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Investigation and Evaluation of Aquiferous Zones Within Orlu and Its Environs, Using a Geo-Electrical and Physiochemical Approach

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Abstract: This study investigated the suitability of drinking water in Orlu, Nigeria, facing challenges due to limited surface water availability and environmental deterioration. To solve the problem of the availability of potable water, electrical resistivity surveys using Schlumberger array were conducted to identify potential groundwater resources. Twelve locations were assessed, revealing resistivity values indicative of potential aquifers. Following the geophysical survey, the physicochemical properties of water samples collected from various locations were analyzed. Parameters including pH, dissolved oxygen (DO), total dissolved solids (TDS), and minerals were evaluated against WHO and Nigerian drinking water standards. The analysis indicated generally good water quality across the sampling sites. pH levels were within the recommended range, and DO concentrations met the minimum requirements. Similarly, TDS and biochemical oxygen demand values suggested low levels of organic matter and dissolved solids. Mineral content also remained below WHO-permissible limits. A Water Quality Index further confirmed that the water quality within the study area can be graded from good to excellent in quality. These findings suggest that the groundwater resources identified in the study hold promise for providing safe drinking water in Orlu and its environs.

Keywords: resistivity, aquifer, terrameter, physiochemical, pH

1. Introduction

The study focuses on the analysis of vertical electrical sounding (VES) data, the interpretation of geo-electric sections to determine the resistivity characteristics of an aquifer, and as well as physiochemical analysis to determine the quality of groundwater within the study environment. This research utilizes the ABEM Terrameter instrument for data collection and analysis.

Water is a crucial component for the sustainability and survival of both flora and fauna in the natural world. The escalating pollution and contamination of surface water due to human activities, particularly in Nigeria, a developing nation, has emerged as a significant cause for alarm. The deteriorating quality of surface water has rendered it highly unsuitable for consumption. This study focuses on the examination and manipulation of aquiferous zones or layers present in the subsurface, with the aim of extracting drinkable water from the underground water reservoir.

The difficulties related to the exploration and exploitation of subterranean water for the purpose of supporting human activities that promote well-being are becoming significant. The obstacles faced in contemporary Nigeria include a dearth of modern infrastructure, exorbitant costs associated with procuring necessary equipment, inadequately trained personnel, and government policies that are not conducive to progress. The significance of lithologies and their associated resistivity values in the assessment of productive and sustainable aquifers and their impact on the exploration and use of high-quality groundwater is of paramount importance and therefore warrants more investigation.

The objective of this study is to utilize VES to detect subsurface aquiferous layers and as well use physiochemical analysis to ascertain the quality of groundwater. The focus is on determining viable aquifers based on their lithologies, associated resistivity values, and corresponding physiochemical water parameters.

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Based on data provided by the United Nations, it is evident that a significant proportion, exceeding 50%, of the global population relies on groundwater as their primary water source. Furthermore, approximately 43% of individuals utilize groundwater specifically for irrigation purposes [1]. The lack of access to safe drinking water by the majority of inhabitants in many developing nations, particularly within the specific region under investigation, has resulted in individuals resorting to the installation of private water boreholes in order to fulfill their household water requirements.

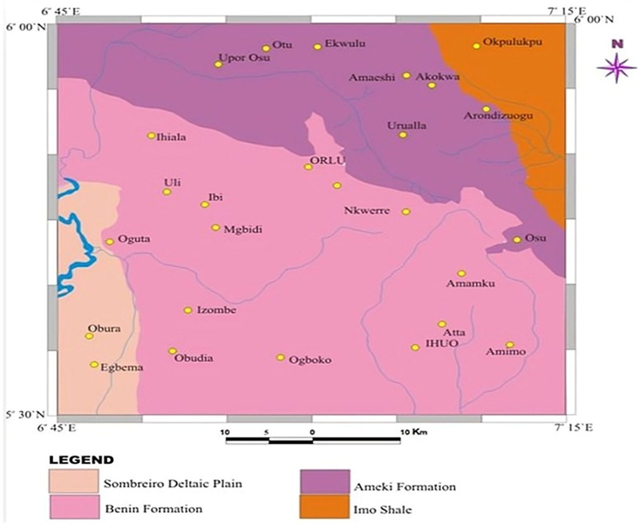
A noninvasive geophysical technique known as VES was used to mitigate the high occurrence of borehole failures in Orlu and its surrounding areas, which resulted in the waste of human resources and financial investments. The goal of this method was to look into the resistivity values of different layers and how they relate to their lithological properties. The goal was to find the best resistivity values and layers for creating an aquifer in the chosen research area. We employed conductive electrodes to introduce electric current into the subsoil. We documented the obtained measurements of potential variations on the ground. The observed potential differences were transformed into apparent resistivity values and subsequently analyzed them using geophysical software to gain insights into the depths and thicknesses of the underlying layers. The present investigation concerns the geographical positioning and geological characteristics of the study region.

1.1. Location and geology of the study area

The research area, Orlu and its surrounding regions, is located within the Imo West Geopolitical Zone of Imo State, which is situated in southeastern Nigeria. The areas under investigation encompass Umueshi, Isiekenesi, Ihioma, and Ogberuru, which are located in the Ideato North and Ideato South regions, as well as the Orlu Local Government Area of Imo State. The geographical coordinates for Umueshi are approximately 504948.50 N latitude and 7° 622.79 E longitude. Isiekenesi is situated at approximately 5047'29.99"N latitude and 708'48.52"E longitude. Ihioma is positioned at approximately 5048' 0" N latitude and 700' 0" E longitude. Lastly, Ogberuru is located at approximately 5049'60.00 N latitude and 701'60.00 E longitude.

Based on the information presented in Figure 1, the primary geological formations observed in the research region consist of the Benin and Ameki Formations, alongside the presence of the Imo Shale and Sombreiro Deltaic planes. The Benin Formation represents the most recent geologic formation observed within the designated study region. Reyment (1965) [2] reestablished the designation "Benin Formation" for the geological formation previously referred to as the "Coastal Plain Sands" formation [3]. The geological composition of the Benin Formation predominantly consists of yellow and white sands, sandstone, and gravel, interspersed with occasional clay lenses. The Benin Formation is comprised of unconsolidated sand particles that vary in size, ranging from fine to medium and coarse. The Benin Formation is characterized by the presence of continental sand and gravels, along with intercalations of clay and shale, which contain fresh water. In comparison to adjacent formations both above and below, it is seen that this particular sand deposit, which contains fresh water, exhibits a significantly elevated resistivity value [4]. The predominant lithological component in the research area is a sandy unit, constituting roughly 95% of the rock composition [4]. There are two primary lithological divisions that have been identified in this study. The lower portion consists of sandstones ranging from fine to coarse, with occasional layers of calcareous shale and thin shelly limestone. Additionally, limestone modules are present in this lower

Figure 1
Geology map of the study area



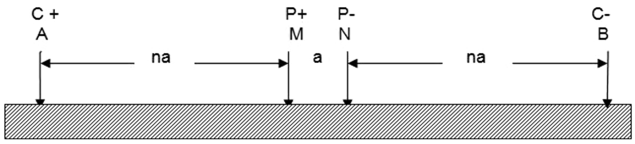
division. On the other hand, the upper portion is characterized by coarse cross-bedded sandstones interspersed with bands of fine gray-green sandstone and sandy clay [5].

2. Material and Method of Study

This research was conducted through a three-step process that involved desk studies, fieldwork, and laboratory analysis. A preliminary literature review was undertaken prior to commencing fieldwork. During the execution of the fieldwork, a preliminary survey of the geographical region was carried out, whereby various characteristics were identified and documented. A total of twelve VESs were conducted at different places within the designated research region, employing the Schlumberger array as illustrated in Figure 2. The site was assigned a numerical identifier of 2, and its precise geographic coordinates were determined using a GPS. Also, water samples were collected from twelve different locations within the study area aseptically using pre-cleaned 2-liter plastic polyethylene bottles coded properly. The collected samples were transported to the laboratory for analysis. All sampling protocols, such as the preservation and transportation of water samples, were consistent with the standards prescribed by the American Public Health Association [6].

