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Geoelectric Probing of Groundwater and Aquifer Protective Capacity in Parts of Asaba, Delta State, Nigeria

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Abstract
The Asaba reserved area in the Oshimili South Local Government Area of Delta State was punctiliously investigated for aquiferous units and protective capacity using vertical electrical sounding (VES). Using the Schlumberger setup, eight vertical electrical soundings were precisely conducted in the research area with maximum current electrode spacing (apart) of 450 to 500 meters. The traditional curve (pattern) matching and computer iteration method was used to quantitatively evaluate the data. The resistivity readings for the first, second, third, fourth, fifth, and sixth geoelectric strata ranged from 135.1 Ωm to 1561 Ωm, 146.4 Ωm to 5910.2 Ωm, 9.0 Ωm to 1663.9 Ωm, 28.6 Ωm to 949.1 Ωm, 114.7 Ωm to 4518.1 Ωm, and 349.9 Ωm to 1172.9 Ωm. Topsoil, clay, clayey sand, fine, medium, semi-coarse, and coarse-grained sands with different thicknesses make up the lithologies. The results of this investigation were discovered to be congruent with several lithologic logs collected from boreholes conducted in the study region, and the aquiferous subunits were primarily restricted. The examined area's aquifers were divided into zones of low and moderate protection capacity (P.C.), with P.C. ranging from 0.011 to 0.657 mhos. Subsequently, in order to prevent polluted sites and failed boreholes, geophysical studies should be conducted in the area prior to drilling.

Keywords: Aquifer, Asaba, Drilling, Geoelectric, Protective capacity

Introduction

Due to the effects of incessant growing populations and industrialization on groundwater resources, there is a greater need for drinkable water to meet both household and commercial demands. Water, as one of nature's basic needs, is necessary for the growth of all forms of life, including plants and also animals (Okolie & Akpoyibo, 2012; Ofomola et al., 2017; Esi et al., 2025a; 2025b; Nwabuoku & Akpoyibo, 2026; Akpoyibo, 2026). It is found in surface basins in springs, streams, creeks, and lakes; it drops as rain; and it is found underground in the creation of porous, permeable rocks such as groundwater. One of the most efficient and effective sources of drinkable water for agricultural, industrial, and human growth is groundwater. Aquifers are layered with rock, sand, and soil where this water is kept and travels gradually. A wet subterranean layer of water that contains permeable rocks or unconsolidated substance (gravel, sand, silt, or clay) from which subterranean water can be retrieved is called an aquifer. Rainfall, melting snow, the composition of the earth's material, and the porosity and permeability of the rock are the main factors that determine whether groundwater is accessible anywhere (Chinyem, 2013). One of the first tasks in each community's water development plan is locating aquifers through subsurface exploration. If surface-level geology is not well understood, boreholes may be troublesome (Chinyem, 2013; Akpoyibo et al., 2022). The structure and nature of water-containing layers is often investigated using a variety of geophysical techniques. The electrical, magnetic, electromagnetic, and seismic refraction techniques stand out among them.

The terrain's characteristics dictate which approach is used. The work of Akpoyibo et al. (2023) confirmed that electrical resistivity is superior to other methods in groundwater examination. Geology plays a significant role in groundwater research, exploitation, and development due to the close relationship between ground-level waters and their host rock. However, the hydro-geophysical analysis of the region has become necessary due to the high prevalence of borehole failures throughout the nation and in Asaba particularly. The neighborhood now has woefully inadequate access to potable water through the water supply program.

To find locations for drilling boreholes that would produce a good yield, this required a thorough hydrogeophysical study of the region and an assessment of groundwater distribution. Therefore, the purpose of this study/research is to examine the local near-surface structure in relation to the bearing strata's water depth.

Location and Geology of Study Area

The study area (Figure 1) is situated between latitudes 6.238°N and 6.27°N and longitudes 6.695°E and 6.71°E. Situated on the northern edge of the Niger Delta Basin, it serves as the seat of government of Delta State. The River Niger, a well-maintained road system, and pathways all provide access to the area. River Atakpo and River Anwai provide good drainage for the region, and the drainage configuration is mostly dendritic. Because the earth is porous, runoff replenishes and infiltrates surface water. The Pleistocene to present-day alluvium, the entire Eocene Ogwashi-Asaba Formation, and the Oligocene to Miocene Ameki structure are the underlying features that also provide subsurface water. The most utilized aquifer at the moment is the alluvium; every other aquifer is unexplored (Chinyem 2013).

Numerous studies have examined the geological makeup of the Niger Delta region's Asaba area (Vwavware et al., 2024a; 2024b; Akpoyibo & Vwavware, 2024; Ogholaja et al., 2025). The primary stratum beneath the area is the formation known as Benin, which is made up of a mixture of riverine and continent-wide sands and gravels. This identifiable formation is a sedimentary construct in the Niger Delta that covers available older subsurface strata like the Agbada and Akata strata (Anomohanran et al., 2023; Akpoyibo et al., 2023; Ikegu et al., 2024).

Other studies, such as Chukwunwike et al. (2024), Molua et al. (2024), and Akpoyibo, (2025), provide concise explanations of the usual and unique components of these identifiable formations. The subsurface of the Akata Formation is composed primarily of detectable sand beds (accumulations) and coastal shale, which are dark gray sands (beach). The thickness of this framework (division) is anticipated to be approximately 7 kilometers (Egheneji et al., 2023; Ogholaja et al., 2025). Esi et al. (2023) describe the higher or top Agbada Series as a succession of predominately sandstone and a few shale dunes. The upper portion, which is absolutely over 3.7 kilometers thick and mostly composed of sand with a little amount of shale, possesses shale at the bottom. Although the upper part of Benin is much more open near the coast, it is coated in thin coverings of laterite of varying widely thicknesses in several places.

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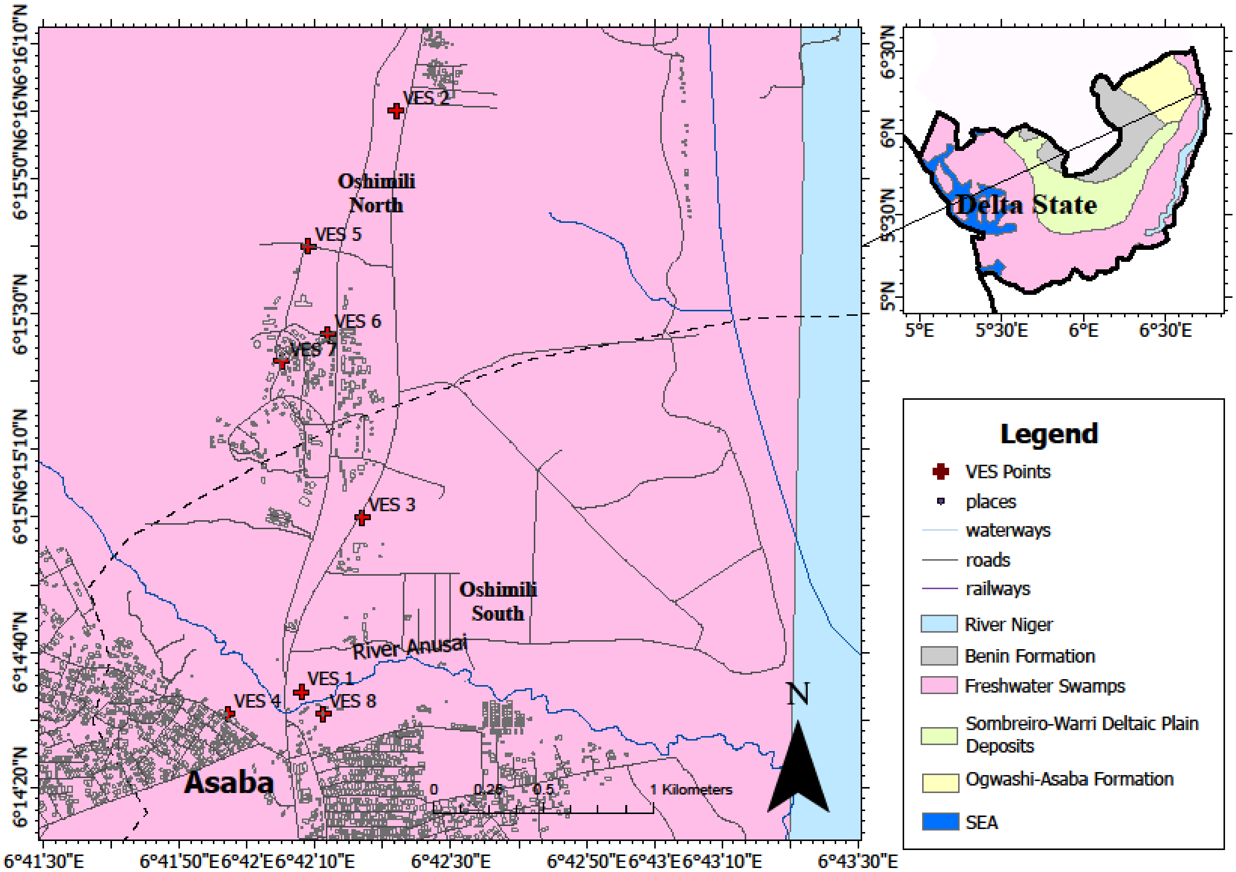

