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Estimation of Aquifer Transmissivity Using Dar Zarrouk Parameters Derived from Resistivity Soundings on the Floodplain of River Dadin Kowa, Gombe State, Northeastern Nigeria

B.A. Ankidawa[1*], J.M. Ishaku[2], A.A. Hassan[3]

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 Geology, School of Physical Sciences, Modibbo Adama University of Technology, PMB 2076, Yola, Nigeria
3. Department of Civil Engineering, School of Engineering and Engineering Technology, Modibbo Adama University of Technology, PMB 2076, Yola, Nigeria

Corresponding author: *ankidawa03@yahoo.com*

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ABSTRACT

The research is aimed to estimate the aquifer transmissivity of the alluvial formations on the floodplain using Dar Zarrouk Parameters derived from geoelectric soundings. Ten profiles of vertical electric soundings (VES) using schlumberger array method was in the investigation. The results revealed five geoelectric layers on the alluvial formation of the floodplain. There were three, four, five, six and seven layers beneath the alluvial formation. The results were compared with the alluvial floodplain lithologies at each sounding points with resistivity values ranging between 0.98 Ωm to 4,113 Ωm and depths varying from 0.01 to 146 m. The geoelectric sequence of the alluvial formations of the flood plain reveals semi aquifer system. The aquifer hydraulic characteristics indicated that the transverse resistance R ranged between 436.8 Ωm^2 to 77,324.40 Ωm^2 with a mean value of 11,963.71 Ωm^2. The longitudinal conductance S ranged between 0.0026 to 1.792 with an average value of 0.26348. The hydraulic conductivity value across the floodplain ranged between 0.16 m/day to 29.79 m/day with a mean value of 5.597 m/day. The transmissivity values obtained for the various layers range between 1.6 m^2/day to 834.1 m^2/day with an average value of 128.86 m^2/day. The results of the hydraulic head reveal that the floodplain recharges the River. High groundwater potential zone occurs in the southern part of the study area. The transmissivity values obtained using Dar Zarrouk Parameters reveal low to high aquifer potentials.

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1. Introduction

Groundwater provides sufficient water sources for the shallow wells which could be easily abstracted by the farmers for irrigation purposes. The movement of groundwater in shallow alluvial aquifers is governed by factors like, lithology, topography, geological structures, slope, drainage pattern and climatic condition [1]. Shallow groundwater on alluvial floodplain is the main source of water supply for dry season farming [2–5]. Shallow groundwater is the principal resource of fresh water and represents much of the potential future water supply [6]. Groundwater is a major contributor to flow in many streams and rivers and has a strong influence on river and wetland habitats for plants and animals Crop requires a certain amount of water at some fixed time interval throughout its period of growth, assessing the shallow groundwater on the floodplain improves the water supply for crops. Assessing the groundwater potential on the alluvial floodplain requires some certain techniques such as vertical electrical soundings. The shallow aquifers on the floodplain of River Dadin Kowa are the main sources of water supply for the dry season farming.

Vertical electrical sounding (VES) is mostly used to measure vertical alterations of electrical resistivity [3]. VES method is widely recognized for hydrogeological survey of alluvial formations than the other resistivity methods [2,4,7]. Schlumberger electrical method is mostly practices in the region, which is the research area [3,8]. Because of the easy application of the Schlumberger array, low-cost and its capability make it acceptable by researchers [9]. The method is used investigate groundwater problems, e.g. understanding groundwater level in an unconfined aquifers formations [10], and which is the focus of the present study, assessment of aquifer vulnerability [11,12], groundwater potentials [13], determination of aquifer characteristics [14], assessment of near-surface alluvial deposits [15,16], estimation of aquifer transmissivity [17–19] and estimation of aquifer specific yield [20].

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 [21,22] derived analytical relations between Dar Zarrouk parameters their result shows that the product of hydraulic conductivity and aquifer conductance remain fairly constant, in areas where the geologic setting and water quality do not show much variation. Thus, if the value of K and aquifer conductance is known, then it is possible to estimate the aquifer transmissivity. Parameters such as lithology, hydraulic conductivity and electrical conductivities are very useful in the process of geological model [23–25], and application of aquifer thickness and resistivity of geoelectric layers in the model [4,21,24,26]. This research is aimed to estimate the transmissivity of shallow alluvial aquifers on the floodplain of Dadin Kowa for dry season farming activities using Dar Zarrouk Parameters derived from geoelectric resistivity soundings.

2. The study area

The Dadin Kowa irrigation project which is the study site is located in Yamaltu Local Government Area of Gombe State in the North East of Nigeria. It lies between latitudes 10° 17′ 22" to 10° 17′ 32"N and longitudes 5° 30′ 34" to 5° 30′ 42" E (Figure 1). The Dam/Irrigation site is located about 35 to 45 kilometers to the east of Gombe town, and provides drinking water for the town. The dam was completed by the Federal government in 1984, with the goal of providing irrigation and electricity for the planned Gongola sugar plantation project. The climate of the study area is bi-seasonal (dry and rainy seasons). The dry season is comparatively longer (November to April) than the rainy season (May to October). The temperature in the area is generally high, the maximum monthly mean temperature range from 26 to 42 °C and minimum temperature range from 13 to 28°C. The total annual precipitation for the period 1977 to 2018 is 615,265.7 mm. On average the annual precipitation of the area is 15,776.04 mm and the total monthly average precipitation is 1314.7 mm. The area can be described as exhibiting the characteristics of the Sahel savannah type of vegetation comprising mainly of different types of grasses, controlled to a large extent by the soil type.

