Current Journal of Applied Science and Technology

27(5): 1-15, 2018; Article no.CJAST.41905
ISSN: 2457-1024
(Past name: British Journal of Applied Science & Technology, Past ISSN: 2231-0843, NLM ID: 101664541)

Dar Zarrouk Parameters for Delineation of Groundwater Potential Zones in Geriyo Irrigation Floodplain of River Benue, Adamawa State, Northeastern Nigeria

B. A. Ankidawa[1*] and A. B. Seli[2]

[1]Department of Agricultural and Environmental Engineering, School of Engineering and Engineering Technology, Modibbo Adama University of Technology, PMB 2076, Yola, Nigeria.
[2]Department of Civil Engineering, Adamawa State Polytechnic, Yola, Nigeria.

Authors' contributions

This work was carried out in collaboration between all authors. Author BAA designed the study, performed the statistical analysis, wrote the protocol, managed the literature searches, wrote the first draft of the manuscript and managed the analyses of the study. Author ABS managed the literature searches. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/CJAST/2018/41905
Editor(s):
(1) Ahmed Fawzy Yousef, Associate Professor, Department of Geology, Desert Research Center, Egypt.
Reviewers:
(1) Yongchun Zhu, Shenyangnormal University, China.
(2) Hermine Ramzy Zaki Tadros, National Institute of Oceanography and Fisheries, Egypt.
(3) Sunday Olufemi Adesogan, University of Ibadan, Nigeria.
Complete Peer review History: http://www.sciencedomain.org/review-history/24838

Original Research Article

Received 8th March 2018
Accepted 17th May 2018
Published 28th May 2018

ABSTRACT

The study is aimed at delineating groundwater potential zones of the alluvial formations using Dar Zarrouk Parameters and groundwater flow direction on the floodplain. This will help the farmers to utilise the floodplain shallow wells during the dry season farming. Shallow wells on the floodplain of River Benue are the primary sources of water supply for irrigation activities. The floodplain is underlain by Bima sand stones. Twenty-four profiles of vertical electric soundings using Schlumberger array method with the aid of a sensitive ABEM Signal Averaging System (SAS) was used to investigate. The results were then compared with the alluvial floodplain lithologies at each sounding points with resistivity values ranging between 0.146 Ωm to 9,873.6 Ωm and depths varying

**Corresponding author: E-mail: ankidawa03@yahoo.com;*

from 0.2 to 38.33 m. The geoelectric sequence of the alluvial formations of the floodplain reveals semi aquifer system. The aquifer hydraulic characteristics indicated that the transverse resistance, R ranged between 2,626.70 Ωm^2 to 241,252.38 Ωm^2 with a mean value of 45,172.17 Ωm^2. The longitudinal conductance, S ranged between 0.001 to 0.221 with an average value of 0.036. The hydraulic conductivity value across the floodplain ranges between 0.21 m/day to 29.06 m/day with a mean value of 11.22 m/day. The transmissivity values obtained for the various layers ranges between 1.68 m^2/day to 808.16 m^2/day with an average value of 214.07 m^2/day. Three groundwater potential zones were delineated on the floodplain. The results of the hydraulic head reveal that the water levels in the floodplain are higher than the River and recharge the River.

Keywords: River Benue; irrigation; alluvial formations; dar zarrouk parameters; groundwater; schlumberger.

1. INTRODUCTION

Groundwater has always been considered to be a readily available source of water for domestic purposes, in agriculture as well as in industries. In many parts of the world, especially arid and semi-arid regions, groundwater extracted for a variety of purposes has made a significant contribution to the improvement of the social and economic circumstances of human beings. A shallow well on the alluvial formations serves as the main water supply for irrigation during the dry season period. For good management of groundwater, aquifer parameters are necessary. As a result shallow groundwater is also the source of much of the water used for irrigation [1], and is the principal resource of fresh water and represents much of the potential future water supply. Resistivity survey, in particular, has the potential for tracing the groundwater levels in an area. Geophysical investigations provide a rapid and cost-effective means of developing information on subsurface hydrogeology [2,3]. For the purposes of this research work, the application of electrical resistivity survey method using vertical electrical sounding was applied. Vertical electrical sounding is a geoelectrical method commonly used to measure vertical alterations of electrical resistivity. This method has been recognized to be more suitable for a hydrogeological survey of sedimentary basins than the other resistivity methods [4,5].

The Dar Zarrouk Parameters derived from surface geoelectric soundings have proven to be important in understanding the spatial distribution of aquifer hydraulic parameters. Studies by [6,7] derived analytical relations between aquifer transmissivity and transverse resistance. [8] first introduced the concept of Dar Zarrouk parameters, when the thickness and resistivity of subsurface layer known, its transverse resistance and longitudinal conductance s can be estimated. The research is aimed at delineating groundwater potential zones on the shallow alluvial aquifers on the floodplain of River Benue using Dar Zarrouk Parameters derived from geoelectric resistivity soundings.

2. STUDY AREA

The study area is located in Adamawa State North Eastern part of Nigeria, between latitudes 9°17′ to 9°19"N and longitude 12°24′30" to 12°28′30"E of the equator of the Greenwich meridian (Fig. 1). It shares a boundary with Cameroon Republic along its eastern border. The state covers a land area of about 38,741 km^2 with a population of 3,168,101 people, and a population density of 82 persons per square kilometre [9]. The floodplain is drained by the River Benue, which is the largest and only perennial river in the area [10]. The River Benue is fed by two major streams in Cameroon; Mayo Kebbi and River Faro and flows into River Niger 1400 km downstream. The elevation of the study area varies from 149 to 172 m above mean sea level and falls within the Upper Benue Basin. Adamawa State has some of the longest mountain ranges and breath-taking landscape sceneries in the country with areas as low as 129 m and as high as 2042 m above sea level [10]. The land rises from the low-lying Gongola and Benue valleys to the rugged hills to the northeast defining the Mandara Alantika Shebshi Mountain Ranges and the central portion, which is dotted with isolated uplift such as the Lamurde Longuda, Song-Bagale and Yardang hills [10].

2.1 Geology of the Research Area

The Benue floodplain in the region of Yola is underlain by sedimentary rocks, which consist of two stratigraphic units [11,12]. The feldspathic

Bima sandstone and the Yola sandstone (Fig. 2) are found along the main course of the bank of the River Benue valley and its tributaries and consist of all grain size between clays and pebbly-sands [13, 14]. Detailed description of the Bima Sandstones were provided by [12,15,16, 17] and [18] into B1, B2 and B3 Bima group. The outcrops of the Bima group belong to the Bima 2 and Bima 3 in the Yola arm [19]. The Bima sandstones (B2) varies from fine to coarse-grained [15], and the deposits were regarded as of proximal braided river origin [20]. The upper Bima Sandstones (B3) is fairly homogenous, relatively mature, and fine to coarse-grained sandstone, characterized by tabular cross-bedding, convolute bedding and overturned cross-bedding [21]). The Bima sandstone occurs in the western and southwestern parts of the study area (Fig. 2). The river alluvium (recent) belongs to the Quaternary age and is found along the main course of the Benue River, and extends towards the northwestern and southeastern parts of the study area (Fig. 2). The river alluvium consists of poorly sorted sands, clays, siltstones and pebbly sand [13,14].

3. MATERIALS AND METHODS

3.1 Resistivity Soundings

Twenty four resistivity soundings were carried out on the floodplain of River Benue Lake Geriyo irrigation project to explore the shallow alluvial groundwater. ABEM (SAS300) Terrameter was used employing the Schlumberger method. Current was introduced into the ground through a pair of current electrodes and with potential electrodes at the center of the array. Measurements were made in a series of readings involving successively larger current electrode separation. The data were plotted on a logarithmic scale to produce a sounding curve representing apparent resistivity variation as a function of half current-electrode separation AB/2. The potential electrodes were installed at the center of the electrode array, with a small separation, typically less than one fifth of the spacing between the current electrodes. The current electrodes were increased to a greater separation during the survey, while the potential electrodes remain in the same position until the observed voltage becomes too small to measure. The depth of the resistivity sounding is typically 1/3 of the electrode spacing [22,23,24]. Apparent resistivity (ρ_a) values were estimated using the following:

$$\rho_a = \frac{V}{I} K \tag{1}$$

where K is the geometric factor, and $\frac{v}{i}$ is the resistance reading.

$$K = \frac{\pi(s-a)}{2a} \tag{2}$$

where "a" is spacing between potential electrode and S is spacing between current electrodes [25].

