International Journal of Earth Sciences Knowledge and Applications
journal homepage: http://www.ijeska.com/index.php/ijeska

Research Article

e-ISSN: 2687-5993

Hydrogeophysical Investigation Using Electrical Resistivity Method within Lead City University Ibadan, Oyo State, Nigeria

Adebo Babatunde A.[1], Ilugbo Stephen Olubusola[1]*, Jemiriwon Emmanuel Tope[1], Ali Adnan Karram[1], Akinwumi Ayomide Kolawole[1], Adeniken Nathaniel Taiwo[1]

[1]*Department of Physics, Lead City University Ibadan, Nigeria*

INFORMATION

Article history
Received 19 August 2021
Revised 02 September 2021
Accepted 05 September 2021

Keywords
Groundwater potential
Coefficient of anisotropy
Overburden thickness
Aquifer resistivity
Aquifer thickness

Contact
*Ilugbo Stephen Olubusola
bussytex4peace44@gmail.com

ABSTRACT

A geoelectric investigation of groundwater potential in some part of Lead City University Ibadan, Southwestern Nigeria was carried out with a view to providing information on the geoelectric characteristic of the subsurface geological structures and their hydrogeologic significance, in order to determine possible areas for groundwater prospect zones. The study involved the use of Schlumberger vertical electrical sounding data at twenty (20) stations. The results from the geoelectric layers were used to determine the second order parameters (Dar-Zarrouk). Groundwater potential map was also generated from the integration of geoelectric parameters using Multi-Criteria Evaluation Technique. The results obtained from this study illustrate that the integration of the data handling method proposed in this study with geophysical technique can provide an accurate method for characterizing and evaluating groundwater prospect. The investigated area has been classified into low, moderate and high groundwater potential zones. It was observed in some parts of northeastern and southwestern parts are indicative of high groundwater potential zone. Moderate groundwater potential zone was observed at the northern, eastern, southwestern, southeastern and northwestern parts of the study area. Also, the low groundwater potential zone was observed at the northwestern, northern and northeastern parts of the study area. From the results obtained, it indicates that the investigated area is an area of low to moderate groundwater potential.

1. Introduction

Groundwater is valuable natural resources on the earth surface and serves as one of the main sources of drinking water. Basement complex rocks have problem of groundwater resources, productivity and management due to the underlying nature of the crystalline rock which lack primary porosity (Adelusi and Balogun 2001; Anudu et al., 2008; Amadi and Olasehinde, 2010; Ilugbo and Adebiyi 2017; Ilugbo et al., 2018a; Adebiyi et al., 2018; Bawallah et al., 2018, Ilugbo et al., 2018b; Adebo et al., 2018; Adebo et al., 2019; Adesola et al., 2020; Bawallah et al., 2020).

Groundwater storage capacity in crystalline environment depends on depth of weathering and degree of fracturing of the basement complex rock. For basement complex rock to have good aquifers, they must be highly fractured and weathered (Ilugbo and Adebiyi 2017; Oyedele 2019; Ilugbo et al., 2019). Thickness of the weathered overburden and fractured zone determined the nature and intensity of hydrodynamic activities within the usually discrete bodies of aquifer in the terrain (Omosuyi et al., 2003; Oladapo et al., 2004).

In the basement complex, ground water normally occurs in the porous and permeable substrate which is an underground layer of water-bearing permeable rock of unconsolidated materials such as gravel, sand, confined by impermeable confining bedrock such as shale. It is however more prominent within the weathered and fractured basement where it could either be confined by overlying impermeable and high resistive rocks, or remains unconfined but trapped by the low permeable and highly resistive fresh basement.

Hydrogeophysics has emerged over the years as one of the dominant sub-disciplines in near surface geophysics (Ademeso et al., 2013; Olurotimi et al., 2015). This worldwide geoscience discipline is ripe with research opportunities and abundance of potential applications. Maintaining and protecting current water supplies and developing new sources of clean water are essential as modern society expands and civilization continues to develop. This research work focuses on the use of surface geophysical method involving electrical resistivity for hydrogeophysical studies.

In hard rock environment, it is not sufficient to consider only the weathered layer, deep saturated fractures in bedrock are also potential targets of groundwater exploration. The electrical methods like vertical electrical sounding (VES) and profiling are widely used for this purpose. Also, vertical or sub-vertical localized fractures can be located at larger depths using the conventional electrical methods. The technique is widely used in soft and hard rock areas and previous study using this technique includes (Anifowose and Borode, 2007; Al-Amoush, 2010; Zeyad, 2013; Ademeso et al., 2013). The difficulty facing the geologist and geophysicist specializing in groundwater exploration has been the area of coverage as a result of limitations in terms of accessibility most especially urban areas (Miller, 2006; Sundararayon et al., 2007; Joel et al., 2016; Djamel, 2017; Ndikilar et al., 2019).

In this situation, the detail geophysical investigation is often problem and accurate interpretation of results is not guaranteed. In solving this problem, the electrical resistivity method has proved to be successful in this regard by mapping geological structures relating to groundwater occurrence on a regional scale.

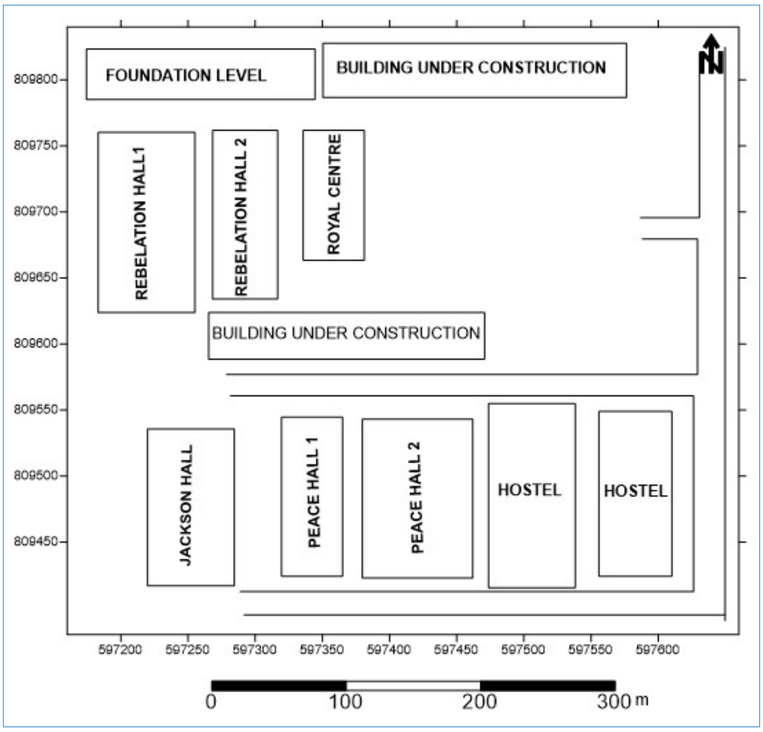

Fig. 1. Location map of the study area

2. Site Descriptions and Geology of the Study Area

The area investigated lies around Lead City University and located along the Ibadan-Lagos express way southwest Nigeria (Fig. 1), located on latitudes 7°14'27. 97''N to 7°14'50.64''N and longitudes 5°10'5.03''E and 5°10'27.95''E that is, (805100 to 805900 Northing and 740200 to 740600 Easting) using the Universal Traverse Mercator (UTM). Major and minor road linkages characterize the study area. The topography of the area is generally undulating by hilly ridges and gently steeping land forms, which consist of lateritic soils, clay, sandy clay, top soil and low-lying outcrops in the few exposures in the study area.

