Ajayi Crowther Journal of Pure and Applied Sciences (ACJPAS)
https://acjpas.acu.edu.ng

Ajayi Crowther J. Pure Appl. Sci. 2023, (2)1, pp. 9-23
https://doi.org/10.56534/acjpas.2023.02.01.09

Article

Hydrogeochemical and Geoelectrical Characterisation of Groundwater around Agudu, Egbeda Area, Ibadan, Southwestern Nigeria

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Article history: *Received: Aug. 2, 2022 Revised: Oct. 1, 2022 Accepted: Oct. 5, 2022 Published: Mar., 14, 2023*.

Abstract

Water is an essential resource for the sustainability of the human race and other biotic lives. This study emerged from variation observed in the groundwater distribution coupled with its quality within the Agudu neighbourhood. This investigation was centred on the geophysical and geochemical characterizations of the aquiferous units. Electrical resistivity method involving Vertical Electrical Sounding (VES) technique and geochemical assessment of groundwater were adopted for the study. A total of twenty VES points were occupied using the Schlumberger electrodes array and the current electrode separation (AB/2) ranged from 2 to 80 m. The data were subjected to both manual processing and computer base iteration using WinResist software. Twenty water samples were collected from wells across the community and subjected to physicochemical assessment. Flame photometry was used in analyzing the cations (Mg^{2+}, Ca^{2+}, Na^{+}, K^{+}) while spectrophotometry was used for chloride, sulphate, bicarbonate, and nitrate. The VES sections revealed two to five geo-electric layers, the weathered and the fractured units were the aquiferous zones. The Dar-Zarrouk parameters were used in establishing the groundwater potential map and classifying the aquifer potential zones. The concentration of major cations was in the order $Ca^{2+}>Mg^{2+}>Na^{+}>K^{+}$ while that of anions were $HCO^{-}{}^{3}>Cl^{-}>SO_4^{-2}>NO^{-3}$. The pH values fall within the World Health Organisation's recommended value, it ranged from slightly acidic to slightly alkaline. All the parameters fall within the permissible level except Ca^{2+} and water hardness at some locations. The techniques engaged were able to reveal the groundwater distribution and also characterised the chemistry of groundwater.

Keywords: Resistivity, aquifer, groundwater, Dar-Zarrouk parameters, water chemistry.

1. Introduction

Nigeria as a developing country has many rural communities that depend largely on groundwater as a source of water for domestic and agricultural needs. Unlike surface water, groundwater provides a reasonable constant supply that is not likely to dry up under normal conditions [1]. Agricultural practice and domestic activities require groundwater for effective delivery. It plays an important role in sustainable ecosystems, enabling humans to adapt to climate change.

The exploitation of groundwater has increased significantly and turns out to be the foremost water source for several functions in the countryside and municipal regions of Nigeria, particularly throughout the dry spell [2]. Availability of water is being influenced by rainfall in both seasons; sources of surface water include lakes, dams, and rivers [2]. The main supplies of water in the countryside are streams, rivers, ponds, and lakes; these sources are susceptible to impurities from anthropogenic events [3].

Private individuals, homeowners, and few contributions from the government have aided proliferation of boreholes and hand dug wells as useful alternative sources to the provision of pipe-borne water, leading to widespread acceptability in the sub-Sahara regions. The suitability of groundwater resources is of enormous significance, and consequently, necessitates regular appraisal of its value [4].

Agudu is a developing area characterised by inadequate water distribution, a teeming population is faced with insufficient water supply and also the groundwater supply is not uniformly distributed. Whereas a few region has vast capacities for this natural resource, others are inadequate because of the multifaceted geologic factors namely rock fracturing, the effect of weathering, degree of rock freshness, and thickness of the overburden are the factors considered in groundwater exploration. Inhabitants growth coupled with the economic improvement (agricultural and industrial engagements) in the study area led to an increase water usage. The demand for groundwater has been on the increase due to agricultural engagement, industrial activity, and the rising population of the inhabitants. Electrical resistivity technique has been notably used in mineral exploration [5], pollution assessment [6-7], groundwater exploration [8-9] and geotechnical studies [10].

In the study area, investigation was done to assess the water facies type present in the area, and their contribution to the natural chemistry of the groundwater. For the purpose of this assessment, the investigation was centered on the use of geochemical and hydrogeophysical data in evaluating groundwater quality. These approaches have been applied to solving engineering, hydrological, environmental, and hydro-geophyhical related problems such as mapping the aquifer and its hydraulic phenomenon [11-13]; thus, aid in describing aquifer pattern, rate of water penetration in the partially saturated zone, and assessment of groundwater infectivity [3, 14-18]. The term hydrochemical facies is used to describe the spatial variations in aquifer groundwater quality variations. The facies are a function of the lithology, solution kinetics, and flow models of the aquifer. Underground water samples were taken and geochemically analyzed to assess the facies type.

The use of geophysical methods has been reported to be effective in characterising groundwater potential, one of the most widely used techniques adopted in groundwater exploration is electrical resistivity [19-20]. This is due to the fact that the field operation is straightforward, the tool is handy, less filled pressure is required, it has a greater depth of incursion, and it is accessible to the computer programming language [21].

The electrical resistivity method is used to distinguish lateral or vertical distinction in the electrical properties of geological materials. Electrical resistivity is used to determine the subsurface resistivity distribution by making measurements on the ground surface. The water content, porosity, lithology, salinity of water contained in the geological material, and degree of water infiltrating the rock are the factors influencing electrical resistivity [22].

The purpose of this investigation in Agudu community, Egbeda, southwestern Nigeria is to appraise the facies type and geoelectric characterization of groundwater occurrence in this area. The area of study (Fig. 1) lies in the southern part of Agudu, within Latitudes $7^{0}22^{1}28^{11}$N and $7^{0}23^{1}10^{11}$N and Longitudes $4^{0}3^{1}15^{11}$E and $4^{0}3^{1}18^{11}$E. The area is prone to erosion, and also has an undulating topography responsible for differential height range (290m-335m).

2. Methods

The research involves the use of the electrical resistivity method involving the Vertical Electrical Sounding (VES) and the chemical analytical method. The VES was carried out at the twenty selected stations, and water samples were collected from the shallow wells located at the same location VES points were established. Twenty (20) representative water samples were collected from hand-dug wells for hydro-chemical properties. The plastic containers used for the collection of the water samples were rinsed with the sample to be collected prior to use. Electrical

Conductivity (EC), Total Dissolved Solids (TDS), and the concentration of hydrogen ions (pH) were determined on spot.

