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Geophysical Investigation of Groundwater Potential in Yobe State University, Damaturu

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ABSTRACT
In order to meet the growing demand for potable water in Yobe State University Damaturu and its environs, due to rapid increase in both students and staff population as well as economic activities within the area, this study investigated the groundwater potential of Yobe State University Damaturu. Vertical electrical sounding method, using Schlumberger configuration was adopted for the study. Five (5) geoelectrical layers were delineated from the study area and these layers were the topsoil which is a mixture of clay and sand, clay, sand, silty clay and sand. The third and the fifth layers were the aquifer systems in the study area. The parameters of the first aquifer were used to evaluate the groundwater potential in the study area. The evaluated parameters of the aquifer were the aquifer thickness, transverse resistance, transmissivity and porosity. The magnitude of the aquifer parameters showed that the study area has good groundwater potential. The aquifer in the study area has an average thickness of 36.3 m and an average porosity of 29.5%. The aquifer transmissivity ranged from 81.8 to 150.6 m^2/day indicating good groundwater yield in the area. Based on the findings of this study, it is recommended that boreholes for groundwater abstraction in the study area should be drilled within the second aquifer.

Keywords:
Groundwater,
Potential,
Porosity,
Transverse resistance,
Transmissivity,
Thickness.

INTRODUCTION

The rapid increase in human population and industrial development has put enormous pressure on groundwater resources. There is a remarkable increase in the demand for potable water in Damaturu and its environs due to great influx of people into the city caused by security challenges. Water is known to be very essential for human existence, and its adequate provision will help to promote healthy living and good sanitation. Groundwater plays a strong role in industrial development and agriculture, especially in areas where there are little or no streams, rivers and lakes.

Yobe State University is located in Damaturu the capital of Yobe State. The study area is located within the semi-arid region of Nigeria that is characterized by erratic rainfall and prolong dry season (Agada *et al*., 2011). The climatic conditions of the study area, alongside with the huge anthropogenic activities such as irrigation farming, animal rearing and industrialization have increased the demand for water that is not readily available in the study area due to lack of streams, rivers and lakes. Adequate groundwater management and provision remain the only alternative, through which sufficient water can be made available to Yobe State University and its environs. The increase in students' and staff population as well as increase in human related activities has placed significant constraints on the available water sources in Yobe State University. Emenike *et al.* (2018) noted that the understanding of groundwater dynamics is essential for effective management of water resources. In view of the challenges associated with the provision of adequate potable water in Yobe State University and its immediate surrounding communities, there is a need for geophysical investigation of groundwater potential of the area.

With regards to insufficient information on groundwater potential and hydrogeological setting of the study area, the results of this study will provide the needed information for proper groundwater resources management and lithological characterization. Many researchers across the world have investigated groundwater potential in many places using electrical resistivity survey method. Amadi *et al.* (2013) investigated the groundwater potential in Paiko, north central Nigeria, and their results showed that the area is composed of three (3) geologic layers, which are topsoil, weathered/fractured basement and the fresh basement. The weathered basement in the area was identified as the aquifer zone. The studied area was considered to possess high groundwater potential. Simon *et al*. (2022) noted that Dar-Zarrouk parameters are reliable tool for mapping out groundwater potential in a given geological setting.

Research reports have confirmed that electrical resistivity method is an effective tool in mapping groundwater potential (Makinde *et al*., 2010; Adebanji, 2012; Obiora *et al*., 2015; Agada *et al*., 2020; Musa *et al*., 2023). One of the challenges facing Yobe State University is the increasing demand for potable water amid surface water scarcity. Water supply challenges in the institution are compounded by the institution's expansion, due to the increasing number of students, staff, and economic activities. Groundwater is the most viable option for meeting the water need of Yobe State University, but its sustainability remains uncertain without a detail geophysical assessment. The assessment of groundwater potential at Yobe State University will serve as a blueprint for water resource management within the institution.

Some Boreholes in the study area have failed while some could not supply water throughout the year due to inappropriate drilling depths which could not support efficient water supply. Considering the increasing cost of Borehole drilling and rampant Borehole failure in the study area, this study seeks to evaluate the groundwater potential in Yobe State University and its environs. The information obtained from this study will help various stake holders in groundwater exploration and exploitation to make appropriate decision that will facilitate effective and optimal utilization of groundwater resources in the study area.