3.2 Dar Zarrouk Parameters

The Dar Zarrouk Parameters was used for the estimation of the aquifer transmissivity of the alluvial floodplain. The Dar Zarrouk parameters (longitudinal conductance S and transverse resistance Tr are defined by using equations 3 and 4 [6,26,27].

$$S = \frac{h_1}{\rho_1} + \frac{h_2}{\rho_2} + \frac{h_3}{\rho_3} + --------- + \frac{h_n}{\rho_n} = \sum_{i=1}^{n} \frac{h_i}{\rho_i} \tag{3}$$

$$Tr = \rho_1 h_1 + \rho_2 h_2 + \rho_3 h_3 + ---- + \rho_n h_n = \sum_{i=1}^{n} \rho_n h_n \tag{4}$$

where h is aquifer thickness, ρ is resistivity. The relationship between aquifer transmissivity and longitudinal conductance is expressed as

$$Tr = K\delta R = \frac{KS}{\sigma} \tag{5}$$

where Tr = aquifer transmissivity, K = hydraulic conductivity, σ = electrical conductivity (reciprocal of resistivity), R = transverse resistance and S = longitudinal conductance.

The hydraulic conductivity K was estimated using [28] method,

$$K = 386.40 Rrw^{-0.93283} \tag{6}$$

where R_{rw} is aquifer resistivity value, which was used in calculating the transmissivity of the alluvial floodplain Geriyo Irrigation Scheme of River Benue.

4. RESULTS AND DISCUSSION

Three groups of electro-stratigraphic earth models were obtained from the analysis of the resistivity data (Table 1): these are five electro-stratigraphic model groups, four electro-stratigraphic model groups and three electro-stratigraphic model groups. It is observed from the geoelectric section that the first layer is characterized by low resistivity values varying between 159.46 Ωm to 327.69 Ωm and aquifer thickness varying from 0.74 to 3.29 m, the low resistivity value of this layer suggests high aquifer potential. [26,27] and [29] stated that aquifer with low resistivity values indicates high aquifer potential. The second layer has resistivity and thickness values varying between 702.03 Ωm to 1,460.00 Ωm and 4.84 m to 11.62 m. The high value of resistivity at the top layer may correspond to the unsaturated zone, as observed by [30], since the soundings were carried out during the dry season period. The third layer has resistivity and thickness value varying between 49.21 Ωm to 545.13 Ωm and 5.45 m to 22.36 m, this layer shows low resistivity, suggesting high aquifer potential. The fourth layers have resistivity values vary from 154.55 Ωm to 174.47 Ωm and thickness varies from 16.12 m to infinite thickness, suggesting high aquifer potential.

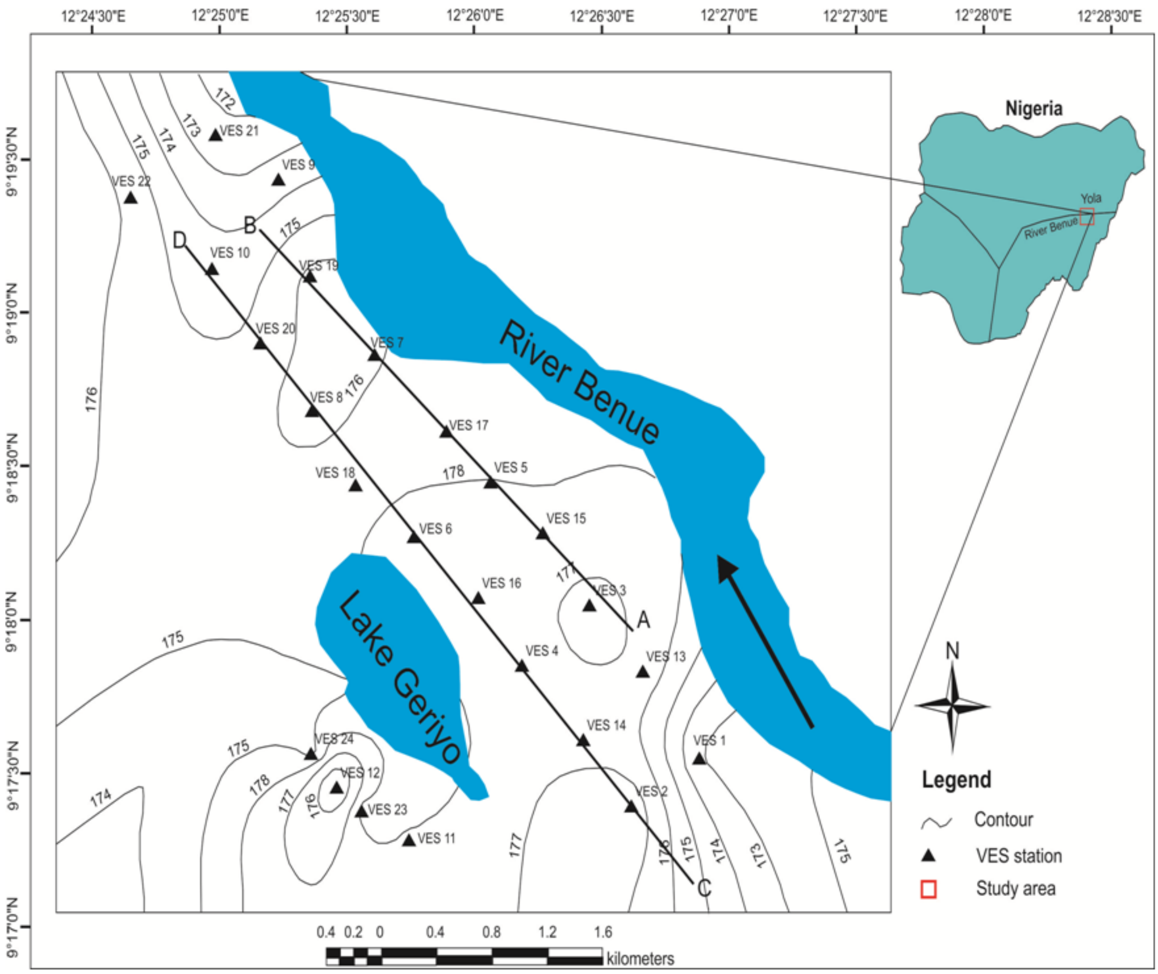

Fig. 1. Topographic map of the research area showing the VES stations

Table 1. Average resistivity and thickness values for the three groups of electro-stratigraphic earth model

Model type		First layer	Second layer	Third layer	Fourth layer	Fifth layer
Five	Resistivity (Ωm)	159.46	1,460.00	49.21	174.47	184.5
	Thickness (m)	0.74	5.44	5.45	16.12	-
Four	Resistivity (Ωm)	246.19	1,402.42	470.07	154.55	-
	Thickness (m)	1.9	4.84	22.36	-	-
Three	Resistivity (Ωm)	327.69	702.03	545.13	-	-
	Thickness (m)	3.29	11.62	-	-	-

