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

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 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 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 segment, 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 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]. 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 integrates lithological and elevation data with geoelectrically derived parameters (primary and secondary) using AHP method [8, 9] in evaluating the groundwater potential of Obanla-Obakekere area, in FUTA campus. 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 the Federal University of Technology, Akure (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 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 identified in the study area; Migmatite-Gneiss, Quartzites, Older Granite and Charnockites (Fig. 3) [11].

2. MATERIALS AND METHOD OF STUDY

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 good resolution and simplicity. A total of 95 vertical electrical sounding (VES) data was acquired across the area. The 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 = $\sum \frac{h_i}{\rho_i} = \frac{h_1}{\rho_1} + \frac{h_2}{\rho_2} + \frac{h_3}{\rho_3} + \cdots \frac{h_n}{\rho_n}$ [15] (1)

Where,
h_i is layer thickness
ρ_i is layer resistivity

2.2 Transverse Resistance (T);

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

Where,
h_i is layer thickness
ρ_i is layer resistiviy

2.3 Longitudinal Resistivity (ρ_L);

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

Where,
T is Total layer thickness
Sis Total longitudinal conductance

2.4 Coefficient of anisotropy;

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

3. DISCUSSION OF RESULTS

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 - 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 and the presumed fresh basement (Table 1). 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 (Table 1).

3.1 Elevation

The elevation map (Fig. 2) shows that the surface elevation across the area varies from 351.06 - 410.98 m and thus the area can 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.

