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Application of multi-criteria decision analysis in prediction of groundwater resources potential: A case of Oke-Ana, Ilesa Area Southwestern, Nigeria

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ABSTRACT

Groundwater Potential of Oke-Ana area southwestern Nigeria have been evaluated using the integration of electrical resistivity method, remote sensing and geographic information systems. The effect of five hydrogeological indices, namely lineament density, drainage density, lithology, overburden thickness and aquifer layer resistivity on groundwater occurrence was established. Multi-criteria decision analysis technique was employed to assign weight to each of the index using the concept of analytical hierarchy process. The assigned weight was normalized and consistency ratio was established. In order to evaluate the groundwater potential of Oke-Ana, sixty-seven (67) vertical electrical sounding points were occupied. Ten curve types were delineated in the study area. The curve types vary from simple three layer A and H-type curves to the more complex four, five and six layer AA, HA, KH, QH, AKH, HKH, KHA and KHKH curves. Four subsurface geo-electric sequences of top soil, weathered layer, partially weathered/fractured basement and the fresh basement were delineated in the area. The analytical process assisted in classifying Oke-Ana into, low, medium and high groundwater potential zones. Validation of the model from well information and two aborted boreholes suggest 70% agreement.

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1. Introduction

The rates of borehole failures in the country have been on the increase in recent times (Eduvie, 2006). This is due to duplication and implementation of similar borehole programmes already executed in some localities instead of extending such projects to newer areas that have not benefited previously. The borehole failures have also led to unnecessary waste of scarce financial resources. In addition, this has resulted to slow level of socio-economic development of the country. Water shortages are acute in the rural communities due to, pollution from point and non-point sources and lack of competent and skilled human resources to execute a well planned pre-drilling geophysical investigation. The Federal Government of Nigeria (FGN) has wholly embraced the Millennium Development Goals (MDGs) of the World Bank to provide potable water for all the citizens of the world (especially those in developing countries like Nigeria (Eduvie, 2006). Subsequently there has been intense sinking of boreholes to provide good quality water supply for the rural communities. Indiscriminate sinking of boreholes without employing systematic scientific approach i.e. pre-drilling geophysical investigation has led to unsuccessful boreholes with poor or low yield (Bayode et al., 2007). The tasks of achieving the Millennium Development Goals (MDGs) therefore pose an enormous challenge to the country and the international community. Water is one of the most precious of all natural resources. However, its availability remains a source of concern for human race. Water is used for agricultural, recreational, domestic and industrial purposes. Groundwater is defined as water that exists below the earth surface within the saturated layers of sand, gravel and pore spaces in crystalline as well as sedimentary rocks (Oseji and Ofomola, 2010). According to Todd (2004), groundwater means the water occupying all the empty

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spaces within a geologic stratum. The formation of this groundwater was primarily from three main sources. The Meteoric water is the one that percolates as see-page from the run-offs after a heavy downpour. The Connate water is the water that is trapped within the pore spaces and fractured zones of the solidification of molten magma. The juvenile water is the underground water found within the layers of the sedimentary rocks after sedimentary digenesis. The occurence of groundwater is largely determined by various factors such as porosity and permeability. These factors, sometimes, may vary from one location to another. Different factors have been used as indices for groundwater resources in different study areas. In a basement complex terrain, the lithologic unit that can be observed comprise of the weathered layer, weathered/fractured basement and fresh basement (Omorinola, 1984). The porosity and permeability capacity of this subsurface lithologies depends on the type of geologic materials occupying them (Ojo and Olorunfemi, 1990). Weathered layers that consist of clay would have less porosity while a highly weathered/fractured basement would be highly porous and permeable (Hazell, 1992).

The use of geophysics in detecting the availability, quality and quantity of groundwater as for many years been employed (Beeson and Jones, 1988; Olayinka and Barker, 1990; Omosuyi et al., 2003; Lenkey et al., 2005; Adepelumi et al., 2006; Omosuyi et al., 2008; Adiat et al., 2009; Omosuyi and Oyemola, 2012; Adelusi et al., 2014). Sub-surface geologic sequence and concealed geological structures can be mapped by geophysical methods, hence geophysics is quite relevant in mapping subsurface lithologic unit. Geophysical survey of the subsurface involves the measurement/establishment of geo-electric parameter such as layer resistivity (ρ_a), thickness and depth for each lithologic unit. This geo-electric parameter can then be used to describe the hydrological condition of the subsurface.

In order to effectively map and characterize lithologic units within subsurface, the knowledge of the various lithologic units, their distribution and characteristic must be put into consideration (Jones, 1985). The degree of saturation (for weathered layer) and fracturing (for fresh basement) is relative to porosity and permeability. In the basement complex, the relative depth and degree of weathering depends on the mineral grain, size of the crystalline rocks, their intensity of fracturing (Chilton and Smith-Carington, 1984).

In rising up to this challenge, there is need to evaluate the groundwater potential of Oke Ana which falls in the rural category that is worst hit by poor access to potable water. The advent of remote sensing (RS) and geographic information system (GIS) provides a cost and time effective means of assessing and managing groundwater resources (Chowdhury, 2006). Several researchers have successfully used different hydrogeologic thematic layers in evaluating the groundwater potential of an environment (Chowdhury et al., 2009; Adiat et al., 2012; Rao and Jugran, 2003; Jha et al., 2010) Lineaments and drainage patterns are some of the hydrogeologic indices that could be extracted from remote sensing data. Furthermore, to produce a groundwater potential model of the area with a high level of reliability and precision, there is need to integrate the important factors that can contribute to the occurrence of groundwater. It is therefore reasonable to say that the prediction of groundwater resources potential is a spatial decision problem involving large set of possible options and several evaluation factors (Adiat, 2013). The multi-criteria decision analysis (MCDA) in the context of Analytical Hierarchy Process (AHP) is

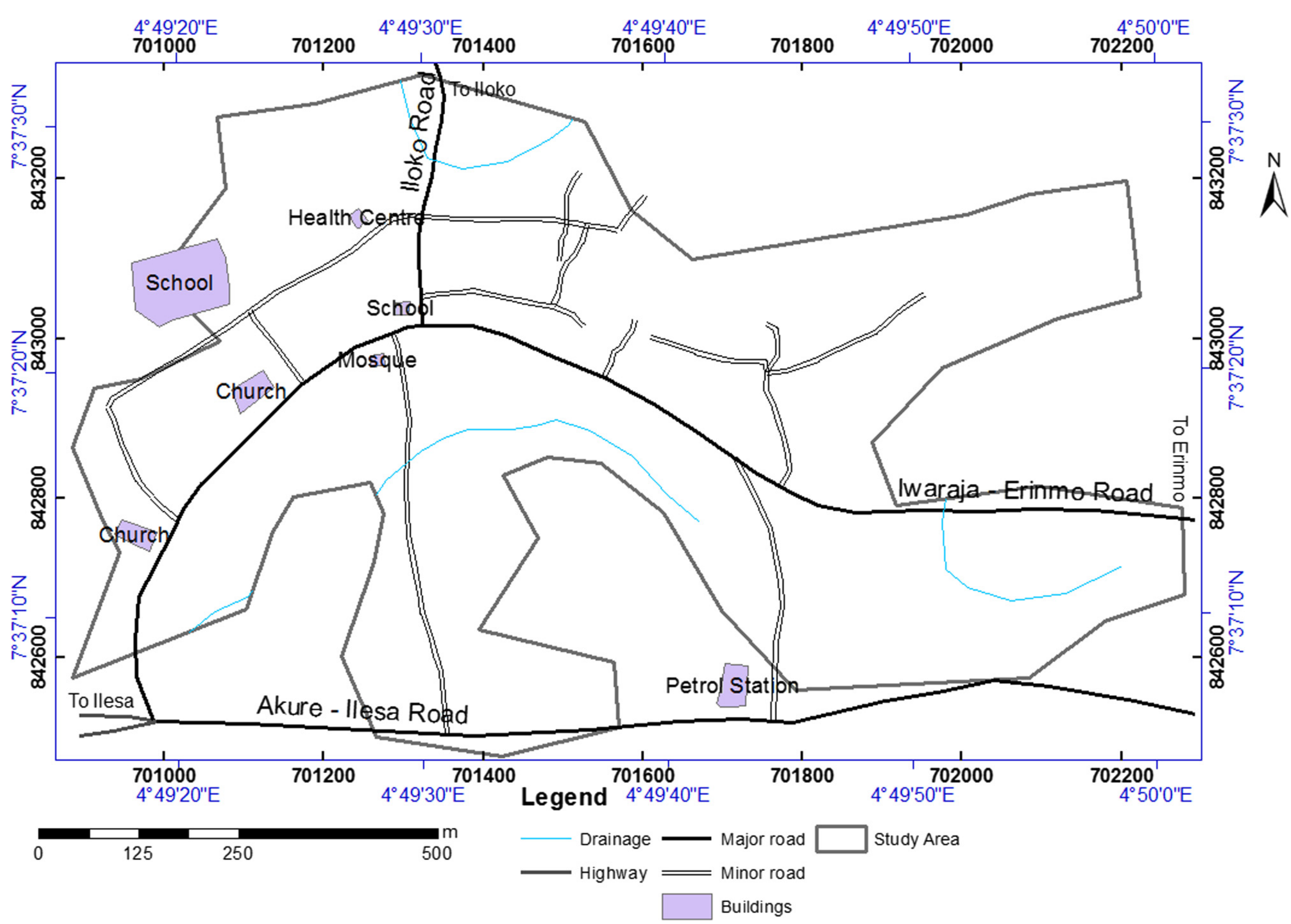

Fig. 1. Base map of the study area.

used in assigning weights to the various hydrogeological indices adopted for this study. The MCDA and AHP combines qualitative and quantitative approaches (Saaty, 1980).

However, for the purpose of this study, surface hydrologic and subsurface hydrogeological parameters were integrated in other to develop a conceptual model for the generation of groundwater potential map of part of the Ilesa Schist Belt southwestern Nigeria using information obtained from remote sensing, geographic information system, geologic information and parameters obtained from electrical resistivity method.

2. Location and geology of the study area

The study area is Oke Ana a village 9 km east of Ilesha, southwestern Nigeria. It occupies an area of 1.27 km^2 and is located between latitudes 7°37′10″ N and 7°37′37″N and longitudes 4°49′19″E and 4°49′58″E (Fig. 1). The closest towns to the study area are Iloko to the North, Erinmo to the East and Ilesha to the West (Fig. 1). The study area is accessible by trunk 'C' roads via Iwaraja and Erinmo and also via trunk 'A' road via Akure – Ilesha expressway. The topography of the area is remarkably undulating with a steady rise in the northeastern and southeastern part. The area is located within areas that correspond to the uplifted areas of the basement complex of the southwestern Nigeria (Effon ridge) (Balogun, 2003). The rocks in the study area belong to the Ilesha-Ife schist belt of southwestern Nigeria and comprise of abundant mafic rocks and a large mafic/ultramafic body that could represent remnants of an oceanic assemblage (Rahaman, 1988). The area is known to have variable metamorphic mineral assemblages ranging from green schist – to amphibolite – facies (Ajibade et al., 1987). Locally, granitic and gneissic basement rocks overlain by relatively thick covering of weathered materials underlie the area. The rock types that can be found in the study area include schist and amphibolites complex, granite-gneiss and quartz and quartz-schist (Fig. 2). The rock units found in Oke Ana typifies the rocks of the Precambrian basement complex of the southwestern Nigeria (Rahaman, 1976, 1988).

3. Materials and method of study

This research work utilizes the integration of remote sensing, geographic information system and geophysical method involving electrical resistivity methods.

3.1. Remotely sensed data

Computer-assisted methods for the detection of structural lineaments were exclusively based on edge enhancement or spatial filtering techniques (directional and/or gradient filters) (Mah et al., 1995). These methods produced edge maps requiring further processing (thresholding and thinning) for lineament segments to appear with one-pixel thickness. Optimal edge detectors e.g. the Canny algorithm (Canny, 1986) have already been successfully applied on natural scenes with quiet satisfactory results.