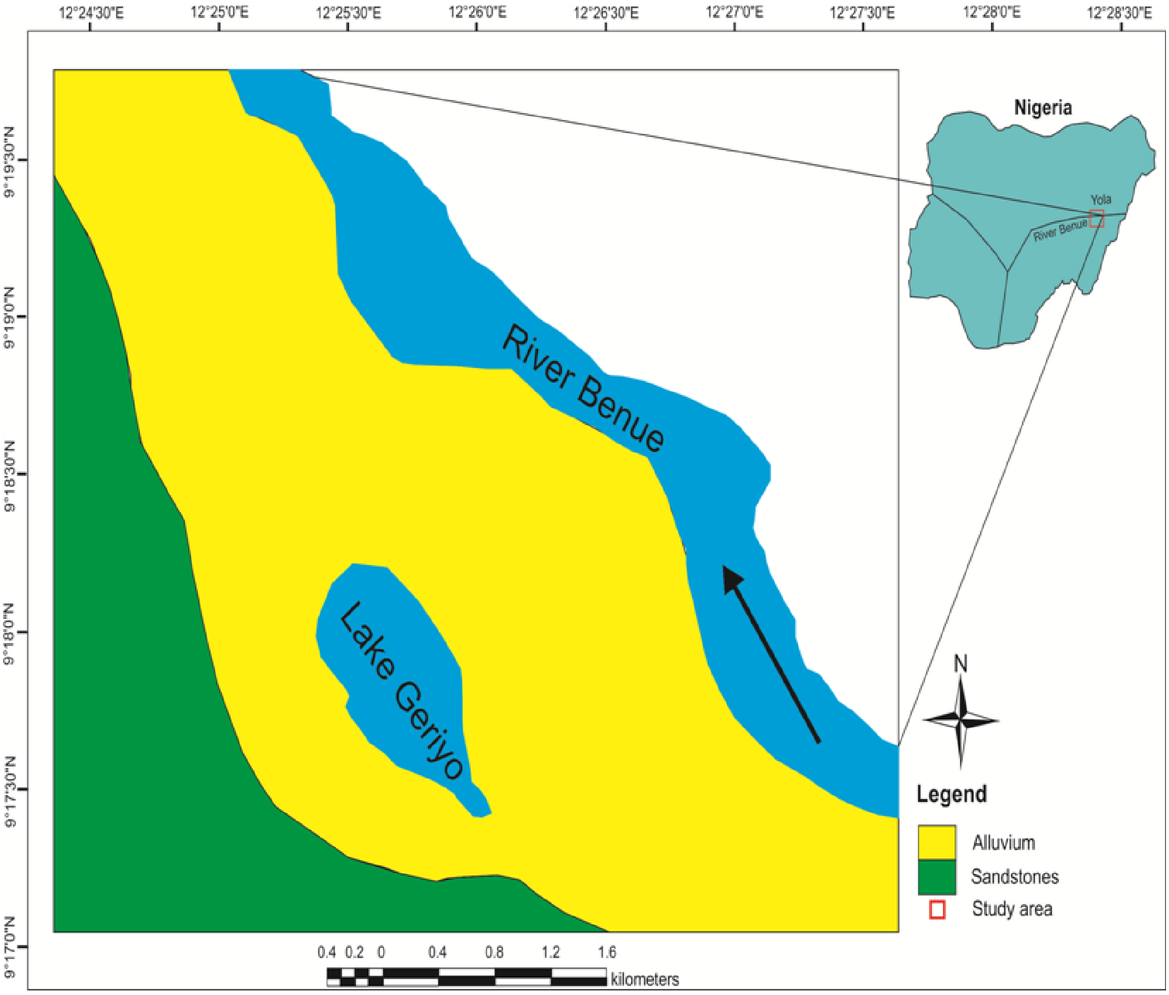

Fig. 2. Geological map of the research area

The resistivity results reveal twelve different types of curves, for the twenty-four resistivity sounding points in the floodplain (Table 1). [31] and [32] stated that the shape of a VES curve depends on the number of layers in the substratum, the thickness of each layer, and the ratio of the resistivity of the layers. The curve types include A= $\rho1<\rho2<\rho3$, AA= $\rho1<\rho2<\rho3<\rho4<\rho5$, AK= $\rho1<\rho2<\rho3>\rho4$, H= $\rho1>\rho2<\rho3$, HK= $\rho1>\rho2<\rho3>\rho4$, K= $\rho1<\rho2>\rho3$, KH= $\rho1<\rho2>\rho3<\rho4$, KHK= $\rho1<\rho2>\rho3<\rho4>\rho5$, KQ= $\rho1<\rho2>\rho3>\rho4$, Q= $\rho1>\rho2>\rho3$, QH= $\rho1>\rho2>\rho3<\rho4$ and QQH= $\rho1>\rho2>\rho3>\rho4<\rho5$. Curve KH is common for the resistivity soundings constituting about 20.83% of the total curves. Curve K constituting about 16.66% of the total curves, HK curve constitute 12.5% of the total curve, A, H and QH curves constitute 8.33% each of the total curve and curves AA, AK, KDK, KQ, Q and QQH constitute only 4.17% each of the total curve. The VES curves were interpreted in terms of the subsurface geoelectric parameters (layer resistivity and thickness) at each location. These enabled the determination of the geoelectric layer depths to the alluvial sediment beneath the VES stations. The VES fitting error obtained ranges between 0.9 to 4.2 %, with an average of 2.73% (Table 2), which falls within the acceptable error limits, which is 0 to 15%.

The geoelectric section along AB and CD (Fig. 1) were used to delineate the aquifer system into semi confined and confined aquifer type (Fig. 3). The aquifer consists of fine, medium to coarse-grained sand as revealed by the geoelectric sequence beneath the floodplain. The thickness of the semi confined and confined aquifers along AB ranged from 0.506 m to 37.46 m with an average of 21.54 m while the thickness along CD ranged from 1.64 m to 28.36 m with a mean value of 17.60 m.

Table 2. Geoelectric parameters and lithology delineation at Alluvial Floodplain of River Benue

VES Station	Layers	Resistivity (Ωm)	Thickness (m)	Depth (m)	Lithology	Curve type	Fitting Error %
1	1	156.8	0.66	0.66	silt	QH	1.85
	2	68.65	5.98	6.64	sand	$\rho_1>\rho_2>\rho_3<\rho_4$	
	3	21.38	13.8	20.44	silt		
	4	135.4			sand		
2	1	10.72	1.65	1.65	Silt	A	2.49
	2	16.02	26.16	27.81	Sand silt	$\rho_1<\rho_2<\rho_3$	
	3	279.2			sand		
3	1	735.5	1.64	1.64	clay	KH	1.72
	2	3600.4	2.14	3.78	sand	$\rho_1<\rho_2>\rho_3<\rho_4$	
	3	128.2	48.1	51.88	silt		
	4	186.1			sand		
4	1	27.48	2.41	2.41	Silt	HK	3.73
	2	18.9	11.5	13.91	Clay	$\rho_1>\rho_2<\rho_3>\rho_4$	
	3	4001.6	3.44	17.35	Sand silt		
	4	1.47			Sand		
5	1	17.26	1.52	1.52	Clay	AA	3.72
	2	20.13	13.65	15.17	Silt	$\rho_1<\rho_2<\rho_3<\rho_4<\rho_5$	
	3	49.39	6.01	21.18	clay		
	4	112	16.28	37.46	Sand silt		
	5	283.1			Sand		
6	1	116.5	3.25	3.25	Silt		2.60
	2	3252.7	2.77	6.02	Sand silt	K	
	3	105.8			Sand	$\rho_1<\rho_2>\rho_3$	
7	1	36.58	4.21	4.21	Silt	H	1.35
	2	3.95	3.1	7.31	clay	$\rho_1>\rho_2<\rho_3$	
	3	318.8			Sand		
8	1	508.8	1.59	1,59	Clay	K	2.41
	2	937.3	11.01	12.6	silt	$\rho_1<\rho_2>\rho_3$	
	3	108.7			Sand		
9	1	193.7	0.26	0.26	silt	KH	3.81
	2	492.1	6.14	6.4	Sand	$\rho_1<\rho_2>\rho_3<\rho_4$	
	3	144.1	85.2	91.6	silt		
	4	391.1			Sand		
10	1	1800.1	3.06	3.06	Silt	Q	0.9
	2	179.4	10.23	13.29	Sand silt	$\rho_1>\rho_2>\rho_3$	
	3	102			Sand		
11	1	260.7	0.49	0.49	Sand	QH	1.66
	2	60.08	6.17	6.66	silt	$\rho_1>\rho_2>\rho_3<\rho_4$	
	3	8.34	3.45	10.11	Sand		
	4	119			Sand		
12	1	432.2	0.2	0.2	clay	QQH	1.1
	2	36.42	1.98	2.18	silt	$\rho_1>\rho_2>\rho_3>\rho_4<\rho_5$	
	3	22.52	7.27	9.45	clay		
	4	14.02	5.55	15	Sand silt		
	5	152			Sand		
13	1	23.89	1.5	1.5	clay	KH	2.03
	2	90.76	1.58	3.08	silt	$\rho_1<\rho_2>\rho_3<\rho_4$	
	3	59.09	33.2	36.28	Sand silt		
	4	128.5			Sand		
14	1	27.12	10.13	10.13	Clay	HK	3.05
	2	2.16	5.13	15.26	Silt	$\rho_1>\rho_2<\rho_3>\rho_4$	
	3	99.01	13.1	28.36	Sand silt		
	4	0.146			Sand		

