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Assessment of Aquifer Resistivity, Depth, and Thickness using Vertical Electrical Sounding (VES) in Parts of Bori Metropolis for Groundwater Exploration

Beabu Gbenete Menegbo, Onengiyeofori Anthony Davies * and Opiriyabo Ibim Horsfall

Rivers State University, Physics Department, Faculty of Science, Port Harcourt, Rivers State, Nigeria.

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Abstract

Groundwater exploration is vital to guaranteeing a reliable water supply in both urban and rural locations. In Bori Metropolis, the growing demand for potable water necessitates a thorough examination of the aquifer system. Therefore, the purpose of this study is to determine the groundwater potential in Bori Metropolis by assessing aquifer resistivity, depth, and thickness using Vertical Electrical Sounding (VES). A total of 13 VES surveys were completed in the study region using the Schlumberger array. The apparent resistivity measurements were analyzed using 1D inversion techniques to determine aquifer depth and thickness. The results showed that aquifer resistivity values ranged from $140\Omega m$ to $3800\Omega m$ at depths ranging from $40m$ to $120m$. Aquifer thicknesses ranged from $20m$ to $115m$, indicating a high groundwater potential in the area. The results indicate that the Bori Metropolis area comprises a well-defined aquifer system with a high potential for groundwater extraction. These findings give important information for future water resource management in the region.

Keywords: Groundwater; Aquifer; Depth; Resistivity; Thickness

1. Introduction

The growing need for clean and reliable water has increased the necessity for groundwater investigation, particularly in rapidly urbanizing areas. Groundwater is a crucial resource for home, agricultural, and industrial use, particularly in locations where surface water sources are limited or excessively contaminated. Groundwater exploration has emerged as a potential method to address rising water demand in several Nigerian cities and semi-urban areas [1, 2]. This research focuses on areas of Bori Metropolis, a fast-rising metropolitan center in Rivers State, Nigeria, where groundwater remains an important source of drinkable water.

According to West and Sinha [3], aquifers are underground layers of water-bearing rocks or sediments that collect and transport groundwater. These aquifers must be identified and characterized in order to ensure sustainable groundwater management. Aquifer depth, resistivity, and thickness are all important factors for groundwater exploration because they determine the quality and amount of available groundwater resources [4, 5]. According to Amechi *et. al.* [6], identifying the regional distribution of these factors is critical for efficient groundwater extraction and long-term conservation. To accomplish this, geophysical techniques such as Vertical Electrical Sounding (VES) have been frequently used.

VES is a non-invasive electrical resistivity technique that can reveal important information regarding subsurface lithology and the presence of groundwater. VES aids in the delineation of aquifers, the assessment of their thickness, and the estimation of groundwater depth by measuring the difference in electrical resistivity at various depths. The method's capacity to distinguish between saturated and unsaturated strata, as well as expose the resistivity contrast between different rock types, make it a dependable instrument for groundwater investigation [7, 8].

* Corresponding author: Onengiyeofori Anthony Davies

In this work, VES was used to analyze the subsurface properties of some parts of Bori Metropolis, with the goal of determining the resistivity, depth and thickness of the area's aquifers. The metropolis, located in the Niger Delta region, has complicated geology, with alternating layers of sand, clay, and gravel that influence groundwater availability and flow [9]. The region's geomorphological features, combined with its humid tropical climate, pose particular hurdles to groundwater exploration, demanding specific and specialized investigations like this one.

The goals of this study are threefold: to define the aquifer systems in the study region, to assess their resistivity levels, to establish their depth and thickness. Understanding these aspects is critical for building long-term water supply solutions for Bori Metropolis' rising population. This study contributes to the larger subject of hydrogeophysics by giving empirical data that will help with the design and execution of groundwater extraction systems. The findings of this study will also have practical applications in urban planning, agricultural development, and environmental management in the region.

2. Geological Framework and Groundwater Potential of Bori Metropolis

Bori Metropolis, located in Rivers State in the Niger Delta region, has a significant groundwater potential due to its geology. This region is distinguished by sedimentary formations, comprising alternating layers of sand, clay, and gravel that have accumulated over millions of years [9]. The geologic structure effects the transportation, storage, and quality of groundwater, making it an important consideration in groundwater exploration.

Bori is built on top of the Benin Formation, which is made up of coarse to medium-grained sandstones mixed with clay lenses. Sandstones, due to their high porosity and permeability, are excellent aquifers, allowing for significant groundwater storage and flow [10]. However, the clay lenses serve as limiting layers, resulting in isolated aquifers with varied properties. These sand-rich layers have low resistivity when saturated, making them detectable using geophysical approaches such as Vertical Electrical Sounding (VES) [11], which was used in this work.