For this project, automated lineament extraction from Landsat satellite data that was based on decision of the most appropriate band for edge enhancement, followed by edge sharpening enhancement technique were employed. The first step was to select the band that should be used for lineament extraction (Süzen and Toprak, 1998). The second step was to select the filter type. Edge sharpening

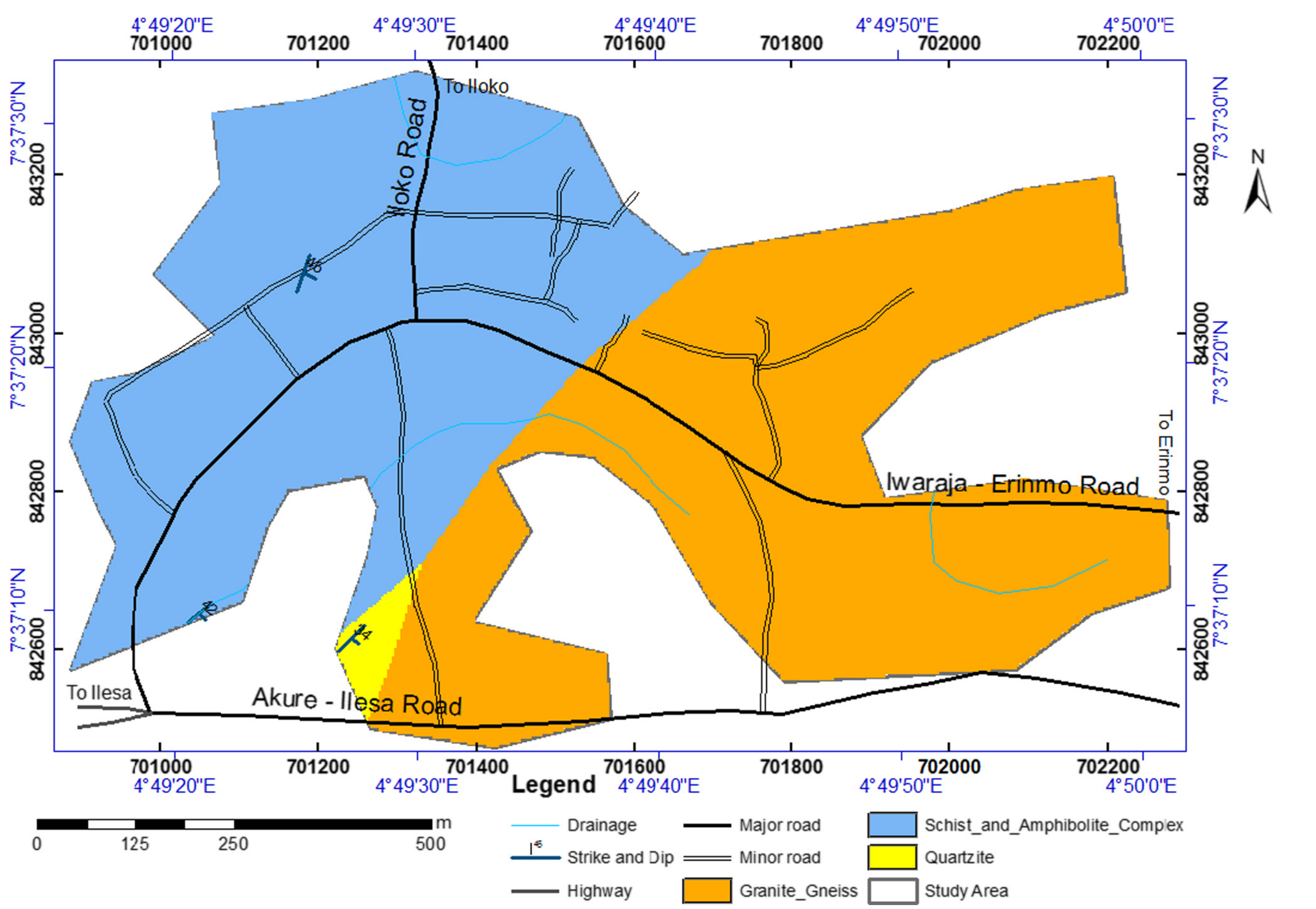

Fig. 2. Geological map of Oke Ana area. Modified after Geological Survey of Nigeria (Iwo sheet 60, 1963).

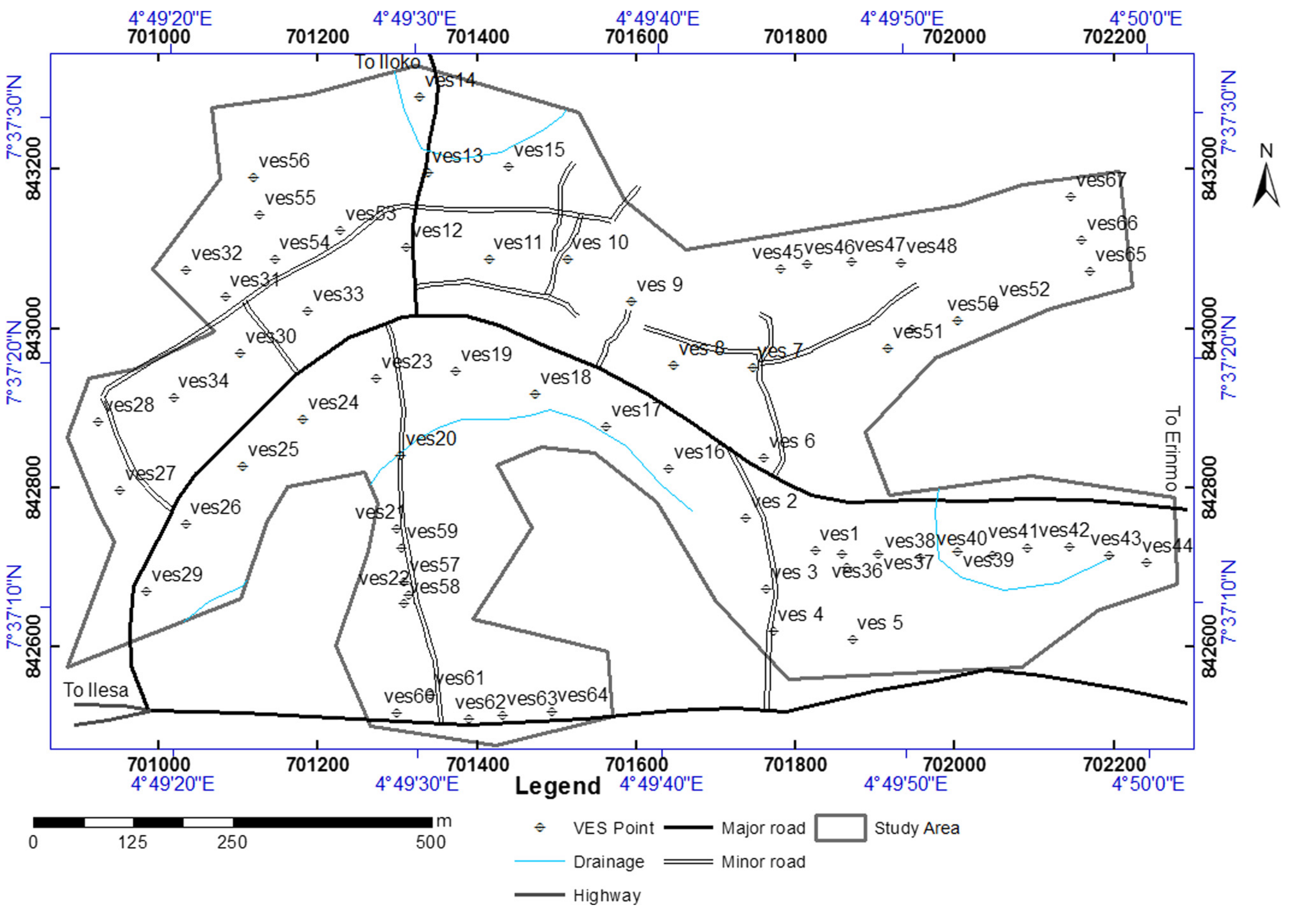

Fig. 3. Data Acquisition Map of Oke-Ana area Southwestern Nigeria.

filter was the best which convolved over band 5. Edge sharpening enhancements make the shapes and details for analyses (Richards, 1986). According to Abdullah et al. (2010), the lineament extraction algorithm of PCI Geomatica software consists of edge detection, thresholding and curve extraction steps.

The lineaments and drainage were extracted from the LANDSAT-TM images of the area. The density of the lineaments and the drainage were obtained by dividing the summation of the total lengths of the lineaments and drainage by the coverage area of the environment under consideration respectively. Krigging technique was used to produce the lineament and drainage density maps.

3.2. Geophysical data

Electrical resistivity data were obtained using the Ohmega terrameter. Materials include metal electrodes, connecting cables, hammer, global positioning system and clips. The survey applied the vertical electrical sounding technique (VES) adopting the Schlumberger electrode configuration.

A total of sixty-seven (67) Vertical Electrical Sounding (VES) stations were occupied in the study area, (Fig. 3). The survey was carried out by gradually expanding the electrode spacing about a fixed center of the array. The electrode spread of AB/2 was varied from 1 m to a maximum 100 m. The ground resistance (Ω) value obtained was multiplied by the corresponding geometric factor (K) for each electrode separation to obtain the apparent resistivity values in Ohm-meter (Ω-m). Data obtained from the vertical electrical sounding (VES) using schlumberger configuration are presented as sounding curves, geo-electric sections, maps and tables. The VES data were presented as depth sounding curves by plotting the apparent resistivity in Ohm-meter (Ω m) on the ordinance (Y axis) against the electrode spacing (AB/2) m on the abscissa (X axis). The curves were plotted on a bi-log paper and traced out on a transparent paper. Typical sounding curves analysis was based on both qualitative and quantitative approach. Quantitative analysis involving partial curve matching and computer iterations was adopted to establish the geo-electric characteristics of the study area.

3.3. Well data acquisition

A total of 35 wells and two abortive Boreholes (BH1&BH2) were visited where well information were taken (Fig. 4). These information consists of the location coordinates, static water level and the well depth for each of the wells. The Global Positioning System (GPS) was used to acquire both the coordinates and the elevation information at each well. From this information, the piezometric level and water column level of each well were estimated. The Piezometric water level was obtained by subtracting the static water level from the well depth for each of the thirty-five (35) wells. The resulting piezometric data were interpolated using inverse distance weighted technique algorithm to generate a surface map.

3.4. The multi-criteria decision analysis (MCDA) and analytical hierarchy process (AHP)

It was suggested by Saaty (1980) and called Analytic Hierarchy Process (AHP). This method allows us to determine the weights

