IOSR Journal of Applied Geology and Geophysics (IOSR-JAGG)
e-ISSN: 2321–0990, p-ISSN: 2321–0982.Volume 6, Issue 3 Ver. II (May. – June. 2018), PP 58-67
www.iosrjournals.org

Modeling Of Groundwater Potential Using GIS And Multi-Criteria Decision Analysis Around Kwara State, Southwestern Nigeria.

Bawallah M.A.[1,2], Aina A.O.[1], Ilugbo S.O.[2*], Olufemi B.[1,] ,Olasunkanmi N.K.[1]
Olaogun S.O,[2], Ajayi-Gidi I.O.[2]
[1]*Department of Geological, Chemical and Physical Sciences, Kwara State University Malete.*
[2]*Department of Applied Geophysics, Federal University of Technology, Akure, Ondo State, Nigeria*
**Corresponding Author; Bawallah M.A*

Abstract: *A geoelectric investigation of groundwater prospect around Kwara State, within the basement complex of 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. The study involved the use of Schlumberger vertical electrical sounding data at seventy three (73) stations. Groundwater potential map was also generated from the integration of geoelectric parameterss using multi-criteria evaluation techniques. The results obtained from this study illustrate 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. Groundwater potential map was also generated from the integration of these maps using multi-criteria evaluation techniques. The study area has been classified into low, moderate, high groundwater potential zones and the results from borehole data and hand pump well data across the entire study area were used to validate the accuracy of the groundwater potential map. From the results obtained, it could be concluded that the study area is an area of low groundwater potential.*

Key words: *Coefficient of anisotropy, Groundwater yield, Overburden thickness, Multi-criteria decision analysis, Aquifer resistivity, GIS*

Date of Submission: 02-06-2018 Date of acceptance: 18-06-2018

I. Introduction

Groundwater is one of the most valuable natural resources on the earth surface and serves as one of the main sources of drinking water. Basement complex have problem of potable groundwater supply due to the crystalline nature of the underlying rock which lack primary porosity [12]. Groundwater storage capacity in those areas is dependent on depth of weathering and intensity of fracturing of the underlying rock. For basement complex rock to become good aquifers, they must be highly fractured and highly weathered. 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 [3], [2]. In typical basement complex areas such as the study area, the occurrence of groundwater in recoverable quantity as well as its circulation is controlled by geological factors *i.e.* faults, joints and fracture zones [13], [2]. Therefore to target potential basement aquifers that can give copious supply of groundwater in these areas, the aforementioned geologic features must be intercepted by boreholes. Thus, groundwater potential of a basement complex area is determined by a complex interrelationship between the geology, post-emplacement, tectonic history, weathering processes and depth, composition of the weathered layer, aquifer types and combination, groundwater flow pattern, climate, recharge and discharge processes [11]. 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. In other words, prediction of groundwater resources potential is a spatial decision problem that typically involves a large set of feasible alternatives and multiple evaluation criteria. Most of the time, these criteria are often evaluated by a number of experts. Aquifer resistivity and thickness have been identified as parameters of hydrogeologic importance that can be used to evaluate groundwater potential of an area [16] citied in [1]. However, some workers see the overburden thickness (i.e. geologic materials that overlie the aquifer) as an important factor that must be considered in evaluating groundwater potential of an area [14] citied in [1], others workers maintained that the factor is of little or no effect, and hence might not be considered during evaluation process [16] citied in [1].

In order to produce a groundwater potential map of higher reliability precision in a given study area, the effects of all the important parameters (geoelectric) that can contribute to the groundwater occurrence in the area must be integrated [1]. However, the methodology of integrating these parameters, such that the relative importance of each is reflected, is still a challenge that has not been efficiently handled. [17], [16] proposed a method for the estimation of Ground water Potential Index (GWPI) at various locations. They showed that the GWPI obtained in this process gives an accurate measurement of ground water potential. However, apart from the fact that the assignment of weights to the parameters was largely subjective, the studies did not also account for the inconsistency that is most likely to characterize such subjective weight assignments [1]. The principle of multicriteria decision analysis (MCDA) in the context of the analytical hierarchy process (AHP) have been adopted by several researchers with the aim of predicting model of higher reliability and precision [1], [5], [8]. The proposed technique is applied to geoelectric parameters derived from electrical resistivity method to evaluate the groundwater popential. The advantage of the proposed technique is that it reduces bias in decision making because it provides a useful mechanism for checking the consistency of the evaluation measures and alternatives suggested by experts [1], [6]. Therefore, this research employed electrical resistivity method with the aim of modeling the groundwater potential.

The present study is to determine the geoelectric parameters in evaluating the groundwater potential of the study area. The groundwater stored is referred to as an aquifer. An aquifer has ability to store and transit water.