The Agbada Formation lies beneath the Benin Formation, and it is made up of alternating layers of sandstone and shale. While best recognized for its oil and gas riches, this formation also contains restricted aquifers at higher depths [12]. The Agbada Formation's shales have limited permeability, limiting vertical groundwater movement and generating circumstances conducive to artesian aquifers in some areas [13].

Bori's geology is hydrogeologically significant, as evidenced by the potential for groundwater exploration in the Benin Formation sand strata. These sands have great transmissivity and storage capacity, making them ideal for dependable groundwater supply [14, 15]. However, the presence of clays and shales disrupts groundwater flow patterns, resulting in isolated aquifers [14]. Groundwater recharge is primarily caused by rainwater infiltration, which is aided by permeable sands; nevertheless, the distribution of impermeable clay layers can produce uneven recharge.

Groundwater exploration in Bori has challenges such as pollution from clay layers that hold surface contaminants and saltwater intrusion from surrounding coastal areas [16]. Over-extraction of groundwater can reduce freshwater pressure and allow saline water to move into aquifers, especially near the shore [17, 18]. Subsidence in the deltaic zone may also threaten groundwater system stability.

Given these geological complexities, Vertical Electrical Sounding (VES) is an effective tool for mapping subsurface layers and detecting aquifer characteristics in Bori. VES detects resistivity contrasts to indicate the depth and thickness of aquifers, as well as the distribution of constraining clay layers. This data is critical for optimizing groundwater extraction and maintaining sustainable water management in the region.

3. Material and methods

3.1. Materials

Materials used in this research include Herojat resistivity meter with an inbuilt battery, 2our (4) pairs of electrodes, measuring tapes, sledge hammer, four reels of cables, four interconnecting wires, Global positioning System (GPS) and Field Data Sheet.

3.2. Method

The method employed in this research work is the general technique employed in vertical electric sounding data acquisition and interpretation.

3.2.1. Field data acquisition

Due to its relatively low cost of field operation and reliability on application to formation and groundwater investigations, the Schlumberger array of electrical resistivity method was applied to thirteen (13) different VES stations, whose coordinates are shown in Table 1.

Table 1 Location of the VES stations.

Location Name	Longitude	Latitude
Kenpoly convocation arena field	7.37414778	4.667667
Kenpoly sec school field	7.37207889	4.665453
BMGS bori field	7.36096	4.67842
Kor road	7.379798	4.676532
Bori police station	7.383455	4.672482
Market road	7.367565	4.677445
Court road	7.375072	4.67591
Tigidam street	7.372935	4.672565
Monokpo street	7.365495	4.66705
Bank road	7.36616	4.67171
Gokana street	7.367968	4.673293
Maakoro street	7.36597	4.665693
Kogam street	7.36778	4.664385

The apparent resistivities of the subsurface layers in our VES stations were measured using the Herojat resistivity meter, which is capable of sending current into the earth subsurface through a pair of conducting electrodes, automatically computing and displaying the apparent resistivity of the subsurface structure under investigation. The Herojat resistivity meter was connected to two pairs of linearly arranged electrodes (a pair for current and a pair for potential) which were hammered into the earth at appropriate intervals to ensure that current electrodes separation is much greater than the potential electrodes spacing as required in the Schlumberger array (whose schematic is shown in figure 1 below).

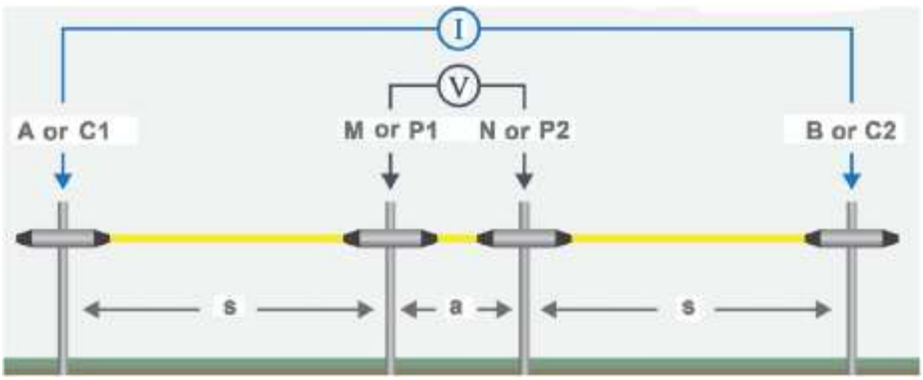


Figure 1 Schematic of Schlumberger electrode array for VES survey [19]