Figure 1: Base map making visible Asaba VES points and formations

Methods and Materials

Data acquisition and analysis

Combining a resistivity meter and a Schlumberger electrode arrangement with a maximum distance (length) of 900 meters between the current electrodes (AB), data gathered from eight vertical electrical sounding (VES) stations were collected over the research region. The VES stations are shown in Figure 2-9. The ABEM SAS 1000 mobile Terrameter, which has an inbuilt booster for greater/deeper depth, was used to get the data. Using the Win Resist software and the findings (outcomes) of the electrical resistivity survey, quantitative and rigorous computer iteration was used to calculate the actual resistivity and stratum thickness (Table 1). The precise locations of the sounding points were measured using the Global Positioning System (GPS).

The overall numbers of strata shown on the reported curves and geologically plausible models that yield a satisfactory match were used to explain the resistivity curves. After several cycles, the geoelectric variables of various layers are found with low RMS error. Geophysical research is essential for identifying aquifers (or possible water-storing geological units) in order to prevent drilling unsuccessful wells. In situations where bore wells are insufficient or unavailable, estimating some aquifer features (protective capacity and aquifer depths) from basic electrical resistivity data (resistivity and thickness) is a quicker and less economical way to determine these parameters (Okolie & Akpoyibo, 2012; Esi et al., 2023; Akpoyibo et al., 2025).

These first-order obtained variables (thickness h_i and resistivity ρ_i) were used to compute the total (complete) longitudinal unit (section) conductance (S), a second-degree or order geoelectric characteristic known as the Dar Zarrouk parameter (Akpoyibo et al., 2022; 2023; Anomohanran et al., 2023; Esi & Akpoyibo, 2023; 2024). The calculated longitudinal unit conductance as a whole is

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$$S = \sum_{i=1}^{n} \frac{h_i}{\rho_i} \qquad (1)$$

Thus, the overburden protection (shielding) capacity was calculated from the whole longitudinal unit (subsection) conductance amounts (values) in the following equation (Oghenevovwero et al., 2025). The modified longitudinal conductance (mhos)/protective capacity rankings by Akpoyibo (2025) were utilized to evaluate the protective capacity. These ratings and evaluations are as follows: >10 = Excellent; 5 to 10 = Very Good; 0.7 to 4.9 = Good; 0.2 to 0.69 = Moderate; 0.1 to 0.19 = Weak; and <0.1 = Poor.

Results

The investigation's findings are displayed as tables, modeled sounding curves, and maps. The geo-electric layer characteristics derived from computer iteration and modeling of VES curves in the research area are laid out in Table 1. KQQ, HKQQ, QHA, KQH, QHAA, HKH, and HAAA curve forms (types) are among the five to six stratum model curve kinds. (Table 1 and Figure 2-9 4). With resistance values between 135.1 Ωm (VES 4) and 1561 Ωm (VES 7), the first layer is thought to be topsoil, with thicknesses between 0.9 and 1.9 m. The resistivity readings in the second section range from 146.4 Ωm (VES 6) to 5910.2 Ωm (VES 4), and the thickness ranges from 4.4 m to 12.1 m. Sand with fine, medium, coarse, and clayey grains are among the inferred lithologies. Within the thickness range of 7.5 m to 33.8 m, the third resistivity values fall between 9.0 Ωm (VES6) and 1663.9 Ωm (VES 2). Clay, coarse, medium-coarse, medium, and finely divided sand are among the predicted lithology categories. Within a broad thickness range of 14.9 m to 38.3 m, the resistivity values of the fourth layer span 28.6 Ωm (VES5) to 949.1 Ωm (VES 8). Clay, medium clay, clayey sand, and fine sand are among the inferred rock categories. Within the thickness interval, ranging from 10.2 m to 16.7 m, the resistivity values of the fifth stratum ranges from 114.7 Ωm (VES 6) to 4518.1 Ωm (VES 3). Medium sand, very fine sand, moderately coarse (medium-coarse sand), and coarse sand are among the inferred lithology varieties. The resistivity values for the sixth (6th) layer range from 349.9 Ωm (VES 2) to 1172.9 Ωm (VES 8). The meticulous inferred lithology encompasses sand, medium sand, and medium-coarse sand extending to an infinite depth dimension range and infinite thickness; the precise thickness of this layer cannot be identified because the electrode terminates within it. The occurrence of in situ weathered clay is responsible for the second and third successive layers for certain sounded points.

As a result, this layer is frequently water-filled and exhibits low resistivity, poor specific production (yield), high porosity, and low (little) permeability. If the clay content is extremely thick, a semi-confirmed aquifer situation may be generated. Conversely, the primary aquiferious zone can be located at the base of the worn profile, where the breakdown of minerals due to in situ weathering from chemicals has produced materials that resemble gravel and have moderate to high permeability (Chinyem, 2013). Because of the considerable thicknesses, VES 1, VES 5, and VES 6 are recommended locations for high-yield boreholes for viable aquifers. The lithologic log of boreholes drilled in the region is correlated with the interpreted and inferred geoelectric data.