Site Description and Geology of the Study Area

The area is geographically enclosed within latitude 8^0 31' 0"N to 8^0 43' 0"N and longitude $4^0$28'00"N to 4^0 34' 0"E, It is sandwich between four local government areas, within the Central of Kwara State in present Nigeria. Moro Local Government to the North and North Eastern part of the study area, Asa Local Government to the West, and Kwara West and Kwara East Local Government to the South of the study area. The area is made up of about forty (40) Towns and Villages accessibility is through major and minor road networks. The topography is generally undulating (Figure 1) with some areas characterized by hilly ridges and gentle steeps. The area enjoys a tropical climate with two distinct seasons, comprising of rainy season (April to October) and dry season (November to March) with the temperature ranging between 23^0C to 32^0C and dry season. The study area is located within north Central Basement Complex region of Nigeria. It belongs to the Precambrian Basement Complex (Figure 2). It is made up of mainly older granite towards the North Western part of the study area, while the rest is of the undifferentiated basement complex rock. The hydrogeology of the study area consists of streams, rivers, drainage and geological structures (like faults, fractures, crack, joints and weathered materials).

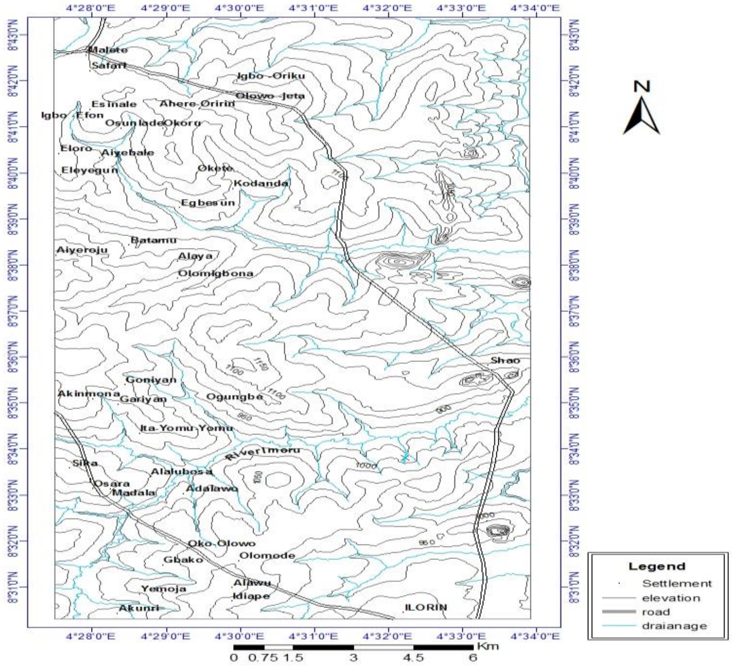


Figure 1. Location Map of the Study Area

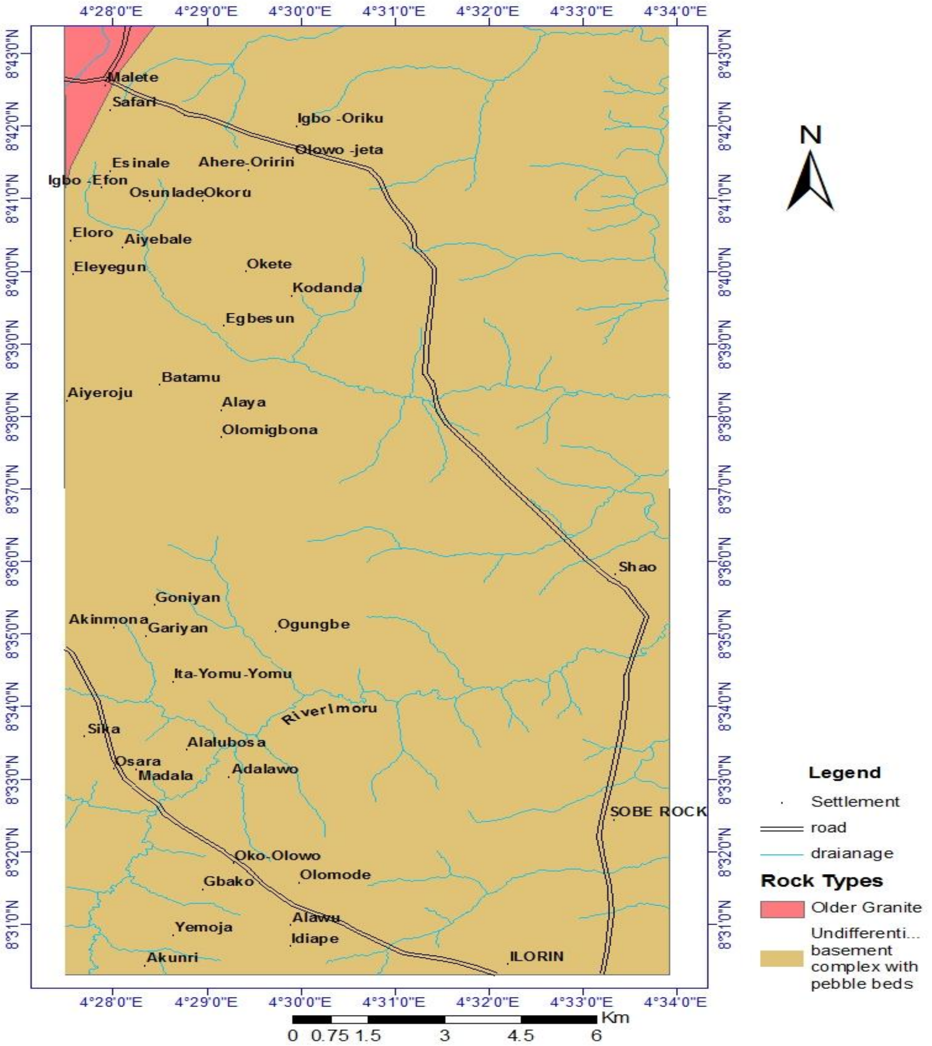


Figure 2. Geological Map of the Study Area

II. Methodology

The Schlumbeger depth sounding was used to investigate the change of resistivity with depth [9], [4]. 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 vertical electrical sounding (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 [18] that is based upon an algorithm of [7]. The quantitatively interpreted sounding curves gave interpreted results as geoelectric parameters (that is, layer resistivity and layer thickness). The choice among a set of zones for evaluation of groundwater potentiality has been based upon multiple criteria decision analysis such as coefficient of anisotropy, aquifer resistivity, Groundwater yield and overburden thickness. The process is known as Multi-Criteria Evaluation (MCE). For a