The study area is generally over 400 m above sea level except few areas that fall just below 400 m with some hills at the northern part of the study area. The area of investigation falls in hard rock terrain and it is underlain by the Precambrian crystalline rocks typical of the Nigeria basement complex (Rahaman, 1976; 1988). The dominant rock types within the study location are migmatite and banded gneiss and quartzite-quartz schist (Fig. 2).

3. Research Methodology

The field survey involves the generation of the base map and establishment of data points in the study area, using the GPS and Surfer software; electrical resistivity data collection using the Omega Resistivity meter and its accessories, respectively. A total of 20 VES points were occupied to cover the study area (Fig. 3). The Schlumberger depth sounding was used to investigate the change of resistivity with depth. The measured unit is the apparent resistivity, ρa, which is the product of a geometrical factor, K and the quotient of the measured potential, ΔU and the source current, I. The apparent resistivity is plotted versus AB/2 in meters on bilogarithmic paper resulting in a VES curve. The VES curve showed the change of resistivity with depth, since the effective penetration increases with increasing electrode spacing. The interpretation of the VES curve is both qualitative and quantitative. The qualitative interpretation involved visual inspection of the sounding curves while the quantitative interpretation utilized partial curve matching technique using 2-layer master curve which was later refined by a computer iteration technique Resist version (Vander-Velpen, 2004). The quantitatively interpreted sounding curves gave interpreted results as geoelectric parameters (that is, layer resistivity and layer thickness).

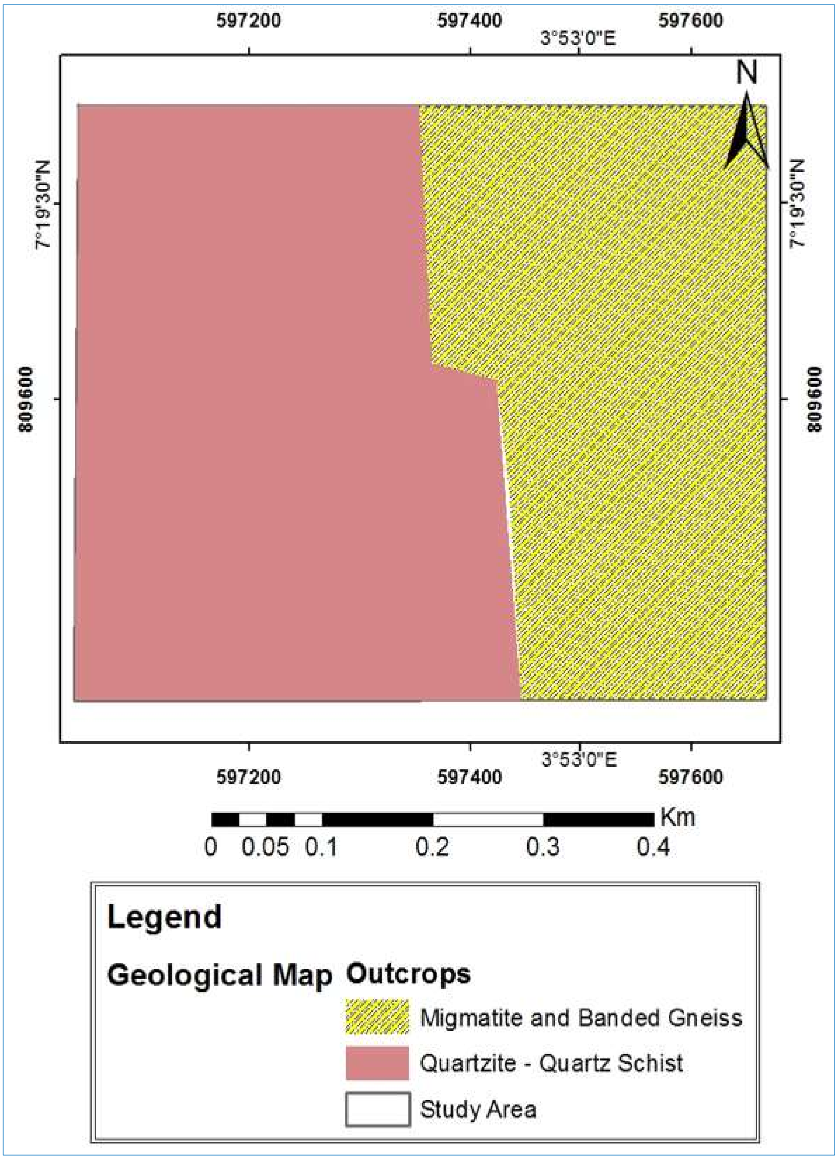

Fig. 2. Geological map of the study area (Rahaman, 1988)

The results from the geoelectric layers were used to determine the second order parameters (Dar-Zarrouk), the choice among a set of zones for evaluation of groundwater potentiality has been based upon multiple criteria such as coefficient of anisotropy, overburden thickness, aquifer resistivity and aquifer thickness. The process is known as Multi-Criteria Evaluation (MCE). For a Multi-Criterial Modeling, firstly a template has been created by identifying the input quadtrees used in the analysis. Different categories of derived thematic maps have been assigned scores in a numerical scale of 1 to 3 depending upon their suitability to holding capacity of groundwater (Preeja et al., 2011; Pietersen, 2016; Ilugbo et al., 2018a). A summation of these values led to the generation of final weight map. Mathematically, this can be defined as:

$$GW = f(CA, OT, AR, AT) \quad (1)$$

where; GW is groundwater, CA is coefficient of anisotropy, OT is overburden thickness, AR is aquifer resistivity and AT is aquifer thickness. The groundwater potential map value, thus derived is given by equation:

$$GWP = \sum WiCVi \,;\, with \sum Wi = 1 \quad (2)$$

where; GWP is the groundwater potential map value. Wi is the probability value of each thematic map, and CVi is the individual capability value to hold groundwater.

4. Results and Discussion

4.1. Characteristic depth sounding curve types

The two different curve types obtained include: A and H, while the curve types are characteristic of the basement complex area (Fig. 4). The H type is the most predominant. It accounts for about 90% of the total. The H curve type has been reported to be associated with high groundwater yield where the weathered layer is sufficiently thick.

