

Application of GIS-Based Frequency Ratio Model to Geoelectric Parameters for Groundwater Potential Zonation in a Basement Complex Terrain

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Abstract: This study applied a geographic information system (GIS) based frequency ratio (FR) model for groundwater potential assessment in a crystalline basement complex terrain, southwestern, Nigeria. The aim of the study is to investigate the proficiency of the model when applied to geo-electric parameters. Four geo-electrically derived groundwater potential conditioning factors (GPCFs) were used, namely; Aquifer resistivity (AQR), Aquifer thickness (AQT), Coefficient of anisotropy (COA), and Bedrock relief (BED). The well location inventories were partitioned randomly into 70% (45 wells) for model training and 30% (19 wells) for model testing. The frequency ratio model algorithm was used to synthesize the GPCFs to produce the groundwater potential index (GWPI). The estimated GWPI was processed in the GIS environment to produce a groundwater potential zonation map which enabled the demarcation of the study area into five potential zones. The produced FR-based model map was validated through the application of the area under the curve (AUC) approach and spatial attribute comparative scheme (SACS). The AUC validation approach for the FR model showed a 64% success rate and 61% for prediction rate. The quantitative SACS result, based on the well data analysis, established 63% agreement with the insitu well water column thickness map. Similarly, the result of the qualitative SACS established a 71% Agreement. The SACS analysis shows that the FR-based model is a good alternative for prediction of groundwater potential zones even when applied to GWCFs that are geo-electrically derived. Thus, the produced map could form part of decision-making mechanisms for groundwater exploitation and management in the area.

Keywords: Frequency Ratio (FR), Geo-electric Parameters, Groundwater Potential Zonation, Area Under the Curve (AUC), Spatial Attribute Comparative Scheme (SACS)

INTRODUCTION

Groundwater can be described as water occupying all the empty spaces within a geologic stratum (Todd, 2004). The origin of groundwater can be traced to three main sources namely the meteoric water, connate water, and juvenile water. The meteoric water occurs near the earth surface and is caused by the percolation of precipitation from atmospheric water. The connate water is the water formed during the sedimentation process and trapped in the pores of rocks. The juvenile water is formed during magmatic processes and it is accompanied by eruption of magma. Groundwater is not as vulnerable to near surface contaminant as the surface water sources (Adiat et al., 2013). Also, it is less affected by climate fluctuations, drought and normal variations in rainfall (Balamurugan et al., 2017). It is the only viable safe source of water in many remote areas where development of surface water is not economically viable (Adeyemo et al., 2017).

Several scientific approaches have been adopted in evaluating the groundwater potential in areas with complex geology. These approaches include; geophysical prospecting, hydro-geological, remote sensing/GIS technique and Multi-criteria decision analysis technique (Ying et al., 2007; Adiat et al., 2013; Balamurugan et al., 2017; Akinlalu et al., 2017) among others. These were

targeted towards developing a more reliable and efficient model tool in optimizing groundwater productivity.

The application of geophysical methods in groundwater resources exploration has gained tremendous accolade (Mogaji & Lim, 2017). This widespread acceptance is because the geophysical technique is non-invasive and cost effective. Various geophysical methods have been applied to explore groundwater resources; most common methods used include electrical resistivity, seismic refraction, electromagnetic and magnetic methods.

Among several prospective geophysical methods, the direct current electrical resistivity (ER) method is the most highly efficient in groundwater studies. The probable reasons are its attributes of simplicity, robustness and cost effectiveness (Rubin & Hubbard, 2005). In addition, the good and direct correlation between geology, fluid content and electrical properties (electrical resistivity, various geoelectric aquifer parameters such as transmissivity, hydraulic conductivity, aquifer apparent resistivity, storability, anisotropy, longitudinal conductance and transverse resistance) put this method at advantage over other geophysical methods in groundwater potential evaluation. In recent years, index based MCDAs such as GRT, GODT and the Analytical Hierarchy Process (AHP) have been adequately utilized in the field of groundwater hydrology. (Chowdhury et al., 2009; Adiat et al., 2012; Mogaji & Omobude, 2017; Adeyemo et al., 2017) among others.

Their results indicated that these techniques require comparison ratings in order to determine the weights of various groundwater potential conditioning factors (GPCFs) considered for these studies. However, as stated in Lawal et al. (2012) and Rahmati et al. (2016), these methods are expert driven, and they involve comparison ratings to define the weights for the thematic layers which often introduce many biases to the researchers' judgment. In this study, the frequency ratio is proposed as a technique that can yield a predictive model of high reliability and precision.

Some renowned GIS-based spatial integration models such as logistic regression, evidential belief function, weight of evidence, artificial neural network, maximum entropy, random forest have been utilized in groundwater potential mapping (Corsini et al., 2009; Ozdemir, 2011; Lee et al., 2012; Nampak et al., 2014; Naghibi et al., 2015; Mogaji & Lim, 2018). However, in the context of the literature reviewed for this research, only few examples of the use of GIS based frequency ratio were found, (Ozdemir, 2011 and Balamurugan et al., 2017). Moreover, the most common groundwater potential conditioning factors (GPCFs) often used in these prior studies include; lineament density, lineament intersection, drainage density, slope etc., which are parameters derived from remote sensing techniques. It is important to note that no account of frequency ratio application to geo-electrically derived parameters was found.

According to Adiat et al. (2013), in order to develop a groundwater resources potential model of high reliability and precision in a given study area, the effect of all-important parameters that can contribute to the groundwater occurrence in the area must be integrated. Hence, the concept of a GIS based frequency ratio model application on geo-electrically derived parameters depicts the originality of this research.

The FR is the probability of occurrence of a certain attribute (Ozdemir, 2011). Balamurugan et al. (2017) and Oh et al. (2011) described frequency ratio (FR) as a bivariate statistical approach that could be used to determine probability of occurrence of an attribute in an area on the basis of the relationships between dependent variable (groundwater potential) and independent variables (groundwater influencing factors). Frequency ratio serves as a simple geospatial assessment tool to calculate the probabilistic relationship between dependent and independent variables, including multi-classified maps. The frequency ratio method is very easy to apply, not bias and the results obtained by (Mohammady et al., 2012; Ozdemir & Altural, 2013; Hong et al., 2015 and Nicu, 2017), in landslide susceptibility mapping are highly informative.