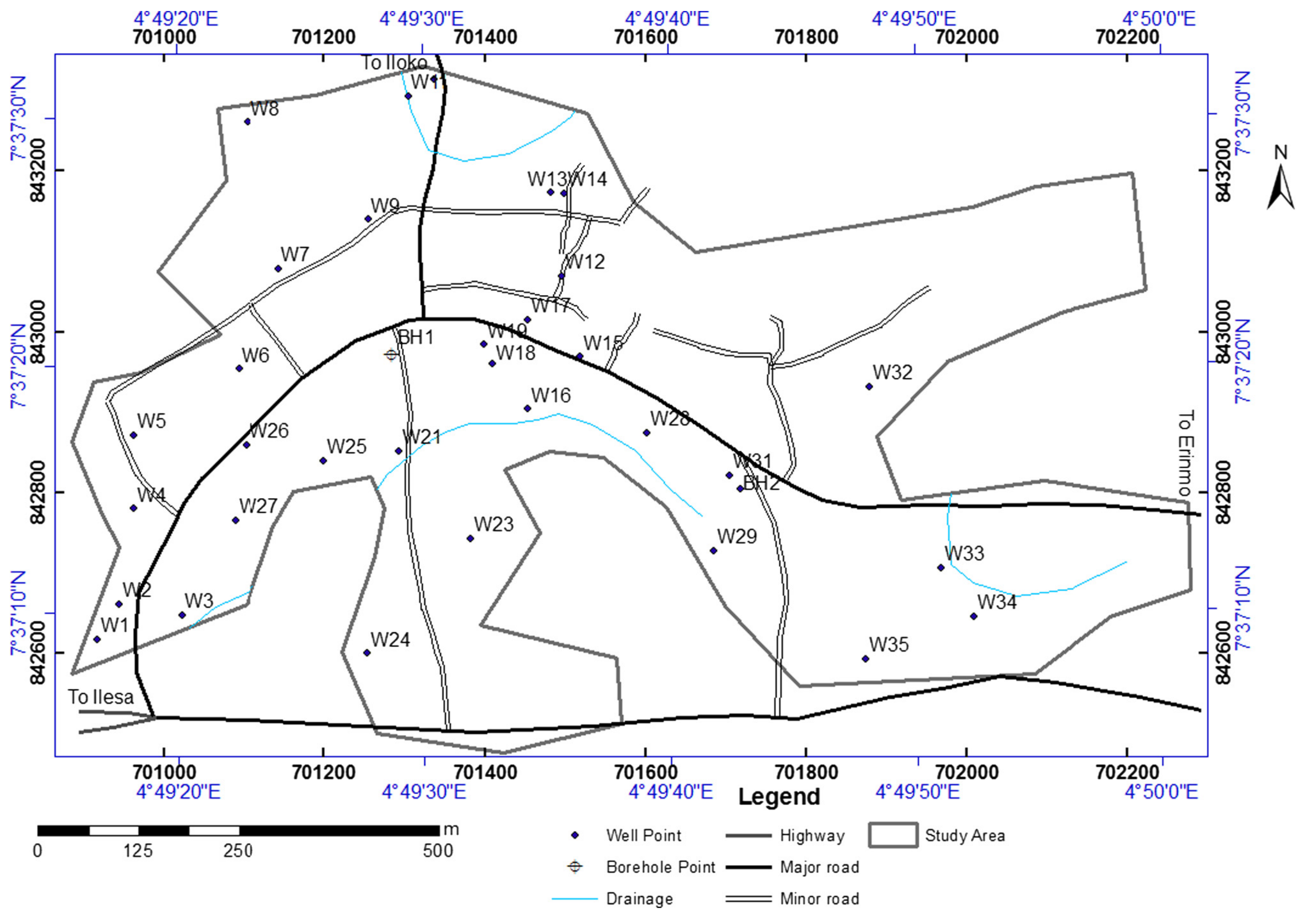

Fig. 4. Map of the study area showing well locations.

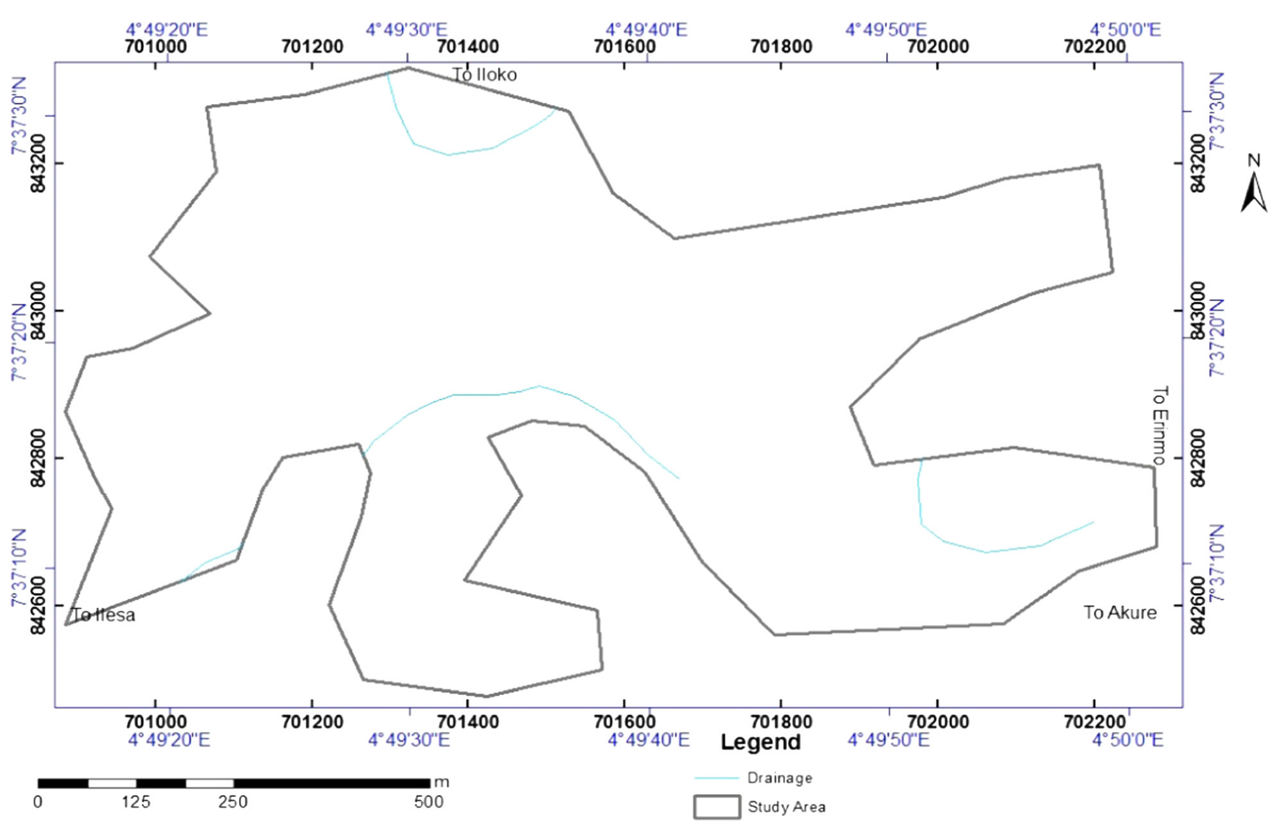

Fig. 5. Drainage map of the study area.

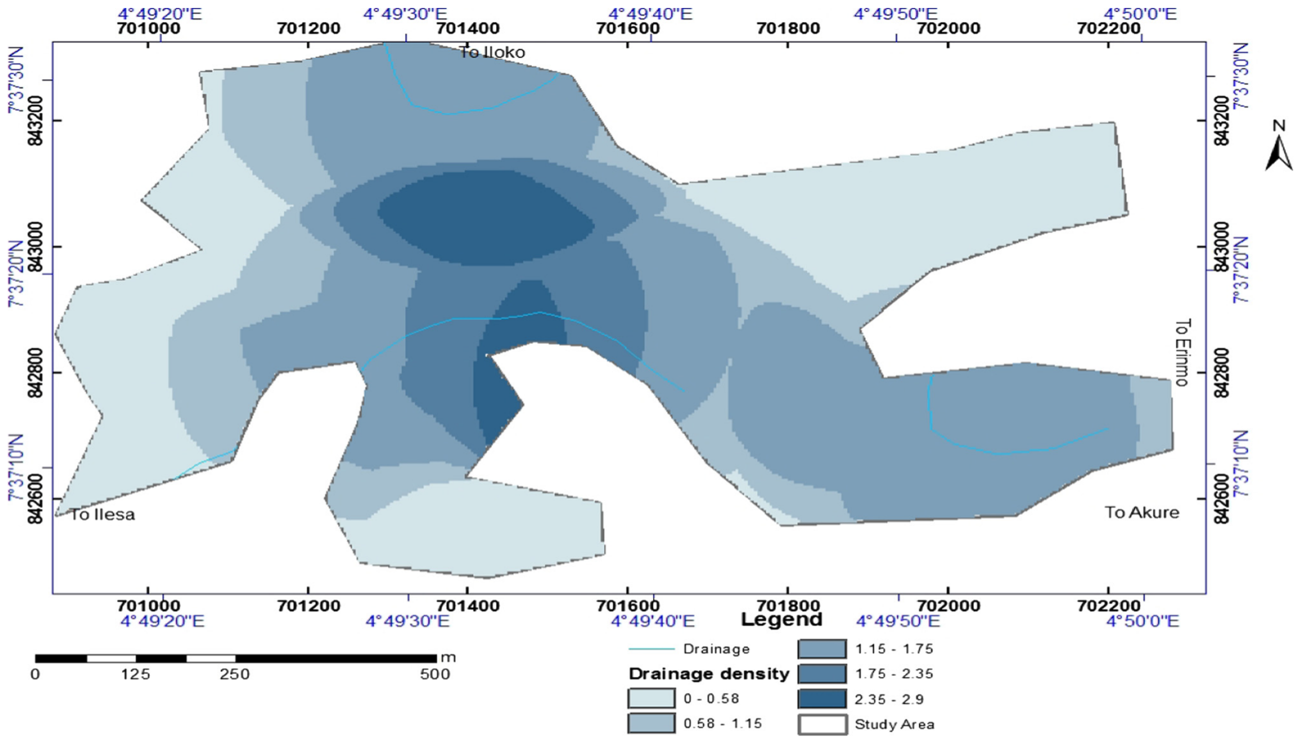

Fig. 6. Drainage density map of the study area.

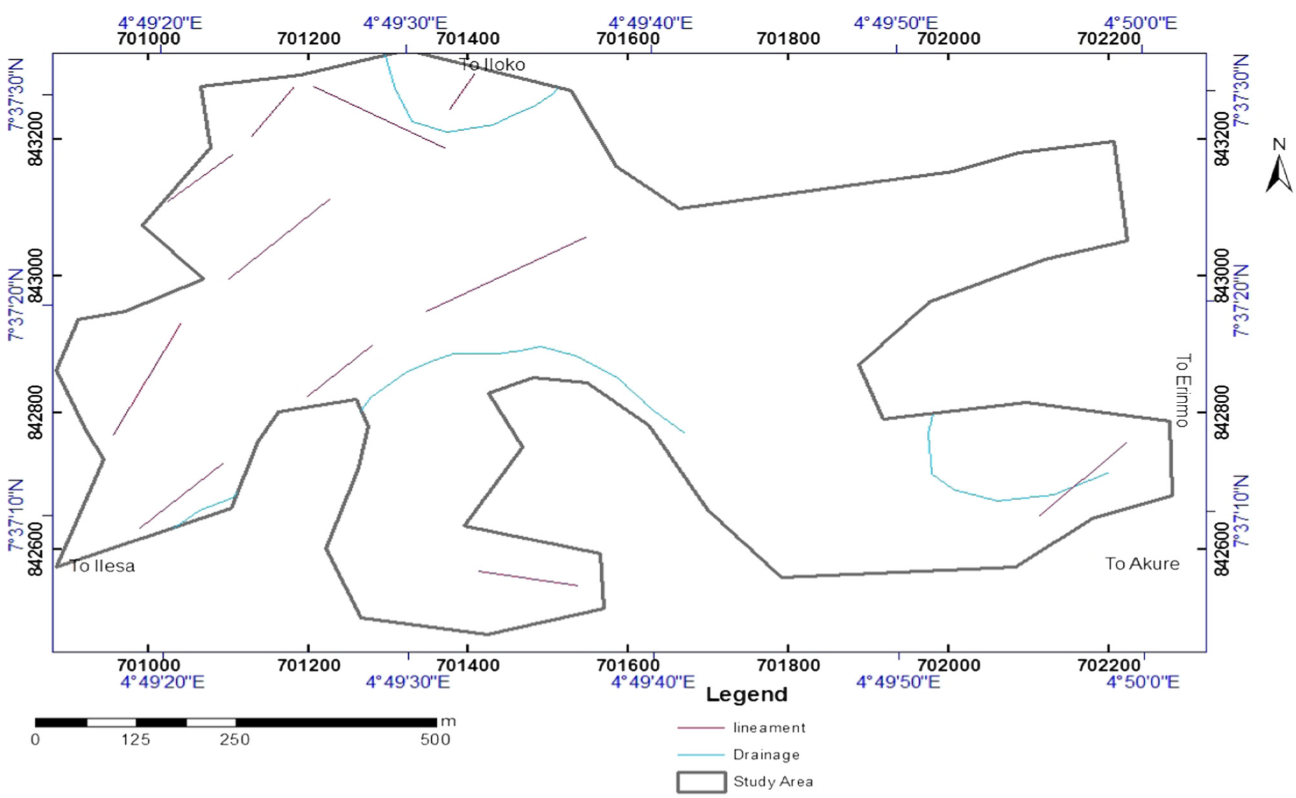

Fig. 7. Lineament map of the study area.

