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Application of Second-Order Geo-electric parameters in the Determination of Groundwater vulnerability in Sedimentary Terrain, Iyowa, Edo State Southwestern. Nigeria

Ojeaga, Kenneth[1]. Totor, Gabriel[1]

[1] Department of Science Laboratory Technology, University of Benin, PMB 1154 Ugbowo Benin City, Nigeria
Corresponding author's email: kenneth.ojeaga@uniben.edu

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Abstract

The application of vertical electric sounding (VES) techniques to evaluate groundwater vulnerability and groundwater potential was carried out in Iyowa, Benin city, Southern part of Nigeria. Five (5) VES points randomly selected in Schlumberger configuration was deployed for the VES with a view to investigate, access and classify areas most vulnerable to contamination. The Petrozenith Terrameter was used with maximum spread of 800m (AB/2=400). The INTERPEX 1D software was used for the data iterations. The study revealed the presence of four curve types which includes: HAK (40%), HAQ (20%), AKQ (20%), and AAK (20%) respectively. The second-order geo-electric parameters interpreted were longitudinal conductance (S), transverse resistance (Tr), longitudinal resistivity (ρ_L), transverse resistivity (ρ_t) and formation anisotropy (λ). The survey was conducted using vertical electrical sounding (VES), employing Schlumberger electrode configuration. The study revealed the presence of four curve types. Namely: HAK (40%), HAQ (20%), AKQ (20%), and AAK (20%) respectively. The second-order geo-electric parameters interpreted were longitudinal conductance (S), transverse resistance (Tr), longitudinal resistivity (ρ_L), transverse resistivity (ρ_t) and formation anisotropy (λ). The values of longitudinal conductance in the study area ranged from 0.13 Ωm to 0.52 Ωm with an average of 0.24 Ωm. thus, the average aquifer protection capacity rating was considered moderate. Tr values ranged from 304038.7 Ωm^2 to 1058541.0 Ωm^2 with an average of 1019307.76 Ωm^2, which indicated that the study area has very high transmissive capacity of regional importance. Longitudinal resistivity of the study area ranged from 373.369Ω-m to 1276.027Ω-m, with an average of 2004.681Ω-m. Transverse resistivity values in the study area ranged from 3755.42 to 1743.662 with an average of 5413.11. The high transverse resistivity values across all VES points imply the existence of impermeable layers like bedrock or clay in the study area. Anisotropy values ranged from 2.627 to 1.244, with an average of 1.83. The anisotropic value revealed that the study area's aquifer generally has good porosity and permeability.

1.0. Introduction

Groundwater is the largest and most easily available freshwater resource on Earth. It is essential to maintaining ecosystem services, economic growth, and human health. Clean, drinkable water is crucial for maintaining good health and attaining the Sustainable Development Goals (SDGs) [1;2]. This is especially true in light of the fact that the amount of clean water that society require for cultivation, municipal usage, and drinking is growing exponentially. [3;4]. However, a quite a number of anthropogenic activities such as oil spills, open dumps, mine tailings, corrosion of underground tanks and other unsustainable groundwater practices has led to deterioration of groundwater quality. Water quality may degrade due to the leaching of geogenic contaminants as a result of weathering during mining operations or as water moves through the hydrologic cycle organic and inorganic contaminants might be transferred from the soil to the infiltrating groundwater. The geology of the parent rocks plays crucial role in the types of aquifer system developed in an area. Hence aquifer vulnerability is influenced by lithologic forms that overlies beneath it ([5;2]. [1;7]. Hence, aquifer susceptibilities will vary in locations with different geology. Several studies on aquifer vulnerability have revealed that the protection of aquifer is hinged on the permeability of the overlying layer to the transportation of contaminants into the underlying aquifer units. Although groundwater potential and aquifer susceptibilities studies have been conducted in Basement Complexes and Sedimentary Basins [8;9] and [10] utilizing geophysical techniques. The appraisal of groundwater potential and the vulnerability of aquifers to contaminants in the Benin Formation has not yet taken centre stage. Hence this research is aimed at delineating the protective capacity of the aquiferous zones and groundwater potentials in Iyowa, community, Edo State utilizing the Dar- Zarrouck parameters derived from vertical electrical sounding techniques. Dar-Zarrouk characteristics can also be used to determine an aquifer’s susceptibility the subsurface and surface contamination [11]. Dar-Zarrouk parameters were first introduced [12], the longitudinal conductance and transverse resistance of the layers are measured using the resistivities and thicknesses of the individual layers. The second-order parameters were Transverse unit Resistance (Ωm^2), Longitudinal Unit Conductance ($\Omega{-1}$), and coefficient of anisotropy (λ).