The groundwater potential conditioning factors (GPCFs) considered in this research are aquifer thickness (AQT), aquifer resistivity (AQR), bedrock relief (BER) and Coefficient of anisotropy COA). According to the studies of Olorunfemi & Fasuyi (1993); Shailaja et al. (2016); and Mogaji (2016), these groundwater conditioning factors have direct bearing on the groundwater potentiality of an area.

The resistivity of the aquifer layer is a reflection of the geologic materials that constitute the unit, and this will determine the effectiveness and degree of saturation of the aquifer. The thickness of such geologic unit determines the volume of groundwater that is likely to be available within the aquifer. Similarly, the coefficient of anisotropy measures the degree of earth's heterogeneity, which depicts the degree of weathering and presence of structural features (Mogaji, 2016). The bedrock relief gives an insight into the basement relief which determine the subsurface inflow into the aquifer or the subsurface recharge rate.

This present study attempts to establish the proficiency of frequency ratio model for regional evaluation of groundwater potentiality in a typical basement complex terrain, by considering groundwater potential conditioning factors that are geo-electrically derived. The specific objectives of this study are as follows: (i) estimate the GWCFs from interpreted vertical electrical sounding data; (ii) determine the groundwater potential prediction index (GWPI), using the GWCFs maps by applying frequency ratio algorithm; (iii) produce groundwater potentiality prediction zones map in GIS environment; (iv) generate a water column map from water column thickness variation across the study area; and (v) validate the produced groundwater potential maps using area under curve (AUC) and spatial attribute correlative scheme (SACS).

THE STUDY AREA DESCRIPTION

The study area is situated in Igoba community within Akure metropolis, Southwestern Nigeria. It is situated about 1 km from Akure metropolis. The study area lies between Easting 746186 to 746880 mE, and Northing 806660 to 807323 mE of the Universal Traverse Mercator (UTM) (Figure 1). The area extent is about 0.75 km². The study area is geographically located within the sub-equatorial climate belt of tropical rain forest vegetation with evergreen and broad-leaved trees luxuriant growth layer arrangement (Adeleke & Cheng, 1978). The area is characterized by uniformly high temperature and heavy, well distributed rainfall throughout the year. The topography of the area is relatively undulating. The elevation of the area ranges between 350 m - 378 m above sea level. The topsoil is composed mainly of sand and laterite.

The study area is underlain by rocks of the Precambrian basement complex of southwestern Nigeria (Rahaman, 1976). The lithological units in the study area include: granite rocks; fine biotite hornblende granite, coarse porphyritic granite and granodiorite (Figure 2.). Some of the rock types underlying the study area are concealed by a sequence of unconsolidated but variably thick basement regolith, (Olajide et al., 2020).

METHODOLOGY

The data used in this study include, the obtained hand dug-well data, geological data and the field acquired geophysical data (Figure 3). Implementation of the FR model approach was carried out in six different phases. Phase 1 is the reconnaissance survey which involves well location inventory and generation of the study area map. Phase 2 involves geophysical data acquisition using the Vertical Electrical Sounding (VES) technique, processing and interpretation of the acquired data and estimation of the groundwater potential conditioning factors (GWCFs) from interpreted geo-electrical parameters. The application of GIS tool constituted the phase 3. At this phase, the Thematic maps of the GWCFs were produced.

Phase 4 deals with estimation of the groundwater potential prediction index (GPPI) using FR model algorithm. The production of the groundwater potential map constitutes the 5th phase. The validation of the produced groundwater potential map is the 6th phase.

Reconnaissance

This phase involved site visitation mainly for familiarization. This helped in understanding the study area better in terms of the nature of the people and the layout of the study area (road network) and features located in the study area. The base map of the study area (Figure 1) was produced at this stage. The ArcGIS 10.1 software was used to generate this map. The inventory of wells in the study area was taken. A total of sixty four (64) wells were selected from the 130 wells

identified in the area. The selection of these wells was informed by the questionnaire carried out in the study to identify non-seasonal wells in the area. The Global Positioning System (GPS) was used to acquire both the coordinates and elevation information at each well.

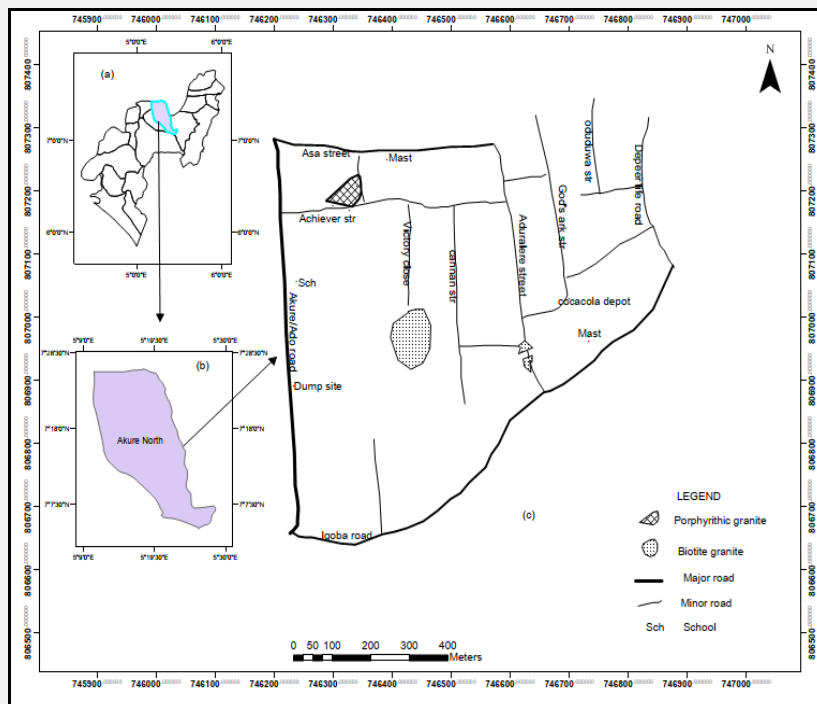


Figure 1. The location maps showing (a) Map of Ondo state (b) Map of Akure North L.G.A (c) Site Map of the study area

