Mining Of Geophysical Data To Predict Groundwater Prospect In A Basement Complex Terrain Of Southwestern Nigeria

Adiat, K.A.N., Osifila, A.J., Akinlalu, A. A., Alagbe, O.A.

Abstract: This study applied the multi criteria decision analysis to geophysical data acquired to achieve an unbiased integration of geoelectric parameters obtained from the results of the interpretation of the geophysical data in the order of their hydrogeologic importance to consequently produce a groundwater prediction model. The geoelectric parameters which were the coefficient of anisotropy, aquifer resistivity, aquifer thickness, overburden thickness and overburden resistivity were the main subsurface factors controlling the flow and accumulation of groundwater resources in the study area. Each parameter was assigned appropriate weight based on Saaty's nine-point scale and the weights were normalized through the Analytic Hierarchy Process (AHP). The assigned weights were adjudged to be consistent and unbiased through the attainment of consistency ratio of less than 10%. The groundwater prediction model of the area was produced from the application of the Groundwater Potential Index (GWPI) model equation developed. The prediction model classified the groundwater potential of the study area into very low; very low – low; low – moderate; moderate - high and high - very high classes. The results obtained from this study established that the groundwater prediction model produced from the GWPI obtained from the application of multi criteria decision analysis to subsurface factors is accurate and reliable. It has also proven the ability of the methodology adopted as a good decision making tool in the presence of two or more conflicting criteria. This ability makes it a useful tool that can be adopted in the groundwater prediction domain.

Index Terms: electrical resistivity, schlumberger array, analytic hierarchy process, prediction model.

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1 INTRODUCTION

Groundwater is described as water that exists below the earth surface within saturated layers of sand, gravel and pore spaces in sedimentary as well as crystalline rocks [1]. [2] explains groundwater to mean the water occupying all the empty spaces within a geologic stratum. It is among the natural resources of prime importance to man throughout the world [3]. A unit of rock or an unconsolidated deposit is called an aquifer when it can yield a usable quantity of water. The depth at which soil pore spaces or fractures and voids in rock become completely saturated with water is called water table [4]. In the unfractured/unweathered state, the basement complex rocks are believed to be poor aquifers. This is because at this state, they have low porosity and permeability hence, the groundwater potential is low. But when these rocks are subjected to stress and several geological processes, they are deformed. These deformations are evident by the presence of geologic structures such as faults, fractures, veins and shears within the rocks. These structural features create inhomogeneities with hydrogeological significance within the rocks which in turn enhance groundwater accumulation and storage. In this state, basement complex rocks serve as large reservoirs of groundwater. However, the extreme variation in lithology and the high localization of geologic structures make geological, hydrogeological and hydrogeophysical exploration for groundwater difficult. The accurate delineation of these highly localized zones is very important to the success of any groundwater development programme carried out within the basement complex terrain. The occurrence of groundwater resources in an area is determined by various factors. Consequently, the geoelectric parameters that would be of hydrologic significance to evaluate the groundwater potential of a given area will be largely determined by the prevailing factors that influence the occurrence of the resources in the area. It has been established that prediction of groundwater resources potential of an area is a spatial decision problem which often involves a large set of factors and multiple evaluation criteria. Most of the time, these criteria are often evaluated by a number of experts [5], [6]. Consequently, integration of these factors to develop a prediction model of high validity and reliability is desirable for the proper management of the resources. This can only be achieved through the application of adequate data mining technique Data mining is an analytic process designed to explore data in search of consistent patterns and/or systematic relationships between variables and then to validate the findings by applying the detected patterns to new subsets of data. The ultimate goal of data mining is prediction. Data mining is often considered to be a blend of statistics, artificial intelligence (AI) and data base research [7]. Due to its applied importance, the field emerges as a rapidly growing and major area where theoretical advances are being made. Data mining is a very versatile analytic tool that has been applied in various fields of study. Multi Criteria Decision Analysis (MCDA) is a data mining technique that includes decision making in the presence of two or more conflicting objectives and/or decision analysis processes, involving two or more attributes [8], [9].

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The general objective of MCDA is to assist a decision maker or a group of decision makers to choose the best alternative from a range of alternatives in an environment of conflicting and competing criteria. MCDA methods differ, however, in the way the idea of multiple criteria is considered, the application and computation of weights, the mathematical algorithm utilised, the model to describe the system of preferences of the individual facing decision-making, the level of uncertainty embedded in the data set and the ability for stakeholders to participate in the process [10]. This study uses the MCDA framework in the context of the Analytical Hierarchy Process (AHP) to produce the groundwater prediction model in a typical basement terrain through an unbiased integration of geoelectric parameters/factors of hydrogeologic importance in the study area. In addition to the attainment of the above aim, the study is also carried out to achieve the following objectives:

i. delineate the subsurface geologic sequence characterizing the study area.
ii. determine the geoelectric parameters of the geologic sequence in the area.
iii. select hydrogeologic factors that are influencing the groundwater occurrence in the area.
iv. assign appropriate weights to each of the selected hydrogeologic factors.
v. examine the consistency of the assigned weights and
vi. produce the groundwater prediction model for the study area.

The uniqueness of the present study lies in the fact that parametric soundings were carried out; this will assist in ascertaining that the subsurface parameters utilised for the study will give in situ information on the subsurface conditions of the wells in the study area.

2 DESCRIPTION OF THE STUDY AREA

The study area is Ijebu-Jesa, the capital of the Oriade Local Government Area of Osun state, southwestern Nigeria. It falls between latitude $7^0$40’N and $7^0$43’N and longitude $4^0$48’E and $4^0$50’E (Figure 1). The topography of the area is gently undulating. The climate is well defined with wet and dry seasons with annual rainfall varying between 150 cm to 200 cm. The annual relative humidity is over 80% with temperature ranging from 24^0C to 27^0C. The vegetation of the area is of rain forest. The study area falls within the basement complex of the southwestern Nigeria. It forms part of the African crystalline shield which consists predominantly of migmatite and undifferentiated gneisses and quartzite [11]. The important structural features in the basement rocks include joints, faults, fractures, lineations and geological boundaries. These structural features are relevant in the control of groundwater accumulation and movement.

