Aquifer Characterization Using Evidences from Hydro-Geophysical Data: A Case Study of Ilorin Crystalline Basement Complex Southwestern Nigeria

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***Abstract*: - Aquifer delineation and characterization pose a challenge due to the complex nature of rocks, tectonic activities that have affected them and the localized nature of aquifers within the crystalline complex. This research aims at presenting characteristics of aquifers in parts of Ilorin municipality using evidences from hydrogeophysical data. Hydrogeophysical field data acquisition were done using Vertical Electrical Sounding and interpreted to infer aquifer characteristics and subsurface lithological succession. Three to six geo-electric layers were obtained across the study area. The curve types obtained were H, K, Q, HK and A. The dominant curve type is H-type which is considered to have three successive layers with resistivities ρ1, ρ2, ρ3 and a central low value (ρ1>ρ2<ρ3). Layer resistivities and thickness geo-electric parameters deducted include Transverse Resistance (T), Longitudinal Conductance (S), Coefficient of Anisotropy (λ) and reflection coefficient (r). The values of transverse resistance (T) ranges between 297740.8 and 510 Ωm ^{2}. The highest values of total transverse unit resistance are observed around the northwestern and north eastern parts of the study area while the lowest value is obtainable in the southern and central parts. Longitudinal unit conductance values within the study area range between 2.157 and 0.07mhos. It is observed that 90% of the study area has a very high longitudinal unit conductance which implies a good aquifer protective capacity. The southeastern area has low values of longitudinal unit conductance. Coefficient of anisotropy (ʎ) values in the area varies between 3.8 and 1.02. A high value of coefficient of anisotropy is observed around central areas of the study area. This area is considered to be a good groundwater potential area. Reflection Coefficient(r)shows the degree of fracturing. It is expected that good aquiferous zones overburden are relatively thick with low reflection coefficient. Reflection coefficient values ranged between 0.91 and 0.02. The western and central part reflected thick overburden and fractured basement. Areas of high, medium and low groundwater potentials have been delineated. Ilorin is considered to be of medium or moderate in terms of groundwater potential.**

***Keywords:* Basement Complex, Geo-electric parameters, Transverse Resistance, Longitudinal Conductance, Coefficient of Anisotropy, reflection coefficient, aquifer characterization.**