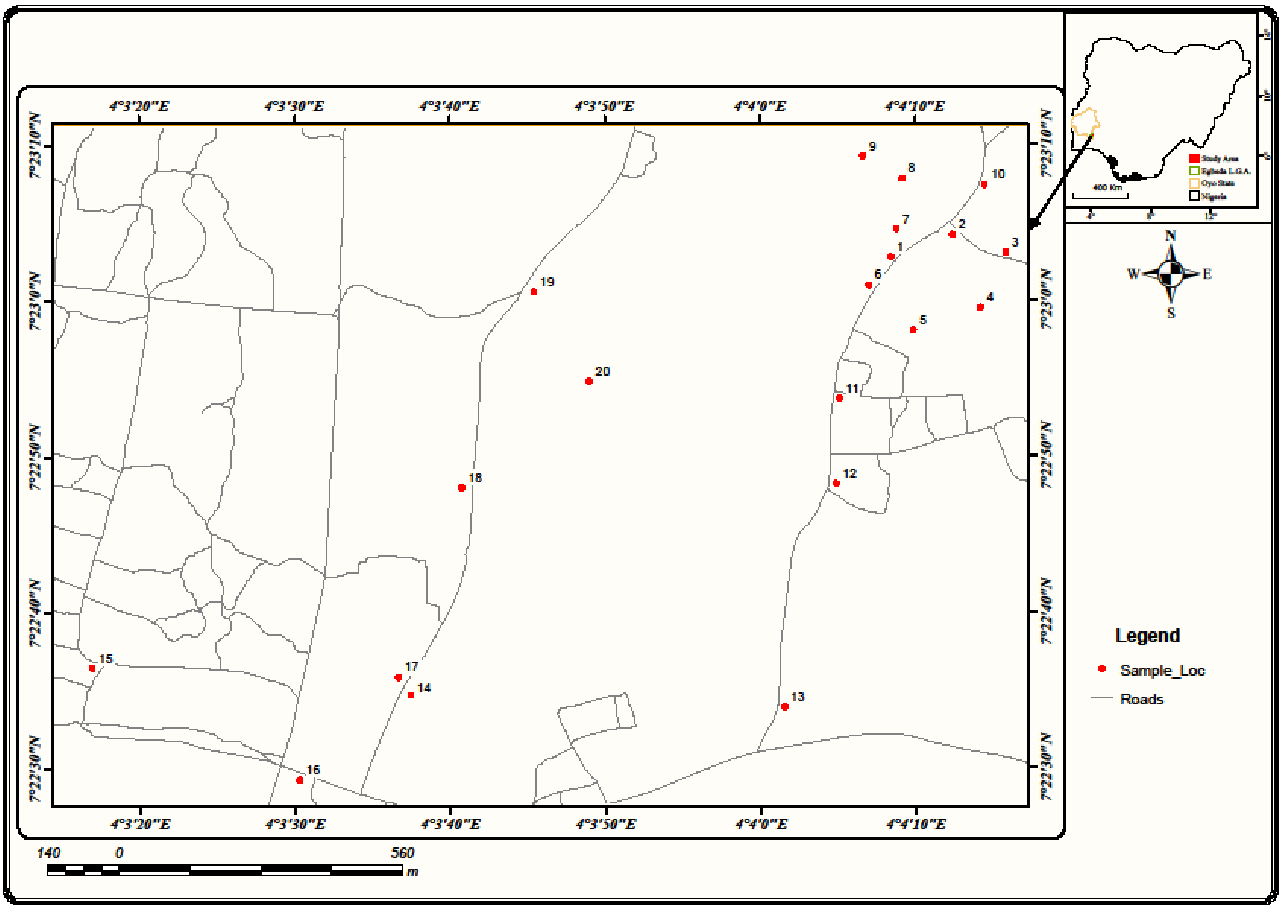

Figure 1: Location map of the study area

2.1 Electrical Resistivity Survey

Resistivity is useful in groundwater exploration due to its ability to delineate various geological sections; this is based on encompassing parameters such as mineral and fluid content, porosity, density, and degree of water saturation in the rock [22] which aid in demarcating geologic unit. The Schlumberger array employed four electrodes arranged collinearly around a common midpoint. The two peripheral current electrodes, A and B, and the two inner potential electrodes, M and N, are placed close together. As a rule of the thumb, the reasonable distance between M and N should be equal to or less than (≤) one-fifth (1/5) of the distance between A and B at the beginning. SSR-MP1 resistivity meter was in the data acquisition. The current electrode spread (AB/2) ranged from 1 m to a maximum of 80 m.

$$\rho_a = \left(\frac{\pi \left(\frac{S^2 - a^2}{4} \right)}{a} \right) \left(\frac{\Delta V}{I} \right)$$

Twenty (20) VES were spatially acquired (Fig. 2) across the area investigated with an observed error of less than 3 %. The data interpretation was done with “RESIST” software where the model derived from the preliminary interpretation (manual curve matching) was inputted into the inversion algorithm. From the final model derived from the software, geo-electric parameters which comprise; overburden thickness, weathered basement resistivity, weathered basement thickness, basement rock topography, basement rock resistivity, resistivity contrast, and reflection coefficient were acquired. A thematic map for each geoelectric parameter was generated and then integrated in establishing the groundwater potential of the area. The basement rock topography was delineated by deducting the thickness of the overburden for each of the VES points from the elevation of the same position. The reflection coefficient was obtained by the formula proposed by [23]. The reflection coefficient shows the degree of freshness of the rock at the bedrock interface and can be defined as the resistivity of the layer overlying the nth layer. The combination of different thicknesses and resistivity for each layer in the model are related to these parameters [24].

$$Reflection\ Coefficient = \frac{\rho_n - \rho_{n-1}}{\rho_n + \rho_{n-1}}$$

Where ρ_n is the resistivity of the nth layer.

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

Where h_i is the thickness of geo-electric layer,

ρ_i is the resistivity of the geo-electric layer

$$Transverse\ Resistivity\ (T) = \sum_{i=1}^{n} h_i * \rho_i$$

$$Resistivity\ Contrast = \frac{\rho_n}{\rho_{n-1}}$$

$$Electrical\ Anisotropy\ (\lambda) = \frac{\sqrt{S * T}}{H}$$

$$H = \sum_{i=1}^{n} h_i$$

2.2 Procedure for Hydrochemical Analysis

The water samples were subjected to various analyses namely, alkalinity and hardness involving titration, pH, conductivity, TDS using HANNA HI 93703 meter, anions (Nitrate, Chloride, Sulphate, Phosphate, Flouride, Nitrite) were determined using Spectrophotometer (JENWAY Aquanova Spectrophotometer). Carbonate was determined from Phenolphthalein alkalinity. Bicarbonate is gotten from the difference between the Total Alkalinity and Carbonate alkalinity. Cations (Sodium, Potassium, Magnesium and Calcium) were determined by the Flame Photometry method.

3. Results and Discussion

3.1 Geo-electrical interpretation

Twenty Vertical Electrical Sounding (VES) were established within the investigated area (Fig 1). A representative sample of four out of the VES curve types was presented in Figure 2. The sounding curves indicate 3 to 5 layers with the H curve type being dominant. The synopsis of the VES explanation is presented in Table 1. The following geo-electric horizons were delineated from the resistivity information and these include the topsoil (35-378 Ωm), clayey unit (18-80 Ωm), weathered layer (107-159 Ωm), fractured and fresh basement (110-1337 Ωm). The groundwater potential of the Agudu area was projected from the geoelectric parameters and these were used to establish the thickness of the overburden, weathered basement and its thickness, the resistivity of the basement, and its topography, and Dar-Zarrouk parameters were used to verify resistivity contrast and reflection coefficient.

3.1.1 Geo-electrical Resistivity Considerations

The list of curve types deduced from the study area includes A, H, HKH, and KH. Table 1 showed the breakdown of the VES elucidation determined from the geoelectric parameters of the investigated area.