The Schlumberger array was selected for implementation in this study due to its exceptional resolution capabilities and significant deep penetration capabilities. The present investigation implemented a progressive variation in electrode spacing to acquire a sequence of potential differences, while maintaining a fixed reference point. For the purpose of inquiry, we observed the induced current reaching deeper layers as the space between electrodes grew. Throughout this procedure, measurements of

Figure 2
Schlumberger array



apparent resistivity values for various layers, as well as the corresponding layer thicknesses and depths, were acquired.

3. Brief Theoretical Background of VES

The VES method uses collinear arrays to make a flat model of the vertical apparent resistivity of the ground at a certain observation point as a function of depth [7]. This methodology involves obtaining a sequence of potential differences by incrementally increasing the distance between electrodes while keeping a constant central reference point. The current induced by larger electrode spacing traverses successively deeper layers [8]. The observed potential difference values exhibit a direct relationship with variations occurring in the underlying subsurface at greater depths. To figure out what the apparent resistivity values mean that come from measuring potential differences, you may need to look at a number of things, such as the thickness of the overburden, the depth of the water table, and the depths and thicknesses of subsurface layers [9]. Figure 2 depicts the electrode arrangement in a linear configuration. We position the electrodes currently in use externally and the electrodes responsible for measuring potential internally. The electrodes denoted as M and N possess a maximum separation that does not exceed one-fifth of the distance between the current electrodes. Generally, we denote the present electrodes as A and B.

Equation (1) delineates the correlation between perceived resistivity and the distance between electrodes. We denote the distance between the current electrodes as AB and the distance between the potential electrodes as MN. We denote the resistance value from the MiniRes device as R and the apparent resistivity as Ra.

The Equation (1) can be expressed as

$$\mathrm{Ra} = \frac{\pi \mathrm{R}(\mathrm{AB})(\mathrm{AB})}{4(\mathrm{MN})} \tag{1}$$

4. Results

4.1. Geo-electrical analysis

This section presents the results of the study. The Njaba River provided quantitative data indicating several depth intervals from the surface. The ranges can be categorized as follows: 0–1.6 meters, 1.6–8.7 meters, 8.7–33.6 meters, 33.6–65 meters, and so on. The depths of the layers are provided as 1.6 m, 7.1 m, 24.9 m, 31.4 m, and so on, respectively. These depths correspond to resistivity values of 186 ohm-m, 10,000 ohm-m, 1,090 ohm-m, 9,500 ohm-m, and 44,800 ohm-m, respectively. It is worth noting that these layers are situated at an elevation of 115 m.

The following values are associated with the site located along the Orlu/Ihiala route: The results presented have numerical values that correspond to various intervals of depth, namely 0–1.1 m, 1.1–14.6 m, 14.6–33.0 m, 33.0–67.5 m, and 67.5–104 m. The location's layer thicknesses, resistivity values, and elevation are as follows: 1.1 m, 13.5 m, 18.4 m, 34.5 m, and 36.5 m; 383 ohm-m, 940 ohm-m, 1,810 ohm-m, 1,190 ohm-m, and 528 ohm-m, 38.9 ohm-m; and elevation of 102 m.

The initial set of results corresponds to the Okwelle/Urualla route, while the subsequent set belongs to the Afor Ukwu-AAfor Nta road. The Okwelle/Urualla road study resulted in a compilation of depth intervals and their corresponding magnitudes. The observed ranges are as follows: 0 to 4.8 m, 4.8 to 34.5 m, 34.5 to 61.8 m, and so on. The thicknesses of the successive layers, starting from the uppermost layer, are 4.8 m, 29.7 m, and 27.3 m. These layers possess equivalent resistivity values of 650 ohm-m, 5,460 ohm-m, and 2,870 ohm-m, respectively. The Okwelle/Urualla road has an elevation of 152 meters. The depth ranges for the Afor Ukwu-AAfor Nta road are as follows: 0–4.7 m, 4.7–10.6 m, 10.6–36.8 m, 36.8–64.9 m, and 64.9–107 m, respectively. The thicknesses of the layers are as follows: 4.7 m, 5.9 m, 26.2 m, 28.1 m, and 42.1 m. The resistivity values for each layer are as follows: 970 ohm-m, 521 ohm-m, 11,600 ohm-m, 3,710 ohm-m, 7,330 ohm-m, and 25,500 ohm-m, respectively. The region's altitude is 155 meters.

The Okwelle/Urualla 2 outcome consists of a series of depth intervals, as well as their respective thickness measurements. The ranges observed in this study are as follows: 0 – 2.5 m, 2.5 – 24.8 m, 24.8 – 66.7 m, 66.7 – 110 m, and so forth. The thicknesses of the layers, starting with the uppermost layer, are 2.5 meters, 22.3 meters, 41.9 meters, and 43.3 meters. These layers have resistivity values of 643 ohm-m, 11,200 ohm-m, 2,210 ohm-m, 3,700 ohm-m, and 1,100 ohm-m, in that order. The recorded elevation of Okwelle/Urualla 2 is 137 meters.

The outcomes linked to the Orlu/Owerri Road, which encompasses several depth ranges, are as follows: 0–0.9 m, 0.9–16.8 m, 16.8–53.6 m, 53.6–78.7 m, and so on. Each range corresponds to a specific layer thickness, namely 0.9 m, 15.9 m, 36.8 m, and 25.1 m, respectively. These strata's resistivity values are as follows: 5,970 ohm-m, 12,800 ohm-m, 24,900 ohm-m, 6,520 ohm-m, and 1,020 ohm-m. The measured elevation is 107 meters.

The Umunguma Ihioma study presents the following findings: The depth ranges observed are categorized as follows: 0–1.3 m, 1.3–4.1 m, 4.1–24.3 m, 24.3–65.5 m, and 65.5–113 m. On the other hand, the layer thicknesses, starting from the top, are measured as 1.3 m, 2.8 m, 20.2 m, 41.2 m, and 47.5 m. The resistivity values for the individual layers are as follows: 1,690 ohm-m, 3,100 ohm-m, 560 ohm-m, 748 ohm-m, 621 ohm-m, and 7,460 ohm-m. The altitude of the given geographical coordinates is recorded as 110 meters.

The findings of the study conducted at the Ikpa Ihioma axis are presented as follows: 0–1.6 m, 1.6–9.9 m, 9.9–64.2 m, 64.2–106 m, etc., and they reflect different depth ranges. The values of 1.6 m, 8.3 m, 54.3 m, and 41.8 m represent the respective thicknesses of these layers, starting from the top. In that order, the resistivity values for each layer are 213 ohm-m, 3,040 ohm-m, and 1,660 ohm-m, respectively. The given location's geographical altitude is 94 m.

The Umuazzala Ogberuru study's findings revealed the following patterns: The depth ranges were categorized as 0–3.0 m, 3.0–12.5 m, 12.5–34.7 m, and 34.7–212.1 m. Additionally, the layer thicknesses from the top were measured at 3 m, 9.5 m, 22.2 m, and 177.4 m. The layers' resistivity values are as follows: 2708.7 ohm-m, 6736 ohm-m, 536.2 ohm-m, 4843.4 ohm-m, and 320.4 ohm-m. The measured elevation is 195 meters.

The findings of Umueshi 1 exhibit the following patterns: the depth ranges are categorized as 0–3.4 m, 3.4–90.7 m, and so on; the layer thicknesses, starting from the top, are measured at 3.4 m and 87.2 m. The resistivity values of the layers are 179.2 ohm-m, 3,498.7 ohm-m, and 879.04 ohm-m, respectively. The measured elevation is 260 m.

The results of Umueshi 2 exhibited the following patterns: the depth ranges were observed to be 0–0.6 m, 0.6–1.5 m, 1.5–2.8 m, 2.8–14.8 m, and 14.8–105.6 m. Additionally, the layer thicknesses from the top were measured to be 0.6 m, 0.9 m, 1.3 m, 12 m, and 90.745 m. The layers' resistivity values are as follows: 65.2 ohm-m, 471.3 ohm-m, 1,000.1 ohm-m, 2,999.2 ohm-m, 2,167 ohm-m, and 325.43 ohm-m. The measured elevation is 270 meters.

The results of Ogberuru 2 exhibit a certain pattern, wherein the depth ranges are categorized as follows: 0–2.9 m, 2.9–119.3 m, 119.3–181.9 m, and so on. Additionally, we measure the corresponding thicknesses from the top as 2.9 m, 116.4 m, and 62.6 m. The resistivity values of the respective layers are 204.4 ohm-m, 4,403.9 ohm-m, 1,883 ohm-m, and 601.7 ohm-m. The measured elevation is 121 meters.