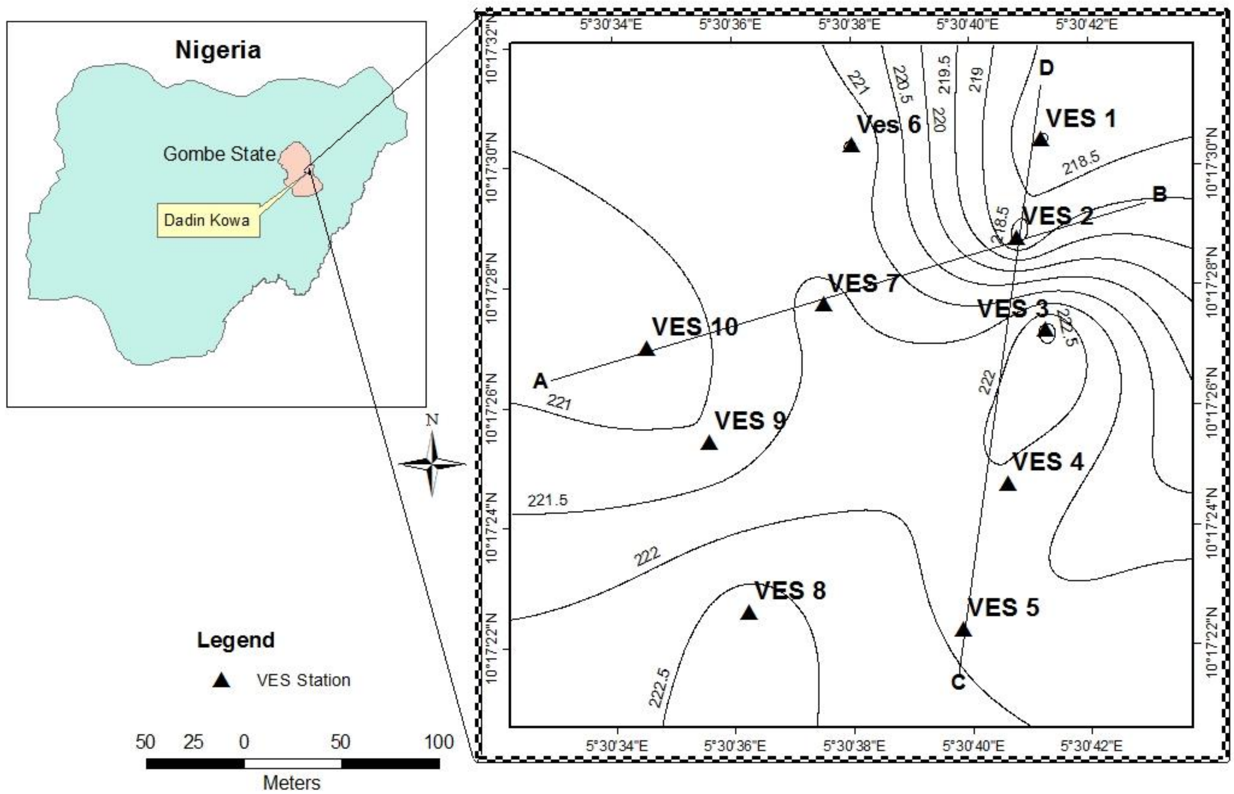

Fig. 1. Topographic of the study area showing VES locations on the floodplain.

2.1. Geology of the area

The stratigraphic sequence in the Gongola sub-basin of the Northern Benue Trough comprises the Aptian-Albian Continental Bima Formation, the Cenoanian transitional-marine Yolde Formation, the Cenomanian-Santonian marine Pindiga Formation, the Campano-Maastrichtian Deltaic Gombe Formation and Tertiary Continental Keri-Keri Formation [27]. The deposition of sediments in the Benue Trough was interpreted as fluvial [28,29]. [30] interpreted the deposition of the formation as marginal marine based on textural and lithologic analysis. The study area is underlain entirely by Cretaceous and Quaternary sedimentary deposits (Figure 2). The Bima sandstone belongs to the Cretaceous while the River Alluvium belongs to the Quaternary geologic period. The Bima sandstone is the oldest formation in the Upper Benue Trough and overlies the Basement Complex [31,32]. The detail descriptions of Bima sandstone was provided by [28]. The Bima sandstone was derived from a granitic terrain [28,33]. The River Alluvium is found along the main course of the River Dadin Kowa and underlies more than half of the area (Figure 2). It is composed of poorly sorted sands, clays, siltstone and pebbly sand [34,35]. The geoelectric section obtained from the analysis of ten VES revealed silt, clayey silt, clayey sand, sand and clay lenses.

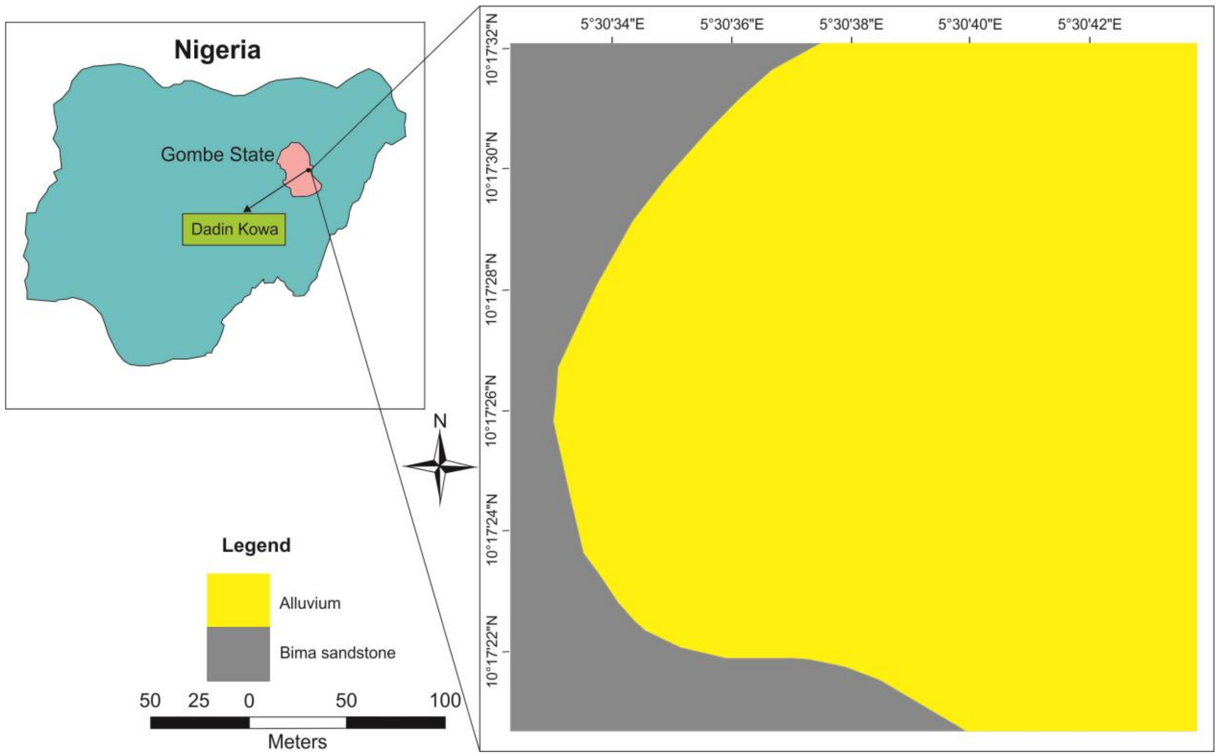

Fig. 2. Geological map of the study area.

