Evaluation of Aquifer Hydraulic Parameters in Gashua Using Electrical Resistivity Method

Agada Livinus Emeka* and Adetola Sunday Oniku

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Abstract: *The aquifer hydraulic parameters of Gashua in Yobe State were evaluated (using electrical resistivity survey method) to describe the hydraulic characteristics of the groundwater in the area. Vertical electrical sounding (VES) with Schlumberger electrode configuration was deployed to obtain the geoelectric data. The results obtained reveals that the transmissivity and porosity of the aquifer were moderately high. The aquifer thickness in the study area ranged from 66.7 m to 120 m with an average value of 84.32 m. The aquifer resistivity in the study area ranged from 100.7 Ωm to 350 Ωm with an average value of 280 Ωm. The transmissivity of the aquifer ranged from 110.91 m^2/day to 348.88 m^2/day with an average value of 182.55 m^2/day. The porosity of the aquifer ranged from 27.7% to 32.9% with an average value of 28.8%. Contour maps developed from the estimated values of the aquifer hydraulic parameters (hydraulic conductivity, porosity, resistivity, formation factor and transmissivity) revealed that the study area has great potential for the production of groundwater. The magnitude and the spatial distribution of the aquifer parameters in the study area also confirmed that the aquifer has moderate groundwater production and sustainability.*

Key Words: *Aquifer, spatial, transmissivity, hydraulic, groundwater, porosity*.

Agada Livinus Emeka
Department of Physics, Faculty of Science,
Yobe State University,
P.M.B 1144, Damaturu, Yobe State, Nigeria
Email: agadaman1908@gmail.com
Orcid id: 0000-0003-2884-8831

Adetola Sunday Oniku
Department of Physics School of Pure and Applied Sciences, Modibbo Adama University of Technology, Yola, Adamawa State, Nigeria.
Email: tolaoniku2013@gmail.com
Orcid id: 0000-0003-0958-3292

1.0 Introduction

Electrical resistivity method has over the years proven to be an effective tool in mapping subsurface geological formations, groundwater and hydrogeological parameters (Agada *et al*., 2020; Obiora *et al*., 2017; Makinde *et al*., 2010; Musa, 2016; Adebanji, 2012). Good management of groundwater resources requires an in-depth understanding of the hydro-geophysical parameters of the area where groundwater resources are to be exploited. Electrical resistivity survey provides a spatial continuous information about subsurface geology. It is less invasive when compared to other hydrogeological methods and it is comparatively cheap. Hydraulic parameters of groundwater such as porosity, transmissivity, permeability and hydraulic conductivity can be determined from electrical resistivity survey data. In recent times, the demand for quality water has increased substantially due to the increase in population in Gashua and its environs. Gashua aquifer is considered to be strategic in the planning of hydrologic resources and management in the study area. The electrical resistivity of rocks in the subsurface depend on several parameters including mineral composition, degree of saturation, porosity, permeability, hydraulic conductivity and others (Niwas and Singhal, 1981). Obiora *et al*. (2017) evaluated aquifer properties in some areas within Nsukka Local Government Area of Enugu State, Nigeria, using electrical resistivity data. The results of their study indicated that the hydraulic conductivity of the aquifer in the study area ranged from 0.0989 to 0.5079 m/day with an average of 0.3025 m/day. Transmissivity in the area ranged from 6.5779 to 57.9546 m^2/day, with an average value of 18.7491 m^2/day. Asfahani (2013) also examined the groundwater potential of aquifer in the semi-arid Khanasser valley region, Syria using vertical electrical sounding measurements. The analysis of his results showed that the mean transmissivity of the Quaternary aquifer is 49 m^2/day and that of the Paleogene aquifer is 0.94 m^2/day. Aweto and Akpoborie (2015) investigated aquifer parameters with geoelectric soundings in shallow formation at Orerokpe western Niger Delta, Nigeria. Their results showed that the study area has four geologic layers which include; topsoil, clay, sandy clay and sand. The fourth layer were considered to be the aquifer. The results indicated that the transmissivity values of the aquifer ranged from 418.6 m^2/day to 1637.3 m^2/day while hydraulic conductivity values ranged from 10.50 m/day to 45.71m/day. Niwas and Singhal (1981) estimated the aquifer transmissivity from the Dar-Zarrouk parameters in porous media by using an analytical relation between aquifer transmissivity and transverse resistance.

It has been confirmed that aquifer parameters can be determined from pumping test but its level of data coverage is highly limited and it is characterized by errors due to some assumptions that are not realistic in the field (Asfahani, 2012). The heterogeneity of the subsurface sometimes renders the pump test results unreliable. The integration of geoelectric surveys and existing borehole data can provide sufficient information for a given region (Asfahani, 2011). Consequently, the aim of this study is to use electrical resistivity data to estimate hydraulic conductivity, porosity, formation factor, tortuosity and transmissivity of the aquifer in the area. The results could be used for further study of groundwater regime in the study area and to improve the quality of groundwater resource and management. Agada *et al.,* 2020 observed that the first aquifer in the study area was contaminated by leachate.

1.1 Theory

Heigold *et al*. (1979) established a relationship between hydraulic conductivity (K) and the resistivity of aquifer (R_ϕ) as,

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

The transmissivity of an aquifer is a measure of its ability to transmit water over its entire saturaT = KSted thickness (Egbai and Iserhien, 2015). The higher the transmissivity the more productive the aquifer (Egbai and Iserhien, 2015). Niwas and Singhal (1981) conducted a study that established an equation (equation 2) for estimating transmissivity values in a saturated aquifer.

$$T = KS = R_\phi = \frac{KS}{\sigma} = Kh \quad (2)$$

R_ϕ is the aquifer resistivity, σ is aquifer electrical conductivity, h is the aquifer thickness, K is the hydraulic conductivity and S is the longitudinal conductance. However, Marotz (1968) in his experiment using sandstones established a relationship between hydraulic conductivity and effective porosity (equation 3),

$$\phi - 25.5 + 4.5lnk \quad (3)$$

Considering a sequence of horizontal, isotropic and homogeneous layers of resistivity ρ_i and thickness h_i, the Dar-Zarrouk parameters (longitudinal conductance S and transverse resistance T_r) are defined according to equations 4 and 5 respectively.

$$S = \sum_{i=1}^{n} \frac{h_i}{\rho_i} \quad (4)$$

$$T_r = \sum_{i=1}^{n} h_i\rho_i \quad (5)$$

Formation factor (F) is a rock parameter which depends on porosity of the formation, tortuosity (pore geometry) lithology and degree of cementation. Winsauer et al. (1952) developed a relationship between formation factor and effective porosity, this relation is also known as Humble's equation. It is expressed as;

$$F = \frac{0.62}{\phi^{2.15}} \quad (6)$$

where F is the formation factor.