1.1. Geology of the study area

The study area is underlain by the Benin formation which is a part of the Niger Delta basin. It is a sedimentary terrain composed of reddish to reddish-brown lateritic hard clay, which forms the top soil [13]. Also present are loose white sands, silts, clays and gravel. These formations were deposited in marine, deltaic, and river settings [14]. The study area is located in Iguekhinkhwin Iyowa, Benin city, and lies between Latitude 6°29.141′N to 6°29.169′N and Longitude 5°36.184′E to 5°36.879′E with an elevation of 165m.

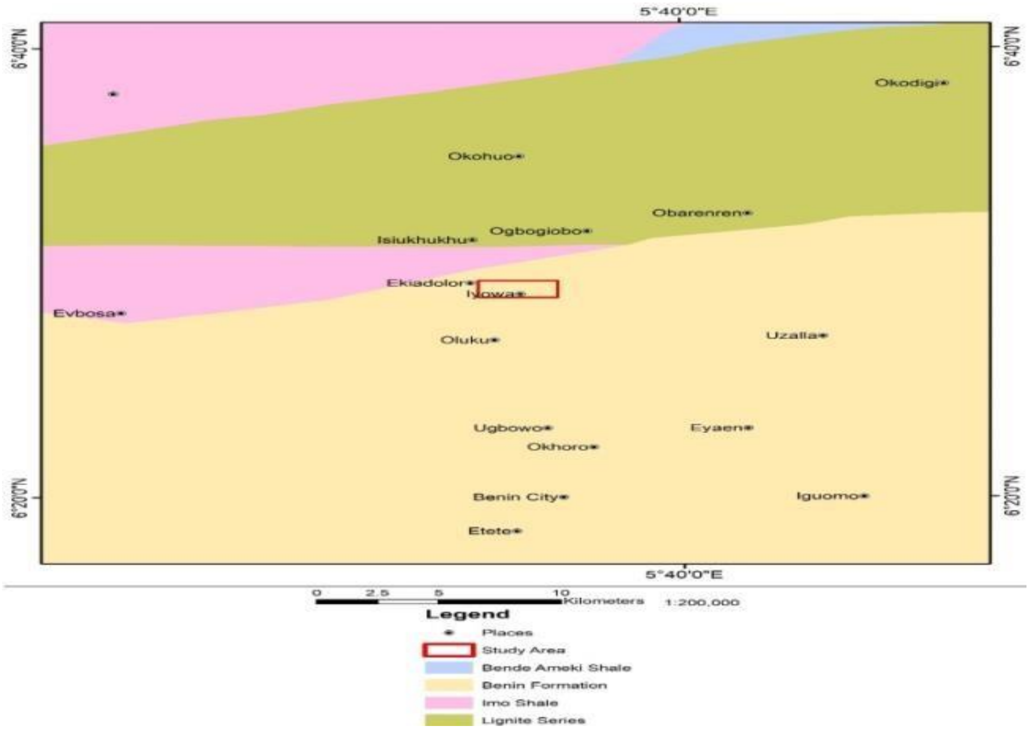

Figure 1: Geologic map of the study area

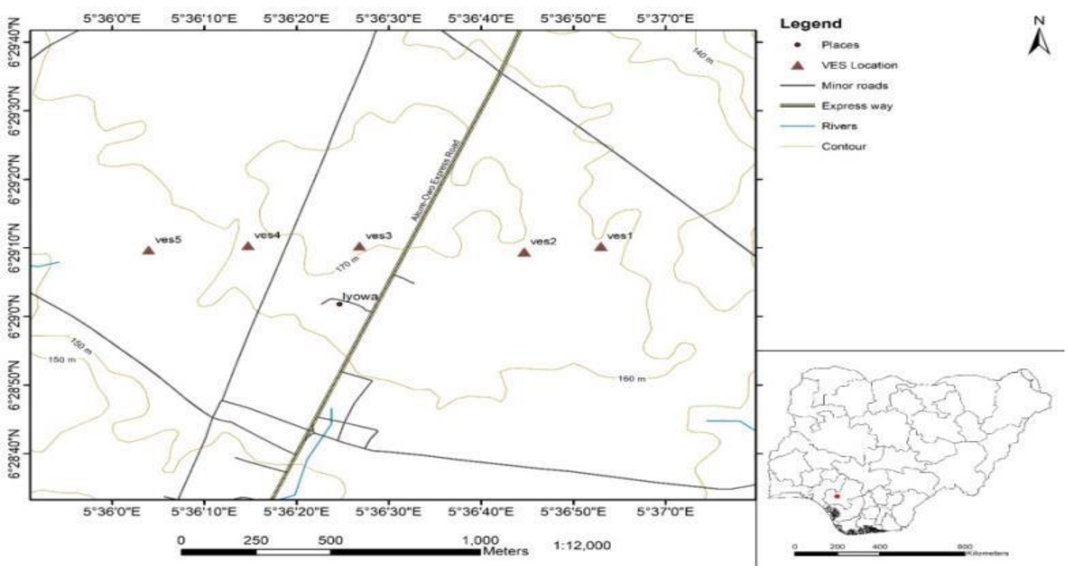

Figure 2: Sampling location map showing VES points

2.0. Methodology

The Vertical Electrical Sounding (VES) was done using the Schlumberger electrode array configuration. The Schlumberger automatic analysis method of interpretation was adopted. The VES data were obtained from the proposed sites at Iyowa, Benin City, Edo State. The total spread length for the VES is 800m. The VES station was located along the tar road borehole point in premises, the VES covered a spread of 400m at left side and 400m on the right side of the spread with AB (total spread) is 800m and AB/2 is 400m. The investigation involved the electrical resistivity method which employs an artificial source of current which is introduced into the ground through point electrodes known as current referred to as potential electrodes. The apparent resistivity of the ground is the product of the measured resistance and the geometric factor of the electrode array employed. The theoretical background of the method is based on the fact that the earth conducts electricity through ionic/electrolytic means, a phenomenon associated with the presence of pore fluids within the subsurface. The Ohm's law was therefore handy as the theoretical basis of the electrical resistivity method based on the aforementioned facts [8].

- Ohm's law: $R=\Delta V/I$
