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Geophysical Investigation of Groundwater Potential in Gauta Buzu, Nigeria

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ABSTRACT
The increase in human activities, population and climate change in Gauta Buzu area of Keffi has put enormous pressure on the existing water resources in the area. There is a high demand for quality drinking water in the area. In order to facilitate the provision of adequate potable water in Gauta Buzu area of Keffi Local Government, Nasarawa State, this study was carried out to evaluate the groundwater potential in Gauta Buzu, using electrical resistivity survey method, with a view to providing useful information that will help stakeholders in the area in adequate groundwater resources management. In this study, vertical electrical sounding data were obtained, using Schlumberger electrode configuration. Four geologic layers were delineated which includes, topsoil, weathered basement, fractured basement and the fresh bedrock. The second and the third geologic layers of the subsurface in the study area constitute the aquiferous layer. The results of the evaluated aquifer parameters showed that the groundwater potential of the study area ranged from intermediate to good categories. The evaluated aquifer characteristics of the study area indicated that the southwestern part of the study area has good groundwater potential and it's the most appropriate location for municipal borehole site. The other parts of the study area have intermediate or moderate groundwater potential, mainly suitable for domestic water provision. The results of this study will serve as a basis for inform decision making on groundwater resources management in the study area.

INTRODUCTION

Groundwater is the sole alternative water source to surface water sources like rivers, streams, lakes, and oceans. It serves as the main source of drinkable water in the basement complex of north-central Nigeria where there are very limited surface water options such as lakes, rivers, oceans, ponds, and streams (Agada and Yakubu, 2023). Groundwater plays a crucial role in providing water for domestic, agricultural, and industrial uses. It is essential for irrigation farming.

Gauta Buzu is located in the north-central basement of Nigeria, distinguished by crystalline igneous and metamorphic rocks. The communities within the study area face challenges related to inadequate water supply, particularly during the dry season when the minimal available surface water is no longer accessible. The insufficient presence of fresh and potable water in the study area has compelled the communities to resort to unhygienic sources such as ponds and non-perennial rivers for water. The intake of contaminated water is known to cause water-related diseases, including cholera, diarrhea, guinea worm, and kidney and liver ailments within these communities.

Ensuring access to sufficient safe drinking water is crucial for a healthy lifestyle and human well-being. Consequently, it is vital to comprehend the occurrence of groundwater and its hydrogeological traits in a specific area for economic growth and sustainability. An aquifer refers to a geological formation that holds and transmits water (Agada *et al.,* 2020). Understanding its characteristics regarding geological settings, depth, thickness, and potential is critical for ensuring adequate water supply in Gauta Buzu and surrounding areas. Knowledge of aquifer parameters is necessary for effective management of groundwater resources. This understanding will facilitate effective planning and allocation of groundwater resources. Assessing groundwater potential in the study area will contribute to enhancing water availability and agricultural productivity in the region.

Gauta Buzu and its surrounding areas are situated above a migmatites-gneiss complex and young meta-sediments, which are recognized for their low groundwater storage due to their unique lithological characteristics, except in regions where there are thick fractured overburden materials that exhibit low resistivity and high water storage capacity (Singhal and Gupta, 1999; Eduvie *et al*., 2011). Groundwater occurrence varies from one location to another and is dependent on the hydraulic properties of the aquifer. The transmissivity and hydraulic conductivity magnitude of an aquifer can be employed to estimate the groundwater potential of a specific region. The escalating impacts of climate change have directly influenced both the quantity and quality of groundwater resources (Agada and Yakubu, 2022). Climate change has led to variations in the water table, groundwater quantity and quality, as well as its recharge capacity (Agada and Yakubu, 2023).

Detailed comprehension of aquifer parameters is crucial for effective administration of groundwater resources (Agada *et al.,* 2020). The growing demand for groundwater in recent years, stemming from population increase, agricultural activities, and industrial developments have put enormous pressure on available groundwater resource in many parts of Nigeria, Gauta Buzu inclusive (Agada and Satendra, 2023). Therefore, a clear and quantitative representation of aquifer parameters are essential for easy access and fair distribution of groundwater resources, as such information will help in overcoming challenges associated with inadequate water provision in the study area and its environs. In view of the need for adequate groundwater resources management in the study area, this study is focused on using aquifer characteristics to evaluate groundwater potential in Gauta Buzu and its environs.

MATERIALS AND METHODS

Materials

The research was executed using the following materials: Allied Ohmega resistivity meter, Global Positioning System (GPS), 12V Car Battery, personal computer, Electrodes, Reels of Cables and Jumpers, Hammers, Measuring tape, UPS, pegs, Surfer 11 Software, WINRESIST version 1. 0 software and Strater 5 software.

The Study Area

The study site is located in Gauta Buzu in Keffi, positioned within the tropical guinea savannah, which features an extended dry season (November – April) followed by a brief rainy season (May-October). The area is underpinned by Basement Complex rocks (Rahaman, 1976). Annual rainfall in the study area varied from 1290 to 1596 mm. The mean annual temperature was between 21. 5°C and 22. 2°C, while the maximum mean annual temperature reached approximately 23. 5°C. The region consists of rocks such as schists, gneisses, migmatites, and granites, with pegmatite, quartz, and aplite veins exposed on the surface (Ahmed *et al*., 2017). The schists are extensively weathered metamorphic rocks with their minerals oriented in a singular direction due to deformation stress. The outcrops are tough, dark-colored, and range from fine to medium coarse-grained, with biotite mica being the predominant mineral.