During the survey, the electrodes were arranged symmetrically in a straight line. The current electrodes (C1 and C2) are set at a distance AB from each other that gradually increases as the survey continues. The potential electrodes (P1 and P2), which are closer together than the current electrodes, separated by a distance MN, remained in the same position for the majority of the survey, shifting outward when the signal strength weakens. This arrangement allows the survey to probe deeper into the subsurface by extending the distance between the current electrodes. The midway of the array is known as the center point, from where the survey for this study extended to a maximum distance of 150m on both sides.

As the survey progressed, we injected current into the ground through the current electrodes and the Herojat resistivity meter measured the potential difference between the potential electrodes, from which it estimated the resistance of the subsurface layer according to Ohm's law as seen in equation 1.

$$R = \frac{\Delta V}{I} \tag{1}$$

The current electrodes are gradually spaced farther apart as the survey goes on, producing different measures of formation resistance, in order to investigate deeper into our VES stations. The Schlumberger array maintains good sensitivity to both shallow and deep layers without adding excessive noise by keeping the potential electrodes largely constant for the most of the survey and shifting them outward only when necessary. The collected data is methodically recorded in the field notebook, together with the relevant electrode spacings and any potential influencing ambient factors.

3.2.2. Data Interpretation

The field data obtained was then used to calculate the apparent resistivity (ρ_a) for the different strata of the subsurface in our VES station using equation 2, on the basic assumptions that these strata have homogenous resistivity.

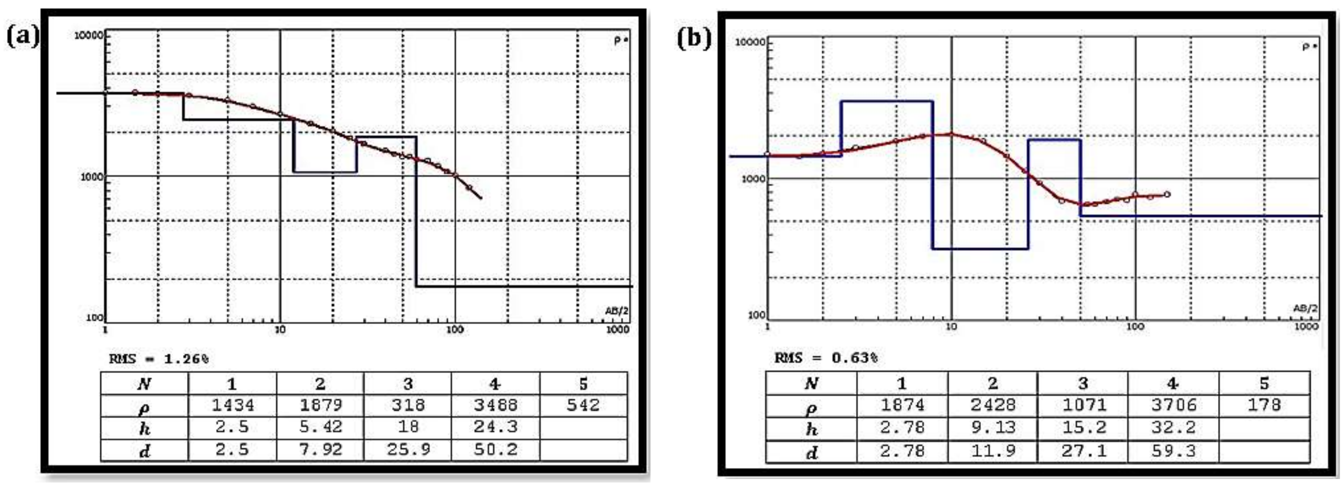
$$\rho_a = \pi\left(\frac{AB^2 - MN^2}{MN}\right)\left(\frac{\Delta V}{I}\right) = K\left(\frac{\Delta V}{I}\right) \tag{2}$$

Where K is usually referred to as the geometric factor.