- Where R = Resistance, ΔV = potential and I= current.

Field data was first subjected to manual processing and secondly to computer processing and analysis using INTERPEX 1-D. The field data inputted into the software (INTERPEX 1-D) for generation of sounding curves were resistance and apparent resistivity. The thickness and apparent resistivity derived from interpretation of sounding curves through partial curve matching techniques was used to calculate the what is referred as Dar Zarrouck parameters. These parameters are important in understanding the spatial distribution of aquifer hydraulic parameters with a view to ascertain susceptibility of aquifer materials to contamination

Dar Zarrouk Parameters were derived via:

Longitudinal unit conductance (S), transverse unit resistance (Tr), longitudinal resistivity (ρL), transverse resistivity (ρt) and formation anisotropy were calculated using equations (1–5).

Longitudinal (S) and transverse (T) parameters were derived via:

$$S = \frac{h}{p} \qquad (1)$$

$$T = hp \qquad (2)$$

Where h is the aquifer thickness and p is the aquifer resistivity.

Longitudinal unit conductance (S) was calculated using Eq. (1).

The longitudinal conductance is equal to the number of layers (n)

$$S = \sum_{i=1}^{n} \frac{hi}{\rho i} = \frac{hi}{\rho i} + \frac{h_2}{\rho_2} \ldots \ldots .. + \frac{h_n}{\rho_n}, \quad (3)$$

As proposed by [15]and [16]. Transverse unit resistance (Tr) was calculated using;

$$Tr = \sum_{i=1}^{n} hi\rho i = hipi + h_2 \rho_2 + \ldots \ldots . h_n \rho_n \quad (4)$$

As proposed by [17] and [18] longitudinal resistance was calculated using Eq. (3)

$$\rho L = \frac{H}{S} = \frac{\sum_{i=1}^{n} h_i}{\sum_{i=1}^{n} \frac{hi}{\rho i}} \quad (5)$$

As proposed by [19] Transverse resistance was determined from Eq. (5)

$$\rho t = \frac{T}{H} = \frac{\sum_{i=1}^{n} h_i \rho i}{\sum_{i=1}^{n} h_I} \quad (6)$$

The coeffcient of anisotropy is a useful parameter of an anisotropic medium which indicates the degree of fracturing. It was determined using Eq. (5)