(significances) of hierarchically non-structured or particular hierarchical level criteria in respect of those belonging to a higher level.

The procedure of MCDA in the context of AHP procedure is as follow.

Step 1: The Pairwise Comparison of Selected Factors

The method is based on the pairwise comparison matrix P = ||pij||(i, j = 1, 2, . . ., m). Experts compare all the evaluation criteria

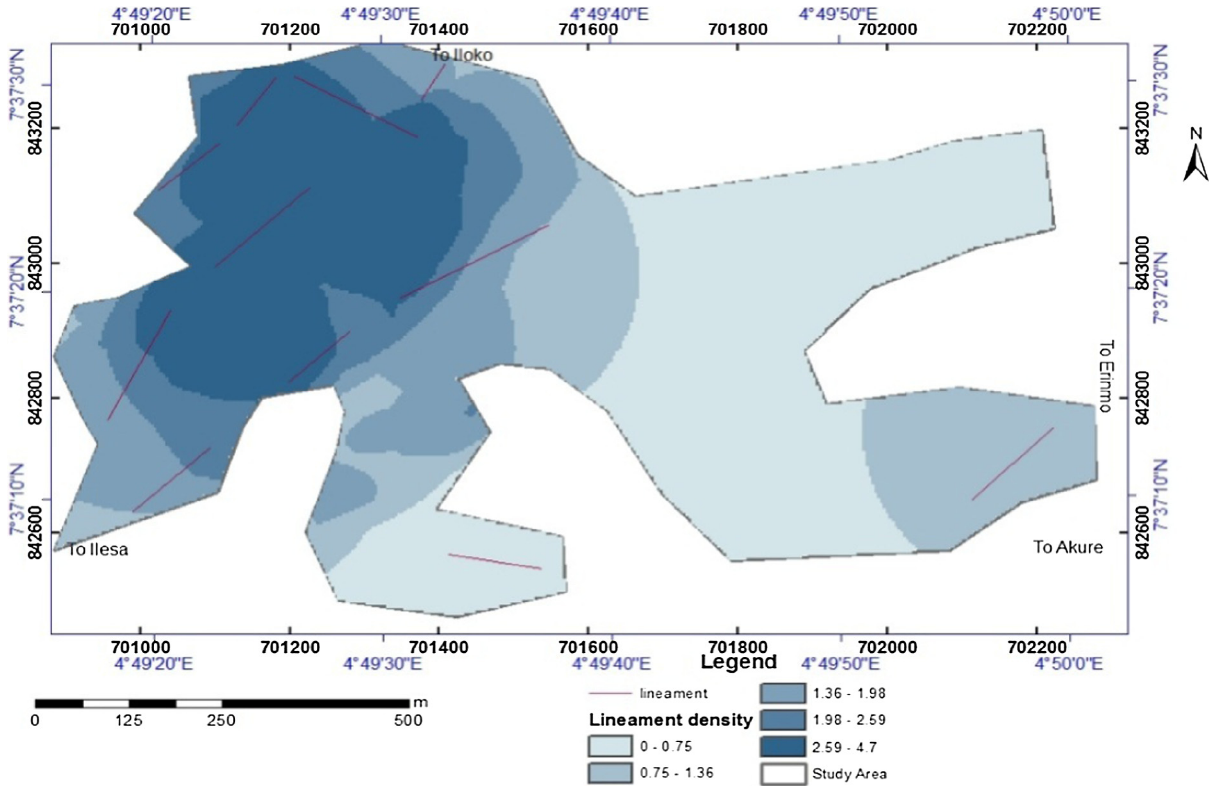

Fig. 8. Lineament density map of the study area.

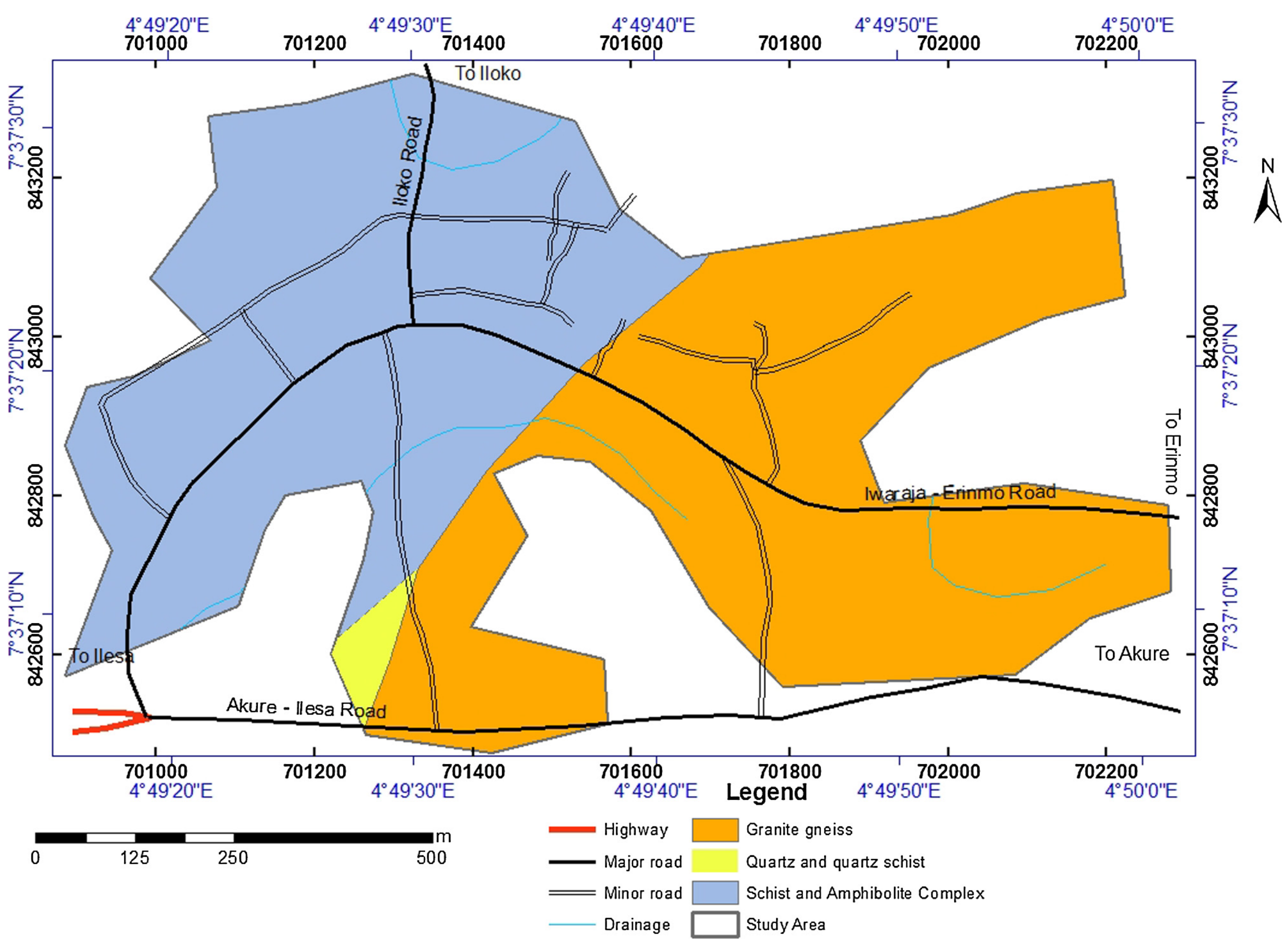

Fig. 9. Lithological map of the study area.

R_i and R_j (i, j = 1, 2, ..., m), where m is the number of the criteria compared. In an ideal case, the elements of the matrix present the relationships between the unknown criteria weights:

$$\mathbf{P} = \begin{pmatrix} p_{11} & p_{12}\cdots & p_{1m} \\ p_{21} & p_{22}\cdots & p_{2m} \\ \vdots & & \vdots \\ p_{m1} & p_{m2}\cdots & p_{mm} \end{pmatrix} = \begin{pmatrix} \frac{\omega_1}{\omega_1} & \frac{\omega_1}{\omega_2}\cdots & \frac{\omega_1}{\omega_m} \\ \frac{\omega_2}{\omega_1} & \frac{\omega_2}{\omega_2}\cdots & \frac{\omega_2}{\omega_m} \\ \vdots & & \vdots \\ \frac{\omega_m}{\omega_1} & \frac{\omega_m}{\omega_2}\cdots & \frac{\omega_m}{\omega_m} \end{pmatrix}$$

The comparison is qualitative and easy to perform. It indicates if one criterion is more significant than the other and to what level the priority belongs. The technique used allows the qualitative estimates elicited from experts to be converted to quantitative ones. The technique is not complicated because it is easier to compare the criteria in pairs than all at a time. It is also well mathematically grounded.

The matrix P is an inverse symmetrical matrix, i.e. pij = 1/pji. It follows that the part of the matrix which is above the main diagonal or below it may be filled in. The number of non-recurrent elements of the m-order matrix P, i.e. the number of elements compared is m (m – 1)/2 (the total number of the comparison matrix elements is equal to m 2).

The main principle of filling in the matrix is simple because an expert should indicate how much moreimportant is a particular criterion than another. Saaty suggested a widely known 5-point scale (1–3–5–7–9) to be used for evaluation. The evaluation of the criteria ranges from pij = 1, when Ri and Rj are equally significant, to pij = 9, when the criterion Ri is much more significant than the criterion Rj with respect to the research aim (Saaty, 1980).

Step 2: Synthesizing the Pairwise Comparison

To calculate the vectors of priorities, the average of normalized column (ANC) method is used (Hsiao, 2002). ANC is to divide the elements of each column by the sum of the column and then add the element in each resulting row and divide this sum by the number of elements in the row (n). This is a process of averaging over the normalized columns. In mathematical form, the vector of priorities can be calculated as

$$W_i = \frac{1}{n}\sum_{j=1}^{n}\frac{a_{ij}}{\sum_i^n a_{ij}}, i,j = 1,2,\ldots n$$

Step 3: Perform the Consistency

Since the comparisons are carried out through personal or subjective judgments, some degree of inconsistency may be occurred. To guarantee the judgments are consistent, the final operation called consistency verification, which is regarded as one of the most advantages of the AHP, is incorporated in order to measure the degree of consistency among the pairwise comparisons by computing the consistency ratio (Ho, 2008). The consistency is determined by the consistency ratio (CR). Consistency ratio (CR) is the ratio of consistency index (CI) to random index (RI) for the same order matrices. To calculate the consistency ratio (CR), there are three steps to be implemented as follows:

(i) Firstly, Calculate the Eigenvalue (λ_{max})
 a. To calculate the eigenvalue (λ_{max}), multiply on the right matrix of judgments by the priority vector or eigenvector, obtaining a new vector.

