Asian Journal of Geological Research

Volume 6, Issue 3, Page 189-203, 2023; Article no.AJOGER.106432

Integration of Elevation, Lithology and Geoelectric Parameters Using Analytical Hierarchy Process for Groundwater Potential Evaluation in Part of Akure Metropolis, Southwestern Nigeria

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Authors' contributions

This work was carried out in collaboration among all authors. Author IAA conceptualized the research, participated in the data acquisition, data interpretation, report writing, reviewing and editing. Author AOA participated in data acquisition, report writing, reviewing and editing. Author OBO participated in data acquisition, ınterpretation, original draft preparation and final report writing. Author OTA participated in data interpretation, figures' generation and original draft preparation. All authors read and approved the final manuscript.

Article Information

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/106432

Original Research Article

Received: 25/07/2023
Accepted: 28/09/2023
Published: 10/10/2023

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ABSTRACT

This hydrogeophysical study was carried out in order to proffer solutions to inadequate water supply plaguing Obanla-Obakekere, in the campus of Federal University of Technology, Akure (FUTA) Nigeria. The depth sounding method engaged the Schlumberger configuration. Three to five geoelectric layers were delineated from the results. The layer resistivities vary from 33 - 548 Ω-m, 13 - 6110 Ω-m, 42 - 90,232 Ω-m, 60 - 89,806 Ω-m and 711 - 100,000 Ω-m in the topsoil, weathered layer, weathered basement, partially weathered/partially fractured basement and the presumed fresh basement respectively. Elevation and lithology data were combined with six geoelectrically derived parameters (aquifer resistivity, aquifer thickness, longitudinal conductance, transverse resistivity, longitudinal resistivity and coefficient of anisotropy) to evaluate the groundwater potential of the study area. Each of these hydrogeological/hydrogeophysical significance parameters were presented as map showing different groundwater potential zones in the area. The maps were integrated using the Analytical Hierarchy Process (AHP) method. The groundwater potential map (GPM) shows that the northcentral area, the western and eastern flanks area has high to very high groundwater potential. These zones constitute about 40% of the study area, while the remaining segments, classified as moderate and low prospect, constitute about 38% and 22% respectively. The model GPM was validated using evidence of producing wells/boreholes. 13.89% of the producing wells/boreholes falls within the low groundwater potential zones, 30.55% falls within moderate groundwater potential zones and 55.56% falls within high and very high potential. This study can serve as guide for future groundwater development efforts in the study area.

Keywords: Lithology; geoelectric; aquifer; groundwater potential.

1. INTRODUCTION

Groundwater constitutes about 90% of fresh water within the earth [1,2]. Groundwater has been a major source of fresh water over the years in many developing countries of the world. There is a large dependent on groundwater in Africa and especially in Nigeria, this is expected because there is very little effort geared towards harnessing freshwater from other sources such as rivers and streams. Water from rivers and streams always require purification and treatment before it could be fit for drinking and other human uses [1,3]. Groundwater on the other hand are usually abstracted in its fresh and chemically stable condition thereby eliminating the need for treatment. This is possible because of the ability of the subsurface geologic materials to filter and sterilize percolating water in the vadoze zone before getting to the saturated zone [1,3,4]. Many property owners prefer to tap from groundwater resources through hand dug wells and motorized boreholes because it is cheaper. The Federal University of Technology, Akure (FUTA) also rely completely on provision of fresh water through boreholes and hand dug wells to meet the water needs of its staff and students. Some hydrogeophysical studies have been done within and immediate environment of FUTA campus with a view to characterize the area into different groundwater potential zones [1,5-7]. All these studies considered very few hydrogeophysical parameters (overburden thickness, aquifer resistivity, aquifer thickness, bedrock relief and fracture zones) in their evaluation of groundwater potential. This new study integrated lithological and elevation data with geoelectrically derived parameters (primary and secondary) using Analytical Hierarchy Process (AHP) method [8,9] in evaluating the groundwater potential of Obanla-Obakekere area, in FUTA campus. The use of AHP is necessary to integrate all the parameters and at the same time taking into consideration their relative importance to ground water potential evaluation. This study covers larger area because area that were not accessible within FUTA campus in the past are now accessible due to construction of many new buildings and roads in the campus.

The study area is the Obanla-Obakekere area in FUTA campus. The area is accessible through Akure-Ilesa express way. The area is located within longitudes $5^0\ 7^1\ 00^{11}$ - $5^0\ 9^1\ 00^{11}$ and latitudes $7^0\ 17^1\ 30^{11}$ - $7^0\ 19^1\ 30^{11}$ and it covers an area of about 8.6 km^2 (Fig. 1). The topography of the area is moderately undulating with elevation varying from 350 to 411 m (Fig. 2). The area falls within tropical rainforest belt of southwestern Nigeria. The study area is characterized by wet (April to October) and dry (November to March) seasons, while the mean annual rainfall in the area ranges between 1000 - 1500 mm [10]. The mean temperature is between 28 - 30°C and the