$$\lambda = \sqrt{\frac{\rho t}{\rho L}} = \frac{\sqrt{ST}}{H} \quad (7)$$

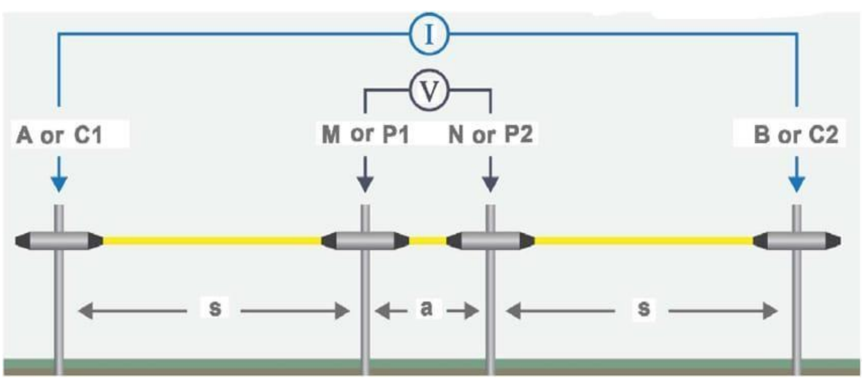

Figure 3: Schlumberger electrode configuration [20]

Table 1: VES data used to create geo-electric layers and curve types in the study area

VES	Latitude	Longitude	Resistivity (Ωm)						layer thickness (m)						curve types	No. of layers
			$\rho 1$	$\rho 2$	$\rho 3$	$\rho 4$	$\rho 5$	$\rho 6$	h1	h2	h3	h4	h5	h6		
VES 1	N6°29'.142''	E5°36.185'	529.62	432.82	819.38	20137	1175.4	56.066	0.60	2.78	11.75	23.55	23.49	∞	HAK	6
VES 2	N6°29'.141''	E5°36.184'	416.26	360.75	8498.7	2435.3	847.91	1076.9	1.83	4.38	21.83	48.51	129.21	∞	HAQ	6
VES 3	N6°29'.171''	E5°36.072'	217.08	398.67	15191	3282.0	516.46	452.03	0.30	4.84	13.08	16.02	24.389	∞	AKQ	6
VES 4	N6°29'.169''	E5°36.879'	301.88	346.63	445.20	1540.9	2603.4	689.51	1.11	1.58	16.81	21.16	63.62	∞	AAK	6
VES 5	N6°29'9.753"	E5°36'3.96"	282.59	171.91	1564.4	14004	1658.9	637.98	0.46	2.81	5.80	24.26	39.93	∞	HAK	6

Table 2: Second- order geoelectric parameters in the study area

VES NO	Longitudinal conductance	Transverse resistance	Longitudinal resistivity	Transverse resistivity	Formation Anisotropy
1	0.518	1058541.0	544.23	3755.422	2.627
2	0.148	427512.8	2176.027	2263.529	1.332
3	0.181	304038.7	373.369	2496.418	1.925
4	0.213	418783.1	1126.488	1743.622	1.244
5	0.131	339393.8	791.589	3273.79	2.034
Mean	0.24	1019307.76	2004.68	5413.11	1.83

Table 3: Rating of protective Capacity of Aquifers [21]

Ranking	Longitudinal Conductance (**S**, Ω^{-1})	Protective Capacity Rating
1	>10	Excellence
2	5-10	Very good
3	0.7-4.9	Good
4	0.2-0.69	Moderate
5	0.1-0.19	Weak
6	0.1	Poor
7	<0.1	Very poor

Table 4: Transmissivity rating [21]

Ranking	Transmissivity (m2/day)	Classification of well
1	>500	High potential
2	50–500	Moderate potential
3	5–50	Low potential
4	0.5–5	Very low potential
5	<0.5	Negligible potential

3.0. Results and Discussion

Dar Zarrouck Parameters

The results of vertical electric sounding (VES) showing layer resistivity, thickness, curve types and number of layers of each interpreted geoelectric section and the Dar Zarrouck parameters obtained from the study area is presented in Tables 1 and 2.

3.1. Aquifer Protective Capacity (Longitudinal Conductance (S))

The vulnerability of aquifer system to contamination is a function of the longitudinal conductance and it is defined as the capacity of overburden materials to allow the leaching of contaminants. The values of longitudinal conductance in the study area range from 0.13 Ωm to 0.52Ωm with an average of 0.24Ωm. The highest value was recorded in VES 1(0.52 Ωm) while the lowest was recorded in VES 5(0.13Ωm). According to aquifer protection capacity rating defined by [21] and [22], areas classified poor and weak are vulnerable or susceptible to contamination. Areas classified moderate and good are less susceptible for contamination. In Table 2 it was observed that the aquifer protection capacity of VES 1 and VES 4 are moderate, while the aquifer protective capacity of VES 2, VES 3 and VES 5 are weak. Suggesting that 40% of the sounding places (VES points) may have a moderate aquiferous protective capability, whereas the remaining 60% are predicted to have a weak protective capacity. However, the average longitudinal conductance in the study area is 0.24Ωm which indicating moderate aquifer protective capacity. It implies therefore that the aquifer units in the study area might be less vulnerable to the leaching of contaminants from decomposing refuse dumps and possible leaks of underground storage tanks. This in turn could be attributed to the presence of clay intercalations in the area that could retard or act as a natural filter to percolating fluids [30].