MATERIALS AND METHODS

The Study Area

Yobe State University is situated in Damaturu, which is located in the Nigeria part of the Chad Basin (Figure 1), which is locally called the Bornu Basin. The Nigeria part of the Chad Basin occupies about one tenth of the entire Chad Basin. The Bornu Basin is located between latitudes 11ºN and 14ºN and longitudes 9ºE and 14ºE (Obaje, 2009). The Chad Basin belongs to the African Phanerozoic sedimentary Basins which was formed due to the dynamic plate divergence process (Obaje, 2009). The study area has a semi-arid climate characterized by long dry season which starts in October and ends in May, and a very short rainy season that normally starts in June and ends in September (Figure 2). The annual rainfall ranged from 500-1000 mm. The Chad formation is sedimentary by nature (Figure 1) and it is made up of sand and clay (Goni *et al*., 2000; Bura *et al*., 2018). The sand bodies in the Chad formation are interbedded by clay and sandy clay. The sand bodies correspond to the upper, middle and lower aquifers (Barber and Jones, 1960). The aquifer characteristics ranged from unconfined to confined (Goni *et al*., 2000; Bura *et al*., 2018).The Chad formation is made up of argillaceous sequence. The aquifers in the Chad Basin were classified into three, namely, the upper aquifer, two confined middle aquifers and a lower aquifer (Barber and Jones, 1965). The Chad Basin is composed of interbedded sands, clays, silts and discontinuous sandy clay lenses which gave rise to aquifer characteristics that ranged from unconfined, semi-confined to confined aquifer (Obaje, 2009).

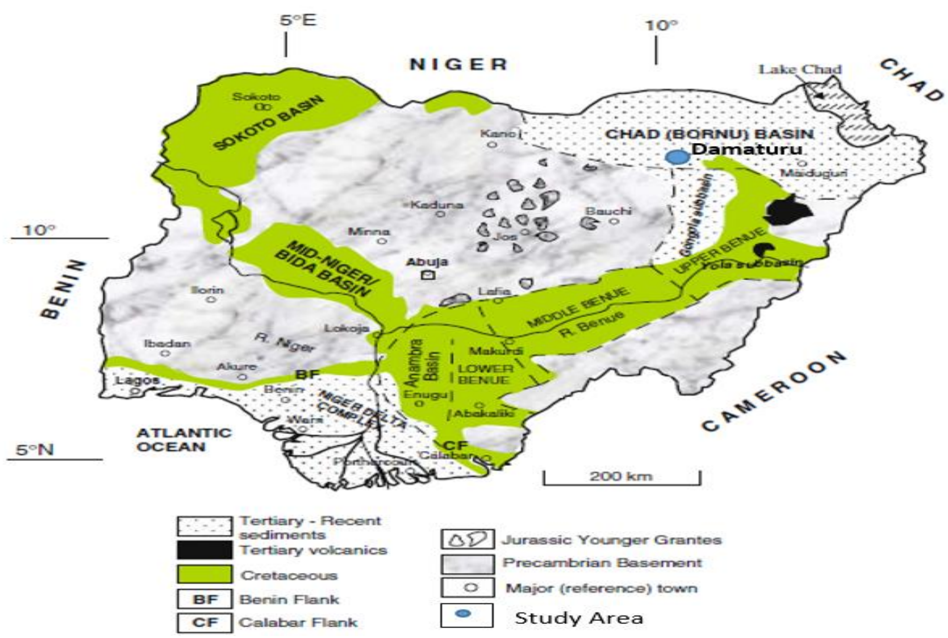

Figure 1: Geological Map of Nigeria showing the study area (Modified after Obaje, 2009)