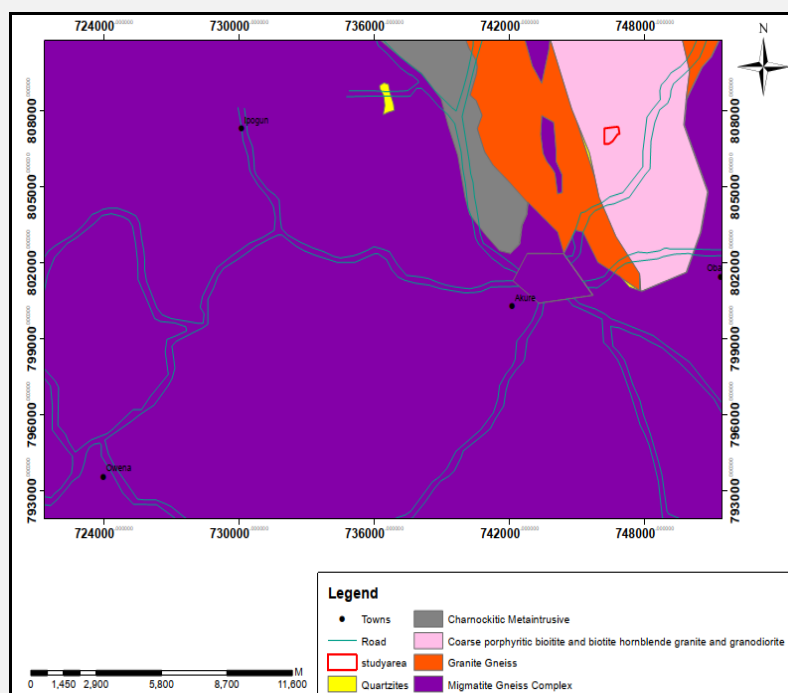


Figure 2. The Geological Map of Akure (Modified after Ademeso, 2009)

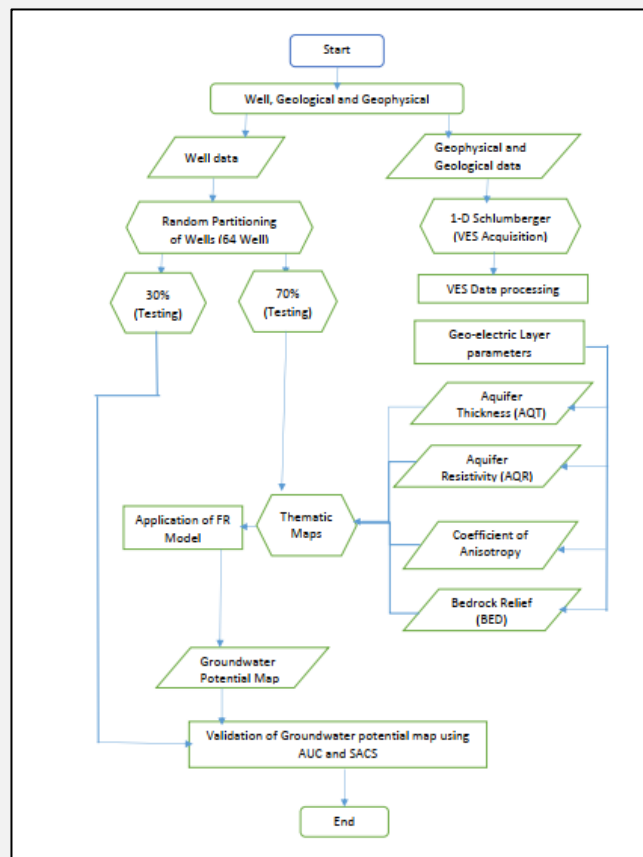


Figure 3. The flow chart of the adopted methodology for this study

Geophysical data acquisition interpretation phase

The geophysical prospecting approach adopted at this phase was the 1-D resistivity technique. A total of Fifty three (53) resistivity soundings were conducted in the study area using the Ohmega Resistivity meter for electrical resistivity measurements. These soundings were carried out close to previously identified wells and the elevation of each VES point was recorded.

The Schlumberger array was adopted with electrode spacing ($AB/2$) ranging from 1-100 m. The VES technique is suitable for determining the subsurface sequence/lithology, degree of saturation, degree of weathering and occurrence of fractures and faults. The VES data processing and interpretation involved the partial curve matching and the computer iteration method. The sounding data were presented as sounding curves, which are plots of apparent resistivity (ρ_a) values against electrode separation ($AB/2$) on bi-log graph. The interpretation of VES curves was done in two steps; the first step is manual curve matching (Keller & Frischnecht, 1966). This involves segment-by-segment curve matching of the sounding curves with the theoretical curves with the assistance of auxiliary curves. This exercise yields geoelectric parameters, which is layer thickness and their resistivity values.

The partial curve matching was done manually, and it involves the two-layer master curves and the corresponding auxiliary curves. The layers resistivity and thicknesses were fed into the computer as a starting model in an iterative forward modeling technique using RESIST version 1.0 (Vander Velpen, 1998). 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. The forward modeling gives information about the first order geoelectric parameters such as the aquifer thickness, aquifer resistivity, overburden thickness etc. Four geoelectric parameters considered are; aquifer thickness (AQT), aquifer resistivity (AQR), bedrock relief (BED) and coefficient of anisotropy (COA). The Bedrock relief was derived by subtracting the overburden thickness at each VES point from the

elevation equation (1). First order geoelectric parameters derived from the iteration were utilized in deriving second order geoelectric parameters or Dar Zarrouk parameters (Maillet, 1947) equation (2). The second order parameters considered in this study is the Coefficient of anisotropy.

These factors were selected based on their established contribution to groundwater potential of an area in past studies as documented in the works of Olorunfemi & Okhue (1992), Omosuyi & Enikanselu (1999) and Shailaja et al. (2016).

$$\text{BED} = \text{elevation} - \text{overburden thickness} \quad (1)$$

$$\lambda = \sqrt{\frac{\rho_T}{\rho_L}} \quad (2)$$

Where, λ is the coefficient of anisotropy, ρ_T is the transverse resistance and ρ_L is the longitudinal resistance.

Generation of thematic maps of the groundwater conditioning factors (GPCFs)

The values of the four conditioning factors at each VES point; Aquifer resistivity (AQR), Aquifer thickness (AQT), Coefficient of anisotropy (COA) and Bed-rock relief (BED) were imported into the GIS environment and interpolated using the inverse distance weighted (IDW) technique of Geostatistical wizard module in ArcMap 10.3, as adopted in the study of Mogaji & Lim (2018). The IDW takes the concept of spatial autocorrelation literally. It is an exact interpolator that assumes that the nearer the sample point whose value is to be estimated, the more closely the cell value will resemble the sample point value.

Application of GIS based Frequency Ratio (FR)

The wells were partitioned randomly into two. Seventy percent (70%, 45 wells) for model training and thirty percent (30%, 19 wells) for model testing, using the subset features option in geostatistical analyst tool of ArcMap 10.3.