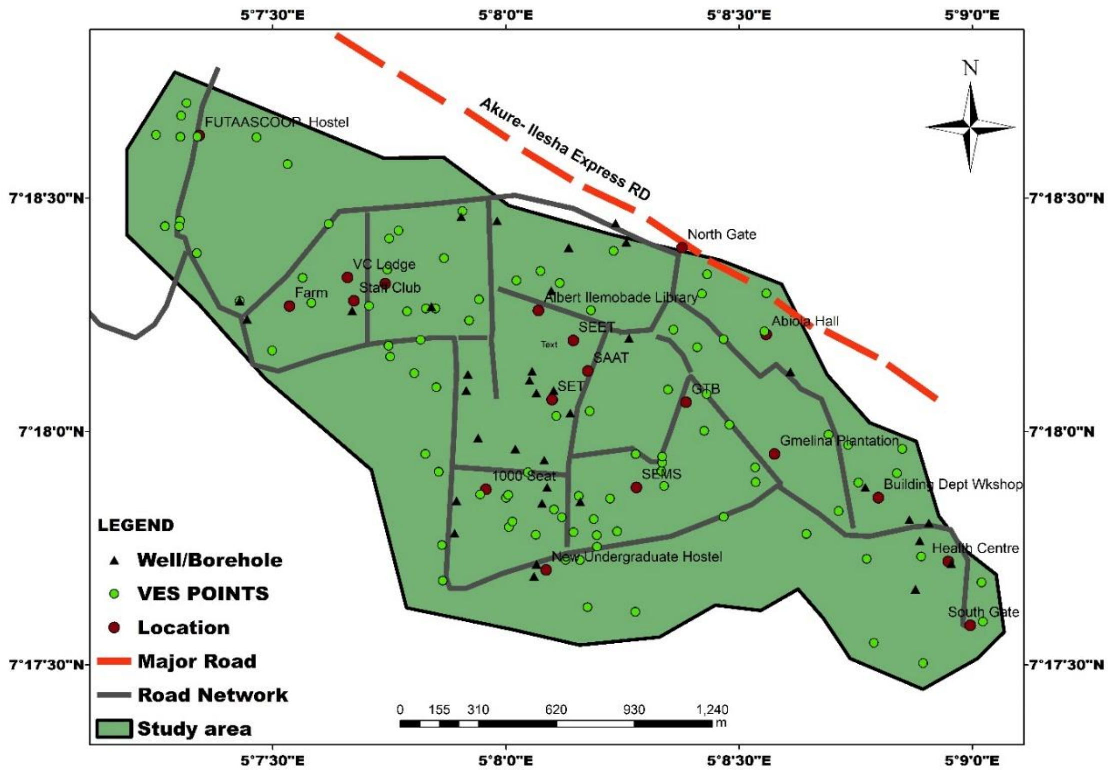

Fig. 1: Location map of the study area showing VES points

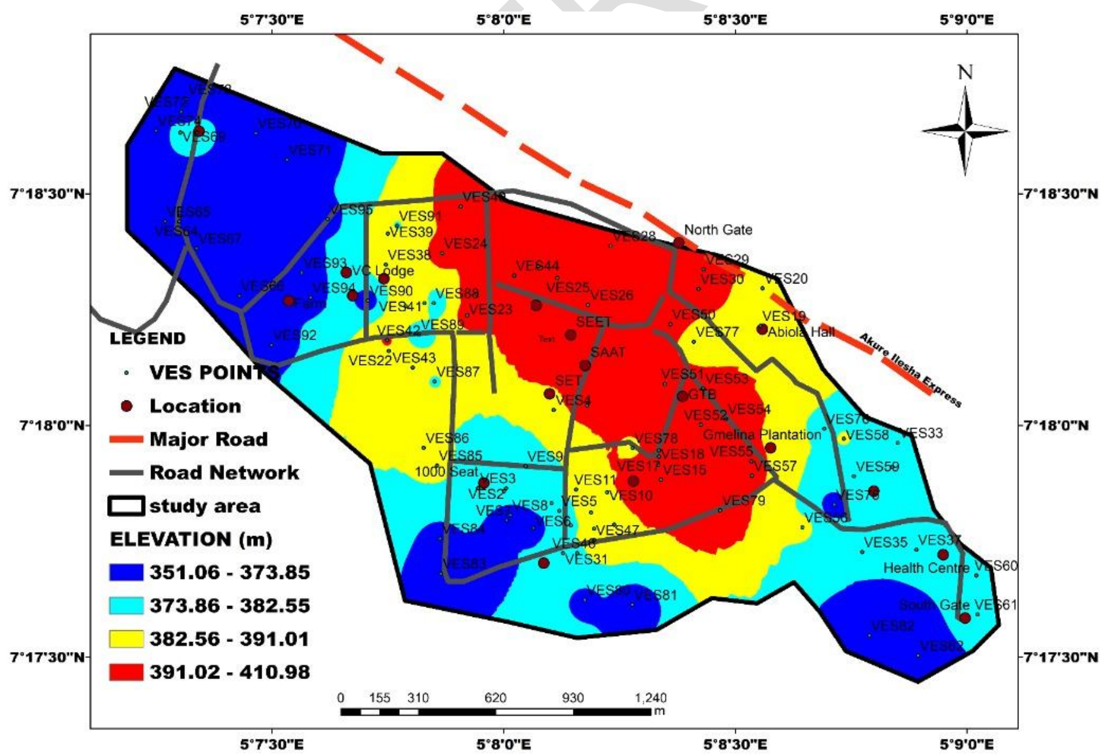

Fig.2: Elevation map of the study area

Table 1a: 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
21	735136	807943	135	41	1695	221	99656	0.7	1.2	9	14	HKH
22	735070	807764	156	78	315	60	711	0.9	1.2	2.5	4.6	HKH
23	735381	807908	236	81	5448			0.8	7.7			H
24	735281	808154	137	76	2398			0.8	2.9			H
25	735738	808058	221	1967	186	3376		1.9	4.8	20.5		H
26	735862	807951	205	151	1170	312	5992	1.6	1.9	23.8	41.6	HKH
27	735662	808105	168	1203	176	1303		1.9	8	25.4		KH
28	735950	808186	105	1809	95	714		1.8	2.8	13		KH
29	736320	808095	214	445	185	1481		2.3	6.3	14.3		KH
30	736300	808018	89	261	432	121	1771	2.2	1.8	3.5	8.3	AKH
31	735767	806964	105	936	457	16243		1.2	3.3	4.6		KH
32	735720	807163	151	297	100	3208		1.4	2.6	5.5		KH
33	737094	807409	134	866	89	3511		1.6	2.7	8.8		KH
34	737073	807313	272	101	715	121	4687	0.5	0.9	2.8	6.8	HKH
35	736955	806974	121	44	1520			0.5	7.7			H
36	735420	807992	122	84	2669			0.7	10.4			H
37	737170	806984	68	25	303	1792	100000	1.4	2.4	30.9	22	HKA
38	735057	808108	421	225	359	83	1278	0.6	2.7	5.7	10.5	HKH
39	735064	808231	230	128	1723			1.9	20.4			H
40	735353	808340	225	254	159	3539		0.6	7	4.1		KH
41	735211	807955	412	60	679			1	3			H
42	735064	807807	247	387	133	395		0.6	2	8.1		KH
43	735166	807699	82	12.8	450	89806		1.1	3	46.9		HA
44	735567	808067	308	206	670	174		1.7	7.4	9.8		HK
45	735797	807074	89	173	1961			1.3	12			A
46	735823	806964	212	124	3041			1.2	5.2			H
47	735890	807017	567	6110	1686			0.6	5			K
48	735859	807552	41	484	1086			1	7.2			A
49	736386	807839	55	166	1633			1.8	20.6			A
50	736188	807876	94	323	1336			1.1	25.7			A
51	736168	807639	169	406	137	2175		2	7	21.5		KH