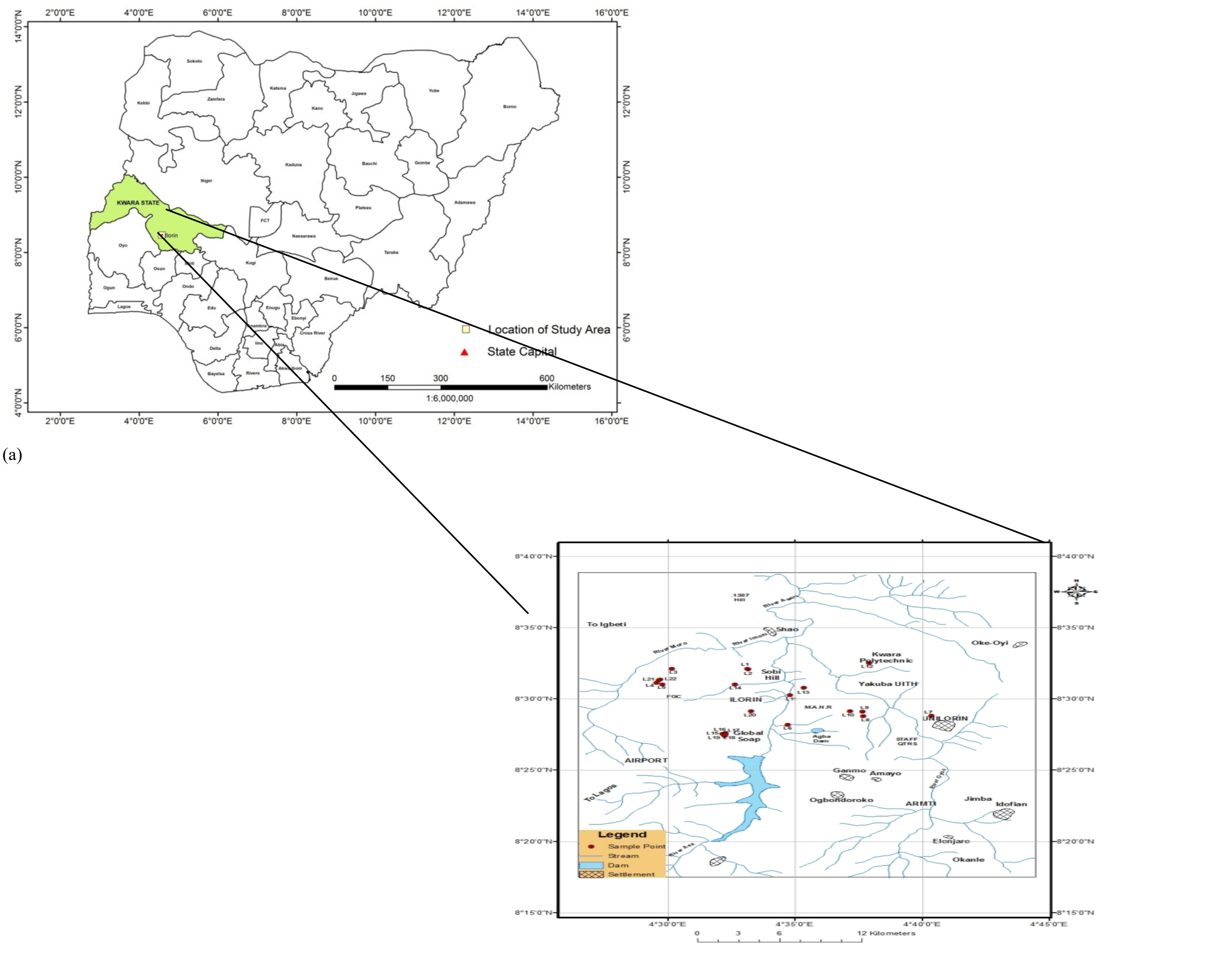
I. INTRODUCTION

The importance of water to human existence cannot be underestimated asthe continuous existence of life depends on regular supply of water in quantity and quality. Evaluation of groundwater potential in the crystalline basement complex has been problematic due to the complex nature of rocks and tectonic activities that has affected them and the localized nature of aquifer within the crystalline terrain[1]. The study aims at characterizing aquifers within the basement complex of Ilorin, south western Nigeria with evidences from integrated geo-electric and geo-sectional data. This study has become necessary in view of the dwindling surface water sources within the area and the complication of water threats such as climate change[2], [3]. The economic recession militating against the construction, managing and maintenance of relatively expensive surface water system such as dams and weirs incorporated with municipal water distribution also makes the affordable option of groundwater exploration imperative.

II. GEOLOGY AND HYDROGEOLOGY OF STUDY LOCATION

The study location falls within parts of Ilorin metropolis. The area is bound by longitudes $4^0 28^' 0''$E and $4^0 38^' 0''$E and latitudes $8^0 27' 0^{''}$N and $8^0 34' 15''$N.The area covered is about 242.79km^2 (Figure 1). Rain and dry seasons typical of tropical climates are experienced within the region. The rain season typically starts late march extending till October the commencement of the dry season, this is may however be interrupted with interchanging pockets of rain and dry spells[4]. The annual average rainfall within the region of 1,200mm, a humidity range of 60 to 89% and a temperature range between of 27 to 30°C all favour considerable groundwater potential [5], [6]. Asa, Agba and Oyun Rivers are the major drains dissecting the undulating topography and assuming a dendritic drainage pattern[7].Sobi Hill, north-eastern part of the study area has the highest altitude of about 1200m above sea level. The vegetation niche is predominantly guinea savannah with sparse forested region along the drains [8].

The Geology of area is falls within the basement complex typical of south western Nigeria. This belongs to the Precambrian to lowe Paleozoic age [9][10]. Major rock type consistent with the Precambrian Crystalline Basement Complex include migmatities, metasediments (schists, quartzites and metavolcanics), late-stage minor pegmatic, Pan- African (older) granite, aplitic instrusives and gneisses [11][10]. Olasehinde*, et. al.,* 1998 suggested that Ilorin is situated on the undifferentiated Precambrian Basement Complex rocks of granitic and metamorphic origin. These rock types typify a deep fractured aquifer partly overlain by a shallow porous aquifer situated in the lateritic soil cover [4][12]. These rock units are interconnected with the south western regional highlands running NW-SE parallel to Niger river drain [13]. The underlying subsurface lithology comprises of weathered, slightly weathered and fresh crystalline basement rocks. Gneiss complex one of the oldest rocks in the region is comprised of biotite-hornblende gneiss coupled with amphibolites this underlies more than half of the region. Other components of the old gneiss complex include porphiritic granite, gneiss and granite-gneiss. Two observable aquifer types are situated in the basement complex of the area, it includes the weathered basement and joint/ fractured basement aquifers. Joint/fractured basement is noted to more prevalent in the area than the weathered basement aquifer. The aquifers are mainly localized and disconnected occurring either as unconfined in semi-confined aquifers.