3. Materials and methods

3.1. Resistivity soundings

Resistivity soundings was carried out on the Dadin Kowa irrigation floodplain farm sited on west of the river 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. Logarithmic scales were used to plot the data which produce a sounding curves 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 [3,5,36]. Apparent resistivity (ρ_a) values were computed 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 [37].

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), transverse resistance (Tr) are computed using equations 3 and 4 [21,23,24].

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

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

where h is aquifer thickness, ρ is resistivity. The aquifer transmissivity can be estimated using equation 5.

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

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 from the relation,

$$K = 386.40 Rrw^{-0.93283} \text{ [38]} \tag{6}$$

where R_{rw} is aquifer resistivity value, which was used in calculating the transmissivity of the alluvial floodplain of River Dadin Kowa.

CorelDraw X5 software was used to draw the geoelectric section along AB and CD transect on the floodplain. Geographical Information System (GIS) software was used to produce the spatial distribution for the Dar Zarrouk parameters.

4. Results and discussion

The VES result reveals five groups of electro-stratigraphic earth models (Table 1). The groups include seven, six, five, four and three electro-stratigraphic model groups (Table 1). It is also observed from the geoelectric section that the first layer is characterized by low resistivity values varying between 39.35 Ωm to 120 Ωm and aquifer thickness varying from 0.32 to 6.55 m. [23] and [24] stated that aquifers with low resistivity values indicates high aquifer potential. The second layer has resistivity and thickness values varying between 41.52 Ωm to 1,277.5 Ωm and 0.81 m to 29.1 m, the low resistivity value of this layer suggests high aquifer potential. Third layer has resistivity and thickness value varying between 31.53 Ωm to 1,531.15 Ωm and 0.21 m to 45.27 m, this layer show increase in resistivity with increase in aquifer thickness, suggesting moderate aquifer potential. The fourth layers whose resistivity values vary from 61.95 Ωm to 1,208.81 Ωm and thickness vary from 0.67 m to 8.75 m, this layer show increase in resistivity with increase in aquifer thickness, suggesting moderate aquifer potential. [39] stated that aquifers with high resistivity values indicate low to moderate aquifer potentials. Fifth layer has resistivity and thickness values varying between 17.41 Ωm to 2056.99 Ωm and 1.89 m to 7.22 m, this shows decrease in resistivity with increase in aquifer thickness suggesting high aquifer potential. The Sixth layer has resistivity and thickness value varying between 152.5 Ωm to 475.3 Ωm and 69.97 m to infinite thickness, suggesting high aquifer potential.

Table 1
Groups of electro-stratigraphic earth model obtained from the resistivity analysis.

	Model type	First layer	Second layer	Third layer	Fourth layer	Fifth layer	Sixth layer	Seventh layer
Seven	Resistivity (Ωm)	65.55	102.25	305.5	148.7	138.5	152.67	127.5
	Thickness (m)	0.57	3.65	1.54	0.67	1.89	69.97	
Six	Resistivity (Ωm)	39.35	41.52	161.73	99.35	2056.99	475.3	
	Thickness (m)	0.319	0.81	1.92	5.21	7.22		
Five	Resistivity (Ωm)	72.51	1277.5	31.53	61.95	17.41		
	Thickness (m)	6.55	2.07	0.21	8.75			
Four	Resistivity (Ωm)	77.1	397.7	235.4	1208.81			
	Thickness (m)	1.86	1.27	45.27				
Three	Resistivity Ωm)	120.09	95.3	1531.15				
	Thickness (m)	3.87	29.1					

Three different types of sounding curves were obtained from resistivity results in the floodplain (Figure 3, Table 2). The curve types include A=ρ1<ρ2<ρ3, H=ρ1>ρ2<ρ3 and K=ρ1<ρ2>ρ3. Curve H is common for the resistivity soundings constituting about 50% of the total curves. Curve K constituting about 40% of the total curves and curve A constitute 10% 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. Study by [5] on similar floodplain of River Benue north eastern Nigeria observed five curve types (A, H, HK, K and Q), three out of the five curve types were observed in the present study (A, H and K).