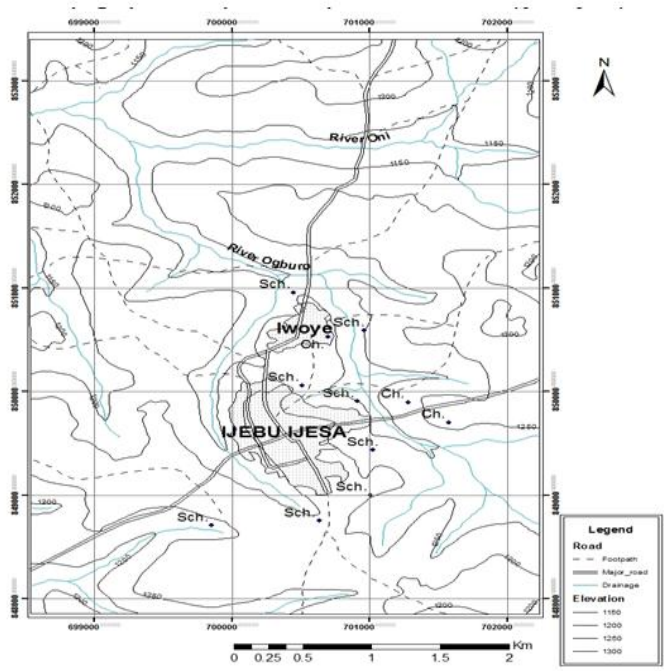

Figure 1: *Topographical Map Showing the Study Area [12].*

The major rock associations of this area form part of the Proterozoic Ilesha schist belt in southwestern part of Nigeria. This is predominantly developed in the western half of the country. In terms of structural features, lithology and mineralization, the schist belts of Nigeria show considerable similarities to the Achaean green stone belts [13]. However, the latter usually contain much larger proportions of mafic and ultramafic bodies and assemblages of lower metamorphic grade [14]. Rocks in the Ilesha schist belt are structurally divided into two main segments, as shown in Figure 2, by two major fracture zones often called the Iwaraja faults in the eastern part and the Ifewara faults in the western part [15], [16], [17]. The northern part of the fault comprises mostly of amphibolites, amphibole schist, meta-ultramafic, and meta-pelites. Extensive psammitic units with minor meta-pelite constitute the eastern segment [18]. These are found as quartzite and quartz schist. All these assemblages are associated with migmatitic gneisses and are cut by a variety of granitic bodies [18], [15], [13], [14]. The rocks of the Ilesha district may be broadly grouped into gneiss-migmatite complex, mafic-ultramafic suite (or amphibolites complex), meta-sedimentary assemblages and intrusive suite of granitic rocks. A variety of minor rock types are also related to these units. The gneiss-migmatite complex comprises migmatitic and granitic, calcereous and granulitic rocks. The mafic-ultramafic suite is composed mainly of amphibolites and amphibole schist and minor meta-ultramafites, made up of anthophillite-tremolite- chlorite and talc schist [18]. The meta-sedimentary assemblages, chiefly meta-pelites and psammitic units are found as quartzite and quartz schist. The intrusive suite consists essentially of Pan African (c.600 Ma.) granitic units. The minor rocks include garnet-quartz-chlorite bodies, biotite-garnet rock, syenitic bodies, and dolerites [13], [16], [18]. The Ijebu-Jesha segment of the Ilesha schist belt falls into the migmatite-gneiss group with metasedimentary assemblages chiefly found as quartz schist (Figure 3). The quartz schist was mainly exposed by erosion within the study area.

3 MATERIAL AND METHODS

The Vertical Electrical Sounding (VES) was adopted for the electrical resistivity survey using Schlumberger array. A total of forty six (46) parametric VES were carried out besides forty six accessible wells identified across the study area (Figure 4). The electrode spacing (AB/2) was varied between 1-100 m. The ABEM-SAS 300 terrameter was used to acquire the field data. The resistivity data were presented as field curves (by plotting the apparent resistivity (ρ_a) against AB/2 or half the spread length on a bi-logarithm paper). The data were interpreted qualitatively by visual inspection of the field curves and further interpreted quantitatively by partial curve matching [19] with the help of master curves [20] and auxiliary point charts [21], [22] to obtain initial estimates of resistivity and thickness of the various geoelectric layers at each VES location. These geoelectric parameters were used as starting models for a fast computer-assisted interpretation [24]. The program took the manually derived parameter as a starting geoelectric model, successively improved on it until the error is minimized to an acceptable level.