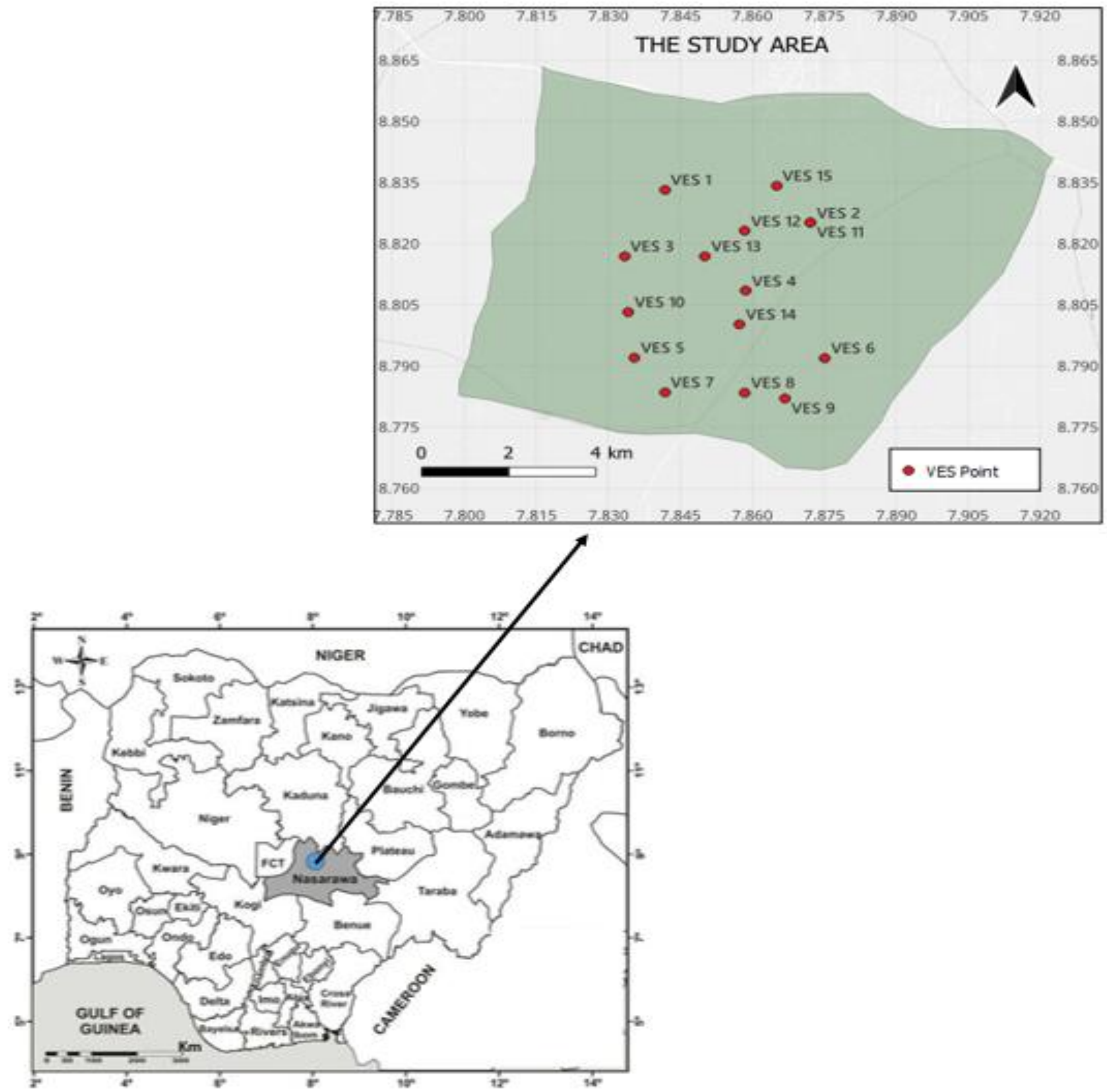

Figure 1: Map of Nigeria showing the study area (modified after Obaje, 2009)

Methods

Electrical resistivity method employing the Schlumberger array was utilized for this study. Field data collection was conducted by laying electrical cables along predetermined profiles, with the cables connected to the ground via sets of electrodes and cable jumpers. An electrode test was administered to confirm that current was flowing through all electrodes. The inner electrodes serve as the potential electrodes, while the outer electrodes act as the current electrodes. A total of fifteen (15) Vertical Electrical Soundings (VES) were carried out in the study area aimed at identifying the various subsurface layers, aquifer thicknesses, depth to groundwater, and overburden thickness. The Allied Ohmega resistivity meter was utilized to measure the resistance, voltage, and current of the soil. The apparent resistivity values were calculated by multiplying the resistance by the geometric factor (K). The resistivities of the subsurface layers were modeled using the United States Geological Survey (USGS) method.

The apparent resistivity data were modeled utilizing the theoretical partial field curve matching method, and the results acquired were employed as input data for iteration, using WINRESIST version 1. 0 Software to determine the true resistivity of the subsurface layers. The various iso-resistivity contour maps were produced using Surfer 11 Software. The parameters of the subsurface rock acquired, include subsurface layers true resistivity and thickness, which were utilized to evaluate the hydrogeological parameters of the study area. The results obtained were constrained with a nearby borehole log for validation.

Theory

Some petrophysical established equations were used to evaluate the aquifer parameters in the study area.

Hydraulic conductivity (K)

Hydraulic conductivity is a porous media property which measures the easy with which a liquid or gas flows through pore spaces. It is measured in meters per second or meters per day. The hydraulic conductivity of the fractured basement was evaluated using Bouwers (1978) characterization. The magnitude of hydraulic conductivity of a geological layer depends on the texture, density, macrostructure of the layer and the grain size. Heigold *et al*. (1979) expresses the relationship between aquifer resistivity ($R_{\emptyset}$) and hydraulic conductivity (*K)* as,

$$K = 386.4\ (R_{\emptyset})^{-0.93283} \quad (1)$$

Where $R_{\emptyset}$ is the aquifer resistivity

Table 1: Hydraulic conductivity value (Bouwers, 1978)

Rock type	Hydraulic conductivity range (m/day)
Clay soil (surface)	0.01-0.2
Deep clay beds	$10^{-8} - 10^{-2}$
Clay, sand and gravel mixture	0.01- 0.1
Loam soil (surface)	0.1-1.0
Find sand	1.0-5.0
Medium sand	5.0-20.0
Sand and gravel mixture	5.0 – 100.0
Coarse sand	20.0-100.0
Gravel	100.0-1000.0

Porosity (*$\emptyset$*)

Porosity is a measure of the volume of voids over the total volume of a given rock materials. It occurs in rocks as a result of the development of weathering, cracks, fissures and joints. It is controlled by the presence and connectivity of fractures which are created by weathering processes. Using the modified Archie law (1942), the porosity of the aquifer was determined using the equation (2).

$$R_{\emptyset} = a.R_w(\emptyset)^{-m} \quad (2)$$

Where a is a formation dependent parameter whose value is assumed to be equal to 1. The constant a is the ease with which the mineral grains permit the free flow of electric current through it (Slater, 2007; Kirsch, 2009). Where m is the porosity exponent or grain-shape (Khalil and Abd-Alla, 2005; George *et al.*, 2015). In this study, R_w is the pore water resistivity obtained from well samples and $\emptyset$ is the aquifer porosity.