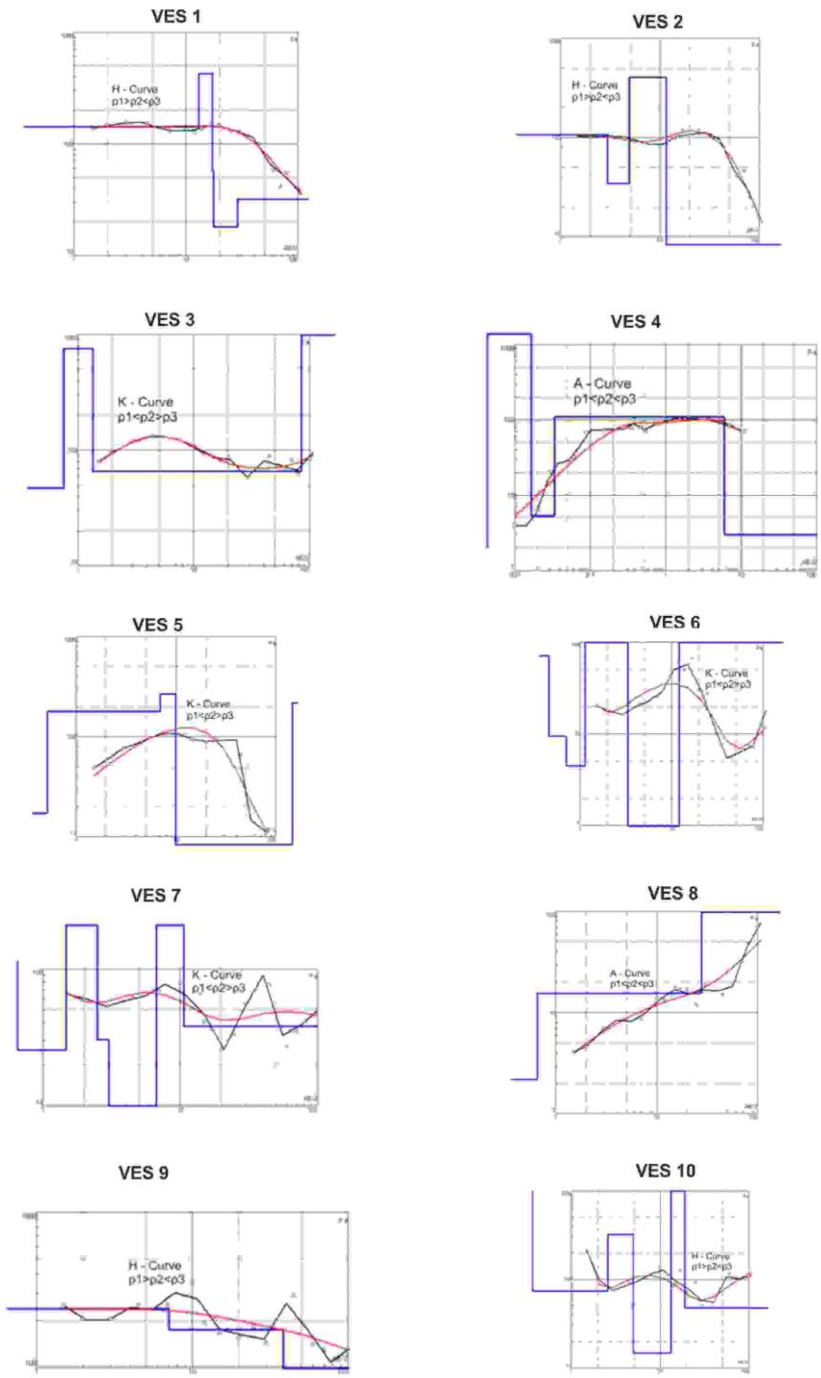

Fig. 3. Field curve types obtained from the ten VES geoelectric sections on the floodplain.

The geolelectric sections were taken along AB and CD (Figure 1), and these sections were used to delineate the aquifer system into semi confined aquifer type (Figure 4). 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 aquifers along AB ranged from 13.2 m to 120 m with an average of 67.7 m while the thickness along CD ranged from 26.4 m to 180 m with a mean value of 153.3 m.

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

VES	Layers	Resistivity	Thickness	Depth	Lithology	Curve Type
1	1	143	13	13	Silt	H ρ1>ρ2<ρ3
	2	426	17	30	Clayey silt	
	3	57.6	18	48	Clayey Sand	
	4	14.9	109	157	Sand	
	5	31.8			Coarse sand	
2	1	107	3	3	Silt	H ρ1>ρ2<ρ3
	2	34.4	52	55	Clayey sand	
	3	405	62	117	Medium Sand	
	4	13.8			Sand	
3	1	47.1	1	1	Silt	K ρ1<ρ2>ρ3
	2	759	2	3	Medium Sand	
	3	65.8	86	89	Sand	
	4	2410			Coarse sand	
4	1	2.02	0.01	0.01	Silt	A ρ1<ρ2<ρ3
	2	2129	0.02	0.03	Clayey silt	
	3	5.25	0.04	0.07	Clayey sand	
	4	109	6.03	6.1	Medium Sand	
	5	3.02			Sand	
5	1	17.1	0.5	0.5	Silt	K ρ1<ρ2>ρ3
	2	179	6.9	7.4	Silt	
	3	267	9	16.4	Clayey silt	
	4	267	10	26.4	Clayey sand	
	5	267	10.1	36.5	Medium Sand	
	6	8.33	146.1	182.6	Sand	
	7	217			Coarse sand	
6	1	70.9	0.5	0.5	Silt	K ρ1<ρ2>ρ3
	2	9.34	0.8	1.3	Clayey sand	
	3	4.45	1.2	2.5	Sand	
	4	184	3.4	5.9	Medium Sand	
	5	0.98	12.2	18.1	Sand	
	6	903			Coarse sand	
7	1	114	1	1	Silt	K ρ1<ρ2>ρ3
	2	25.5	2	3	Clayey silt	
	3	344	3	6	Clayey silt	
	4	30.4	4	10	Clayey sand	
	5	10	8	18	medium sand	
	6	297	12	30	Sand	
	7	38			Coarse sand	
8	1	2.17	1	1	Clayey sand	H ρ1>ρ2<ρ3
	2	15.6	28	29	Medium Sand	
	3	2964			Sand	
9	1	238	7.1	7.1	Clayey sand	H ρ1>ρ2<ρ3
	2	175	38.3	45.4	Medium Sand	
	3	98.3			Sand	
10	1	7.8	0.2	0.2	Silt	H ρ1>ρ2<ρ3
	2	73.3	1.6	1.8	Clayey silt	
	3	319	5	6.8	Clayey sand	
	4	14.7	13.2	20	Medium Sand	
	5	4113	18.8	38.8	Coarse sand	
	6	47.6			Sand	