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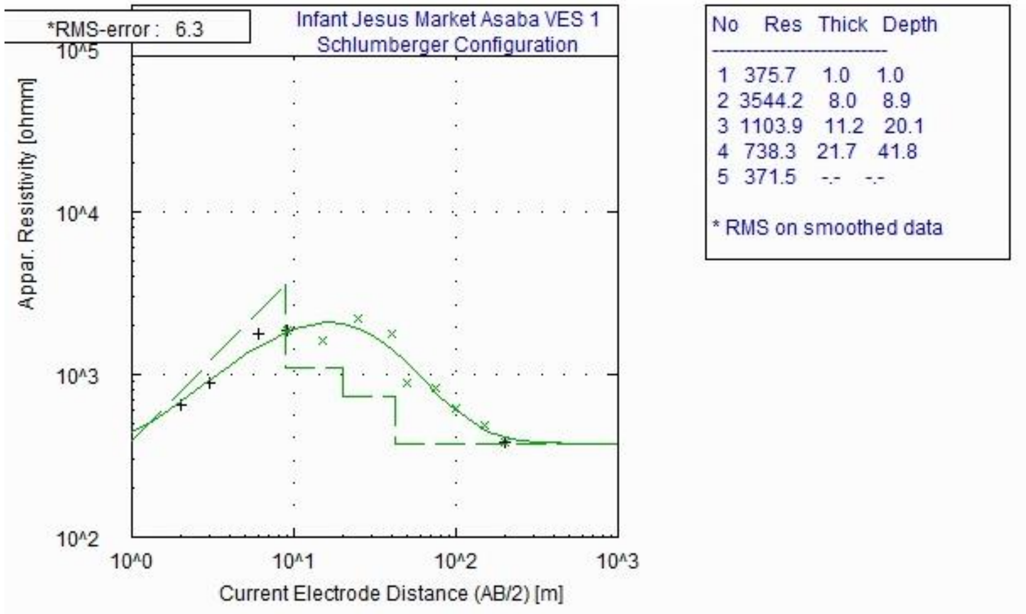

Figure 2: Hydro-geophysical computed curve across Infant Jesus Market Asaba VES 1

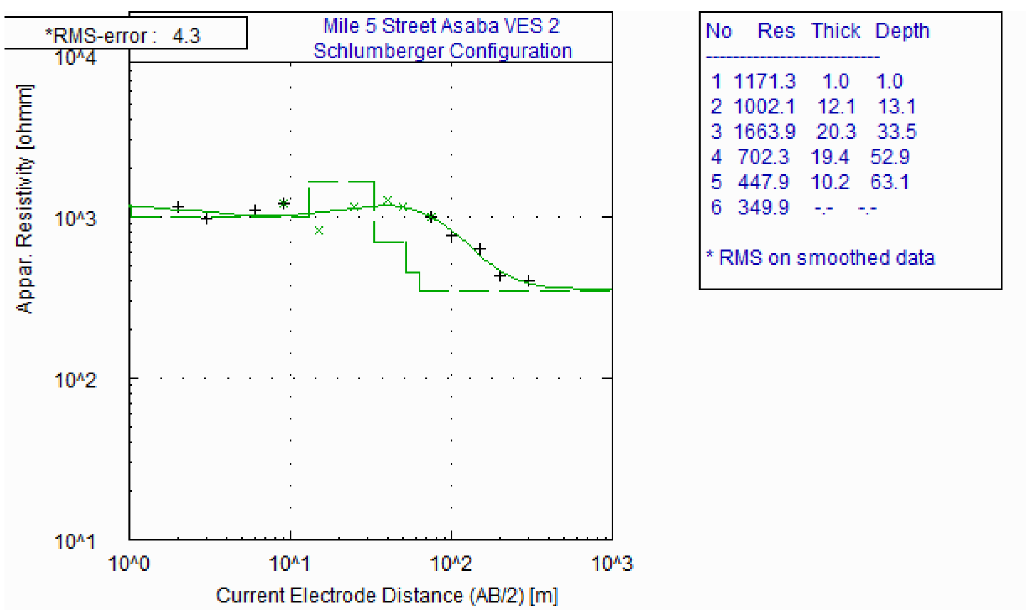

Figure 3: Hydro-geophysical computed iterated trajectory along Mile 5 Street Asaba VES 2

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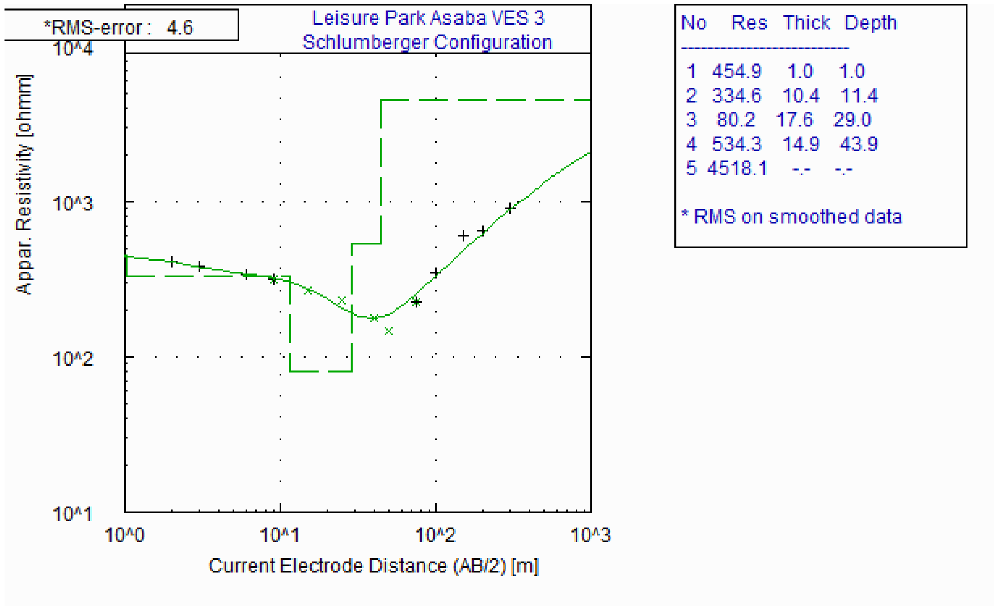

Figure 4: Hydro-geophysical determined iterated formation at Leisure Park Asaba VES 3

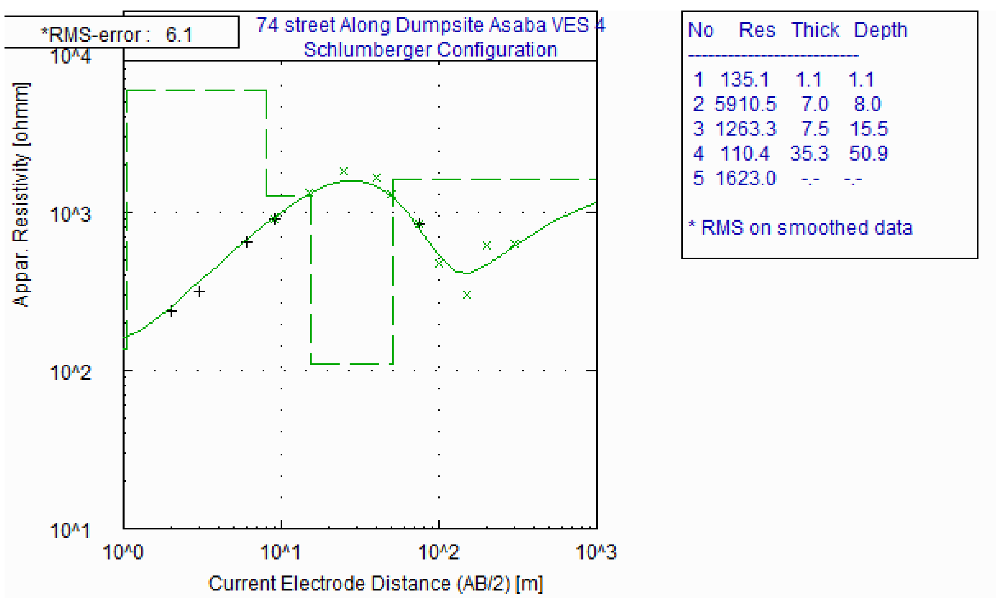

Figure 5: Hydro-geophysical generated evolved curve around 74 Street along dumpsite Asaba VES 4.