4.2. Geoelectric sections

Three geoelectric sections were drawn from the layer resistivity and thicknesses obtained from the interpretation of the depth sounding curves. The sections drawn along the Northwest – Southeast (Fig. 5a) and Southwest – Northeast (Fig. 5b) directions of the study area show a total of three subsurface layers namely: the topsoil, weathered layer and fresh basement.

4.2.1. Geoelectric section along the NW – SE direction

The first layer constitutes the topsoil with layer resistivity ranging from 166 to 217 Ωm. the layer thickness varies from 0.8m to 1.0m. The varying resistivity suggests topsoil of clayey sand, sandy clay and sand. The second layer with resistivity ranging from 93 to 122 Ωm is the weathered layer. The layer thickness varies from 1.2 to 17.2 m. The third layer constitutes the fresh basement with resistivity of 429 to 1433 Ωm (Fig. 5a). The recognizable structural feature in this section is the weathered layer which could be a good aquifer.

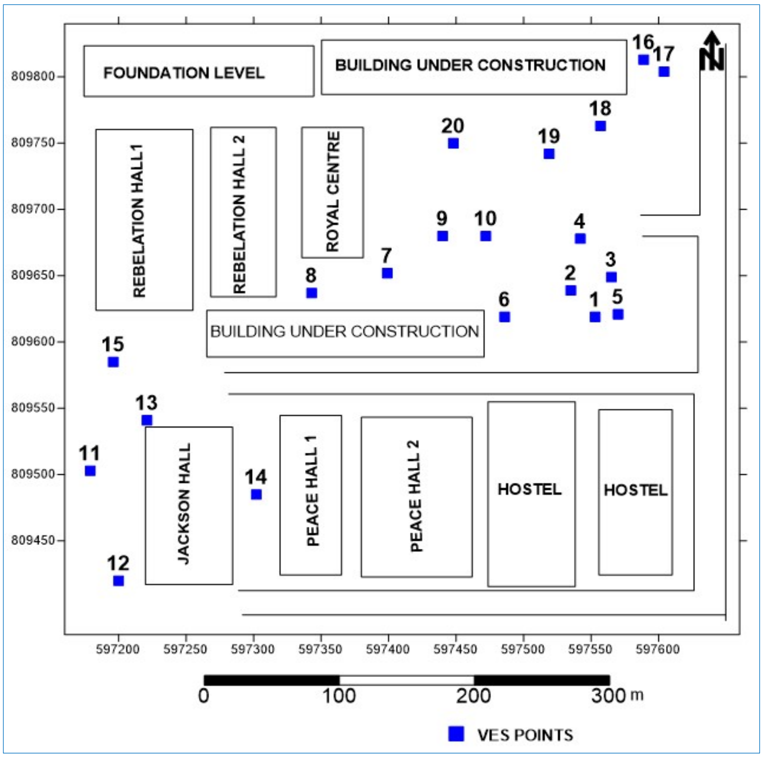

Fig. 3. Data acquisition map of the study area

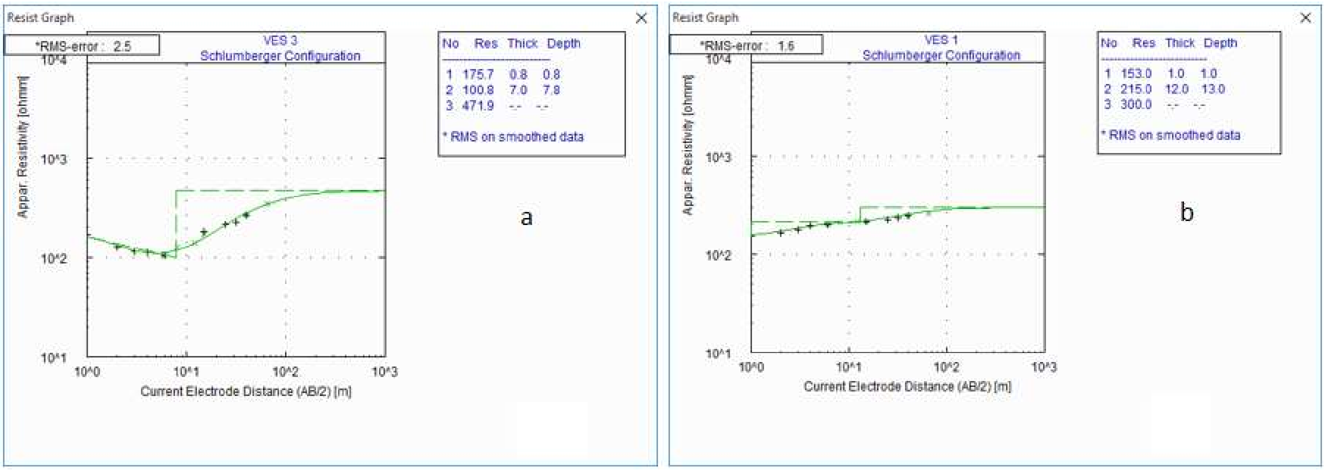

Fig. 4. Typical H curve type (a) and typical A curve type (b)in the study area

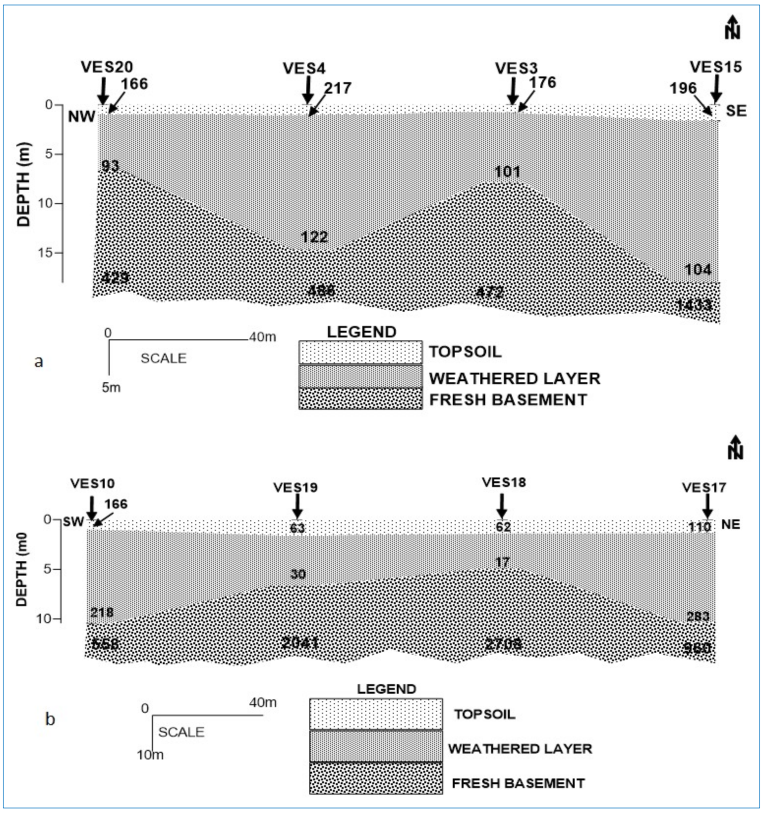

Fig. 5. Geoelectric section; (a) along NW – SE direction and (b) along SW – NE direction