Multi-criterial Modelling, firstly a template has been created by identifying the quadtrees used in the analysis. The number of input quadtrees that can be selected is reduced to one less than the total number. A default weight is calculated by dividing 100 by the number of quadtrees used in the overlay and is assigned to each quadtree class. Each class is labeled with the short legend title taken from the input quadtree. 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. A summation of these values led to the generation of final weight map.

Mathematically, this can be defined as:

GW = f(CA, AT, GY, OT) Where, GW is groundwater, CA is coefficient of anisotropy, AR is aquifer resistivity, GY is groundwater yield and OT is overburden thickness. The groundwater potential index value, thus derived is given by equation:

$GWPI = \sum WiCVi$; with $\sum Wi = 1$;

Where, GWPI is the groundwater potential index value. Wi is the probability value of each thematic map, and CVi is the individual capability value to hold groundwater.

III. Result and Discussion

Aquifer Layer Resistivity Map

Figure 3 illustrate the aquifer resistivity map of the study area. The eastern part, down to the south eastern, and up to the north eastern, part of the south western end and pocket of the northwestern end of the study area has low aquifer resistivity. While the rest of the study area is characterized by moderate aquifer resistivity and a little pocket of the northwestern end has a high aquifer resistivity. it has geologic implication to groundwater occurrence in the study area. The aquifer of the entire area is good expected for the region of low aquifer resistivity.

Overburden Thickness Map

Figure 4 displays the overburden thickness map which shows the variation in overburden of the study area, from the topsoil down to the fresh bedrock. The overburden thickness varies from 1.4 to 42.7 m. the overburden thickness is very thin between 1.4 to 12 m at the north western extreme end, the central towards the eastern and part of the south western end, while it is moderately thick between 12 to 20 m in the rest of the area, expect for the part of the central and part of the south western end where the highest overburden thickness ranges between 20 to 42.7 m were recorded.