VES Station	Layers	Resistivity (Ωm)	Thickness (m)	Depth (m)	Lithology	Curve type	Fitting Error %
15	1	28.93	0.506	0.506	Silt	KHK	3.76
	2	4324	0.673	1.179	Clay	ρ1<ρ2>ρ3<ρ4>ρ5	
	3	75.71	3.08	4.259	Silt		
	4	397.4	26.5	30.76	Sand silt		
	5	118.4			Sand		
16	1	50.86	7.5	7.5	Silt	H	2.92
	2	8.01	5.29	12.79	Sand silt	ρ1>ρ2 <ρ3	
	3	456			Sand		
17	1	43.17	1.36	1.36	Silt	K	2.98
	2	1003.7	2.71	4.07	Sand silt	ρ1<ρ2>ρ3	
	3	133			Sand		
18	1	61.65	1.32	1.32	Clay	AK	3.34
	2	255	1.72	3.04	Sand	ρ1<ρ2<ρ3>ρ4	
	3	6.14	4.6	7.64	Silt		
	4	400.8			Sand		
19	1	869.5	1.28	1.28	Silt	KQ	4.2
	2	1664.4	6.71	7.99	Clay	ρ1<ρ2>ρ3>ρ4	
	3	372.9	20.1	28.09	Sand silt		
	4	73.77			Sand		
20	1	373.6	1.45	1.45	Sand	K	2.94
	2	888.7	5.89	7.34	Silt	ρ1<ρ2>ρ3	
	3	132.2			Sand		
21	1	100.5	0.577	0.577	Clay	KH	3.92
	2	9873.6	1.18	1.757	Sand silt	ρ1<ρ2>ρ3<ρ4	
	3	26.37	5.14	6.897	Sand		
	4	216.3					
22	1	491.2	1.38	1.38	Clay	KH	2.98
	2	701.6	5.78	7.16	silt	ρ1<ρ2>ρ3<ρ4	
	3	24.28	4.89	12.05	Clay		
	4	187.4			Sand		
23	1	8.91	5.54	1.54	Clay	A	2.06
	2	29.02	36.8	42.34	Sand silt	ρ1<ρ2<ρ3	
	3	3270.5			Sand		
24	1	6.23	1.12	1.12	Silt	HK	3.99
	2	1.43	3.91	5.03	Clay	ρ1>ρ2<ρ3>ρ4	
	3	740.4	33.3	38.33	Sand silt		
	4	14.56			Sand		

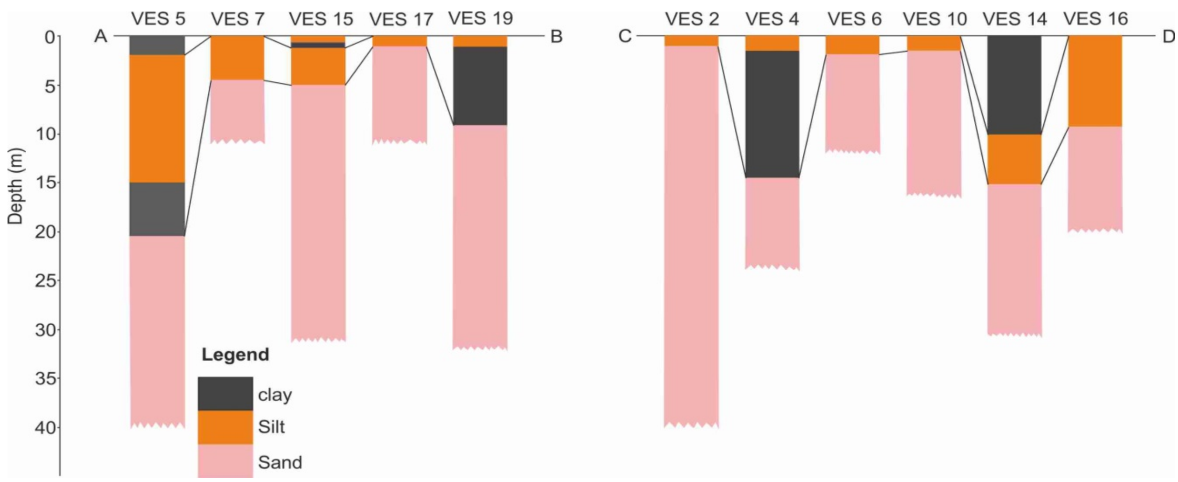

Fig. 3. The geoelectric section along AB and CD transect (in Fig. 1.) on the floodplain

The aquifer hydraulic characteristics of the floodplain were estimated using Dar Zarrouk Parameters (transverse resistance, R and longitudinal conductance, S in porous media) [33]. The longitudinal conductance range between 0.001 to 0.221 with an average value of 0.036 (Table 5). The longitudinal conductance was used to predict the aquifer protective capacity [34]. The longitudinal conductance is low in the northwest part of the study area and high in the southeastern part of the study area (Fig. 4). [35] stated that longitudinal conductance S>1.0 indicates high aquifer protection while longitudinal conductance S<1.0 indicates probable risks of contamination. The longitudinal conductance obtained is low this suggests that aquifers across the floodplain are liable to probable risks of contamination. The aquifers on the floodplain are underlain by loose permeable layer. A study by [36] in their study observed good to poor protective capacity on the floodplain of Igbara southwestern Nigeria. Transverse resistance is used in the determination of zones of groundwater potential [35, 37, 38]. The transverse resistance obtained ranges between 2,626.70 Ωm^2 to 241,252.38 Ωm^2 with a mean value of 45,172.17 Ωm^2 (Table 5). The maximum transverse resistance was obtained in the eastern part of the study area while the minimum transverse resistance was obtained in the northwestern, western, southwestern and southern parts of the study area (Fig. 5). This suggests that aquifer potential is high in the eastern part of the study area, and therefore the yield is high. A similar study was carried out in Behbahan Azad University farm, Khuzestan Province, Iran by [38] observed high aquifer potential. [39] stated that low transverse resistance indicates inadequate aquifer thickness or highly mixed finer sediments on the floodplain. The hydraulic conductivity result range between 0.21 m/day to 29.06 m/day with a mean value of 11.22 m/day (Table 5). Based on [40] standard, 75% of the values indicated hydraulic conductivity of fine, medium and coarse sand which allows free flow of water to recharge the aquifers and 25% of the values indicated loam soils (Table 3). The hydraulic conductivity is low in the northwestern, western and southwestern parts of the study area and high in the northern, southern and southeastern parts of the study area (Fig. 6). This suggests that the northern, southern and southeastern parts of the study area have high permeability in the floodplain sediments. The transmissivity values for the various layers range between 1.68 m^2/day to 808.16 m^2/day with an average value of 214.07 m^2/day (Table 5), which indicates low to high aquifer potentials and groundwater supply potential of small withdrawal for local water supply to the withdrawal of lesser regional importance (Table 4). The transmissivity is low in the eastern, northwestern, western and southwestern parts of the study area and high in the northern, southern and southeastern parts of the study area (Fig. 7). Studies by [41] in Nile Delta, Egypt and [42] in southern parts of Kaduna State, North Western Nigeria reported transmissivity ranges from low to high. Groundwater potential zones were delineated on the Geriyo irrigation floodplain of River Benue. [39] stated the Transverse Resistance TR<200,000 is very low, TR<400,000 is low, TR<600,000 is moderate, TR<800,000 is high and TR<1,000,000 is very high groundwater potential. This suggests that three groundwater potential zones (very low, low and moderate potential) were delineated on the floodplain of the study area (Fig. 8.)

