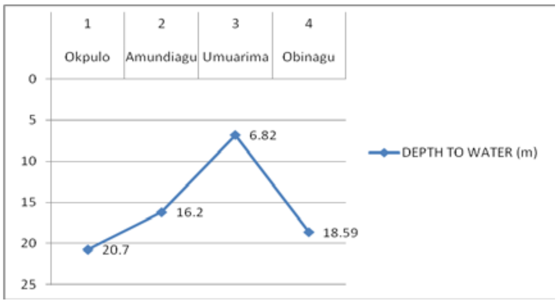


Figure 8. Cross-Section along A-B showing the depth to water

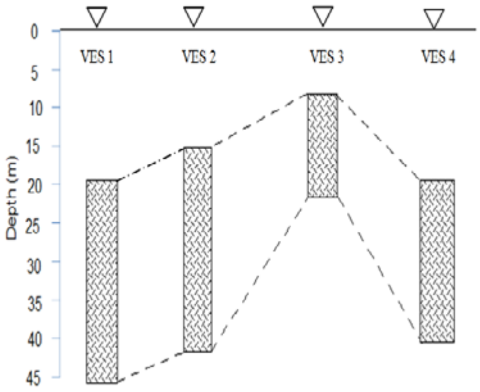


Figure 9. Cross-Section along A-B showing Aquifer thickness.

4.3. Aquifer Characteristics and Hydraulic Properties

From a simple hydraulic conductivity test carried out in the field, a calculated average hydraulic conductivity (K) value of 2.6195 x 10^{-3} was used to determine the transmissivities of all the sounding locations (Table 1). Transmissivity values range from 2.34 x 10^{-2} m^2/day to 7.02 x 10^{-2} m^2/day with an average of 4.31 x 10^{-2} m^2/day. According to Todd (1980), aquifers, with hydraulic conductivity (K) range of 0.05-10^{-3} m/day, are classified as moderately good to poor aquifers. Thus, Ehandiagu is characterized by a moderately good to poor aquifer system that is regionally discontinuous, shallow and thin.

Table 1: Calculated aquifer parameters in the study area.

VES No.	Location	Depth to water (m)	Aquifer thickness (m)	Apparent Resistivity (Ωm)	Transverse resistance (Ωm^2)	Hydraulic Conductivity (m/day)	Transmissivity T=KH (m^2/day)
1	Okpulo	20.7	10.59	122.6	1298.334	-	2.77 x 10^{-2}
2	Amundiagu	16.2	26.79	25.26	676.72	2.4133 x 10^{-3}	7.02 x 10^{-2}
3	Umuarima	6.82	8.95	127.3	1139.34	2.8056 x 10^{-3}	2.34 x 10^{-2}
4	Obinagu	18.59	19.52	22.36	436.47		5.11 x 10^{-2}
					Average	2.6195 x 10^{-3}	4.31 x 10^{-2}

Hydrogeochemical Analysis Results and Interpretation

The result of hydrogeochemical analysis is presented in Table 2.

Charts and graphs were used to present the hydrogeochemical results for easy assessment of water compositions.

Stiff diagrams

Stiff patterns can be a relatively distinctive method of showing water composition differences and similarities (Hem, 1985). The size of the pattern is approximately equal to the total ionic content (Hounslow, 1995). The sizes of the plots in Fig. 6 show that TDS (total dissolved solids) values do not differ significantly for all the samples, except for sample No. 8. The shapes of the stiff diagrams are quite similar, suggesting that the water samples are of the same source, with Na+ and HCO3- as the predominant cation and anion, respectively. A little variation in the shape the patterns can be attributed to fluctuations in the relative concentrations of Ca2+ and Mg2+ in the samples.

Piper diagram

Piper diagram can be used to determine water type, hydrochemical facies and ion exchange (Freeze and Cherry, 1979; Hounslow, 1995). The diamond part of the Piper diagram may be used to characterize waters of different types (Hounslow, 1995). Water plotted at the lower corner of the diamond is primarily composed of alkali carbonates (Na++k+ & HCO3-+ CO32-); this is typical of figure 7. Based on this, the groundwater in Ehandiagu area can be classified as Sodium-Potassium-Bicarbonate type.