Tortuosity (τ) is an intrinsic property of porous material usually defined as the ratio of actual flow path length to the straight distance between the ends of the flow path (Bear, 1972). It can be estimated using the relation;

$$T = (F\phi)^{1/2} \quad (7)$$

Tortuosity is used to characterize the structure of porous media, to estimate their electrical and hydraulic conductivity.

1.2 Study area

Gashua is a town in Yobe State, northeastern Nigeria, situated close to the convergence of Hadeija and Jama'are rivers in the Chad Basin. It is located on latitude 12^0 $52^{'}$ North and Longitude 11^0 $2^{'}$ East. The Chad constitutes of three water bearing aquifers i.e. the upper aquifer, middle aquifer, and the lower aquifer (Matheis, 1976). Lithologically, the upper zone is composed of layers of clayed grits, sands and sandy clay of varying thickness (Makinde et al., 2010). It has a population of about 125, 000 according to 2006 national population census result. The climate is characterized by short wet season (June – September) and long dry season (October to May), with high temperatures of about 39^0C to 45^0C. During the raining season, temperatures fall to 25^0C with annual rainfall of about 500 to 1000 mm.

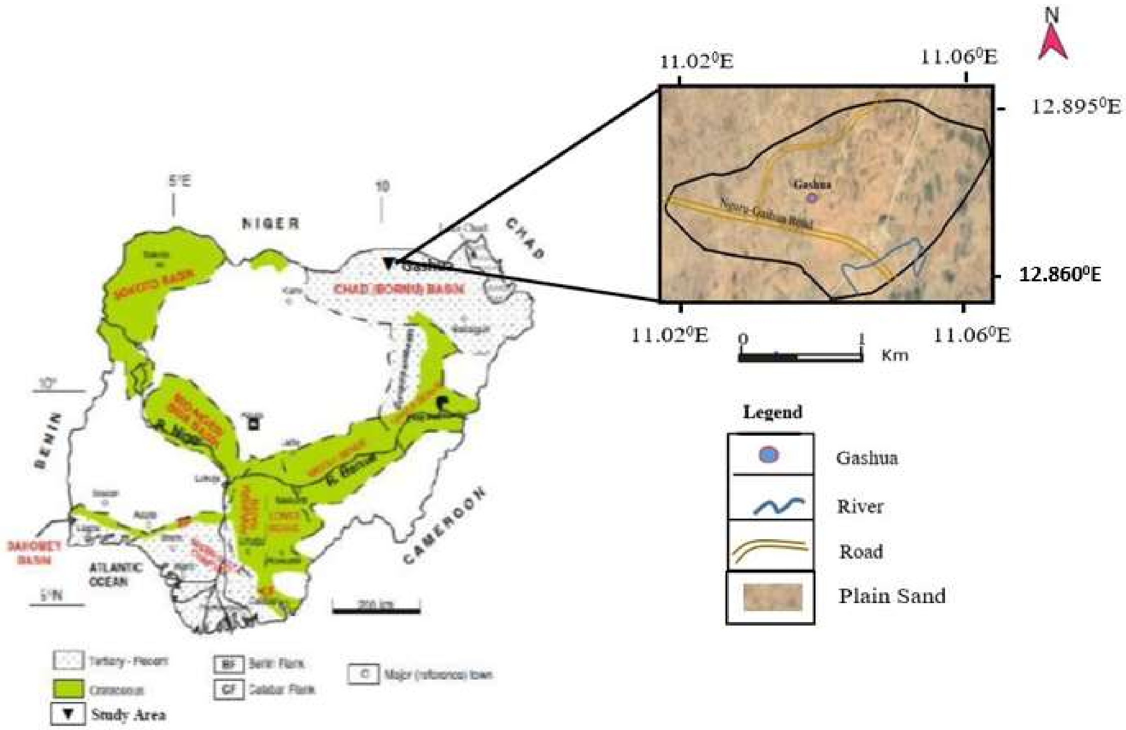

Fig. 1: Geological map of Nigeria (modified after Adebanji, 2012) showing sedimentary basins and the study area

1.3 Geology of the study area

Gashua is located within the Chad basin. The Chad basin extends to five countries in Africa, namely, Chad, Nigeria, Cameroon, Central Africa Republic, and Niger. The Basin lies between latitudes 11^0 N and 14^0 N and longitude 9^0 E and 14^0 E, covering Borno State, parts of Yobe and Jigawa States in Nigeria. About ten percent of the Chad Basin lies in the North-eastern part of Nigeria (Fig. 1). The Chad basin resulted from plate divergence along the West Africa continental margin (Yikarebogha *et al*., 2013). The various process which led to the plate divergence started with regional thermal doming, volcanism, rifting, formation of oceanic crust, marine incursion and subsequent widening and deepening of young oceans (Yikarebogha et al., 2013). Sedimentation in the Chad basin started in Albian times, the basal sedimentary sequence is the Bima sandstone, which was deposited unconformably over the Precambrian crystalline basement rock (Yikarebogha *et al*., 2013). Deposition of the Bima sandstone continued up to the Cenomania. The Turonian was characterized by extensive transgression during which the Gongila Formation was deposited as a transitional sea deposit (Avbovbo *et al*., 1986). The Fika shale was deposited during the transgression which began in the Turonian and continued up to the Senonian period (Matheis, 1976). Towards the end of the Cretaceous, during the Maastrichtian time, an estuarine deltaic environment prevailed in the basin and the Gombe sandstone, shale and limestone were deposited (Yikarebogha *et al*., 2013). The Keri-Keri Formation was deposited unconformably on the eroded surface of the Gombe sandstone in the Pleistocene (Matheis, 1976). An unconformable Pleistocene deposit of the Chad formation was deposited on the Keri-Keri Formation (Matheis, 1976). The Keri-Keri formation is Eocene in age (Ola-Buraimo and Boboye, 2011).