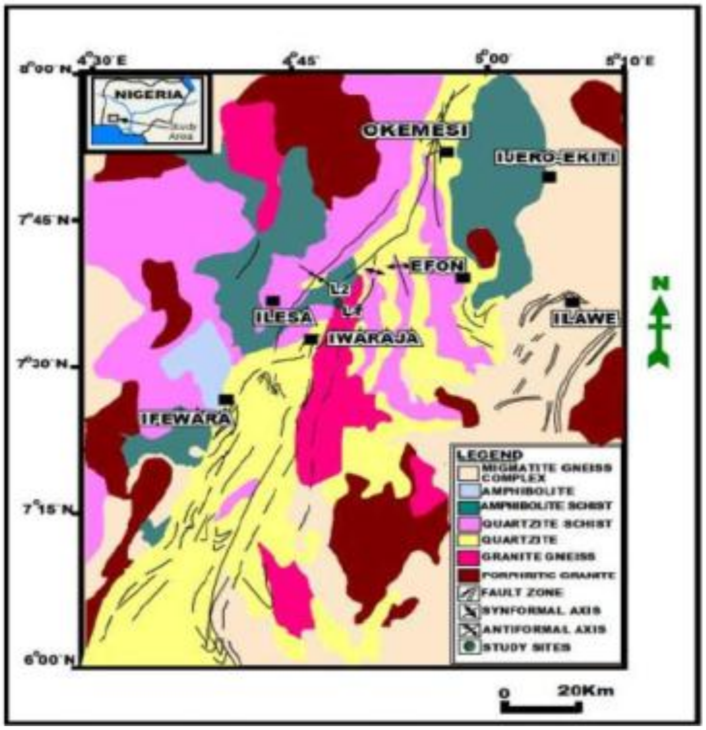

Figure 2: *Geological Map of Okemesi Fold Belt Showing Study Area [23].*

From the interpretation of the resistivity data, layers resistivity and thicknesses were derived. Also, wherever possible, likely aquifer zones were delineated in each of the resistivity sounding stations. From the first order geoelectric parameters (layers resistivity and thickness), a secondary geoelectric parameter, coefficient of anisotropy (λ), was obtained for all the VES stations.). Electrical anisotropy is a measure of the degree of the earth's inhomogeneity [25], [26]. The coefficient of anisotropy is the square root of the ratio of the resistivity measured perpendicular to the bedding to that parallel to the bedding [27]. In a typical basement complex terrain, this electrical effect is due to near surface features such as variable degree of weathering and structural features like faults, fractures, joints, foliations and beddings. These in turn are responsible for creating secondary porosity (Φ_s) and effective porosity (Φ_e) [28]. These are very important factors that influence groundwater occurrence and accumulation. The methodologies of the MCDA in the context of AHP were thereafter applied to the geoelectric parameters obtained from the results of the interpretation of the VES data.

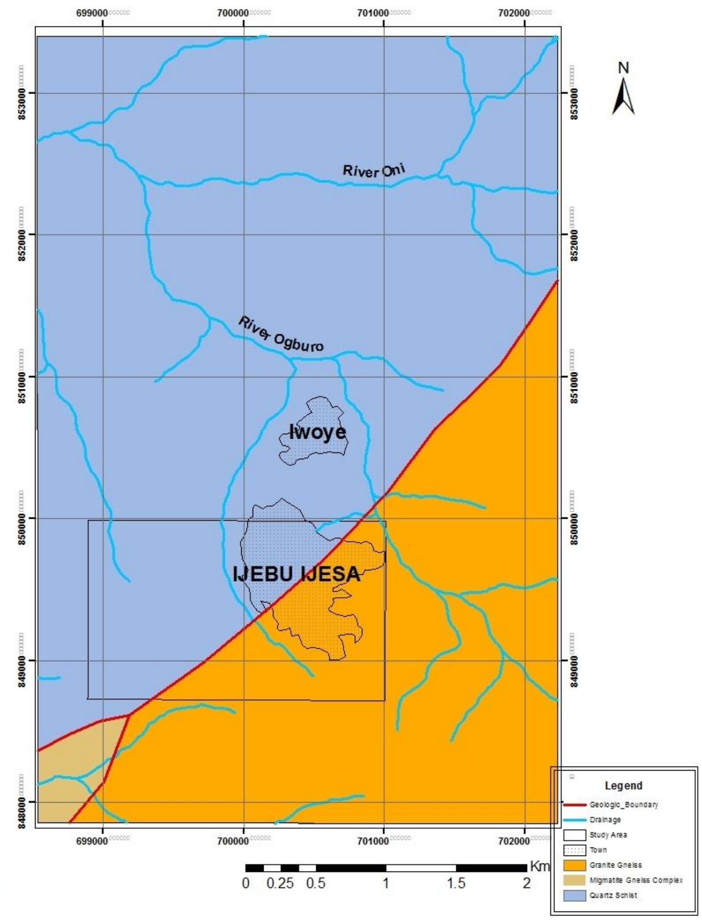

Figure 3: *Geological Map of the Study Area [29].*

These methodologies involved: selection of hydrogeologic factors that are influencing the groundwater occurrence in the study area; the pair-wise comparison of the selected factors; determination of factors weights/consistency examination of the determined weights; classification/rating of the parameters; estimation of the groundwater potential index (GWPI) and preparation of the groundwater potential prediction model.

4 RESULTS AND DISCUSSIONS

The results of the interpretation of the VES showed that the curve types obtained from the area vary from a simple three-layer curve to a relatively complex five-layer curve types typical of basement complex terrain. The subsurface layer parameters and their possible lithological equivalence obtained from the VES interpretation are presented in Table 1. Furthermore, the results shown in Table 1 were used to construct three geoelectric sections which assist in establishing the subsurface layers obtainable in the area. (Figure 5). It was established from the geoelectric sections that the study area is characterized with maximum of six subsurface layers which are the top soil, the clayey layer, the lateritic hardpan, the weathered layer, the fractured basement and the fresh basement layer. It is important to add that the groundwater in the area is largely abstracted from the weathered layer and or the fractured basement. Based on the literature review and consultation with experts, five geoelectric parameters considered to be significantly controlling the flow and accumulation of groundwater in the study area were selected; these factors were the coefficient of anisotropy (CoA), aquifer resistivity (AQR), aquifer thickness (AQT), overburden thickness (OVT) and overburden resistivity (OVR). These parameters, as obtained from the results of the interpretation of VES data, are presented in Table 2. The pairwise comparison of the five selected factors was used to construct the pairwise comparison matrix shown in Table 3. Each element of the matrix in Table 3 was divided by the sum of corresponding column (i.e. $\frac{w_{ij}}{\sum w_{ij}}$) where w_{ij} is the element in row I column j and $\sum w_j$ is the sum of the elements in the column.