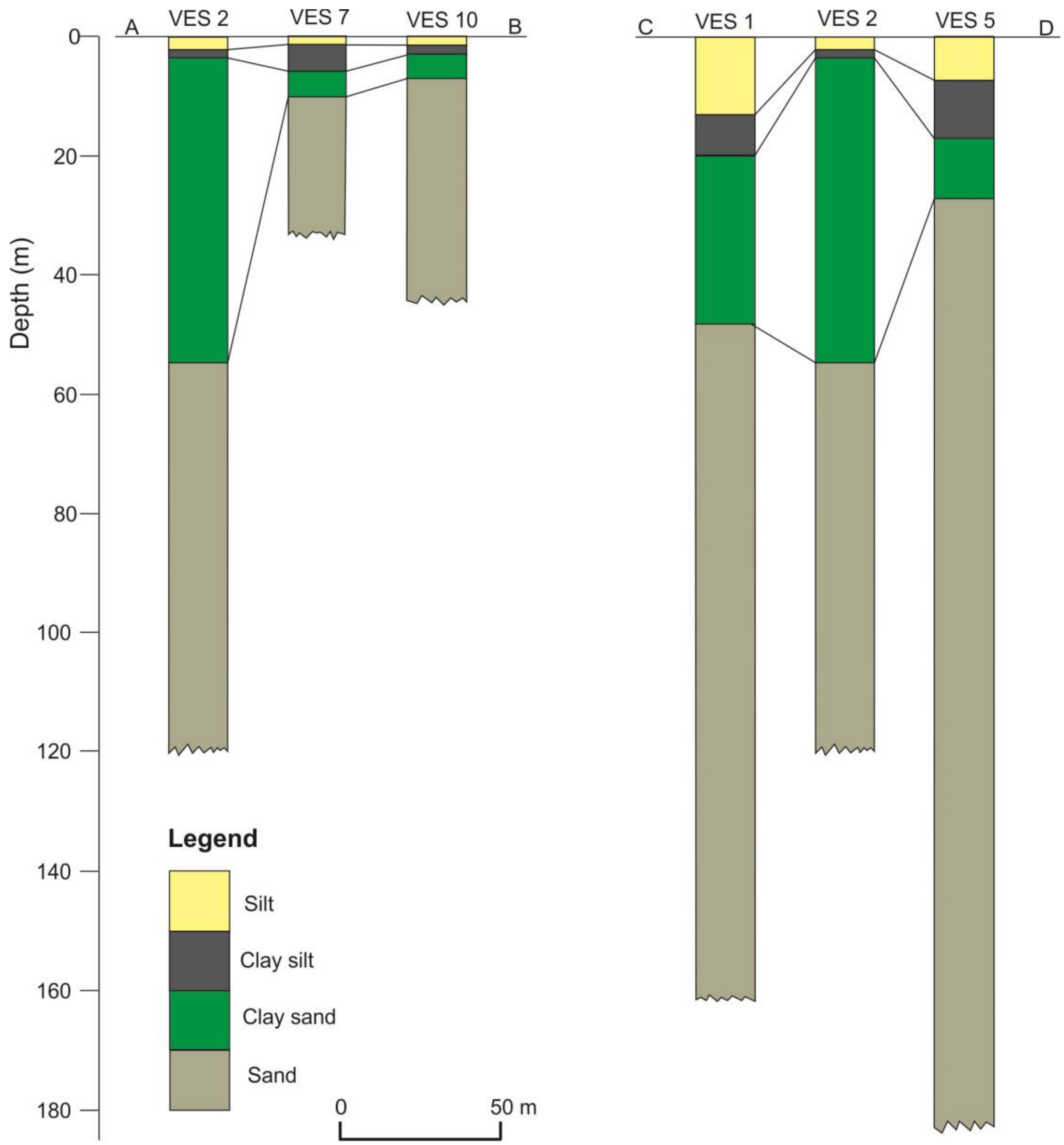

Fig. 4. The geoelectric section along AB and CD transect on the floodplain.

Dar Zarrouk Parameters was used to estimate the aquifer hydraulic characteristics of the floodplain [25]. The longitudinal conductance range between 0.0026 to 1.792 with an average value of 0.26348 (Table 4). The longitudinal conductance was used to predict the aquifer protective capacity [40]. The longitudinal conductance is low in the northeast, northwest and southeastern parts of the study area and high in the southern part of the study area (Figure 5). [26] stated that longitudinal conductance S>1.0 indicates high aquifer protection while longitudinal conductance S<1.0 indicates probable risks of contamination. Transverse resistance is used in the determination of zones of groundwater potential [26,41,42]. The transverse resistance obtained ranges between 436.8 Ωm^2 to 77,324.40 Ωm^2 with a mean value of 11,963.71 Ωm^2 (Table 4).The transverse resistance increases towards the northwestern and southwestern parts of the study area (Figure 6). The maximum transverse resistance were obtained in the northwestern part of the study area while the minimum transverse resistance were obtained in the north, northeast and sotheastern parts of the study area (Figure 6). This suggests that aquifer potential is high in the northwestern and sothwestern parts of the study area, and therefore the yield is high. Similar study was carried out in Behbahan Azad University farm, Khuzestan Province, Iran by [42] and observed high aquifer potential. [43] stated that low transverse resistance indicates inadequate aquifer thickness or highly mixed finer sediments on the floodplain. This suggests that aquifers in the north, northeast and southeastern parts of the study area are likely to have inadequate aquifer thickness. The hydraulic conductivity estimated on the floodplain range between 0.16 m/day to 29.79 m/day with average value of 5.597 m/day (Table 4). Based on [44] standard, 75% of the values indicated hydraulic conductivity of fine, medium and coarse sand which allows free flow of water to recharge the aquifers. The hydraulic conductivity is low in the northwestern and southeastern part of the study area and high in the southwestern part of the study area (Figure 7). This suggests that the southwestern part of the study area have high permeability in the floodplain sediments. The transmissivity values for the various layers range between 1.6 m^2/day to 834.1 m^2/day with an average value of 128.86 m^2/day (Table 4), which indicates low to high aquifer potentials and groundwater supply potential of withdrawal for local water supply to withdrawal of lesser regional importance (Table 3). The transmissivity is low around the northwestern and southeastern part of the study area and increases towards the southwestern part of the study area (Figure 8). The maximum transmissivity is found in the southwestern part of the area while low transmissivity is found in the northwestern and southeastern parts of the area (Figure 8). Similar study was carried out by [24], they estimated aquifer transmissivity in Abudu area, Edo State, Nigeria using Dar Zarrouk Parameters. Their findings are similar to what was obtained in the present research work, the transmissivity values obtained ranges between 288 m^2/day to 133 m^2/day. Studies by [45] in Nile Delta, Egypt and [46] in southern parts of Kaduna State, North Western Nigeria reported trransmissivity ranges from low to high.

Table 3
Standard for Transmissivity Classification [47].

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

Table 4
Dar Zarrouk Parameters at Alluvial Floodplain of River Dadin Kowa.