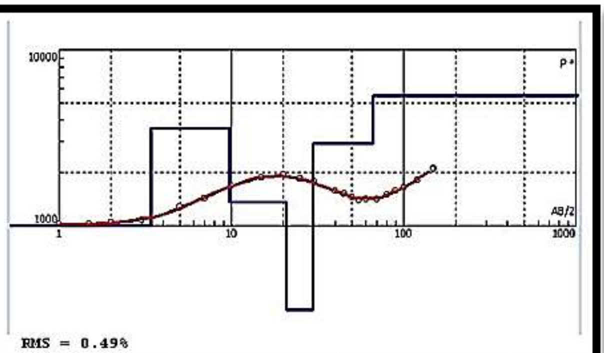
Furthermore, data obtained from equation 2 was then combined with field data and interpreted using the windows-based IPI2win software, producing initial layer parameters which was then curved-matched by comparing this initial model to theoretical models, making necessary corrections. Using an iterative least square algorithm, an inversion of this final accepted model was then carried out on IPI2win to produce subsurface layer resistivity, depth and thickness. Using kriging grid method, a contour map for resistivity, depth and thickness of the identified aquifer was produced.

4. Results

The VES sounding curves for the resistivity data obtained in the study area is shown in Figure 2, with a summary of the identified resistivities, depths and thicknesses for the aquifer from VES sounding curves in Table 2. Additionally, contour maps of the resistivity, depth and thickness of the aquifer is shown in Figures 3-5 respectively.



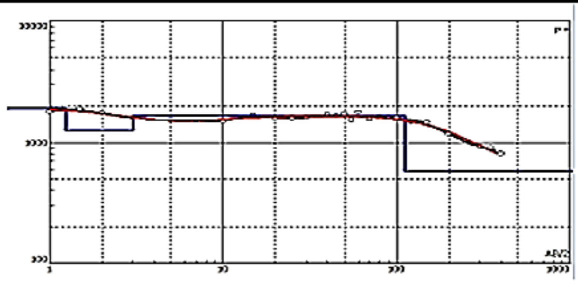
(c)



RMS = 0.49%

N	1	2	3	4	5	6
ρ	1005	3588	1358	333	2950	5469
h	3.42	6.33	10.9	9.08	36.8	
d	3.42	9.76	20.7	29.7	66.5	

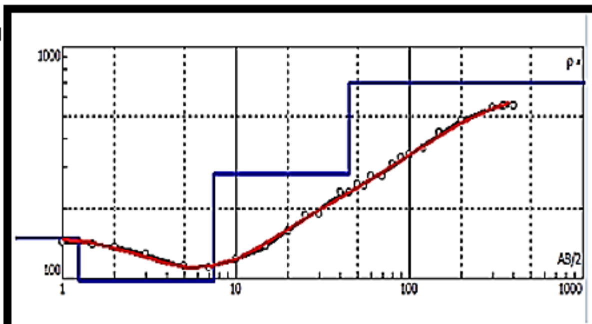
(d)



RMS = 3.12%

N	1	2	3	4
ρ	1916	1252	1658	581
h	1.24	1.79	108	
d	1.24	3.03	111	

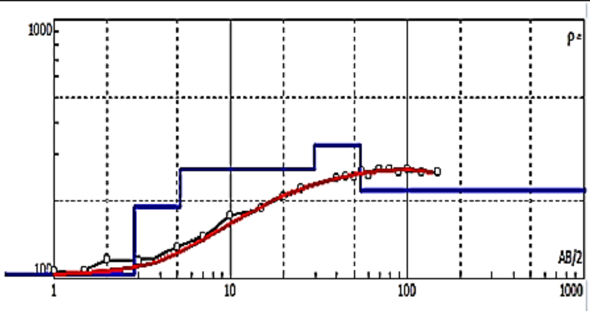
(e)



RMS = 2.05%

N	1	2	3	4
ρ	150	97.1	284	700
h	1.23	6.21	37.5	
d	1.23	7.44	45	

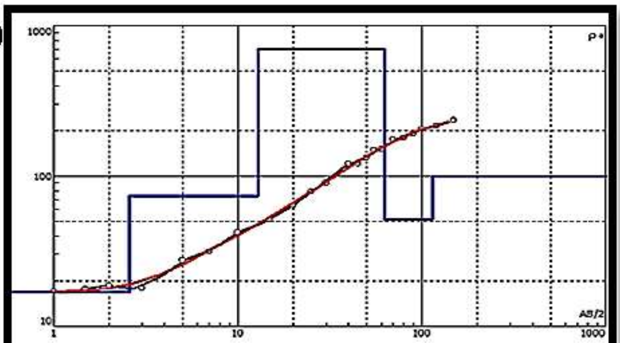
(f)