52	736311	807477	148	553	2836			1.8	11.3			A
53	736320	807622	120	174	2430			1.8	5.3			A
54	736411	807501	130	60	4843			1.3	5.4			H
55	736513	807333	98	21	30298			0.6	1.7			H
56	736717	807071	142	93	90232			1.4	3.9			H
57	736515	807275	395	216	656	3014		0.5	2.7	20.3		HA
58	736880	807424	75	654	6039			1.6	4.7			A
59	736921	807275	52	92	419			2.3	5.7			A
60	737409	806883	47	330	42	2797		1.5	4.3	11.5		KH
61	737415	806728	33	15	223			0.4	9.2			H
62	737180	806563	100	276	69	5626		2.7	7.4	25.5		H
63	734238	808297	66	38	1656			1	6			H
64	734235	808275	102	33	946			0.7	7.7			H
65	734179	808275	105	27	592			1	7			H
66	734475	807981	218	66	838			5.1	15			H
67	734305	808169	90	42	1226			1	4.5			H
68	734305	808630	229	103	361			3.5	15.7			H
69	734238	808629	137	66	29			1.3	7.6			H
70	734539	808628	227	66	780			5.2	12			H
71	734662	808523	168	158	1328			1.3	6			H
72	734241	808712	79	62	416			2.7	12.4			H
73	734262	808762	211	101	378			2.5	12.4			H
74	734142	808636	50	90	976			5.2	13.2			A
75	736843	807162	120	3062	908	321	5130	1.3	3.3	3.9	15.4	KQH
76	736802	807464	95	187	3120			1	7.3			A
77	736282	807807	89	102	1325			1.2	7.9			A
78	736041	807383	221	428	7300			2.3	7.3			A
79	736390	807137	85	1203	4999			1.2	16.4			A
80	735854	806778	112	68	3811			5.3	5.6			H
81	736043	806760	60	104	1012			1.4	4.8			A
82	736985	806642	44	76	42	684		1.1	1.9	15.6		KH
83	735282	806880	40	23	1451			0.8	7.6			H
84	735278	807020	111	67	176			2.8	6.2			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 1b: 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
21	735136	807943	5.771084	14	0.103112	143.7	241.4859	0.154591
22	735070	807764	25.43478	4.6	0.105757	234	86.99186	0.540723
23	735381	807908	95.58824	7.7	0.098452	812.5	86.33688	1.052214
24	735281	808154	89.18919	2.9	0.043997	330	84.09605	1.029837
25	735738	808058	362.5551	20.5	0.121253	9861.5	224.3251	1.2713
26	735862	807951	8.924528	41.6	0.174063	614.9	395.834	0.150154
27	735662	808105	281.6771	25.4	0.162278	9943.2	217.5283	1.137936
28	735950	808186	298.5341	13	0.155533	5254.2	113.1594	1.624245
29	736320	808095	143.917	14.3	0.102202	3295.7	224.0655	0.801436
30	736300	808018	201.3861	8.3	0.108313	3181.9	145.8741	1.174967
31	735767	806964	584.2857	4.6	0.02502	5317	363.7111	1.26746
32	735720	807163	161.4316	5.5	0.073026	1533.6	130.0911	1.113962
33	737094	807409	254.6412	8.8	0.113934	3335.8	114.9784	1.488183
34	737073	807313	277.4273	6.8	0.070864	3051.7	155.2279	1.336872
35	736955	806974	48.69512	7.7	0.179132	399.3	45.77624	1.031389
36	735420	807992	86.3964	10.4	0.129547	959	85.68304	1.004154
37	737170	806984	863.1728	22	0.230845	48941.9	245.6191	1.87464
38	735057	808108	193.7385	10.5	0.155809	3777.9	125.1535	1.244189
39	735064	808231	136.6906	20.4	0.167636	3048.2	133.0264	1.013679
40	735353	808340	219.2222	4.1	0.056012	2564.9	208.8842	1.024447
41	735211	807955	148	3	0.052427	592	76.2963	1.392769
42	735064	807807	186.8692	8.1	0.068499	1999.5	156.2058	1.093755
43	735166	807699	416.3451	46.9	0.352012	21233.6	144.8815	1.695197
44	735567	808067	455.7672	9.8	0.056069	8614	337.0866	1.162789

45	735797	807074	164.7895	12	0.083971	2191.7	158.3882	1.020007
46	735823	806964	140.5	5.2	0.047596	899.2	134.4655	1.022193
47	735890	807017	5516.107	5	0.001877	30890.2	2984.229	1.359566
48	735859	807552	429.9756	7.2	0.039266	3525.8	208.8306	1.434911
49	736386	807839	157.0804	20.6	0.156824	3518.6	142.8356	1.048679
50	736188	807876	313.6007	25.7	0.091269	8404.5	293.6385	1.033432
51	736168	807639	200.8361	21.5	0.18601	6125.5	163.9697	1.106723
52	736311	807477	497.3511	11.3	0.032596	6515.3	401.8878	1.112446
53	736320	807622	160.3099	5.3	0.04546	1138.2	156.182	1.013129
54	736411	807501	73.58209	5.4	0.1	493	67	1.04797
55	736513	807333	41.08696	1.7	0.087075	94.5	26.41406	1.247195
56	736717	807071	105.9434	3.9	0.051795	561.5	102.3272	1.017516
57	736515	807275	599.8936	20.3	0.044711	14097.5	525.5984	1.068342
58	736880	807424	506.9524	4.7	0.02852	3193.8	220.8986	1.514911
59	736921	807275	80.5	5.7	0.106187	644	75.33858	1.033687
60	737409	806883	114.0173	11.5	0.318755	1972.5	54.27371	1.449408
61	737415	806728	15.75	9.2	0.625455	151.2	15.34884	1.012984
62	737180	806563	114.3792	25.5	0.423377	4071.9	84.08585	1.166305
63	808297	734238	42	6	0.173046	294	40.45161	1.018959
64	808275	734235	38.75	7.7	0.240196	325.5	34.97143	1.052638
65	808275	734179	36.75	7	0.268783	294	29.76378	1.111181
66	807981	734475	104.5672	15	0.250667	2101.8	80.18599	1.141953
67	808169	734305	50.72727	4.5	0.118254	279	46.51007	1.044353
68	808630	734305	125.9688	15.7	0.167711	2418.6	114.4826	1.048966
69	808629	734238	76.37079	7.6	0.124641	679.7	71.40532	1.034185
70	808628	734539	114.6744	12	0.204726	1972.4	84.01487	1.168302
71	808523	734662	159.7808	6	0.045713	1166.4	159.6928	1.000276
72	808712	734241	65.03974	12.4	0.234177	982.1	64.48108	1.004323
73	808762	734262	119.4564	12.4	0.134621	1779.9	110.6814	1.038885
74	808636	734142	78.69565	13.2	0.250667	1448	73.40426	1.035416
75	807162	736843	784.318	15.4	0.064181	18745.2	372.3827	1.451281
76	807464	736802	175.9157	7.3	0.049564	1460.1	167.4611	1.024933
77	807807	736282	100.2857	7.9	0.090934	912.6	100.0724	1.001065
78	807383	736041	378.4063	7.3	0.027463	3632.7	349.5572	1.040447
79	807137	736390	1126.773	16.4	0.02775	19831.2	634.2289	1.332893
80	806778	735854	89.3945	5.6	0.129674	974.4	84.0567	1.031262
81	806760	736043	94.06452	4.8	0.069487	583.2	89.22509	1.026761
82	806642	736985	45.5914	15.6	0.421429	848	44.13559	1.016359
83	806880	735282	24.61905	7.6	0.350435	206.8	23.97022	1.013444
84	807020	735278	80.68889	6.2	0.117763	726.2	76.42498	1.027517
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

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.