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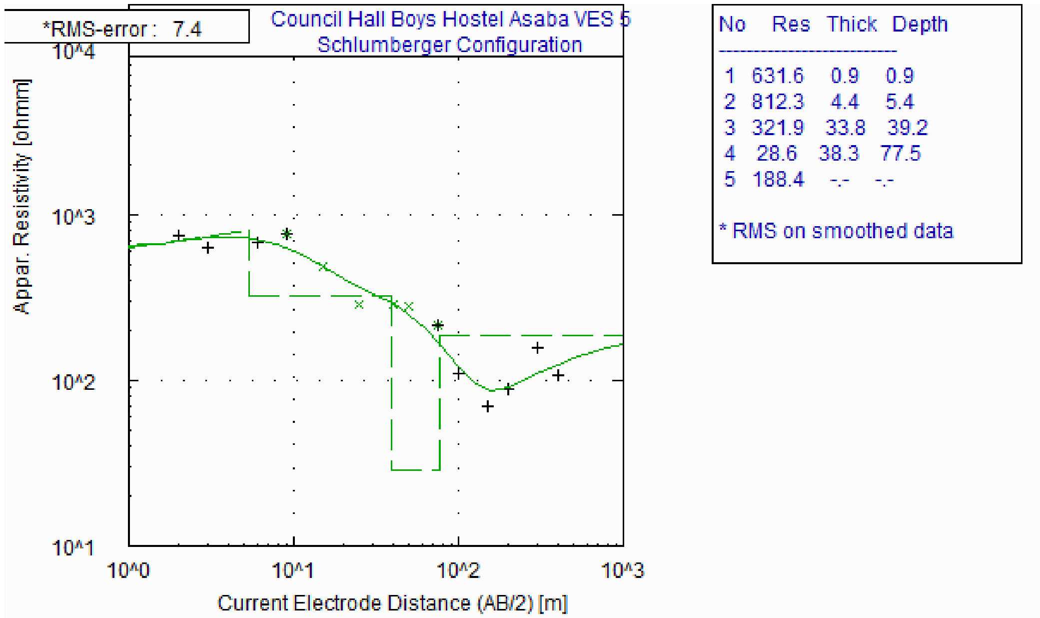

Figure 6: Hydro-geophysical estimated iterated curve along Council Hall Boys Hostel Asaba VES 5.

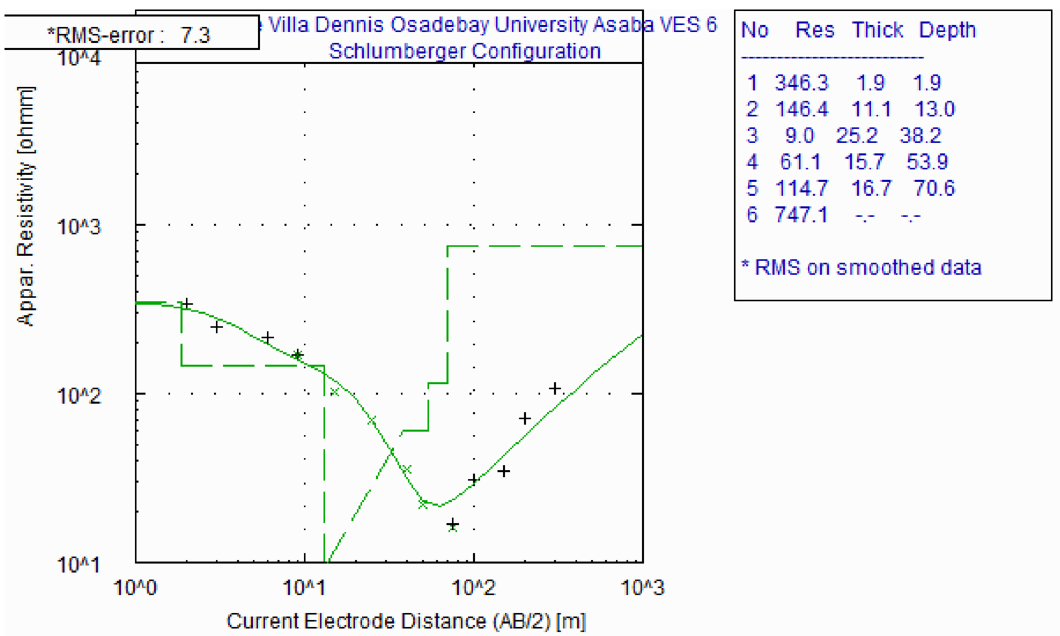

Figure 7: Hydro-geophysical obtained iterated curve type at Coke Villa Dennis Osadebay University Asaba VES 6.

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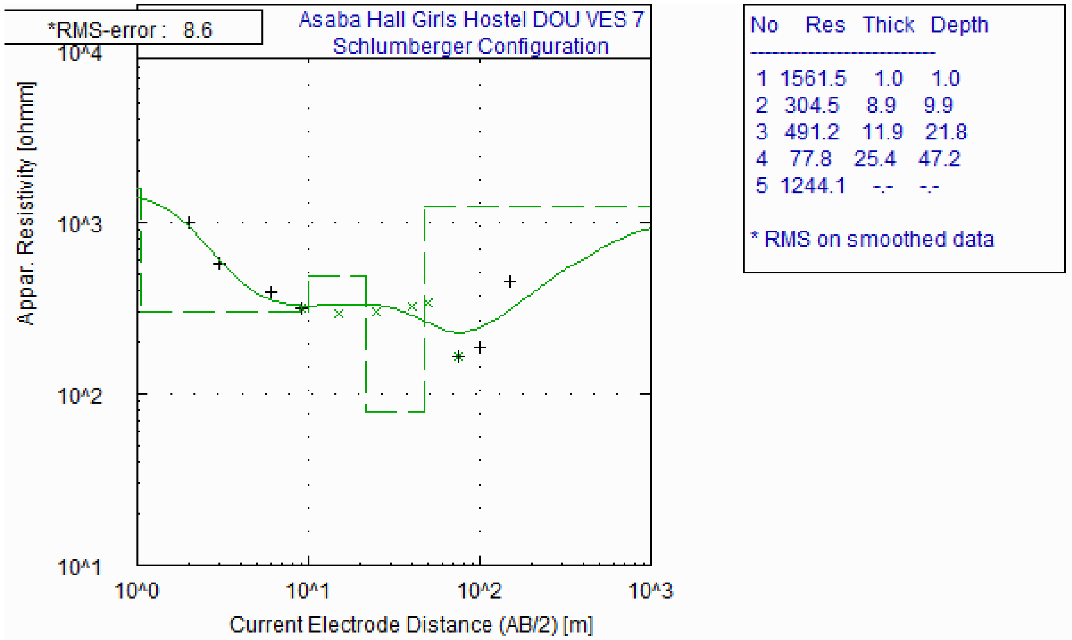

Figure 8: Iterated curve calculated by hydro-geophysics at Asaba Hall Girls Hostel DOU Asaba VES 7.