RMS = 4.01%

N	1	2	3	4	5
ρ	104	186	266	327	219
h	2.86	2.38	24.7	24.6	
d	2.86	5.24	29.9	54.6	

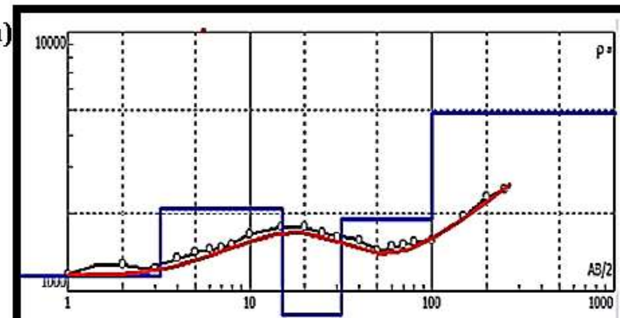
(g)



RMS = 3.48%

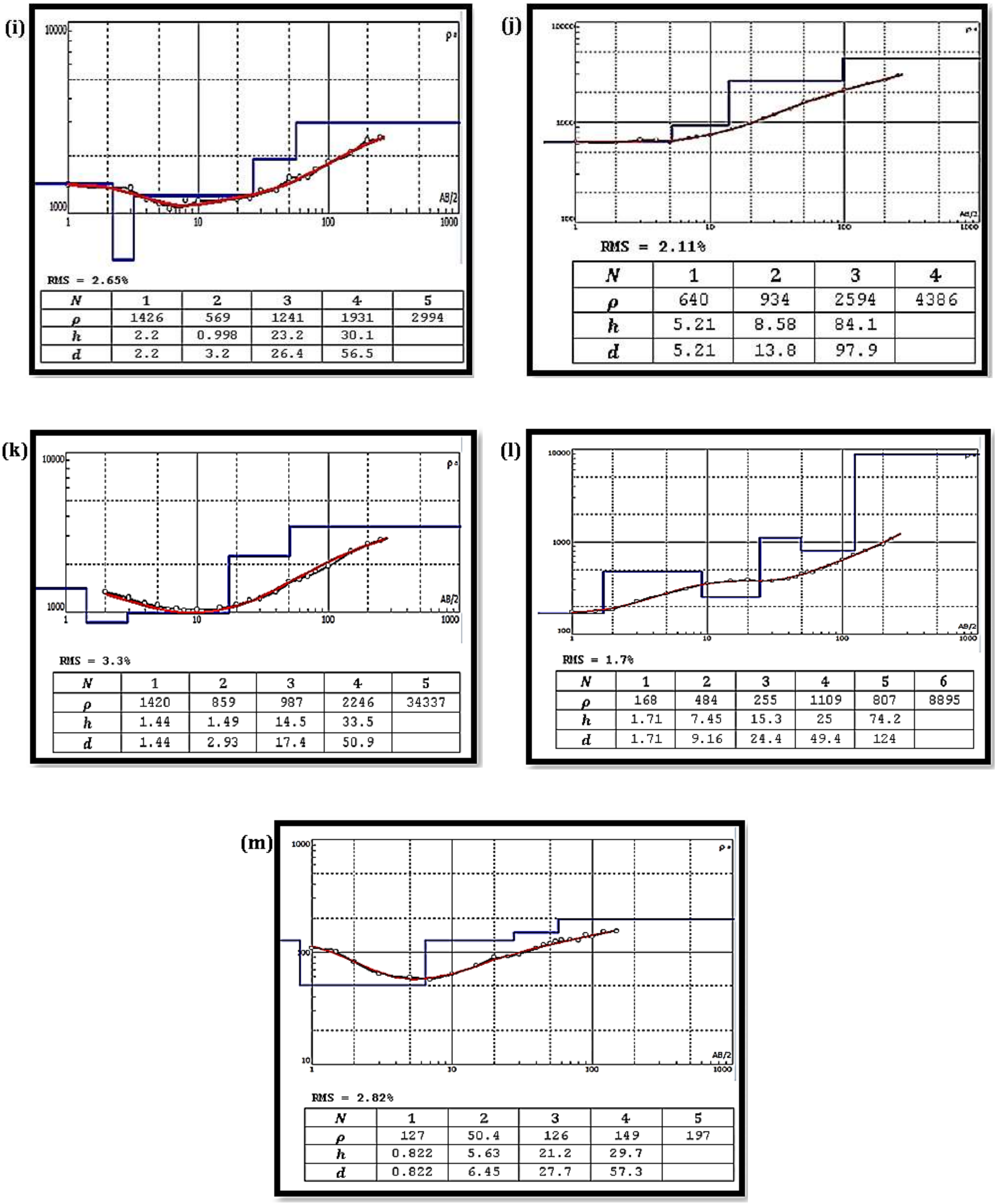
N	1	2	3	4	5
ρ	16.8	73.3	701	51.6	99.8
h	2.56	10.4	49.9	51.4	
d	2.56	12.9	62.9	114	