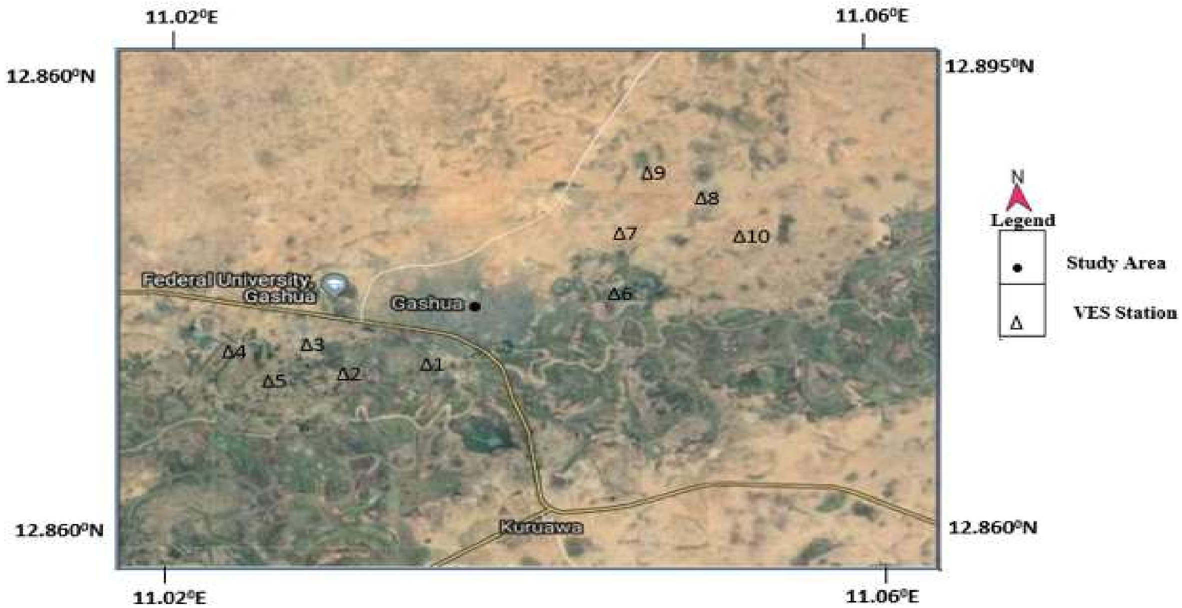

Fig. 2: Map of the Study area showing the VES stations

2.0 Materials and Method

2.1 Materials

The electrical resistivity survey was carried out with ABEM SAS1000 digital Terrameter, personal computer, Global Positioning System (GPS), Hammers, Measuring tape, UPS Battery and Charger, pegs, ABEM SAS external Battery Adapter (EBA), Electrodes, Reels of Cables and Jumpers.

2.2 Methodology

Electrical resistivity method involving Schlumberger array was used for this study, it involves the placement of four (4) electrodes collinearly. The electrical cables were laid along the profile and they were then linked to the ground using the electrodes through the sets of cable jumpers. The contact between the electrode cables, electrode take-outs and cable jumpers were checked for proper connections. The electrode test was performed to ensure that current was flowing through all the electrodes. The inner electrodes are the potential electrodes and the outer electrodes are the current electrodes. Ten (10) vertical electrical resistivity soundings were carried out in the study area with the aim of delineating the depth to the groundwater, aquifer thickness and lithology of the study area. The Terrameter measures the resistance, voltage and current which are indicated by R, V, I respectively. The apparent resistivity values were obtained by multiplying the resistance by the geometric factor (*K*), that is, (*R* x *K)*, where *K* is determined by using equation 8,

$$K = \frac{\left[\left(\frac{AB}{2}\right)^2 - \left(\frac{MN}{2}\right)^2\right] X\, 3.142}{\left(\frac{MN}{2}\right) X\, 2} \qquad (8)$$

where AB is the current electrode spacing and MN is the potential electrode spacing.

During sounding, apparent resistivity of the subsurface material was measured as a function of depth. The progressive increase in the distance between the current electrodes causes the current lines to penetrate to greater depths. The geoelectric data obtained from the field were modeled using

WINRESIST version 1.0 software to obtain the true resistivity values, depths and thickness of each layer. The results obtained were constrained using nearby borehole data. The aquifer hydraulic parameters were obtained from the integration of both geophysical and geological data obtained from the study area. The hydraulic parameters maps were developed with the aid of Surfer 11 software.

Table 1. Aquifer Potential (After Gheorghe, 1978)

Transmissivity (m^2/day)	Aquifer Potential
>500	High
50 – 500	Moderate
5 - 50	Low
0.5 – 5	Very low
< 0.5	Negligible

3.0 Results and Discussion

The results of the study revealed that the study area is composed of five to six geoelectric layers which includes topsoil, clay, sand, sandy clay, sand and clayey sand (Fig. 3). The resistivity and thickness of the various layers are shown in Table 2. The geoelectric sections (Fig. 4) were obtained from the results of the vertical electrical resistivity sounding survey using Schlumberger array. The results showed good correlation in terms of layers when compared with an existing borehole log from Katuzo area of the study area (Fig. 4).