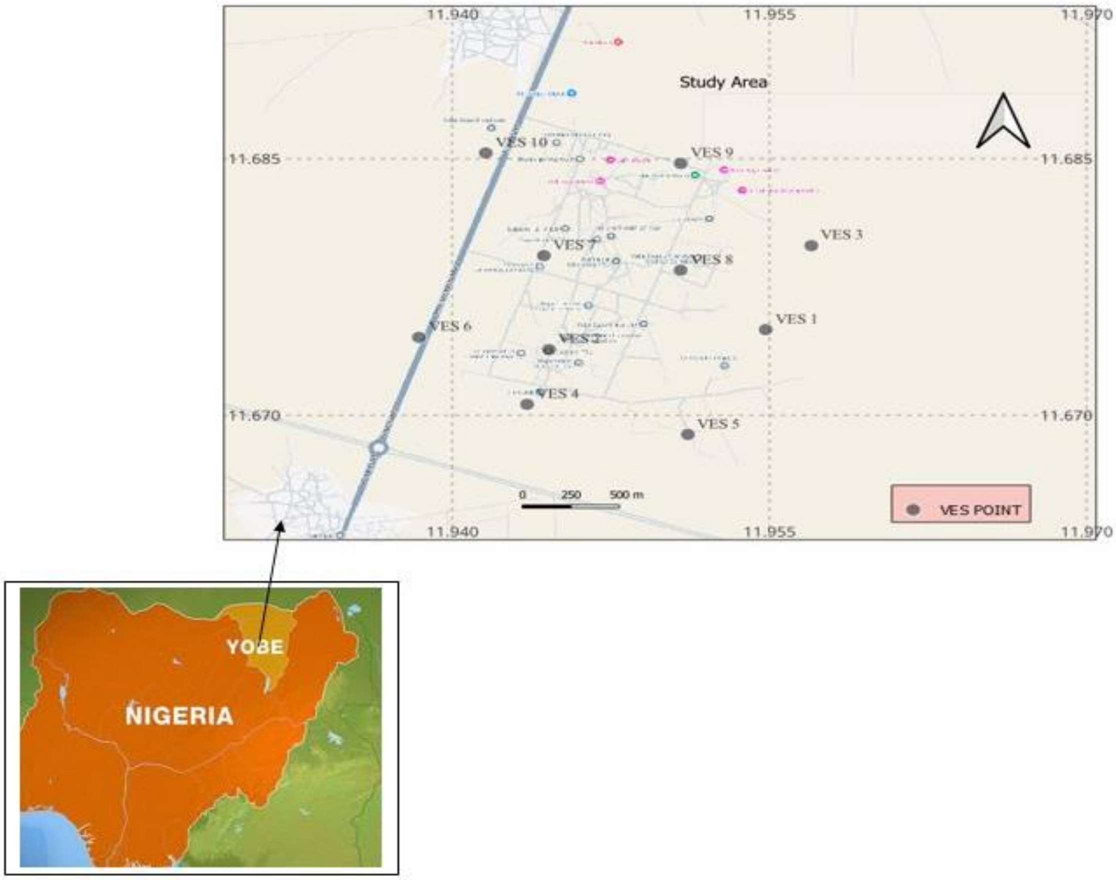

Figure 2: Map of Nigeria showing the study area in Yobe State

These sand layers in the Basin corresponds to the upper, middle and lower aquifers (Barber and Jones, 1960). These sand layers area separated by thick bodies of clay or sandy clay.

Data Acquisition and Interpretation

The study was carried out using electrical resistivity method. Instruments such as ABEM SAS1000 Digital Terrameter, Electrical cables, Steel electrodes, Hammers, Measuring tapes, Compass clinometer, Laptop computer, and 12V Battery were used to acquire the Vertical Electrical Survey (VES) data. Schlumberger electrode configuration was adopted for the VES data acquisition.

The VES stations were carefully selected with regards to the depth of investigation. The current electrode spacing ($^{AB}/_{2}$) ranged from 1.5 to 300 m. Ten (10) Vertical Electrical Sounding (VES) were carried out in the study area with the intention of delineating the overburden thickness, aquifer thickness and the lithology of Yobe State University and its environs. The field data were interpreted using partial curve matching and were later modeled with WINRESIT version 1.0. The obtained results were compared with a nearby borehole log for validation.

Theory

Established theories were used to determine the groundwater potential in Yobe State University, Damaturu. Considering the homogeneity and the isotropic nature of each layer in the study area, the Transverse resistance (T_r) of the area was evaluated using equations 1.

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

The magnitude of the transverse resistance is associated with the aquifer productivity. The ability of an aquifer to transmit water over its entire saturated thickness is called transmissivity (Egbai and Iserhien, 2015). The higher 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. The equation is expressed as:

$$= KSR_{\emptyset} = \frac{KS}{\sigma} = Kh \qquad (2)$$

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.

Archie (1942) established a relationship between water resistivity and aquifer resistivity which is known as

Formation factor. The formation factor of an aquifer is characterized by factors such as Tortuosity (a) and Porosity ($\emptyset$).

$$F = \frac{a}{\emptyset^m} = \frac{R_O}{R_W} \quad (3)$$

Where m is the cementation factor. Doveton (1986) modified equation (3) to establish the relationship between an aquifer materials and formation factor. For a saturated sandy aquifer a = 0.62 and m = 2.15 (Repsold, 1989). The formation factor depends on the lithology and it is usually consistent in any given sedimentary unit.

$$\frac{0.62}{\emptyset^{2.15}} = \frac{R_O}{R_W} \quad (4)$$

Where R_O is the aquifer resistivity, R_W is the pore water resistivity obtained from well samples, and $\emptyset$ is the porosity.

Heigold *et al*. (1979) established a relationship between aquifer resistivity $R_\emptyset$ and hydraulic conductivity (K) as,

$$K = 386.4\,(R_\emptyset)^{-0.93283} \quad (5)$$

Where Porosity, $\phi = 25.5 + 4.5Ink$ (6)

Equations 1, 2, 5 and 6 were used to compute the aquifer parameter in the study area.

Bouwer (1978) established a hydraulic conductivity standard values (Table 1).