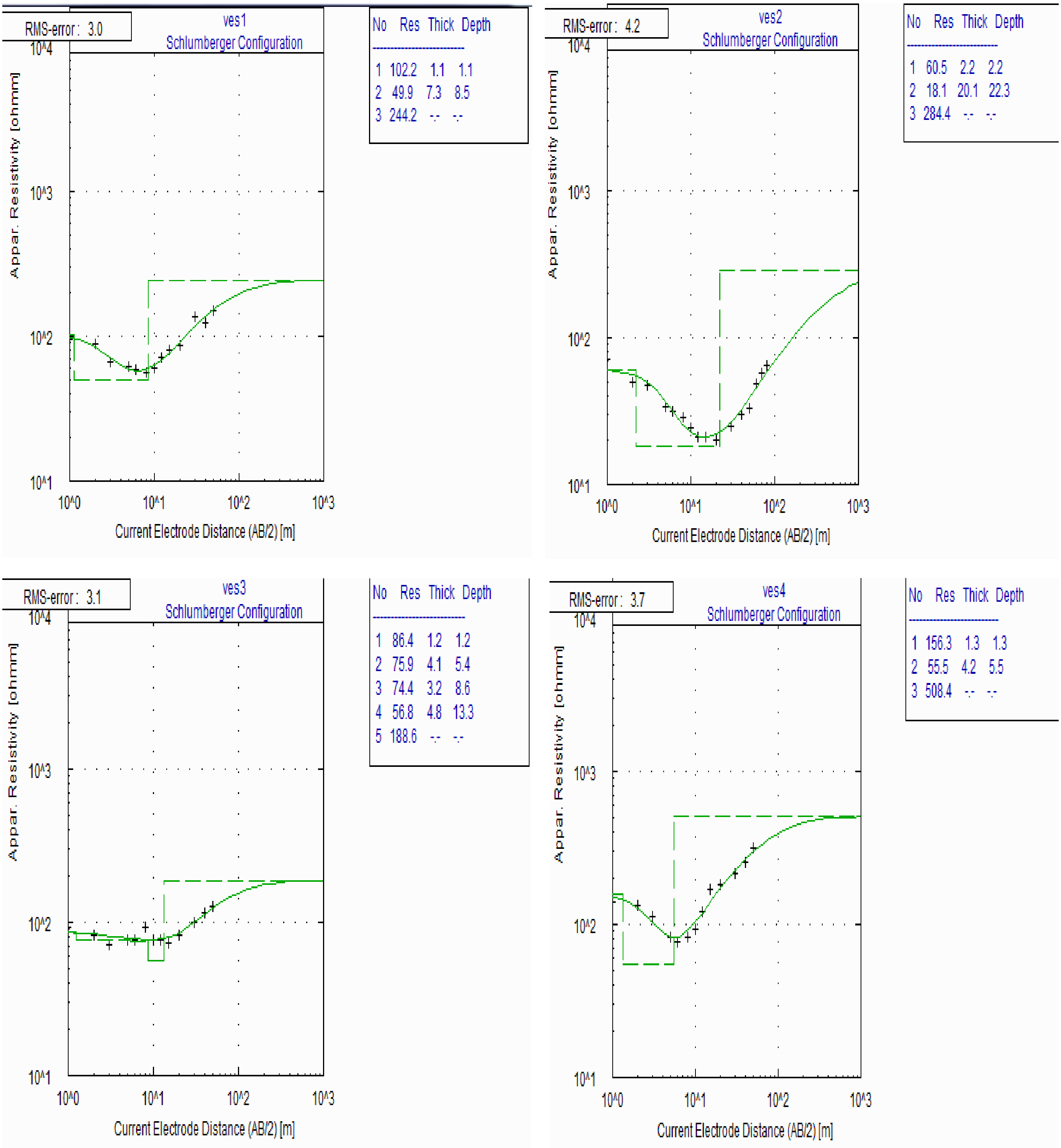

Figure 2: Representative VES curve types from the study area.

Table 1: Synopsis of Geo-electrical parameter and Dar-zarrouk parameters of the VES curves.

VES no	Resistivity(m)					Layer Thickness (m)				Resistivity Contrast	Reflection Coefficient	longitudinal Conductance S (mho)	Transverse Resistance T	Electrical Anisotropy
	ϱi	ϱii	ϱiii	ϱiv	ϱv	hi	hii	hiii	hiv					
1	102.2	49.9	244.2			1.1	7.3			4.89	0.66	0.157056	476.69	1.03007
2	60.5	18.1	284.4			2.2	20.1			15.71	0.88	1.146861	496.91	1.07051
3	86.4	79.9	74.4	54.8	188.6	1.2	4.1	3.2	4.8	3.32	0/54	0.192721	941.99	1.01306
4	156.3	55.6	508.4			1.3	4.2			9.14	0.81	0.083857	436.71	1.10028
5	118.3	30.1	122.9			1.7	29.5			4.1	0.81	0.994436	1089.06	1.05478
6	94	43.9	110.2			0.8	4.5			2.51	0.43	0.111016	272.75	1.03825
7	94.9	159.2	54.5	384.4		0.6	1.3	2.7		7.11	0.67	0.064029	411.05	1.11527
8	242.4	38.6	206.3			2.3	26.9			5.35	0.69	0.706379	1595.86	1.14983
9	85.5	33.3	240			1.9	3.1			7.21	0.76	0.115315	265.68	1.10701
10	185.4	68.4	179			2.2	18.9			2.62	0.45	0.288182	1699.76	1.0492
11	377.6	80.4	217			3.1	20.2			2.71	0.46	0.259454	2794.64	1.15568
12	216.8	51	160.3			2.9	20.9			3.14	0.52	0.423181	1694.62	1.12518
13	150.9	53.8	1336.8			1.6	3.5			24.84	0.92	0.075659	429.74	1.11805
14	122.6	35.5	305.5			1.1	4.1			8.61	0.79	0.124465	280.41	1.1361
15	35.4	107.4	62.4	173.6		0.7	5.2	6.9		2.78	0.47	0.178768	1012.44	1.05176
16	136.4	46.7	377.3			0.9	5.6			8.11	0.77	0.127288	384.28	1.0727
17	128.6	47.3	755			1.2	2.3			15.96	0.88	0.057957	263.11	1.11572
18	145.8	55.1	404.8			1.3	6.7			7.35	0.76	0.130513	558.71	1.06741
19	77.9	21.9	192.1			0.8	3.4			8.77	0.79	0.165521	136.78	1.13289
20	130	48.4	208			2	13.6			4.31	0.62	0.296376	918.24	1.05749

3.1.2 Resistivity of the Aquifer Unit (The Weathered Horizon).

The unit is characterised by resistivity values ranging from 18 to 159 Ωm with a common resistivity of 56 Ωm. The distribution of resistivity across the aquifer unit is shown in figure 3. The electrical resistivity of the weathered horizon is influenced by the contents of the clay, rock type, and the prevailing climatic condition [25]. The resistivity values revealed that the weathered layer is composed of clayey soil, sandy clay, and clayey sand. These units are considered high groundwater potential zone due to their capability to transmit and store the percolating soil water. The occurrence of clay within this horizon could impede the permeability; although it is porous but not permeable, thus lowering the aquifer potential [25-26]. It is worthy to note that weathered layer resistivity cannot be used singly to deduce groundwater prospective, other attributes of great significance are the thickness of the regolith, the resistivity of the basement, bedrock topography, and reflection coefficient [25].

3.1.3 The Thickness of Weathered horizon

The horizon is situated between the topsoil and the bedrock. The aquifer thickness ranged between 1.3 and 29.5 m with a prevailing thickness of 10.27 m. The distribution of the weathered basement thickness within the study district is shown in figure 4. The prevailing aquifer thickness is less than 15 m which cut across 0.65 section of the whole, which is, representing about 65% of the study vicinity. The northwestern portion of the study area is characterised with a greater than or equal 20 m thick aquifer unit whereas the thickness varied from 15 to 19 m in the middle segment and the remaining segment is less than 10.27 m (average thickness). The zone of interest is the segment with an average of 20 m thick and it could serve as an ideal groundwater potential zone.