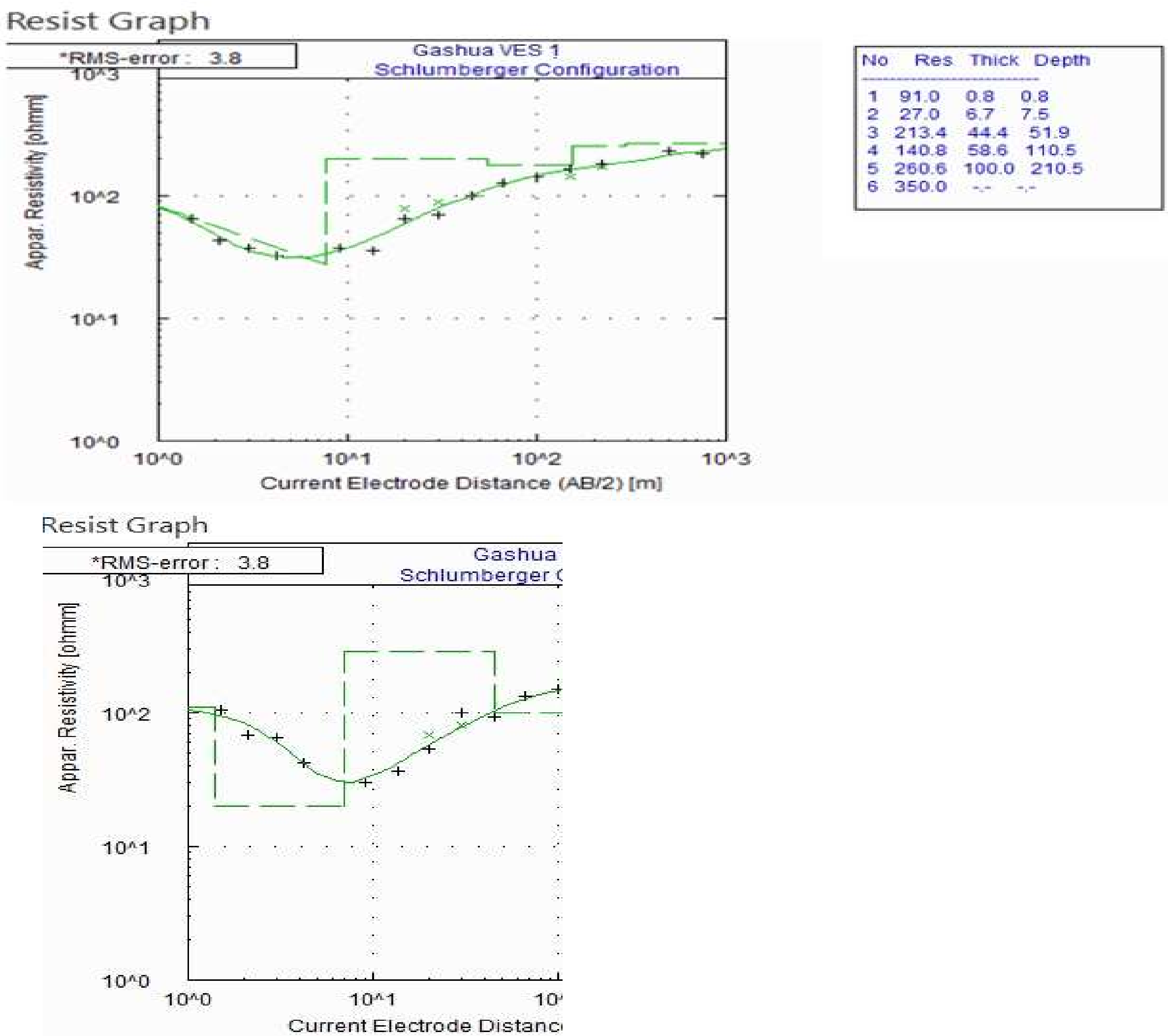

Fig. 3: Typical VES curves obtained for Gashua in Yobe state.

Table 2. Geoelectric and Lithologic Parameters of the Study Area.

S/N	Layers	Resistivity (Ωm)	Thickness (m)	Depth (m)
	1	91	0.8	0.8
	2	27	6.7	7.5
VES 1	3	213.4	44.4	51.9
	4	104.8	58.6	110.5
	5	260.6	100	210.5
	6	350.0	----	----
	1	109.4	1.4	1.4
	2	19.9	5.5	6.9
VES 2	3	288.2	38.9	45.8
	4	100.7	66.7	112.5
	5	314.8	----	-----
	1	111.3	1.0	1.0
	2	31.7	5.0	6.0
	3	101.2	46.5	52.5
VES 3	4	214.3	49.0	101.5
	5	281.4	75.0	176.5
	6	370.0	----	----
	1	107.5	1.4	1.4
	2	16.5	4.5	5.9
VES 4	3	189.7	99.7	105.6
	4	136.5	37.6	143.2
	5	350.1	67.8	211.0
	6	402.0	----	----
	1	189.3	0.6	0.6
	2	29.9	7.0	7.6
VES 5	3	196.0	50.5	58.1
	4	184.4	94.0	152.1
	5	307.4	73.6	225.7
	6	382.0	----	----
	1	42.7	1.1	1.1

	2	30.1	4.3	5.4
VES 6	3	101.4	58.6	64.0
	4	171.4	28.5	92.5
	5	318.7	107.3	199.8
	6	367.8	----	----
	1	59.9	1.6	1.6
	2	15.9	4.1	5.7
	3	266.9	73.4	79.1
	4	125.3	47.5	126.6
VES 7	5	291.8	76.9	203.5
	6	405.2	----	----
	1	169.3	1.1	1.1
	2	25.1	7.0	8.1
VES 8	3	242.0	44.1	52.2
	4	118.1	30.5	87.3
	5	253.8	70.5	157.8
	6	290.0	----	---
	1	113.3	1.9	1.9
	2	32.4	10.3	12.2
VES 9	3	194.8	45.6	57.8
	4	149.7	29.5	87.3
	5	306.3	85.4	172.7
	6	371.6	----	----
	1	99.7	0.8	0.8
	2	37.9	10.7	11.5
VES 10	3	274.1	46.9	58.4
	4	132.8	69.4	127.8
	5	326.8	120	217.4
	6	427. 4	----	----

The study area is composed of two aquifers, the first aquifer is unconfined while the second aquifer is confined. The geo-hydraulic parameters of the second aquifer was evaluated because of its appropriateness for both domestic and industrial water supply.

The hydraulic parameters (hydraulic conductivity, transmissivity, porosity, formation factor and tortuosity) were computed from the geoelectric parameters of the aquifers (Table 3).

3.1 Conductivty Distribution

The aquifer resistivity in the study area ranged from 100.7 Ωm to 350 Ωm with an average of 280 Ωm. The comparison of the isoresistiviy contour map (Fig. 5) with the isohydraulic conductivity contour map (Fig. 6) revealed that there is an inverse relationship between aquifer resistivity and its hydraulic conductivity. Zones of high aquifer resistivity correspond to zones of low hydraulic conductivity. Hydraulic conductivity controls the rate at which groundwater flows under gravity and hydraulic gradient (Hazel, 1975). The aquifer hydraulic conductivity ranged from 1.636 m/day to 5.231 m/day (Table 3). The isohydraulic conductivity map shows the spatial distribution of the aquifer hydraulic conductivity (Fig. 6). The hydraulic conductivity increases from the Northeastern part to the Southwestern part of the study area (Fig. 6).