Transverse resistance (*T_r*)

The magnitude of the transverse resistance of aquifer is associated with its productivity. The higher the transverse resistance the more productive the aquifer. The transverse resistance of the aquiferous layer was determined using the expression,

$$T_r = \sum_{i=1}^{n} h_i p_i \quad (3)$$

Where h_i and p_i are the layer thickness and resistivity of the ith layer respectively.

Transmissivity

Egbai and Iserhien (2015) defined transmissivity as the ability of an aquifer to transmit water over its entire saturated thickness. The more the transmissivity, the greater the aquifer productivity (Egbai and Iserhien, 2015). Niwas and Singhal (1985) established an equation for evaluating transmissivity in a saturated aquifer as:

$$T = KSR_{\emptyset} = \frac{KS}{\sigma} = Kh \quad (4)$$

Where, *K* is the hydraulic conductivity, *S* is the longitudinal conductance, *h* is the aquifer thickness, $R_{\emptyset}$ is the aquifer resistivity and σ is the aquifer electrical conductivity.

Table 2: Aquifer transmissivity rating (Freeze and Cheery, 1972)

Aquifer Transmissivity (m^2/day)	Aquifer Rating
1000	Very good
100-999	Good
10-99	Intermediate
1-9	Low
0.1-0.9	Very low
< 0.1	Impermeable

RESULTS AND DISCUSSION

The quantitative interpretation of the vertical electrical sounding data obtained from the study area showed that the study area is composed of four (4) geologic layers (Table 3).

Table 3: Vertical Electrical Sounding (VES) survey results of the study area

VES	Layer Resistivity (Ωm)				Thickness (m)			Depth (m)		
	ℓ_1	ℓ_2	ℓ_3	ℓ_4	h_1	h_2	h_3	d_1	d_2	d_3
1	108.2	11.9	264.4	4937.8	2.9	4.7	5.1	2.9	7.6	12.7
2	375.6	27.2	624.9	2888.7	3.0	8.2	12.8	3.0	11.2	24.0
3	200.1	34.8	312.0	829.1	0.5	5.5	27.6	0.5	6.0	33.6
4	324.6	19.3	185.4	766.1	0.8	2.9	20.7	0.8	3.7	24.3
5	324.0	225.6	210.5	2370	0.7	6.5	28.0	0.7	7.1	35.1
6	549.6	74.5	235.0	1765	0.9	12.8	19.4	0.9	13.7	33.1
7	99.5	209.8	38.9	1512	1.1	10.9	22.3	1.1	12.0	34.3
8	556.7	124.1	212.4	4113	1.0	12.3	24.8	1.0	13.3	38.1
9	492.6	796.0	192.5	5200.7	0.5	8.9	20.7	0.5	9.4	30.1
10	169.5	273.8	304.0	4521	0.7	13.5	16.5	0.7	14.2	20.7
11	180.7	59.8	209.7	987.3	1.2	20.7	17.4	1.2	21.9	39.3
12	185.0	674.0	232.5	3125	0.9	8.4	24.5	0.9	9.3	33.8
13	305.6	501.8	217.2	4127	1.0	12.6	27.3	1.0	13.6	40.9
14	284.0	97.4	318.0	5122	2.1	10.7	22.6	1.1	12.8	34.4
15	189.6	126.3	276.5	1157.3	0.6 1	1.4	18.5	0.6	12.0	30.5
Average	289.7	217.1	255.6	2894.8	1.1	10	20.5	1.1	11.1	31.0

The topsoil is characterized by resistivity values which ranged from 99.5 to 549.6 Ωm. The resistivity characteristics of the topsoil showed that it is a lateritic soil. Its thickness ranged from 0.5 to 3.0 m, with an average thickness of 1.1 m (Figure 2a). The resistivity of the second layer ranged from 11.9 to 796 Ωm, with an average of 217.1 Ωm (Table 3). The resistivity characteristics of the second layer indicate that it is a weathered layer whose thickness ranged from 2.9 to 20.7 m. It has an average thickness of 10.0 m (Figure 2b).