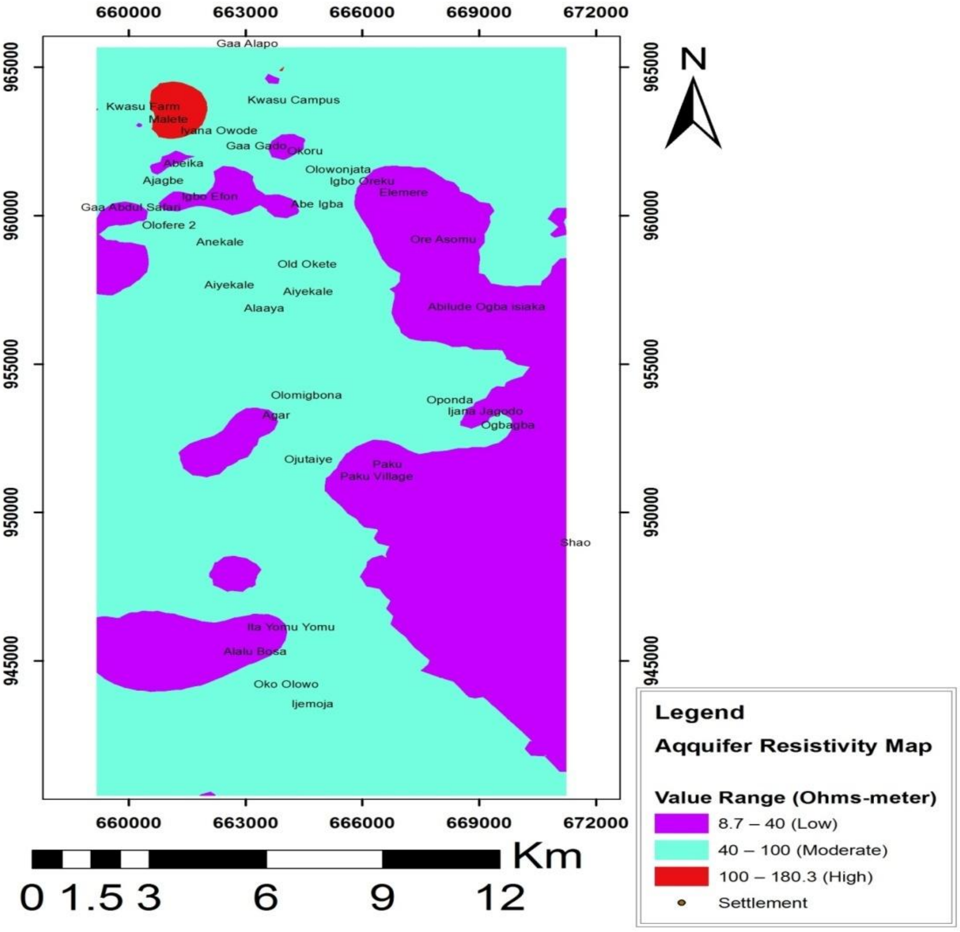


Figure 3. Aquifer Resistivity Map of the Study Area

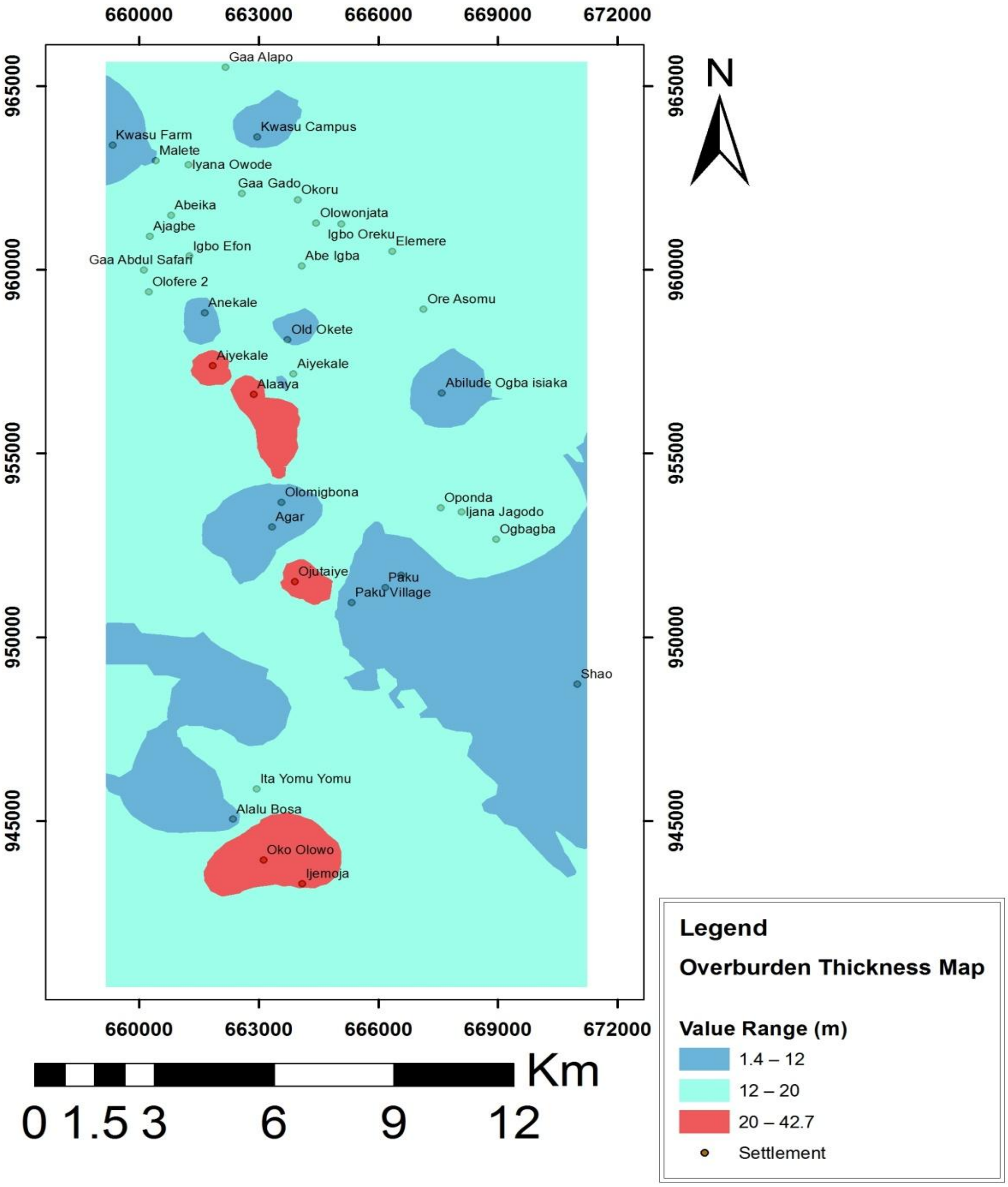


Figure 4**.** Overburden Thickness Map of the Study Area

Coefficient of Anisotropy Map

The coefficient of anisotropy is estimated along with the secondary geoelectric parameters. Based on these estimates it was found that the coefficient of anisotropy ranges from 0.06 to 1.96, which depicts the true variation of the anisotropy character of rock formation. 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. Consequently, it indicates the presence of macro-anisotropy in the present geoelectric structures in the area.