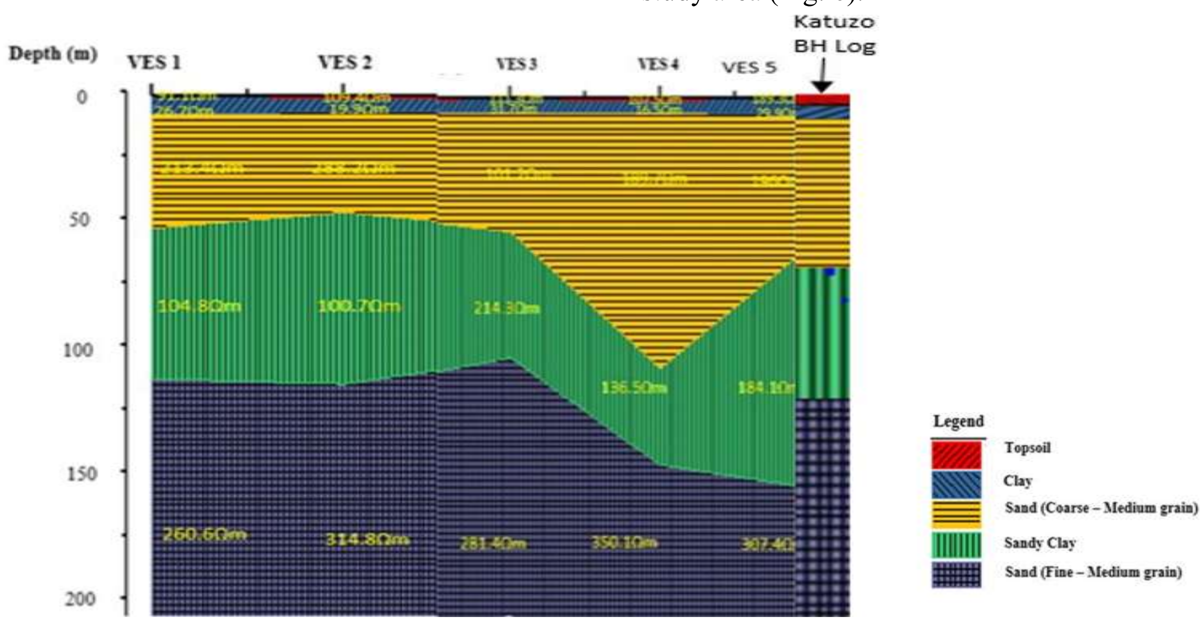

Fig. 4: Correlation of the geoelectric sections of VES 1-5 (first five layers) with an existing Borehole from Katuzo area of the study area.

Table 3: Computed aquifer geo-hydraulic parameters

VES	Latitude (⁰N)	Longitude (⁰E)	Aquifer Resistivity (Ωm)	Aquifer Thickness (m)	Hydraulic Conductivity (m/day)	Transmissivity (m²/day)	Porosity (%)	Formation factor	Tortuosity
1	12.86309	11.03716	260.6	100.0	2.1545	215.4486	28.9540	0.00045	0.1137
2	12.86468	11.03493	100.7	66.7	5.2306	348.8807	32.9454	0.00034	0.1055
3	12.86585	11.03205	281.4	75.0	2.0055	150.4165	28.6316	0.00046	0.1144
4	12..86705	11.02919	350.1	67.8	1.6358	110.9093	27.7147	0.00049	0.1166
5	12.86880	11.02538	307.4	73.6	1.8468	135.9284	28.2607	0.00047	0.1153
6	12.86610	11.05085	318.7	107.3	1.78557	191.6050	28.1091	0.00048	0.1156
7	12.86769	11.04965	291.8	76.9	1.9388	149.0932	28.4793	0.00046	0.1148
8	12.87476	11.05257	253.8	70.5	2.2083	155.6841	29.0650	0.00044	0.1134
9	12.87567	11.05047	306.3	85.4	1.8530	158.2496	28.2757	0.00047	0.1148
10	12.87127	11.05348	326.8	120.0	1.7444	209.3248	28.0038	0.00048	0.1159
	Average		279.76	84.32	2.2403	182.5540	28.8439	0.00045	0.1140
	Maximum		350.10	120.0	5.2306	348.8807	32.9454	0.00049	0.1166
	Minimum		100.70	66.70	1.6358	110.9093	27.7147	0.00034	0.1055

This observation is in agreement with the report of Agada *et al*. (2020), which in their investigation of groundwater contamination by leachate in Gashua area established that the groundwater flows from southwest to northeast direction. The aquifer thickness in the study area ranged from 66.7 to 120 m with an average value of 84.32 m. The aquifer transmissivity ranged from 110.91 m^2/day to 348.88 m^2/day with an average value of 182.55 m^2/day (Table 3). This indicates that the aquifer potential is moderate (Table 1). These values were used to generate an iso-transmissivity map (Fig. 8). The iso-transmissivity contour map showed the spatial distribution of the aquifer transmissivity. The transmissivity increases from the Northern part to the Southern part of the study area. The aquifer transmissivity in the study area is moderate with a porosity ranging from 27.7% to 32.9% with an average value of 28.8% (Table 3) and it is spatially related to the hydraulic conductivity. The porosity contour map shows the spatial distribution of porosity in the study area.