Table 1
Summary of the geographical positions

			Depth range of layers					Thickness of layers					Resistivity of layers						
Locations	Long.	Lat.	L1(m)	L2(m)	L3(m)	L4(m)	L5(m)	T1(m)	T2(m)	T3(m)	T4 (meters)	T5(m)	R1 (Ohm-m)	R2 (Ohm-m)	R3 (Ohm-m)	R4 (Ohm-m)	R5 (Ohm-m)	R6 (Ohm-m)	Elev. (m)
Njaba River	7.193056	5.774167	0 – 1.6	1.6 – 8.7	8.7 – 33.6	33.6 – 65	65 – ∞	1.6	7.1	24.9	31.4		186	10,000	1,090	9,500	44,800		115
Orlu/Ihiala road	7.060278	5.878056	0 – 1.1	1.1 – 14.6	14.6 – 33.0	33.0 – 67.5	67.5 – 104	1.1	13.5	18.4	34.5	36.5	383	940	1,810	1,190	528	38.9	102
Okwelle/ Urualla road	7.3125	5.886667	0 – 4.8	4.8 – 34.5	34.5 – 61.8	61.8 – E		4.8	29.7	27.3			650	5,460	2,870				152
Afor Ukwu – Afor Nta	7.360556	5.861944	0 – 4.7	4.7 – 10.6	10.6 – 36.8	36.8 – 64.9	64.9 – 107	4.7	5.9	26.2	28.1	42.1	970	521	11,600	3,710	7,330	25,500	155
Okwelle/ Urualla Road 2	7.322222	5.810833	0 – 2.5	2.5 – 24.8	24.8 – 66.7	66.7 – 110	110 – ∞	2.5	22.3	41.9	43.3		643	11,200	2,210	3,700	1,100		137
Orlu/Owerri Road	7.253889	5.761111	0 – 0.9	0.9 – 16.8	16.8 – 53.6	53.6 – 78.7	78.7 – ∞	0.9	15.9	36.8	25.1		5,970	12,800	24,900	6,520	1,020		107
Umunguma Ihioma	7.263889	5.927222	0 – 1.3	1.3 – 4.1	4.1 – 24.3	24.3 – 65.5	65.5 – 113	1.3	2.8	20.2	41.2	47.5	1,690	3,100	560	748	621	7,460	110
Ikpa Ihioma	7.142778	5.96	0 – 1.6	1.6 – 9.9	9.9 – 64.2	64.2 – 106	106 – ∞	1.6	8.3	54.3	41.8		213	3,040	76.2	152	1,660		94
Umuazzala Ogberuru	7.028722	5.830389	0 – 3.0	3.0–12.5	12.5 – 34.7	34.7 – 212.1		3	9.5	22.2	177.4		2708.7	6,736	536.2	4,843.40	320.4		195
Umueshi 1	7.110472	5.829	0 – 3.4	3.4 – 90.7	90.7 – E			3.4	87.2				179.2	3,498.70	897.07				260
Umueshi 2	7.109669	5.830806	0 – 0.6	0.6 – 1.5	1.5 – 2.8	2.8 – 14.8	14.8 – 105.6	0.6	0.9	1.3	12	90.745	65.2	471.3	1,000.10	2,999.20	2,167	325.43	273
Ogberuru 2	7.015389	5.832028	0 – 2.9	2.9 – 119.3	119.3 – 181.9	181.9 – E		2.9	116.4	62.6			204.4	4,430.90	1,883	601.7			121

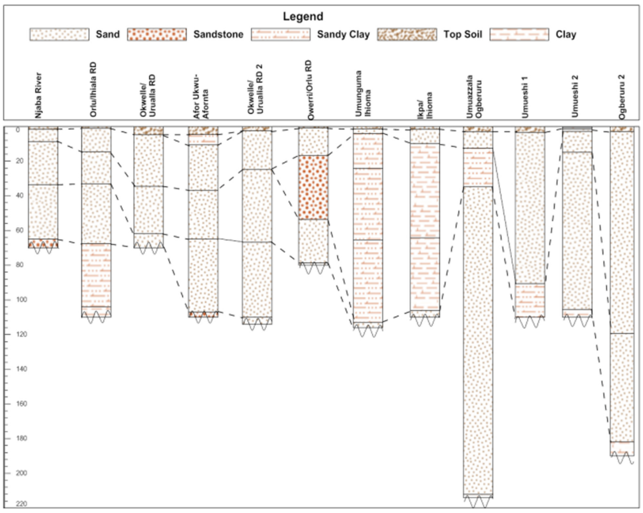
Table 1 provides a detailed summary of the geographical positions and accompanying coordinates, depths, thicknesses, and resistivity values of different layers associated with specific investigation sites.

The variables employed in this study consist of Long. to represent Longitude, Lat. to denote Latitude, L to signify Layer, T to represent Thickness, R to symbolize Resistivity, and Elev. to indicate Elevation.

4.1.1. Geo-electric sections of the study

The geo-electric sections and geo-electric profiling of the study locations are shown in Figure 3.

Figure 3
Geo-electric sections and profiling of the study locations



4.1.2. Resistivity curves, interpretation, and resistivity contours of the study area

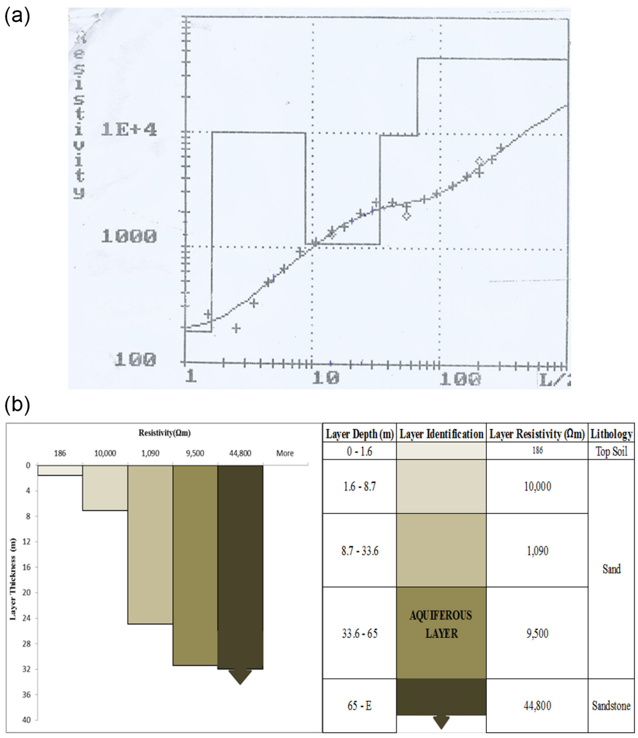
The resistivity signatures generated within the study area and corresponding interpretation are given in Figures 4–22.

4.2. Physiochemical analysis

The water samples collected underwent physicochemical analysis for various parameters, including pH, dissolved oxygen (DO), total suspended solid, total dissolved solid (TDS), biochemical oxygen demand (BOD), calcium, hardness, magnesium, alkalinity, nitrate, sulfate, total chlorine, manganese, turbidity, and conductivity, following the procedure outlined by [10]. The results obtained were compared against the permissible limits set by the World Health Organization (WHO) for drinking water and the Nigerian Standard (NS) for drinking water quality. Table 2 provides a comparison of the drinking water quality standards for selected parameters set by both WHO and NS, while Table 3 outlines the rating system [12, 13].

Table 4 details the physicochemical properties of the water samples collected from various sampling locations. The analysis revealed that the pH values of the water samples ranged from 6.8 to 8.1 across the locations, falling within the WHO-permissible limit of 6.8 to 8.2. This indicates that the pH levels of the water samples from all locations studied were within the normal range.

Figure 4
(a) Apparent resistivity versus electrode spacing for Njaba River and environs. (b) Njaba River and environs subsurface layer thickness distribution versus resistivity, showing aquiferous layer and lithologies



As noted by [14], pH serves as a crucial indicator of water quality, playing a pivotal role in assessing the health and environmental implications of water. pH values below 6.5 hinder the absorption of essential vitamins and minerals by the human body, while values exceeding 8.5 render water caustic and irritating [15]. The findings of this investigation align with those documented by [16–19]. Table 5 presents the Water Quality Index (WQI) values derived from the twelve samples obtained from twelve distinct locations surveyed.