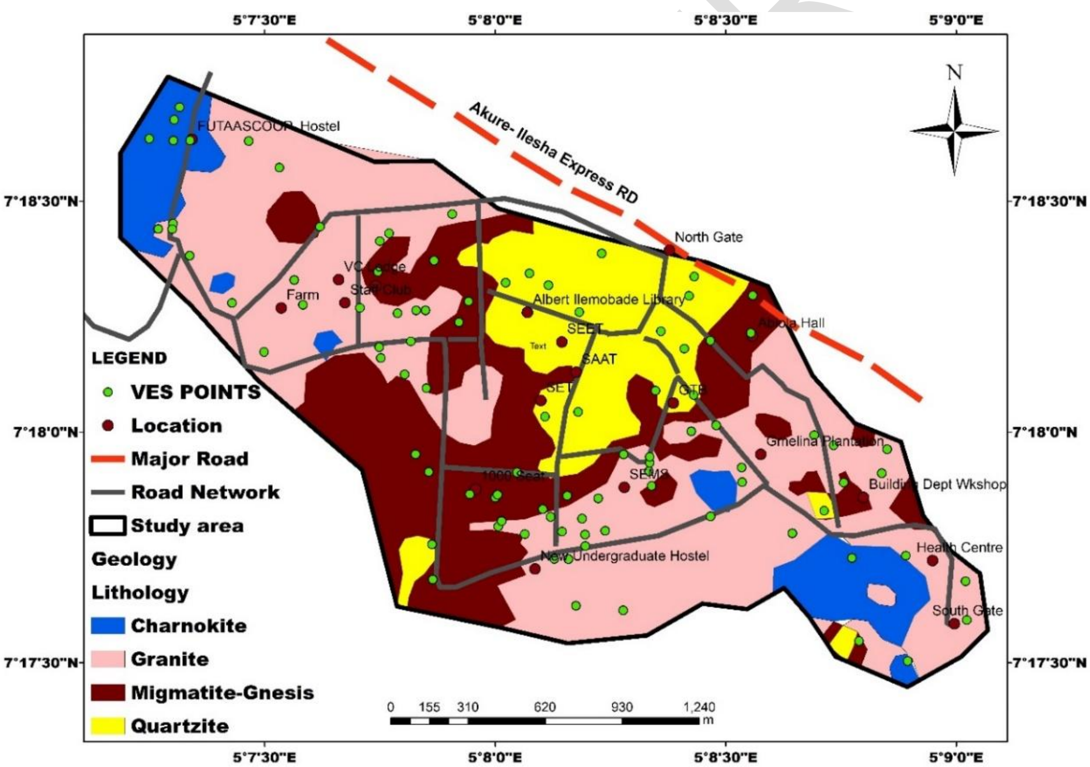

Fig. 3: Simplified geologic map of the study area [11]

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 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 aquifer resistivity correlates with relatively high groundwater potential with the exception of some low permeability rocks, such as clay, which may present low resistivity but poor groundwater potential [17, 21]. The aquifer resistivity map indicates that most parts of the northern, southern and southeastern parts of the area are of high to very high groundwater potential, while the southwestern part of the area are of low to moderate groundwater potential.