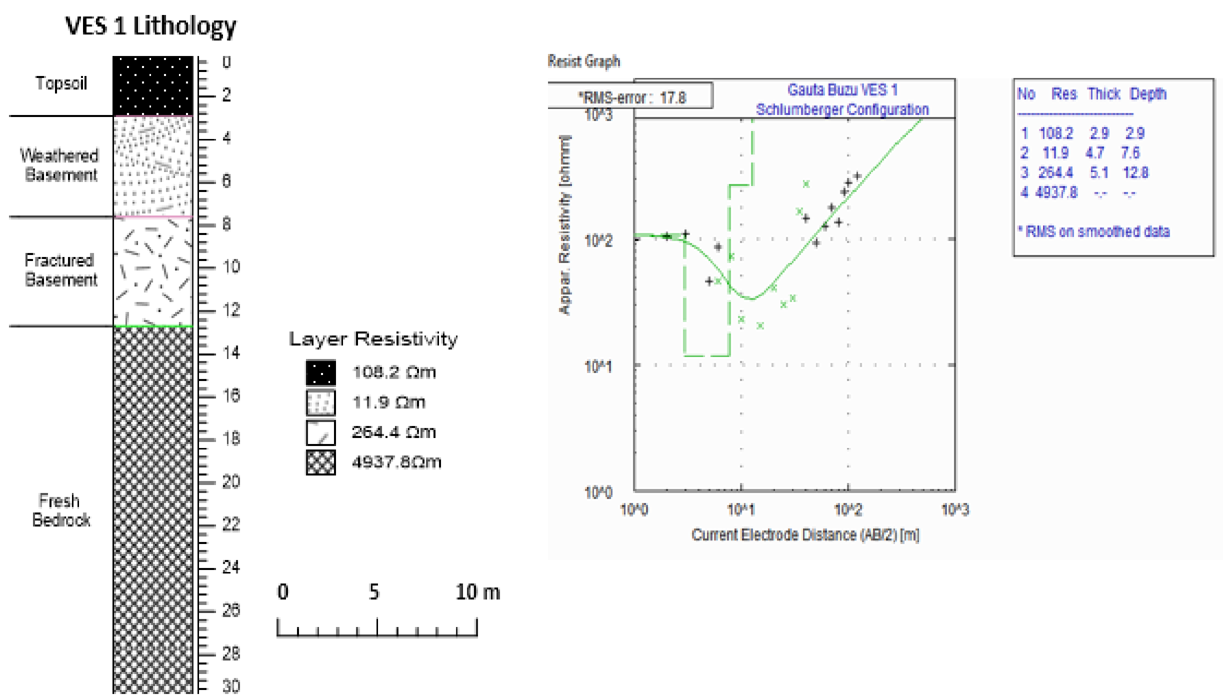

Figure 2a: The vertical electrical curve and the lithology of VES 1 in the study area

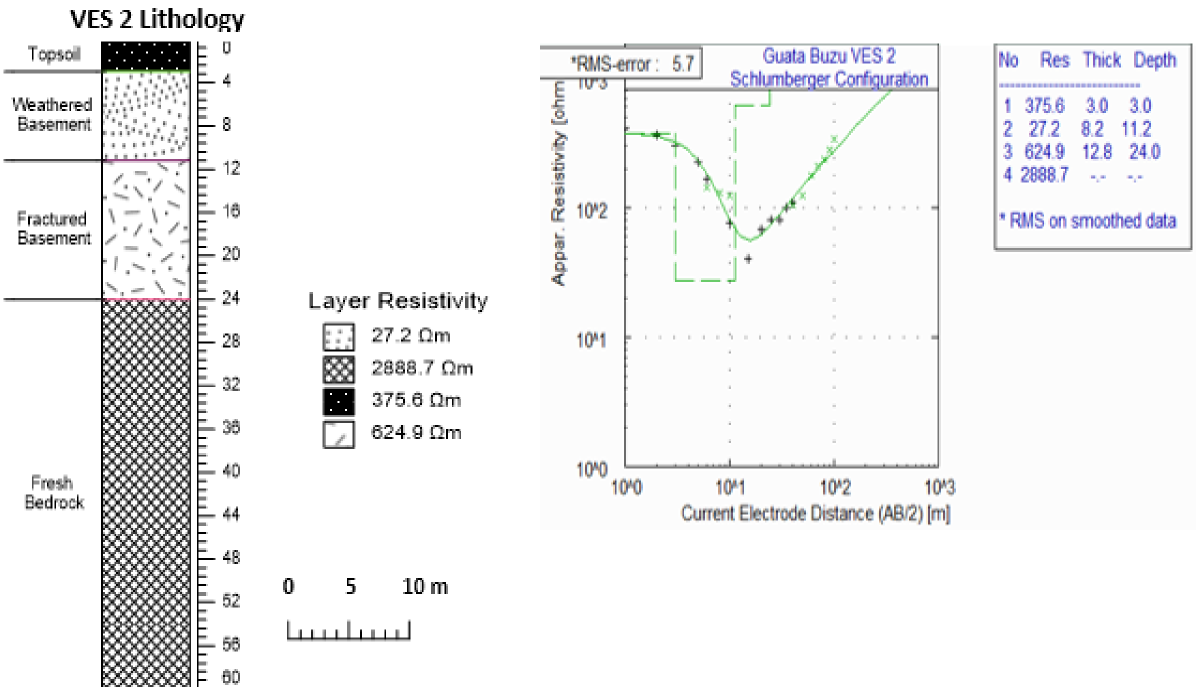

Figure 2b: The vertical electrical curve and the lithology of VES 2 in the study area

The resistivity of the third layer ranged from 38.9-624.9 Ωm with an average of 255.6 Ωm. The resistivity values of the third layer revealed that it is a weathered basement whose thickness ranged from 5.1 to 28.0 m and has an average thickness of 20.5 m (Figure 2c). Both the second layer and the third layer constitute the aquifer zones of the study area. The average thickness of the third layer indicate that the aquifer is has good potential for groundwater.