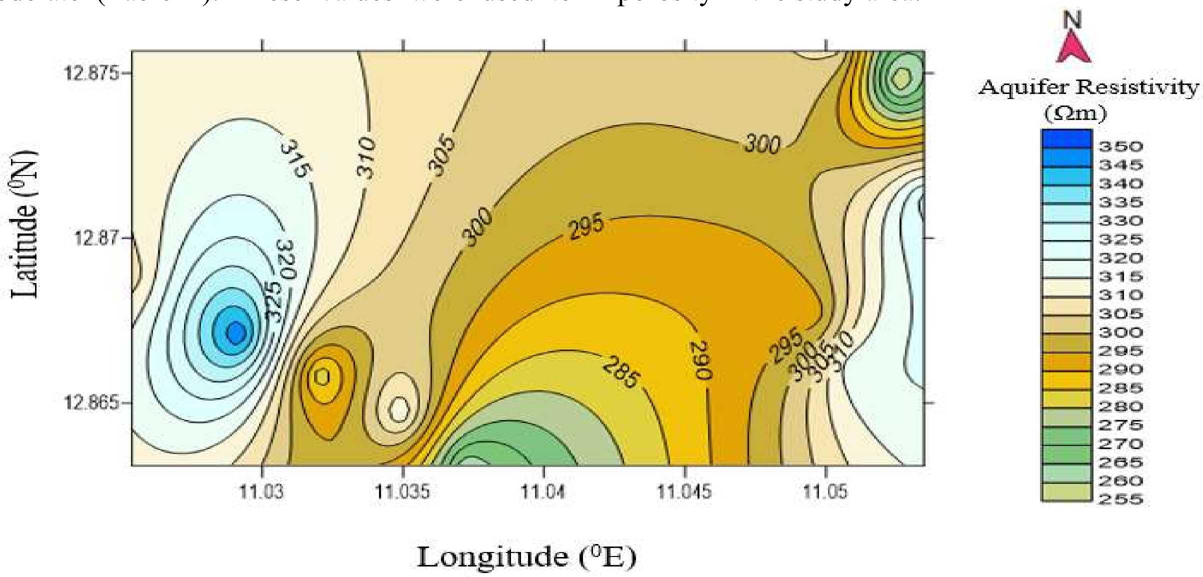

Fig. 5: Contour map of aquifer resistivity

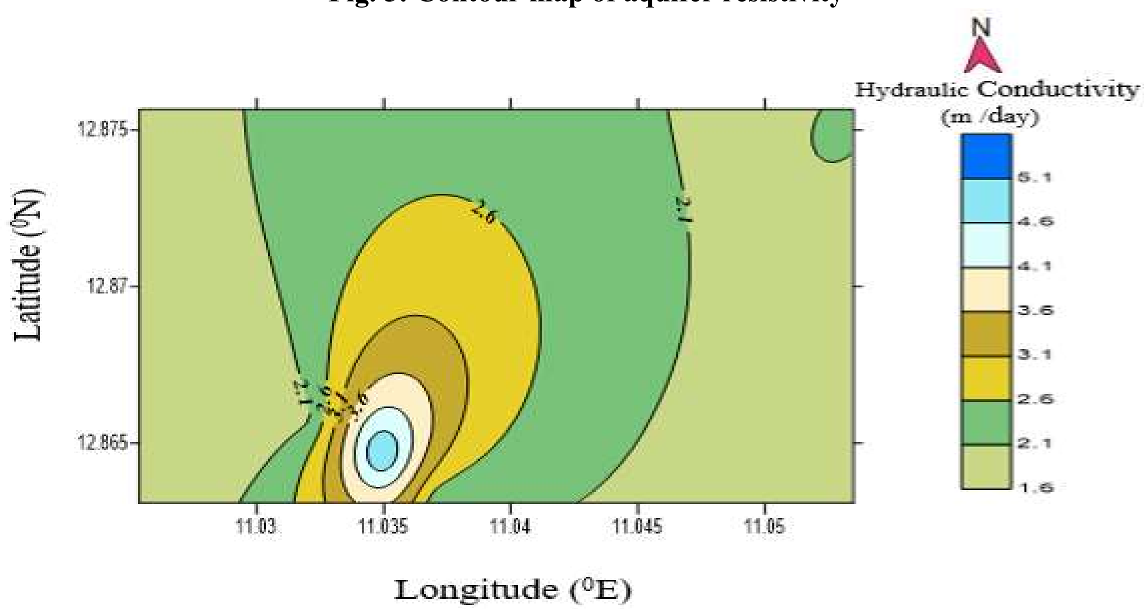

Fig. 6: Contour Map of Hydraulic