(a)

(b)

Figure 1 **a**. Map of Nigeria and **b.** Road network map of Ilorin the study area

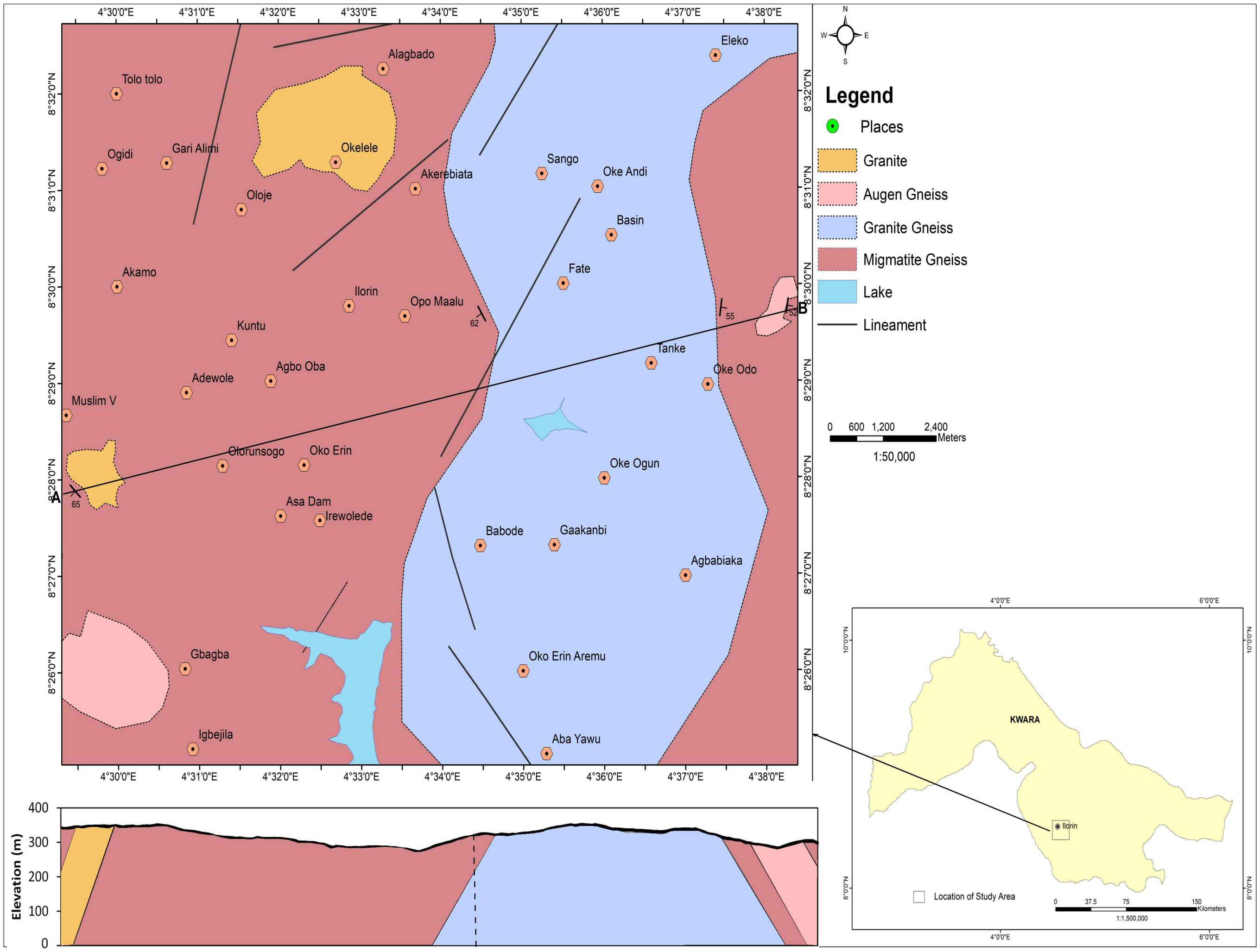


Figure 2 Geological map and Cross Section of Part of Ilorin

III. MATERIALS AND METHOD

Hydrogeophysical field data acquisition was done using VES technique. This was done to deduce and unraveled the subsurface lithological succession, aquifer characteristics and depth to basement. The primary purpose of this is to locate areas with thick weathered zone and fractures containing groundwater. The VES were done using Allied Ohmega digital resistivity equipment using Schlumberger electrode configuration with a maximum current electrode separation between 150 – 200m[14]. The equipment measures vertical changes in lithological succession in depth this is done to delineate horizontal layers and aquifers. Ninety-eight (98) VES points were investigated and analyzed to obtain the layer resistivity values and corresponding thickness. The geo-electric parameters manually plotted were cross referenced with results form expert iteration software, RESIST Version 1.0. The comparison of field and computer-generated curves was carried out to reduce errors and improve the goodness of fit. The geo-electric parameters deduce were evaluated and classified. In the same light a groundwater potential ranking patterned after Olayinka et. al (1997) was developed which incorporated aquifer potential as a function of depth to bedrock, saprolite resistivity and fractured bedrock resistivity[15]

IV. RESULTS AND DISCUSSION

The VES data were interpreted quantitatively and qualitatively and three to six geo-electric layers were obtained. The curve types obtained are H, K, Q, HK and A. The dominant curve types is H-type which is considered to have a three successive layers with resistivities $\rho 1$, $\rho 2$, $\rho 3$ with a central low sounding curve ($\rho 1>\rho 2<\rho 3$).

4.1 Geo-Electric Sections

Four geo-electric sections were delineated along NW-SE, N–S, W-E, NE-SW. This consist of subsurface/ geo-electric layers raging from three to six, it includes; topsoil, lateritic-clay, highly weathered layer, moderately weathered, poorly weathered rock and fresh basement. Figures 3-6 show four geo-electric sections delineated in the NW-SE, N–S, W-E and NE-SW directions.