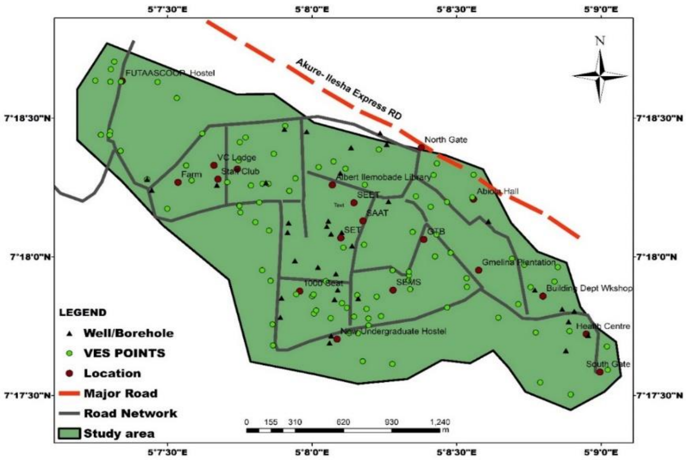

Fig. 1. Location map of the study area showing VES points

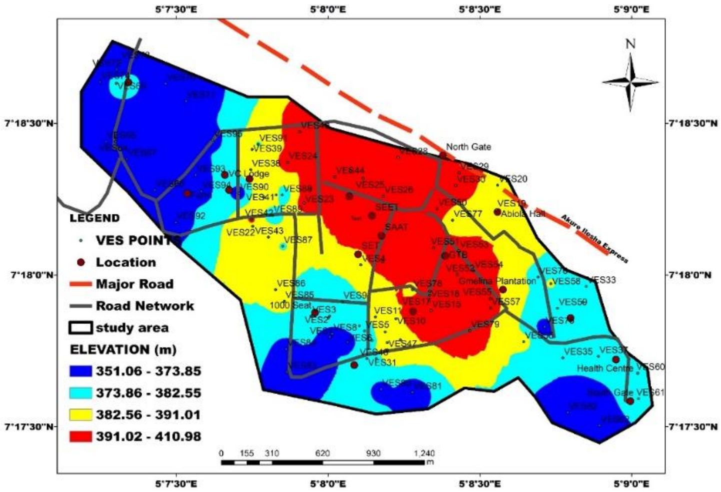

Fig. 2. Elevation map of the study area

humidity is constantly high, enhancing proper precipitation [10]. The vegetation in the area is typical of tropical rain forest which is characterized by thick forest. Four rock units were identified in the study area; Migmatite-Gneiss, Quartzites, Older Granite and Charnockites (Fig. 3) [11].

2. MATERIALS AND METHODS

Electrical resistivity was adopted for this work because it has been used successfully in many hydro-geophysical studies [1, 5 - 7], it has good resolution and it is non-intrusive. The Schlumberger configuration was adopted for the work because of its simplicity and good resolution. A total of 95 vertical electrical sounding (VES) data was acquired across the area. The half current electrode spacing (AB/2) was varied from minimum of 1 to maximum of 65 - 100 m. The field obtained data were presented on log-log graph sheets and were consequently interpreted using conventional manual curve matching technique [12,13] with the aid of theoretical curves and auxiliary curves. The manual interpretation exercise yielded the geoelectric parameters consisting of the layer parameters (resistivities and thicknesses). These results were further enhanced using Window Resist version 1.0 [14], a forward modelling software. The aquifer layers were identified based on the layer resistivity values obtained from VES results and consequently the aquifer layer resistivity and thickness values were extracted from the geoelectric parameters. Four second order geoelectric parameters were also derived from the initial geoelectric parameters using the following four (4) relationships;

2.1 Longitudinal Conductance (S)

$$S = \sum \frac{h_i}{\rho_i} = \frac{h_1}{\rho_1} + \frac{h_2}{\rho_2} + \frac{h_3}{\rho_3} + \cdots \frac{h_n}{\rho_n} \text{ [15]} \quad (1)$$

Where,
h_i is layer thickness
ρ_i is layer resistivity

2.2 Transverse Resistance (T)

$$T = \sum h_i\rho_i = h_1\rho_1 + h_2\rho_2 + h_3\rho_3 + \cdots + h_n\rho_n \text{ [15]} \quad (2)$$

Where,
h_i is layer thickness
ρ_i is layer resistiviy

2.3 Longitudinal Resistivity (ρ_L)

$$\rho_L = {}^{T}/_{S} \text{ [15]} \quad (3)$$

Where,
T is Total layer thickness
S is Total longitudinal conductance

2.4 Coefficient of Anisotropy

$$\lambda = \left(\frac{\rho_t}{\rho_l}\right)^{1/2} \text{[15]} \quad (4)$$

Where,
ρ_t is transverse resistance
ρ_t is longitudinal conductance

The eight parameters consisting of lithology, elevation and six geoelectrically derived parameters were integrated using AHP method.

2.5 Analytic Hierarchy Process (AHP)

AHP was first introduced by Saaty [8] and it breakdown problems into a hierarchy of criteria for easy analysis and to be compared in an individual manner. The following are the stages of AHP method.

Step 1: The pairwise comparison of selected factors

This involves selection of those factors responsible for groundwater potential evaluation. It is expert driven. It is by comparing two different factors at the same time using Saaty [9] scale which range from 1 - 9 (Table 1).

Step 2: Construction of pairwise comparison matrix

The method is based on the pairwise comparison matrix using the following equation

$$p = \parallel pij \parallel (i, j = 1,2, \ldots\ldots -m) \quad (5)$$

Ri and Rij (I, j = 1, 2, ….., m)

Where m is the number of the criteria compared.

$$p = \begin{pmatrix} p_{11} & p_{12} \cdots & p_{1m} \\ p_{21} & p_{22} \cdots & p_{2m} \\ \vdots & \vdots & \vdots \\ p_{mi} & p_{m2} \cdots & p_{mm} \end{pmatrix} = \begin{pmatrix} \frac{w_1}{w_1} & \frac{w_1}{w_2} \cdots & \frac{w_1}{w_m} \\ \frac{w_2}{w_1} & \frac{w_2}{w_2} \cdots & \frac{w_2}{w_m} \\ \frac{w_m}{w_1} & \frac{w_m}{w_2} \cdots & \frac{w_m}{w_m} \end{pmatrix} \quad (6)$$

This comparison is qualitative. It indicates how significant each criterion is to the other.