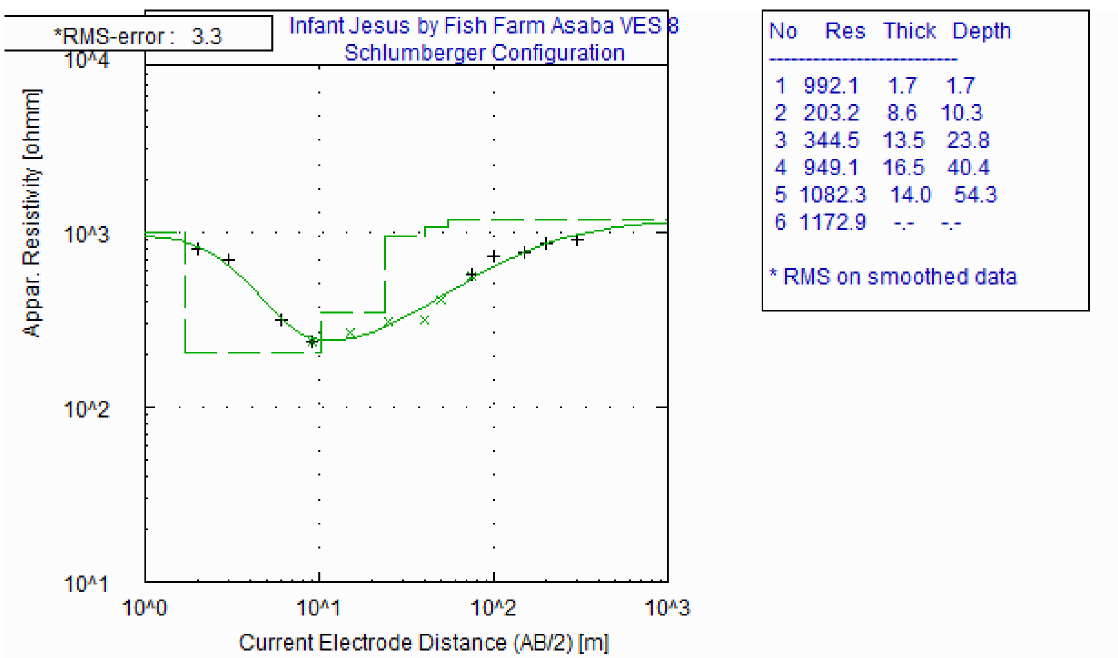

Figure 9: Hydro-geophysical iterated result curve along Infant Jesus by Fish Farm Asaba VES 8.

Table 1: VES geoelectric parameters and longitudinal conductance values of the study area

VES	Strata	Resistivity(Ω m)	Thickness (m)	Depth (m)	Lithology	$S = \sum_{i=1}^{n} \frac{h_i}{\rho_i}$	Protecting Layer Longitudinal Conductivity

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VES 1	1	375.7	1.0	1.0	Topsoil	0.002662	
	2	3544.2	8.0	8.9	Coarse sand	0.002257	
	3	1103.9	11.2	20.1	Medium sand	0.010146	0.011114
	4	738.3	21.7	41.8	Fine Sand	0.029392	
	5	371.5	-----	-----	Fine sand		
VES 2	1	1171.3	1.0	1.0	Topsoil	0.000854	
	2	1002.1	12.1	13.1	Medium sand	0.012075	
	3	1663.9	20.3	33.5	Medium-Coarse sand	0.012200	0.015105
	4	702.3	19.4	52.9	Medium sand	0.027624	
	5	447.9	10.2	63.1	Fine sand	0.022773	
	6	349.9	-----	-----	Fine sand		
VES 3	1	454.9	1.0	1.0	Topsoil	0.002198	
	2	334.6	10.4	11.4	Fine sand	0.031082	
	3	80.2	17.6	29.0	Clay	0.219451	0.070155
	4	534.3	14.9	43.9	Fine sand	0.027887	
	5	4518.1	-----	-----	Coarse sand		
VES 4	1	135.1	1.1	1.1	Topsoil	0.008142	
	2	5910.5	7.0	8.0	Coarse sand	0.001184	
	3	1263.3	7.5	15.5	Medium-coarse sand	0.005937	0.083752
	4	110.4	35.3	50.9	Clayey sand	0.319746	
	5	1623.0	-----	-----	Medium-coarse sand		
VES 5	1	631.6	0.9	0.9	Topsoil	0.001425	
	2	812.3	4.4	5.4	Medium sand	0.005417	
	3	321.9	33.8	39.2	Fine sand	0.105002	0.362751
	4	28.6	38.3	77.5	Clay	1.339161	
	5	188.4	-----	-----	Fine sand		
VES 6	1	346.3	1.9	1.9	Topsoil	0.005487	
	2	146.4	11.1	13.0	Clayey sand	0.075820	
	3	9.0	25.2	38.2	Clay	2.800000	0.656772
	4	61.1	15.7	53.9	Clay	0.256956	
	5	114.7	16.7	70.6	Fine sand	0.145597	
	6	747.1	-----	-----	Medium sand		
VES 7	1	1561	1.0	1.0	Topsoil	0.000641	
	2	304.5	8.9	9.9	Fine sand	0.029228	
	3	491.2	11.9	21.8	Fine sand	0.024226	0.095143
	4	77.8	25.4	47.2	Clay	0.326478	
	5	1244.1	-----	-----	Medium sand		
VES 8	1	992.1	1.7	1.7	Topsoil	0.001714	
	2	203.2	8.6	10.3	Fine sand	0.042323	
	3	344.5	13.5	23.8	Fine sand	0.039187	0.022709
	4	949.1	16.5	40.4	Medium sand	0.017385	
	5	1082.3	14.0	54.3	Medium Sand	0.012935	
	6	1172.9	-----	-----	Medium-coarse sand		

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Table 2: Computed aquifer parameters from determined resistivity and thickness

VES Stations	Latitude(°N)	Longitude(°E)	p_a (Ωm)	h_a(m)	Aquifer depth (m)	Elevation (m)	Protective Capacity (P.C)
VES 1	6.2428	6.7022	738.3	21.7	41.8	38	0.011114
VES 2	6.2667	6.7061	447.9	10.2	63.1	50	0.015105
VES 3	6.2500	6.7047	534.3	14.9	43.9	44	0.070155
VES 4	6.2419	6.6992	1263.3	7.5	15.5	42	0.083752
VES 5	6.2611	6.7025	321.9	33.8	39.2	50	0.362751
VES 6	6.2575	6.7033	114.7	16.7	70.6	50	0.656772
VES 7	6.2564	6.7014	491.2	11.9	21.8	60	0.095143
VES 8	6.2419	6.7031	1082.3	14.0	54.3	29	0.022709

The intrinsic electrical characteristics and makeup of the formations of rock are the main causes of the considerable variety in aquifer resistivities. The resistivity values shown in Vertical Electrical Sounding (VES) data are shaped by this fundamental link between kinds of rocks and their corresponding resistivities (Akaolisa et al., 2022; Ojo et al., 2023). Furthermore, the measured resistivity values are significantly influenced by the regional geological features and the unique contours and shapes of the model curves. This complex interaction of variables highlights the lack of a single, fixed range for aquifer resistivity. The VES measurements show that the range of aquifer resistivity measured values is noticeably varied. A thorough examination shows that the VES 6 dataset has the lowest possible resistivity measurement in this spectrum, at 114.7 Ωm. On the other hand, as the illustrated Figure 9 clearly illustrates, the VES 4 dataset has the greatest known resistivity, totaling an astounding 1263.3 Ωm, and examining the spatial arrangement of aquifer resistivity reveals a striking pattern. The research area's central core is notable for having exceptionally high aquifer resistivity readings. This conspicuous landmark dominates the research area's southeast quadrant, which has a noticeably elevated, albeit modestly elevated, aquifer resistivity. Understanding aquifer dynamics in this area is strengthened by the interaction between these confined resistivity trends and geologic characteristics.