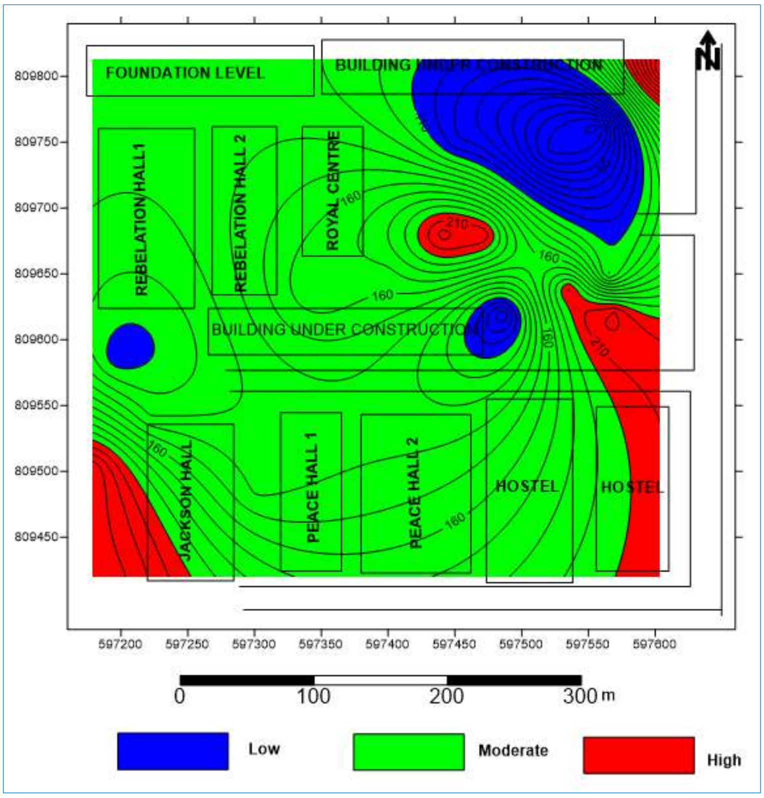

Fig. 6. Aquifer resistivity map of the study area

4.2.2. Geoelectric section along the SW–NE direction

The first layer constitutes the topsoil with layer resistivity ranging from 62 to 166 Ωm with the layer thickness varies from 0.8 to 1.1 m. The varying resistivity suggests topsoil of clay, clayey sand and sand. The second layer with resistivity ranging from 17 to 283 Ωm is the weathered layer. The layer thickness varies from 1.1 to 10.5 m. The third layer constitutes the fresh basement with resistivity of 558 to 2708 Ωm (Fig. 5b). The weathered layer is predominantly clayey. Hence, it offers little or no groundwater prospect. The recognizable structural feature basement complex is the weathered and fracture basement which constitute groundwater exploration.

4.3. Geoelectric Maps

4.3.1. Aquifer resistivity and thickness map

The aquifer resistivity map (Fig. 6) generated shows that aquifers with relatively low resistivity values are found around northeastern with small closure at eastern and southwestern parts while moderate aquifer resistivity cover 90% of the entire area and high aquifer resistivity values are restricted to some part of southeastern, southwestern and small closures in some portions of the study area. High aquifer thickness units are found at southern, western, southwestern, northwestern with small closures within the portion of the study area (Fig. 7). These areas of moderate aquifer resistivity and moderate to high thickness aquifer are relatively good prospects for groundwater development.

4.3.2. Overburden thickness map

The overburden thickness in the study area is assumed to include the topsoil, the weathered layer and the fractured basement. Hence, the established depths to bedrock beneath all the VES stations were contoured to produce the overburden thickness map (Fig. 8). The overburden thickness varies from 4.9 to 25.7 m. The map shows a small closure of relatively thick overburden (above 20 m) in the southwestern part which correlate with area of moderate aquifer resistivity. These areas correspond to basement depression which is groundwater convergent zones. Hence, they are relatively good prospects for groundwater development. The relatively thin overburden (less than 11m) corresponding to basement highs. Groundwater flow pattern is from the basement highs to the basement depression.

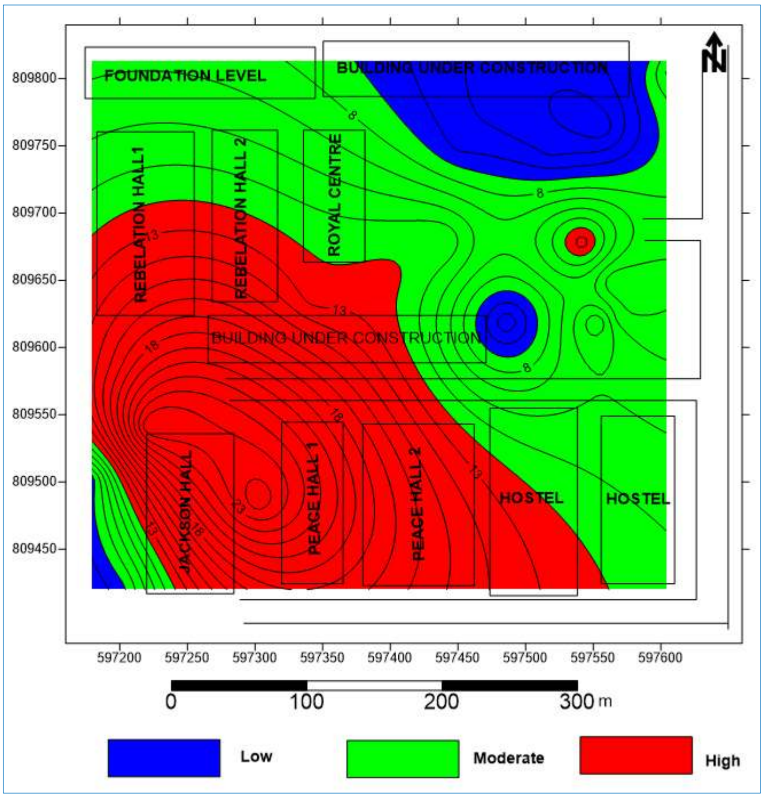

Fig. 7. Aquifer thickness map of the study area

4.4. Dar Zarrouk parameters for groundwater characteristics

The coefficient of anisotropy is estimated along with the secondary geoelectric parameters. The estimation shows that the total longitudinal conductance varies from 0.04 to 0.23 Ω-1 in the investigated area (Fig. 9).