Step 3: Determination of factors weightage

To determine the weightage factors, the average of normalized column (ANC) method was used. This was done by dividing the factors of each column by the sum of the column and then add the factors in each resulting row and divide the sum by the number of factors in the row (n). This is a process of averaging over the normalized column. Mathematically, it can be calculated as;

$$W_i = \frac{1}{n}\sum_{j=1}^{n} \frac{a_{ij}}{\sum_i^n a_{ij}}, i, j = 1,2, \ldots n \quad (7)$$

Step 4: Consistency index examination of the pair-wise matrix

Since the comparisons are done using subjective or exert opinion approach, some degree of insistency may have occurred. To be sure that the judgement is consistent, the consistency ratio (CR) which will show the consistency among the pairwise compared. The consistency ratio (CR) is determined by the ratio of consistency index (CI) to Random index (RI) (Table 2). This involves three steps which are as follow;

Step 1: Calculation of the eigenvalue ($\lambda\lambda_{max}$).

Step 2: By calculating the consistency index (CI). The formula below was used.

$$CI = \frac{\lambda_{max} - n}{n-1} \quad (8)$$

Table 1. Saaty Scale of Relative Importance [9]

Scale	Numerical Rating	Reciprocal
Extremely preferred	9	1/9
Very strong to extreme	8	1/8
Very strongly preferred	7	1/7
Strongly to very strongly	6	1/6
Strongly preferred	5	1/5
Moderately to strongly	4	¼
Moderately preferred	3	1/3
Equally to moderately	2	½
Equally preferred	1	1

Table 2. Random Index (RI) Table (Saaty, 2005)

N	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.32	1.41	1.45	1.45	1.49

Table 3a. Geoelectric sounding results

VES No	Easting	Northing	ρ_1	ρ_2	ρ_3	ρ_4	ρ_5	h_1	h_2	h_3	h_4	Curve Type
1	735530	807208	249	93	982			1	4.1			H
2	735539	807220	548	62	1527			1	3			H
3	735428	807221	228	85	1636			1.3	8			H
4	735727	807533	90	145	11238			1.1	6.7			A
5	735751	807132	371	22	14991			1	2.3			H
6	735648	807063	162	285	115	2227		0.6	1.4	3.8		KH
7	735542	807093	169	86	2246			1.3	5.9			H
8	735556	807114	309	82	1273			0.7	4.7			H
9	735616	807309	193	363	77	989		0.7	2.5	8.3		KH
10	735941	807207	191	104	813	1326		0.5	1.5	14.9		HA
11	735817	807217	147	112	1145			0.8	7.3			H
12	735877	807126	122	76	3863			1.3	3.3			H
13	735969	807078	90	1413	1517			2.5	8.8			A
14	735889	807062	148	34	2189			0.9	2.2			H
15	736154	807258	850	95	2945			1.9	10.6			H
16	736143	807316	141	203	52	1820		0.8	2	10.1		KH
17	736146	807350	449	111	1199			1.4	12.2			H
18	736146	807374	413	127	1587			2.7	12.2			H
19	736547	807871	176	50	2914			1.5	16.7			H
20	736554	808021	225	57	949			0.9	8.9			H
-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-
85	735264	807310	209	142	327			4.6	11.9			H
86	735211	807380	195	69	568			5	23			H
87	735253	807644	67	56	2149			1.7	7.2			H
88	735248	807955	347	69	2926			1.1	7.5			H
89	735190	807831	120	99	1791			1.5	14.4			H
90	734986	807964	154	141	613			1.6	37.7			H
91	735101	808262	197	195	1149			3.7	14.7			H
92	734604	807786	96	136	109	363		1	4.1	17.9		KH
93	734723	808074	269	477	77	958		1.9	3.7	16.9		KH
94	734758	807975	175	210	90	190		1.9	4.6	9.3		KH
95	734825	808287	184	315	2023			2.8	17.6			A

Table 3b. Geoelectric sounding derived parameters

VES No.	Easting	Northing	AR	AT	LC	TR	LR	COA
1	735530	807208	123.5882	4.1	0.048102	630.3	106.0245	1.079656
2	735539	807220	183.5	3	0.050212	734	79.66237	1.517719
3	735428	807221	104.9892	8	0.099819	976.4	93.16826	1.061545
4	735727	807533	137.2436	6.7	0.058429	1070.5	133.4951	1.013943
5	735751	807132	127.7576	2.3	0.107241	421.6	30.77185	2.037589
6	735648	807063	85.55172	3.8	0.041659	496.2	139.2241	0.783894
7	735542	807093	100.9861	5.9	0.076297	727.1	94.36811	1.034471
8	735556	807114	111.4259	4.7	0.059582	601.7	90.63072	1.108806
9	735616	807309	146.2348	8.3	0.118306	1681.7	97.20538	1.226536
10	735941	807207	731.6686	14.9	0.035368	12365.2	477.8322	1.237427
11	735817	807217	115.4568	7.3	0.070621	935.2	114.6972	1.003306
12	735877	807126	89	3.3	0.054077	409.4	85.06422	1.022873
13	735969	807078	1120.301	8.8	0.034006	12659.4	332.2976	1.836131
14	735889	807062	67.09677	2.2	0.070787	208	43.79337	1.237789
15	736154	807258	209.76	10.6	0.113814	2622	109.8281	1.381989
16	736143	807316	80.93023	10.1	0.209757	1044	61.49981	1.147146
17	736146	807350	145.7941	12.2	0.113028	1982.8	120.3242	1.100762
18	736146	807374	178.8255	12.2	0.102601	2664.5	145.2234	1.109676
19	736547	807871	60.38462	16.7	0.342523	1099	53.13516	1.066037
20	736554	808021	72.42857	8.9	0.16014	709.8	61.19632	1.087908
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
85	807310	735264	160.6788	11.9	0.105812	2651.2	155.9364	1.015092
86	807380	735211	91.5	23	0.358974	2562	78	1.083087
87	807644	735253	58.10112	7.2	0.153945	517.1	57.81302	1.002489
88	807955	735248	104.5581	7.5	0.111866	899.2	76.87791	1.166214
89	807831	735190	100.9811	14.4	0.157955	1605.6	100.6619	1.001585
90	807964	734986	141.5293	37.7	0.277765	5562.1	141.4863	1.000152
91	808262	735101	195.4022	14.7	0.094166	3595.4	195.3989	1.000008
92	807786	734604	113.2478	17.9	0.204784	2604.7	112.3135	1.004151
93	808074	734723	158.9911	16.9	0.234301	3577.3	96.03051	1.286713
94	807975	734758	135.1582	9.3	0.136095	2135.5	116.0952	1.078982
95	808287	734825	297.0196	17.6	0.07109	6059.2	286.9585	1.017379