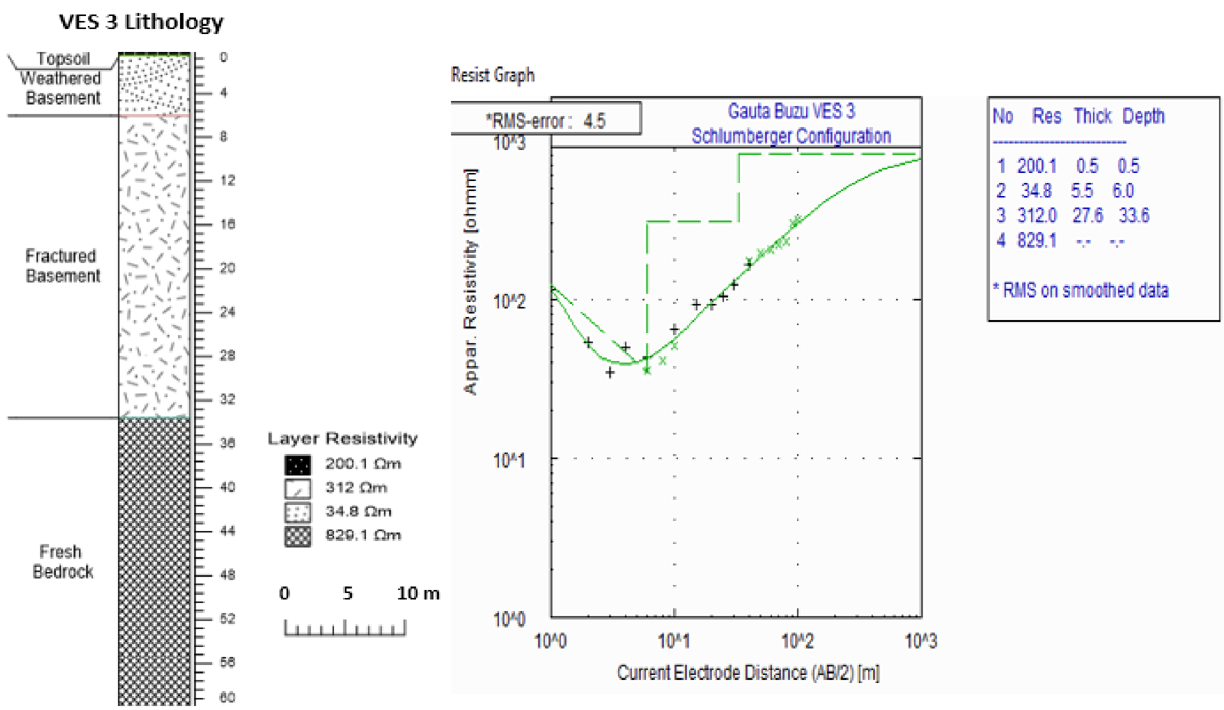

Figure 2c: The vertical electrical curve and the lithology of VES 3 in the study area

The layer below the third layer has resistivity values which ranged from 766.1 to 5200.7 Ωm and has an average resistivity of 2894.8 Ωm. These values revealed that the fourth layer in the study area is fresh bed rock (Figure 2d). The aquifer thickness in the vicinity of VES 1 and VES 2 appeared to be relatively low compared to other parts of the study area.

Aquifer thickness

Aquifer thickness is one of those factors which determine the groundwater potential of an area. The thickness of an aquifer is a function of its ability to store and transmit groundwater. The thicker an aquifer the more its storage capacity. The aquifer thickness varies from one part to another.

The thicknesses of these aquifer indicates that VES 1 and VES 2 areas have intermediate groundwater potential. The thickness of the aquifer in the study area varied from one VES point to another indicating the variability in the groundwater potential of the study area (Table 4).

Hydraulic conductivity, aquifer thickness, groundwater transmissivity and the longitudinal conductance are fundamental indices which help in the estimation of aquifer potential.

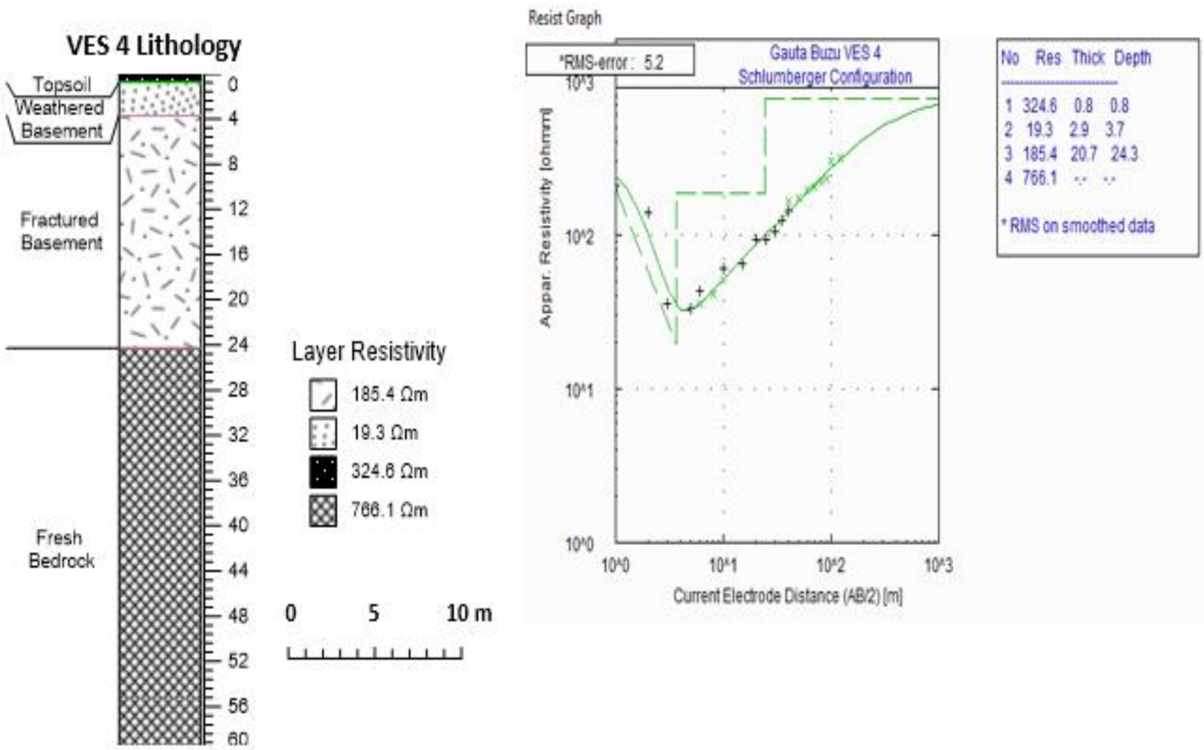

Figure 2d: The vertical electrical curve and the lithology of VES 4 in the study area