The qualitative use of this parameter is to demarcate changes in total thickness of low resistivity materials. The total transverse resistance ranges from 149 to 3566 Ωm, which gives information both about the thickness and resistivity of the area (Fig. 10). The average longitudinal resistivity calculated from sounding curves ranges from 29.07 to 311.9 Ωm in the area, which helps in calculating the total depth H to the high resistivity bedrock and the average transverse resistivity varies from 39.75 to 640.09 Ωm, which clearly displays that it is more than the average longitudinal resistivity.

This indicates that the true resistivity normal to the plane of structural features is greater than the true resistivity parallel to the plane of structural features. Based on these estimates it was found that the coefficient of anisotropy ranges from 1.0 to 1.18, which depicts the true variation of the anisotropy character of rock formation (Fig. 11).

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 show low values of coefficient of anisotropy.

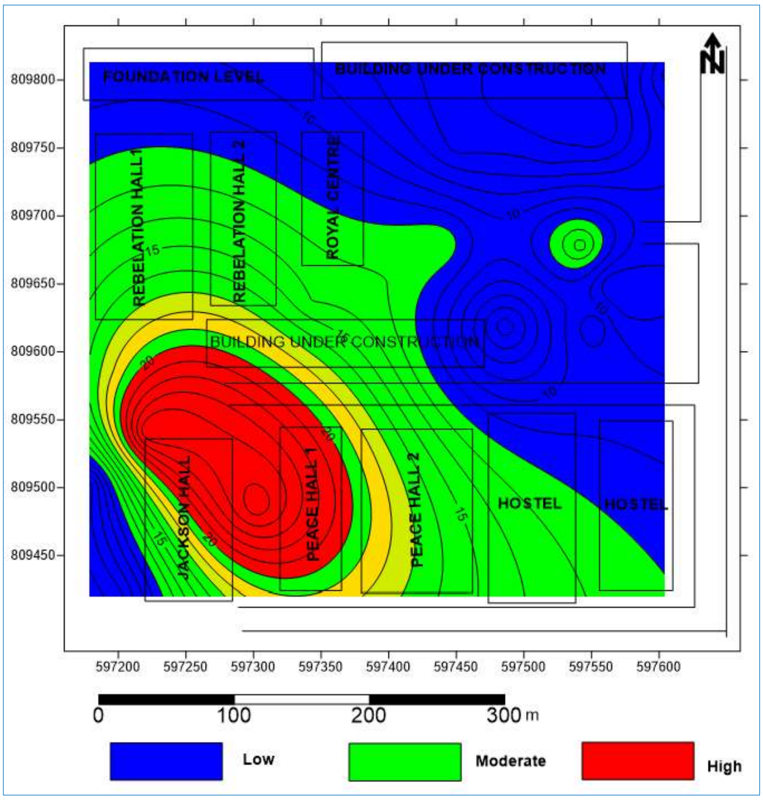

Fig. 8. Overburden thickness map of the study area

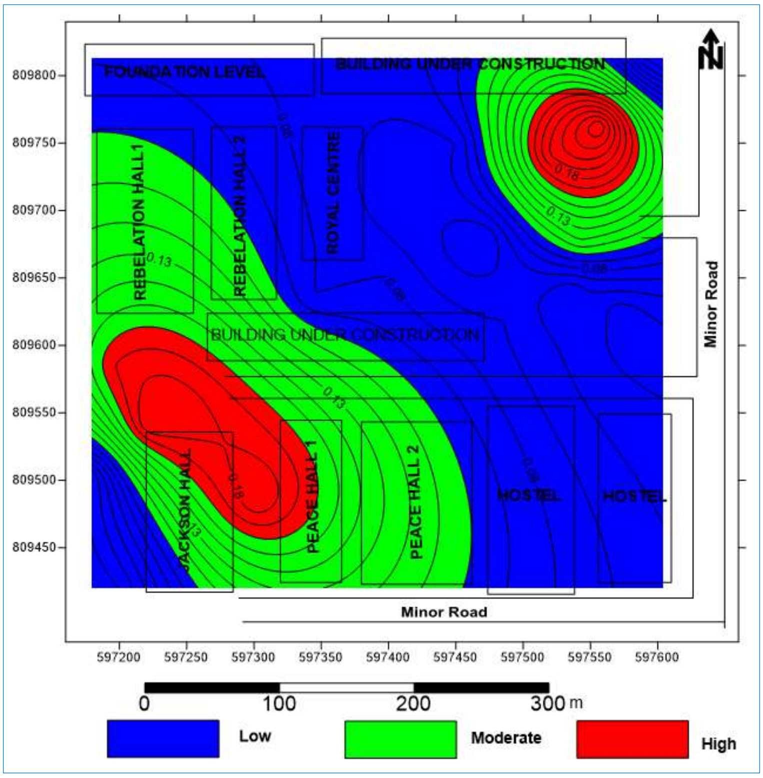

Fig. 9: Total longitudinal conductance map of the study area

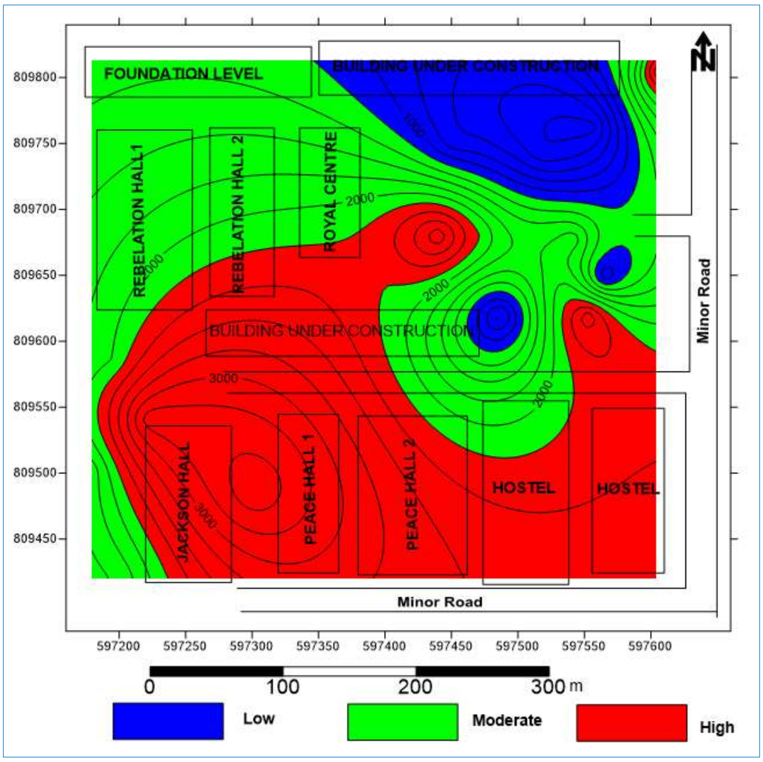

Fig. 10. Total transverse resistance map of the study area

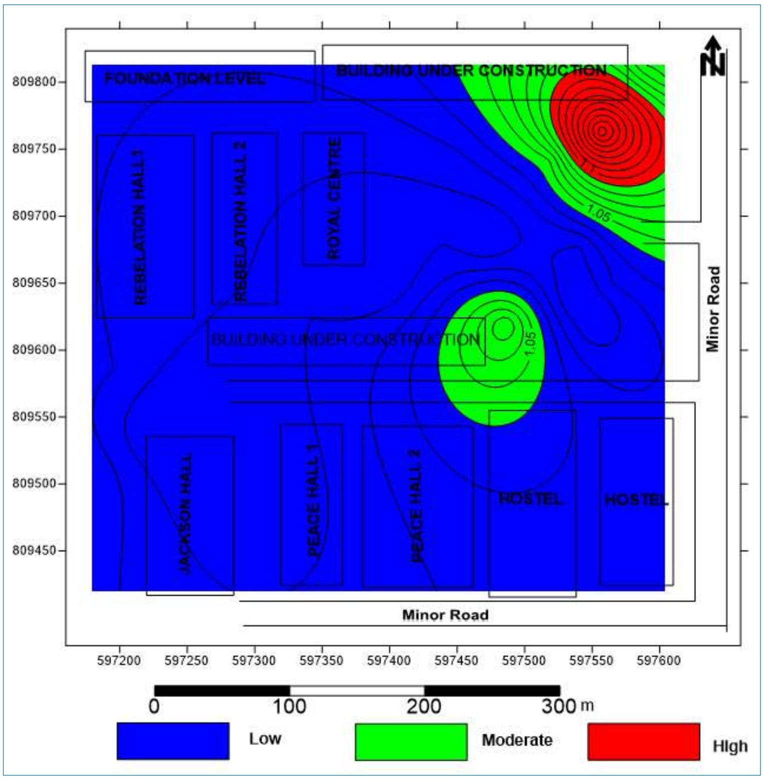

Fig. 11. Coefficient of anisotropy map of the study area

Consequently, it indicates the presence of macro-anisotropy in the present geoelectric structures in the area. The coefficient of anisotropy indicates it has high increases at NE direction and reaches a maximum value close to 1.18, as shown in anisotropy map. It indicates that this physical property is not uniform in all directions and anisotropy plays a major role in fracturing. Here, it indicates more fracturing toward NE direction and thus suggests comparatively more groundwater potential zone and hence better prospect for groundwater availability.

4.5. Modeling of groundwater potential map

The groundwater potential map was generated by integration of the coefficient of anisotropy, overburden thickness, aquifer resistivity and aquifer thickness using multi-criteria evaluation techniques. The groundwater potential rate (*R*) gives the ranges of groundwater storage potentiality within each parameter. Each parameter was classified and rated based on their hydrogeological significance. However, since resistivity and thickness do not have the same units, a unified scaling technique was adopted in rating these parameters according to their degree of influence on groundwater occurrence. Different types of lithology with different resistivity and thickness ranges will have different groundwater occurrence (Ariff et al., 2008, Fechner, 1965 and Thurstone, 1927 cited in Ilugbo et al., 2019). Therefore, different range of values or features should have a different rating (*R*) in a scale according to its importance in accumulating groundwater.