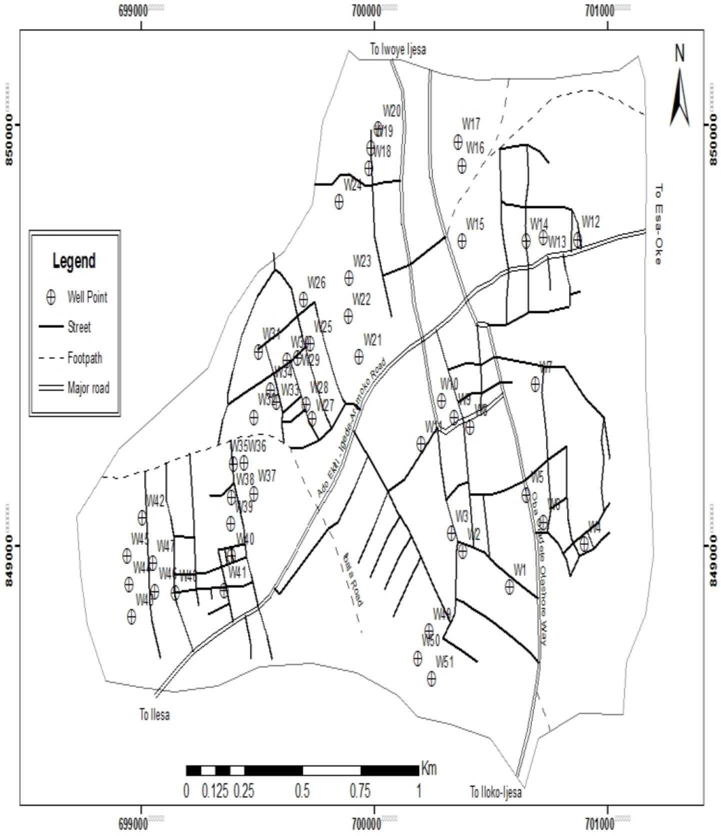

Figure 4: *Base Map of the Study Area Showing Well Locations.*

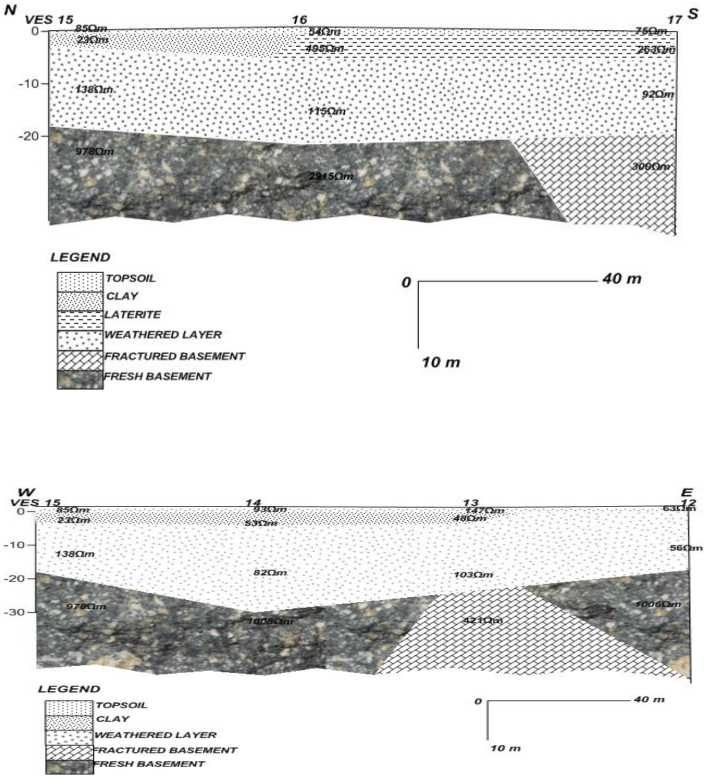

Figure 5: *Geoelectric Sections along S-N and W-E directions*

Table 1: *VES Interpretations Results ver, derivative filters are particularly susceptible to distortion from noise (e.g. due to near surface topographic irregularities) and data errors are accentuated in the process of calculation [22], [23].*