Key;
AR is Aquifer Resistivity
AT is Aquifer Thickness
LC is Longitudinal Conductance
TR is Transverse Resistance
LR is Longitudinal Resistivity
COA is Coefficient of Anisotropy

Step 3: This is by calculating the consistency ratio (CR). The formula used is:

$$CR = \frac{CI}{RI} \quad (9)$$

If the consistency ratio is equal or less than 10 percent, it is considered consistent.

3. RESULTS AND DISCUSSION

The three to five geoelectric layers were delineated from the VES results across the study area. The layer resistivities varies respectively from 33 - 548 Ω-m, 13 - 6,110 Ω-m, 42 - 90,232 Ω-m, 60 - 89,806 Ω-m and 711 - 100,000 Ω-m in the topsoil, weathered layer, weathered basement, partially weathered or partially fractured basement and the presumed fresh basement (Table 3). Nine curve types were obtained from the study area, namely; A, H, K, HA, HK, AKH, HKA, HKH and KQH. The H, KH and A are the predominant curve types in the area (Tables 3a & 3b).

3.1 Elevation

The elevation map (See Fig. 2) shows that the surface elevation across the area varies from

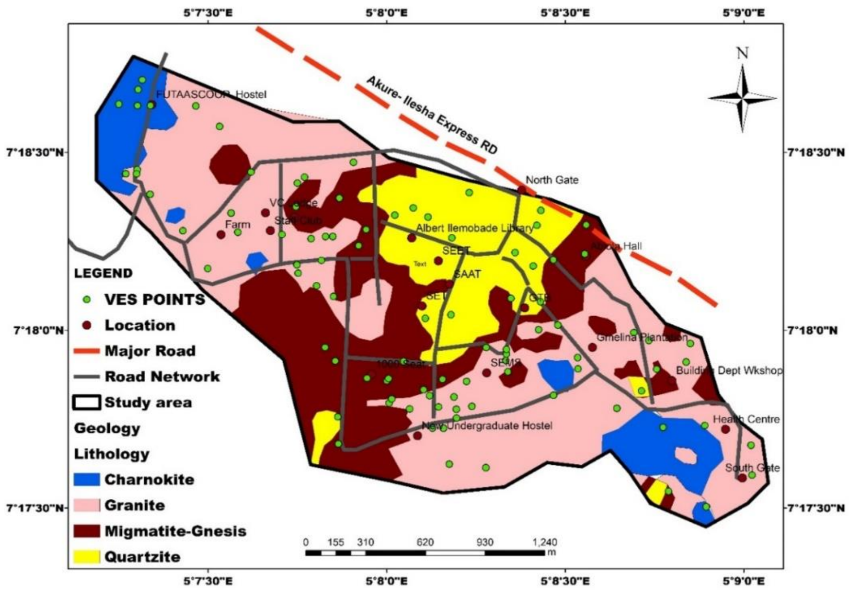

Fig. 3. Simplified geologic map of the study area [11]