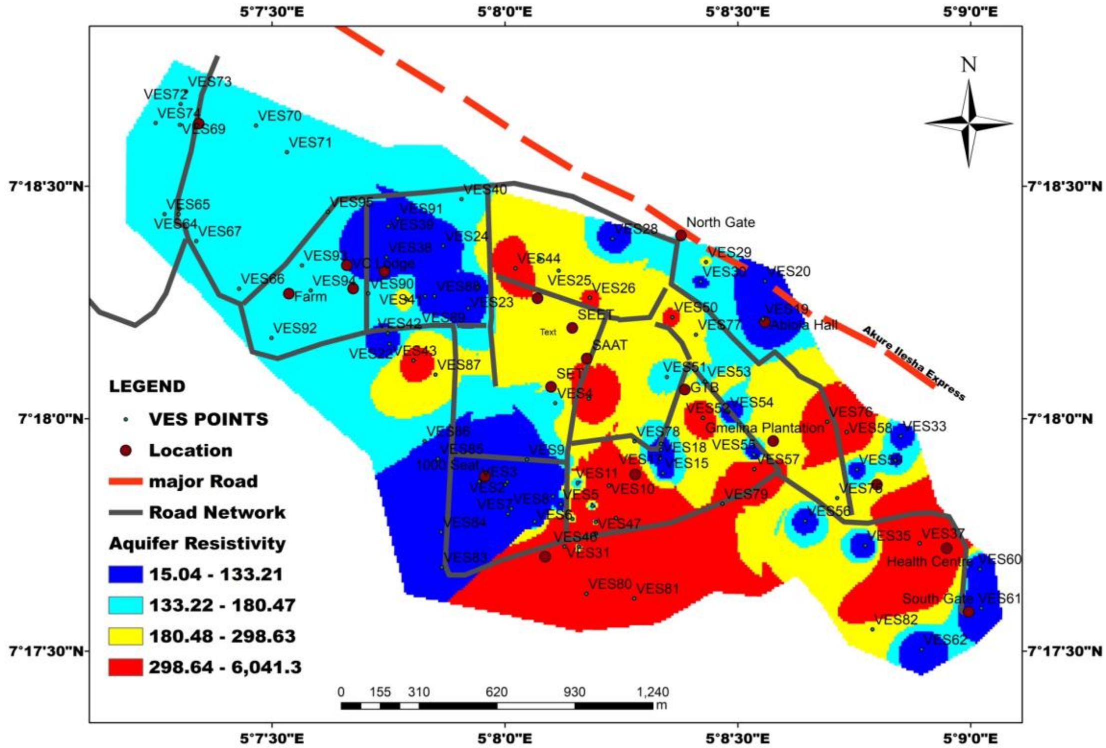

Fig. 4: Aquifer resistivity map of the area

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 north central, south eastern and some pockets of southwestern parts of the study area were of very groundwater potential. The whole of southern part of the area were either of low to moderate groundwater potential.

3.5 Longitudinal Conductance

The derived longitudinal conductance values across the area varies from 0 mhos to 0.63 mhos (Fig. 6). The 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 values of longitudinal conductance 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 northcentral, southwestern and southwestern 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.