Table 4: Hydraulic properties of the aquifer in the study area

VES	Latitude (°N)	Longitude (°E)	Overburden Thickness (m)	Aquifer Resistivity (Ωm)	Aquifer Thickness (m)	Hydraulic Conductivity (m/day)	Transmissivity (m^2/day)	Transverse Resistance (Ωm^2)	Porosity (%)
1	7.8417	8.8330	12.7	264.4	5.1	2.1	10.8	1348.4	4
2	7.8720	8.8250	24.0	624.9	12.8	0.9	12.2	7998.7	2
3	7.8333	8.8167	33.6	312.0	27.6	1.8	50.3	8611.2	3
4	7.8585	8.8083	24.3	185.4	20.7	2.9	61.3	3837.8	6
5	7.8353	8.7918	35.1	210.5	28.0	2.6	73.6	5894.0	5
6	7.8750	8.7917	33.1	235.0	19.4	2.4	46.0	4559.0	4
7	7.8417	8.7833	34.3	38.9	22.3	12.7	283.3	867.5	27
8	7.8583	8.7832	38.1	212.4	24.8	2.7	64.7	5267.5	5
9	7.8667	8.7818	30.1	192.5	20.7	2.8	59.2	3984.7	6
10	7.8340	8.8030	20.7	304.0	16.5	1.9	30.8	5016.0	3
11	7.8720	8.8250	39.3	209.7	17.4	2.6	46.0	3648.8	5
12	7.8583	8.8230	33.8	232.5	24.5	2.4	58.7	5696.3	4
13	7.8500	8.8167	40.9	217.2	27.3	2.5	69.7	5929.6	5
14	7.8572	8.8000	34.4	318.0	22.6	1.9	40.4	7186.8	3
15	7.8650	8.8340	30.5	276.5	18.5	2.0	37.7	5115.3	4
		Average	31.0	255.6	20.5	2.9	63.0	4997.4	6

The aquifer thickness ranged from 5.1 to 28.0 m and has an average value of 20.5 m. The variability of the aquifer thickness in the study area is one of the physical features of a basement terrain (Table 4). The aquifer resistivity in VES 7 is significantly low with a value of 38.9 Ωm, which indicate that this part of the study area is highly weathered and fractured (Table 4).

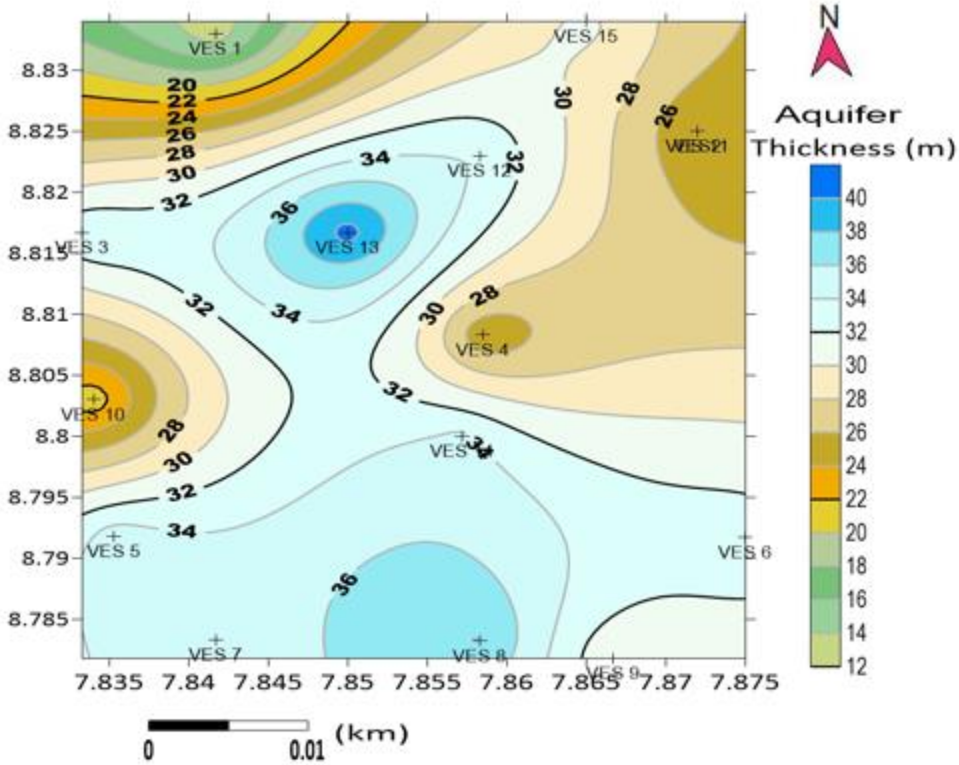

Figure 3: Spatial distribution of aquifer thickness in the study area

The aquifer thickness in the study area is higher in the northcentral part of the study area (Figure 3). The aquifer thickness in the vicinity of VES 1 is significantly small compared to other parts of the study area (Table 4) indicating that the area around VES 1 has low groundwater potential due to less weathered and fractured rock materials that could store groundwater. The aquifer in the southern part of the study area has high thickness value indicating its capacity to store and transmit large volume of water (Figure 3).

Aquifer transmissivity

Aquifer transmissivity is the rate at which water flows through the aquifer. The aquifer transmissivity in the study area ranged from 10.8 to 283.3 m^2/day with an average of 63 m^2/day. The aquifer transmissivity in the vicinity of VES 7 was exceptionally high compared to other parts of the study area due to the presence of highly weather and fractured materials in that part of the study area. The magnitude of aquifer transmissivity in the study area showed that the southeastern part of the study area has good groundwater potential while other parts of the study area have intermediate groundwater potential (Figure 4). The aquifer transmissivity is higher towards the southeastern part of the study area (Figure 4).