VES NO	Layers Geoelectric Parameters (Resistivities (Ohm-m)/Thicknesses (m)	Curve Type	Possible Lithologic Equivalence
1	57/2.9;150/12.2;1487	A	Top soil/Partly weathered Basement / Basement
2	73/0.5; 43/10.2;7000	H	Top soil/Clayey weathered Basement / Basement
3	50/1.7;132/18.1;1090	A	Same for VES 1
4	148/0.3;38/2.2;311/22; 1628	HA	Top soil/Clay/Partly weathered Basement / Basement
5	425/0.5; 215/15.1; 2937	H	Same for VES 2
6	130/0.3; 476/1.5; 79/33.2; 1753	KH	Top soil/Lateritic Hardpan/weathered Basement / Basement
7	32/0.4;52/10.6; 648	A	Same for VES 1
8	84/0.5; 24/1.9; 75/20.5; 335	HA	Same for VES 4
9	143/0.5; 58/3.7; 145/8.3; 50/7.4; 190	HKH	Top soil/Clay/Sandy Clay/Fractured Basement/Basement
10	36/0.6; 162/10.9; 117/10.6; 5210	KH	Same for VES 6
11	63/0.6; 56/16.7; 6000	H	Same for VES 2
12	147/0.3; 48/3; 103/20.1; 421	HA	Same for VES 4
13	93/0.5;53/3.6;82/26.1; 1008	HA	Same for VES 4
14	88/0.4; 23/2.7; 138/15; 978	HA	Same for VES 4
15	54/0.5; 495/4.4;115/16.5; 2915	KH	Same for VES 6
16	75/0.6; 263/4.7; 92/14.3;300	KH	Same for VES 6
17	65/3.7; 195/7.5; 87/26.2; 1027	KH	Same for VES 6
18	143/1.7; 675/2.6; 104/28.7; 5693	KH	Same for VES 6
19	59/2.4; 547/3; 34	K	Top Soil/Lateritic Hardpan/Fractured Basement
20	109/2.1; 95/18; 1319	H	Same for VES 2
21	71/0.8; 144/3.4; 316	A	Same for VES 1
22	204/0.9; 744/5.1;129/20.2; 956	KH	Same for VES 6
23	121/0.5; 254/17.2; 685	A	Same for VES 1
24	145/0.4; 570/20.5; 61	K	Same for VES 19
25	36/1.3; 114/1.7; 75/5; 1614	KH	Same for VES 6
26	167/0.4; 56/1.1;438/7.4; 167	HK	Top Soil/Clay/Lateritic Hardpan/Fractured Basement
27	176/0.6; 521/2.9; 260/22.7; 4881	KH	Same for VES 6
28	100/0.4; 294/1.7; 545	A	Same for VES 1
29	127/0.4; 42/0.9; 1961/4.7; 649	HK	Same as VES 26
30	76/0.5; 82/1.7; 524	A	Same for VES 1
31	45/0.6; 225/16.5; 143/18.8; 1900	KH	Same for VES 6
32	217/3.3; 1809/8.3; 347/23.2; 1749	KH	Same for VES 6
33	279/3.8; 994/4.8; 2295/21.7; 312	AK	Top Soil/Clay/Lateritic Hardpan/Basement/Fractured Basement
34	53/0.5; 261/1.9;49/28.9;601	KH	Same for VES 6
35	141/1.7; 552/2.3; 102/15.1; 970	KH	Same for VES 6
36	164/3.7; 2173/9.7; 229	K	Same for VES 19
37	480/0.4; 298/1.5;2101/29.5; 387	HK	Same as VES 26
38	344/3.0; 1192/7.6; 382/28.4; 621	KH	Same for VES 6
39	115/1.8; 1052/3.2;123/23./7.0; 2038	KH	Same for VES 6
40	138/1.2; 1057/14.3; 510/18.1; 404	KH	Same for VES 6
41	41/1.4; 83/1.6; 606	A	Same for VES 1
42	112/0.4; 204/1.8; 973	A	Same for VES 1
43	187/0.4; 161/5.9; 329	H	Same for VES 2
44	113/1.3; 1781/7.7;289/27.6; 1668	KH	Same for VES 6
45	207/0.7; 137/3.8; 1378	H	Same for VES 2
46	212/2.6; 570/19.1; 1198	A	Same for VES 1

Table 2: *Summary of the obtained values for the parameters from VES data interpretation*

VES NO	**Location (UTM)** Easting	Northing	**CoA**	**AQR**	**AQT**	**OT**	**OR**
1	700578	848903	1.08	150	12	3.0	57
2	700381	849000	1.00	43	10.2	0.5	73
3	700328	849028	1.08	132	18.1	1.7	50
4	700652	849118	1.23	311	22	2.5	38
5	700744	849031	1.00	215	15.1	0.5	425
6	700694	849386	1.80	79	33.2	1.8	476
7	700409	849280	1.00	52	10.6	0.4	32
8	700340	849291	1.05	75	20.5	2.3	24
9	700273	849355	1.13	145	8.3	4.3	58
10	700198	849245	1.05	117	10.6	11.4	162
11	700868	849728	1.00	56	16.7	0.6	63
12	700733	849740	1.03	103	20.1	3.4	48
13	700651	849730	1.02	82	26.1	4.0	53
14	700372	849722	1.24	138	15.0	3.1	23
15	700388	849906	1.20	115	16.5	4.9	495
16	700354	849963	1.11	92	14.3	5.3	263
17	699978	849904	1.06	87	26.2	11.1	195
18	699985	849940	1.09	104	28.7	4.2	675
19	700013	849990	1.92	34	**	5.4	547
20	699949	849449	1.01	95	18.0	2.0	109
21	699886	849543	1.07	144	3.4	0.8	71
22	699850	849817	1.26	129	20.2	6.1	744
23	699716	849480	1.01	254	17.2	0.5	121
24	699701	849577	1.02	570	20.5	0.4	145
25	699700	849322	1.88	114	1.7	1.3	36
26	699671	849444	1.27	167	12.6	8.9	438
27	699622	849448	1.03	260	22.7	3.4	521
28	699502	849456	1.09	294	1.7	0.4	100
29	699479	849305	2.64	649	**	6.0	1961
30	699575	849325	1.05	82	1.7	0.5	76
31	699549	849373	1.04	225	16.5	0.6	45
32	699389	849199	1.19	347	23.2	11.7	1809
33	699440	849190	1.38	312	**	30.3	2295
34	699483	849119	1.06	49	28.9	2.4	261
35	699381	849125	1.18	102	15.1	4.0	552
36	699375	849054	1.99	229	**	13.4	673
37	699339	848984	1.13	387	**	31.4	2101
38	699354	848896	1.20	382	28.4	10.6	1192
39	699005	848059	1.29	123	23.7	5.0	1052
40	698981	848831	1.10	510	18.1	15.6	1057
41	698948	848905	1.00	83	1.6	0.2	81
42	698941	848975	1.03	204	1.8	0.4	112
43	699056	848891	1.05	161	6.0	0.4	187
44	699050	848954	1.31	289	27.6	9.0	1781
45	700239	848794	1.62	1378	10.5	4.4	137
46	700246	848680	1.11	570	19.1	2.6	212

*NOTE: ** means no AQR or AQT.*

Thereafter, all elements of each row were averaged to obtain the weight of each factor as shown in Table 4. In order to establish the consistency of the judgment and hence the usability of the weights shown in Table 4, the consistency ratio (CR), the ratio of consistency index (CI) to random index (RI), must be less than or equal to 0.1 (10%) [30], [31], [32]. The CR was calculated to be 0.08 (8%) thus establishing the consistency and appropriateness of the weights of the factors as shown in Table 4.Rating scale of 1-5 was adopted for this study. Each parameter was scored in the 1-5 scale in the ascending order of hydrogeological significance. Thematic layers of the selected factors were generated and these were used to do the classification and ratings of factors as shown in Table 5. Groundwater Potential Index (GWPI) is the sum of the products of weights (w) and ratings (R) over all the factors used for the evaluation [33], [34]. Weighted linear average technique was used to estimate GWPI. This technique is usually specified in terms of weightings (w) for each factor as well as rating score (R) for all options relative to each of the factor.

$$GWPI = \sum W_i R_i \ldots\ldots\ldots\ldots 1$$

Where W_i is the weight (w) of parameter i and R_i is the rating score of parameter i.