Hydrochemical facies are distinct zones that have cation and anion concentrations describable within defined concentration categories (Freeze and Cherry, 1979). The designation of hydrochemical facies is based on the manner suggested by Back (1966) and Back and Hanshaw (1965), in which facies are designated according to the domain in which they occur on the segments of a piper diagram. Thus, the groundwater in Ehandiagu belongs to Sodium-Potassium facies and Bicarbonate facies.

Ehandiagu is underlain by shales, which are made up clay minerals. Clay minerals can have high cation-exchange capacities and may exert a considerable influence on the proportionate concentrations of the different cations in the water associated with them (Hem, 1985). The piper diagram clearly shows that cation exchange softening has increased the sodium (Na) concentration at the expense of calcium (Ca) and magnesium (Mg) concentrations.

Gibbs diagram

Gibbs diagram is a diagram that gives a clear indication of the mechanisms that control groundwater chemistry, considering evaporation, dilution, weathering and precipitation processes. It was developed by Gibbs (1970). In the Gibbs plot (Fig.8), the majority of the points fall within the region of weathering. This clearly shows that weathering is the dominant process that controls the groundwater chemistry. This indicates that the water has possible strong interaction with the geologic material underlying the area (Olayinka and Olayiwola, 2001; Tijani, 2003; Wang *et al*., 2004; Rao, 2006), possibly facilitated by its acidic condition. Weathering gives rise to different products, such as hydrolysates. Hydrolysates (e.g. shale) are secondary products of the chemical breakdown of aluminosilicates, such as feldspar, and they are made up of clay minerals (Hounslow, 1995). According to Todd (1980), clay minerals are one of the major natural sources of cations, such as Na, K, Mg, Ca, Fe; these cations are in significant quantities in the water chemistry data of Ehandiagu.

Table 2: Hydrogeochemical data of sampled wells in the study area.

SAMPLE ID	PH	Temperature Degree Celsius	EC (μ/cm)	Hardness (CaCO3)	CONCENTRATION (mg/l)													
					TDS	Na^+	K^+	Mg^{2+}	Mn^{2+}	Fe^{2+}	Pb^{2+}	Ca^{2+}	Cu^{2+}	Ti	NO^{2-}	$SO4^{2-}$	Cl^-	HCO_3^-
1	6.6	27.2	64	6.26	81	36.9	36.93	0.26	1.88	0.05	ND	2.08	1.9	0.07	3.25	0.7	0.06	56.42
2	4.7	27.1	99	5.6	67	17.65	96.43	0.7	0.95	4.28	0.05	1.09	0.93	0.02	1.45	1.91	0.07	98.75
3	3.4	27.5	35	56.71	13	34.98	7.42	0.31	2.02	0.16	0.02	22.2	0.06	0.04	7.2	1.4	0.06	212
4	3.6	27	26	7.16	22	46.29	22.22	0.46	0.06	0.27	ND	2.11	0.09	0.06	3.6	1.85	0.07	85.18
5	3.7	27.6	30	4.24	15	39.41	28.9	0.4	1.68	0.19	0.13	1.04	0.13	0.09	8	0.4	0.07	176
6	3.8	28	154	11.24	95	57.52	40.31	2.73	0.98	0.27	0.1	ND	0.18	0.1	5.55	0.45	0.13	143.4
7	4.3	27	113	9.1	68	17.12	32.11	1.07	1.65	0.31	0.03	1.88	0.45	0.07	6.1	2.1	0.13	152
8	3.5	27.5	55	8.94	27	8.56	19.45	0.34	1.5	0.17	ND	3.02	0.78	0.04	4.2	0.7	0.05	88.1
9	3.6	27.4	100	11.56	59	49	40	0.26	2.23	0.06	ND	4.2	0.57	0.02	4.3	1.4	0.09	112.6
10	3.4	27.4	138	9.77	88	45.21	22.87	0.76	0.08	0.23	0.11	2.66	0.08	ND	14.7	1.9	0.05	105.5
11	4.5	28.2	654	4.2	1342	21.22	19.45	1.02	0.39	0.52	0.19	ND	0.11	ND	8.4	0.65	0.07	74.79
12	4.4	27.4	60	11.25	35	15.52	19.05	0.72	1.31	0.24	0.04	3.32	0.98	0.01	6.6	0.3	0.06	142.65