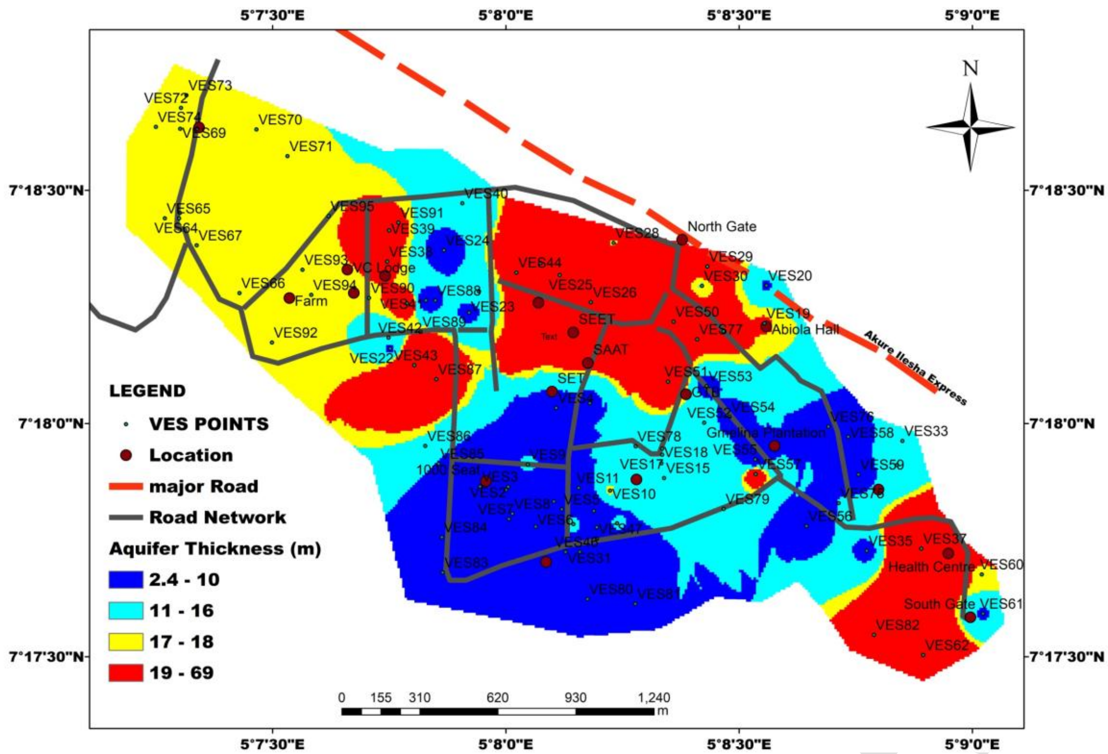

Fig. 5: Aquifer thickness map of the area

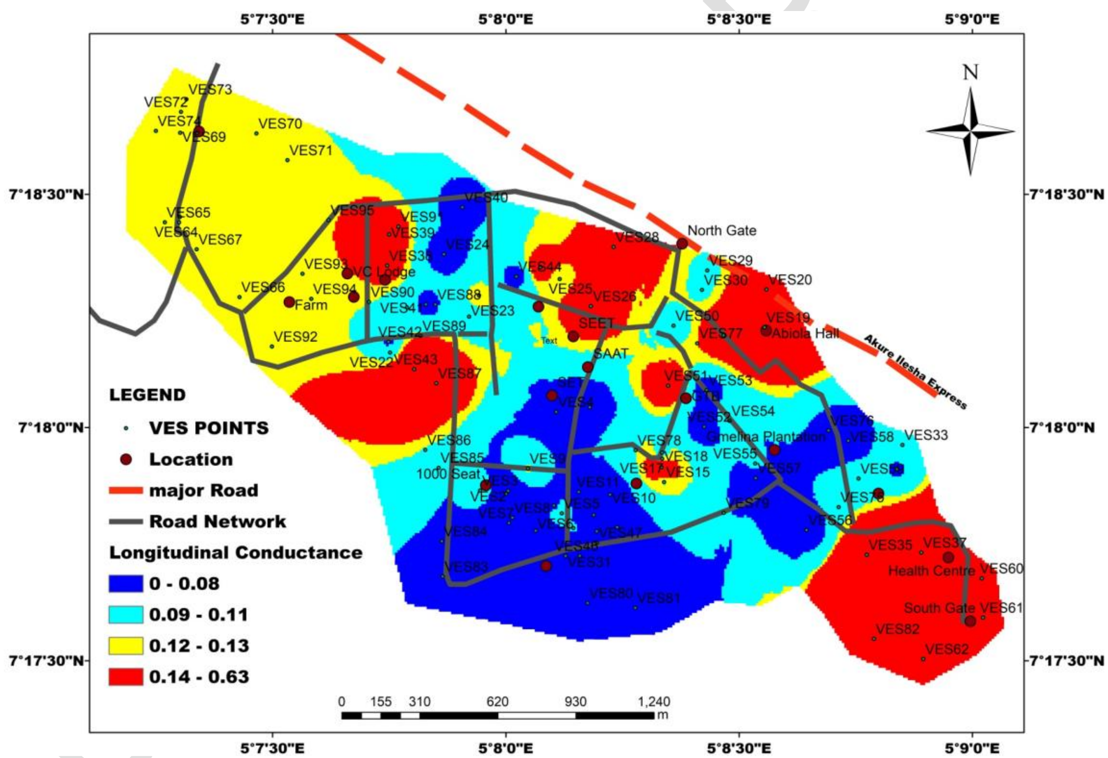

Fig. 6: Longitudinal conductance map of the area

3.6 Transverse Resistance

The transverse resistance 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 transverse resistance 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 transverse resistance values indicates low porosity, low permeability and low water content along the vertical direction [15]. Therefore, only parts of the study with low transverse resistance values will be considered as zones of high to very groundwater potential zones. The northwestern, northeastern and southern parts of the area all falls within the high to very high groundwater potential zones.

3.7 Longitudinal Resistivity

The longitudinal resistivity 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 longitudinal resistivity values. Areas with longitudinal resistivity 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 longitudinal resistivity 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.

3.8 Coefficient of Anisotropy

Coefficient of anisotropy 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 coefficient of anisotropy 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 anisotropy coefficient, 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 coefficient of anisotropy. High values of coefficient of anisotropy indicate areas of high groundwater material with exception of lithologies like clay which could be an aquiclude.