Table 1: Hydraulic conductivity value (Bouwers, 1978)

Rock type	**Hydraulic conductivity range (m/day)**
Clay soil (surface)	0.01-0.2
Deep clay beds	$10^{-8} - 10^{-2}$
Loam soil (surface)	0.1-1
Find sand	1-5
Medium sand	5- 20
Coarse sand	20-100
Gravel	100-1000
Sand and gravel mixture	5 – 100
Clay, sand and gravel mixture	0.01-0.1

RESULTS AND DISCUSSION

The Vertical Electrical Sounding (VES) results of the study area showed good correlation when constrained with an existing borehole log record from a nearby borehole. The dominant VES curves obtained from the study area were HA curves (Figure 3). The VES results revealed a heterogeneous subsurface lithological sequence of topsoil, clay, sand, silty-clay and sand. The results are in consonance with the observations of Goni *et al.* 2000 and Bura *et al*. 2018, which reported that the Chad formation is sedimentary by nature and it is made up of sand and clay.

The first layer is the topsoil and its resistivity values ranged from 44 to 228 Ωm, it has an average resistivity value of 147.5 Ωm (Table 2). The thickness of the first layer ranged from 0.5 to 1.4 m and its average thickness is 1.0 m. The first layer is a mixture of sand and little amount of clay. The second layer has resistivity values which ranged from 17 to 95 Ωm and an average resistivity value of 44 Ωm. It is a clay formation whose thickness ranged from 4.9 to 2.2 m. The average thickness of the second layer is 8.0 m. The third layer has resistivity values which ranged from 159 to 283 Ωm and an average resistivity value of 232 Ωm which indicates that it is a sand formation. Its thickness ranged from 36.3 to 58.1 m, with an average value of 48.4 m (Table 2).

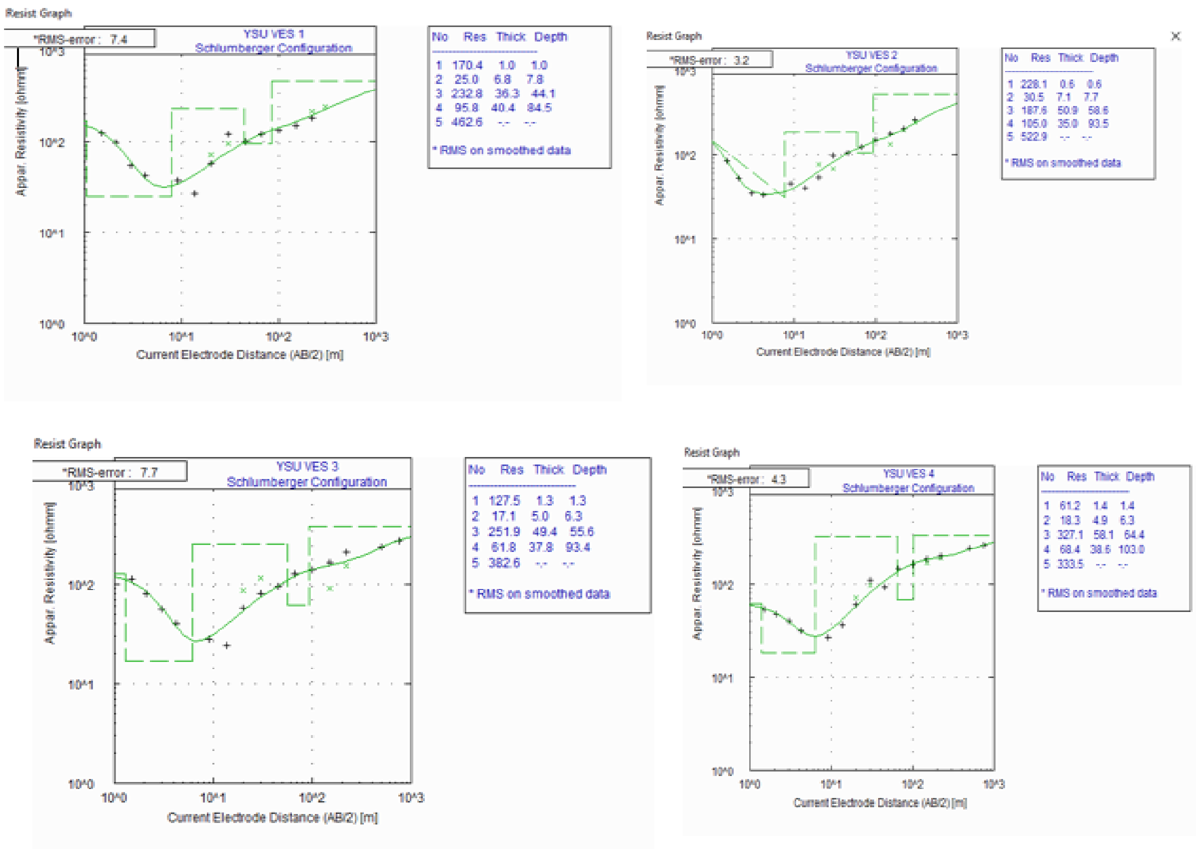

Figure 3: Typical Vertical Electrical Sounding (VES) curves obtained from the study area