Table 3. Standards for Hydraulic Conductivity (K) [40]

Materials	K Ranges (m/day)
Clay Soils (surface)	0.01 – 0.2
Deep clay beds	10^{-8} to 10^{-2}
Loam soils (surface)	0.1 to 1
Fine Sand	1 to 5
Medium sand	5 to 20
Coarse Sand	20 to 100
Gravel	100 to 1000
Sand and gravel mixes	5 to 100
Clay, sand, and gravel mixes (till)	0.01 to 0.1

Table 4. Standard for Transmissivity (T) [43]

T (m^2/day)	Designation	Groundwater Supply Potential
>1000	Very high	Withdrawal of great regional importance
100 - 1000	High	Withdrawal of lesser regional importance
10 - 100	Intermediate	Withdrawal for local water supply (small community, plants etc)
1 - 10	Low	Small withdrawals for local water supply (private consumption etc)
0.1 -1	Very low	Withdrawal for local water supply with limited consumption
<0.1	Impermeable	Sources for local water supply are difficult if possible to ensure

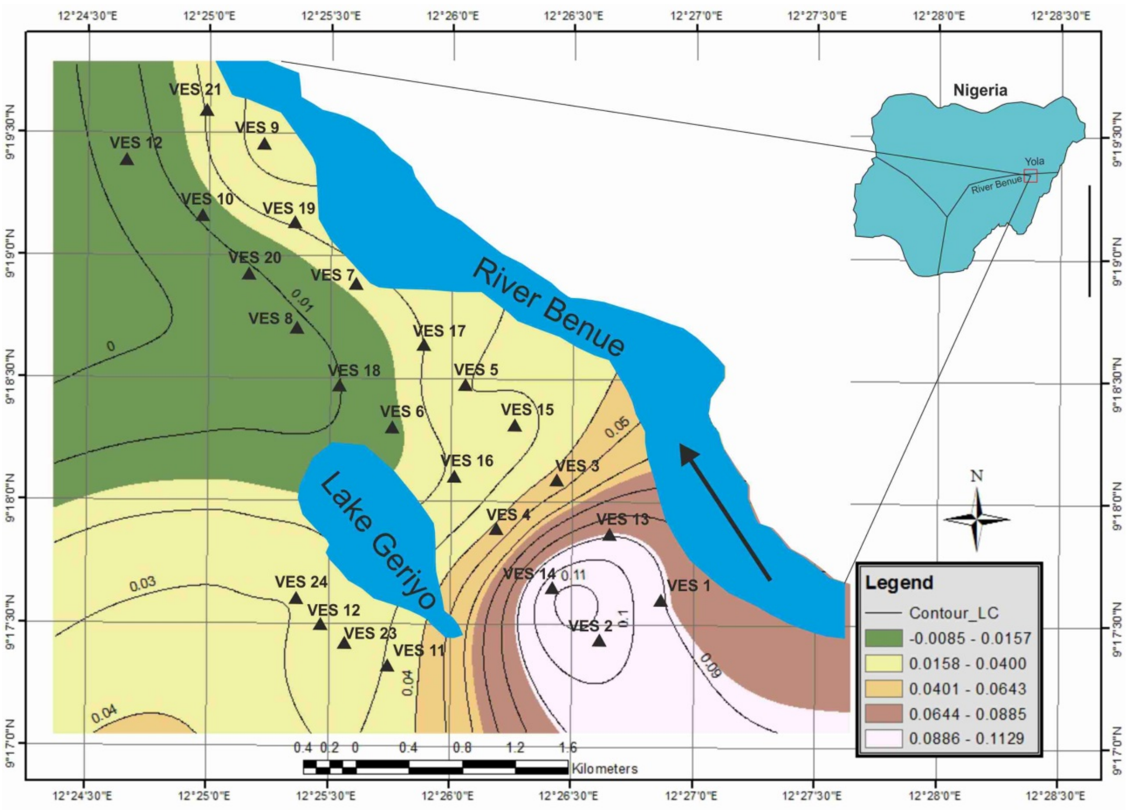

Fig. 4. Aquifer longitudinal conductance across the floodplain

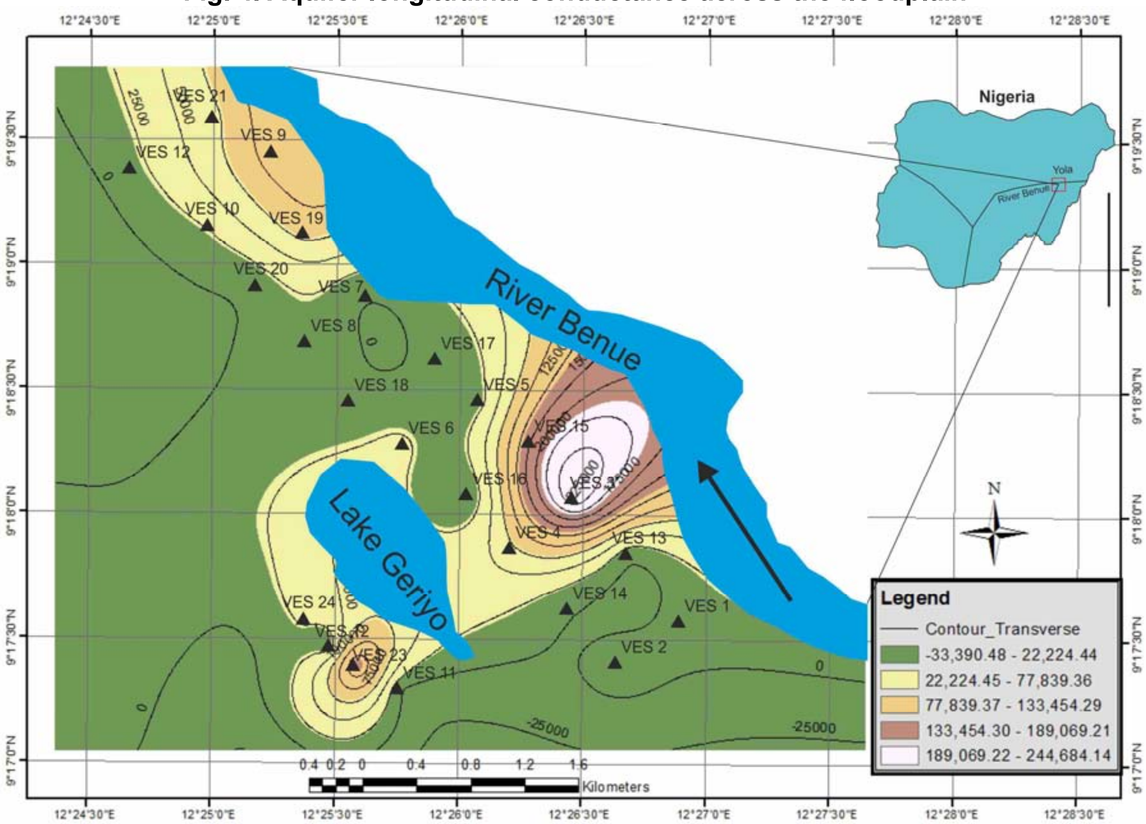

Fig. 5. Aquifer transverse resistance across the floodplain

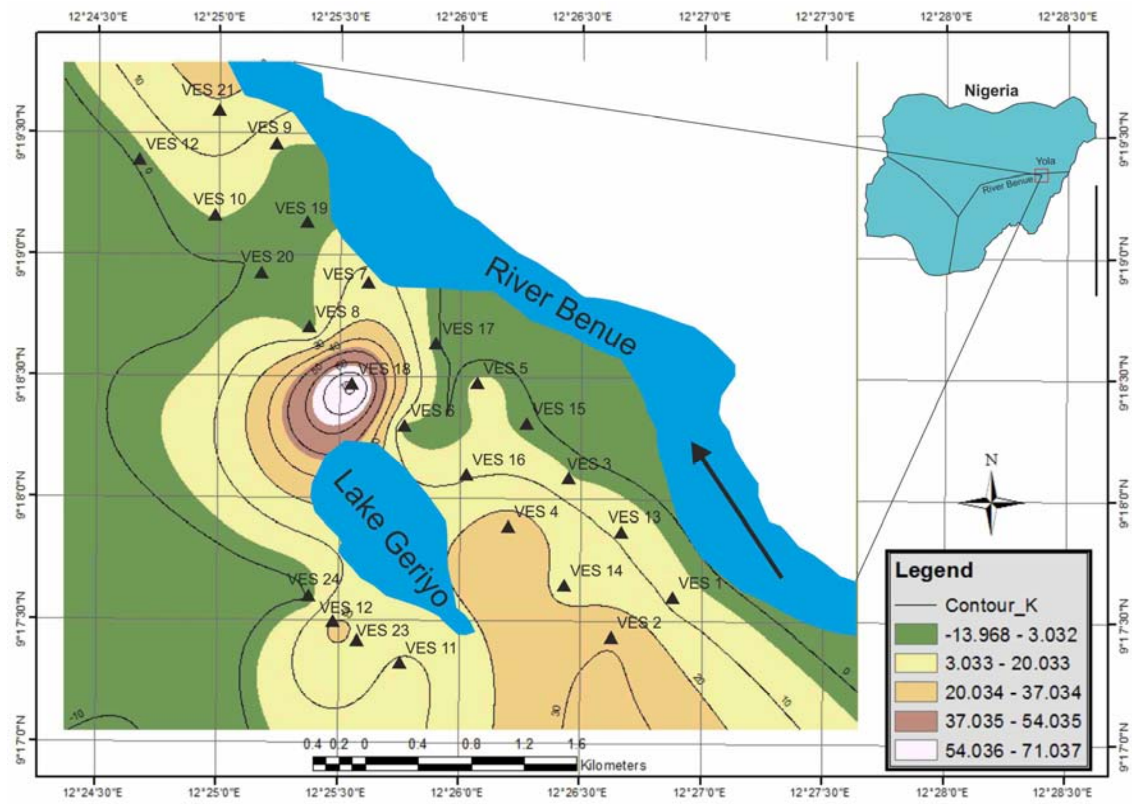

Fig. 6. Aquifer hydraulic conductivity across the floodplain