VES	Aquifer Resistivity ρ (Ωm)	Aquifer Thickness h	Aquifer Conductivity σ = 1/ρ	Longitudinal Conductance S = σh	Transverse Resistance R = hρ	K m/day	Transmissivity Tr = kh	Quantity kσ
1	57.6	18	0.0174	0.3132	1,036.80	8.81	158.6	0.174
2	405	62	0.0025	0.155	25,110	1.43	88.7	0.025
3	759	2	0.0013	0.0026	1,518	0.79	1.6	0.013
4	109	6.03	0.0092	0.055	657.27	4.86	29.3	0.092
5	267	10.1	0.0037	0.037	2,696.70	0.16	21.3	0.037
6	184	3.4	0.0054	0.0184	625.6	2.99	10.2	0.054
7	297	12	0.0034	0.0408	3,564	1.91	22.9	0.034
8	15.6	28	0.064	1.792	436.8	29.79	834.1	0.64
9	175	38.1	0.0057	0.217	6,667.50	3.12	118.9	0.057
10	4113	18.8	0.0002	0.0038	77,324.40	2.11	3.0	0.002
Mean	638.22	19.843	0.01128	0.26348	11963.71	5.597	128.86	0.1128

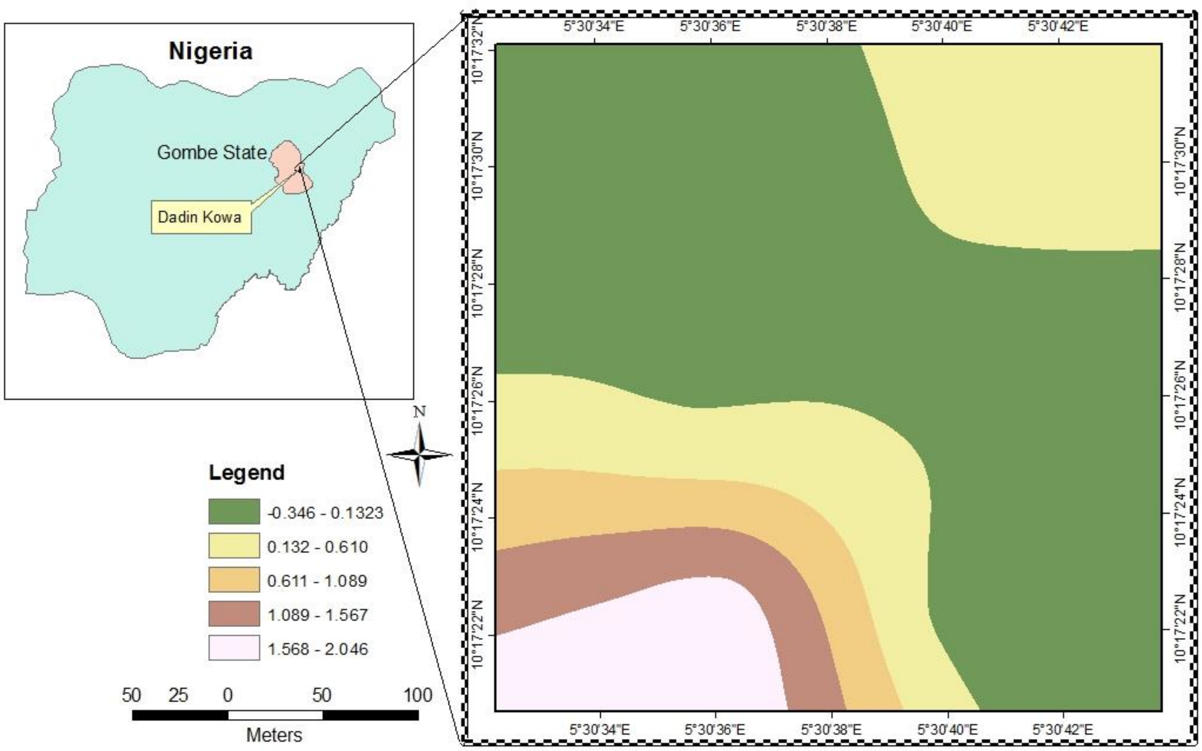

Fig. 5. Aquifer longitudinal conductance across the floodplain.

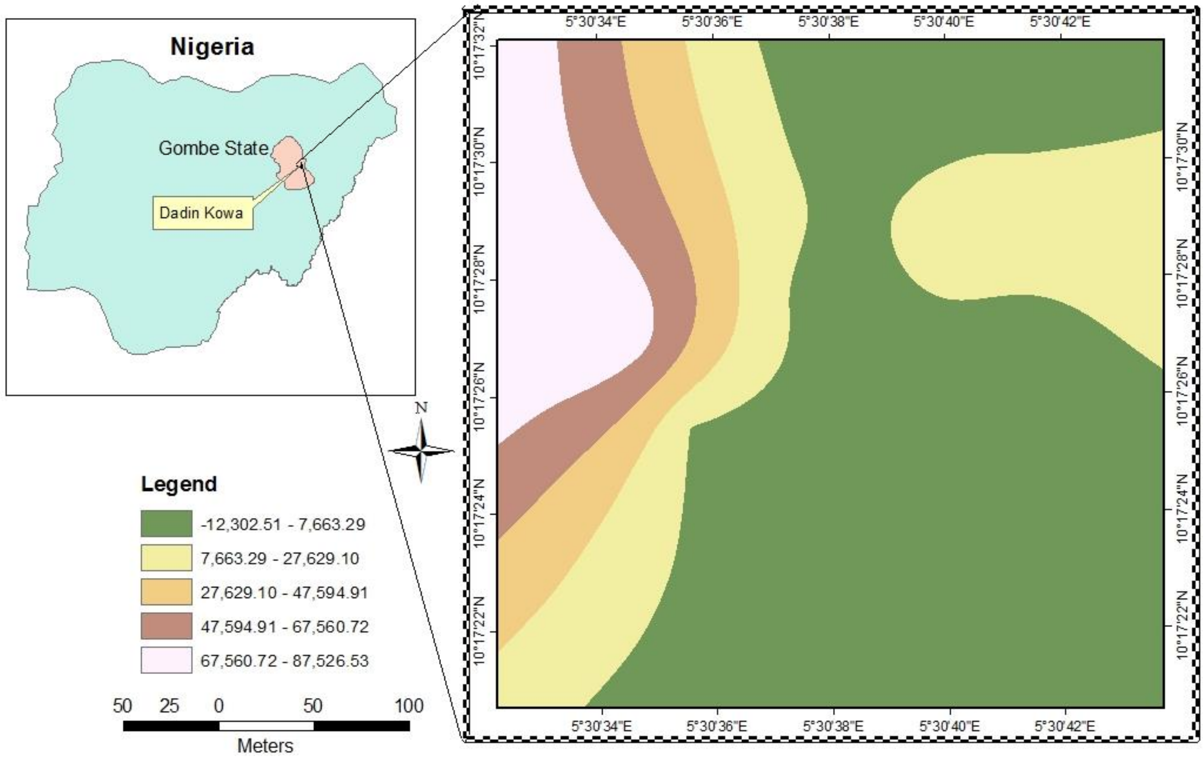

Fig. 6. Aquifer transverse resistance across the floodplain.