(h)



RMS = 5.13%

N	1	2	3	4	5
ρ	1148	2087	808	1896	4854
h	3.21	11.9	16.8	68.5	
d	3.21	15.12	32	100	



(i)

N	1	2	3	4	5
ρ	1426	569	1241	1931	2994
h	2.2	0.998	23.2	30.1	
d	2.2	3.2	26.4	56.5	

(j)

N	1	2	3	4
ρ	640	934	2594	4386
h	5.21	8.58	84.1	
d	5.21	13.8	97.9	

(k)

N	1	2	3	4	5
ρ	1420	859	987	2246	34337
h	1.44	1.49	14.5	33.5	
d	1.44	2.93	17.4	50.9	

(l)

N	1	2	3	4	5	6
ρ	168	484	255	1109	807	8895
h	1.71	7.45	15.3	25	74.2	
d	1.71	9.16	24.4	49.4	124	

(m)

N	1	2	3	4	5
ρ	127	50.4	126	149	197
h	0.822	5.63	21.2	29.7	
d	0.822	6.45	27.7	57.3	

Figure 2 VES sounding curves for (a)Kenpoly convocation arena field (b) Kenpoly sec school field (c) BMGS bori field (d) Kor road (e) Bori police station (f) Market road (g) Court road (h) Tigidam street (i) Monokpo street (j) Bank road (k) Gokana street Gokana street (l)Maakoro street (m) Kogam street

Table 1 Summary of relevant variables extracted from VES sounding curves.

VES STATIONS IN BORI	COORDINATES		AQUIFER RESISTIVITY (Ωm)	DEPTH (m)	AQUIFER THICKNESS (m)
	LATITUDE	LONGITUDE			
Kenpoly convocation arena field	7.37414778	4.667667	3488	50.2	24.3
BMGS bori field	7.37207889	4.665453	3706	59.3	32.2
Kenpoly sec school field	7.36096	4.67842	2950	66.5	36.2
Kor road	7.379798	4.676532	1658	111	108
Bori police station	7.383455	4.672482	284	45	37.5
Market road	7.367565	4.677445	327	54.6	24.6
Court road	7.375072	4.67591	701	62.9	49.9
Tigidam street	7.372935	4.672565	1896	100	68.5
Monokpo street	7.365495	4.66705	1931	56.5	30.1
Bank road	7.36616	4.67171	2594	97.9	84.1
Gokana street	7.367968	4.673293	2246	50.9	33.5
Maakoro street	7.36597	4.665693	1109	49.4	25
Kogam street	7.36778	4.664385	149	57.3	29.7