3.1.4 Thickness of Regolith

The regolith consists of all the horizons that mount the bedrock, namely the topsoil, and weathered basement. The regolith thickness varied from 1.9 to 31.2 m and the mean thickness is 16.55 m (Fig.

9). [26-28] suggested that the average regolith thickness of 20 to 30 m is considered a viable groundwater potential zone that would support good yield. Based on the average regolith thickness within Agudu (16.55 m), nearly all the areas is not viable for groundwater abstraction except the northwestern part suggesting a moderate groundwater prospecting zone.

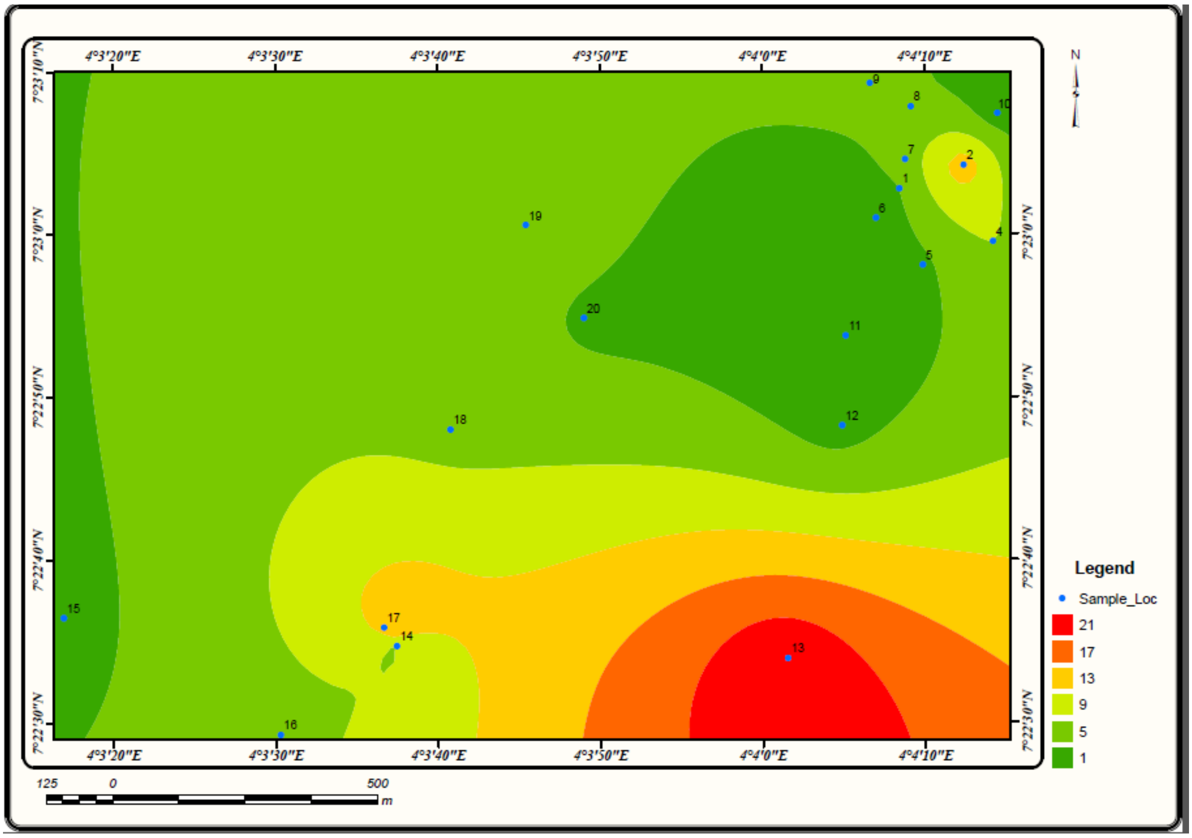

Figure 3: Aquifer unit resistivity map of the study area.

3.1.5 Resistivity of the Basement

The resistivity values of the basement ranged from 110 to 1336.8 Ωm and its mean resistivity is 330 Ωm. The basement rocks are known for poor permeability due to an interlocking mosaic of minerals, this result in the spatial inconsistency of the groundwater-bearing zone. Mineralogy of rock influences the measured resistivity and also the presence of rock structures play a role in bedrock resistivity [28]. Fractured bedrock is the potential groundwater zone being targeted in basement rock due to its high permeability, thereby aiding the transmission of groundwater. [27] classified the aquifer potential of the basement rock based on its resistivity; the basement rock that has resistivity less than (<) 750 Ωm is classified as fractured with high permeability and this resistivity was observed at L1-L12, L14-L16, L18-L20 suggesting good aquifer potential. The medium aquifer potential (750-1500 Ωm) was noticed in L13 and L17; it is worthy to note that the degree of weathering and presence of fluid influence the basement resistivity (Fig. 4).

3.1.6 The Reflection Coefficient and Resistivity Contrast of the Basement rock

These parameters aid in determining the degree of freshness or fracturing of basement rock, that is, delineating the aquiferous zone from the basement resistivity [5]. The basement rock is considered fresh if the reflection coefficient has a maximum value of 1 and the resistivity contrast is greater than 19 [23]. A zone with a reflection coefficient and resistivity contrast of less than (<) 0.75 and 19 respectively together with an overburden thickness of greater than (>) 25 m, is considered as a good aquiferous zone [25]. The distribution of the reflection coefficients was used in generating the reflection coefficient map (Fig. 5). It was observed that L2, L4, L9, L13-L14, and L16-L19, have reflection coefficient greater than 0.75 which is not considered a good groundwater prospecting zone. Also, L1, L3, L5-L8, L10-L12, L15, and L20 have a reflective coefficient of less than 0.75, which make a good aquiferous zone. The study area has a resistivity contrast of less than 19 in all location except for L13 which have resistivity contrast of 24.84.