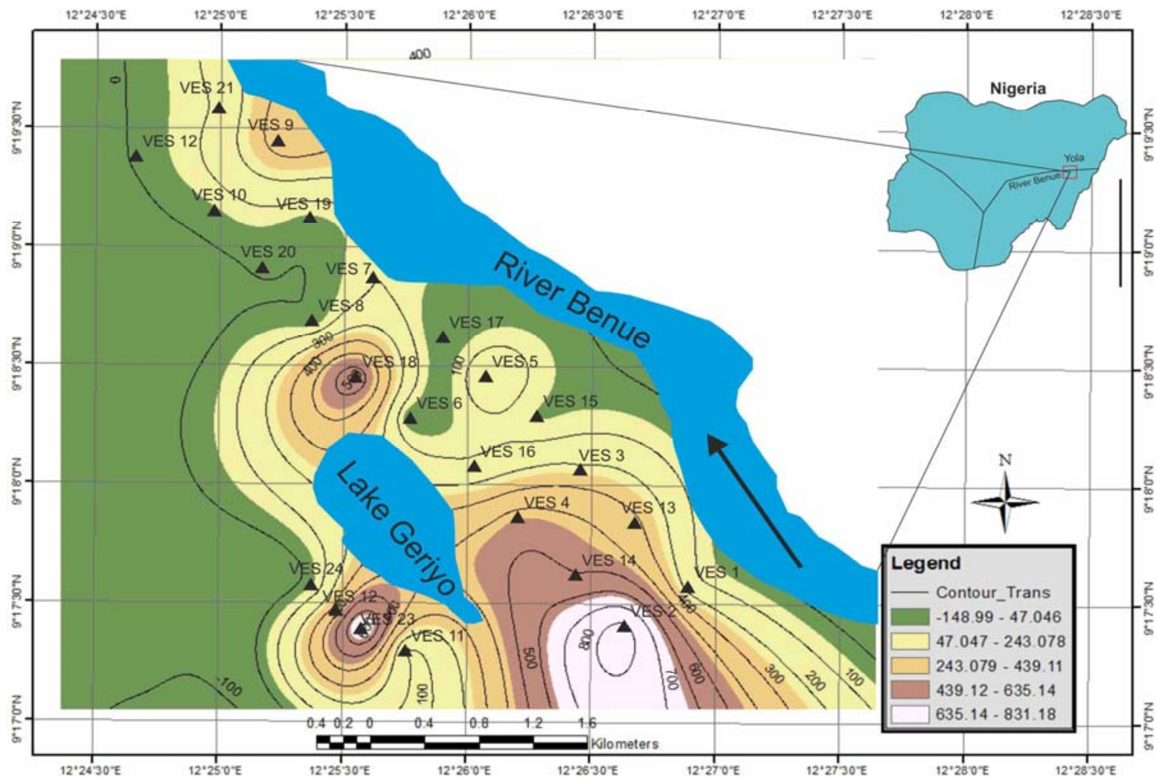

Fig. 7. Aquifer tarnsmissivity across the floodplain

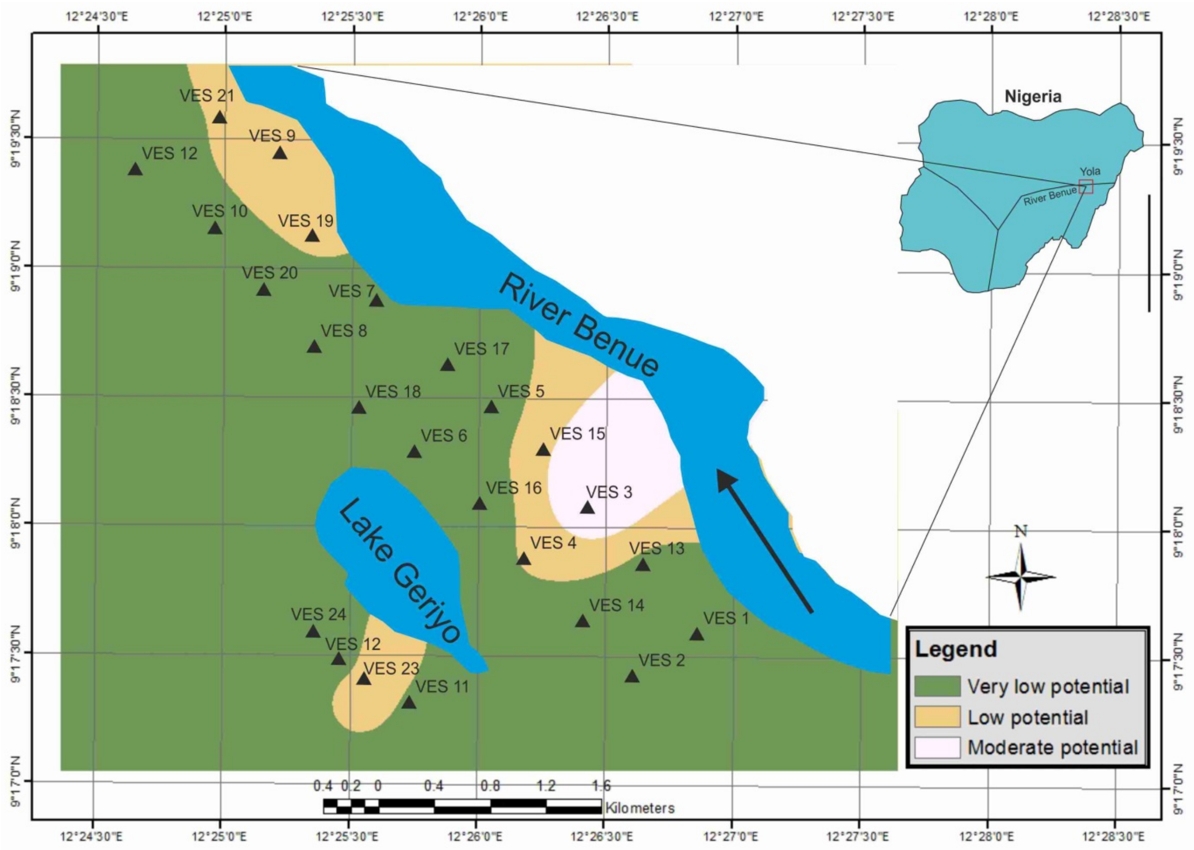

Fig. 8. Groundwater potential map of the study area

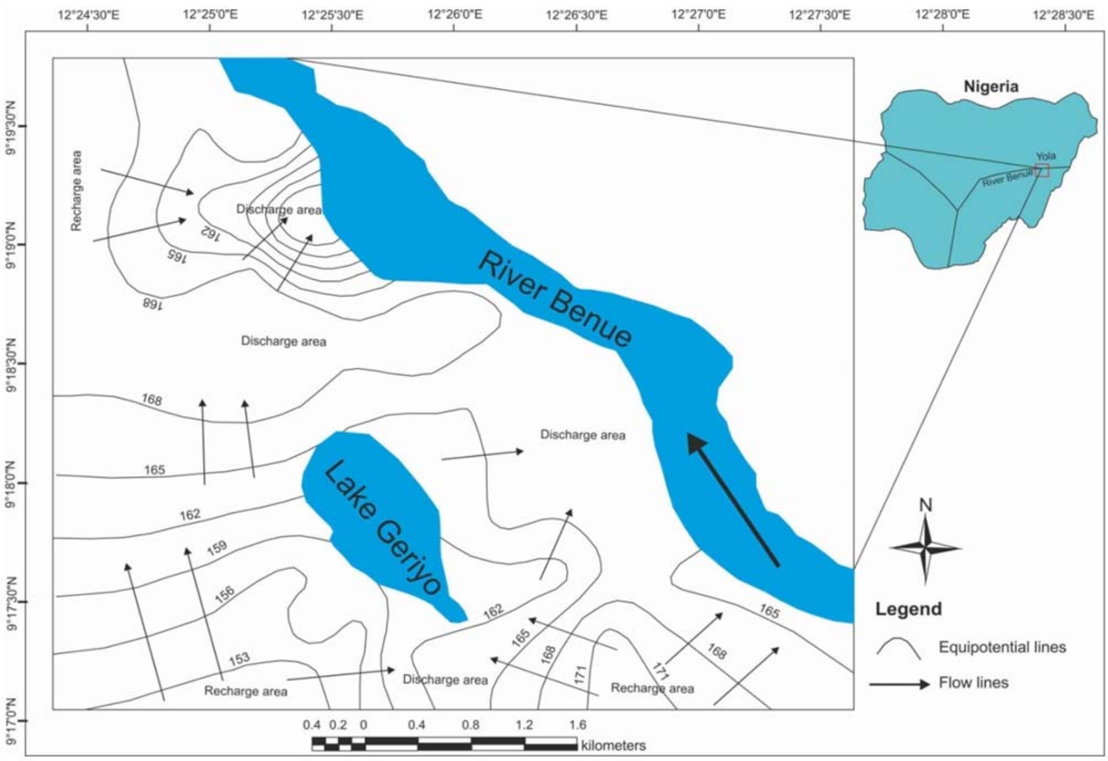

Fig. 9. Hydraulic head distribution in unconfined aquifer in the study area

Table 5. Dar Zarrouk Parameters at Alluvial floodplain of river Benue

VES	Aquifer Resistivity ρ (Ωm)	Aquifer Thickness h (m)	Aquifer Cond. σ = 1/ρ	Transverse Resistance $Tr = \sum_{i=1}^{n} \rho_n h_n$	Longitudinal Conductance $S = \sum_{i=1}^{n} \frac{h_i}{\rho_i}$	Hydraulic cond. K(m/day)	Transmissivity Tr=Kh
1	382.23	20.44	0.0026	7812.78	0.053	7.48	152.89
2	305.94	27.81	0.0033	8508.19	0.091	29.06	808.16
3	4650.2	51.88	0.0002	241252.38	0.011	4.18	216.86
4	4049.45	17.35	0.0002	70257.96	0.004	24.91	432.19
5	481.88	37.46	0.0021	18051.22	0.078	4.74	177.56
6	3475	8.02	0.0003	27869.50	0.002	0.21	1.68
7	359.33	7.31	0.0028	2626.70	0.020	13.45	98.32
8	1554.8	12.6	0.0006	19590.48	0.008	0.65	8.19
9	1221	91.6	0.0008	111843.60	0.075	3.74	342.58
10	2081.5	13.29	0.0005	27663.14	0.006	3.06	40.67
11	448.12	10.11	0.0022	4530.49	0.023	8.47	85.63
12	657.16	15	0.0015	9857.40	0.023	21.15	317.25