In this study, each parameter has been scored in the 1–3 scale in the ascending order of hydrogeologic significance. However, the resistivity range of any given rock type is wide and overlaps with other rock types. Therefore, different types of lithology may have same resistivity values. The integration of the coefficient of anisotropy, overburden thickness, aquifer resistivity and aquifer thickness in the area were considered to obtain the classifications and ratings shown in Table 1.

The weighted linear combination (WLC) is applied according to the following equation to estimate the GWPI. This technique is usually specified in terms of normalized weightings (*w*) for each criterion as well as rating scores (*R*) for all classes relative to each of the criteria. The final utility GWPI for each option O_i is then calculated as follows:

$$GWPI = W_i R_i \tag{3}$$

where w_i is the weight (*w*) of parameter *i* and R_i is the rating score (*R*) of parameter *i* (Table 1). Therefore, the groundwater potential index (GWPI) for each VES locations was computed using

$$GWPI = CA_W CA_R + OT_W OT_R + AR_W AR_R + AT_W AT_R \tag{4}$$

The subscripts *w* and *R* indicate weights and ratings for each parameter, respectively. The GWPI obtained for all the locations is shown in Table 2.

Table 1. Probability rating (R) for classes of the parameters

Influencing Factors	Category (Classes)	Potentiality for Groundwater Storage	Rating (R)	Normalized Weight (W)
Coefficient of Anisotropy (CA)	1.00 – 1.03 1.03 – 1.08 1.08 – 1.18	Low Moderate High	1 2 3	0.48
Overburden Thickness (OT)	4.9 – 10 10 –15 15 – 25.7	Low Moderate High	1 2 3	0.28
Aquifer Resistivity (AR)	17 – 100 100 – 190 190 – 282	Low High Moderate	1 3 1	0.18
Aquifer Thickness (AT)	3.4 – 6 6 – 11 11 – 25.7	Low Moderate High	1 2 3	0.06

Table 2. Groundwater potential index estimation

VES Locations	CA (W=0.48)		OT (W=0.28)		AR (W=0.18)		AT (W=0.06)		GWPI
	R	WXR	R	WXR	R	WXR	R	WXR	∑WXP
1	1	0.48	2	0.56	1	0.18	3	0.18	1.40
2	1	0.48	2	0.56	1	0.18	3	0.18	1.40
3	1	0.48	1	0.28	1	0.18	2	0.12	1.06
4	1	0.48	1	0.28	3	0.54	3	0.18	1.48
5	1	0.48	1	0.28	3	0.54	2	0.12	1.42
6	1	0.48	1	0.28	3	0.54	3	0.18	1.48
7	1	0.48	2	0.56	2	0.36	3	0.18	1.58
8	2	0.96	2	0.56	2	0.36	2	0.12	2.00
9	1	0.48	1	0.28	3	0.54	2	0.12	1.42
10	3	1.44	3	0.84	1	0.18	2	0.12	2.02
11	3	1.44	1	0.28	1	0.18	1	0.06	1.96
12	1	0.48	2	0.56	1	0.18	3	0.18	1.40
13	2	0.96	1	0.28	2	0.36	1	0.06	1.66
14	1	0.48	1	0.28	1	0.18	2	0.12	1.06
15	1	0.48	2	0.56	3	0.54	3	0.18	1.76
16	2	0.96	2	0.56	1	0.18	3	0.18	1.88
17	1	0.96	2	0.56	3	0.54	2	0.12	2.18
18	3	1.44	1	0.28	2	0.36	1	0.06	2.14
19	2	0.96	1	0.28	3	0.54	1	0.06	1.84
20	2	0.96	1	0.28	2	0.36	1	0.06	1.66