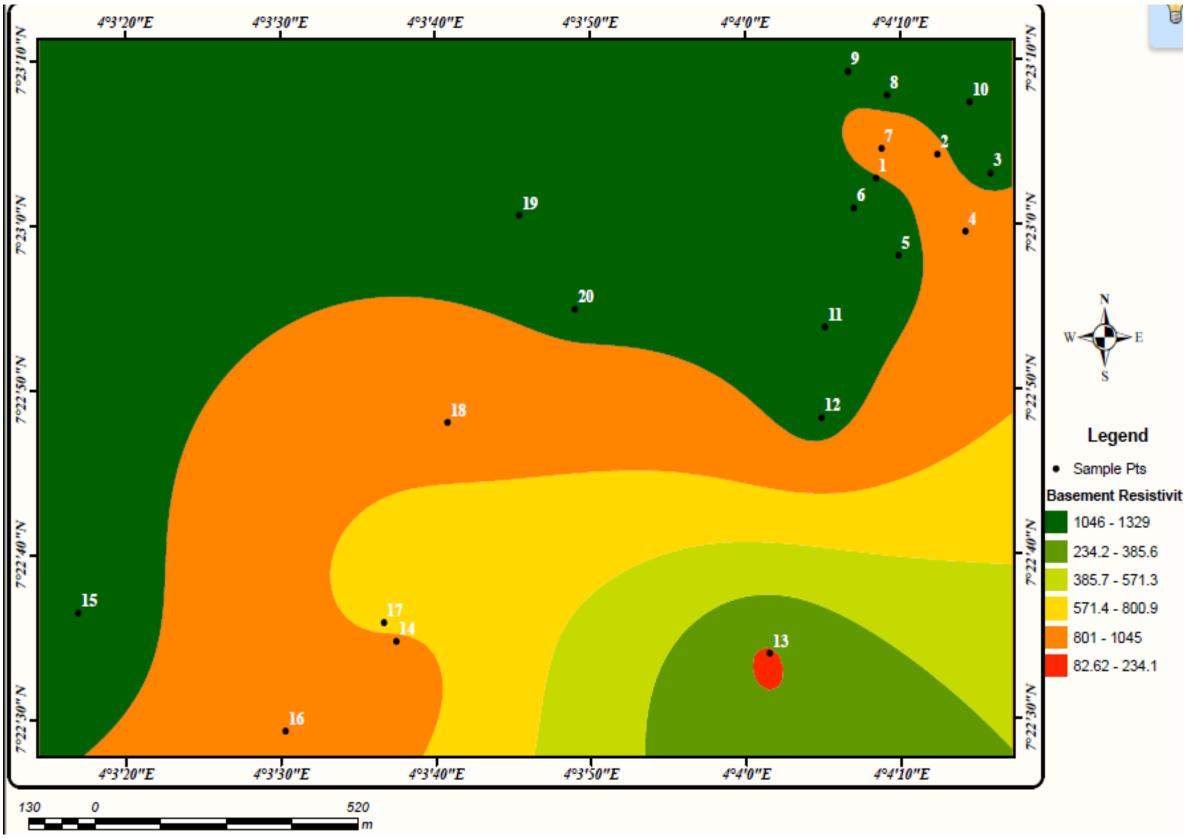

Figure 4: Basement resistivity map of Agudu community, Egbeda, Ibadan

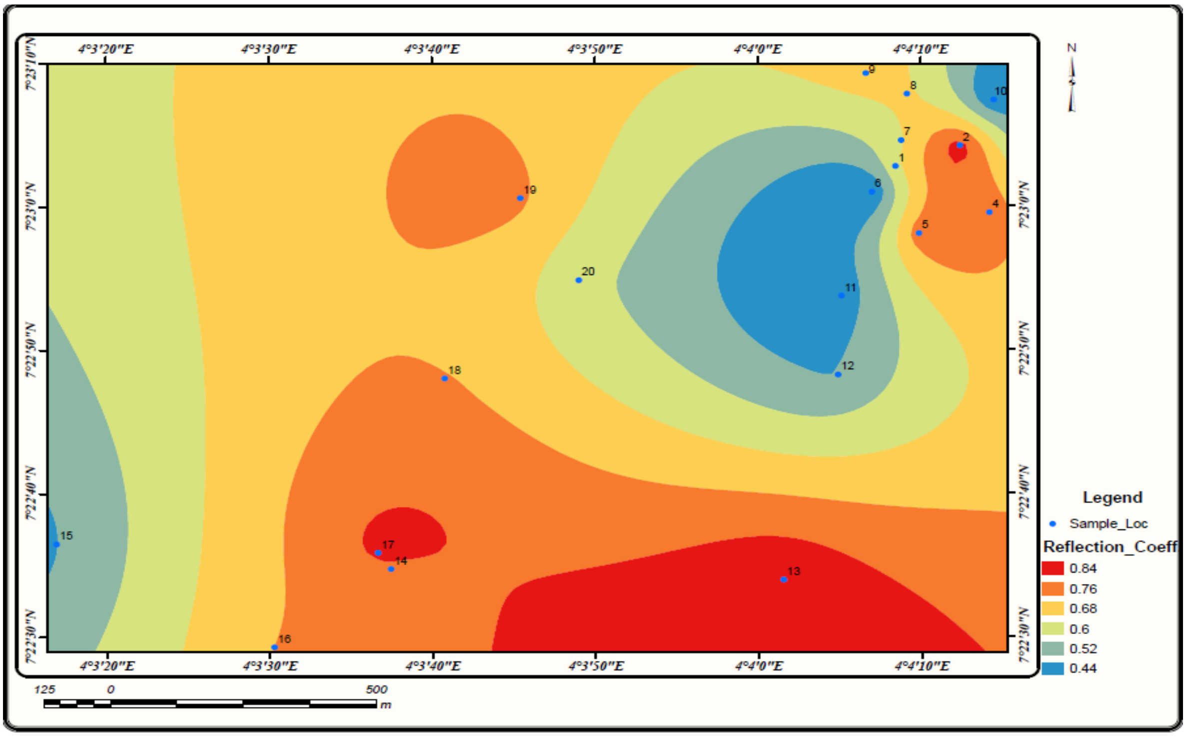

Figure 5: Reflection coefficient map of Agudu community, Egbeda area, Ibadan.

3.1.7 Total Longitudinal Conductance

The distribution of the longitudinal conductance in the investigated area ranged between 0.057957 Ω^{-1} and 1.148861 Ω^{-1} with a peculiar value of 0.271979 Ω^{-1} (Fig. 6). It is a qualitative expression of changes noted in the total thickness of low resistivity units observed in the overburden. An increase in the longitudinal conductance value is an indication of an increase in the content of clay fraction, thereby reducing the transmissivity of the segment. It could serve as a protective unit of the underlying aquifer unit. An overburden with a protective capacity (longitudinal conductance) less than 0.1 is classified as poor (the southern to the central part), Then longitudinal conductance of 0.1 to 0.19 is classified as having a weak protective capacity (north central part) though 0.2 to 0.69 was classified as having moderate aquifer protective capacity (north eastern part), 0.7-0.9 is classified high aquifer protective capacity (upper north eastern part) as reported by [28-29].

3.1.8 Total Transverse Resistance

The higher the transverse resistance value, the higher the transmissivity value of the aquiferous zone [30]. The total transverse resistance across the area ranged from 136.78 to 2794.64 Ωm^2 and has a mean value of 807.96 Ωm^2 (Fig. 7). The total transverse resistance with less than 400 Ωm^2 is considered poor having a negligible transmissivity; 400 to 1000 Ωm^2 is regarded as weak, while 1000 to 2000 Ωm^2 has moderate transmissivity and greater than 2000 Ωm^2 is considered very good indicating good aquifer transmissivity [25]. Greater than 55 % of the studied area is classified as poor to weak transmissivity. The north central part is regarded as having good transmissivity while the Northeastern part has moderate transmissivity as observed from its distribution.