3.2. Transverse Resistance (Tr)

Transverse resistance is utilised to identify the most productive region of groundwater potential for hydrogeological research **[23; 9]**. Larger Tr values typically correspond to higher levels of aquifer transmissivity **[10]**. In this study, transverse resistance (Tr) of each VES points as shown in Table 2 indicates that (Tr) values for VES 1, 2, 3, 4, and 5 were 1058541.0 Ωm^2, 427512.8 Ωm^2, 304038.7 Ωm^2, 418783.1 Ωm^2 and 339393.8 Ωm^2 respectively with an average of 1019307.76 Ωm^2. Therefore, implication of values of transverse resistance obtained in the study area is that the thickness of the aquiferous units is high or adequate for favourable aquifer conditions. **According to [29] transverse resistance below 200,000m^2 may indicates absence of aquifer attributed to inadequate thickness of the aquiferous unit.**

3.3. Longitudinal Resistivity (ρ_L)

Longitudinal resistance serves as a useful tool for determining the potential rate of penetration of aquiferous units which also reveals the type of lithology [24]. Longitudinal resistivity of the study area varies from 373.369Ω-m at VES 3 to 1276.027Ω-m at VES 2, with an average of 2004.681Ω-m. The highest ρ_L value was recorded in VES 2 and the lowest was recorded in VES 3. VES 1, VES 4 and VES 5 have resistivity values of 544.23Ω-m, 1126.488Ω-m and 791.589Ω-m respectively. According to the classification by [25] the lithologic units in VES 1, VES 2, VES 4 and VES 5 were inferred as laterite with susceptibility index of 1, which indicates impermeability and therefore not prone to infiltration of contaminants. VES 3 inferred as lateritic sand with susceptibility of 2 was also considered mildly permeable and resistant to contamination.

3.4. Transverse Resistivity (ρ_t)

The highest ρt value in the study area was recorded in VES 1 at 3755.42 and the lowest was recorded in VES 4 at 1743.662 and an average of 5413.11. According to [26], high transverse resistivity usually indicates places with less conductive subsurface materials, which can lead to slower pollutant transmission and less groundwater movement. Thus, the high transverse resistivity values across all VES points may imply the existence of impermeable layers, like bedrock or clay in the study area, which could essentially serve as barriers to the flow of contaminants and lessen the vulnerability of groundwater in those areas.

3.5. Formation Anisotropy (λ)

According to [27] and [28], high anisotropy values are an indication of low porosity and permeability, which implies low hydrogeologic viability. At a specific depth, areas with low anisotropy values indicate strong porosity and permeability with some degree of fractures. Generally, electrical anisotropy is 1 and does not exceed 2 in most geological conditions. Compact/ hard rocks at shallow depth increases the electrical anisotropy. In this study the average anisotropic value is 1.83. VES 1 had the highest anisotropic value of 2.62. VES 4 had the lowest anisotropic value of 1.24. It was observed that since VES 1and 5 had values greater than 2, it implies that they are not hydrogeologically viable while VES 2, VES 3 and VES 4 all had anisotropic values less than 2 indicating that they had promising hydrogeologic potentials. This variation in anisotropy could be linked to fracture systems that may have extended in different directions, thus resulting in higher porosity and permeability of the rock. Therefore, it could be inferred that the study area's aquifer generally has good porosity and permeability.

4.0. Conclusion

Five (5) VES in Schlumberger electrode configuration were performed in order to determine resistivity, thickness and depth of subsurface lithology and delineate aquifer vulnerability and groundwater potentials. The lithologies of the study area are medium sand, fine to medium sand, fine sand, medium to coarse sand, sandstone and lateritic clay. The curve types are HAK, HAQ, AAK, AKQ and HAK were identified. The aquifer systems in the study area could therefore be delineated as medium to coarse grained sand. Transmissivity results indicate that the groundwater potential (water bearing capacity) of the area was high. Aquifer protection capacity of the subsurface layers was of moderate aquifer protective capacity. The result of anisotropy indicates that the area is of good porosity and permeability. Hence, capable of resisting infiltration that may contain biological and chemical contamination. In order to sustain and ensure clean portable groundwater in the area residents and prospective developers must continue to adhere strictly to environmental best practices in the siting of waste diposals/landfill systems and in groundwater development

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