4.3. Discussion

4.3.1. Discussion of geo-electrical result

Interpretation of VES data, alongside lithological logs from nearby boreholes, reveal key characteristics of the subsurface in the Orlu region of Nigeria. The geo-electric sections' uppermost boundaries (Figure 3) exhibit low resistivity, likely due to the presence of decomposed organic materials buried within these strata. Laterite underlies this overburden, followed by a layer of medium-grained, reddish sand. The dominant composition of the geo-electric sections is medium- to coarse-grained white sands with minimal clay content. Resistivity values range from 65 to 44,800 ohm-m, suggesting freshwater aquifers.

Figure 5
(a) Apparent resistivity versus electrode spacing for Orlu/Ihiala Road axis. (b) Orlu/Ihiala Road subsurface layer thickness distribution versus resistivity, showing aquiferous layer

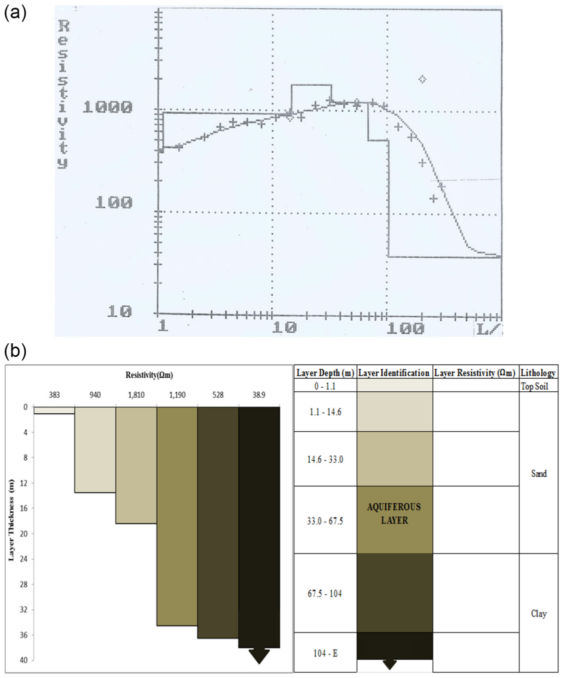


Figure 6
(a) Apparent resistivity versus electrode spacing for Okwelle/Urualla and environs. (b) Okwelle/Urualla Road subsurface layer thickness distribution versus resistivity, showing aquiferous layer

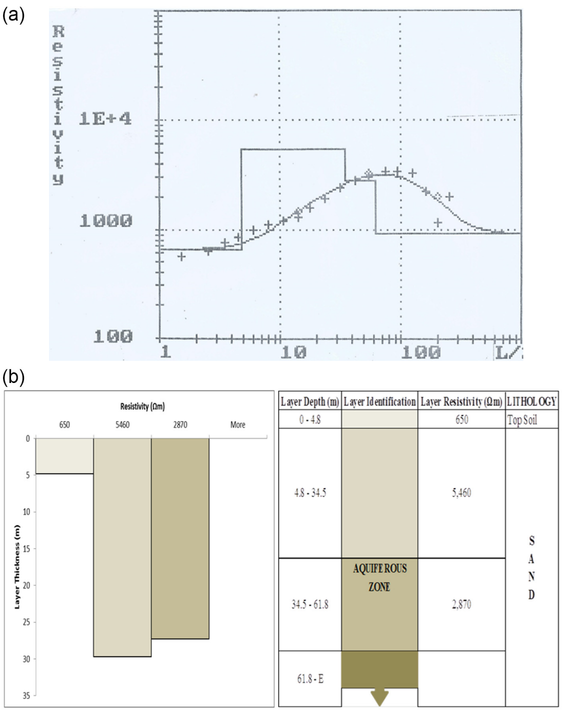


Figure 7
(a) Apparent resistivity versus electrode spacing for Afor Ukwu-Afor Nta axis. (b) Afor Ukwu-Afor Nta axis subsurface layer thickness distribution versus resistivity, showing aquiferous layer

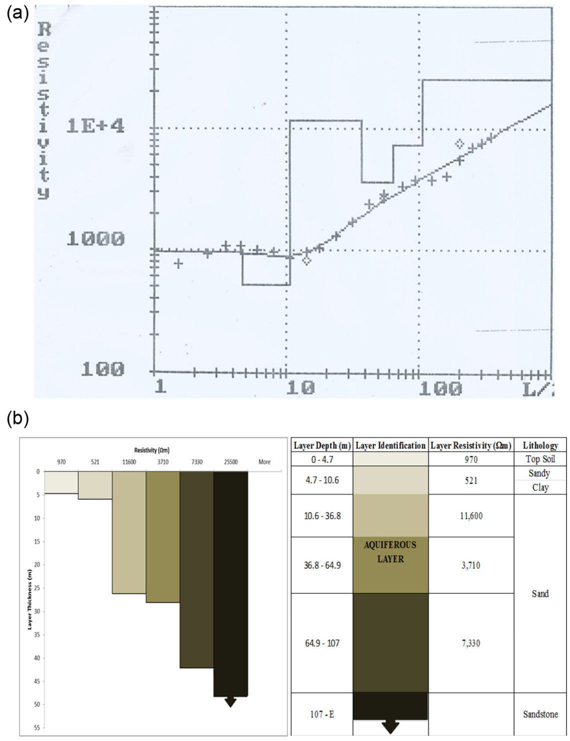


Figure 8
(a) Apparent resistivity versus electrode spacing for Okwelle/Urualla 2. (b) Okwelle/Urualla Road 2 axis subsurface layer thickness distribution versus resistivity, showing aquiferous layer

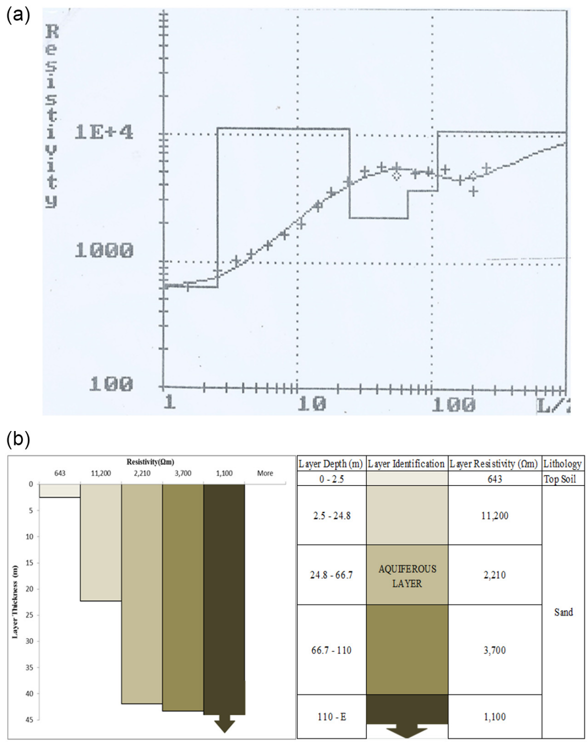


Figure 9

(a) Apparent resistivity versus electrode spacing for Orlu/Owerri Road axis. (b) Orlu/Owerri Road axis subsurface layer thickness distribution versus resistivity, showing aquiferous layer

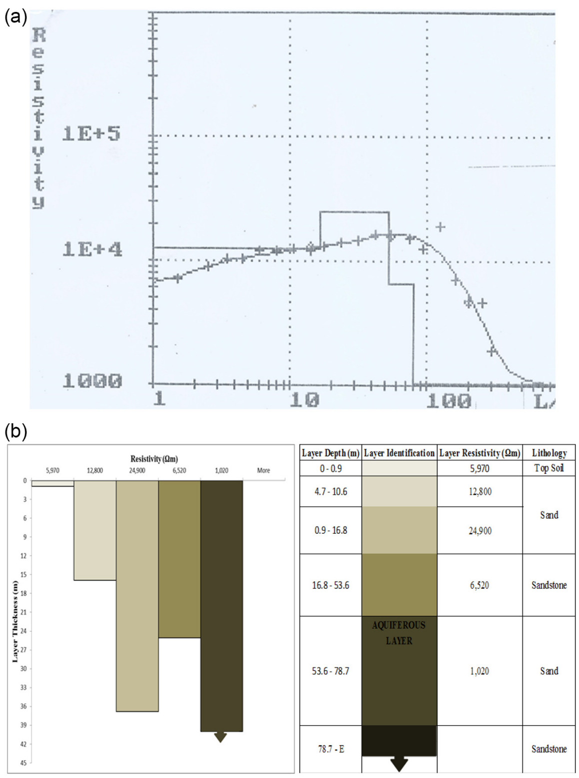


Figure 11

(a) Apparent resistivity versus electrode spacing for Ikpa Ihioma. (b) Ikpa Ihioma axis subsurface layer thickness distribution versus resistivity, showing aquiferous layer