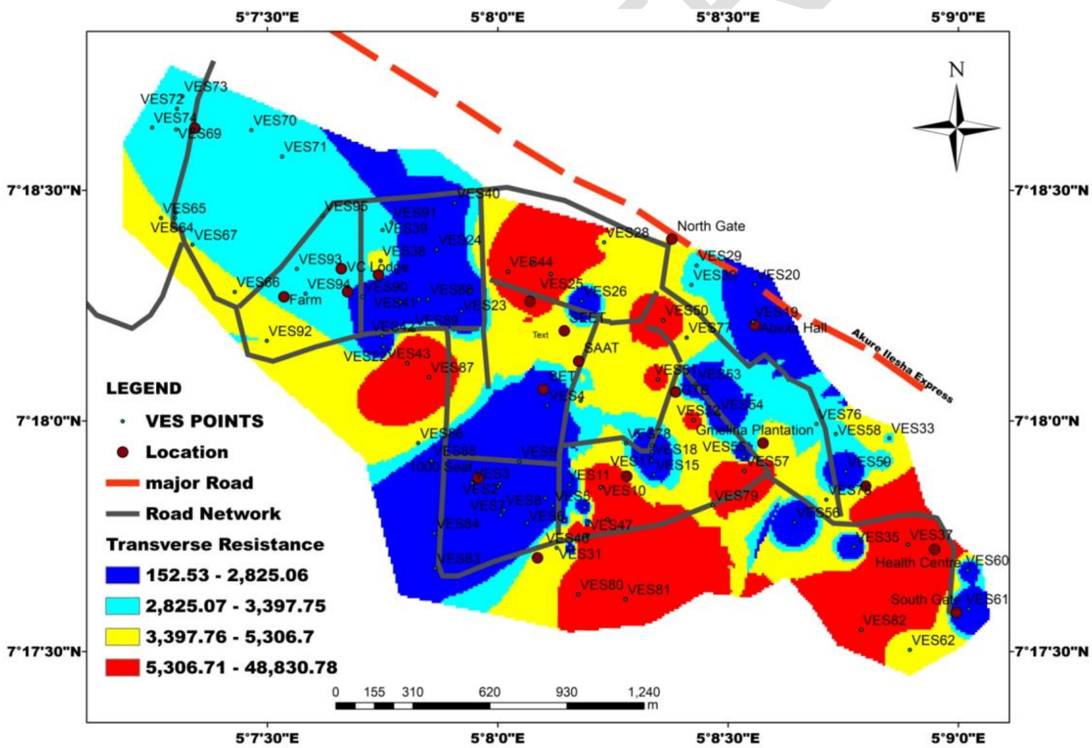

Fig. 7: Transverse resistance map of the area

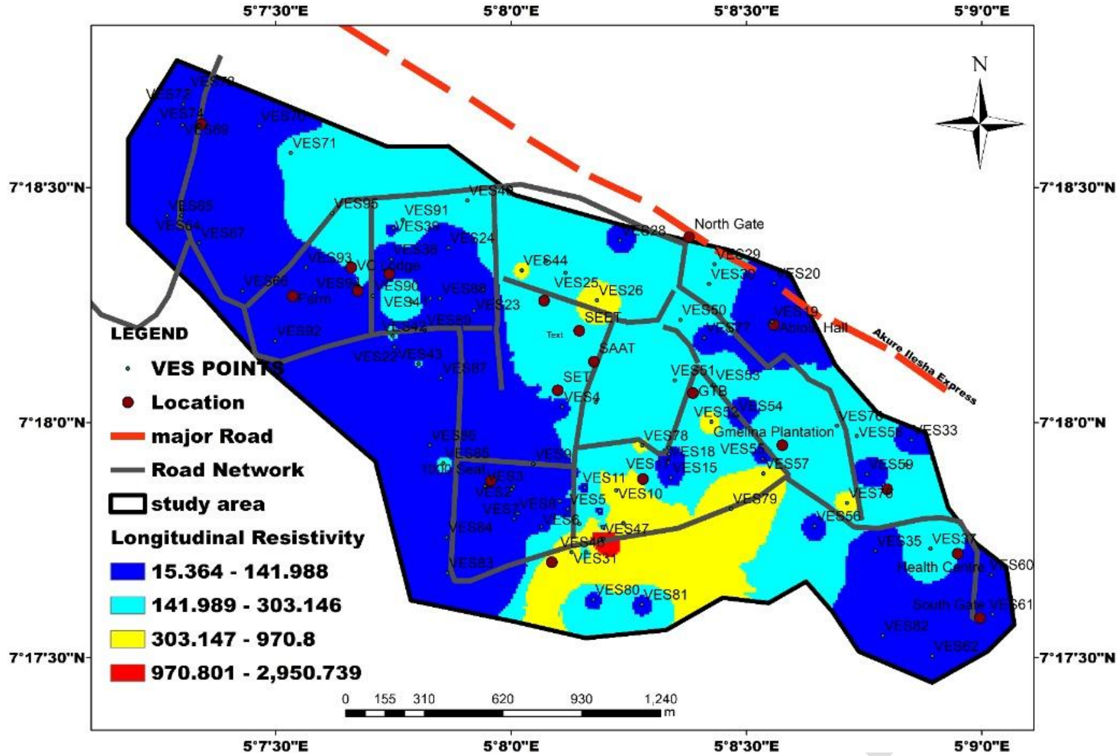

Fig. 8: Longitudinal resisitivity map of the area

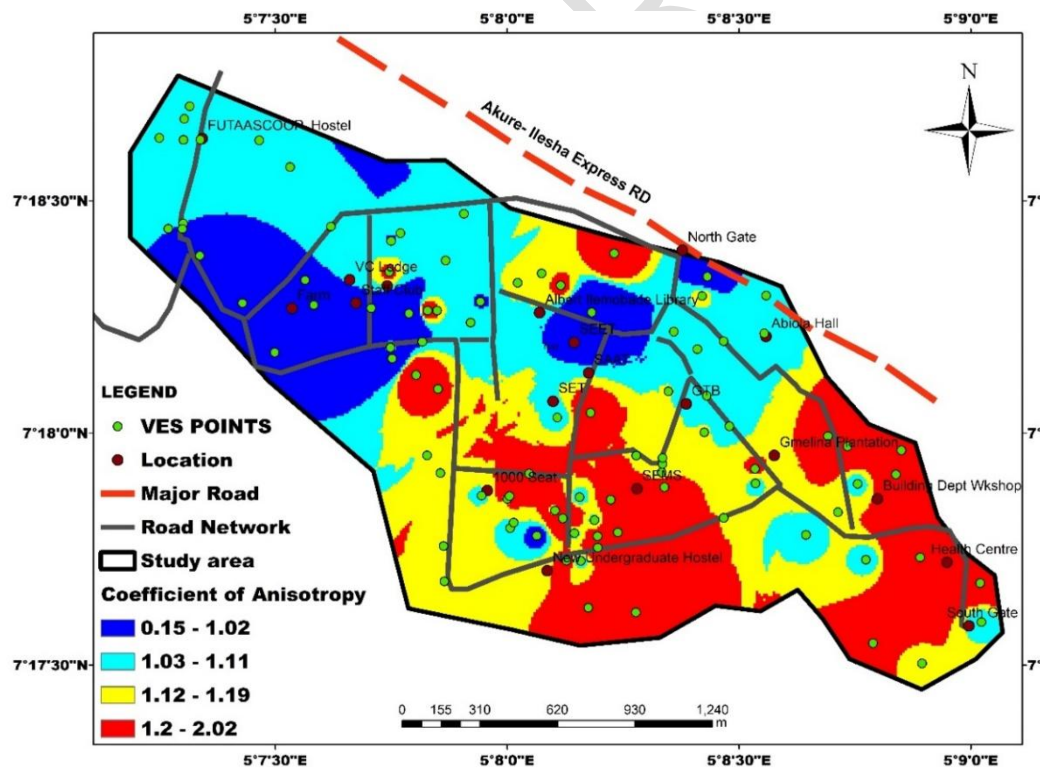

Fig. 9: Coefficient of anisotropy map of the area

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 2 - 5). 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*.

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.