Table 2: Summary of Vertical Electrical Sounding (VES) Results

VES	Layer Resistivity (Ωm)					Layer Thickness (m)				Depth (m)			
	ℓ_1	ℓ_2	ℓ_3	ℓ_4	ℓ_5	h_1	h_2	h_3	h_4	d_1	d_2	d_3	d_4
1	170.4	25.0	232.8	95.8	462.6	1.0	6.8	36.3	40.4	1.0	7.8	44.1	84.5
2	228.1	30.5	187.6	105.0	522.9	0.6	7.1	50.9	35.0	0.6	7.7	58.6	93.5
3	127.5	17.1	251.9	61.8	382.6	1.3	5.0	49.4	37.8	1.3	6.3	55.6	93.4
4	61.2	18.3	327.1	68.4	333.5	1.4	4.9	58.1	38.6	1.4	6.3	64.4	103.0
5	185.1	39.4	274.4	112.3	386.4	0.9	8.5	47.2	65.3	0.9	9.4	56.6	121.9
6	169.5	25.8	159.0	85.0	307.1	1.1	9.2	44.1	72.4	1.1	10.3	54.4	126.8
7	199.2	64.0	204.5	119.0	245.0	0.7	10.2	54.1	61.6	0.7	10.9	65.0	126.6
8	109.4	29.5	213.4	75.6	300.0	0.9	8.5	49.0	72.1	0.9	9.4	58.4	130.5
9	181.2	95.0	189.0	101.0	214.0	1.2	7.8	51.3	70.0	1.2	9.0	60.3	130.3
10	43.9	91.2	283.0	98.2	220.0	0.5	12.2	41.0	63.7	0.5	12.7	53.7	117.4
AVE	147.5	43.6	232.2	85.4	.337.4	1.0	8.0	48.4	51.8	1.0	9.0	57.1	103.4

The third layer is considered to be the first aquifer in the study area of which most shallow Boreholes and hand dug wells were drilled. The first aquifer in the study area is semi-confined and it is susceptible to contamination. Boreholes drilled within the first aquifer in the study area often dry up during the peak of the dry season (April and May) leading to borehole failure and low Borehole yields. The resistivity values of the fourth layer ranged from 62 to 119 Ωm, and its average resistivity is 85 Ωm. Its resistivity values indicate that it is a silty clay with an average thickness of 51.8 m and it overlies the fifth layer.

The fifth layer has resistivity values which ranged from 214 to 463 Ωm and an average resistivity of 337 Ωm (Table 2). The resistivity of the fifth layer showed that it is a sandy formation. It is the second aquifer in the study area. It is a confined artisan aquifer with great groundwater potential.

The parameters of the first aquifer was modeled to estimate the groundwater potential in the study area.

Aquifer Parameters of the Study Area

Since the thickness of the second aquifer was not delineated in this study due to its intense depth, the first aquifer parameters were used to evaluate the groundwater potential of the study area.

The first aquifer thickness of the study area ranged from 36.3 to 58.1 m (Table 3).

Table 3: Aquifer parameters of the study area

VES No.	Latitude (°N)	Longitude (°E)	Thickness (m)	Transverse Resistance (Ωm²)	Transmissivity (m²/day)	Porosity (%)
1	11.67500	11.95485	36.3	8450.64	86.88624	29.42752
2	11.67383	11.94460	50.9	9548.84	149.0099	30.33367
3	11.67991	11.95701	49.4	12443.86	109.8567	29.09652
4	11.67063	11.94357	58.1	19004.51	101.2614	27.99993
5	11.66887	11.95117	47.2	12951.68	96.91283	28.73738
6	11.67455	11.93845	44.1	7011.90	150.6421	31.02801
7	11.67933	11.94436	54.1	11063.45	146.1337	29.97159
8	11.67847	11.95082	49.0	10456.60	127.2011	29.79277
9	11.68471	11.95083	51.3	9695.70	149.1429	30.30246
10	11.68533	11.94161	41.0	11603.00	81.79392	28.60784

The aquifer has an average thickness of 48.4 m. The aquifer thickness varies across the study area. The thickness of an aquifer is an important factor that determines groundwater yield in a sedimentary environment. The greater the thickness of an aquifer, the higher its ability to store and transmit water. The average thickness of the aquifer in the study area was quite significant and it can store huge volume of groundwater. The aquifer thickness is higher towards the southwestern part of the study area and it decreases gradually towards the southeastern part. The aquifer thickness in the northern part of the study area is quite moderate in comparison to other parts of the study area (Figure 4).