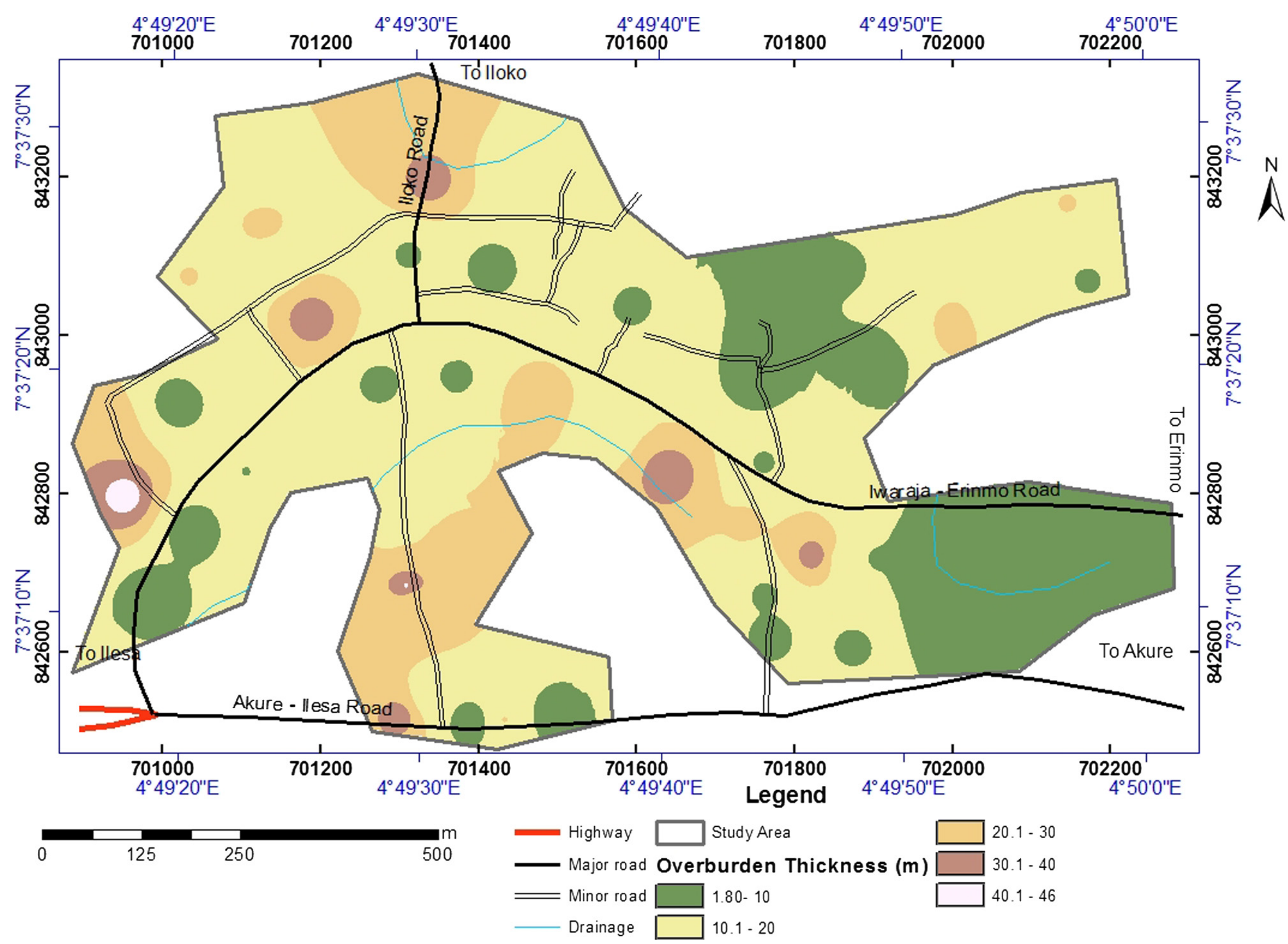

Fig. 10. Overburden thickness map of the study area.

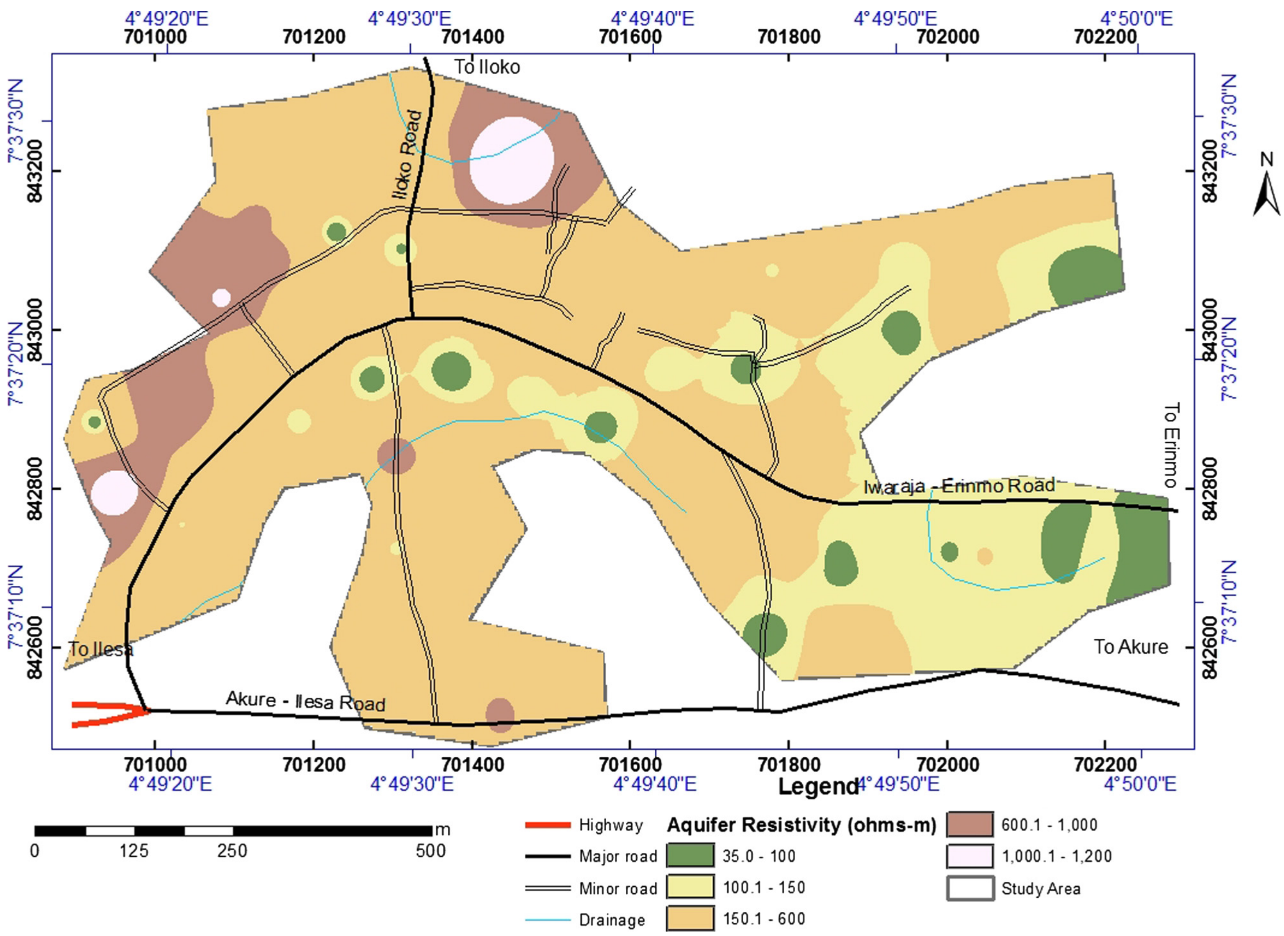

Fig. 11. Aquifer resistivity map of the study area.

(ii) Secondly, Calculate the Consistency Index (CI).
   a. $CI = (\lambda_{max} - n)/(n - 1)$
(iii) Finally, Calculate the Consistency Ratio (CR).
   a. The CR can be calculated using the formula,
   b. CR = CI/RI.

The value of consistency index S which is smaller than or equal to 0.1 is acceptable, implying that the matrix is consistent. Consistency ratio (CR) is the ratio of consistency index (CI) to radon index (RI). Generally, if CR is less 0.1, the judgments are consistent, so the derived weights can be used.

If $CR \leq 0.1$ (10%), then the comparison value are still considered as consistent (Saaty, 1980). On the other hand, if $CR \geq 0.1$, then the entry values are not consistent, and the pairwise comparison matrix has to be reconstructed. And so, if CR = 0, then the matrix is perfectly consistent.

For the purpose of this research, five parameters were considered namely; drainage density, lineament density, lithology, aquifer resistivity and overburden thickness.

4. Discussion of results

4.1. Factors influencing groundwater potential in the study area

4.1.1. Drainage/drainage density

How drained an environment is, determines the degree of infiltration of that particular area. When the drainage density is very high, the runoff will be very high and consequently the rate of infiltration will be very low. Conversely, the lower the drainage density the lower the runoff and the higher the degree of infiltration. Oke-Ana is not well drained (Figs. 5 and 6) and therefore it is expected to have high level of infiltration.

4.1.2. Lineament/lineament density

Lineament are surface manifestations of structurally controlled subsurface features such as fractures (faults and or Joints). They are usually linear features represented on satellite images. Lineaments play a great role in the movement and storage of groundwater. Oke-Ana is relatively dense in terms of lineament and the lineaments is denser in the center of the study location. The lineaments trends predominantly in the NE-SW direction with few trending approximately E-W and some in the NW-SE direction (Figs. 7 and 8). Lineaments serves as pathways for surface runoffs to infiltrate into the subsurface thereby enhancing groundwater storage. Therefore the lineament and lineament density map of Oke-Ana suggest an area with a relatively good groundwater storage potential.

4.1.3. Lithology/geology

Lithology/geology is an important factor that controls groundwater accumulation in an environment especially in terms of quality and quantity. The characteristics of soil influence the amount of recharge infiltrating the ground surface. The presence of fine grain size materials, such as clay, peat or silt, and the percentage of organic matter within the soil cover can decrease intrinsic permeability and retard or prevent infiltration of surface water. The study area are characterized by three major rock types namely, Granite gneiss, Quartz and Quartz schist, and Schist and Amphibolite

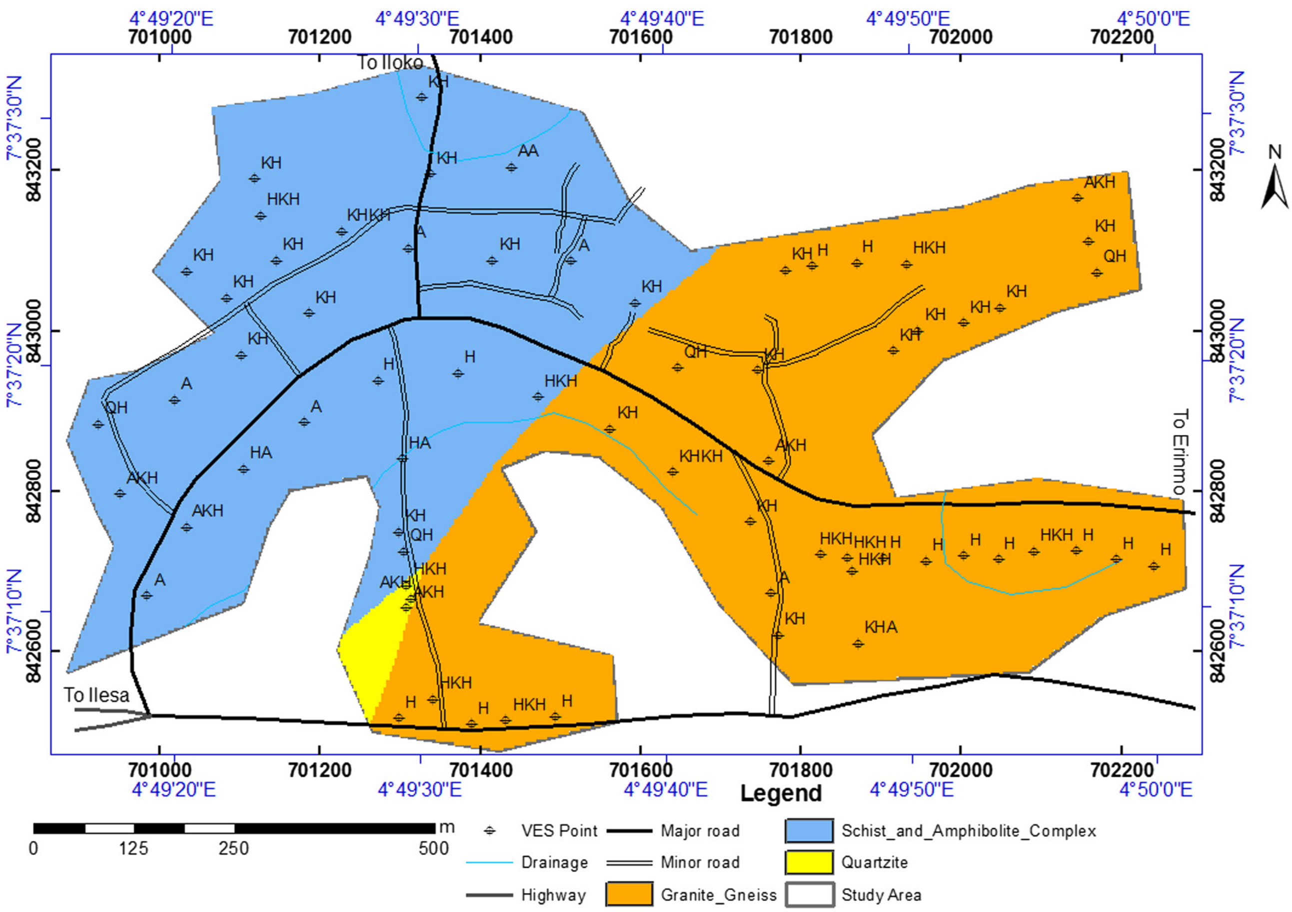

Fig. 12. Curve type distribution map of the study area.