Table 2: 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 3: 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 4: 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 5: Consistency Ratio (CR)

CR	0.094455

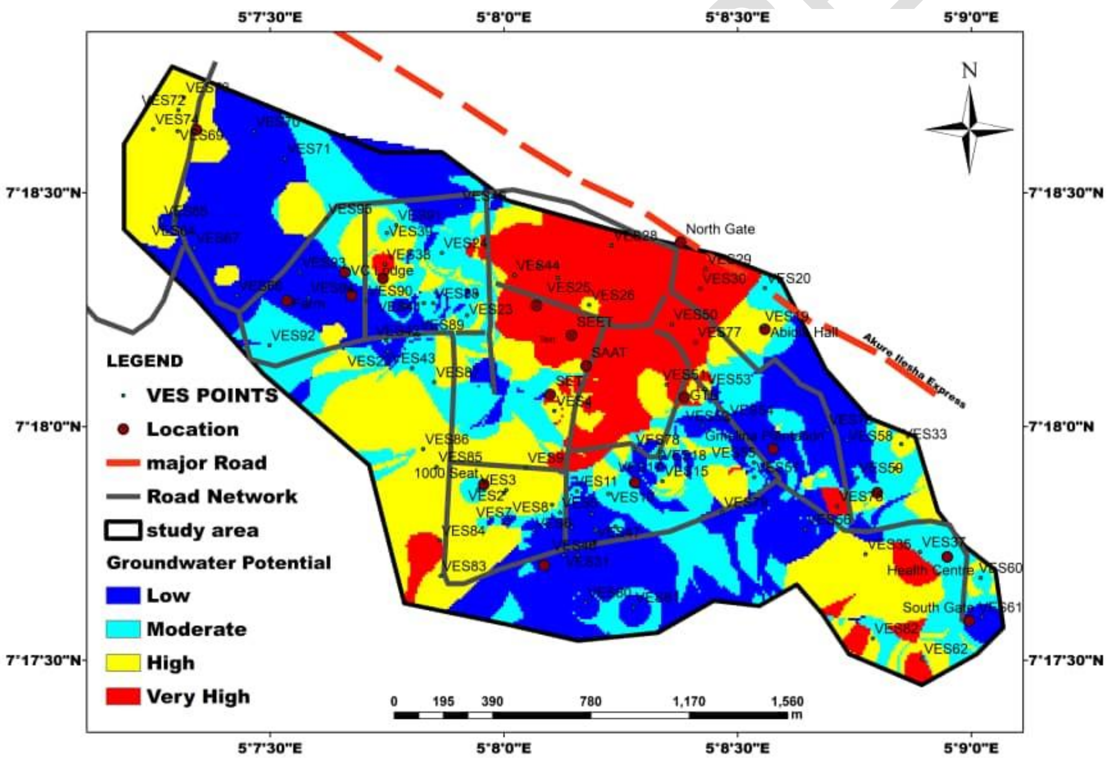

Fig. 10: Groundwater potential map of the area

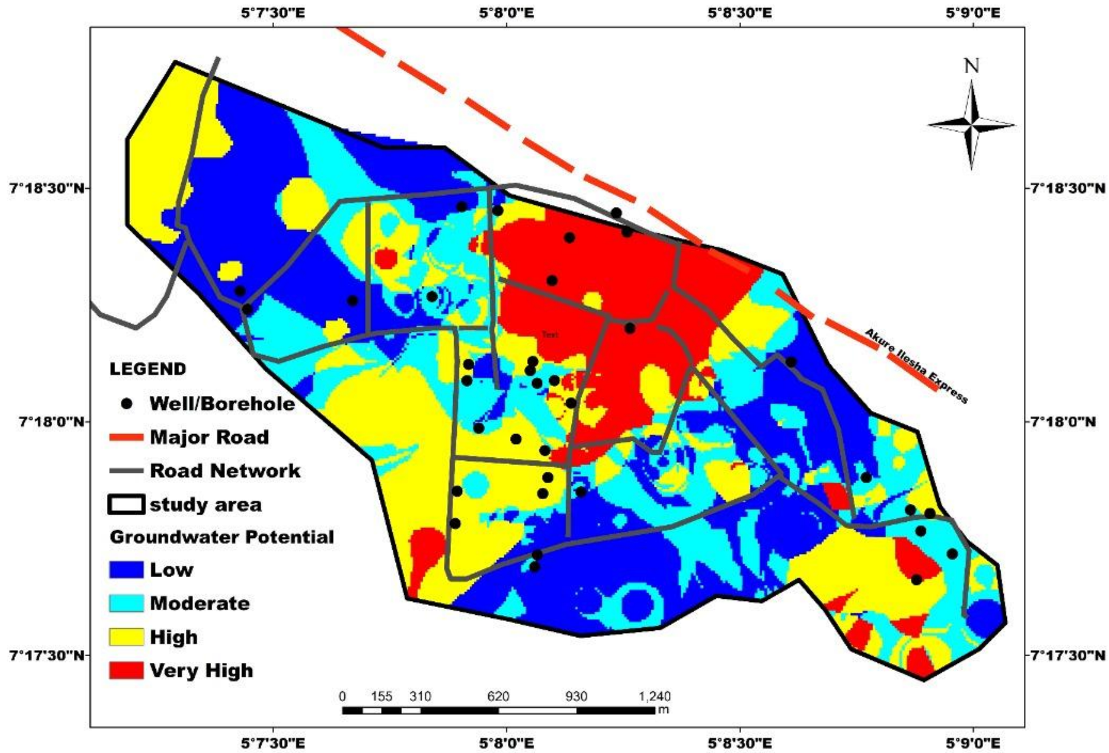

Fig. 11: Groundwater potential map of the area showing the producing boreholes and hand-dug wells locations

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 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 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. Future efforts on groundwater development in the study area should focus on the high and very high potential zones.

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