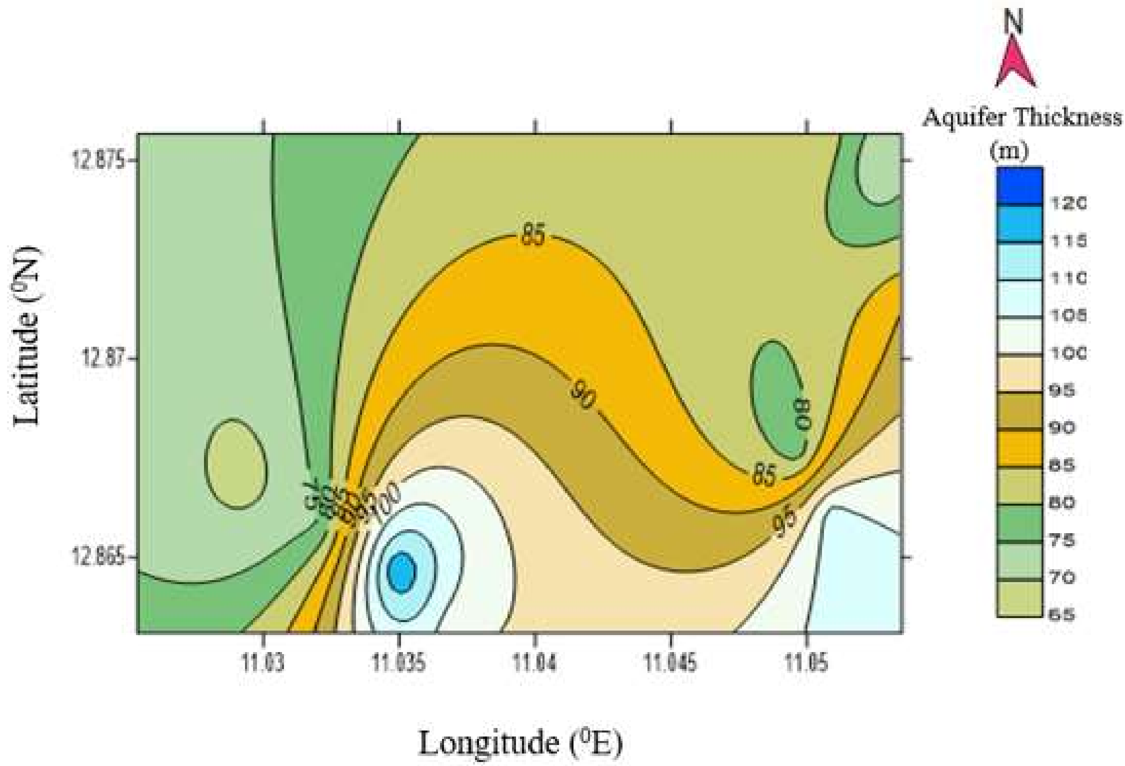

Fig. 7: Contour map of aquifer thickness

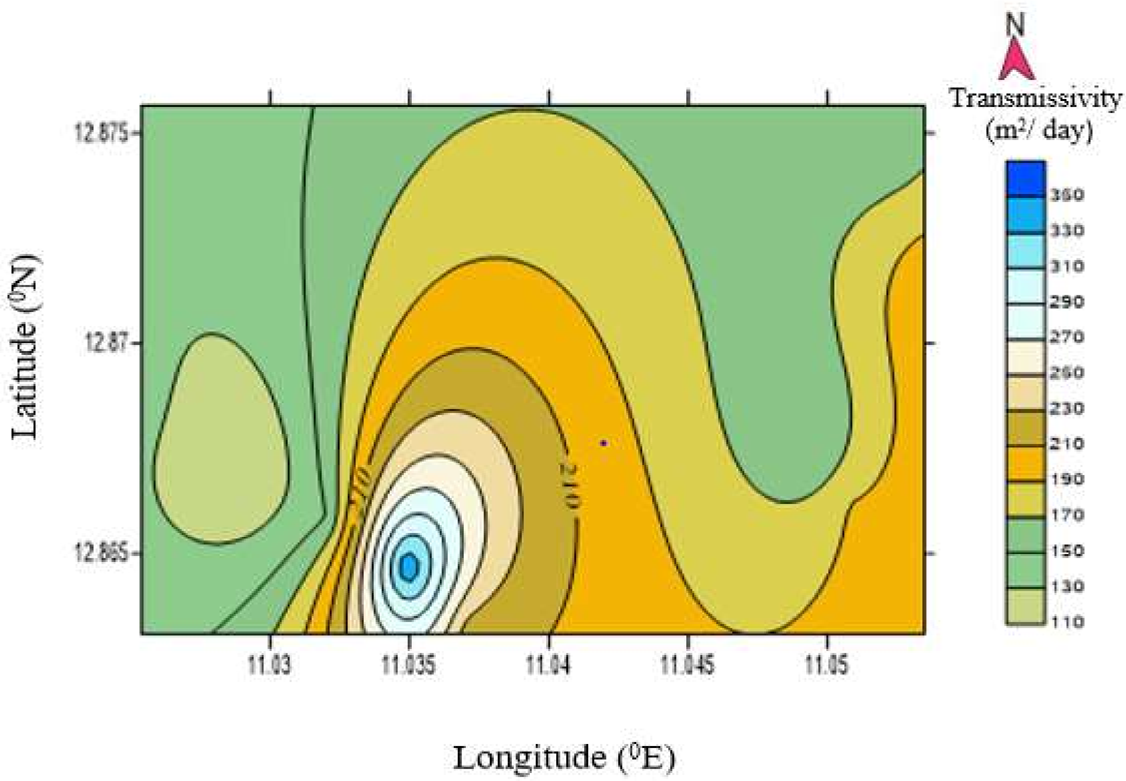

Fig. 8: Contour map showing the variation of aquifer transmissivity.