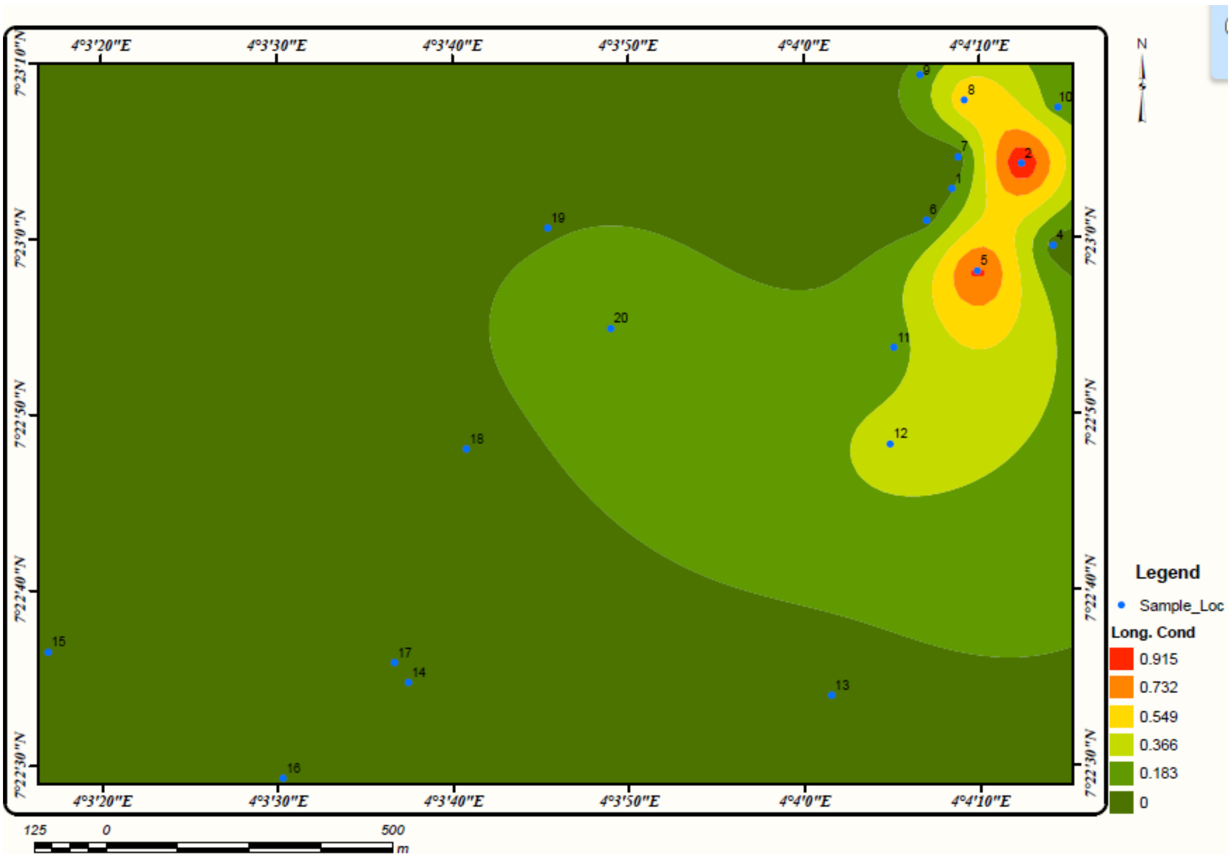

Figure 6: Total longitudinal conductance map of Agudu community, Egbeda, Ibadan

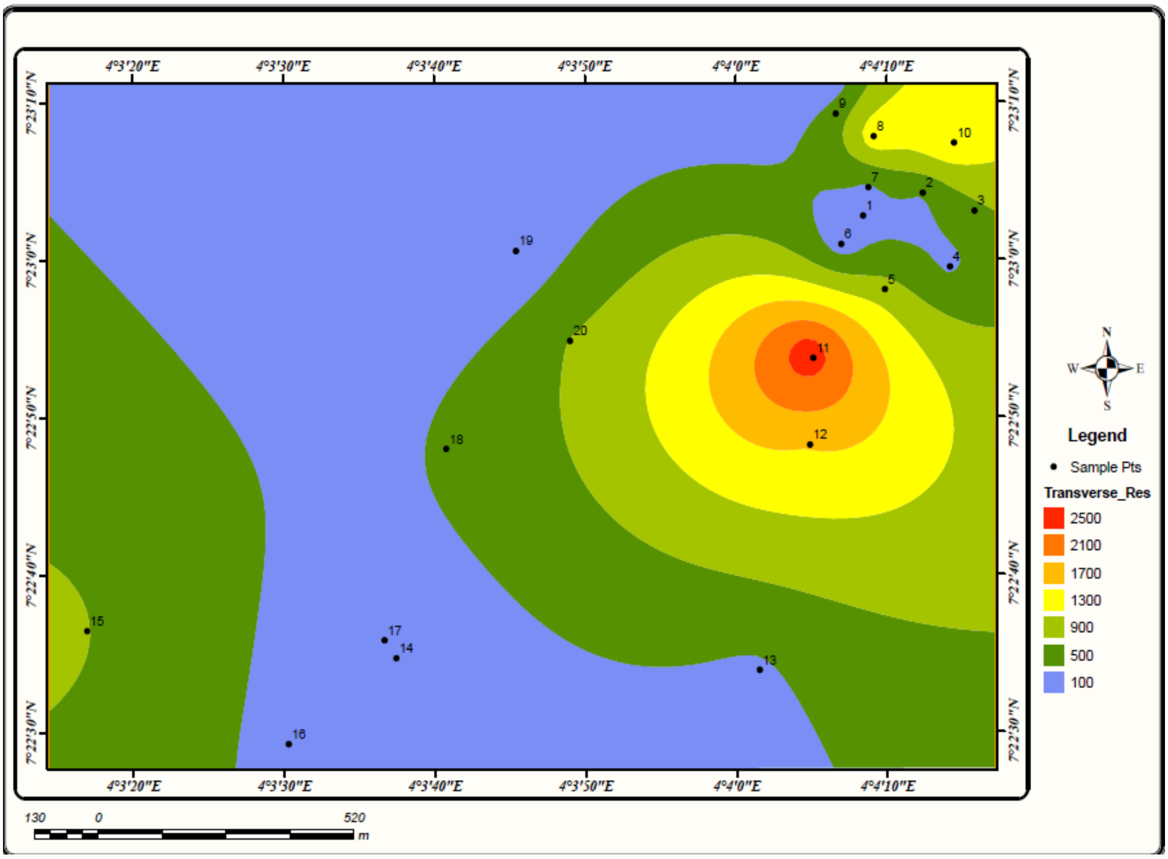

Figure 7: Total transverse resistance map of Agudu community, Egbeda area, Ibadan