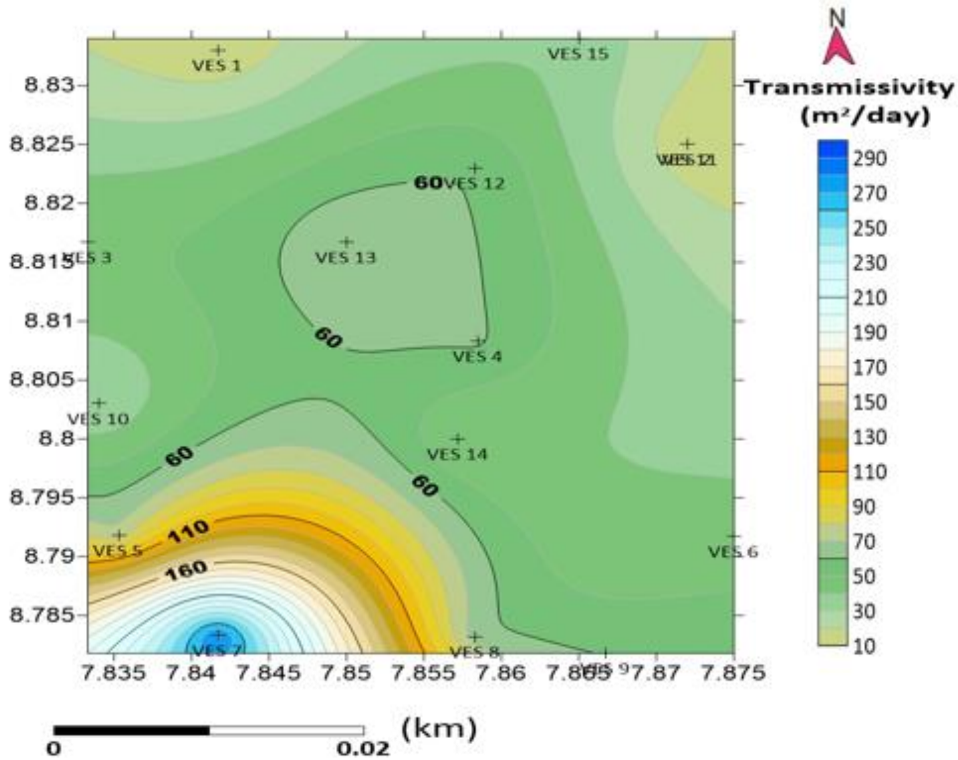

Figure 4: Spatial distribution of aquifer transmissivity in the study area

Aquifer porosity

Aquifer porosity is the percentage of open space in an aquifer's rock or weathered and fractured rock that can store water. It primarily controls the storage and transmission of water in rocks. The aquifer porosity in the study area ranged from 2 to 27 %, with a mean porosity of 6% (Figure 5). The aquifer porosity is higher within the southwestern part of the study area which indicates that the area has good ground water potential compared to other parts of the study area. The aquifer porosity varied from one location to another within the study area (Figure 5). The vicinity of VES 2 has less porous aquifer indicating that the aquiferous zone in that area is less weathered and fractured compared to other parts of the study area.

Aquifer hydraulic conductivity

Aquifer hydraulic conductivity is a measure of the ease at which groundwater flows through the aquiferous materials. The southwestern part of the study area is characterized by high hydraulic conductivity, indicating that the areas has good groundwater potential compare to other part of the study area (Figure 6). The aquifer hydraulic conductivity of the study area ranged from 0.9 to 12.7 m/day, with an average value of 2.9 m/day (Table 4). The vicinity of VES has low aquifer
hydraulic conductivity (Figure 6) which indicates that the vicinity of VES 1 is characterized by low groundwater yield and storage.