Using the weights (W) and rating (R) of each factor, equation 4.3 now becomes

$$GWPI = 0.43\ R_{CoA} + 0.28\ R_{AQR} + 0.15\ R_{AQT} + 0.09\ R_{OT} + 0.05\ R_{OR} \ldots\ldots\ldots\ldots 2$$

Where the subscripts *CoA, AQR, AQT, OT and OR* are the coefficient of anisotropy, aquifer resistivity, aquifer thickness, overburden thickness and overburden resistivity respectively.

Table 3: *Pairwise Comparison Matrix of the Criteria*

		A *CoA*	B *AQR*	C *AQT*	D *OT*	E *OR*
CoA	A	1	**3**	**3**	**5**	**5**
AQR	B	1/3	1	**3**	**5**	**5**
AQT	C	1/3	1/3	1	**3**	**3**
OT	D	1/5	1/5	1/3	1	**3**
OR	E	1/5	1/5	1/3	1/3	1
Column Total		2.07	4.73	7.67	14.33	17

Table 4: *Determination of Factors Weightage (W)*

	CoA w_{ij} (j = 1)	*AQR* w_{ij} (j = 2)	*AQT* w_{ij} (j = 3)	*OT* w_{ij} (j = 4)	*OR* w_{ij} (j = 5)	Weights (W) = $1/n\sum w_{ij}$
CoA (i = 1)	0.48	0.63	0.39	0.35	0.29	**0.43**
AQR (i = 2)	0.16	0.21	0.39	0.35	0.29	**0.28**
AQT (i = 3)	0.16	0.07	0.13	0.21	0.18	**0.15**
OT (i = 4)	0.10	0.04	0.04	0.07	0.18	**0.09**
OR (i = 5)	0.10	0.04	0.04	0.02	0.06	**0.05**
∑Column	1	1	1	1	1	1

Application of the above model (equation 2) to the parameters obtained at all VES stations produced the results shown in Table 6. Since the rating scale of 1-5 was adopted for the study, it means that five possible groundwater potential classifications as shown in Table 7are obtainable in the study area. The GWPI obtained for each VES station in Table 6 was used to produce the groundwater prediction model (Figure 6). It was observed from the model that the GWPI values for the study area vary between 1.36 and 4.07 (Table 6) hence; the groundwater potential index for the area can be classified into five classes as shown in Table 7. The groundwater prediction model produced described the groundwater potential of the study area. The model classified the groundwater potential into regions of very low, very low to low, low to medium, medium to high and high to very high. The classification shows that no VES station falls in the very low and medium to high regions both accounting for 0% of the total. Twenty two stations fall in the very low to low region accounting for 47.8% of the total. In the same vein, twenty three stations fall in the low to medium region accounting for 50% of the total. Only one station falls in the high to very high region accounting for just 2.2% of the total. Since the very low to low and low to medium regions jointly accounted for 97.2% of the total area, it can thus be said that the groundwater potential of the study area largely varies between very low to medium. This is a reflection of a typical basement complex terrain.

5 CONCLUSION

In this study, an attempt was made to develop groundwater potential prediction model in a typical basement complex terrain. This was achieved through the application of data mining technique to geoelectric parameters obtained from the results of the interpretation of VES carried out in the area.

Table 5: *Ratings (R) for Classes of Factors*

Influencing Factors	Category (Classes)	Potentiality for Groundwater Storage	Rating (R)	Normalized Weight (*W*)
Coefficient of Anisotropy (CoA)	1.00 – 1.28	Very Low	1	**0.43**
	1.29 – 1.62	Low	2	
	1.63 – 1.96	Moderate	3	
	1.97 – 2.30	High	4	
	2.31 – 2.64	Very High	5	
Aquifer Resistivity (AQR) (Ωm)	1– 100 Ωm (Clay)	Very Low	1	**0.28**
	101 – 250 Ωm (Sandy clay)	Low	2	
	251 – 350 Ωm (Clayey sand)	Moderate	3	
	351 – 450 Ωm (Sand)	High	4	
	451 – 650 Ωm (Fractured basement)	Very High	5	
Aquifer Thickness (AQT) (m)	0.1 – 9.0 m	Very Low	1	**0.15**
	9.1 – 12.0 m	Low	2	
	12.1 – 15.0 m	Moderate	3	
	15.1 – 25.0 m	High	4	
	25.1 – 34.0 m	Very High	5	
Overburden Thickness (OT) (m)	> 10.1 m	Very Low	1	**0.09**
	7.1 – 10.0 m	Low	2	
	4.1 – 7.0 m	Moderate	3	
	1.1 – 4.0m	High	4	
	0.1 – 1.0 m	Very High	5	
Resistivity of Materials that Directly Overly the Aquifer (Ωm)	1 – 100 Ωm (Clay)	Very Low	1	**0.05**
	101 – 250 Ωm (Sandy clay)	Low	2	
	250 – 350 Ωm (Clayey Sand)	Moderate	3	
	351 – 750 Ωm (Sand)	High	4	
	> 750 Ωm (Fractured basement)	Very High	5	