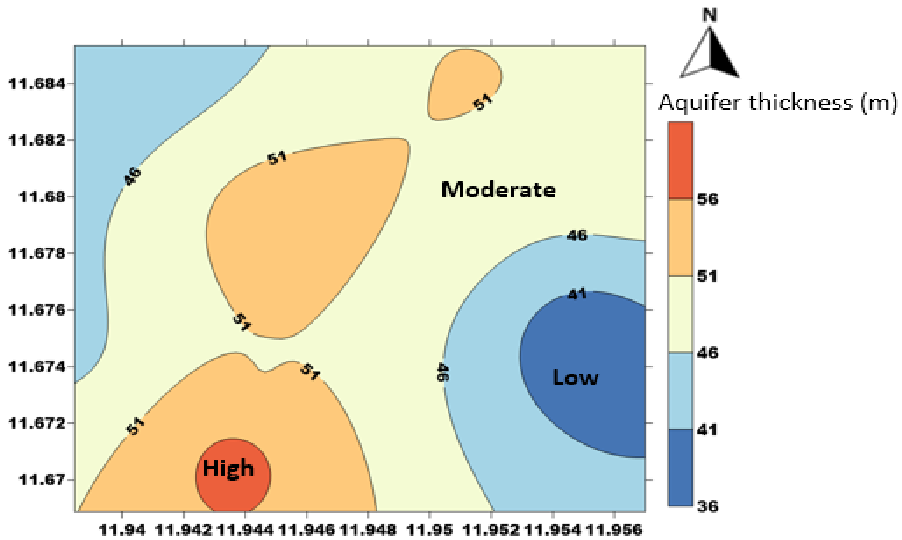

Figure 4: Aquifer thickness map of the study area

The transverse resistance value of the aquifer in the study ranged from 7011.90 to 19004.51 Ωm^2 and has an average value of 11223 Ωm^2 (Table 3). The southern part of the study is characterized by high values of transverse resistance which suggests that the area has high groundwater yielding potential compare to north and central parts of the study area (Figure 5). The western part of the study area has low transverse resistance in comparison to other parts of the study area (Figure 5).

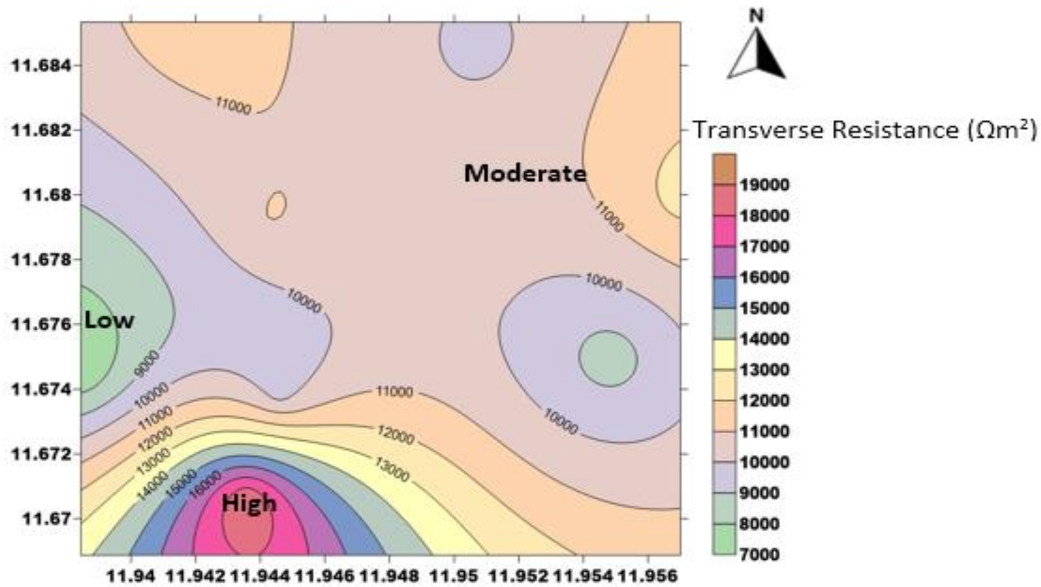

Figure 5: The study area transverse resistance contour map

Aquifer transmissivity is the rate at which water flows through an aquifer. The aquifer transmissivity of the study area ranged from 81.8 to 150.6 m^2/day (Table 3). The aquifer transmissivity in the study area is higher in the western part of the study area than other parts due to hydraulic gradient (Figure 6).