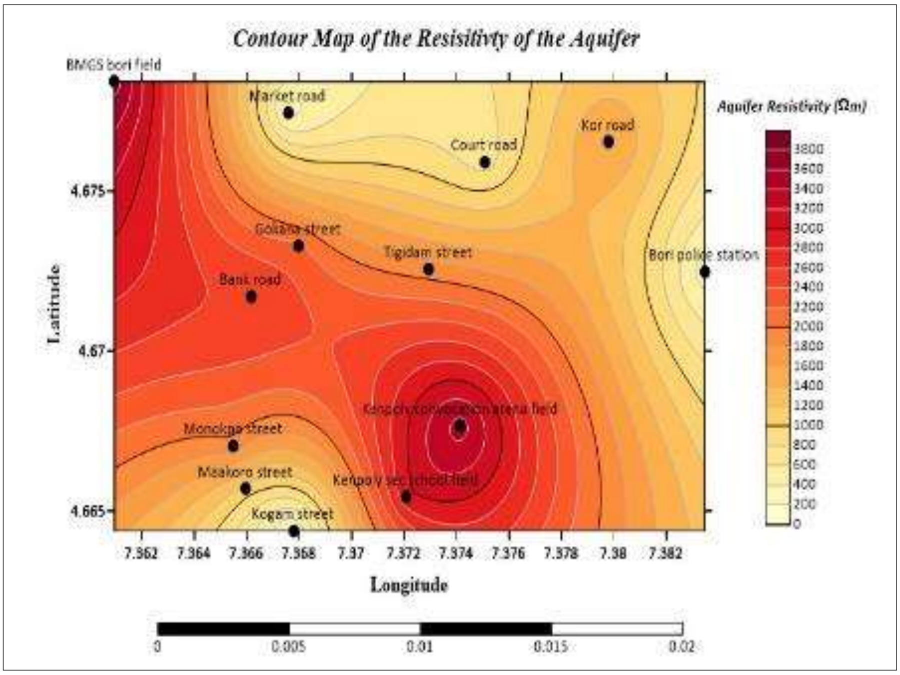


Figure 3 Contour map of aquifer resistivity in the study area

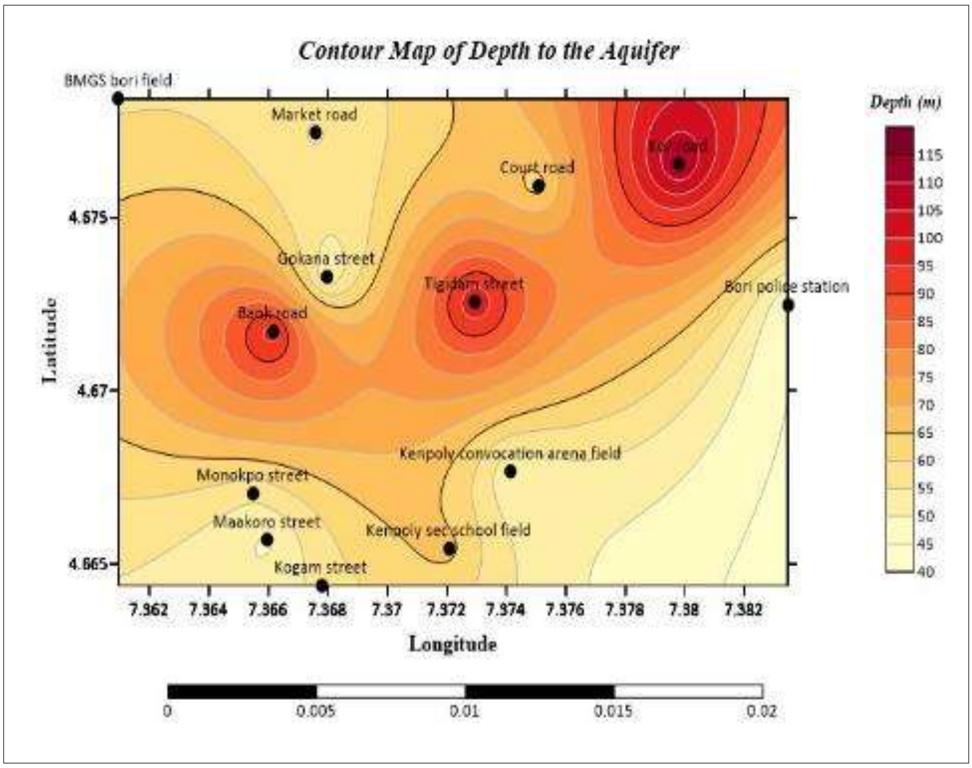


Figure 4 Contour map of aquifer depth in the study area

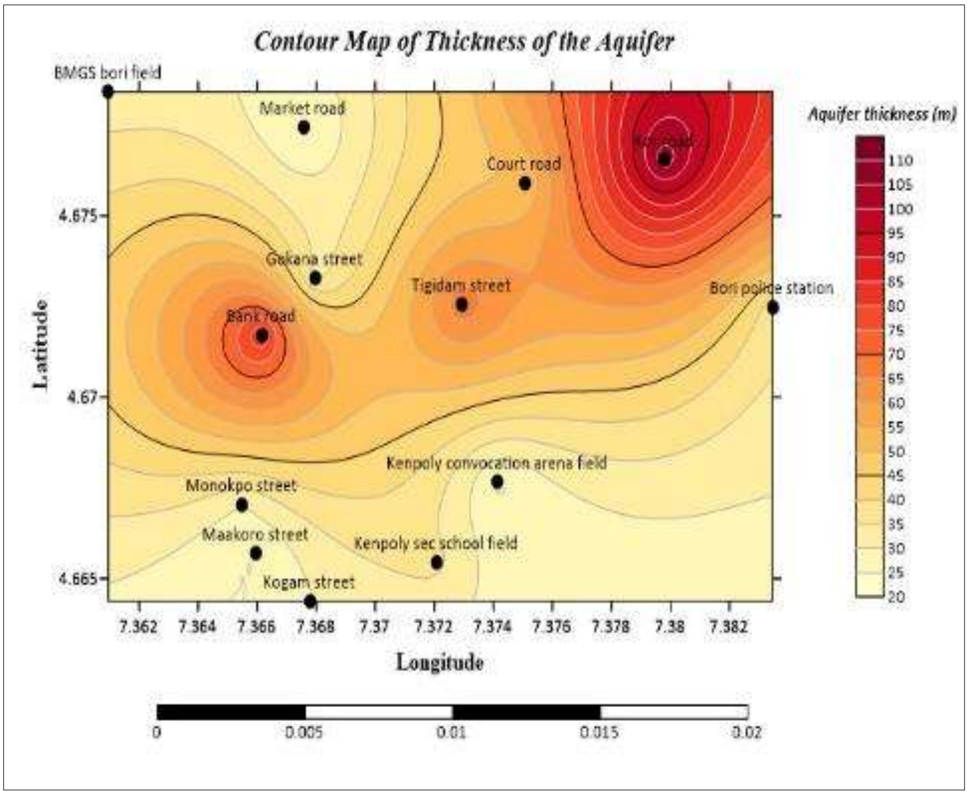


Figure 5 Contour map of aquifer thickness in the study area

5. Discussion

Aquifers are usually found in permeable materials such as sand or gravel, which have a higher resistivity than impermeable, water-saturated materials like clay [20, 21]. In other words, if a layer of low-resistivity clay (impermeable and saturated) sits directly above a layer of more resistive sand or gravel (which may contain water), the sudden increase in resistivity may indicate an aquifer. Based on this premise, the resistivity of the aquifer in the study area, as summarised in Table 1, was identified in our study area from the obtained VES sounding curve in this research. This shows that the aquifer resistivity in the study area ranged from $140\Omega m$ to $3800\Omega m$, as shown in Figure 3.

This wide range of resistivity in our study area could be indicative of water-bearing sandy or gravel zones at the lower end of the resistivity spectrum, typical of moderate to high water saturation zones according to Mohamed *et. al.* [22], and fractured or less saturated rock at the upper end of the spectrum, typical of less conductive materials (potentially fractured igneous or metamorphic rocks or low-salinity groundwater) according to Obasi *et. al.* [23]. Additionally, the wide range of aquifer resistivity in our study area could also be suggestive of the fact that the aquifer system in our study area is heterogeneous, containing both unconsolidated and consolidated materials, as well as varied degrees of water saturation and purity according to González *et. al.* [24].