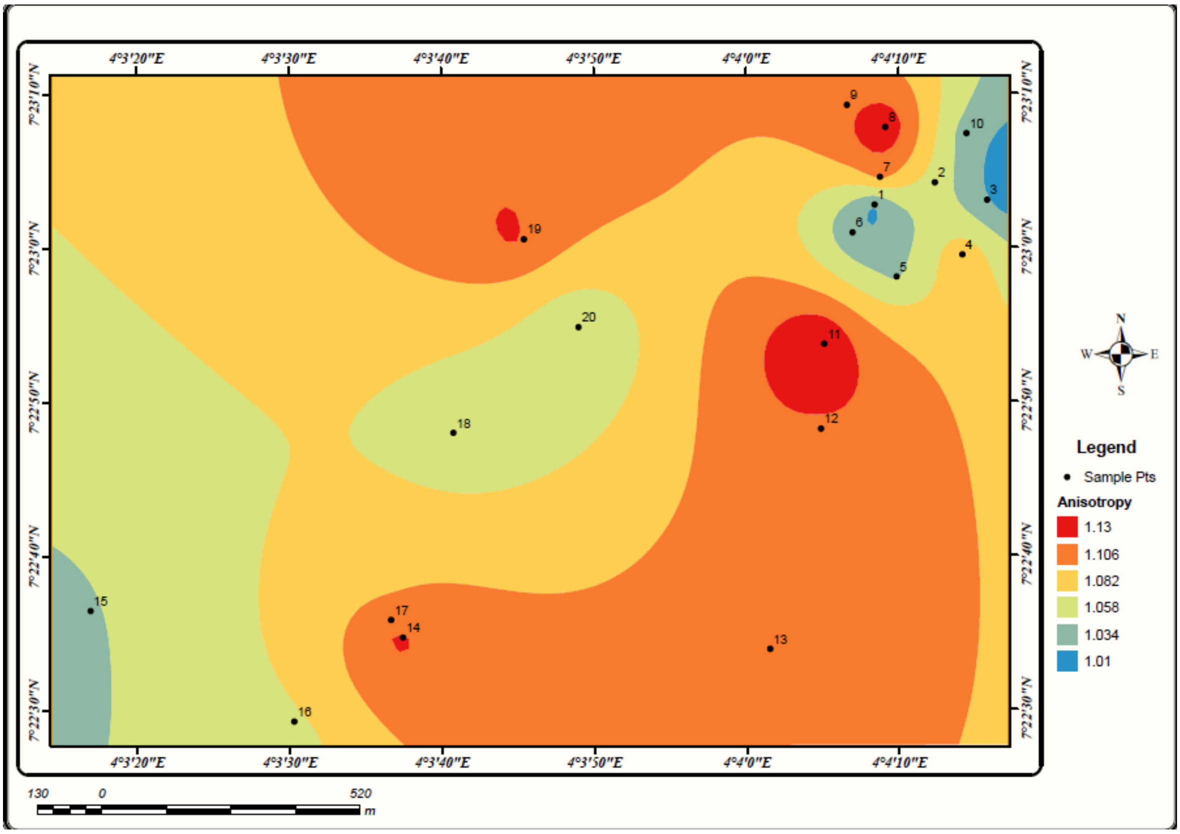

Figure 8: Electrical anisotropy/coefficient of anisotropy map of Agudu community, Egbeda area, Ibadan

3.1.9 Electrical Anisotropy/Coefficient of Anisotropy

The coefficient of the anisotropy map (Fig. 8) showed the distribution of the coefficients for the subsurface material overlying the bedrock; it ranged in value from 1.01 to 1.16 and has a common value of 1.03 [31] revealed the coefficient of anisotropy for igneous and metamorphic rocks (crystalline rock) to be 2.12 and 1.56 respectively. The underlying rock in the study area is regarded as a metamorphic rock as determined by its coefficients. The electrical anisotropy has a direct relationship with groundwater yield, that is, a rise in electrical anisotropy results in an increase in groundwater yield [28, 31]. It was noted that the north central and part of the north east area have high electrical anisotropy values denoting a good groundwater aquifer.

3.1.10 Assessment of Aquifer potential

The aquifer potential of the study area was delineated from the combination of weathered basement resistivity, the thickness of the overburden, resistivity basement and its topography, coefficient of reflection, longitudinal conductance, transverse resistance, and electrical anisotropy.

Groundwater potential of an area is based on its overburden thickness and fractured bedrock; a zone with an overburden thickness of greater than 10 m together with bedrock resistivity of less than or equal to (≤) 800 Ωm and resistivity of the weathered horizon is situated between 50 and 300 Ωm is considered good groundwater potential zone [32]. In furtherance to this, basement rock characterised by depressed topography, also the bedrock having < 0.75 reflection coefficient, >1.2 coefficient of anisotropy, low longitudinal conductance, high transmissivity, and transverse resistance are indications of fractured bedrock; this is classified as potential groundwater bearing zone [25].

The use of geo-electric and Dar-Zarrouk parameters has aided in classifying the aquifer potential of the Agudu area into poor, low, and good groundwater-bearing zones. The northeastern, central region, and southeastern parts of the investigated regions were considered as good aquifer potential accounting for approximately 70% of the entire area; the northwest and southwestern were categorised as low-medium (28%) and low (2%) groundwater potential zone respectively.

3.2 Hydro-chemical characteristics

The chemical constituent of groundwater depends on the chemistry of the host rock, most especially the dissolvable portions of the rocks and soils that interacted with the percolating water through the porous and permeable paths/ways [33]. The content of the soil unit in the partially saturated zone and the rock chemistry play a leading role in resultant cation and anion concentrations in the groundwater. It could be anthropogenic in nature, emanating from the industrial effluents, indiscriminate dumping of municipal waste, non-sewered sanitary facilities, or from soil conditioners in agro-chemicals, when they are not impeded during the process of leaching will negatively modify the physical, chemical, and biological components of the groundwater [34].

Results of the hydro-chemical laboratory analyses of groundwater in the study area are presented in Table 2. From Table 2, the pH ranged from 5.64 to 7.09 with an average of 6.13 indicating that the groundwater varied between weak acid and very weak alkaline. Electrical Conductivity (EC) and Total Dissolved Solids (TDS) varied from; 100 to 540 µS/cm with a mean value of 250 µS/cm and 70 to 360 mg/l with a mean value of 173.5 mg/l respectively. The TDS is generally low in the study area, that is, all the values are <500 mg/l. Groundwater from the area generally is freshwater type as all the sampled water has TDS values below 500 mg/l. The Total Hardness (TH) of groundwater samples in the study area varied between 66 and 360 mg/l with a mean value of 198.35 mg/l. TH in the area is generally <250 mg/l except for locations L17 with values of 362 mg/l. The very high values in this location can be attributed to the influence of bedrock geology and anthropogenic activities in these areas. The hardness of water is the amount of calcium and magnesium, and iron

TABLE 2: Result of hydrochemical analysis of water samples from Egbeda area

S/N	TEST	SAMPLES																			
		L1	**L2**	**L3**	**L4**	**L5**	**L6**	**L7**	**L8**	**L9**	**L10**	**L11**	**L12**	**L13**	**L14**	**L15**	**L16**	**L17**	**L18**	**L19**	**L20**
1	pH	6.79	6.83	6.80	6.39	6.62	6.17	6.20	6.67	6.46	6.49	6.29	6.31	6.52	6.36	6.38	6.29	7.03	7.09	6.33	5.64
2	Conductivity(μS/cm)	200	300	300	190	240	300	290	240	100	260	210	160	280	250	260	230	540	230	330	250
3	Turbidity (FTU)	0.09	0.11	0.13	0.10	0.09	0.05	0.11	0.13	0.09	0.08	0.09	0.11	0.13	0.10	0.09	0.05	0.11	0.13	0.10	0.08
4	Total Dissolved Solid (mg/L)	135	200	200	130	160	200	195	160	70	175	140	110	190	170	175	155	360	155	220	170
5	Total Hardness (mg/L $CaCO_3$)	222	226	220	200	166	244	240	170	66	200	230	220	200	212	216	200	362	150	160	88
6	Total Alkalinity (mg/L $CaCO_3$)	152	154	154	144	130	162	160	168	50	140	150	150	146	158	158	140	180	120	166	70
7	Chloride (mg/L)	16.75	17.01	17.23	11.87	16.11	19.19	18.68	18.91	5.32	17.87	15.71	15.63	15.29	11.87	9.92	9.96	28.68	9.96	18.71	15.94
8	Bicarbonate(mg/L)	152	154	154	144	130	162	160	168	50	144	150	150	146	158	158	140	180	120	166	70
9	Nitrate (mg/L)	0.68	0.65	0.65	0.63	0.96	0.67	0.95	0.63	0.21	0.72	0.89	0.82	0.75	1.10	1.06	0.63	1.17	0.63	0.18	0.16
10	Sulphate (mg/L)	6	6	6	4	4	12	10	10	2	4	10	8	8	12	10	10	24	6	18	8
11	Calcium (mg/L)	56.02	56.80	56.80	52.81	38.40	57.61	56.02	42.41	16.00	48.80	56.00	58.41	48.01	55.20	55.22	52.01	82.41	35.20	36.79	9.63
12	Magnesium (mg/L)	23.45	24.02	24.50	19.45	20.02	28.62	28.60	18.30	7.44	22.31	24.02	22.88	22.88	21.66	22.31	20.02	26.31	17.73	19.45	18.30
13	Sodium (mg/L)	10.16	10.21	10.42	9.90	10.13	12.75	13.01	9.99	4.12	12.31	12.19	12.03	12.67	13.38	13.41	10.26	13.49	9.11	10.52	7.45
14	Potassium (mg/L)	6.19	6.16	6.20	6.12	6.14	6.29	6.12	5.15	2.81	5.12	5.05	5.07	5.03	7.18	7.32	6.11	6.45	5.57	5.12	4.88