The thematic map of each groundwater conditioning factor was re-classified using the spatial analyst tools of Arc toolbox in ArcMap 10.3. The re-classified maps were converted from raster to vector and the frequency ratio algorithm was utilized by overlaying the wells for model training. Thus, the relationship between the wells and the groundwater conditioning factors were used to calculate the frequency ratio index, using equation 3.

$$\text{FR} = \frac{W}{\text{TW}} \div \frac{\text{CP}}{\text{TP}} = \frac{E}{F} \quad 3$$

Where W is the number of pixels of well locations for each class of the thematic maps; TW is the number of total pixels of well in the study area, CP is the number of pixels in each thematic class and TP is the total number of pixels in the study area. In the FR model, FR is the weight of each class in the thematic parameters. To obtain the groundwater potential index (GWPI), the weight of each factors was summed at each VES point using equation 4.

$$\text{GWPI} = (\text{FR})_i \quad (i = 1, 2, \dots, n) \quad 4$$

Where GWPI is the groundwater potential index and FR is the weight of each factor.

Therefore, the groundwater potential indexes (GWPI) for each VES points were computed using equation 5.

$$\text{GWPI} = \text{COA}_{\text{FR}} + \text{BER}_{\text{FR}} + \text{AQT}_{\text{FR}} + \text{AQR}_{\text{FR}} \quad 5$$

Where, COA is the coefficient of anisotropy, BER is the bedrock relief, AQT is the aquifer thickness and AQR the aquifer resistivity respectively.

Groundwater potential zonation mapping

The GWPI obtained for each VES point was interpolated, using the kriging interpolation technique and classified into five classes using the natural break classification method (Jenks, 1967) in GIS environment. These classifications are Very low, Low, Medium, High and Very high zones.

Validation of the FR Model

Validation is the very apt scheme for establishing the reliability of any proposed model in decision making process (Mogaji & Omobude, 2017). Two validation techniques were adopted for the study. They are the Area under Curve (AUC) and the Spatial Attribute Correlation Scheme (SACS) validation techniques.

Area under Curve (AUC) Validation Technique

The area under curve technique (AUC) as used in the study of Balamamurugan et al. (2017) was used in this study. According to Lee & Pradhan (2007), the prediction rate and the success rate indicates the prediction capacity of the model as well as predictor variables to predict groundwater potential zones. AUC value near 1.0 indicates highest degree of accuracy and a value near 0.5 indicate inaccuracy in a model (Fawcett, 2006). On this basis, the relationship of AUC value and prediction accuracy can be divided into the following classes: 0.9-1.0 (excellent), 0.8-0.9 (very good), 0.7-0.8 (good), 0.6-0.7 (average) and 0.5-0.6 (poor) (Naghibi et al., 2015).

In this study, the prediction rate curve was derived using test data of 19 wells which were not utilized for the preparation of GWPZ in the FR model used, while the success rate curve was derived using the wells for training (45 wells). This was done by plotting the cumulative percentage of groundwater occurrence against the percentage groundwater potential zonation index. The process was carried out using the spatial analyst tools in ArcMap.

SACS Validation Techniques

Qualitative and quantitative spatial attribute correlation scheme (SACS) as supported in the study of Mogaji & Omobude (2017), was also considered in this study. The qualitative approach involves qualitative comparison between the predicted potential zones attribute with the produced well water column thickness (WWCT) map obtained in the study area. Using the spatial attribute boundary classes of range 1.12 – 2.00, 2.01 - 2.69, 2.70 - 3.28, 3.29 – 4.06, and 4.07 – 5.13, the WWCT values observed at each located hand-dug well and existing boreholes were calibrated and qualitatively compared with the spatial attribute of the predicted potential zones on the groundwater potential zonation (GWPZ) map.

The quantitative approach was carried out by extracting the spatial pixel values of the spatially modeled well water column thickness estimates against the corresponding estimated values of the FR based GWPI at each VES location in the study area. The result obtained were used to develop a correlative graph plots, and the regression coefficient 'r' used to measure the quantitative relationship between the FR based GWPI values and the well water thickness map values.

RESULTS AND DISCUSSION

Groundwater potential conditioning factors in the study area

Aquifer Resistivity (AQR)

The aquifer resistivity depicts how saturated a geologic unit is. The lower the resistivity, the higher the saturation, hence AQR is a great contributor to the groundwater potential of a location. Generally, aquifers in basement complex are qualitatively classified as either weathered fractured basement or partly weathered or fractured basement aquifer (Akinlalu et al., 2017). The aquifer units delineated in the study area are partly weathered/fractured basement and Weathered Basement aquifers. The aquifer resistivity in the study area ranges from 9 - 420 Ω m (Figure 4).

The resistivity values were classified into five (5) classes, with aquifer resistivity values ranging from 9- 51 Ω m characterizing the southern, central and northwestern parts of the study area. The resistivity values obtained are typical of clay/clayey sand or sandy clay which are inimical to groundwater extraction in an area. This could be attributed to lack of interconnected pores within the layer. The southeastern, a section of the central zone and the eastern/northeastern sections of the study area are characterized by resistivity values ranging from 51 -102 Ω m and 102-180 Ω m, which is typical of sandy layer with good aquifer properties (i.e. permeability). Permeability of a formation is the ability of that formation to recharge and discharge groundwater in a useable quantity.

Nevertheless, it is important to note that aquifer resistivity alone cannot be used to infer the groundwater potentiality of an area. The eastern and part of the northeastern area are characterized by resistivity values ranging from 180 - 254 Ω m and 254 - 420 Ω m, which is typical of lateritic, partly weathered and fractured basement aquifers. The permeability of this type of aquifer layer is generally low thus exhibiting low groundwater potentiality.