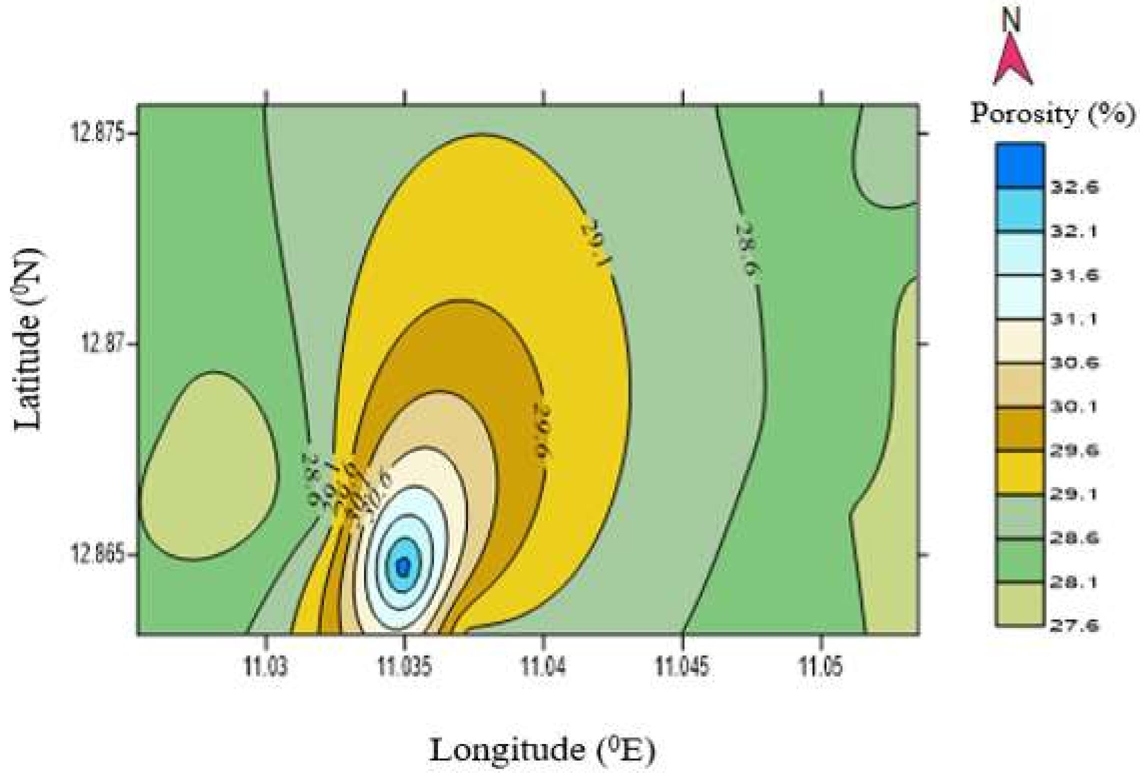

Fig. 9: Contour map showing the distribution of porosity

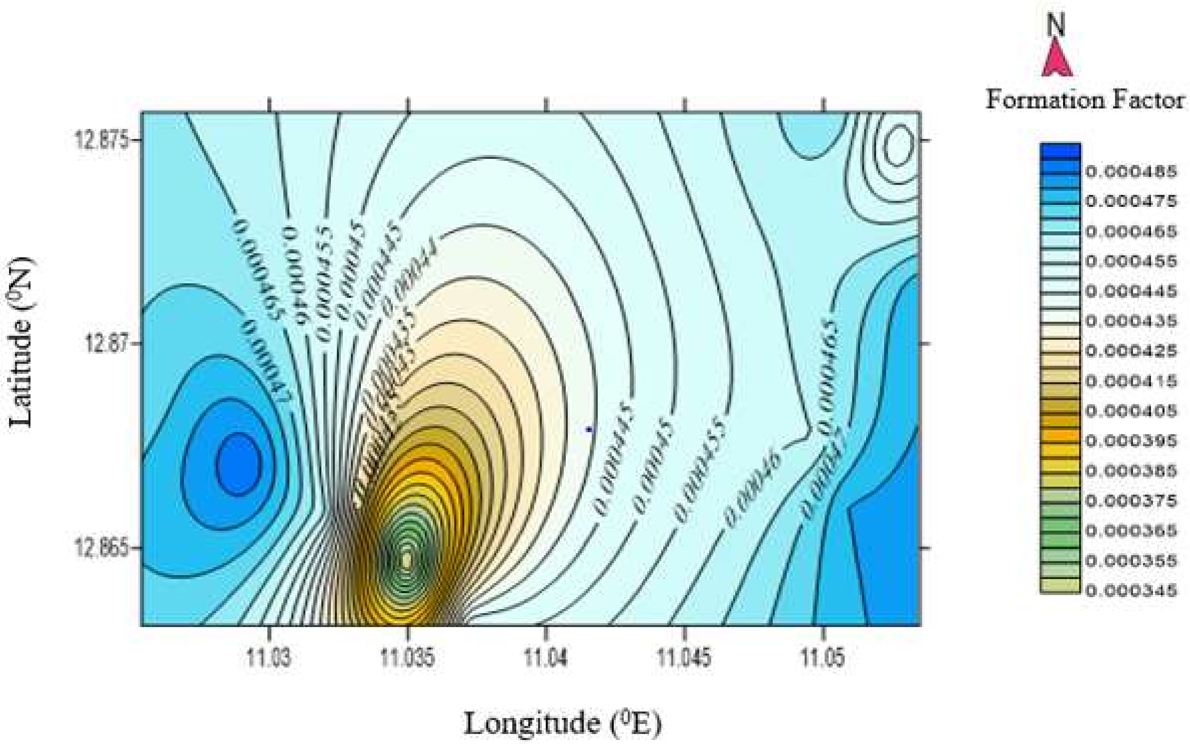

Fig. 10: Contour map showing the variation of aquifer formation factor

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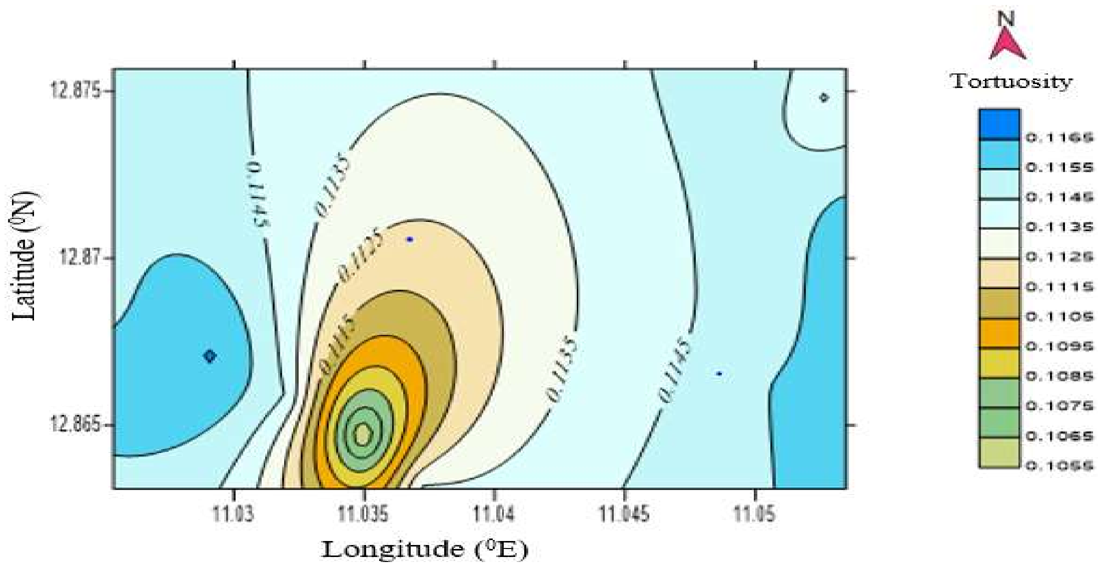

Fig. 11: Contour map showing variation of tortuosity

Also, the analysis of the tortuosity contour map (Fig. 11) shows that tortuosity increases with formation factor and decreases with porosity. The hydraulic properties of the aquifer parameters are good indices for groundwater evaluation and management. The spatial distribution of the aquifer hydraulic parameters in the study area shows that the aquifer in the study area has high potential.

4.0 Conclusion

Findings from this study showed that the aquifer hydraulic parameters are related to one another. The results suggest that the hydraulic parameters that control the occurrence of groundwater in the area are heterogeneous in behavior, a decrease in the magnitude of one parameter could lead to an increase in the magnitude of another parameter or a decrease in another parameter. The results of the study present important information that will facilitate accurate modeling of groundwater flow and distribution in the area. It also provides the needed information for efficient groundwater resources management in the study area. The porosity, hydraulic conductivity and transmissivity values indicate moderate productivity and good yield for the aquifer unit.

5.0Reference

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Conflict of Interest

The authors declare no conflict of interest