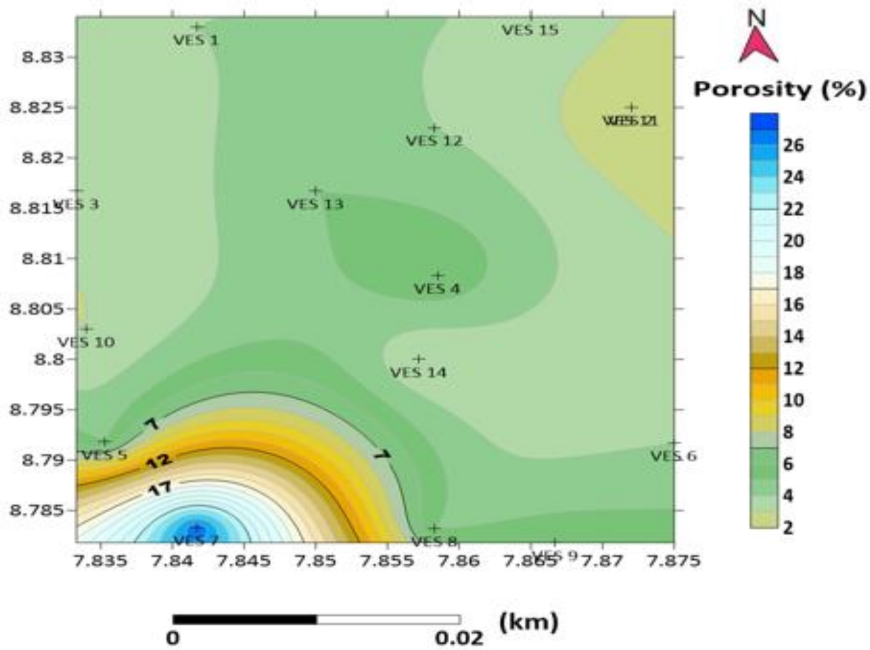

Figure 5: Spatial distribution of aquifer porosity in the study area

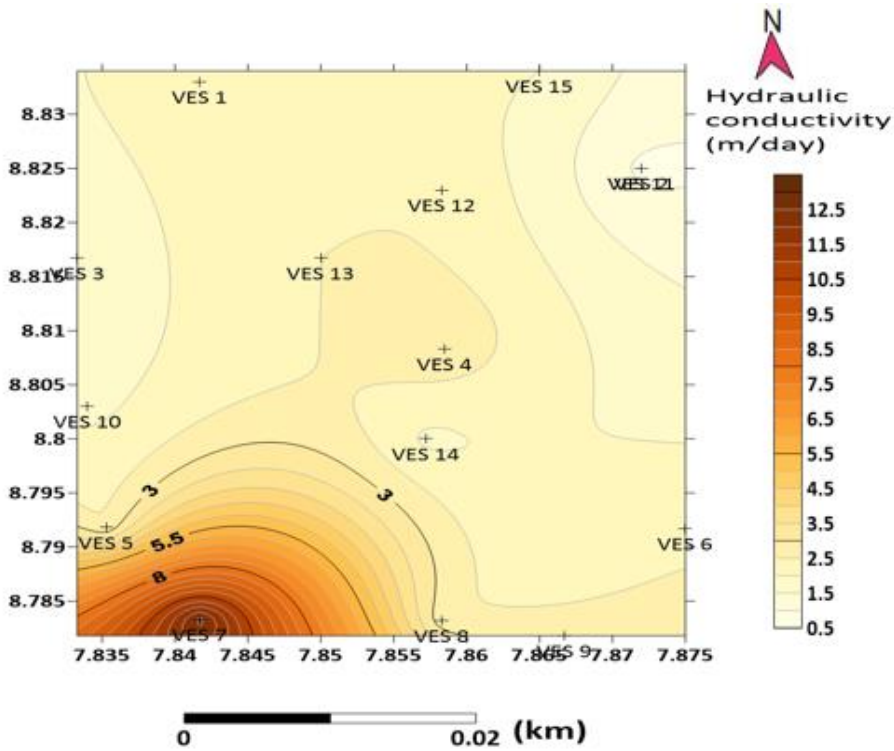

Figure 6: Spatial distribution of hydraulic conductivity in the study area

Transverse conductance

The transverse conductance of the aquifer in the study area ranged from 867.5 to 8611.2 Ωm^2 and has a mean value of 4997.4 Ωm^2 (Table 4). The aquifer transverse resistance of the study area in the vicinity of VES 1 and VES 7is low transverse resistance compare to other parts of the study area (Figure 7). The low aquifer transverse conductance in the vicinity of VES 1 is due to low aquifer thickness in the area.

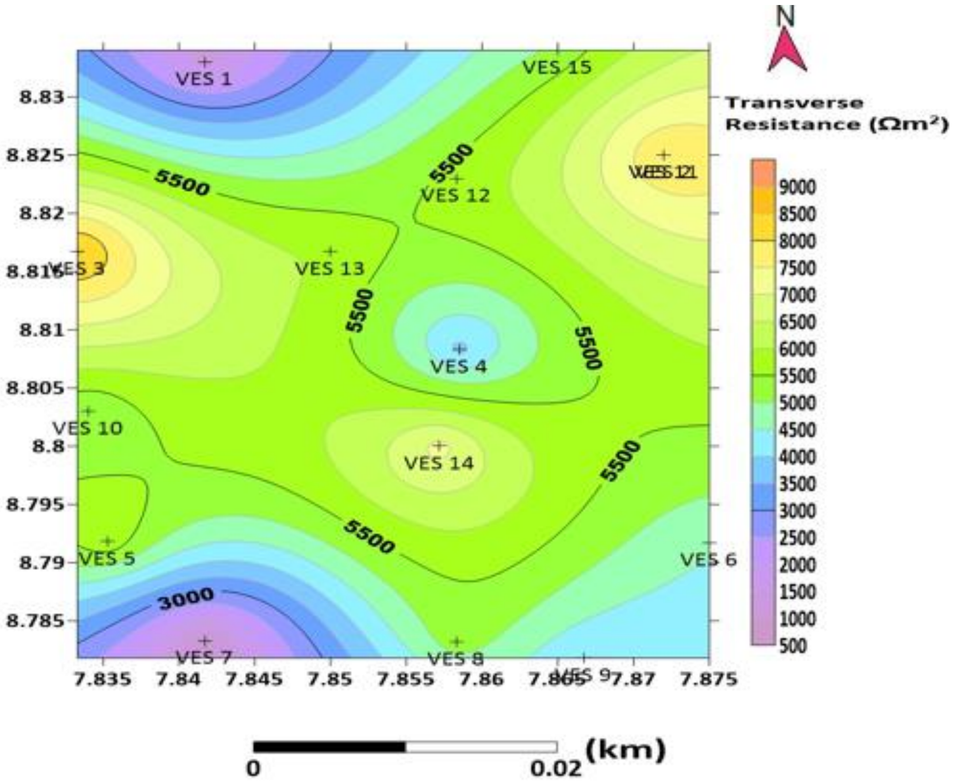

Figure 7: Spatial distribution of aquifer transverse resistance in the study area

The low aquifer transverse resistance in the vicinity of VES 7 is due to low resistivity values exhibited by the highly weathered and fractured aquiferous materials in the region which stores significant amount of groundwater. These observations clearly demonstrated that higher transverse resistance does not always translate to high groundwater potential in a given area, since transverse resistance is a product of formation resistivity and thickness. The northeastern and the western parts of the study area characterized by high transverse resistance due high aquifer resistivity compared to other parts of the study area.

Groundwater in the study area is located within the aquiferous zones as reported in most basement complex areas (Rahaman, 1976; Clerk, 1985; Obaje, 2009; Eduvie, 2011).

CONCLUSION

Considering the enormous challenges associated with efficient provision of potable water in a developing area, such as Gauta Buzu in Keffi Local Government, Nasarawa State, this study evaluated the groundwater potential of the locality with a view to providing useful information that will help stakeholders in groundwater resources management in the area to provide efficient and equitable distribution of potable water. In this study, four geologic layers were delineated using electrical resistivity survey method. The second and the third geologic layers of the subsurface in the study area constitute the aquiferous layer. The delineated geologic layers are the topsoil which is lateritic, weathered basement, fractured basement, and the fresh bedrock. The results of the evaluated aquifer characteristics of the study area indicated that the southwestern part of the study area has good groundwater potential and it's the most appropriate location for municipal borehole site. The other parts of the study area have intermediate or moderated groundwater potential mainly suitable for domestic water provision. The results of this study will serve as a basis for inform decision making on groundwater resources management in the study area.

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