The coefficient of anisotropy is very high at North western, western and small pocket at south western part of the study area and reaches a maximum values 1.96, as shown in anisotropy map (Figure 5). 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 north western direction and thus suggests comparatively more groundwater potential zone and hence better prospect for groundwater availability.

Groundwater Yield Capacity

The Dar-zarrouk parameters are exclusively relevant in the lithological differentiation and delineation of aquifer geometry. In these applications, full advantage is taken of the combinations of thickness and resistivities into one single variable that is the coefficient of anisotropy which is used as bases for the evaluation of properties. However, in this present study, these parameters have been developed further through the application of the product of the coefficient of anisotropy (λ) and the total transverse resistance (T) i.e. (λ*T) to determine the groundwater yield index value which was found to be very relevant and useful in determination and evaluation of groundwater yield capacity.

The groundwater yield capacity index value was used to model the groundwater yield capacity map (Figure 6) which has a value ranging between 32 groundwater yield capacity index to 5945.59 groundwater yield capacity index, with the least rating being from 32.88 to 850 G.W.Y.I. which implies low yield, while between 850 to 3000 G.W.Y.I., implies moderate yield and 3000 to 5945 G.W.Y.I., implies high yield.

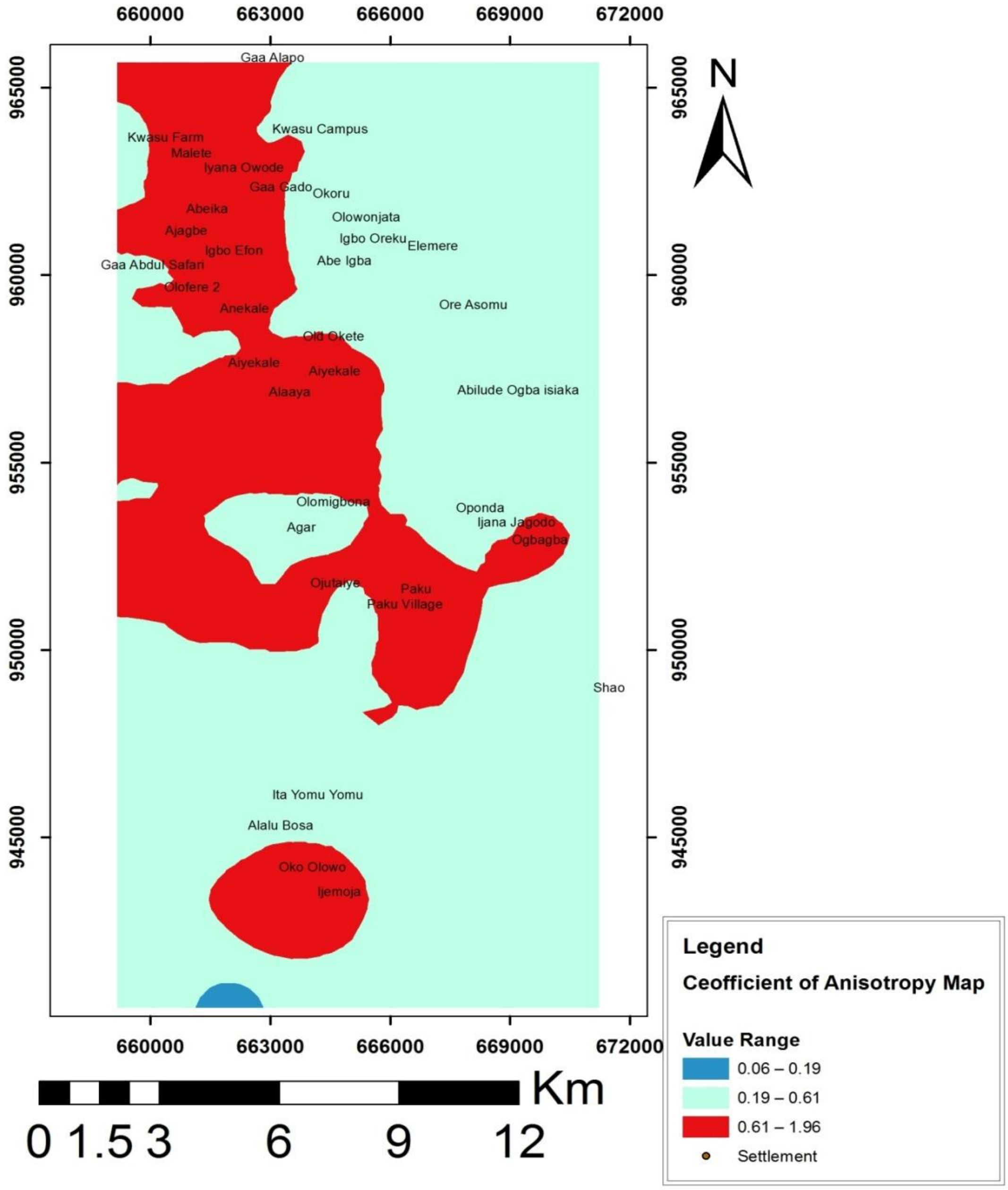


Figure 5 Coefficient of Anisotropy Map of the Study Area

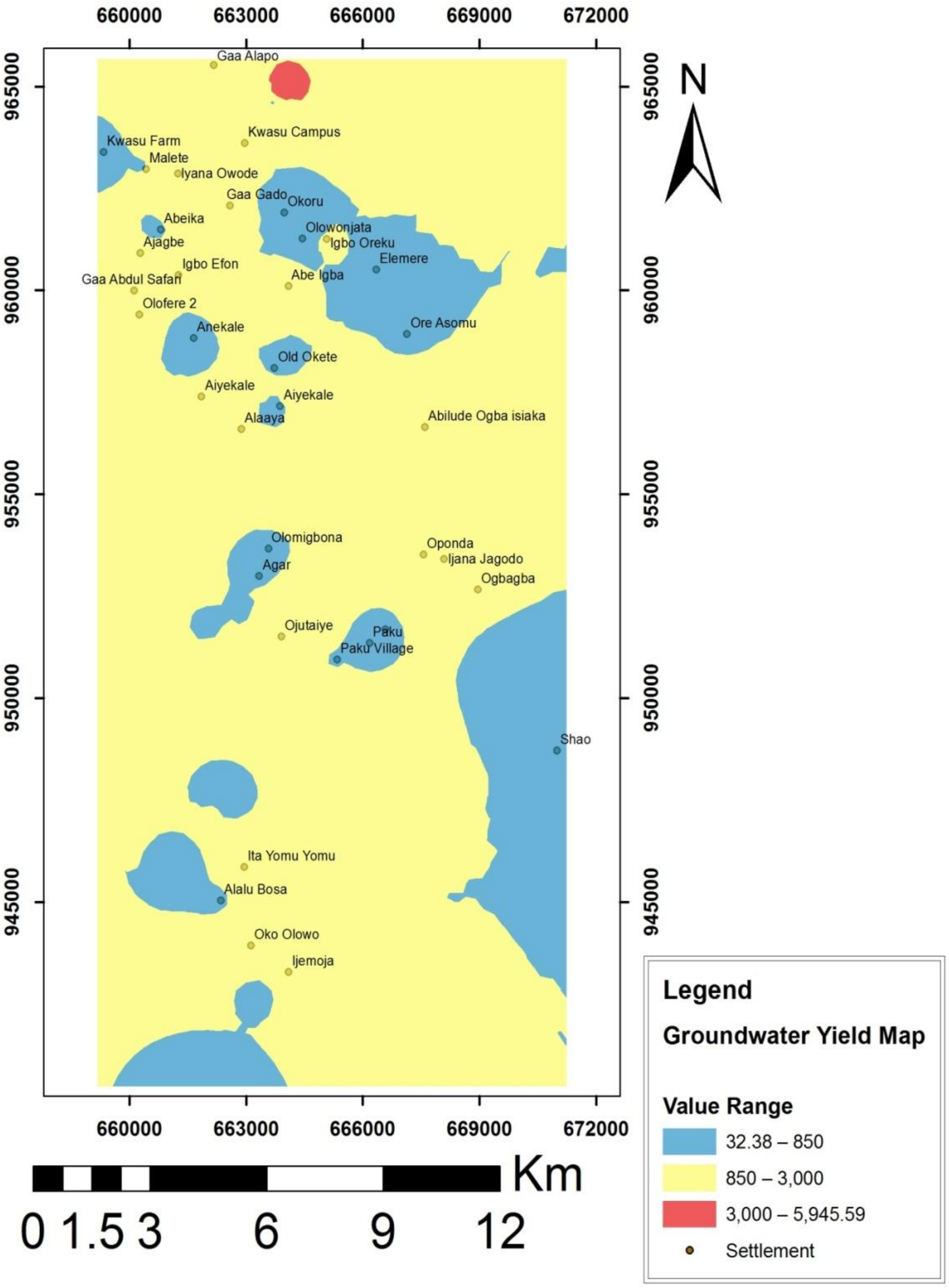


Figure 6. Groundwater Yield Capacity Map of the Study Area

Modeling of Groundwater potential

The groundwater potential rate (R) gives the ranges of groundwater storage potentiality within each parameter. Each parameter was classified and rated. 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 prospect. 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. Coefficient of anisotropy, aquifer resistivity, groundwater yield and overburden 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 groundwater potential index values (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 is then calculated as follows:

$GWPI = W_iR_i$

where w_i is the weight (w) of parameter i and R_i is the rating score (R) of parameter i (Table 1)