Furthermore, the identified aquifer in the study area existed at depths ranging from $40m$ to $120m$, as seen in Figure 4, with thicknesses ranging from $20m$ to $115m$, as seen in Figure 5. Aquifers at these depth and thickness ranges are usually suggestive of a strong and sustainable groundwater system with the potential for substantial water supply [25, 26]. These aquifers are likely to be free from surface contaminants, producing high-quality water [27]. Their depth and thickness could also indicate that they are either confined or semi-confined aquifers, with materials such as sands, gravels, or fractured rock, and their significant thickness predicts long-term water supply according to Wright and Novakowski [28].

6. Conclusion

Using Vertical Electrical Sounding (VES), this study was able to determine the resistivity, depth and thickness of the aquifer in several areas in Bori Metropolis. According to the results obtained, the aquifer in the study area have resistivity values ranging from $140\Omega m$ to $3800\Omega m$ and are situated between $40m$ to $120m$ below the surface. Aquifer thicknesses ranged from $20m$ to $115m$.

These findings highlight the significance of sustainable groundwater research in metropolitan areas with rising water needs, in addition to offering crucial insights into the hydrogeological features of Bori Metropolis. If appropriate water resource management techniques are put into practice, the indicated aquifers should provide a consistent supply of water.

The study was constrained, nevertheless, by the use of only one geophysical approach (VES). To confirm water quality and yield, additional research utilizing supplementary methods, such as groundwater sampling and pumping testing, is advised. To ensure the sustainable management of this priceless resource, future studies could concentrate on the long-term monitoring of groundwater levels and possible causes of pollution.

Compliance with ethical standards

Acknowledgements

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Disclosure of Conflict of interests

All authors declare that there are no conflicts of interests regarding this paper publication.

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