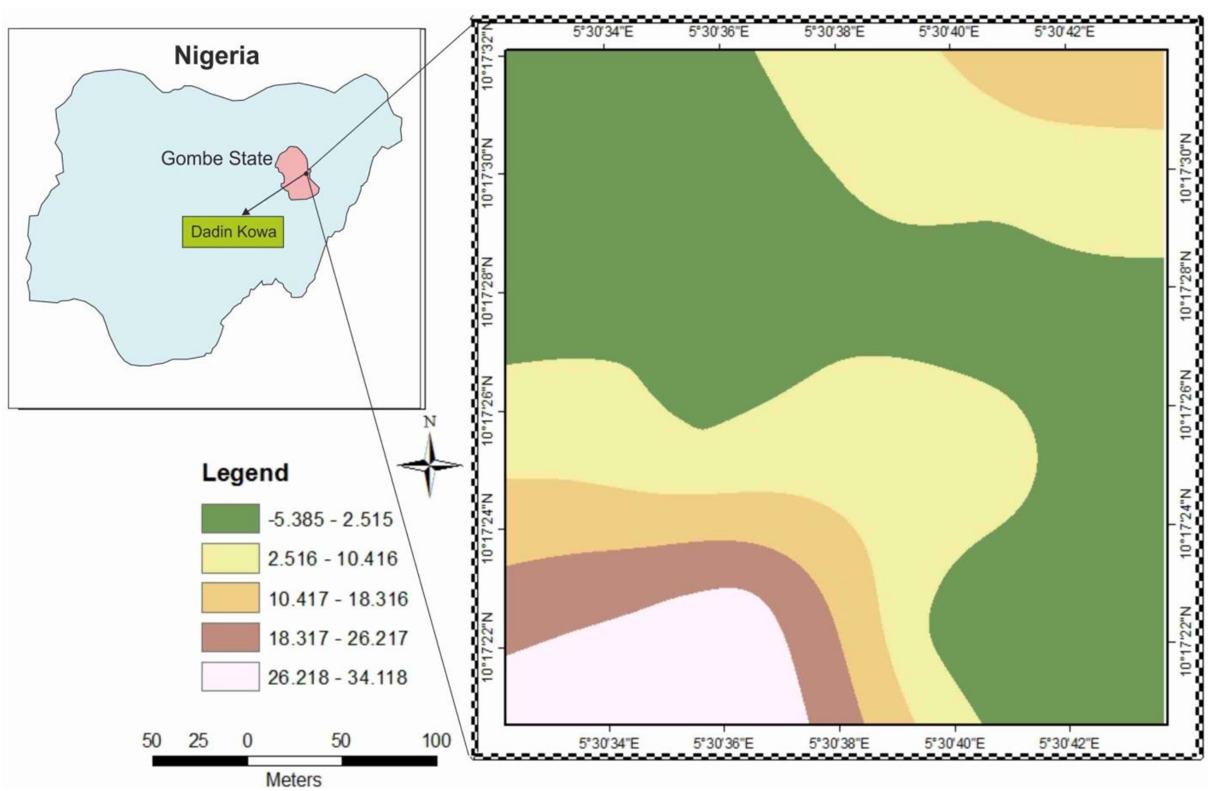

Fig. 7. Hydraulic conductivity across the floodplain.