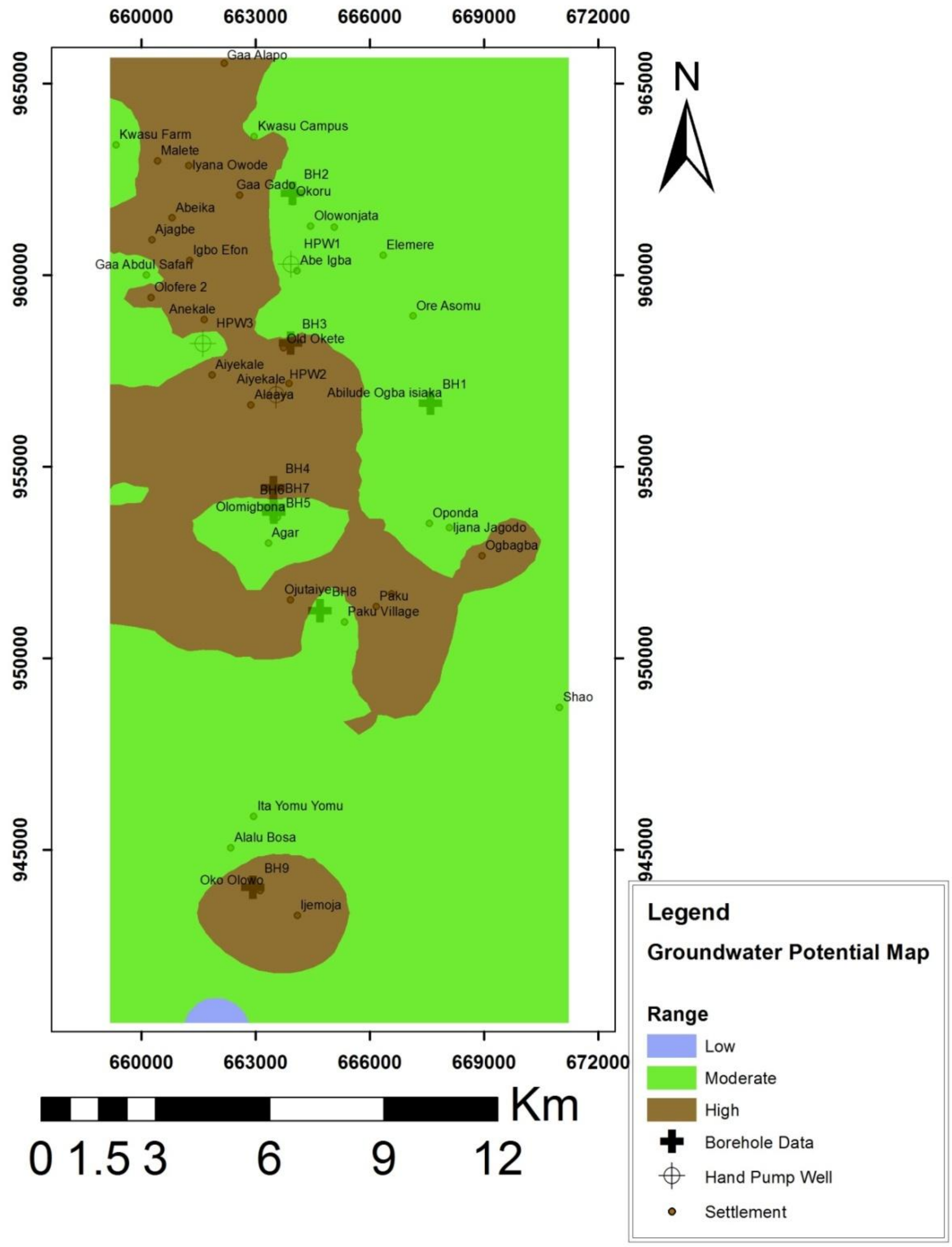
Therefore, the groundwater potential index (GWPI) for each VES locations was computed using

$GWPI = CA_WCA_R + AR_WAR_R + GY_WGY_R + OT_WOT_R$The subscripts w and R indicate weights and ratings for each parameter, respectively. The groundwater potential index obtained for each location was interpolated, using inverse distance weighting (IDW) techniques in ArcGIS 10.1 to produce the groundwater potential map shown in Figure 7 and the zones are summarized in Table 2.

The groundwater potential map is classified into three (3) with high groundwater potential which dominated the northern end, north western, south western and small closure at the southern part of the investigated area. Area with moderate groundwater potential dominated largest part of the study area and was observed at the part of the northern, north western, Middle Eastern, part of the centre and part of the south western central. Area with low groundwater potential dominated the smallest part of the area and was observed as small closure at the south western end. The boreholes data and hand pump well across the entire study area, were used to validate the accuracy of the groundwater potential map and hence of the proposed methodology. The locations and names descriptions of these boreholes and hand pump well were displayed on the groundwater potential map Figure 7. The validation was carried out by superimposing the boreholes and hand pump well data on the groundwater yield capacity map.

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)	0.06 – 0.19 0.19 – 0.61 0.61 – 1.96	Low Moderate High	1 2 3	0.48
Groundwater Yield (GY)	32 – 850 850 – 3000 3000 - 5945	Low Moderate High	1 2 3	0.28
Overburden Thickness (OT)	1.4 - 12 12 - 20 20 – 42.7	Low Moderate High	1 2 3	0.18
Aquifer Resistivity (AR)	8.7 - 40 40 - 100 100 - 180	Low Moderate Moderate	1 2 3	0.06



Groundwater Potential Map of the Study Area

Table 2. Groundwater Potential Classifications

Groundwater Potential Value	Classification
1.1 – 2.1	Low
2.1 – 2.9	Moderate
2.9 – 3.5	High

IV. Conclusion

A geoelectric investigation of groundwater potential around Ilesha, 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 MCDA 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 very low, low, moderate and high groundwater potential zones and the results from borehole and well data across the entire study area were used to validate the accuracy of the groundwater potential map.