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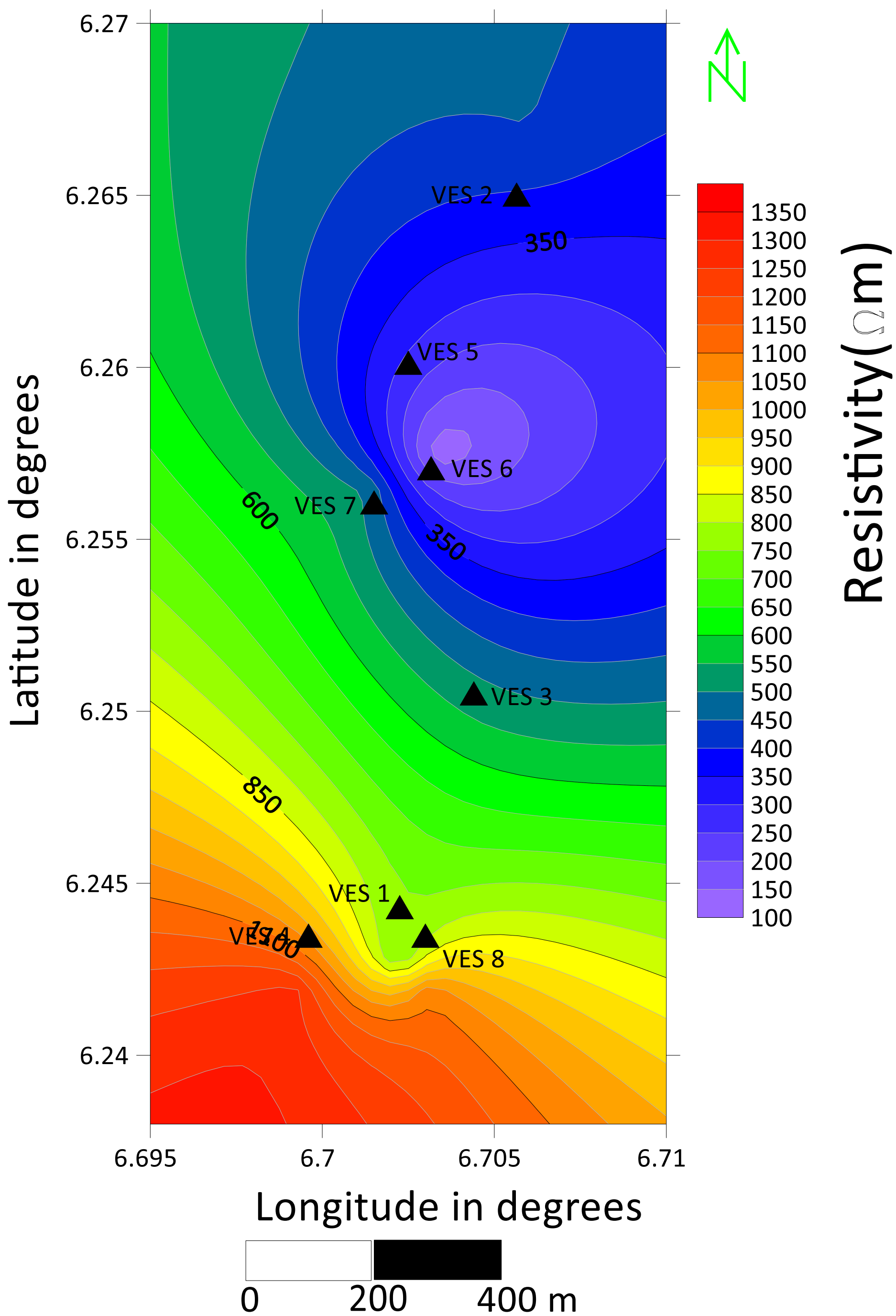

Figure 9: Map depicting the research area's underlying aquifer resistivity

Aquifer thickness is a crucial hydrogeological measure that describes the size of subterranean water reservoirs in your current location. When defining regions with consistent aquifer thickness, the concept of isopachs is quite helpful. This method makes it easier/more convenient to represent areas with similar thickness values, which improves our comprehension of the circulation of subsurface water. Figure 10 provides a meaningful illustration of the aquifer width throughout the research area. A thorough analysis of this map representation reveals clear differences in aquifer thickness. In particular, the aquifer thickness connected to VES 4 is the thinnest, at 7.5 meters. VES 5, on the other hand, draws notice due to its exceptional aquifer thickness of 33.8 meters, which is evidence of the geographical

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heterogeneity in subsurface water reserves. Surprisingly, a dominant pattern emerges when the regional distribution of aquifer thickness is examined more closely. The focal point of this fascinating pattern is located in the middle of the research area, where an abundance of somewhat thick aquifers becomes prominent.