Complex as shown earlier in Fig. 9. The degree of weathering varies from one rock types to another based on their resistance to environmental factors. This is easily reflected on the degree on fracturing of the rock. In the study area, Quartzite and Quartz Schist have the highest degree of fracturing, while the rock with the least degree of fracturing is Granite Gneiss.

4.1.4. Overburden thickness

The isopach map of the overburden (Fig. 10) reveals the thickest overburden at the central and northeastern part of the area. The overburden thickness ranges from 1.8 to 46 m in Oke-Ana. The average value of overburden thickness in the area is 15 m. Generally areas with thick overburden and low percentage of clay where there is a pronounced inter-granular flow are known to have high groundwater potential 'particularly in basement complex terrain (Okhue and Olorunfemi, 1991).

4.1.5. Aquifer resistivity

The resistivity of the aquifer is a great contributor to the groundwater potential of a location. Low resistivity zones are typical of low groundwater potential zones. The aquifer is defined as a rock formation which can yield sufficient quantities of water for use (Anwar et al., 2003). In the study area, the weathered layer constitutes the main aquifer unit and areas with fractured basement also constitute an added advantage and are also classified as aquifers in the area. Aquifer resistivity in the area generally ranges from 35 to 1200 ohm m (Fig. 11). Aquifers in basement complex are qualitative classified as either weathered fractured basement or partly weathered or fractured basement aquifer, and this classes can be related to the resistivity of the subsurface layer. In the study area, the aquifers are partly weathered, weathered/fractured basement and fractured basement. The resistivity range of layer classified as partly weathered are 150–350 ohms m, the weathered/fractured basement aquifer resistivity ranges from 350 to 600 ohms m and the fresh basement aquifer resistivity ranges from 600 to 1200.

4.2. Vertical electrical sounding (VES) curves analysis

Ten curve types exist in the study area, namely: A, AA, AKH, H, HA, HKH, KH, KHA, KHKH and QH. The KH, H and HKH VES curves are the predominant curve types as they account for 32%, 21% and 10%, respectively (Fig. 12). The high degree of variation in curve types confirms the heterogeneity of the geology of a typical basement complex.

4.3. Geo-electric sequence

Generally, the geo-electric section lines were drawn along four (4) traverses denoted A-A′, B-B′, C-C′ and D-D′ (Fig. 13). The geo-electric sections mainly delineated four subsurface layers namely; the topsoil, the weathered layer, the partly weathered/fractured basement and the presumed fresh basement (Fig. 14). The relatively high degree of variation in both the resistivity and thickness values of these layers, further confirms the in-homogeneity and unpredictable attribute of the geology of a typical basement complex. Furthermore, the boundaries of the geologic units and even within the geologic units marked by varying thickenings of the overburden also suggest fracturing. Similarly, the bedrock layer resistivity suggests fracturing due to its low resistivity. The top soil resistivity ranges between 50 and 2359 ohm m with thickness ranging between 0.6 and 2.0 m which indicates that the composition of the topsoil is clay and sand of various grades to lateritic hardpan. The weathered layer resistivity ranges from 35 to 1300 ohm m which indicates lithological units varying from clay, clayey sand, sandy clay and sand. The weathered layer thickness ranges from 3 to 40 m. The partially weathered/fractured layer has resistivity values generally less than 1000 ohm m which indicates the degree of fracture and/or water saturation. The last layer is the fresh basement with resistivity values 1200–40,231 ohm m.

4.4. Assignment of weights to factors

Table 1 shows the Saaty's scale for weight assignment and its interpretation. The weights were assigned on scale 1–9. In the procedure for Multi-Criteria Evaluation, it is necessary that the weights sum to 1. In Saaty's technique (Saaty, 1980), weights of this nature can be derived by taking the principal eigenvector of a square reciprocal matrix of pairwise comparisons between the variables (criteria) (Table 2).

Table 3 shows the weight assigned to each of the hydrogeological indices considered in this study. The weights were produced from the computation of the Eigen vector of the matrix.

On this table, two factors are considered per time. The contribution of the factor under consideration relative to the other is the basis for assigning weight. For our comparison to be acceptable, the consistency ratio (CR) must be less than 10%. For this study, the CR is 8.34%.

4.4.1. Rating

Rates (R) were given to each of the parameters within the factors influencing the groundwater potential of Oke-Ana (Table 4). The rating will assist in the estimation of the groundwater potential index (GWPI) of Oke-Ana.

4.5. Groundwater potential index estimation (GWPI)

GWPI is obtained from the summation of the products of the assigned weights often denoted as w and the ratings denoted as (R).

$$GWPI = Dd_w Dd_R + Ld_w Ld_R + Lt_w Lt_R + Ot_w Ot_R + Ar_w Ar_R$$

$$GWPI = 0.03482\ Dd_R + 0.06777\ Ld_R + 0.13435\ Lt_R + 0.26023\ Ot_R + 0.5028\ Ar_R$$

where Dd_R = drainage density rating
Ddw = drainage density weight
Ld_R = Lineament density rating
Ldw = Lineament density weight
Lt_R = Lithology rating
Ltw = Lithology weight
Ot_R = Overburden thickness rating
Otw = Overburden thickness weight
Ar_R = Aquifer resistivity rating
Arw = Aquifer resistivity weight

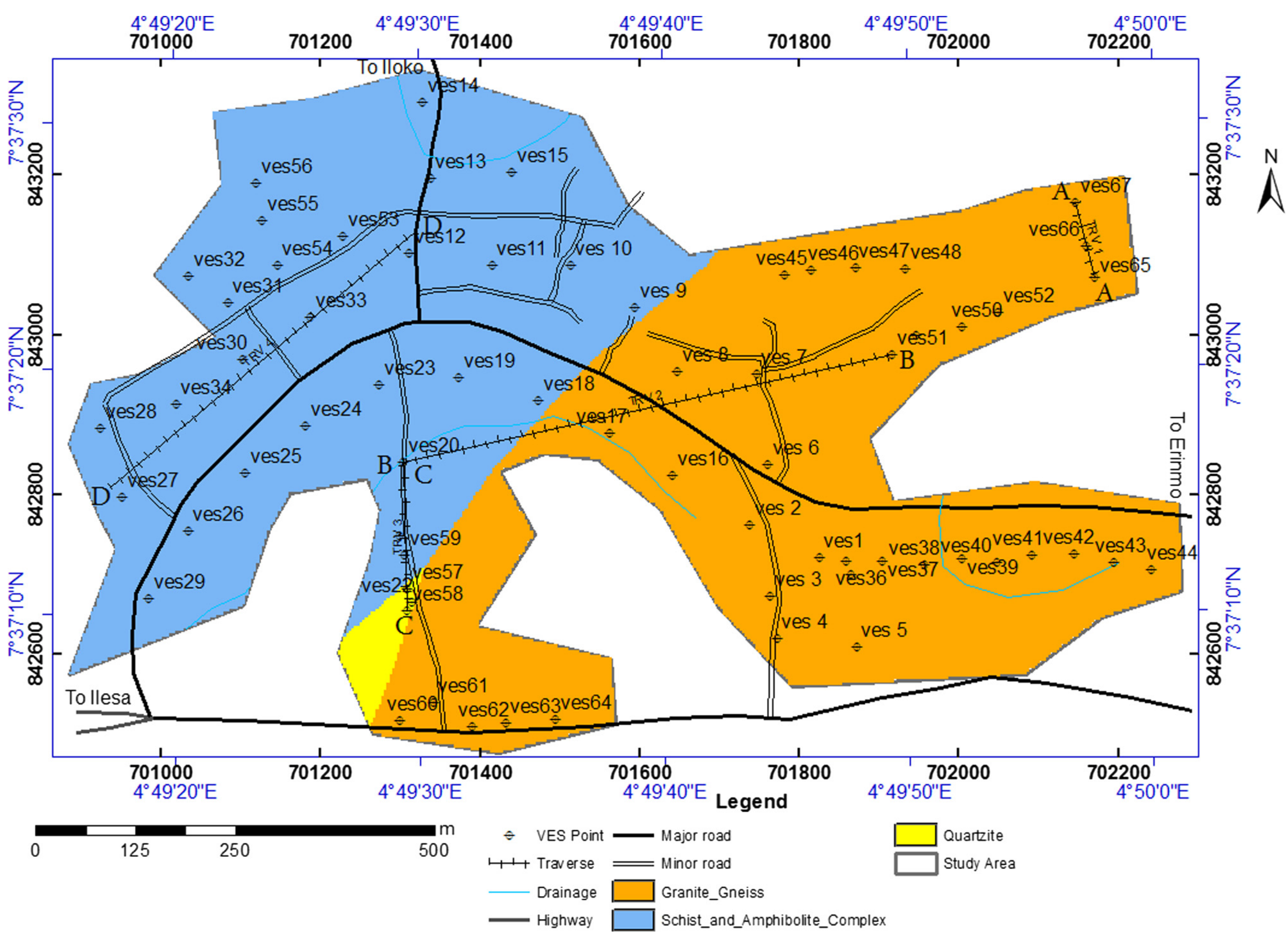

Fig. 13. Geological map showing the distribution of geo-electric sections.

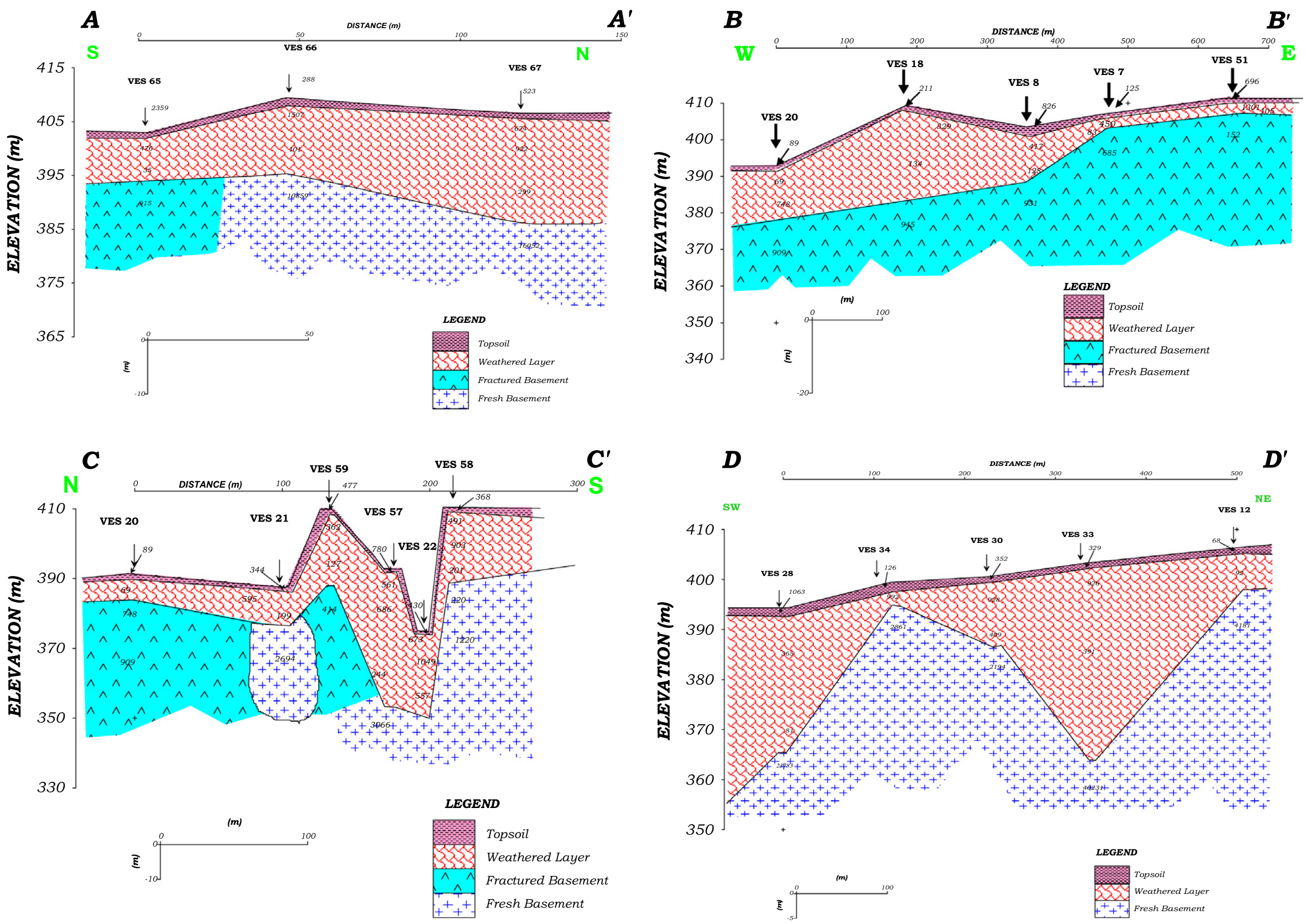

Fig. 14. Geo-electric sections obtained along A-A′, B-B′, C-C′ and D-D′.