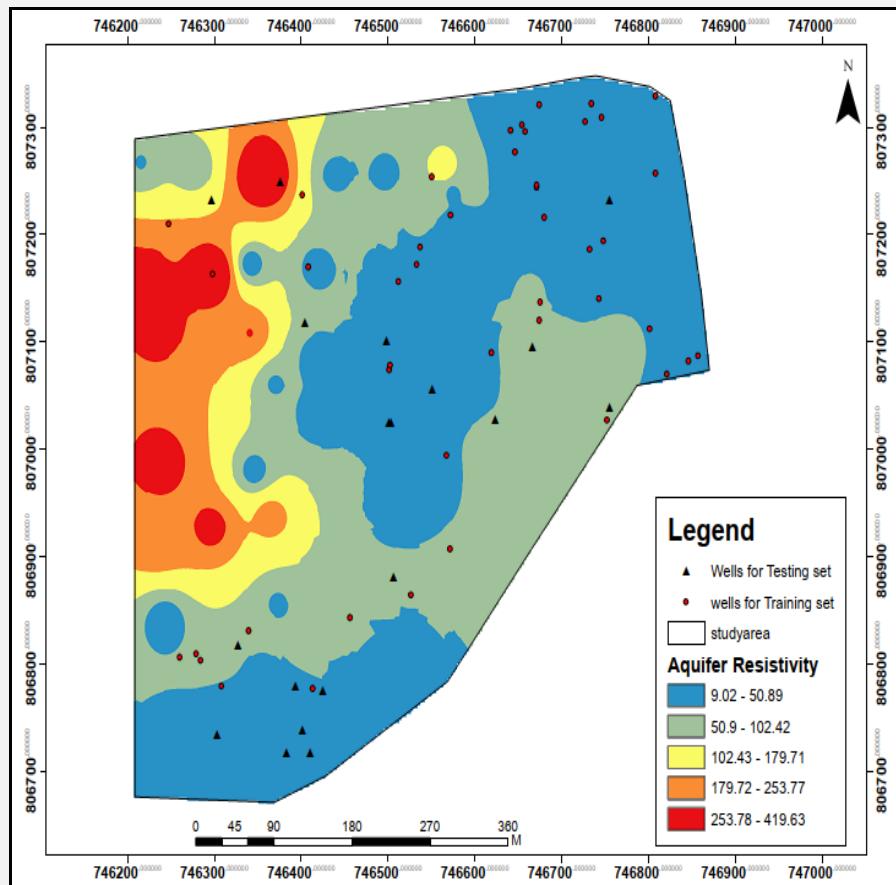


Figure 4. Aquifer Resistivity Thematic Map of the Study area

Aquifer Thickness (AQT)

The aquifer thickness in the study area ranges from 0.2 – 20.4 m (Figure 5). The thickness of an aquifer depicts its storage capacity, which is the ability of the medium to accumulate groundwater. An aquifer with high thickness value has ability to store large quantity of groundwater. The southern part is majorly characterized by aquifer thickness of 0.20 - 2.97 m with patches across the study area which is a pointer to low groundwater accumulation capability of such aquifer layer. Aquifer thickness value of 2.96 - 4.63 m and 4.64 - 6.77 m characterized the major part of the study area, this is typical of low - moderate aquifer storage capacity. Aquifer

thickness value of 6.78 - 11.12 m occurs as patches across the study area, with more of the patches characterizing the northern part of the study area. This suggests good target for groundwater development with moderate potentiality. The aquifer thickness value of 11.13 – 20.37 m only occurs at some points in the northern part of the study area. This is typical of good aquifer with appreciable thickness. However, it is important to note that thickness of aquifer alone could not be the sole determinant for groundwater potentiality.

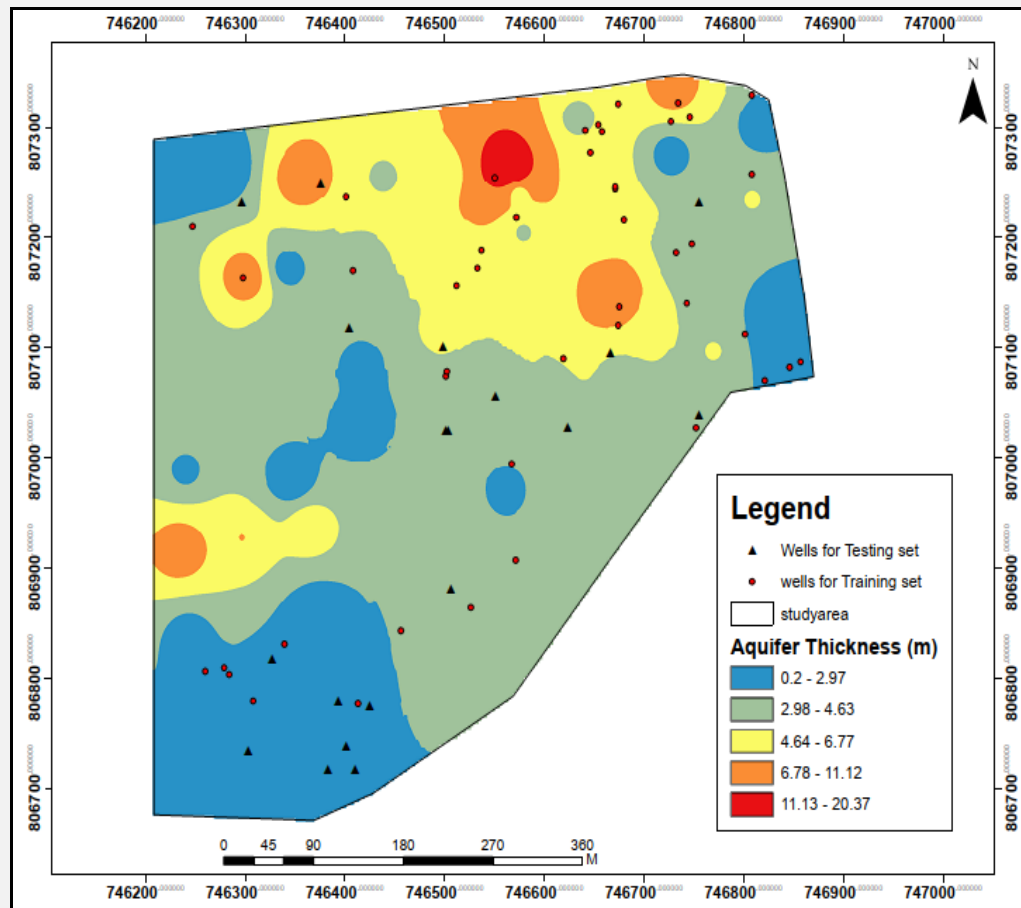


Figure 5. Aquifer Thickness Map of the Study Area

Coefficient of Anisotropy (COA)

Coefficient of anisotropy defines the degree of heterogeneity of an area. This is used to decipher the presence or absence of geologic features such as fractures, joints etc. These geologic features aid the rate of recharge of an aquifer. In other words, the higher the coefficient of anisotropy value, the more likely the presence of these geologic features, the better the groundwater potentiality.