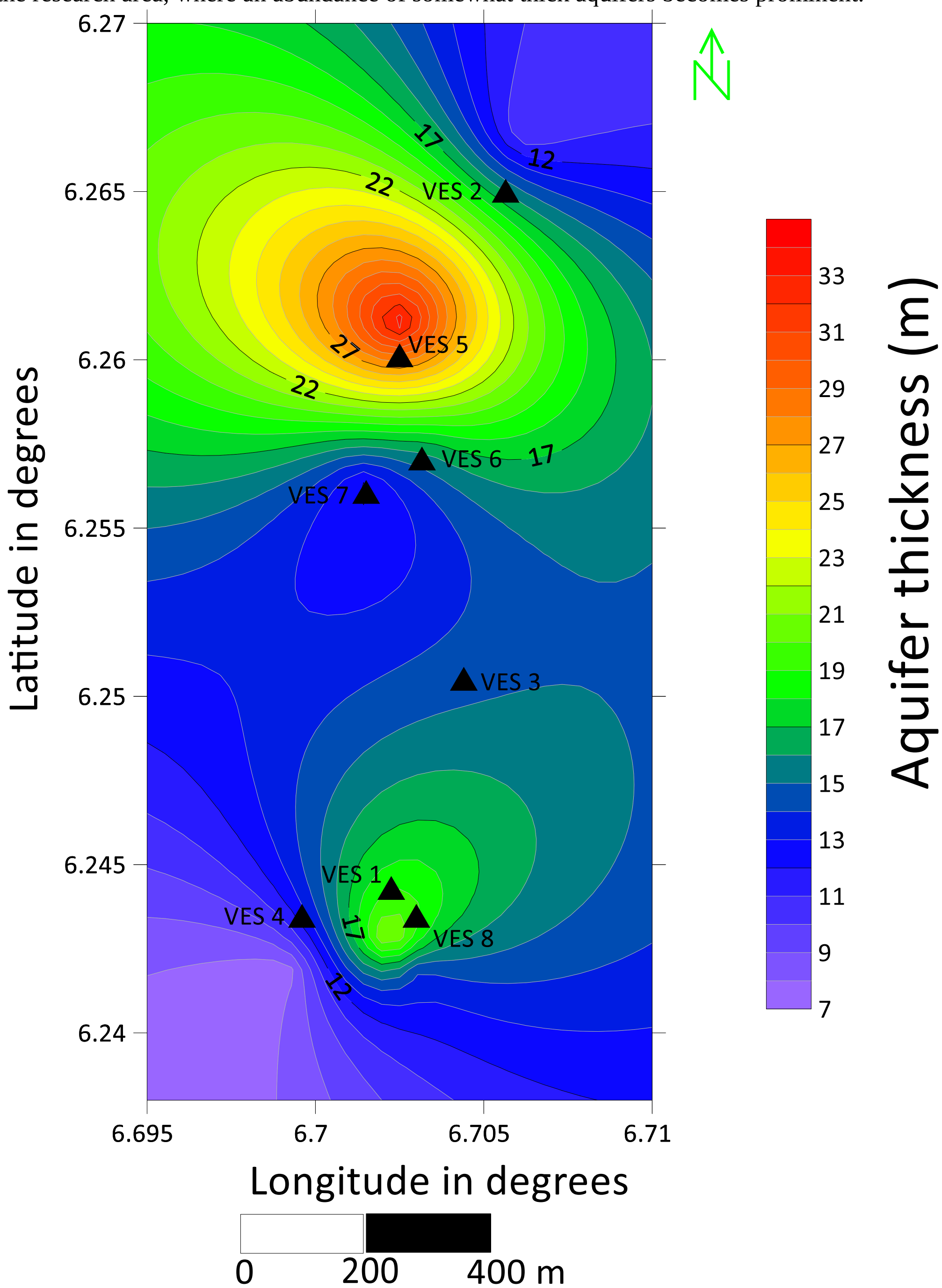

Figure 10: Aquifer thickness contour map of Asaba study area

Aquifer depth is an estimation of the vertical distance between the aerated sections above the water table, which is below the groundwater table, and the saturated portion, where water penetrates the Earth's pores and crevices. Rainfall serves as a catalyst, initiating an enthralling series of events: precipitation seeps through soil and bedrock fissures, obeying gravity's laws as it descends farther into the Earth. Water eventually builds up in lower parts, signaling the

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creation of the overflow zone when subsurface areas are overflowing with water. The fluctuating rate of precipitation highlights the complex ballet between natural components that follows. Changes in rainfall patterns cause the water table's placement to fluctuate, which in turn affects how much water enters the saturation point zone. Climate rhythms are closely linked to the dynamical characteristic of the water table's closeness to the Earth's surface. A symphony of hydrological dynamics is brought about by the water table's altitude fluctuating in tandem with water outflows or use from the saturated zone. By graphically depicting the range of aquifer depth in the research area, Figure 6 conveys this complex story. Interesting observations are uncovered by the visual signals. The aquifer depth reveals its shallowest dimension at VES 4, which is only 15.5 meters. The expedition at VES 6, on the other hand, descends to previously unheard-of depths of an astounding 70.6 meters.

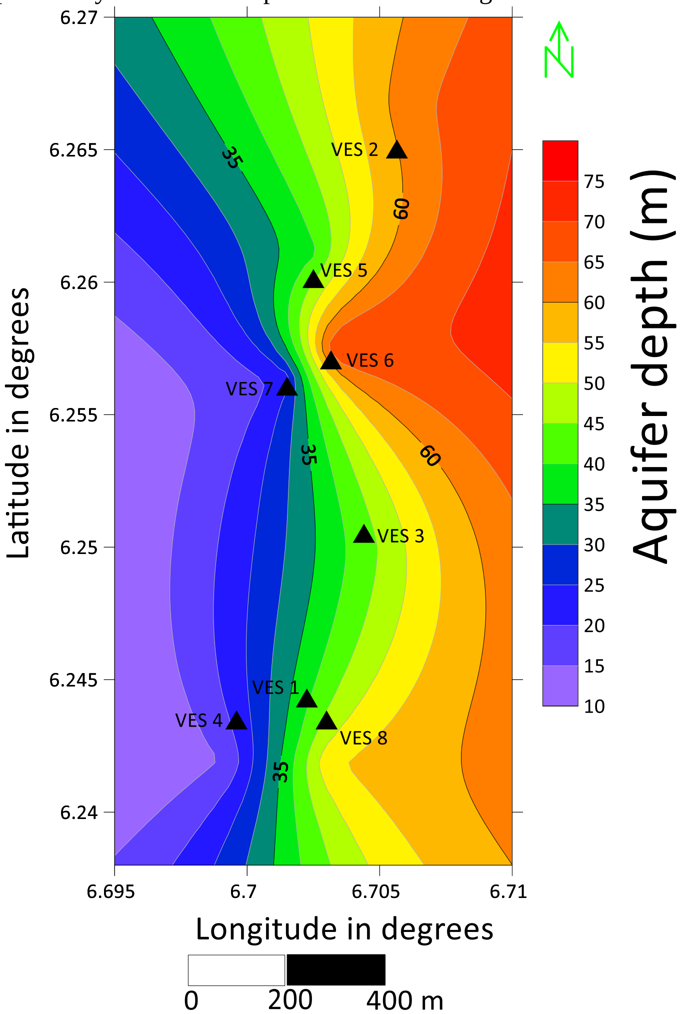

Figure 11: Aquifer depth sketch map of Asaba investigated area

The elevation of the research area rises from the north to the southeast, ranging from 29 to 60 meters. The movement of the flow of groundwater within the research region can be ascertained using this. It runs from higher-elevation areas to lower-elevation areas; thus, caution should be used when drilling (sinking) boreholes in low-elevation areas to avoid contaminating aquifers (Fig. 12).

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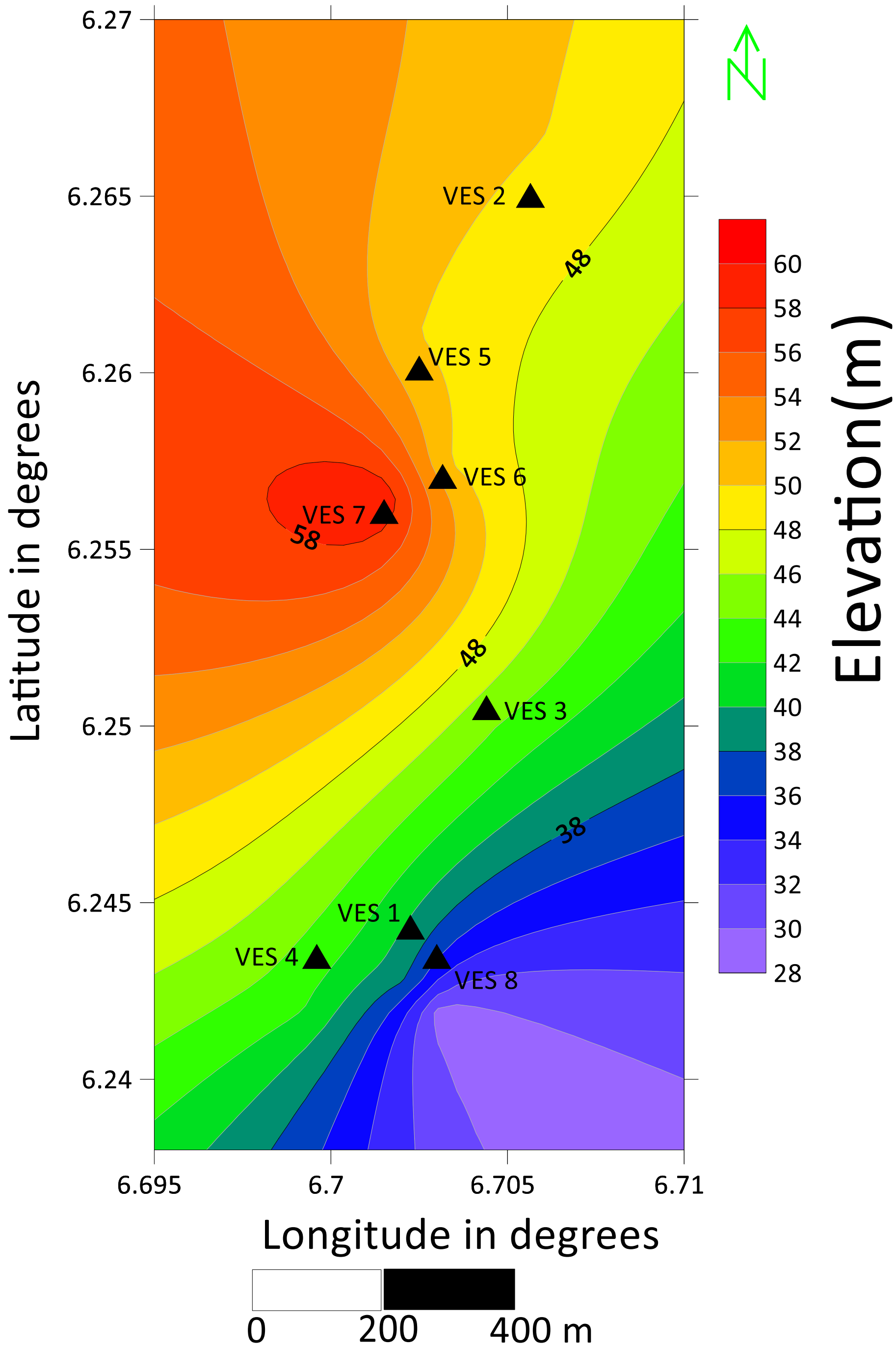