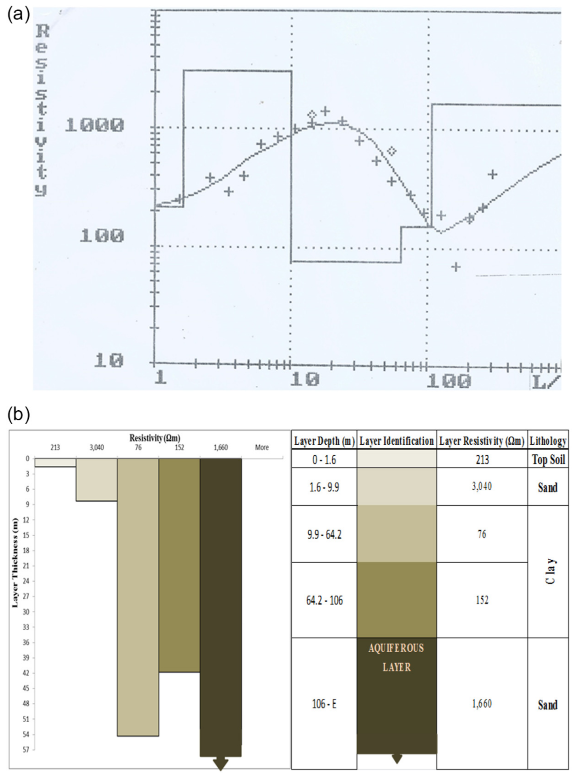


Figure 10

(a) Apparent resistivity versus electrode spacing for Umunguma Ihioma. (b) Umunguma Ihioma axis subsurface layer thickness distribution versus resistivity, showing aquiferous layer

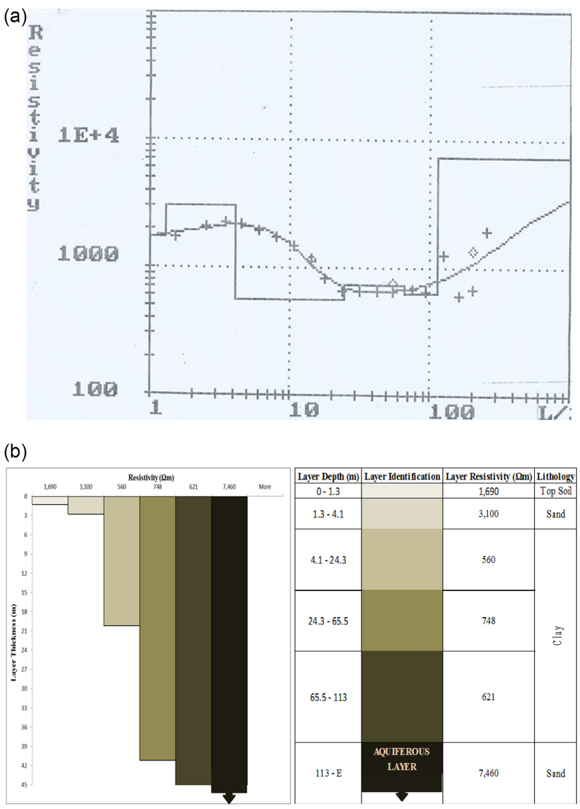


Figure 12

(a) Apparent resistivity versus electrode spacing for Umuazzala Ogberuru. (b) Umuazzala Ogberuru subsurface layer thickness distribution versus resistivity, showing aquiferous layer

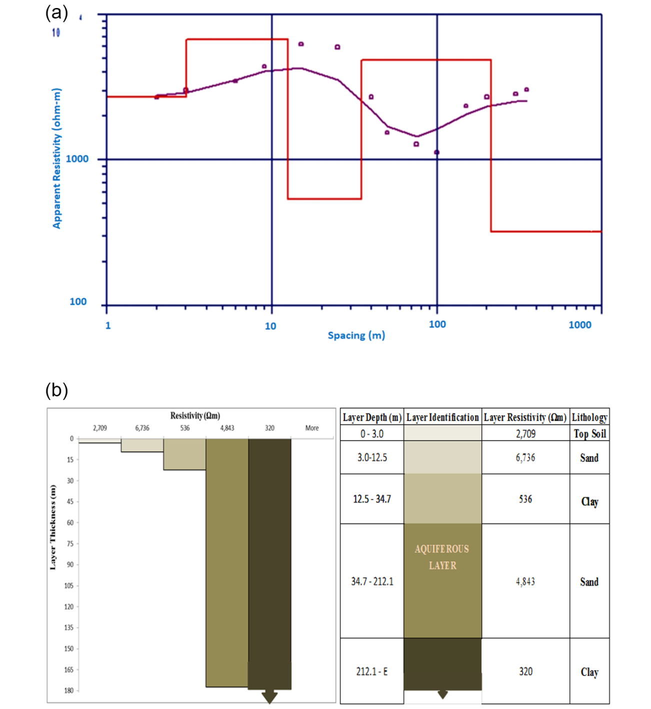


Figure 13
(a) Apparent resistivity versus electrode spacing for Ogberuru II. (b) Ogberuru 2 subsurface layer thickness distribution versus resistivity, showing lithologies and aquiferous layer

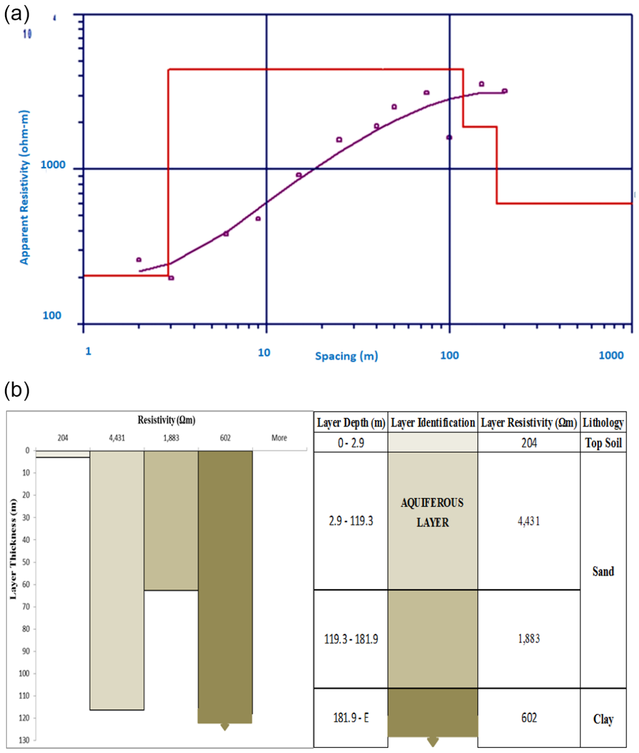


Figure 14
(a) Apparent resistivity versus electrode spacing for Umueshi I. (b) Umueshi I subsurface layer thickness distribution versus resistivity, showing lithologies and aquiferous layer

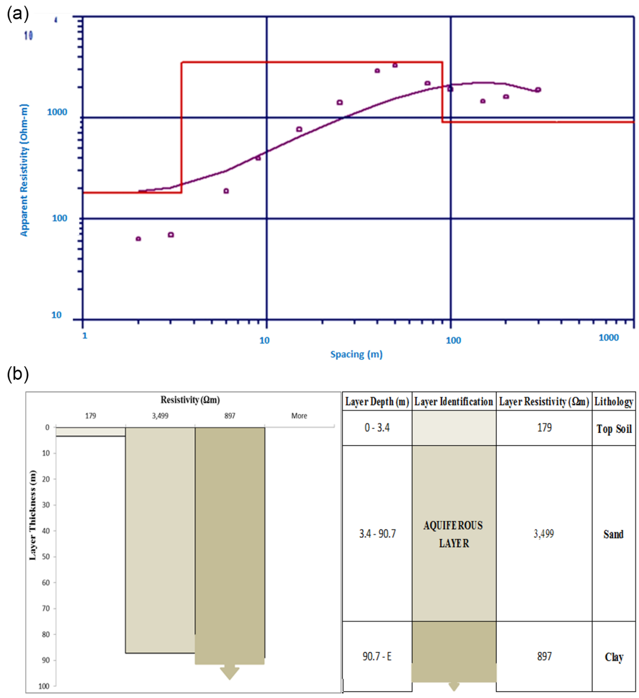


Figure 3 shows the stratified subsurface layering based on apparent resistivity from VES depth probing. Figures 4–15 illustrate the variations in apparent resistivity observed at different depths within each station. Layer resistivity contours across multiple stations (Figures 17–22) reveal significant spatial variability, highlighting the inherent heterogeneity of the subsurface, even within a localized area.