13	302.24	36.28	0.0033	10965.27	0.120	8.6	312.01
14	128.436	28.36	0.0078	3642.44	0.221	17.78	504.24
15	4944.44	30.759	0.0002	152086.03	0.006	1.45	44.60
16	514.87	12.79	0.0019	6585.19	0.025	9.89	126.49
17	1179.87	4.07	0.0008	4802.07	0.003	0.61	2.48
18	723.59	7.64	0.0014	5528.23	0.011	71.1	543.20
19	2980.57	28.09	0.0003	83724.21	0.009	1.54	43.26
20	1394.5	7.34	0.0007	10235.63	0.005	0.69	5.06
21	10216.77	6.897	0.0001	70465.06	0.001	18.26	125.94
22	1404.48	12.05	0.0007	16923.98	0.009	0.86	10.36
23	3308.43	42.34	0.0003	140078.93	0.013	16.7	707.08
24	762.62	38.33	0.0013	29231.22	0.050	0.81	31.05
Mean	1980.31	23.66	0.0015	45172.17	0.036	11.22	214.07

Fig. 9 show the hydraulic heads across the floodplain obtained from twenty four VES stations. The flow is from southern part of the study area towards the northeastern part of the study area (Fig. 9). The south, southeast, eastern and northern parts of the study area constitute the discharge areas, while northwest and southwest constitutes the recharge area (Fig. 9). It is also observed that the floodplain groundwater is higher than the River during the dry season period and it recharges the River [44].