Figure 12: Map illustrating the research area's elevation

An aquifer's "protective capacity" is its ability to stop and clean up contaminated groundwater that seeps in from the surface. An aquifer's vulnerability to pollution is determined by the characteristics of the materials or strata that make up its overburden. According to Ojo et al. (2023), the longitudinal conductance of the underlying units directly affects an aquifer's capacity to offer protection. An important measure of an aquifer's capacity to shield nearby soil and groundwater from possible corrosive impacts is its protective capacity assessment. When it comes to protecting the environment around them from potential corrosive chemicals, the aquifers are consistently rated as having a "poor" protective capability classification. This rating highlights these aquifers' low capacity to counteract or lessen the

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impacts of corrosive materials that might seep into the groundwater. This first evaluation emphasizes the necessity for cautious management of any contamination sources that might mixed or interact with the valuable aquifer system, even if more research is necessary to determine the precise nature of this vulnerability. VES 1, 2, 3, 4, 7, and 8 of the research region have poor protective capacity grades, whereas VES 5 and 6 have intermediate ratings, according to the P.C. map (Figure 13). The lack of a substantial and sufficient quantity of clay as an overburden impermeability in the research area increases the migration of contaminants into the viable aquifer, which accounts for the low protective capacity level. In the event of unpredictable pollution, the aquifer in the studied area will be vulnerable to poisoning.

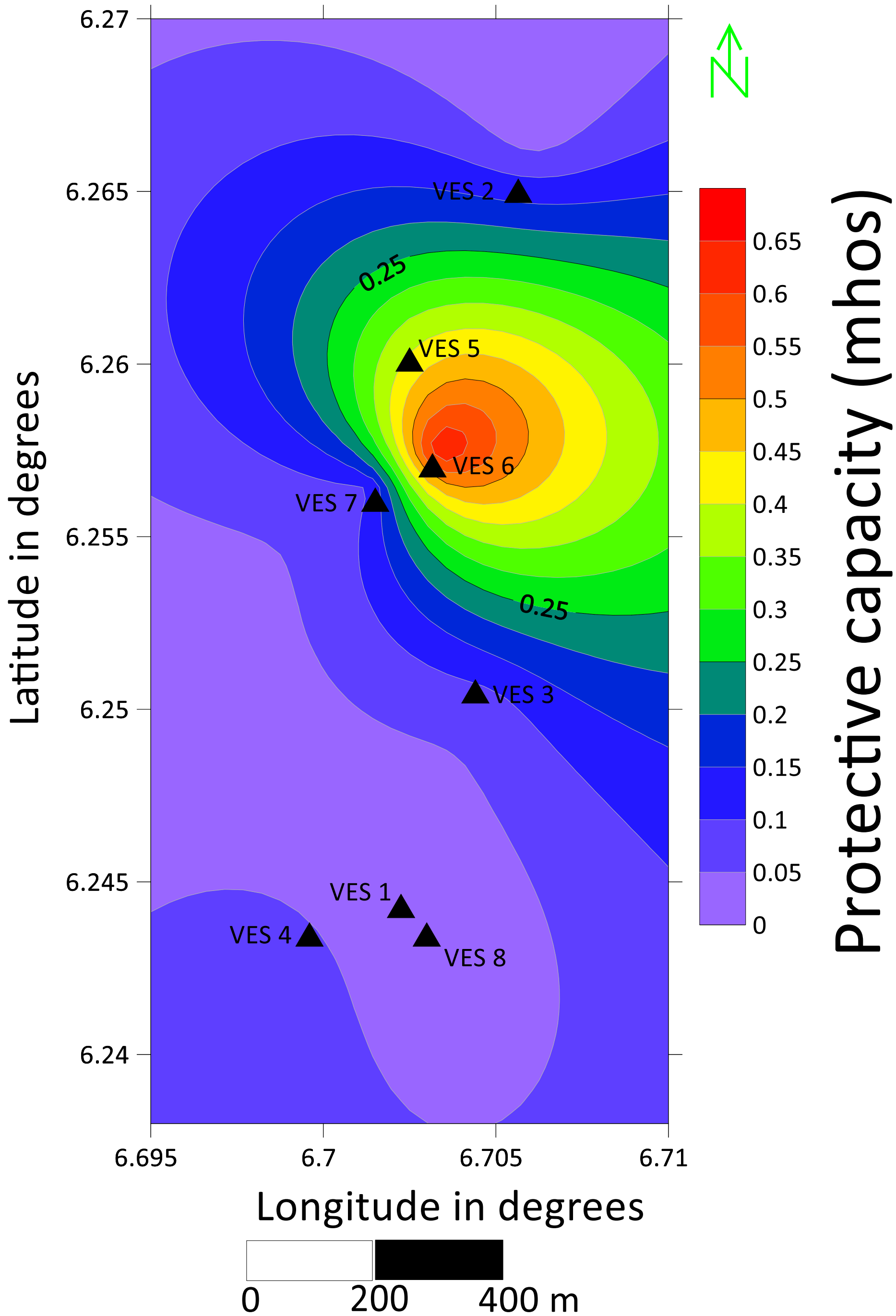

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Figure 13: Map of the study area's protective capacity (P.C.)

Conclusion

In the Asaba region of Delta State, eight (8) Schlumberger vertical electrical soundings were conducted. The geo-electric inquiry's findings showed that the topsoil, clay, clayey sand, and sand (fine, medium, medium-coarse, and coarse-grained sand) were geo-electric layers that actually matched the lithology found in the borehole logs. It is strongly advised that boreholes in the vicinity be constructed to a depth of roughly 50 to 70 meters in order to have good and dependable water yields, in particular at sites of VES 1, VES 5, and VES 6, respectively, as the geo-electric survey conducted indicates and shown that the aquifer type is primarily confined. It is also advised to use a good drilling rig, particularly in the Asaba Hall Girls' Hostel (VES 7) area, which is higher above sea level, and in VES 6, where clayey formations are found. In order to distinguish between different types of sand and guarantee that drilling sufficiently approaches the water table, drilling must be additionally overseen by an experienced geologist and geophysicist. More significantly, there is a strong correlation between the geo-electric sounding and drilling findings. This study has shed light on how surface electrical resistivity surveys are used to identify subsurface formations in the Asaba region.

Recommendations

- Based on the discoveries (findings) of the investigation, boreholes in the studied area should be carefully drilled to a sufficient depth of beyond 75 m to tap from uncontaminated and quantifiable groundwater,
- Radioactive, chemical analysis and other geophysical techniques have been advised to be undertaken to ascertain and correlate the correctness of the electrical method used.

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