Table 1
Saaty's scale for assignment of weight (Saaty, 1980).

Less important				Equally important	More important			
Extremely	Very strongly	Strongly	Moderately		Moderately	Strongly	Very strongly	Extremely
1/9	1/7	1/5	1/3	1	3	5	7	9

Table 2
Pairwise comparison 1 matrix table for the hydrogeologic indices.

	Dd	Ld	Lt	Ot	Ar
Dd	1	1/3	1/5	1/7	1/9
Ld	3	1	1/3	1/5	1/7
Lt	5	3	1	1/3	1/5
Ot	7	5	3	1	1/3
Ar	9	7	5	3	1
Sum	25	49/3	143/15	491/105	1689/945

Table 3
Determination of relative weights for the hydrogeological indices.

	Dd	Ld	Lt	Ot	Ar	Weights
Dd	1/25	1/49	3/143	15/491	105/1689	0.03482
Ld	3/25	3/49	5/143	21/491	135/1689	0.06777
Lt	1/5	9/49	15/143	35/491	189/1689	0.13435
Ot	7/25	15/49	45/143	105/491	315/1689	0.26023
Ar	9/25	21/49	75/143	315/491	945/1689	0.5028
Sum	1	1	1	1	1	0.9997–1

Table 4
Ratings for classes of the parameters.

Hydrogeological indices	Classes	Potential for groundwater	Rating (R)	Normalized weight (w)
Drainage density (Dd)	0–0.000834	Very high	5	0.03482
	0.000834–0.00167	High	4	
	0.00167–0.00250	Medium	3	
	0.00250–0.00334	Low	2	
	0.00334–0.00417	Very low	1	
Lineament density (Ld)	0.138–0.752	Very low	1	0.06777
	0.752–1.366	Low	2	
	1.366–1.981	Medium	3	
	1.981–2.595	High	4	
	2.595–3.21	Very high	5	
Lithology (Lt)	Quartzite and Quartz Schist	Very high	5	0.13435
	Schist and Amphibolite	Medium	3	
	Granite Gneiss	Very low	1	
Overburden thickness (Ot)	1.8–10	Very low	1	0.26023
	10.1–20	Low	2	
	20.1–30	Medium	3	
	30.1–40	High	4	
	40.1–46	Very high	5	
Aquifer resistivity (Ar)	35–100	Very high	5	0.5028
	100.1–150	High	4	
	150.1–600	Medium	3	
	600.1–1200	Low	2	
	1200.1–1800	Very low	1	

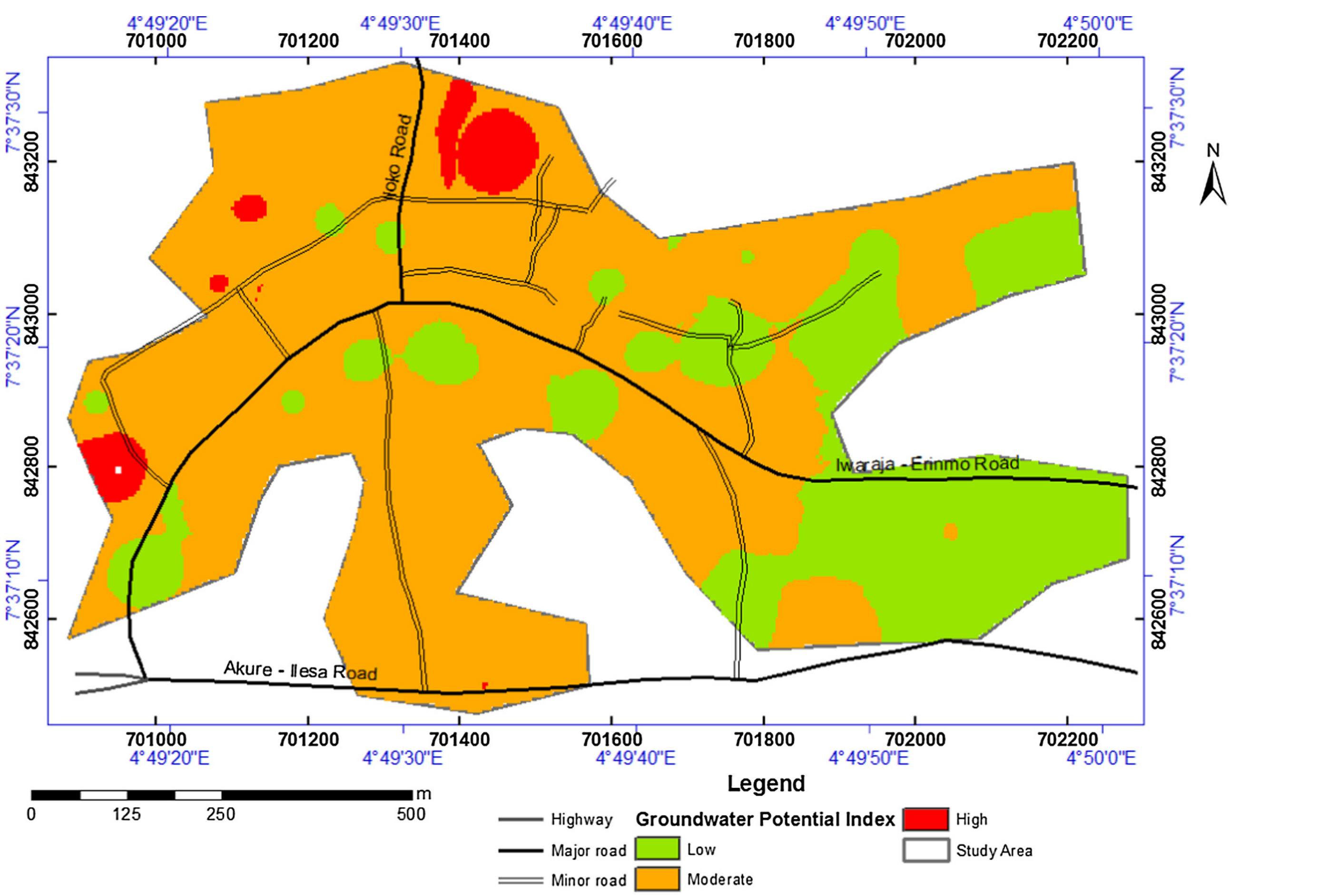

Fig. 15. Groundwater potential index map of the area.

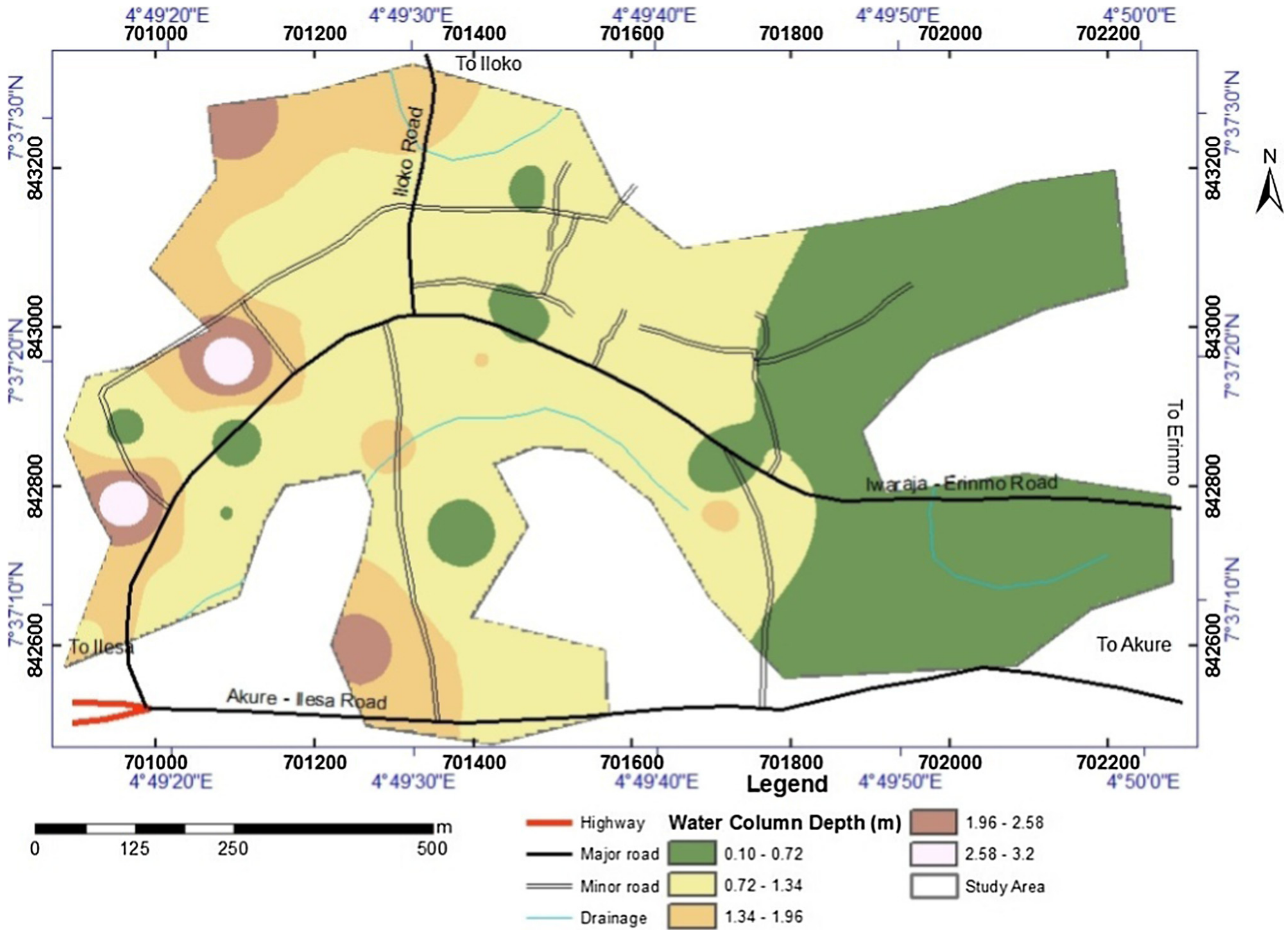

Fig. 16. Water column map of the study area.

4.6. Groundwater potential index map of Oke-Ana

The groundwater potential index map (Fig. 15) was produced by overlaying the GWPI index obtained for each of the contributing factors to the groundwater storage in the area using the ArcGIS 10.0 software. From the study, it was revealed that Oke-Ana can be zoned into Low, Moderate and High groundwater potential zones. Oke-Ana is predominantly low - moderate in groundwater potential. Low zones characterize the eastern part of the town. Pockets of high groundwater potential zones were also observed at the northern part of the area.