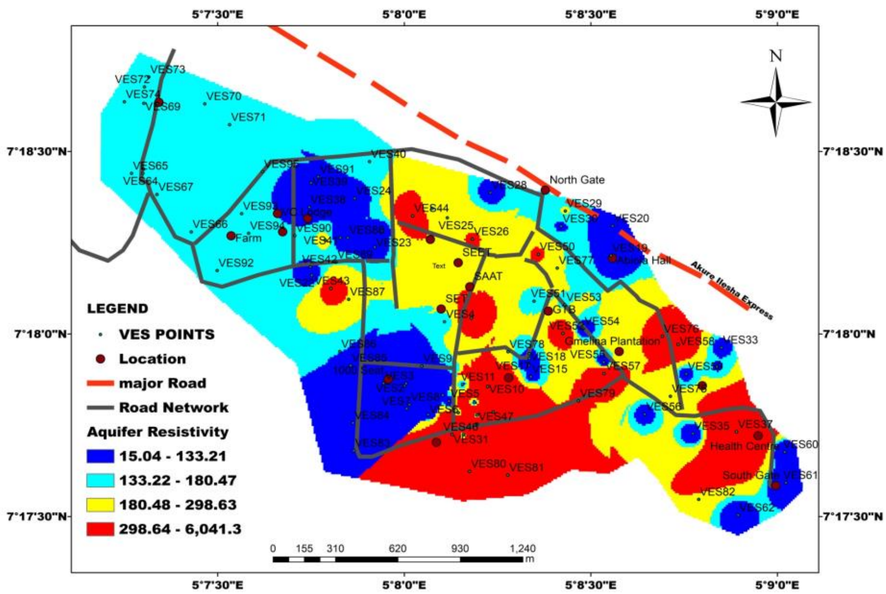

Fig. 4. Aquifer resistivity map of the area

351.06 - 410.98 m. The area can thus be described as moderately to highly undulating. The surface elevation of an area can influence both the amount of run-off and infiltration. At higher elevation there will be more of run-off than infiltration, while at lower elevation there will be more infiltration than run-off [16]. Elevation map is therefore very relevant to groundwater potentiality evaluation. The study area was grouped into four different groundwater potential zones based on variation in elevation; 351.06 - 375.85 m (very high groundwater potential), 373.86 - 382.55 m (high groundwater potential), 382.56 - 391.01 m (moderate groundwater potential) and 391.02 - 410.98 m (low groundwater potential). The northcentral and central parts of the study area correspond to low and moderate groundwater potentials, while the western and eastern flanks suggest high and very high groundwater potentials.

3.2 Lithology

The four rock types identified in the study area are; Charnockites, Older granites, Migmatites-Gneiss and Quartzites (Fig. 3). These rock units have varying hydrogeologic importance [17]. The quartzites and the migmatite-gneiss normally perform better as aquifer largely due to their high degree of weathering and fracturing which are reflection of their age and the number of tectonic events they have experienced and they are follow by the Older granite [5,17-20]. The least in terms of groundwater potential is the charnockite which is the youngest and usually found in its fresh form.

3.3 Aquifer Resistivity

The aquifer resistivity map (Fig. 4) shows the variation of resistivity within the aquifer units in the study area. The area was categorized into four zones based on the developed class interval in the aquifer resistivity (AR) map, 15.04 - 133.21 Ω-m (very high) 133.2-180.47 Ω-m (high), 180.48 - 298.63 Ω-m (moderate) and 298.64 - 6041.3 Ω-m (low) respectively. Low AR correlates with relatively high groundwater potential with the exception of some low permeable rocks, such as clay, which may present low resistivity but poor groundwater potential [17, 21]. The AR map (Fig. 4) indicates that most parts of the western and the southwestern parts of the area are of high to very high groundwater potential, while the eastern and the southeastern parts of the area are of low to moderate groundwater potential.

3.4 Aquifer Thickness

The thickness of the aquifer unit across the study area were presented as aquifer thickness map (Fig. 5). The thickness of an aquifer layer has significant impact on groundwater potentiality. The thicker the aquifer layer the more its capacity to store water and consequently the more its groundwater potential [2,7]. The map categorized the study area into four groundwater potential zones based on the aquifer layer thickness; 2.4 - 10 m (low), 11 - 16 m (moderate), 17 - 18 m (high) and 19 - 69 m (very high). Based on this classification the southern, north central and south eastern parts of the study area were of low to moderate groundwater potential. The whole of western, northwestern and extreme eastern parts were of high to very high groundwater potential.

3.5 Longitudinal Conductance

The derived longitudinal conductance (LC) values across the area varies from 0 to 0.63 mhos (Fig. 6). The study area is zone into four groundwater potential zone based on class distribution of longitudinal conductance values. the blue-coloured zones indicate zones of very low LC values. 0 - 0.08 mhos (very high potential), 0.09 - 0.11 mhos (high potential), 0.12 - 0.13 mhos (moderate potential) and 0.14 - 0.63 mhos (low potential). This classification is based on the fact that higher LC values indicates high clay content in the weathered materials. High clay content on the other hand reduces aquifer yield due to clay strong water adhesion. The western, northeastern and eastern parts of the area are classified as high to very groundwater potential zones, while the southern part of the area is majorly of low groundwater potential.

3.6 Transverse Resistance

The transverse resistance (TR) values across the area varies from 152.53 - 48830.78 Ω-m (Fig. 7). The area was classified into four groundwater potential zone based on class distribution of TR values. The 152.53 - 2825.06 Ω-m (very high potential), 2825.07 - 3397.75 Ω-m (high potential), 3397.76 - 5306.7 Ω-m (moderate potential) and 5306.71- 48830.78 Ω-m (low potential potential). This classification is based on the fact that higher TR values indicates low porosity, low permeability and low water content along the vertical direction [15]. Therefore, only parts of the study with low TR values will be considered as zones of high to very groundwater potential zones. The northwestern, northeastern and southwestern parts of the area all falls within the high to very high groundwater potential zones.

3.7 Longitudinal Resistivity

The longitudinal resistivity (LR) values across the study area varies from 15.364 - 2950.739 Ω-m (Fig. 8). The area was classified into four groundwater potential zone based on class distribution of LR values. Areas with LR values of 15.364 - 141.988 Ω-m were classified as very high potential, 141.989 - 303.146 Ω-m as high potential, 303.147 - 970.8 Ω-m as moderate potential and 970.901- 2950.739 Ω-m as low potential. This classification is hinged on the fact that higher LR values suggests low porosity, low permeability and low water content along the horizontal direction [15]. Most parts of the area fall within high to very high groundwater potential. The only exception is the southern part of the area which is characterized by moderate groundwater potential.