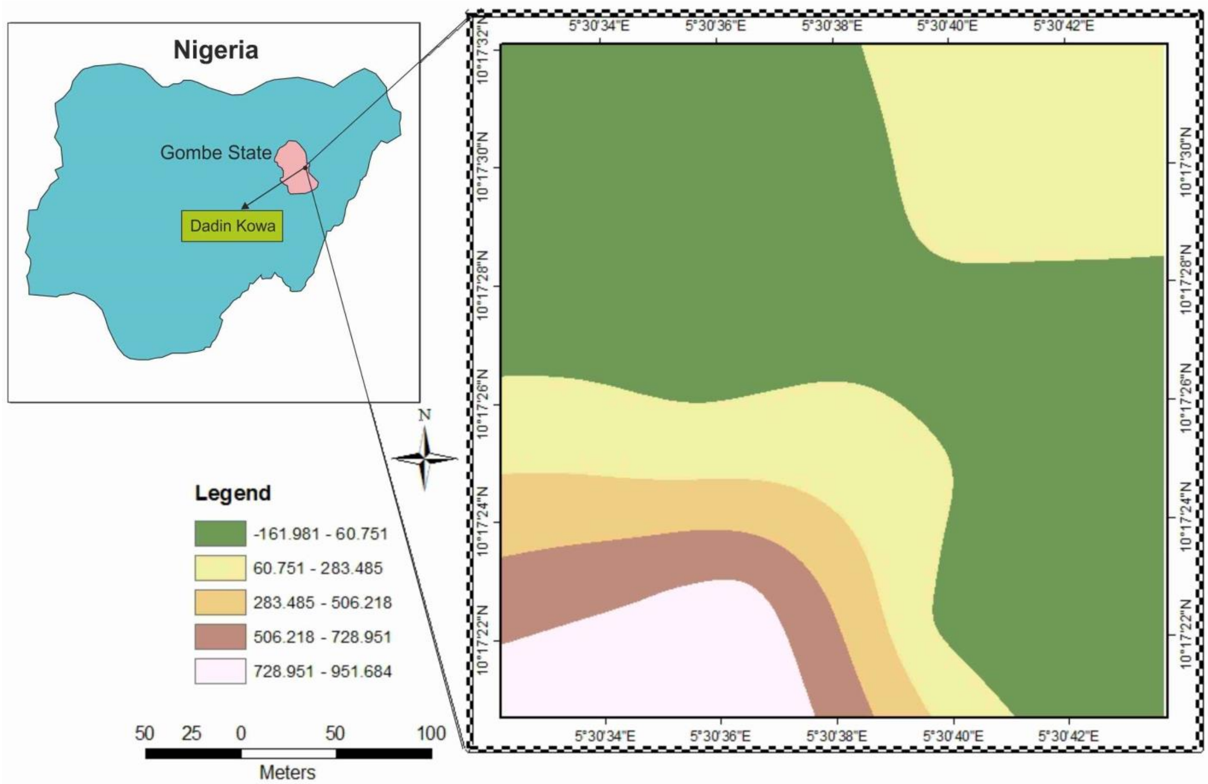

Fig. 8. Distribution of Aquifer Transmissivity across the floodplain.

Based on spatial distribution of hydraulic parameters on Figures 5, 7 and 8, high groundwater potential zone occurs in the southern part of the study area. This zone also serves as the recharge area, and revealed the lowest aquifer resistivity and highest aquifer conductivity, longitudinal conductance, hydraulic conductivity and transmissivity (Table 4).

Figure 9 show the hydraulic heads distribution across the floodplain. Groundwater flow is from northwestern and southwestern part of the study area towards the River Dadin Kowa (Figure 9). River Dadin Kowa serves as the main discharge area during the dry season period. The groundwater level in the floodplain is higher than the River during the dry season period and therefore recharges the River. Similar observation was made by [48] on River Benue floodplain northeastern Nigeria. In their study the floodplain groundwater recharges the River during the dry season period.

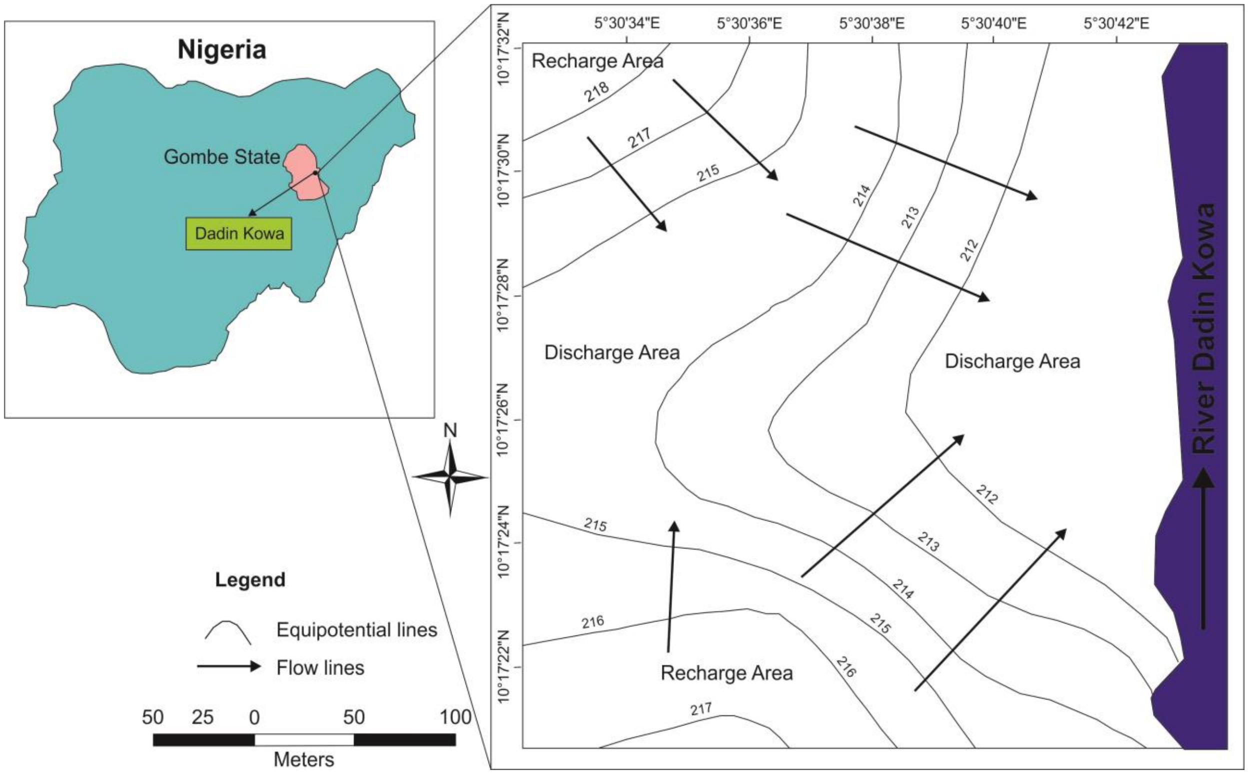

Fig. 9. Hydraulic heads distribution across the floodplain.

5. Conclusion

Dar Zarrouk parameter was used to estimate the floodplain aquifer parameters using resistivity sounding results. The resistivity sounding results reveal five groups of electro-stratigraphic earth models; these are three, four, five, six and seven geologic layers beneath the alluvial formation. The resistivity sounding results reveal three different types of curves, which include A, H and K, with curve H is most common among the curves. The geoelectric section revealed that the aquifer type on the floodplain is semi confine aquifer system and consists of fine, medium to coarse grained sand. The longitudinal conductance reveals that aquifers in the northwestern part of the research area are well protected. The hydraulic conductivity result shows permeability of fine, medium and coarse sand which allows free flow of water for recharging shallow wells on the floodplain. The transverse resistance result shows that aquifer potential is high in the northwestern and sothwestern parts of the study area. The hydraulic conductivity shows that the southwestern part of the study area have high permeability in the floodplain sediments. High groundwater potential zone occurs in the southern part of the study area. This zone also serves as the recharge area, and revealed the lowest aquifer resistivity and highest aquifer conductivity, longitudinal conductance, hydraulic conductivity and transmissivity. The result of the hydraulic head shows the floodplain recharges the River during the dry season period.

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