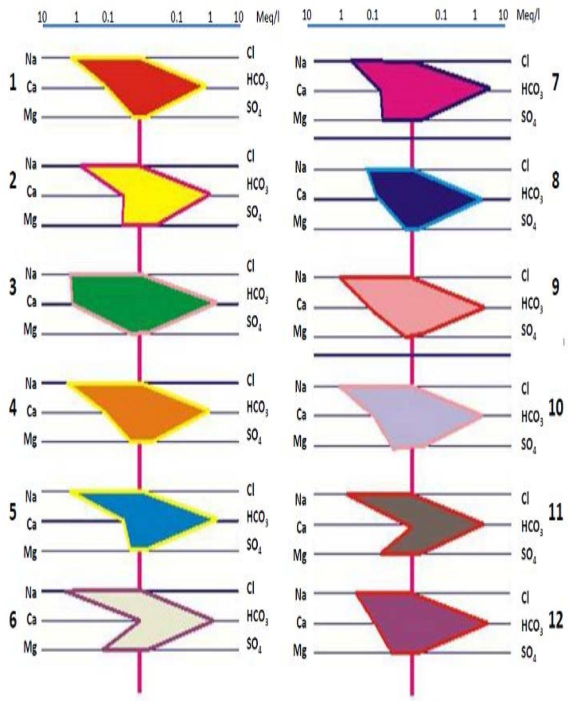


Figure 6: Stiff diagram of water samples.

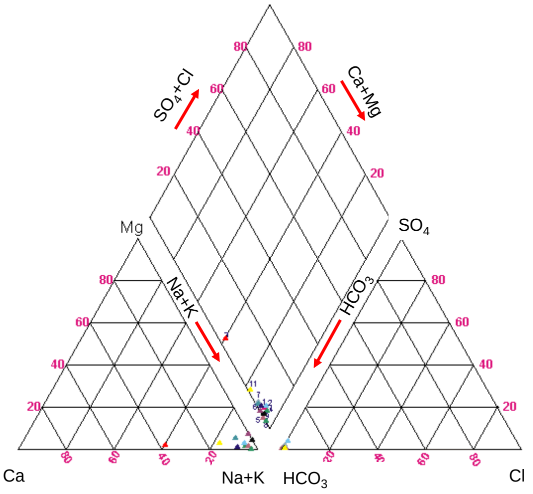


Figure 7: Piper diagram of water samples.

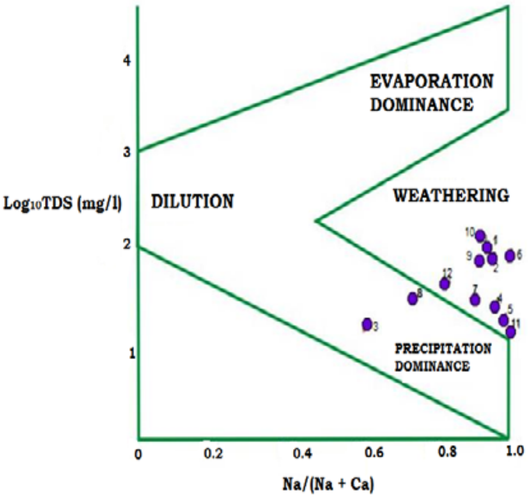


Figure 8: Gibbs diagram of water samples.