The coefficient of anisotropy in the study area ranges from 1.0 - 3.0 (Figure 6). Anisotropy value of 1 - 1.24 characterized the northeastern part and trend towards the southern and central part of the study area. The northern and central zones of the study area is majorly characterized by anisotropy value of 1.25 - 1.74. While the anisotropy value of 1.75 - 2.21 and 2.22 – 3.00 occur as patches across the study area. These values are characteristics of high groundwater potential environment with consideration given to other groundwater conditioning factors.

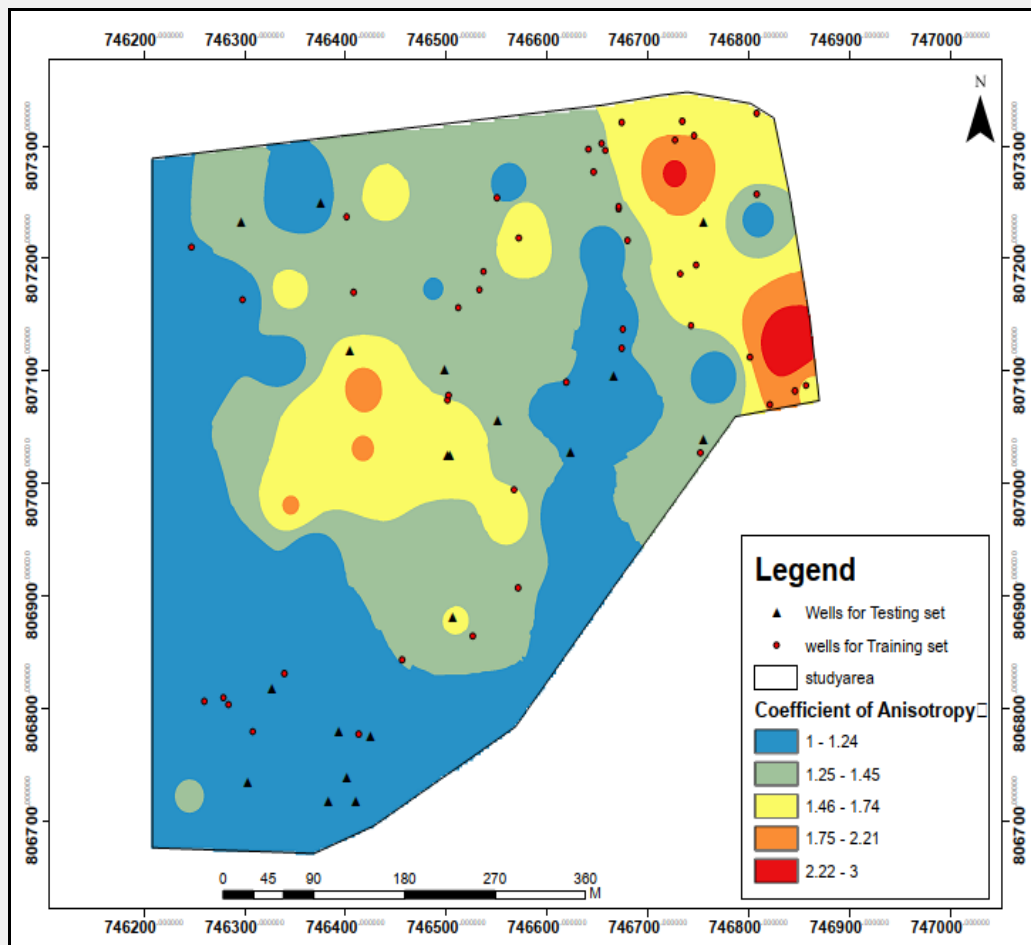


Figure 6. Coefficient of Anisotropy Map of the Study Area

Bed-rock Relief (BER)

Studies have it that the basement in addition to joints and fractures may be characterized by ridges and depression which can serve as conduit for groundwater flow into an aquifer (Olorunfemi & Okhue, 1992; Omosuyi & Enikanselu, 1999). The bed-rock relief in the study area varies from 354 - 365m (Figure 7).

The bedrock relief values of 345.21 - 354.95 m and 354.96 - 358.52 m characterized the northeastern part and trends toward the central part with patches across the study area. These points are delineated to be depressions and act as the end point of groundwater flow within the subsurface in the study area. Hence it is anticipated to be of high groundwater potential, but it is important for other influencing factors to be considered.

The bedrock relief value of 358.53 - 361.65 characterized the central part of the study area and trends towards the southwestern, northern and northeastern parts of the study area. This represents the intermediate bedrock relief between the basement ridges and the depressions. The northwestern and the eastern parts of the study area are characterized with bedrock relief value of 365.45 - 372.68. These areas represent part of the study area located on the basement ridge. It can then be said that groundwater flows from this part towards the basement depression.