In addition to this, the study was also carried out to determine the subsurface geologic sequences and corresponding geoelectric parameters obtainable in the area. Furthermore, geoelectric factors believe to be controlling the flow and accumulation of groundwater resources in the area were selected and appropriate weights were assigned to each of these factors in the order with which they affect the flow and accumulation of groundwater resources in the area. The appropriateness of the assigned weights was established in the study through the examination of their consistency. In order to achieve the aforementioned aim and objectives, forty six parametric VES was carried out in the study area. Schlumberger array configuration was adopted. The electrode spacing (AB/2) was varied between 1-100 m using. The ABEM-SAS 300 terrameter was used to acquire the field data. The results of the interpretation of the VES yielded the geoelectric parameters characterizing the subsurface of the area. These parameters were used to develop, among other things, geoelectric sections which assisted in unraveling the nature and number of subsurface geoelectric and or geologic layers obtainable in the area. It was established that the obtainable geoelectric layers in the area vary from minimum of three to a maximum of six. These layers are largely characterized by varying thicknesses and resistivity values suggestive of the heterogeneous nature of typical basement complex terrain. Five factors which were the coefficient of anisotropy (CoA), aquifer resistivity (AQR), aquifer thickness (AQT), overburden thickness (OVT) and overburden resistivity (OVR) established to be controlling the flow and accumulation of groundwater resources in the area were selected. These factors were assigned weights in accordance with the degree with which each factor is contributing to the flow and accumulation of the resources in the area.

Table 6: *Groundwater potential index estimation for all the VES stations.*

VES No	**Location (UTM)**		**CoA (w=0.43)**		**AQR (Ωm) (w=0.28)**		**AQT (Ωm) (w=0.15)**		**OT (m) (w=0.09)**		**OR (w=0.05)**		**GWPI**
	Easting	Northing	R	W*R	R	W*R	R	W*R	R	W*R	R	W*R	∑W*R
1	700578	848903	1	0.43	2	0.56	3	0.45	4	0.36	1	0.05	**1.85**
2	700381	849000	1	0.43	1	0.28	2	0.30	5	0.45	1	0.05	**1.51**
3	700328	849028	1	0.43	2	0.56	4	0.60	4	0.36	1	0.05	**2.00**
4	700652	849118	1	0.43	4	1.12	4	0.60	4	0.36	1	0.05	**2.56**
5	700744	849031	1	0.43	2	0.56	4	0.60	5	0.45	4	0.20	**2.24**
6	700694	849386	3	1.29	1	0.28	5	0.75	4	0.36	4	0.20	**2.88**
7	700409	849280	1	0.43	1	0.28	2	0.30	5	0.45	1	0.05	**1.51**
8	700340	849291	1	0.43	1	0.28	4	0.60	4	0.36	1	0.05	**1.72**
9	700273	849355	1	0.43	2	0.56	1	0.15	3	0.27	1	0.05	**1.46**
10	700198	849245	1	0.43	2	0.56	2	0.30	1	0.09	2	0.10	**1.39**
11	700868	849728	1	0.43	1	0.28	4	0.60	5	0.45	1	0.05	**1.81**
12	700733	849740	1	0.43	2	0.56	4	0.60	4	0.36	1	0.05	**2.00**
13	700651	849730	1	0.43	1	0.28	5	0.75	4	0.36	1	0.05	**1.87**
14	700372	849722	1	0.43	2	0.56	3	0.45	4	0.36	1	0.05	**1.85**
15	700388	849906	1	0.43	2	0.56	4	0.60	3	0.27	4	0.20	**2.06**
16	700354	849963	1	0.43	1	0.28	3	0.45	3	0.27	3	0.15	**1.58**
17	699978	849904	1	0.43	1	0.28	5	0.75	1	0.09	2	0.10	**1.65**
18	699985	849940	1	0.43	2	0.56	5	0.75	3	0.27	4	0.20	**2.21**
19	700013	849990	3	1.29	1	0.28	0	0	3	0.27	4	0.20	**2.04**
20	699949	849449	1	0.43	1	0.28	4	0.60	4	0.36	2	0.10	**2.05**
21	699886	849543	1	0.43	2	0.56	1	0.15	5	0.45	1	0.05	**1.64**
22	699850	849817	1	0.43	2	0.56	4	0.60	3	0.27	5	0.25	**2.29**
23	699716	849480	1	0.43	3	0.84	4	0.60	5	0.45	2	0.10	**2.42**
24	699701	849577	1	0.43	5	1.40	4	0.60	5	0.45	2	0.10	**2.98**
25	699700	849322	3	1.29	2	0.56	1	0.15	4	0.36	1	0.05	**2.41**
26	699671	849444	1	0.43	2	0.56	3	0.45	2	0.18	4	0.20	**1.82**
27	699622	849448	1	0.43	3	0.84	4	0.60	4	0.36	4	0.20	**2.43**
28	699502	849456	1	0.43	3	0.84	1	0.15	5	0.45	1	0.05	**1.92**
29	699479	849305	5	2.15	5	1.40	0	0	3	0.27	5	0.25	**4.07**
30	699575	849325	1	0.43	1	0.28	1	0.15	5	0.45	1	0.05	**1.36**
31	699549	849373	1	0.43	2	0.56	4	0.60	5	0.45	1	0.05	**2.09**
32	699389	849199	1	0.43	3	0.84	4	0.60	1	0.09	5	0.25	**2.21**
33	699440	849190	1	0.43	3	0.84	0	0	1	0.09	5	0.25	**1.61**
34	699483	849119	1	0.43	1	0.28	5	0.75	4	0.36	3	0.15	**1.97**
35	699381	849125	1	0.43	2	0.56	4	0.60	4	0.36	4	0.20	**2.15**
36	699375	849054	4	1.72	2	0.56	0	0	1	0.09	4	0.20	**2.57**
37	699339	848984	1	0.43	4	1.12	0	0	1	0.09	5	0.25	**1.89**
38	699354	848896	1	0.43	4	1.12	5	0.75	1	0.09	5	0.25	**2.64**
39	699005	848059	2	0.86	2	0.56	5	0.75	3	0.27	5	0.25	**2.69**
40	698981	848831	1	0.43	5	1.40	4	0.60	1	0.09	5	0.25	**2.77**
41	698948	848905	1	0.43	1	0.28	4	0.60	5	0.45	1	0.05	**1.81**
42	698941	848975	1	0.43	2	0.56	4	0.60	5	0.45	2	0.10	**2.14**
43	699056	848891	1	0.43	2	0.56	1	0.15	5	0.45	2	0.10	**1.69**
44	699050	848954	2	0.86	3	0.84	5	0.75	2	0.18	5	0.25	**2.88**
45	700239	848794	2	0.86	5	1.40	2	0.30	3	0.27	2	0.10	**2.93**
46	700246	848680	1	0.43	5	1.40	4	0.60	4	0.36	2	0.10	**2.89**