Variations in layer resistivity indicate differences in formation composition. Clayey formations and topsoil (overburden) exhibit the lowest resistivity values (4–15 ohm-m). Interestingly, resistivity variations occur even within layers of the same lithology. This phenomenon may be attributed to variations in pore fluid content, the dissolution of minerals within specific layers, or differences in grain size and pore space connectivity.

Shallow depths typically have less groundwater compared to deeper layers. Additionally, regions with higher fluid retention capacity may exhibit lower resistivity due to the dissolution of conductive minerals, leading to increased conductivity and decreased resistivity. Consequently, aquifers with high water retention capacity and high resistivity are considered optimal, as these characteristics suggest cleaner water.

This analysis provides valuable insights into the subsurface structure and potential groundwater resources within the Orlu region. However, further investigation is necessary to assess the long-term viability and yield of these aquifers for sustainable water management.

4.3.2. Discussion of physiochemical analysis

The findings regarding DO for the twelve collected samples varied from 0.9 to 4.9, all within the minimum DO concentrations permissible for drinking water according to WHO standards [20]. The TDS in the samples ranged from 4.1 to 62, falling within the WHO's recommended TDS range of 0–250 mg/L, with water below 250 mg/L generally considered safe [20]. BOD values, ranging from 0.7 to 1.8, were below the maximum limit set by WHO, indicating a lower presence of organic matter in the water [20]. BOD levels reflect the amount of oxygen required for microorganisms to decompose organic matter, with higher values suggesting increased pollution and greater demand for oxygen [12, 21, 22].

Calcium content in the samples ranged from 0.97 to 2.5 mg/L, all below the WHO recommendation of 75 mg/L. Calcium-rich water can provide supplemental calcium but may inhibit parathyroid hormone secretion and bone resorption, potentially affecting growth [13, 16, 19]. Total hardness, ranging from 0.39 to 1.98, was within the WHO's permissible limit of 500 mg/L. Excess calcium, magnesium, and iron salts primarily cause hardness, which can impact human health and potentially lead to cardiovascular issues, reproductive failure, and cancer [17, 23, 24].

Magnesium, alkalinity, nitrate, sulfate, chlorine, and manganese values were all below WHO's permissible limits, as outlined in Table 4. High sulfate levels can cause dehydration and

Figure 15
(a) Apparent resistivity versus electrode spacing for Umueshi II. (b) Umueshi II subsurface layer thickness distribution versus resistivity, showing lithologies and aquiferous layer

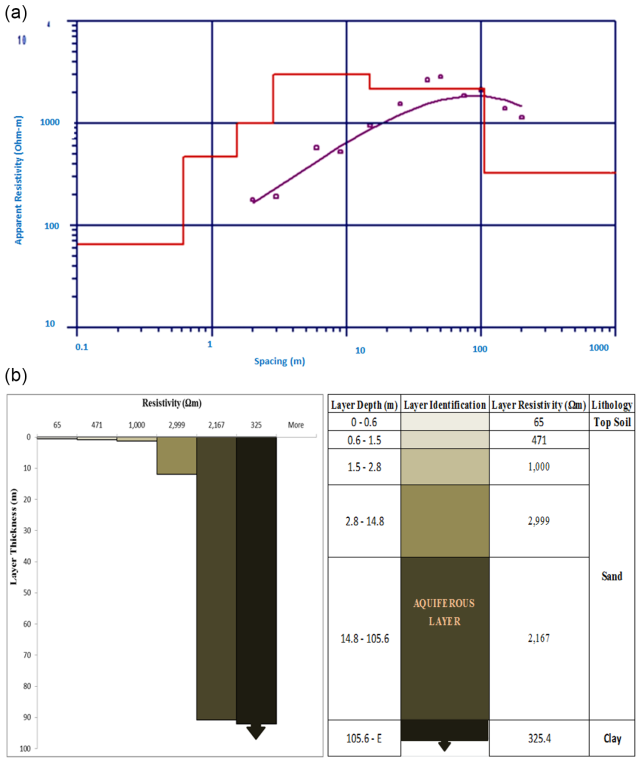
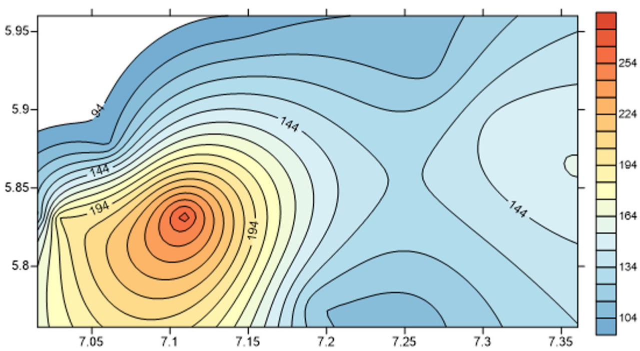


Figure 16
Elevation contour map of the study area



diarrhea, while high nitrate concentrations pose risks to infants due to their conversion to nitrite, reducing the blood's oxygen-carrying capacity [18, 25–27]. Turbidity, a measure of water clarity, ranged from 1.9 to 4.9 NTU, falling within the WHO's recommended limit of 5 NTU. Elevated turbidity can indicate potential microbial contamination [14, 28]. Conductivity ranged from 15.5 to 27.2, reflecting the water's ability to conduct electricity.

The calculated WQI for all locations ranged from 17.6 to 39.65, falling within the excellent to good drinking quality ranges as delineated in Table 3 [12, 13].