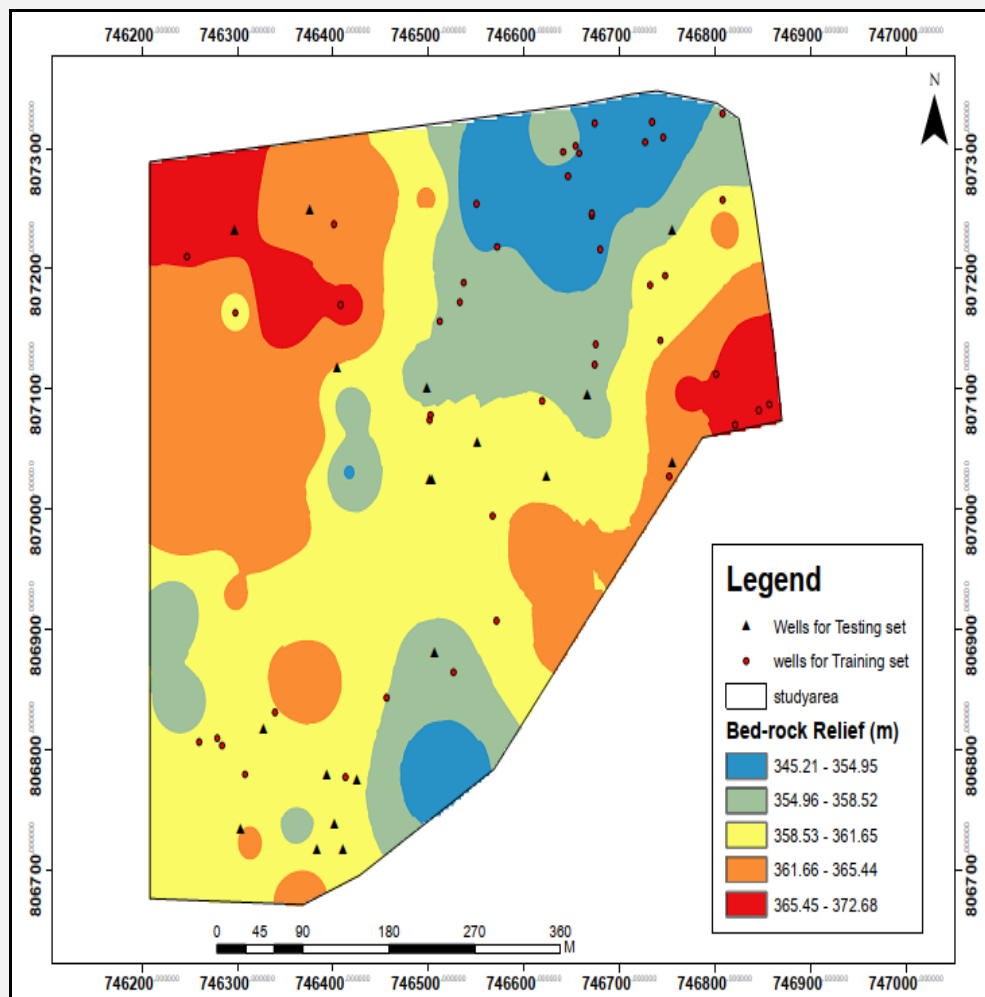


Figure 7. Bedrock Relief Map of the Study Area

GIS-Based FR Model for Groundwater potential Mapping

The frequency ratio values for different thematic attributes for groundwater potential mapping are presented in Table 1. It ranges from 0 - 3.4190. The groundwater potential map is presented in Figure 8. The frequency ratio groundwater potential map produced was classified into five potential classes based on Jenks (1967) natural breaks classification method, i.e. very low, low, moderate, high, and very high.

The low (3.07-3.84) and very low (1.95-3.06) potential zones characterized the western, northwestern and southwestern parts of the study area. It important to note that these areas are characterized by high aquifer resistivity, high bed-rock relief, low coefficient of anisotropy and thin aquifers. The moderate potential zones (3.85-4.57) characterized the southwestern part trending towards the central, eastern and the northwestern zones. This part of the study area is characterized with intermediate bedrock relief, aquifer resistivity, aquifer thickness and coefficient of anisotropy values. The high (4.58-5.49) and very high (5.5-6.83) potential zones characterized the northeastern part trending towards the central part and with patches across the study area.

These zones coincide with part of the study area characterized by high coefficient of anisotropy, low bed-rock relief, high/medium aquifer thickness and low aquifer resistivity. It can therefore be said that the effect of the influencing factors manifested vividly on the final map.

Table 1. Frequency ratio value of different thematic attribute for groundwater potential mapping

Thematic maps	Classes	number of wells (W)	Number of pixels (CP)	FR
COA	1- 1.24	11	19410	0.583
	1.25-1.45	20	17212	1.196
	1.46-1.74	10	7925	1.299
	1.75-2.21	4	1328	3.100
	2.22-3	0	436	0
		Total = 45	Total = 46311	
BER	345.21-354.95	11	4489	2.522
	354.96-358.52	10	8578	1.200
	358.53-361.65	16	18090	0.910
	361.66-365.44	2	11821	0.174
	365.45-372.68	6	3322	1.859
AQT	0.2-2.97	9	10219	0.906
	2.98-4.63	16	22974	0.717
	4.64-6.77	16	10225	1.610
	6.78-11.12	3	2592	1.191
	11.13-20.37	1	301	3.419
AQR	9.02-50.89	31	20648	1.545
	50.9-102.42	11	15705	0.721
	102.43-179.71	1	3559	0.289
	179.72-253.77	1	4171	0.247
	253.77-419.63	1	2228	0.462

Validation of the FR model Map

Area under Curve (AUC) Validation Technique Results

The result of the AUC validation technique is presented in [Figure 8](#). The success rate curve is 0.6447 or 64%. The prediction rate indicates the prediction capacity of the model as well as the predictor variables to predict GWPZ ([Lee & Prahan, 2007](#)). The AUC value of the prediction rate is 0.6135 or 61% accuracy. Thus, considering the AUC value, it can be concluded that the FR model result perform averagely in this study. This could be as a result of the nature of data used or the inherent error introduced during data processing.

SACS Validation Techniques Results

The qualitative comparison between the predicted potential zones attributes with the produced well water column thickness map ([Figure 9](#)) shows 71 % level of agreement. This indicates that there exists a close similarity between the FR model groundwater prediction map and the in-situ water column map in the study area. The quantitative SACS was carried out by quantitatively comparing the spatial attribute of the predicted zones on the FR model with the WWCT map at each VES points. The correlative graph plots provide a regression coefficient 'r' of 63% ([Figure 10](#)). This result further corroborates the result of the qualitative SACS.