5. CONCLUSION

The resistivity sounding results reveal three groups of electro-stratigraphic earth models; these are three, four and five geologic layers beneath the alluvial formation. The resistivity sounding results reveal twelve different types of curves, which include A, AA, AK, H, HK, K, KH, KHK, KQ, Q, QH and QQH, with curve KH is most common among the curves constituting about 20.83% of the total curves. The geoelectric section revealed that the aquifer type on the floodplain is semi confine to confined aquifer system and consists of fine, medium to coarse-grained sand. The longitudinal conductance reveals that aquifers across the floodplain are liable to probable risks of contamination and the underlain by permeable layer. The transverse resistance result shows that aquifer potential is high in the eastern part of the study area. The hydraulic conductivity result shows permeability of fine, medium and coarse sand which allows free flow of water to recharge the aquifers. The hydraulic conductivity shows that the northern, southern and southeastern parts of the study area have a high permeability in the floodplain sediments. The transmissivity values reveal low to high aquifer potentials and groundwater supply potential of small withdrawal for local water supply to the withdrawal of lesser regional importance. Three groundwater potential zones (very low, low and moderate potential) were delineated on the floodplain of the study area. The hydraulic head results reveal that the flow is from the southern part towards the northeastern part of the study area.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Hamidu H, Lawal M, Abdulganiyu Y, Kwaya M, Grema HM, Ibrahim HA, Kitha M, Yelwa NA. Re-evaluation of shallow floodplain aquifers groundwater potentials and storage of Sokoto Basin, Northwestern Nigeria. Am. J. Water Resour. 2017;5(3): 72-84.
2. Mohamaden MII. Delineating groundwater aquifer and subsurface structures by using geoelectrical data: Case study (Dakhla Oasis, Egypt). NRIAG J. Astro. Geophy. 2016;5:247–253.
3. Helaly AS. Assessment of groundwater potentiality using geophysical techniques in Wadi Allaqi basin, Eastern Desert, Egypt – Case study. NRIAG J. Astro. Geophy. 2017;6:408–421.
4. Chambers JF, Wilkinson PB, Penn S, Meldrum PI, Kuras O, Loke MH, Gunn DA. River terrace sand and gravel deposit reserve estimation using three-dimensional electrical resistivity tomography for bedrock surface detection. J. Appl. Geophy. 2013;93:25-32.
5. Orlando L. Some considerations on electrical resistivity imaging for characterization of waterbed sediments. J. Appl. Geophy. 2013;95:77-89.
6. Zohdy AAR. Use of Dar Zarrouk curves in the interpretation of vertical electrical sounding data. US Geological Survey Bulletin, 1313-D. 1974;1-419.
7. Nwosu LI, Nwankwo CN, Ekine AS. Delineating aquifer systems using dar Zarouk parameters determined from Surface Geoelectric Survey: Case Study of Okigwe District, Southeastern Nigeria. British J. Appl. Sci. & Technol. 2014;4(34): 4751-4770.
8. Maillet R. The fundamental equations of electrical prospecting. Geophy. 1947;12: 529-556.
9. Census. Population of the Federal Republic of Nigeria, Adamawa State statistical Tables. National Population Commission Final Results of Population of Nigeria; 2006.
10. Ankidawa BA. Assessing the sedimentology along river Benue floodplain for application using manual drilling, North Eastern Nigeria. J. Basic Appl. Res. Int. 2015;7(4):211-219.
11. Cratchley CR. Geological survey of the South Western part of the Chad Basin. C.C.T.A. Publication. 1960;1-31.
12. Carter JD, Barber W, Tait EA. The geology of parts of Adamawa, Bauchi and Bornu Provinces in North-Eastern Nigeria. Geological Survey of Nigeria Bulletin. 1963;30:1-109.
13. Ishaku JM, Ezeigbo HI, Water quality of Yola, northern Nigeria. Water Resour. J. Nigerian Assoc. Hydrogeol. 2000;1:39-48.
14. Yenika ME, Uma KO, Obiefuna GI. A case studies of shallow aquifer in Jimeta-Yola metropolis, north eastern Nigeria. Water Resour. J. Nigerian Assoc. Hydrogeolo. 2003;14:84-91.
15. Allix P. Environments me’sozoïques de la partie nord-orientale du fosse de la Bénoué (Nigeria). Stratigraphie, sédimentologie, evolution géodynamique. Trav. Lab. Sci. Terre, St. Jéróme, Marseille (B). 1983;21:1-200.
16. Popoff M, Wiedmann J, De Klasz I. The Upper Cretaceous and Gongila and Pindiga Formations, northern Nigeria: Subdivisions, age, stratigraphic correlations and paleogeographic Implications. Eclogae geol. Helv. 1986; 79:343-363.
17. Popoff M. Du Gondwana ă l’ AtÍantique sud: les connexions du fosse de la Bénoué avec les basins du Nord Est brësilion jusqúá Í ouverture du golfe de Guinée au Crétacé inferior. J. Afr. Earth Sci. 1988;7:409-431.
18. Guiraud M. Mécanisme de formation du basin crétacé sur décrochements multiples de la Haute-Bénoué (Nigeria). Bull. Centres Rech. Explor.-Prod. Elf-Aquitaine. 1991;15:11-67.
19. Braide SP. Studies on the Sedimentation and Tectonics of the Yola arm of the Benue Trough. Facies Architecture and their Tectonic significance. J. Min. Geol. 1992;28(1):23-31.
20. Zaborski P. A review of the Cretaceous system in Nigeria. Afr. Geosci., Rev. 1998; 5(4):385-483.
21. Zaborski P, Ugodulunwa F, Idornigie A, Nnbo P, Ibe K. Stratigraphy and structure of the cretaceous Gongla Basin, Northeast Nigeria. Elf exploration production, F-64018 Pau; 1997.

22. Park YH, Doh SJ, Yun ST. Geoelectric resistivity sounding of riverside alluvial aquifer in an agricultural area at Buyeo, Geum River watershed, Korea: An application to groundwater contamination study. Env. Geol. 2007;53:849-859.
23. Ankidawa BA. Sustainability of water abstraction by hand drilling in the floodplain of River Benue of Yola, NE Nigeria. Published PhD Thesis, Brunel University London, United Kingdom. 2014;383.
24. Ankidawa BA. Discovery of perched aquifer when assessing aquifer potential along the floodplain of the Upper Benue River, NE Nigeria. The Int. J. Eng. Sci. 2015;4(4):11-22.
25. Raimi J, Abdulkarim MS, Hamidu I, Arabi AS. Application of Shlumberger vertical electrical sounding for determination of suitable sites for construction of boreholes for irrigation scheme within a Basement complex. Int. J. Multidisplinary Sci. Eng. 2011;2(6):81-84.
26. Utom AU, Odoh BI, Okoro AU. Estimation of aquifer transmissivity using dar Zarrouk parameters derived from surface resistivity measurements: A Case history from Parts of Enugu Town (Nigeria). J. Water Resour. Protec. 2012;4:993-1000.
27. Egbai JC, Iserhien-Emekeme RE. Aquifer transmissivity Dar Zarrouk Parameters and Groundwater Flow Direction in Abudu, Edo State, Nigeria. Int. J. Sci., Env. Technol. 2015;4(3):628-640.
28. Todd DK. Groundwater hydrology, 2^{nd} ed., John Wiley and Sons, assessment of groundwater quality using chemical indices, New York. 1980;535.
29. Coker JO. Vertical electrical sounding methods to delineate potential groundwater aquifers in Akolo area, Ibadan, South-western, Nigeria. J. Geol. Min. Resour. 2012;4(2):35-42.
30. Van Overmeeren RA. Aquifer boundaries explored by geoelectrical measurements in the coastal plain of Yemen: A case equivalent. Geophy. 1989;54(1):38-48.
31. Schwarz SD. Application of geophysical methods to groundwater exploration in the Tolt river basin, Washington State. Geotech. Env. Geophy. 1988;1:213-217.
32. Iduma REO, Abam TKS, Uko ED. Dar Zarrouk parameter as a tool for evaluation of well locations in Afikpo and Ohaozara, Southeastern Nigeria. J. Water Resour. Protec. 20168:505-521.
33. Mwangi LW, Munyithya JM, Githiri JG, K'orowe MO. Evaluation of groundwater potential using geoelectric method in Mutito Fault Zone, Kitui County, Kenya. IOSR J. Appl. Geol. Geophy. 2016;4(1):43-48.
34. Okonkwo AC, Ugwu GZ. Determination of Dar-Zarrouk parameters for prediction of Aquifer protective capacity: A case of Agbani Sandstone Aquifer, Enugu State, Southeastern Nigeria. Int. Res. J. Geol. and Min. 2015;5(2):12-19.
35. Braga AC, de Oliveira, Filho WM, Dourado JC. Resistivity (DC) method applied to aquifer protection studies. Revista Brasileira de Geofisica. 2006;24(4):573-581.
36. Oni TE, Omosuyi GO, Akinlalu AA, Groundwater vulnerability assessment using hydrogeologic and geoelectric layer susceptibility indexing at Igbara Oke, Southwestern Nigeria. NRIAG J. Astro. Geophy. 2017;6:452–458.
37. Toto EA, Kerrouri C, Zouhri I, El Basri M. Geoelectrical exploration for groundwater in Al Maha forest, AinJouhra, Morocco. Hydrol. Process. 2008;22:1675-1686.
38. Nejad HT. Geoelectric investigation of the aquifer characteristics and groundwater potential in Behbahan Azad University farm, Khuzestan Province, Iran. J. Appl. Sci. 2009;9(20):3691-3698.
39. Ezeh CC. Hydrogeophysical studies for the delineation of potential groundwater zones in Enugu State, Nigeria. Int. Res. J. Geol. Min. 2012;2(5):103-112.
40. Bouwers H. Groundwater hydrology. McGraw Hill book company, New York. 1978;402-406.
41. Guideal R, Bala AE, Ikpokonte AE. Preliminary Estimates of the hydraulic properties of the quaternary aquifers in N'Djaména Area, Chad Republic. J. Appl. Sci. 2011;1-7.
42. Hamidu H, Bala AE, Ikpokonte AE. Assessment of groundwater potentials of the crystalline aquifers using hydraulic properties for Gidan Waya Town and its Environs, Southern Parts of Kaduna State, North Western Nigeria. J. Env. Earth Sci. 2013;3(14):153-163.
43. Krasny J. Classification of transmissivity magnitude and variation. Groundwater J.

Assoc. Groundwater Scient. Engineer. 1993;31:230-236.

44. Ankidawa BA, Ishaku JM, Mada DA. Studies on the seasonal variation and behaviour of hydraulic head along river Benue floodplain, Yola, North Eastern Nigeria. Res. J. Appl. Sci., Eng. Technol. 2015;11(11):1280-1287.

Peer-review history:
The peer review history for this paper can be accessed here:
http://www.sciencedomain.org/review-history/24838