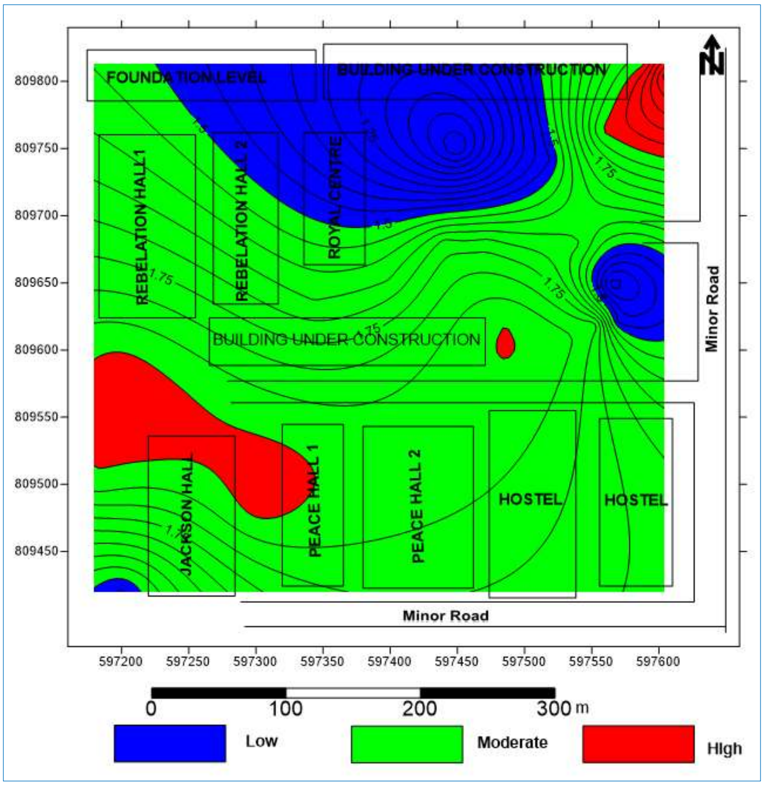

Fig. 12. Groundwater potential map of the study area

The groundwater potential index obtained for each location was interpolated, using Surfer 12 software to produce the groundwater prospect map shown in Fig. 12 and the zones are summarized in the Table 3. It was observed in some parts of northeastern and southwestern parts are indicative of high groundwater prospect zone. Moderate groundwater prospect zone was observed at the northern, eastern, southwestern, southeastern and northwestern parts of the study area. Also, the low groundwater prospect zone was observed at the northwestern, northern and northeastern parts of study area.

Table 3. Groundwater potential classifications

Groundwater Potential Values	Classifications
1.0 – 1.45 (Blue)	Low
1.45 – 1.85 (Green)	Moderate
1.85 – 2.17 (Red)	High

4. Conclusions

A geoelectric investigation of groundwater potential in some part of Lead City University Ibadan, southwestern Nigeria was carried out with a view to providing information on the geoelectric characteristic of the subsurface sequence, bedrock topography, subsurface structural features and their hydrogeologic significance, in order to identify aquifer units and determine possible areas for groundwater potential zones. We proposed an accurate way to integrate all the parameters that are significant to evaluate groundwater potential. The approach is based on the principle of MCE in the context of the AHP. It allows the weighting and integrating of all the parameters in the order of their relative importance to groundwater occurrence. The method was used to prepare a prediction map for groundwater potentials in the area of our case study. In addition to this, the geoelectric parameters were used to characterize the geological setting and the hydrogeological conditions of the area as well as to evaluate and assess the aquifer of the area. The results obtained from this study show that the integration of the data handling method proposed in this study with geophysical technique can provide inexpensive, reliable and accurate method for characterizing, assessing and evaluating an aquifer system. The method can also be adopted in other geophysical studies, where challenges of making accurate and reliable decision from set of multiple criteria are faced. The investigated area has been classified into low, moderate and high groundwater potential zones. It was observed in some parts of northeastern and southwestern parts are indicative of high groundwater prospect zone. Moderate groundwater prospect zone was observed at the northern, eastern, southwestern, southeastern and northwestern parts of the study area. Also, the low groundwater prospect zone was observed at the northwestern, northern and northeastern parts of the study area. From the results obtained, it indicates that the investigated area is an area of low to moderate groundwater prospect.

Data Availability Statement

The authors confirm that the data supporting the findings of the study are available within the article and its supplementary materials. Authors have declared that no competing interests exist and the data was not use as an avenue for any litigation but for the advancement of knowledge.

References

Adebo, B.A., Layade, G.O., Ilugbo, S.O., Hamzat, A.A., Otobrise, H.K., 2019. Mapping ofSubsurface Geological Structures using Ground Magnetic and Electrical Resistivity Methods within Lead City University, Southwestern Nigeria. Kada Journal of Physics 2 (2), 64-73.

Adebo, A.B., Ilugbo, S.O., Oladetan, F.E., 2018. Modeling of Groundwater Potential Using Vertical Electrical Sounding (VES) and Multi-caterial Analysis at Omitogun Housing Estate, Akure, Southwestern Nigeria. Asian Journal of Advanced Research and Reports 1 (2), 1-11.

Ademeso, O.A., Adekoya, J.A., Adetunji, A., 2013. Further evidence of cataclasis in the ife ilesa schist belt, Southwestern Nigeria. Journal of Natural Sciences Research 3 (11), 50-59.

Adelusi, A.O, Balogun, O., 2001. A geoeletric investigation for groundwater development of Orita Obele area, near Akure SW Nigeria. Global Journal of Pure and Applied Sciences 7 (4), 707-717.

Adebiyi, A.D., Ilugbo, S.O., Bamidele, O.E., Egunjobi, T., 2018. Assessment of Aquifer Vulnerability Using Multi- Criteria Decision Analysis around Akure Industrial Estate, Akure, Southwestern Nigeria. Journal of Engineering Research and Reports 3 (3), 1-13.

Adesola, B.M., Abdul-Nafiu, A.K., Adewale, A.A., Olubusola, I.S., Omowonuola, A.F., Taiwo, O.B., Akinola, O.A., Adunola, B.O., Olusola, O.O., Zayyanu, M.U., 2020. Resistivity Contrast andthe Phenomenon of Geophysical Anomaly in Groundwater Exploration in A Crystalline Basement Environment, Southwestern Nigeria. International Journal of Earth Sciences Knowledge and Applications 3 (1) 23-36.