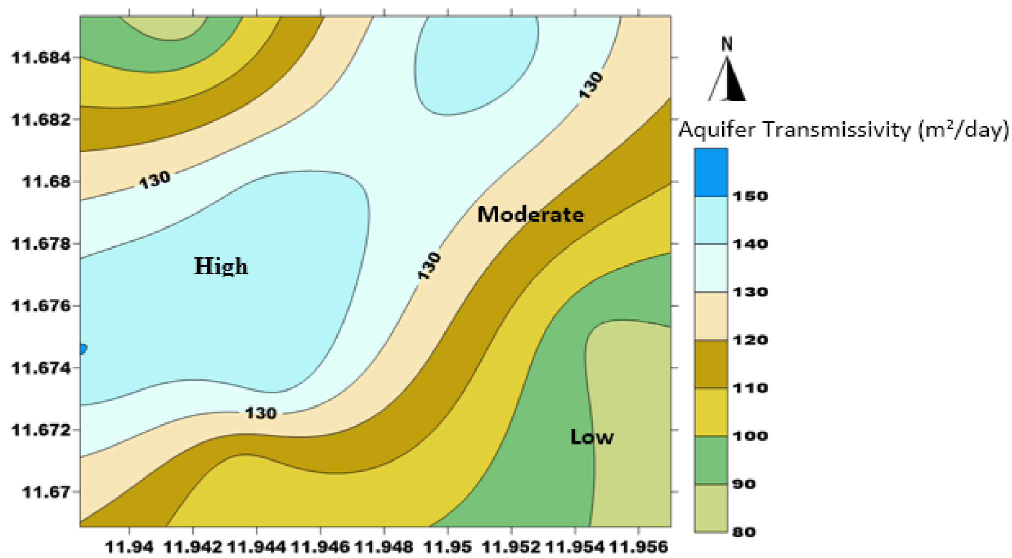

Figure 6: Aquifer transmissivity contour map of the study area

Porosity is a measure of how much an aquifer can hold water. The porosity of the aquifer in the study area ranged from 28.6 % to 31.0 % (Table 3). The aquifer in the study area has an average porosity of 29.5 % which indicates that the aquifer has huge volume for storing groundwater. The aquifer porosity distribution of the study area showed that the western part of the study area has the highest porosity compared to other parts of the study area (Figure 7). The porosity of the aquifer gradually decreases towards the southwestern part of the study area (Figure 7). The magnitude of the aquifer parameters indicate that the study area has high groundwater potential. The groundwater in the study area is capable to sustain the growing population of the study area and its environs.

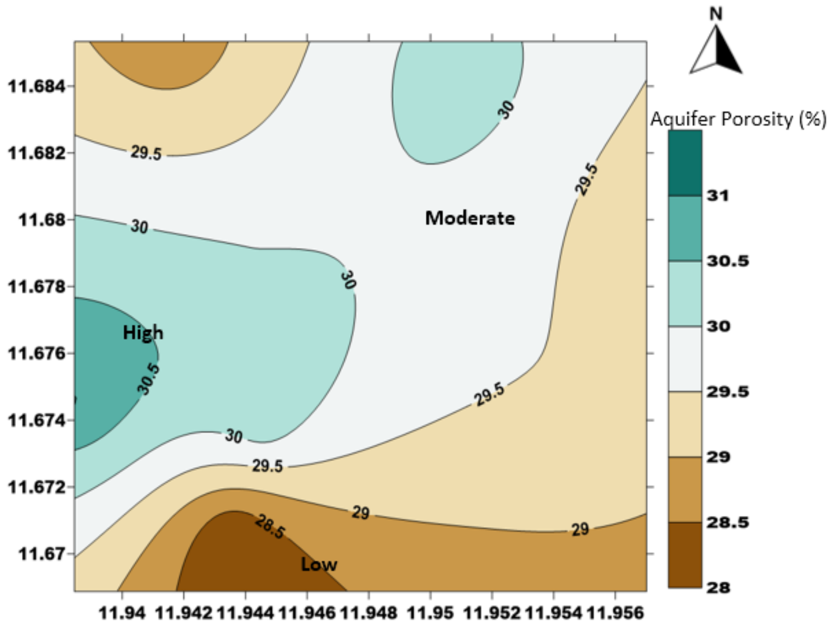

Figure 7: The study area porosity contour map

The petrophysical properties of the aquifer in the study area showed that the study area has high groundwater potential for exploitation. The results of this study are vital for effective and efficient groundwater management in Yobe State University and its environs.

CONCLUSION

This study investigated the groundwater potential of Yobe State University using vertical electrical sounding method. The study was carried out to meet the growing demand for water in the institution and its environs. The geoelectrical parameters obtained from the study area were used to evaluate the hydraulic properties of the aquifer in the study area. The computed aquifer thickness, transverse resistivity, transmissivity and porosity values of the study area gave indication that the study area has high groundwater potential to meet the needs of the growing population and economic activities within the University community and its environs.

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REFERENCES

Adebanji, K. A. (2012). Biostratigraphy and Depositional Environment of the sediments in Borno Basin, Northeastern Nigeria. *Indian Journal of Science and Technology*, 5(6): 2800-2809. http://www.indjst.org

Agada, L.E., Adetola, S.O., & Osita, C.M. (2020). Investigation of the effects of leachate from solid waste dumpsite on groundwater usi ng electrical resistivity method. *Global Scientific Journal*, 8(1), pp. 2371-2401. ISSN: 2320-9186 www.globalscientificjournal.com

Agada, L.E., Malgwi, D.I., &Abbas, B.K. (2011). Harmattan dust and its effects in semi-arid zone of Nigeria. Acase study of Maiduguri metropolis and its environs. *Techno Science Africana Journal*, 6, 19-25. ISSN: 2006-2273.