The groundwater potential map is classified into three (3) with high groundwater potential which dominated the northern end, north western, south western and small closure at the southern part of the investigated area. Area with moderate groundwater potential dominated largest part of the study area and was observed at the part of the northern, north western, Middle Eastern, part of the centre and part of the south western central. Area with low groundwater potential dominated the smallest part of the area and was observed as small closure at the south western end. The boreholes data and hand pump well across the entire study area, were used to validate the accuracy of the groundwater potential map and hence of the proposed methodology. The locations and names descriptions of these boreholes and hand pump well were displayed on the groundwater potential map. The validation was carried out by superimposing the boreholes and hand pump well data on the groundwater yield capacity map.

References

[1]. K.A.N. Adiat, M.N.M. Nawawi and K. Abdullah, “Application of Multi-Criteria DecisionAnalysistoZGeoelectric andGeologyParameters for Spatial Prediction of Groundwater Resources Potential and Aquifer Evaluation”, Pure Appl. Geophys, Vol. 170, No. 3, 170, 453–471 ISSN 0033 4553, (2013)

[2]. A.N. Amadi and P.I. Olasehinde, “Application of Remote Sensing Techniques in Hydrogeological Mapping of parts of Bosso Area, Minna, North Centra Nigeria”. International Journal of the Physical Sciences, 5, 1465-1474, (2010).

[3]. G. K. Amudu, A. G. Onwuemesi, N. E. Ajaegwu, L. N. Onuba and A. O. Omali, “Electrical resistivityinvestigation for groundwater inthe Basement Complex terrain: acase study of Idi-Ayunre and its environs, Oyo State, Southwestern Nigeria”, Natural andAppliedSciences Journal, 9(2), 1-12, (2008).

[4]. R. Barker, I. Blunk and I. Smith, “Geophysical consideration in the design of U.K. National Resistivity Sounding database. First Break” 14(2):45-53, (1996),

[5]. M. Deepesh, K. Madan and C. Bimal, “Assessment of groundwater potential in a semi arid region of india using remote sensing, GIS and MCDM techniques”. Water Resource Manage 25:1359-1386, (2010).

[6]. A.E. Edet and C.S. Okereke, “Assessment of hydrogeological conditions in basement aquifers of the Precambrian Oban massif, southwestern Nigeria”, Journal ofApplied Geophysics, 36(1997), 195–204, (1996).

[7]. D.P. Ghosh, “The application of linear filter theory to the direct interpretation of geoelectrical resistivity sounding measurements” Geophys. Prospecting 19:192-217, (1971).

[8]. T. Kardi, “Analytic Hierarch Process (AHP) Tutoria (accessed on the 10th June, 2009)”, (2006).

[9]. G. Kunetz, “Principles of Direct current prospecting”, Geophys. Monogr. 1(1):103, (1966).

[10]. M.A. Olade, “General features of a Precambrian iron deposit and its environment at Itakpe Ridge Okene, Nigeria”, Trans. Inst. Min. Metallurgy, Sect. B87 pp. 81-89, (1978).

[11]. M.O. Olorunfemi, “Voyage on the skin of the earth”: A geophysical experience. Inaugural Lecture Series 211, Obafemi AwolowoUniversity, Ile-Ife, pp. 1-2, (2007).

[12]. M.O. Olorunfemi and S.A. Fasuyi, “Aquifer Types and theGeoelectric/Hydrogeologic Characteristics of Part of the Central Basement Terrain of Nigeria (Niger State)”, Journal of African Earth Sciences, 16, 309-317, (1993).

[13]. M.O. Olorunfemi, V.O. Olarewaju and O. Alade, “On the Electrical Anisotropy andGroundwater Yield in a Basement complex Area ofS.W. Nigeria”, J. Afr. Earth Sci. 12(3):462-472, (1991).

[14]. M.O. Olorunfemi, “The hydrogeological implication of topographic variation withoverburden thickness in Basement Complex area of S.W.Nigeria”, J. Min. Geol., 26(1), 145–152, (1990).

[15]. M.A. Rahaman, “Review of the basement of S.W. NigeriaInc. Kogbe (ed) Geology of Nigeria”, Elizabethan press, Lagos, pp. 41 – 58, (1976).

[16]. B.V. Rao and B.H. Briz-Kishore, “A methodology for locating potential aquifers ina typical semi-arid region in India usingresistivityand hydrogeologic parameters. Geoexploration”, 27, 55 64, (1991).

[17]. S. Shahid and S.K. Nath, “GIS integration of remote sensing and electrical soundingdata for hydrogeological exploration”, J Spat Hydrol, 2(1), 1–10, (2002).

[18]. B.P.A. Vander Velpen, “RESIST Version 1.0. M.Sc. Research Project, ITC, DelftNetherland”, (2004).

Bawallah M.A "Modeling Of Groundwater Potential Using Gis And Multi-Criteria Decision Analysis Around Kwara State, Southwestern Nigeria." IOSR Journal of Applied Geology and Geophysics (IOSR-JAGG) 6.3 (2018): 58-67.