to a lesser extent in water commonly expressed as milligram of calcium carbonate equivalent per liter. According to [35] water containing calcium carbonate <75 mg/l is considered soft, 75-150 mg/l as moderately hard, 150-300 mg/l as hard, and >300 mg/l as very hard.

The classification of groundwater based on TH reveals that 20 groundwater samples L9, fall within the soft water group, samples L18and L20 fall in the moderately hard group, samples (L1-L8, L10-L16, and L19) fall in the hard group and sample L17 falls in the very hard group. The concentration of major cations decreases from Ca^{2+} to K^{+} ($Ca^{2+}>Mg^{2+}>Na^{+}>K^{+}$) respectively even as those of anion decreases from carbonate to nitrate concentration ($HCO^{-3}>Cl^{-}> SO_4^{-2}>NO^{-3}$).

3.2.1 Hydro-chemical facies

Piper trilinear diagram was used to infer hydro-chemical facies. The diagram consists of two triangles for plotting the cations and the anions. The cation and anion fields are combined to show a single point in a diamond-shaped field, from which inferences are drawn on the basis of the hydro-chemical facies concept (cations and anions) for evaluating their concentrations in the analysed water [36]. The chemical characteristic of the water itself is a function of the pathways as it interacts with the various components. Water samples having similar chemistry lean to cluster as groups [37]. Two hydro-chemical facies were delineated from the Piper trilinear plot of groundwater samples and they are $CaHCO_3$, and MgCl. 95% of the water samples fell into $CaHCO_3$ facies type, while only sample L20 representing 5% of the sampled water was MgCl facies (Fig. 9)

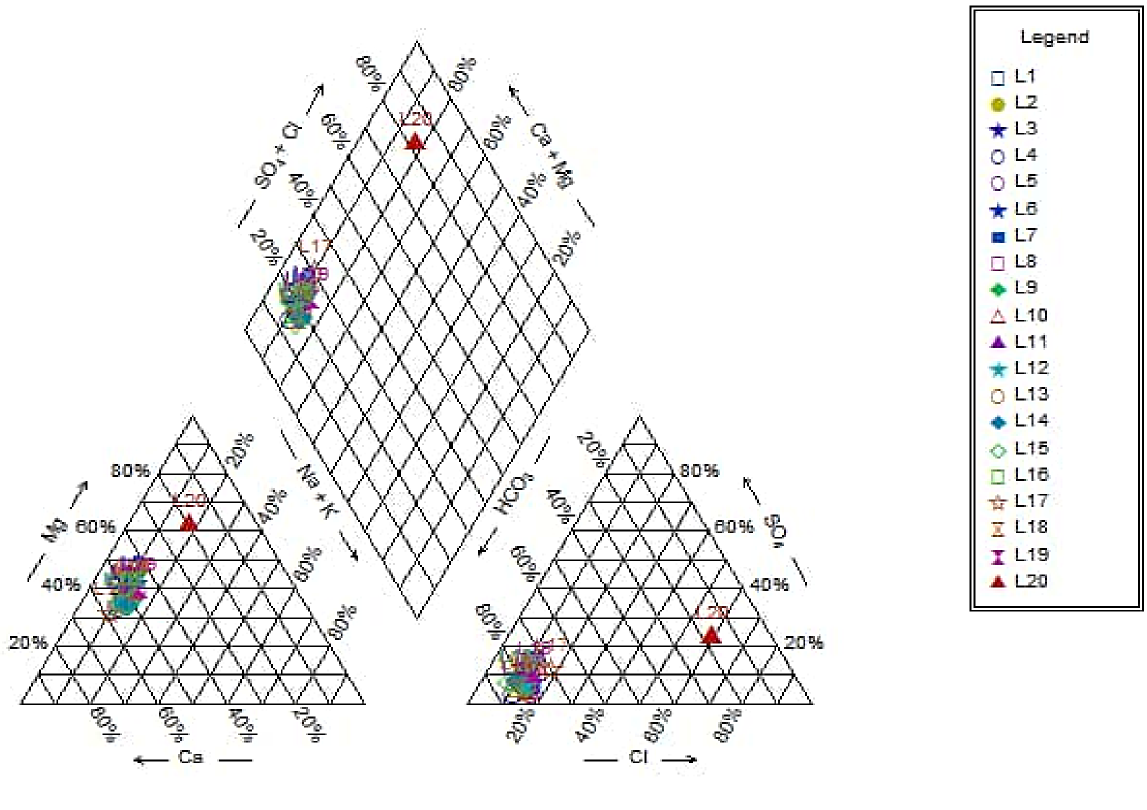

Figure 9: Piper diagram indicating the water sample content

4. Conclusions

The analyses of the 20 VES points were used in delineating the geo-electric layer and the Dar-Zarrouk parameters within Agudu community; the results showed three to four geo-electric layers, namely topsoil, clayey unit, weathered basement, and fractured/fresh basement. The geo-electric parameters together with the Dar-Zarrouk parameters were used in differentiating the groundwater prospect of the community into poor, low, and good aquifer districts. The high groundwater prospect zone is situated around the northeastern to the central part of the area.

The physicochemical composition of groundwater revealed the concentration of major cations to be in the order of Ca^{2+}> Mg^{2+}> Na^{+}> K^{+} even as that of anion were HCO^{-3}>Cl^{-}>SO_4^{2-}>NO^{-3}. The drinking water quality assessment showed that the pH values were within the World Health Organisation (2006) recommended value and it varies between slightly acidic and slightly alkaline. The water hardness is within the maximum permissible except for six locations and nitrate also has all values within the maximum permissible limit while values for all other parameters are within the limit, except for $Ca^{2+}$with one sample above the maximum permissible limit.

Electrical resistivity and hydrochemical investigations were able to substantiate the quantity and quality of the groundwater potential within the community; thus, the techniques were effective evaluators in characterising the subsurface groundwater distribution. The results of these investigations will serve reliable baseline for subsequent studies on groundwater development in Agudu community.

Funding: Not applicable

Institutional Review Board Statement: Not applicable

Informed Consent Statement: Not applicable

Acknowledgments: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest

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Cite article as:

Isibor, R. A., Olaojo, A. A., Oyelade, A. Y. Hydrogeochemical and Geoelectrical Characterisation of Groundwater around Agudu, Egbeda Area, Ibadan, Southwestern Nigeria. *Ajayi Crowther J. Pure Appl. Sci.* **2023**, 2(1), pp. 9-23. https://doi.org/10.56534/acjpas.2023.02.01.09