Amadi, A. N., Ameh, M. I., Idris-Nda, A., Okoye, N. O., Ejiofor, C. I. (2013). Geological and Geophysical Investigation of Groundwater in Parts of Paiko, Sheet 185, North-Central Nigeria. *International Journal of Engineering Research and Development*, 6, 23-25. https://www.ijerd.com

Archie, G.E. (1942). The Electrical Resistivity Log as an aid in determining some Reservoir Characteristics. American Institute of Mineral and Metal Engineering. Technical publication 1422, *Petroleum Technology*, pp.8-13. https://doi.org/10.2118/942054-G

Barber, W., and Jones, D.G. (1960). The Geology and hydrology of Maiduguri, Borno Province. *Records Geol. Surv. Nigeria*, 1958, p. 5-20.

Bura, B., Goni, I.B., Sheriff, B.M., and Gazali, A.K. (2018). Occurrence and distribution of Fluorides in Groundwater of Chad formation aquifers in Borno.

International Journal of Hydrology, 2 (4), pp.528-537. https://doi.org/10.15406/ijh.2018.02.00121

Bouwer, H. (978). Groundwater Hydrology. McGraw Hill Book Company, pp. 402-406.

Doveton, J.H. (1986) Log Analysis in Subsurface Geology: New York. John Wiley and Sons, 2nd edition, p.273.

Egbai, J.C., & Iserhien-Emekeme, R.E. (2015). Aquifer Transmissivity, DarZarrouk Parameters and Groundwater flow direction in Abudu, Edo State, Nigeria. *International Journal of Science, Environmental and Technology*. 4(30), pp. 628-640. https://ijset.net/journal/685.pdf

Emenike, P.C., Nnaji, C.C., & Tenebe, I.T. (2018). Assessment of geospatial and hydrochemical interractions of groundwater quality, southwestern Nigeria. *Environmental Monitoring and Assessment*. 190(440).pp. 1-17. https://doi.org/10.1007/s10661-018-6799-8 .

Goni, I.B., Kaachalla, M., Aji, M.M. (2000). Another look at the piezometric head decline in the middle zone aquifer of the Chad Formation. *Born Journal of Geology*, 2, pp. 53-64.

Heigold, P.C., Gilkson, R.H., Cartwright, K., Reed, P.C. (1979). Aquifer transmissivity from surficial electrical methods. *Groundwater*, 17, pp. 338-345. https://doi.org/10.1111/j.1745-6584.1979.tb03326.x

Makinde, V., Alagbe S.A, Coker, J.O., & Bello, A.M.A. (2010). Determination of borehole sities for extensive irrigation work in Yobe State, *Nigeria. Journal of American Science*, 6(2), 58-61. https://www.jofamericanscience.org/journals/am-sci/am0602/am0602.pdf

Musa, K.O., Jamilu, B.A., Fabian, A. A., Ernest, O.A., Ikenna, A., Solomon, S.J., Andrew, C.N. & Jacob, B.J. (2023). Assessment of Groundwater Potential and Aquifer Characteristics Using Inverted Resistivity and Pumping Test Data within Lokoja Area, North-central Nigeria. *Communication in Physical Sciences*, 9(3), pp. 336-349. https://journalcps.com/index.php/volumes/article/view/381

Niwas, S, & Singhal, D.C. (1985). Aquifer transmissivity of porous media from resistivity data. *J Hydrol*.82: 143-153. https://www.sciencedirect.com/science/article/abs/pii/0022169485900502

Obaje, N.G. (2009). Geology and Mineral Resources of Nigeria, Lecture Notes in Earth Sciences 120, https://doi.org/10.1007/a78-3-540-92685-6-6

Obiora, D.N., Ibuot, J.C. George, N.J. (2015). Evaluation of aquifer potential, geoelectric and hydraulic parameters in Ezza North, southeastern Nigeria, using geoelectric sounding. *Int. J. Environ. Sci. Technol*. http://dx.doi.org/10.1007/s13762-015-0886-y

Repsold, H. (1989). Well logging in groundwater development, Heise Publisher, Handover, Germany, p.136.

Simon, S.S., Jackson, M.I., Ahmed, B.S, Finthan, B. (2022). Evaluation of Groundwater Potentials Using DarZarrouk Parameters in Mapeo and Environs, Northeastern Nigeria. *Dutse Journal of Pure and Applied Sciences*, 8(3b), pp.124-135. https://doi.org/10.4314/dujopas.v8i3b.13