Assessment of Groundwater Quality

Hydrochemical results show that the groundwater has pH range of 4-6.5, and thus is moderately acidic. The hardness is <60mg/l, and thus is classified as soft water. Fetter (1990) classified water with TDS of < 1,000mg/l as fresh. The groundwater in Ehandiagu has a TDS range of 13-95mg/l and, thus, can be regarded as fresh water. The concentration of the ionic components was compared with the Nigerian standard for drinking water quality (NSDWQ, 2007) and WHO (2005) standards for drinking water quality. All ionic components in the water samples are within the acceptable limits, with the exception of some heavy/trace metals such as Mn2+ (1.22mg/l), Fe2+ (0.56mg/l), and Pb2+ (0.06mg/l), whose average concentrations are above the acceptable limits for potability. Although heavy metals result from human activities (industrial and agricultural) and radioactivity (Matthes and Miller, 1994), the elevated concentrations of iron, manganese and lead cannot be attributed to any of these sources because Ehandiagu is neither an industrial nor a heavy agricultural area. These metals may have originated from natural process(s). Their high concentrations may be attributed to geochemical redox processes in the area. Hounslow (1995) defined geochemical redox zones as zones, which are of great importance in determining the rate of organic biodegradation that may affect the mobility of trace metals in a predictable way. Hounslow came up with a classification for geochemical redox zones and one of the zones, designated as mildly reducing anaerobic waters, is characterized by the presence of soluble Fe2+, Mn2+, NO3- and absence of H2S. Oxygen-consuming processes such as microbial degradation of organic matter, may give rise to oxygen free reduction zones characterized by the presence of ferrous ion, manganese, ammonia, nitrite, and sulphide; by the deficiency of nitrate; and by a diminished content or absence of sulphate and sometimes chloride also. In such reduction zones, heavy metals are precipitated as sulphides when sulphide ions are present (Schwille, 1976). This explains why Mn2+, Fe2+ and Pb2+ concentrations are high, and suggests that sulphate reduction may have taken place.

Direct measurements of redox potential were not made during the study, but the relative redox status of the groundwater can be inferred from the abundance of redox sensitive solutes such as Fe and Mn. Elevated concentrations of these metals in water are commonly used as indicators of reduced conditions (Neil *et al*., 1991). Moreover, sulphate reduction caused by anaerobic bacteria may have contributed to the elevation of HCO3-, partly at the expense of SO42-, whose concentration in the groundwater is minute relative to HCO3-. This also indicates a reducing environment for the groundwater in Ehandiagu.

5. Summary and Conclusions

The result of the VES survey shows that the study area has shallow groundwater, which explains the abundance of hand-dug wells. The absence of boreholes in Ehandiagu was attributed to the low permeability of the fractured shale aquifer material. The depth to water ranges from 6.82m at Umuarima to 20.7m at Okpulo. Aquifer thicknesses range between 8.95m at Umuarima and 26.79 m at Amundiagu. The hydraulic conductivity of 2.62 x 10-3m/day and transmissivity (T) value of 4.31 x 10-2 m2/day, was used to classify the aquifer as moderately good to poor aquifer. The improved hydraulic conductivity value is closely linked to the existence of fractures, which improved the connectivity between the pores. The depth to water, measured directly from hand-dug wells, varies between 6.20m and 15.18m.

Hydrochemical analysis of water samples from hand-dug wells reveals that all ionic components are within the acceptable limits for potability, with the exception of heavy metals like Fe, Mn, and Pb. Gibbs plot shows that weathering is the major factor that controls the groundwater chemistry. The piper diagram shows that the water type is Sodium-Potassium-Bicarbonate water. The geochemical redox zone that characterize Ehandiagu area, as inferred from the high concentration of heavy metals (Fe, Mn, and Pb), implies that groundwater in the study area occurs in a reducing environment. The very low concentration of sulphate and high bicarbonate suggests that sulphate reduction may have increased bicarbonate at the expense of sulphate. This also indicates that the study area is a reducing environment.

A natural process causes the elevated concentration of Fe, Mn, and Pb. The high concentrations of heavy metals in the groundwater, in addition to the acidity, as indicated by low water pH, portend danger to human health if people continue to drink the water. It is therefore suggested that the groundwater from hand-dug wells be treated before use. Since hand-dug, wells prove to be the major source of potable water in Ehandiagu, the technology of digging and completing the wells should be improved and probably modernized.

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