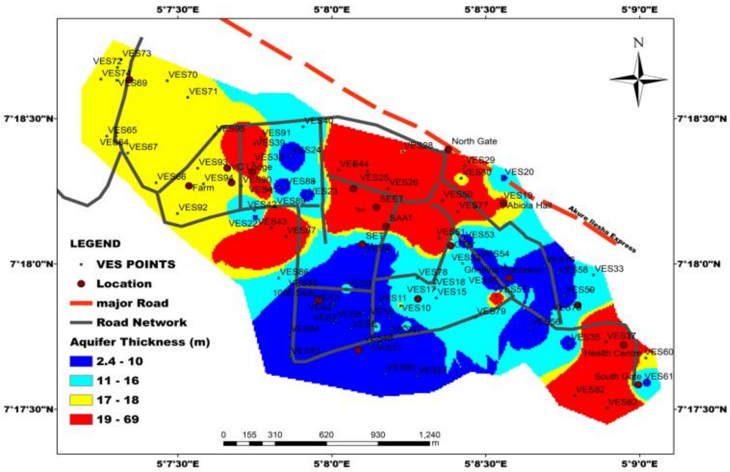

Fig. 5. Aquifer thickness map of the area

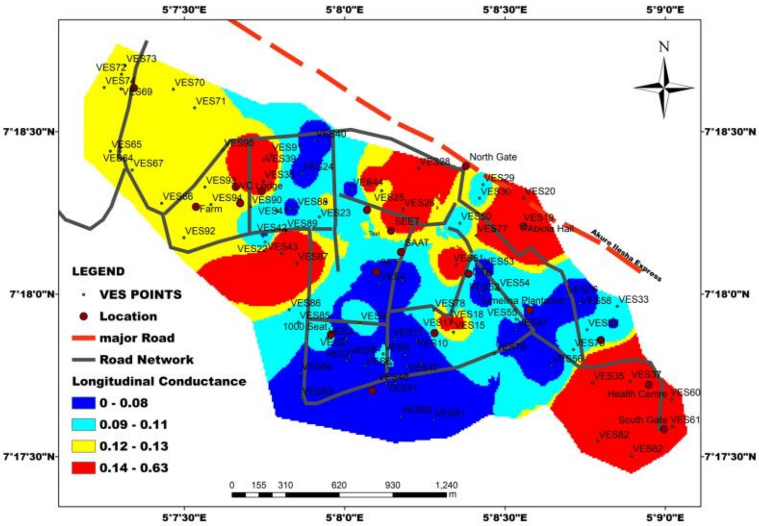

Fig. 6. Longitudinal conductance map of the area

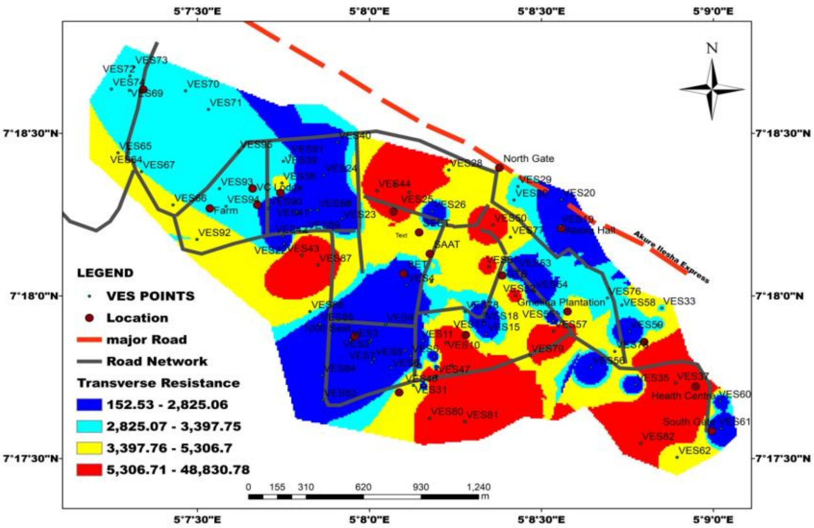

Fig. 7. Transverse resistance map of the area

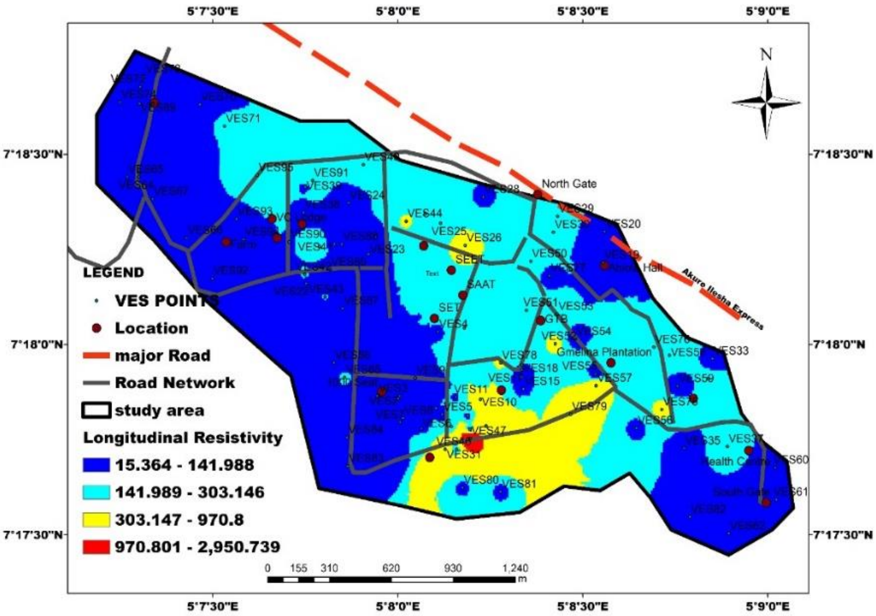

Fig. 8. Longitudinal resisitivity map of the area

3.8 Coefficient of Anisotropy

Coefficient of anisotropy (COA) is an indirect measure of the degree of fracturing, which is an important hydrological factor favorable for groundwater storage and movement [15]. The study area was classified into four zones (Fig. 9). The anisotropy coefficient values obtained range from 0.15 to 2.02. The southern flank is characterized by high COA values, which is attributed principally to the influence of the shallow bedrock and adjacent fluid-saturated reservoirs (Fig. 9). However, the northwestern flank exhibits a low COA, which extends eastward through the center, with pocket of low values at the southern parts. The area with high values of coefficient of anisotropy suggests that the fracture system must have extended in all the directions with different degrees of fracturing, which had greater water-holding capacity from different directions of the fracture(s) within the rock resulting in higher porosity. At the same time, unidirectional fracture may not produce good yield of water and such areas will show low values of COA. High values of COA indicate areas of high groundwater material with exceptions of lithologies; like clay which could be an aquiclude.