4.7. Water column map of the study area

The water column map (Fig. 16) was produced from the column occupied by water in the wells studied using ArcGIS 10.0 software. From the study, it was revealed that quantity of water available in wells at Oke-Ana is relatively low. The well data were acquired during the start of the raining season, and the wells were assumed to be at the peak of their yield. The water column in the well largely ranges from 0.10 m to 3.2 m. It is on this basis that the area is classified into classes using equal interval. The well in the area are characterized by seasonal yield, non-seasonal yield and abortive wells. The information about the reaction of the wells to seasonal variations were obtained through communication with the inhabitants of the community where the wells are dug. About 74% of the wells in the area are seasonal wells, 17% are non-seasonal while the remaining 9% are failed boreholes in the study area. The wells in Oke-Ana are generally shallow with depth ranging from 4.2 m to 10.3 m. Consequently implying that most of the wells are recharged by surface infiltration. The non-seasonal well in the study area have appreciable depth compared with the other wells.

4.8. Validation of the groundwater potential index map using well information

Validation of the groundwater conceptual model produced was done by comparing the produced conceptual model and the water column map generated from well inventory within the study area. Figs. 17 and 18 were used to illustrate the relationship between the variations in quantity of water available in the well to the groundwater potential map. It was observed that the area is mainly low to moderate in terms of groundwater potential. Although the water column is generally relatively thin. The two abortive boreholes (BH1 and BH2) perfectly agrees with the groundwater potential model. The failed borehole BH1 is located in a zone of low groundwater potential index while the second abortive borehole is BH2 is located in moderate groundwater potential index. It should be noted that the boreholes are shallow pumps drilled by government in the study area.

The reason(s) for the failure of the boreholes can easily be inferred from the model parameters that contributes to groundwater potential. The depth of the failed boreholes terminates at 5.7 m and 6.3 m respectively for BH1 and BH2. The resistivity at that layer from the neighbouring vertical electrical sounding (VES 23 and 16) are 75 Ω m and 517 Ω m and, the overburden thickness

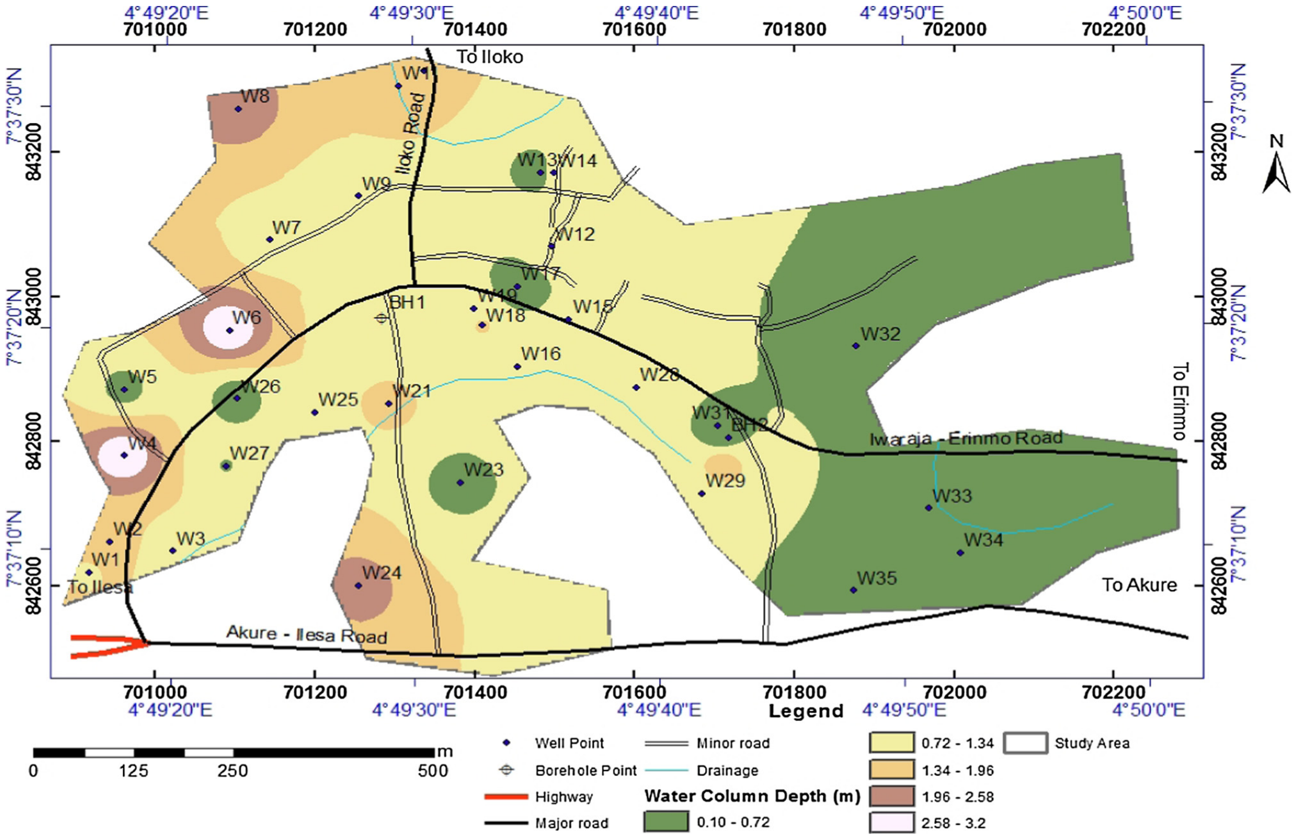

Fig. 17. Water column map with well and borehole distribution in the study area.

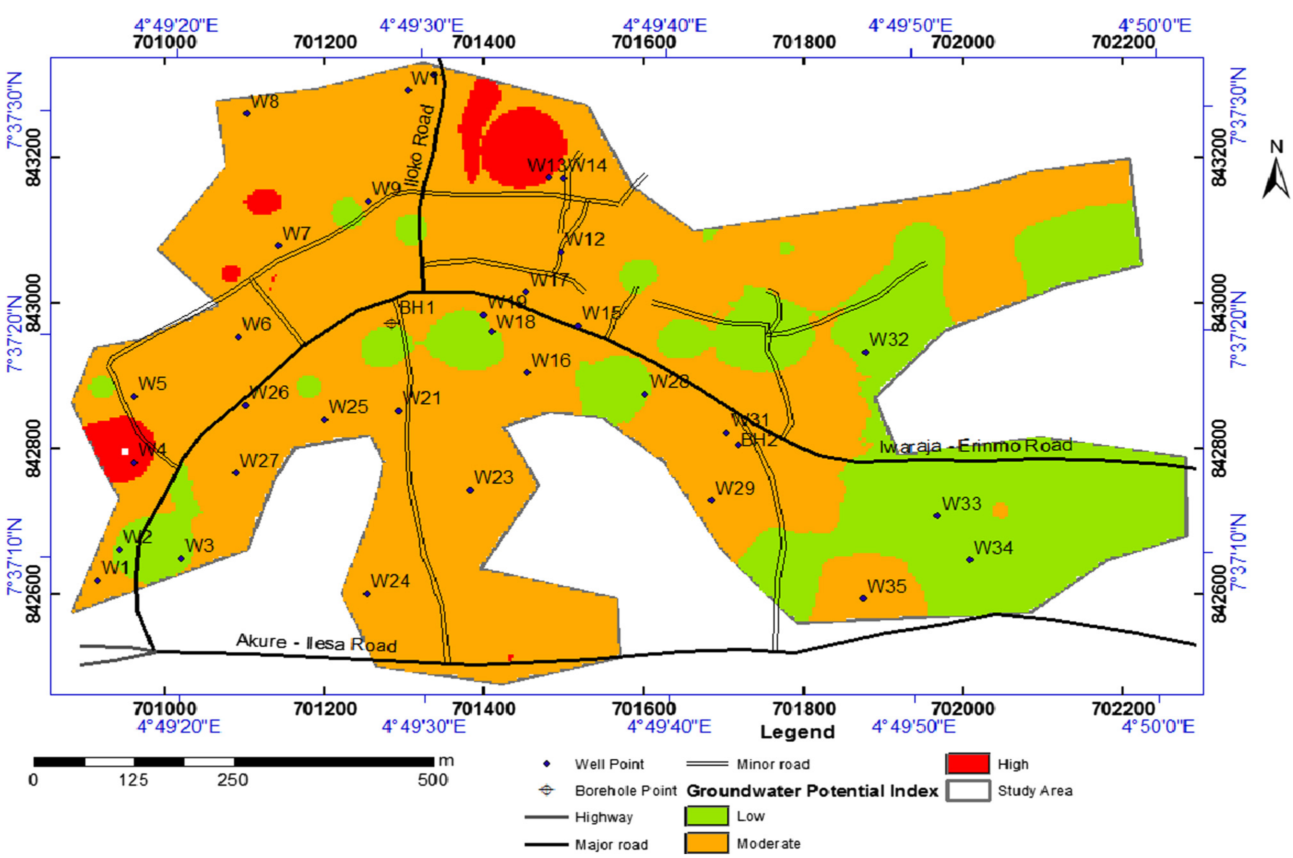

Fig. 18. Groundwater potential map with well and borehole distribution in the study area.

of these two points are very thin (0.6 m and 1.6 m) respectively. All these factors contributed to the failure of the borehole.

Furthermore, most of the non seasonal wells are located in the zones of moderate groundwater potential zones. Wells (W6 and W12) is of appreciable depth of 7.6 m and 7.5 m and Vertical electrical sounding (VES 10 and 33) resistivity value of 486 Ω m and 240 Ω m. The overburden thickness and aquifer thickness of these two points are 1.1 m, 8.8 m and 7.0 m, 18.0 m respectively. All these factors contribute to the reason why the wells in these zones have moderate yield as suggested by the groundwater potential model.

Also, Well 32 and Well 34 are characterized by low yield of groundwater. This perfectly agrees with the groundwater potential model.

However, some exception occurs, where the conceptual model do not agree with the validation data. Well 9 is observed on the field to be seasonal with low yield of groundwater, this disagree with the groundwater potential model that showed moderate groundwater potential. The possible explanation for this disagreement is the depth at which the well was dug. From VES 53 which is very close to the well, the aquifer occurs at depth of 8.8 m and the well terminates at depth 7.4 m. The well is not drilled to the depth of the aquifer and this is responsible for poor yield recorded in the location.

Area of low groundwater potential coincides with area that has thin water column in the wells. Abortive borehole BH1 also falls into the same area of low groundwater potential as shown on Fig. 18. Moreover, the area of moderate groundwater potential coincides with area that has relatively thick water column values although some of the area of moderate groundwater potential coincides with area that have wells of seasonal yield which are due to the depth at which the wells were dug.

In conclusion, the groundwater potential map shows high level of reliability, the abortive boreholes show total agreement with the model and twenty-four (24) wells and the two (2) abortive boreholes out of the thirty-five (35) wells show agreement with the model. The eight (8) of the eleven (11) wells that shows disagreement is due to depth at which the wells were dug. On this basis, the conceptual model is accurate and reliable with percentage agreement of 70% with the water column map.

5. Conclusion

In an attempt to offer solution to the spatial problem associated with heterogeneity phenomenon in groundwater exploration in basement complex terrain. Integration of remote sensing, geographic information system, geological and geophysical method involving electrical resistivity method was adopted to understand the groundwater regime of Oke-Ana, southwestern Nigeria. Five hydrogeological parameters favourable to groundwater abstraction were considered. The lineament and drainage density were mapped, geo electrical parameters (Aquifer resistivity, Overburden thickness) were determined from VES and geology and hydraulic parameters were measured. These were combined using Multi criteria decision analysis in the context of analytical hierarchy process. Appropriate weights and ratings were assigned to each contributing factors. The data were managed in a GIS environment in other to produce the groundwater potential map of Oke-Ana.

The resulted groundwater potential map was validated using Well information obtained in the study area. The study concludes that groundwater prospect of Oke-Ana is low to moderate groundwater potential, and the observed poor yield of the well dug in the area was due to lack of knowledge of hydro-geological information that can guide groundwater exploration in the area. Schist and amphibolite complex constitute the lithology with the moderate prospect and the granite gneiss constitutes with low prospect and the depth for good groundwater prospect in the area is around 18 m. The study also established the efficacy of MCDA and AHP Vis a Vis the relevance of integrated approach between remote sensing, GIS and geophysical method in effectively evaluating groundwater potential of an area.

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