Al-Amoush, H.R., 2010. Integration of Vertical Electrical Sounding and Aeromagnetic DataUsing GIS Techniques to Assess the Potential of Unsaturated Zone and Natural Basalt Caves for Groundwater Artificial Recharge in NE-Jordan international Jordan Journal of Civil Engineering 4 (4), 389-408.

Amadi, A.N., Olasehinde, P.I., 2010. Application of Remote Sensing Techniques in Hydrogeological Mapping of Parts of Bosso Area, Minna, North-Central Nigeria. International Journal of the Physical Sciences 5, 1465-1474.

Anifowose, A.Y.B., Borode, A.M., 2007. A Photogeological study of the fold structure in Okemesi Area. Niger. Journal of Mining and Geology 43 (2), 125-130.

Anudu, G.K., Onwuemesi A.G, Ajaegwu N.E, Onuba L.N, Omali A.O., 2008. Electrical resistivity investigation for groundwater in the Basement Complex terrain: a case study of Idi Ayunre and its environs, Oyo State, Southwestern Nigeria. Natural and Applied Sciences Journal 9 (2), 1-12.

Ariff, H., Salit, M.S., Ismail, N., Nukman, Y., 2008. Use of Analytical Hierarchy Process (AHP) for selecting the best design concept. Jurnal Teknologi, 49 (A), 1-18.

Bawallah, M.A., Ofomola, M.O., Ilugbo, S.O. Aina, A.O., Olaogun, S.O., Olayiwola, K.O, Awoniran D.R., 2020. Effect of Lineament and drainage orientation on groundwater potential of Moro Area Central Kwara State Nigeria. Indian Journal of Science and Technology 13 (10), 1124-1134.

Bawallah, M.A., Aina, A.O., Ilugbo, S.O., Ozegin, K.O., Olasunkanmi, K.N., 2018. Evaluation of Groundwater Yield Capacity Using Dar-zarrouk Parameter of Central Kwara State, Southwestern Nigeria. Asian Journal of Geological Research 1 (1), 1-13.

Djamel, B., 2017. Combining Resistivity and Aeromagnetic Geophysical Surveys for Groundwater Exploration in the Maghnia Plain of Algeria. Journal of Geological Research 1309053, 1-14.

Fechner, G.T., 1965. Elements of Psychophysics. Volume 1, (Holt, Rinehart and Winston, New York 1965); translation by H.E.Adler of Elemente der Psychophysik. (Breitkopf und Haˆrtel, Leipzig 1860).

Ilugbo, S.O., Adebo, B.A., Olomo, K.O., Adebiyi, A.D., 2018a. Application of Gis and multi criteria decision analysis to geoelectric parameters for modeling of groundwater potential around Ilesha, Southwestern Nigeria. European Journal of Academic Essays 5 (5), 105-123.

Ilugbo, S.O., Adebiyi, A.D., Olomo, K.O., 2018b. Modeling of Groundwater Yield Using GIS and Electrical Resistivity Method in a Basement Complex Terrain, Southwestern Nigeria. Journal of Geography, Environment and Earth Science International 16 (1), 1-17.

Ilugbo, S.O., Edunjobi, H.O., Alabi, T.O., Ogabi, A.F., Olomo, K.O., Ojo, O.A., Adeleke, K.A., 2019. Evaluation of Groundwater Level Using Combined Electrical Resistivity Log with Gamma (Elgg) around Ikeja, Lagos State, Southwestern Nigeria. Asian Journal of Geological Research 2 (3), 1-13.

Ilugbo, S.O., Adebiyi, A.D., 2017. Intersection of lineaments for groundwater prospect analysis using satellite remotely sensed and aeromagnetic dataset around Ibodi, Southwestern Nigeria. International Journal of Physical Sciences 12 (23), 329-353.

Joel, E.S., Olasehinde, P.I., De, D.K., Maxwell, O., 2016. Regional Groundwater Studies Using Aeromagnetic Technique. Adapted from extended abstract based on oral presentation given at AAPG/SEG International Conference & Exhibition (September 6-9, 2016), Cancun, Mexico.

Miller, R., 2006. Hydrogeophysics: Introduction to this special section. The Leading Edge. P.713. Sundararajan N, Nandakumar G, Chary NK Ramam K, Srinivas Y. 2007. The Leading Edge. pp. 708-715.

Ndikilar, C.E., Idi, B.Y., Terhemba, B.S., Idowu, I.I., Abdullahi, S.S., 2019. Applicationsof Aeromagnetic and Electrical Resistivity Data for Mapping Spatial Distribution of Groundwater Potentials of Dutse, Jigawa State, Nigeria. Modern Applied Science 13 (2), 11-20.

Oladapo, M.I., Mohammed, M.Z., Adeoye, O.O., Adetola, B.A., 2004. Geoelectrical investigations of the Ondo state Housing Corporation Estate Ijapo Akure, Southwestern Nigeria. Journal of Mining and Geology 40 (1), 41-48.

Olurotimi, A.J., Faruwa, R.A., Komolafe, A.A., 2015. Integrated Landsat Imagery and Geophysical Exploration for Groundwater Potential Evaluation of Okene and Its Environs, Southwestern Nigeria. International Journal of Geosciences 6, 209-229.

Omosuyi, G.O., Ojo, J.S., Enikanselu, P.A., 2003. Geophysical Investigation for groundwater around Obanla-Obakekere in Akure area within the basement complex of southwestern Nigeria. Journal of Mining and Geology 39 (2), 109-116.

Oyedele, A.A., 2019. Use of remote sensing and GIS techniques for groundwater exploration in the basement complex terrain of Ado-Ekiti, SW Nigeria. Applied Water Science 9, 51.

Preeja, K.R., Sabu, J., Jobin, T., Vijith, H., 2011. Identification of Groundwater Potential Zones of a Tropical River Basin (Kerala, India) Using Remote Sensing and GIS Techniques. Journal of the Indian Society of Remote Sensing 39 (1), 83-94.

Pietersen, K., 2006. Multiple criteria decision analysis (MCDA): A tool to support sustainable management of groundwater resources in South Africa. Water SA 32 (2), 119-128.

Rahaman, M.A., 1976. Review of the basement of S.W. NigeriaInc. Kogbe (ed) Geology of Nigeria. Elizabethan press, Lagos, pp. 41-58.

Rahaman, M.A., 1988. Recent advances in the study of the basement complex of Nigeria. In Precambrian geology of Nigeria, Geological survey of Nigeria, Kaduna South. pp. 11-43.

Thurstone, L.L., 1927. A law of comparative judgements. Psychological Reviews 34, 273-286.

Vander-Velpen B.P.A., 2004. RESIST Version 1.0. M.Sc. Research Project, ITC, Delft, the Netherland.

Zeyad, J.A., 2013. Lineament extraction for assessment of groundwater potential in west of Iraq. Euphrates Journal of Agriculture Science 5 (1), 54-63.