Table 7: *Possible groundwater potential classifications*

GWPI Value	**Classifications**
0 – 1.0	Very Low
1.01 – 2.0	Very Low - Low
2.01 – 3.0	Low - Moderate
3.01 – 4.0	Moderate - High
4.01 – 5.0	High – Very High

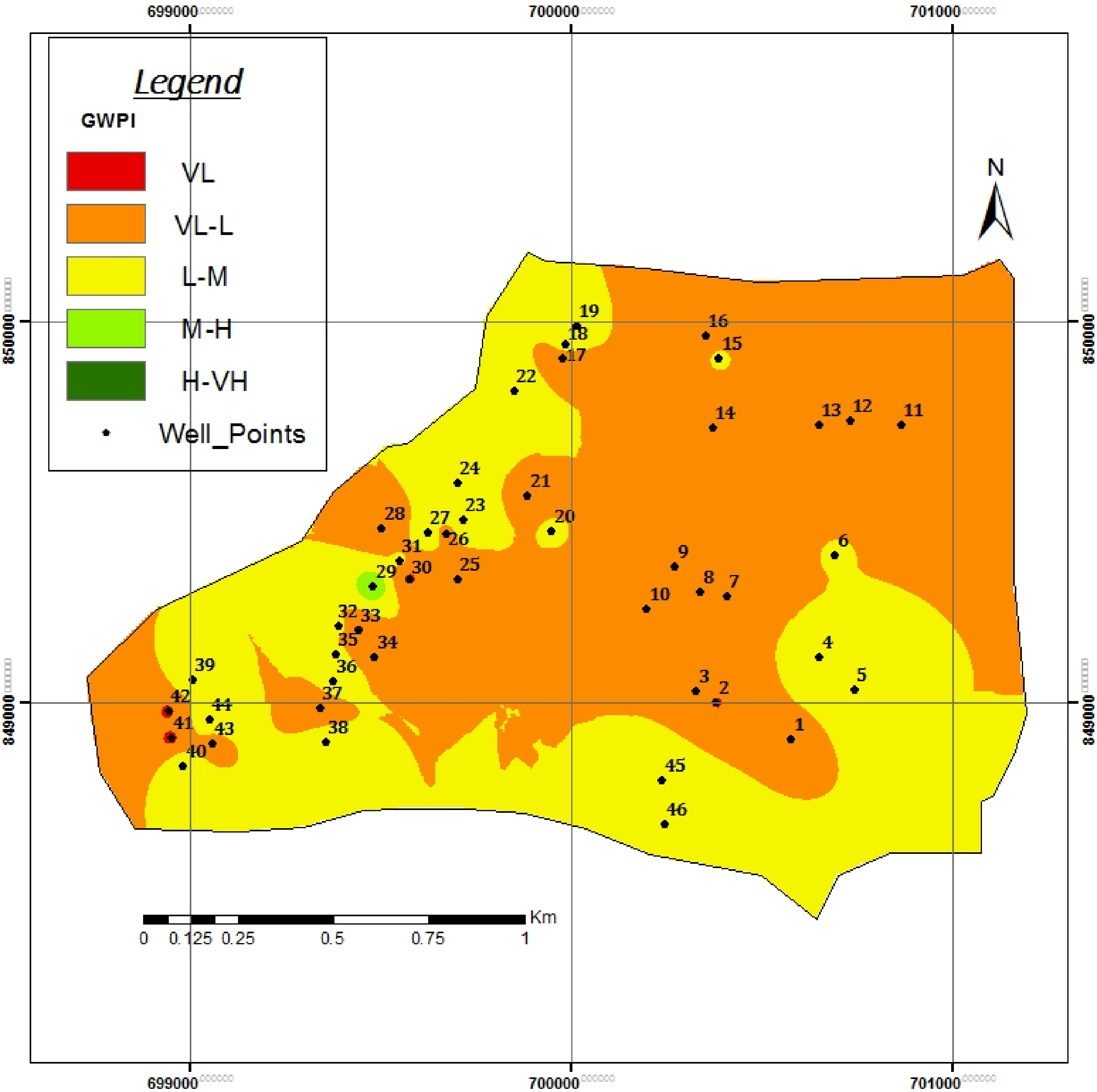

Figure 6: *Groundwater Prediction Model of the Area*

The assigned weights were adjudged to be consistent and hence usable having established the consistency ratio (CR) to be less than one. The rating of 1-5 was adopted for the study. Average linear equation was applied to both the weights and ratings of each factor to obtain groundwater potential index (GWPI) at each of the VES location. The GWPI obtained for each VES location was used develop groundwater potential prediction model. The prediction model developed described the groundwater potential of the study area. The model classified the groundwater potential into: very low, very low to low, low to medium, medium to high and high to very high. However, very low – low and low – medium groundwater potential classifications account for 47.8% and 50% of the study area respectively. Only 2.2% of the study area was classified to be of high – very high groundwater potential thus suggesting that very low to low and low to medium regions dominate the study area. The results obtained account for the reason why most of the wells in the study area are seasonal. Furthermore, the prediction map developed gives an appropriate reflection of groundwater potential expectation of any typical basement complex terrain. It thus suggests that the methodology adopted for the study is reliable and hence can be replicated elsewhere.

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