Figure 17
The contour of the resistivity values of the first layers

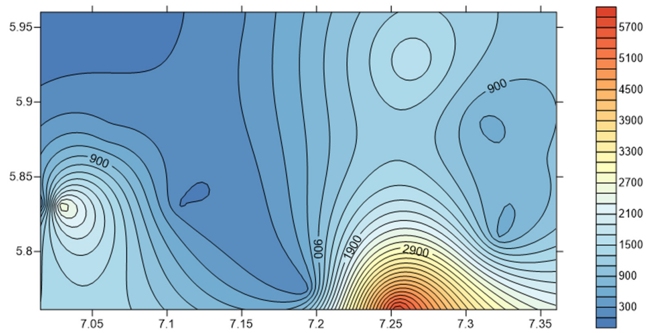


Figure 18
The contour of the resistivity values of the second layers

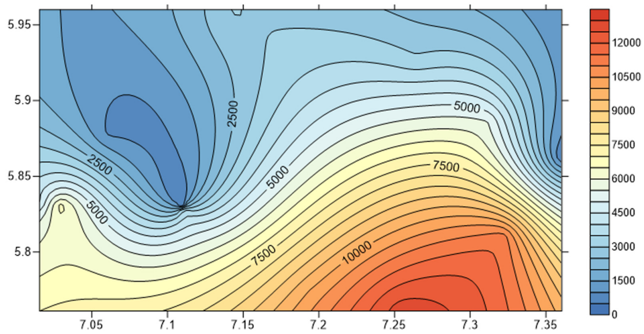


Figure 19
The contour of the resistivity values of the third layers

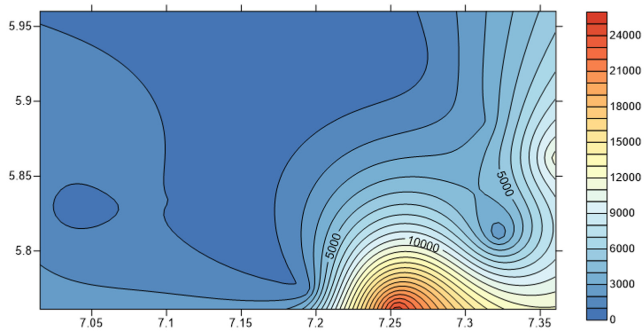


Figure 20
The contour of the resistivity values of the fourth layers

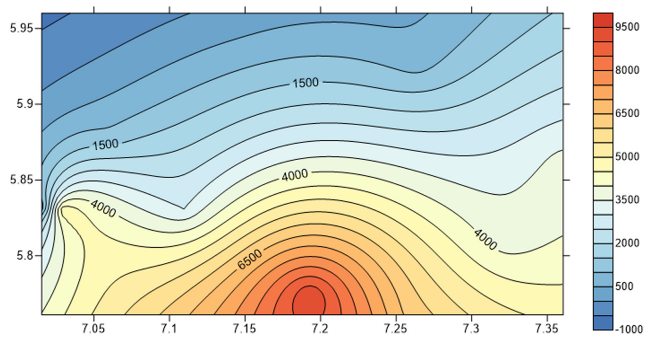


Figure 21
The contour of the resistivity values of the fifth layers

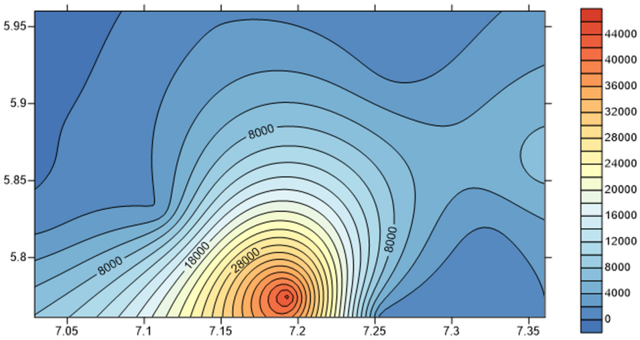


Figure 22
The contour of the resistivity values of the sixth layers

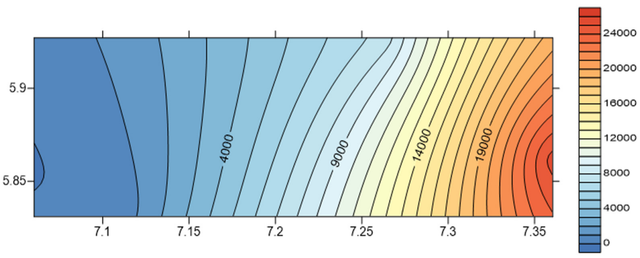


Table 2
Drinking water quality standards for selected parameters according to WHO and NS [11]

Parameters	Agency	Standards	Relative weight
Turbidity	WHO	0.5	0.1931124
pH (mg/L)	WHO	6.5 –8.5	0.12069525
TDS (mg/L)	WHO	500	0.001931124
EC	WHO	500	0.001931124
TH (mg/L)	WHO	500	0.001931124
Mg (mg/L)	NS	20	0.0482781
Ca (mg/L)	WHO	75	0.01287416
Nitrates	WHO	50	0.01931124
Sulphate	NS	100	0.00965562
Phosphate	WHO	5	0.1931124
Chlorine	WHO	250	0.003862248
DO	WHO	>5	0.1931124
BOD	WHO	5	0.1931124

Table 3
Water quality rating [12, 13]

Water Quality Index level (WQI)	Water quality status	Grade
0 – 25	Excellent	A
26 – 50	Good	B
51 – 75	Poor	C
76 – 100	Very poor	D
>100	Unsuitable for drinking	E

Table 4
Physicochemical analysis of water from different locations within Orlu and environs

Parameters	Locations												WHO
	Njaba River	Orlu/Ihiala road	Okwelle/ Urualla road	Afor Ukwu – Afor Nta	Okwelle/ Urualla Road 2	Orlu/ Owerri Road	Umunguma Ihioma	Ikpa Ihioma	Umuazzala Ogberuru	Umueshi 1	Umueshi 2	Ogberuru 2	
pH	7.1	7.4	7.2	7.9	8.1	6.9	8.2	7.6	6.8	6.9	7.2	7.4	8.5
DO (mg/L)	4.9	1.2	0.9	2.9	3.1	2.7	3.2	2.8	0.9	1.3	1.5	1.2	5
TSS (mg/L)	113	142	80	88	97	115	79	82	107	98	99	105	250
TDS (mg/L)	10.3	8.5	4.1	15	62	17	16	19	33	18	16	37	250
BOD	1.8	1.7	0.8	0.95	1.2	1.3	1.6	1.3	0.7	0.7	0.9	1.5	5
Mg (mg/L)	0.2	0.1	0.03	0.06	0.05	0.1	0.05	0.07	0.03	0.09	0	0.01	250
Ca (mg/L)	2.5	1.7	0.97	1.55	0.99	1.75	1.89	1.79	2.1	1.71	1.8	1.9	75
Nitrates (mg/L)	35.5	40.5	48.5	33.7	49	38.1	40.3	27	45	26.8	33.8	37.9	50
Sulphate (mg/L)	70.1	66.6	89.1	76.9	68.9	77.8	88.6	91.1	66.7	66.05	77.12	89.5	100
Alkalinity	88	97	59	78	88	97	89	83	77	81	78	74	100
Total Chlorine (mg/L)	0.36	0.33	0.27	0.3	0.29	0.27	0.36	0.39	0.33	0.33	0.37	0.38	250
Manganese (mg/L)	0.09	0.12	0.11	0.08	0.03	0.07	0.03	0.04	0.11	0.07	0.06	0.02	0.2
Turbidity	4.1	2.4	3.2	1.9	4.2	3.5	4.7	4.3	3.7	3.6	4.6	4.9	5
Conductivity	27	26.9	17.9	15.8	17.9	15.5	19.3	20.1	27.2	18.9	16.9	19.3	100
Hardness	1.05	1.09	1.13	0.89	0.54	1.57	1.98	1.82	0.97	0.63	0.39	0.75	500

Table 5
Summary of water quality status based on computed WQI from all the locations

Locations	WQI value	WQI grade	Remark
Njaba River	17.6	A	Excellent
Orlu/Ihiala road	33.7	B	Good
Okwelle/Urualla road	37.8	B	Good
Afor Ukwu – Afor Nta	24.5	A	Excellent
Okwelle/Urualla Road 2	33.7	B	Good
Orlu/Owerri Road	23.7	A	Excellent
Umunguma Ihioma	30.9	B	Good
Ikpa Ihioma	34.1	B	Good
Umuazzala Ogberuru	26.7	B	Good
Umueshi 1	39.65	B	Good
Umueshi 2	36.7	B	Good
Ogberuru 2	29.1	B	Good

5. Conclusion

The write-up on the interpretation of VES data and physiochemical analysis of groundwater samples in the Orlu region of Nigeria provides a comprehensive insight into the subsurface geology and water quality parameters. The integration of VES data with lithological logs from boreholes facilitates a detailed characterization of subsurface formations, identifying potential aquifer zones and delineating lithological boundaries. Additionally, the physiochemical analysis of groundwater samples offers valuable information regarding water quality, assessing parameters crucial for portability.

The study's academic merit lies in its systematic approach to data collection, analysis, and interpretation, supported by relevant literature and international standards such as those set by the WHO. The discussion on the interpretation of resistivity variations in VES data underscores the complexity of subsurface heterogeneity, highlighting the need for further investigation to understand groundwater dynamics fully. Furthermore, the physiochemical analysis provides essential insights into the suitability of groundwater for drinking purposes, considering parameters like pH, DO, TDS, and various ions.

This write-up contributes significantly to the understanding of hydrogeological and geochemical processes in the Orlu region, serving as a valuable resource for researchers, hydrogeologists, and policymakers. Its findings can inform future studies on groundwater exploration, management, and sustainability in similar geological settings. However, to enhance its academic value further, the write-up could benefit from a more detailed discussion on the methodologies employed, data limitations, and potential implications of the findings on water resource management strategies.

The write-up on the interpretation of VES data and physiochemical analysis of groundwater samples in the Orlu region of Nigeria presents crucial insights with practical implications for industrial stakeholders involved in water resource management, particularly in the context of groundwater exploration and quality assessment.