3.9 Groundwater Potential Index Map of the Study Area

The weighted values obtained for each conditioning factors were ranked and interpolated with kriging technique to produce the groundwater potential map for the area.

Using the natural classification method in GIS environment, the map was reclassified to classes of the proposed potential zones ranked in ascending order in the area. Weighted linear combination techniques were employed in combining the various thematic layer maps. The weighted linear combination, or simple additive weighting, is based on the concept of a weighted average in which continuous criteria are standardized to a common numeric range, and then combined by means of a weighted average. The decision maker assigns the weights of relative importance directly to each attribute map layer (Tables 4-7). The total score for each alternative is obtained by multiplying the importance weight assigned to each attribute by the scaled value given for that attribute to the alternative and then summing the products over all attributes [9, 21-24]

The GWPI is obtained as a sum of the product of each criterion and its weight as follows

$$GWPI = \sum_{i=1}^{n} Qipi \quad (5)$$

Where,

GWPI is groundwater potential index; *Qi* is the weight of factor *i*, and p*i* is the criterion score or rating of factor *i*.

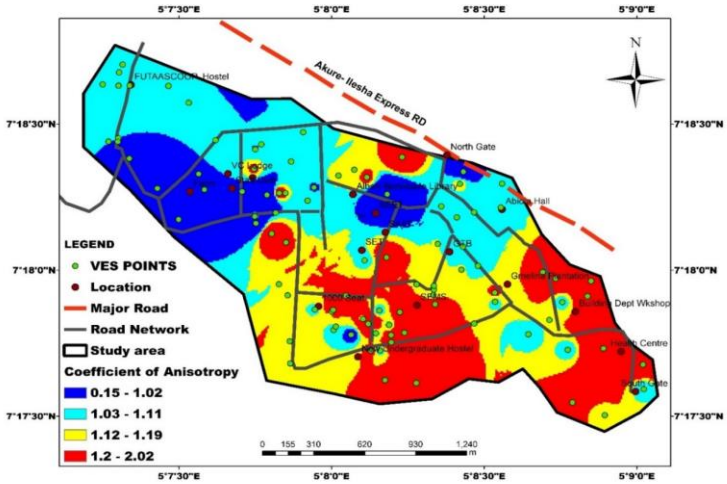

Fig. 9. Coefficient of anisotropy map of the area

Table 4. Pairwise comparism matrix of groundwater potential criteria

Criteria	Li	AR	AT	COA	TR	LC	LR	Elevation
Li	1	3	3	5	5	5	9	7
AR	0.333333	1	3	3	2	5	5	7
AT	0.333333	0.333333	1	2	2	3	5	7
COA	0.2	0.333333	0.5	1	2	3	5	7
TR	0.2	0.5	0.5	0.5	1	3	2	7
LC	0.2	0.2	0.333333	0.333333	0.333333	1	2	7
LR	0.111111	0.2	0.2	0.2	0.5	0.5	1	7
Elevation	0.142857	0.142857	0.142857	0.142857	0.142857	0.142857	0.2	1
	2.520635	5.709524	8.67619	12.17619	12.97619	20.64286	29.2	50

Table 5. Criteria weigthtage normalization

Li	AR	AT	COA	TR	LC	LR	Elev	Weight
0.40	0.53	0.35	0.41	0.39	0.24	0.31	0.14	0.34
0.13	0.18	0.35	0.25	0.15	0.24	0.17	0.14	0.20
0.13	0.06	0.12	0.16	0.15	0.15	0.17	0.14	0.14
0.08	0.06	0.06	0.08	0.15	0.15	0.17	0.14	0.11
0.08	0.09	0.06	0.04	0.08	0.15	0.07	0.14	0.09
0.08	0.04	0.04	0.03	0.03	0.05	0.07	0.14	0.06
0.04	0.04	0.02	0.02	0.04	0.02	0.03	0.14	0.04
0.06	0.03	0.02	0.01	0.01	0.01	0.01	0.02	0.02
1	1	1	1	1	1	1	1	1
Normalized								

Table 6. Criteria weigthtage

Criteria	Weight
Li	0.34
LR	0.20
LC	0.14
AT	0.11
AR	0.09
COA	0.06
Elev	0.04
TR	0.02

Table 7. Consistency Ratio (CR)