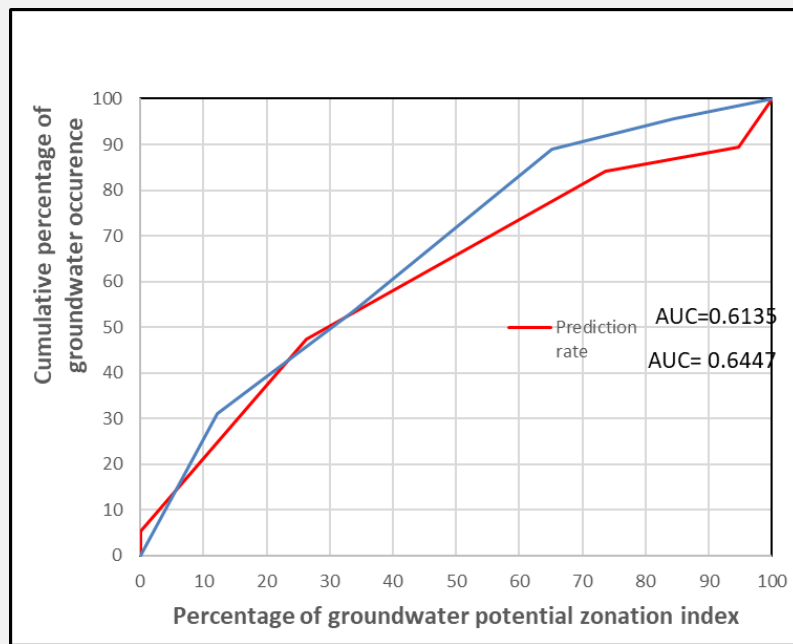


Figure 8. Validation Derived from AUC Method

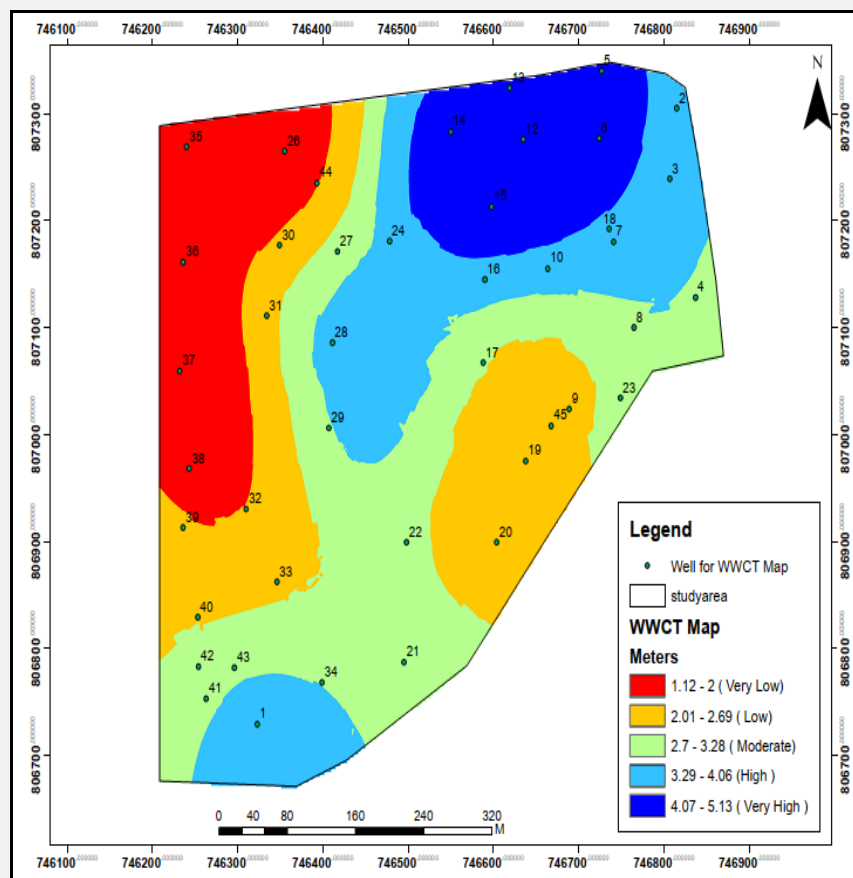


Figure 9. Well Water Column Map of the study Area

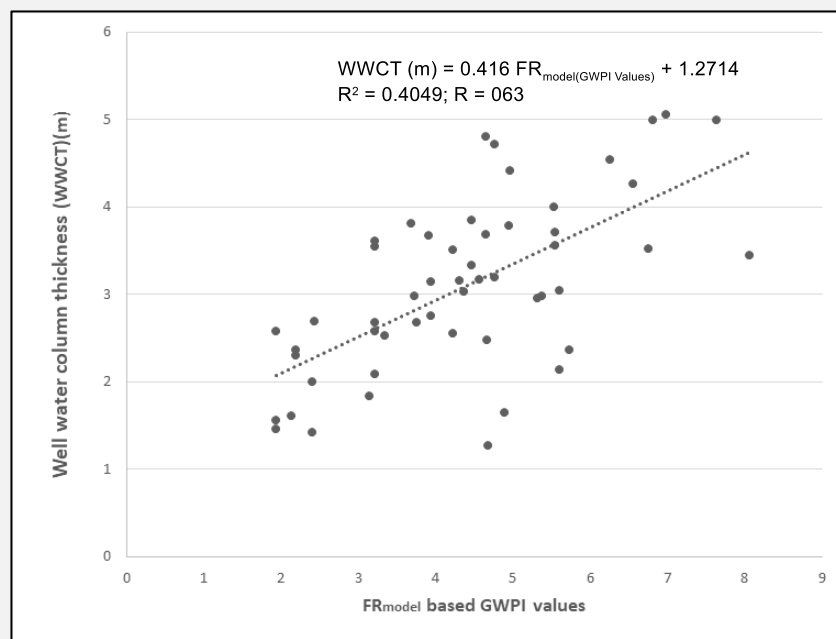


Figure 10. Plot between FR based GWPI and well water column thickness

CONCLUSION

To develop a more accurate groundwater potential conceptual model map for part of Igoba community, the FR modeling algorithm was applied to synthesize the GPCFs hydrologic thematic maps to obtain the GWPI values. The estimated GWPI values were processed in the GIS environment to produce FR model based GWPZ map of the study area. The produced map was classified into five classes which includes; very low, low, moderate, high, and very high. To produce the groundwater potential zonation maps (GWPZ), the four geo-electrically derived groundwater potential conditioning factors (GPCFs; Aquifer resistivity, Aquifer thickness, Coefficient of anisotropy, and Bed-rock relief) obtained from the interpreted fifty-three (53) Schlumberger depth sounding data acquired in the study area were converted to thematic maps in GIS platform. To validate the produced map the water column thickness map of the study area was produced using the acquired hand dug well data. The FR prediction map was validated using area under curve (AUC) method, qualitative and quantitative spatial attribute correlation scheme (SACS). The study therefore, concludes that the FR model performance is high when applied to geo-electrically derived parameters and the degree of accuracy confirms the reliability of the methodology adopted for this research. Similarly, the literature review of the study area reveals that it is underlain by coarse porphyritic biotite, biotite hornblende granite and granodiorite considering the mineral constituent of these rocks (i.e. feldspar, quartz, biotite and hornblende), it therefore means that the weathered/ aquifer layers are largely occupied by clayey sand and sandy clay being the likely weathering product of these rocks. This could be the reason why over 65 % of the study area falls between very low – moderate potential zones. This study has further established the reliability of the FR model and showcases its performance when applied to geo-electrically derived parameters. Hence, this method can be deployed routinely in groundwater exploration in a similar geologic terrain.

DECLARATION OF INTEREST

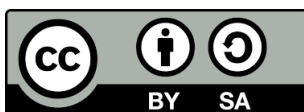
Authors declare that there is no funding for this research. Also, there is No Conflict of Interest.

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