The integration of geophysical data with lithological logs from boreholes offers a cost-effective and efficient means of delineating subsurface lithological boundaries and identifying potential aquifer zones. Such information is invaluable for industries reliant on groundwater resources, including agriculture, manufacturing, and urban development. Understanding the subsurface geology enables informed decision-making regarding well siting, borehole construction, and groundwater extraction strategies, thereby optimizing resource utilization and minimizing operational risks.

Moreover, the physiochemical analysis of groundwater samples provides essential information for industries dependent on water for various processes, such as irrigation, cooling, and potable water supply. By assessing parameters like pH, DO, and ion concentrations, industries can ensure compliance with regulatory standards, mitigate potential health risks, and maintain the efficiency and longevity of equipment and infrastructure.

The systematic approach adopted in this study, coupled with adherence to international standards such as those set by the WHO, underscores its reliability and relevance for industrial applications. However, to maximize its utility for industrial stakeholders, the write-up could benefit from additional insights into the spatial distribution of groundwater quality parameters and their potential implications for specific industrial activities. Additionally, practical recommendations for sustainable groundwater management practices tailored to industrial needs would enhance the write-up's value as a practical resource for decision-makers and practitioners in the field.

Ethical Statement

This study does not contain any studies with human or animal subjects performed by any of the authors.

Conflicts of Interest

The authors declare that they have no conflicts of interest to this work.

Data Availability Statement

Data available on request from the corresponding author upon reasonable request.

Author Contribution Statement

Chukwuebuka Nnamdi Onwubuariri: Conceptualization, Methodology, Software, Formal analysis, Investigation, Resources, Data curation, Writing – original draft, Visualization, Supervision, Project administration. **Chidimma Onyinye Ikeme:** Methodology, Formal analysis, Investigation, Resources, Data curation, Writing – original draft, Supervision. **Joseph Ugochukwu:** Software, Formal analysis, Data curation. **Chidiebere Charles Agoha:** Software, Formal analysis, Investigation, Resources, Data curation, Writing – review & editing. **Joshua Udoka Ugwu:** Validation. **Lawson Jack Osaki:** Validation, Resources, Writing – review & editing. **Tochukwu I. Mgbeojedo:** Investigation, Resources, Writing – review & editing.

References

[1] Inverse [Online]. *Water war, The primary source of water for 2.5 billion people in danger*. Retrieved from: https://www.inverse.com/science/climate-crisis-groundwater-study/amp

[2] Reyment, R. A. (1965). *Aspects of geology of Nigeria*. Nigeria: University of Ibadan Press.

[3] Avbovbo, A. A. (1978). Tertiary lithostratigraphy of Niger delta. *AAPG Bulletin*, *62*, 297–306.

[4] Onyeagocha, A. C. (1980). Petrography and depositional environment of the Benin formation, Nigeria. *Journal of Mining Geology*, *17*(1), 147–151.

[5] Whiteman, A. (1982). *Nigeria: Its petroleum geology, resources and potential*. UK: Graham and Trotman Ltd.

[6] Rice, E. W., Baird, R. B., & Eaton, A. D. (2017). *Standard methods for the examination of water and wastewater*. USA: American Water Works Association.

[7] Herman, R. (2001). An introduction to electrical resistivity in geophysics. *American Journal of Physics*, *69*(9), 943–952.

[8] Telford, W. M., Geldart, L. P., & Sheriff, R. E. (1990). *Applied geophysics* (2nd ed.). UK: Cambridge University Press. https://doi.org/10.1017/CBO9781139167932

[9] Onwubuariri, C. N., & Mgbeojedo, T. I. (2018). Investigation of electrical properties of soil in relation to gully development in Orlu, South-eastern Nigeria. *IOSR Journal of Applied Geology and Geophysics*, *6*(6), 40–50.

[10] Butt, I., & Ghaffar, A. (2012). Ground water quality assessment near Mehmoodboti landfill, Lahore, Pakistan. *Asian Journal of Social Sciences and Humanities*, *1*(2), 13–24.

[11] Sukamari, I. A., Kwaji, B., Alheri, J., & Abia, I. O. E. (2020). Application of water quality index to assess the portability of some domestic water supply sources in Mubi North, Nigeria. *International Journal of Engineering Research & Technology*, *9*(8), 848–860.

[12] Brown, R. M., Mcclelland, N. I., Deininger, R. A., & O'Connor, M. F. (1972). Water quality index-crashing, the psychological barrier. In *Proceedings of 6th Annual Conference, Advances in Water Pollution Research*, 787–794.

[13] Chatterjee, P. R., & Raziuddin, M. (2007). Studies on the water quality of a water body at Asansol. *Nature Environment and Pollution Technology*, *6*(2), 289–292.

[14] World Health Organization. (2019). *Exposure to cadmium: A major public health concern*. Retrieved from: https://www.who.int/publications/i/item/WHO-CED-PHE-EPE-19-4-3.

[15] Abdus-Salam, N., Ibrahim, M. S., & Fatoyinbo, F. T. (2011). Dumpsites in Lokoja, Nigeria: A silent pollution zone for under-ground water. *Waste Management and Bioresource Technology*, *1*, 21–30.

[16] Abbasnia, A., Yousefi, N., Mahvi, A. H., Nabizadeh, R., Radfard, M., Yousefi, M., & Alimohammadi, M. (2019). Evaluation of groundwater quality using water quality index and its suitability for assessing water for drinking and irrigation purposes: Case study of Sistan and Baluchistan Province (Iran). *Human and Ecological Risk Assessment*, *25*(4), 988–1005.

[17] Alaya, M. B., Saidi, S., Zemni, T., & Zargouni, F. (2014). Suitability assessment of deep groundwater for drinking and irrigation use in the Djeffara aquifers (northern Gabes, south-eastern Tunisia). *Environmental Earth Sciences*, *71*(8), 3387–3421. https://doi.org/10.1007/s12665-013-2729-9

[18] Adebayo, A. A. (2004). Soil and vegetation. In A. A. Adebayo (Ed.), *Mubi region: A geographical synthesis* (pp. 38–43). A Division of Paraclete and Sons.

[19] Saidu, S. M. (2011). Effect of refuse dumps on groundwater quality. *Advances in Applied Science Research*, *2*(6), 595–599.

[20] Ahmad, A. B. (2014). Evaluation of groundwater quality index for drinking purpose from some villages around Darbandikhan district, Kurdistan Region-Iraq. *IOSR Journal of Agriculture and Veterinary Science*, *7*(9), 34–41 https://doi.org/10.9790/2380-07913441

[21] Chaurasia, A. K., Pandey, H. K., Tiwari, S. K., Prakash, R., Pandey, P., & Ram, A. (2018). Groundwater quality assessment using water quality index (WQI) in parts of Varanasi district, Uttar Pradesh, India. *Journal of the Geological Society of India*, *92*, 76–82. https://doi.org/10.1007/s12594-018-0955-1

[22] American Public Health Association. (1998). *Standard methods for the examination of water and wastewater*. USA: American Public Health Association.

[23] D'Alessandro, W., Bellomo, S., Parello, F., Bonfanti, P., Brusca, L., Longo, M., & Maugeri, R. (2012). Nitrate, sulphate and chloride contents in public drinking water supplies in Sicily, Italy. *Environmental Monitoring and Assessment*, *184*(1–3), 1461–1470. https://doi.org/10.1007/s10661-011-2155-y

[24] Colombo, A. F., & Karney, B. W. (2002). Energy and costs of leaky pipes: Toward comprehensive picture. *Journal of Water Resources Planning and Management*, *128*(6), 441–450. https://doi.org/10.1061/(ASCE)0733-9496(2002)128:6(441)

[25] Colombo, A. F., Karney, B. W., & Asce, M. (2014). Energy and costs of leaky pipes: Toward comprehensive picture. *Journal of Water Resources Planning and Management*, *140*(4), 303–306. https://doi.org/10.1061/(ASCE)0733-9496(2002)128:6(441)

[26] APHA. (1992). *Standard methods for the examination of water and wastewater* (18th ed). USA.

[27] WHO. (2011). *Guidelines for drinking-water quality* (4th ed). Switzerland: World Health Organization.

[28] Sokolova, L., Ghole, V., & Mukherjee, R. (2011). Water quality assessment and pollution source identification for the Gomti River, India. *Environmental Monitoring and Assessment*, *177*(1–4), 357–374. https://doi.org/10.1007/s10661-010-1703-x

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