CR	0.094455

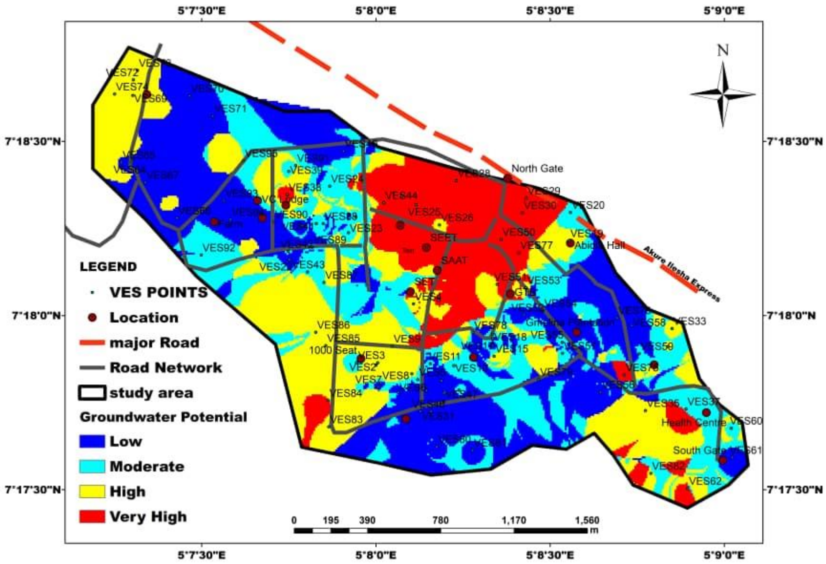

Fig. 10. Groundwater potential map of the area

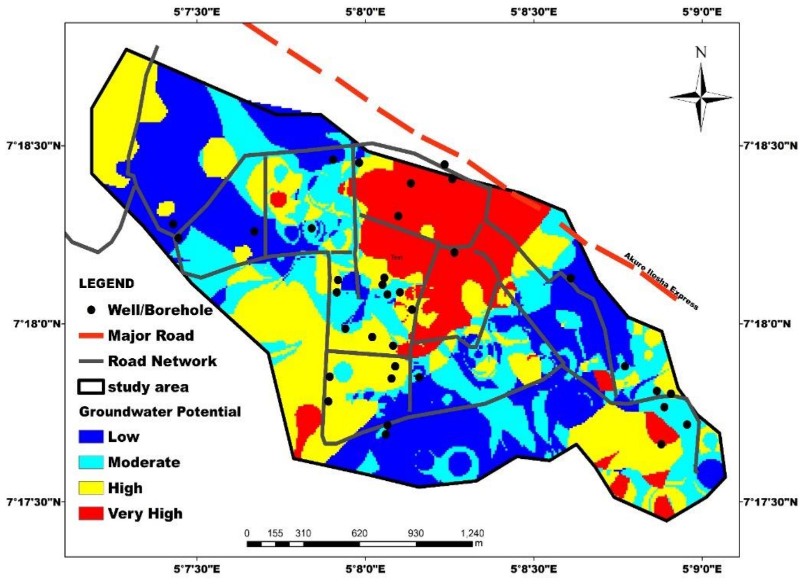

Fig. 11. Groundwater potential map of the area showing the producing boreholes and hand-dug wells locations

3.10 Synthesis of Results Using Analytical Hierarchy Process (AHP)

The weighted linear average (WLA) algorithm used is shown in equation 6 below,

$$GWPI = (Li_w Li_r + Elev_w Elev_r + AR_w AR_r + AT_w AT_r + LC_w LC_r + TR_w TR_r + LR_w LR_r + COA_w COA_r) \quad (6)$$

Where, Li is Lithology, AR is aquifer resistivity, AT is Aquifer thickness, LC is Longitudinal Conductance, Tr is Transverse Resistance, LR is Longitudinal Resistivity and COA is Coefficient of Anisotropy.

The developed GWPI model algorithm in equation 6 was applied to synthesize the GPFs maps using both the assigned rating (R) and

AHP normalize weight. The developed GWPI model was used to generate the groundwater potential map (GPM) of FUTA campus (Fig. 10). The GPM shows that the northcentral are of very high groundwater potential, while the extreme western and eastern parts, and the southwestern part are classified as high groundwater potential. The high and very high potential area constitute about 40% of the study area. The remaining parts are classified as moderate and low potentials and they constitute about 38% and 22% of the area respectively. This GPM was subjected to validation by posting the coordinates of all the producing boreholes and hand-dug wells within the campus on the GPM. Coordinates of 36 water sources consisting of 16 boreholes and 20 wells were taken across the area (Fig. 11). 5 falls within the low groundwater potential zones (13.89%), 11 falls within moderate potential (30.55%) and 20 falls within high and very high potentials (55.56%). As a matter of fact, all the prolific boreholes in the FUTA campus were within the very high potential zones, thus the groundwater potential model map was validated.

4. CONCLUSION

This hydrogeophysical study was carried out in order to proffer solutions to inadequate water supply plaguing the Obanla-Obakekere are of FUTA, Nigeria. The Schlumberger array was adopted for the study. The three to five geoelectric layers were delineated from the VES results across the study area. The layer resistivities varies from 33 - 548 Ω-m, 13 - 6110 Ω-m, 42 - 90,232 Ω-m, 60 - 89,806 Ω-m and 711 - 100,000 Ω-m in the topsoil, weathered layer, weathered basement, partially weathered basement/partially fractured basement and the presumed fresh basement respectively. Lithology and elevation data were combined with six geoelectrically derived parameters (aquifer resistivity, aquifer thickness, longitudinal conductance, transverse resistivity, longitudinal resistivity and coefficient of anisotropy) for groundwater potential evaluation of the study area. Each of these hydrogeological and hydrogeophysical maps were used to classify the area into different groundwater potential zones. The eight parameters (or maps) were integrated using the AHP technique.

The final GPM shows that the northcentral area, the extreme western and eastern flanks are classified as high to very high groundwater potential. These areas constitute about 40% of the study area, while the remaining parts classified as moderate and low potential constitute about 38% and 22% respectively. 13.89% of the producing wells/boreholes falls within the low groundwater potential zones, 30.55% falls within moderate potential (30.55%) and 55.56% falls within high and very high potentials. This good agreement validated the generated GPM model of the study area. Therefore, future efforts on groundwater development in the study area should focus on the high and very high potential zones.

ACKNOWLEDGEMENT

The authours appreciate numerous students of applied geophysics department, FUTA who assisted in acquiring data for this works. We also appreciate the Department of Applied Geophysics, FUTA for making the Omega Resistivity Meter and its accessories available for our use.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/106432