The geo-electric sections display the various geo-electric parameters within the subsurface along the delineated directions.

4.1.1 Geo-electric Section NW-SE

This geo-electric section cut across VES stations 80, 36, 30,83,22,24 and 86 on it in the Northwest and Southeast direction. Four to six geologic units were also delineated as shown in figure 3. The topsoil has resistivity values ranged between 14.0 and 3225.5Ωm with thickness ranges from 0.4 and 4.1m. Location 86 located at Kilanko area has relatively thick top soil of about 4.1m with resistivity value 1517.2Ωm. The lateritic layers have resistivity value between 6.9 and 224.9Ωm while the thickness ranges from 2.3 and 10.0m. A highly weathered basement was observed in VES location 22, 24 and 86. The thickness and resistivity of highly weathered basement ranged between 5.7 and 35.6m and 15.4 and 2379.2Ωm. The thickest part is in the northeastern part particularly Gaa -Akanbi area. Hence good groundwater potential can be obtained from this area. This is due to its weathered/fractured basement with a basement depression overlain by thick overburden [16]. A moderately weathered formation was also deduced. The thickness and resistivity values ranged between 11.7and55.4m and 75.2 and187.9Ωm.The resistivity and thickness of 176.5-497.3Ω and 19.0-88.7m respectively were considered as a poorly weathered basement which cut across the transverse direction. The last but not the least is the underlying fresh basement with resistivity value of 6359.0Ωm.

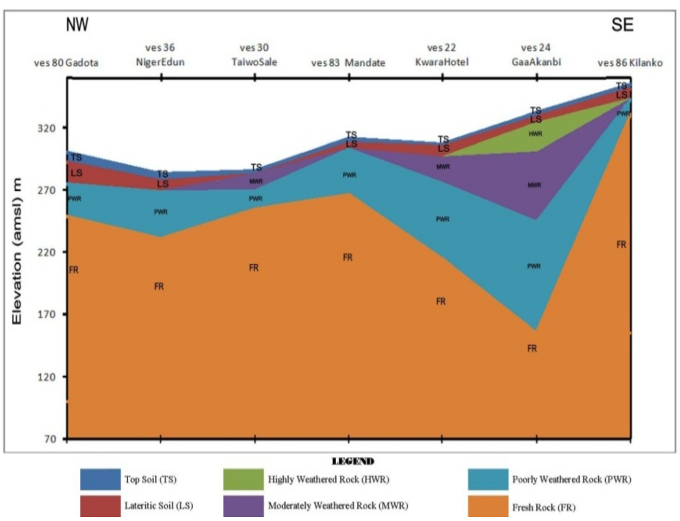


Figure 3 Geo-electric section of Ilorin Metropolis along NW-SE direction

4.1.2. Geo-electric Section N-S

Figure 4 shows the geo-electric section drawn through VES transverse locations N-S and consist of VES location 33,28,31,44,15,21,63 and 58. The top soil, which is relatively thin, is characterized by resistivity values between 83.5 Ωmand1979.7Ωm and thickness values between 0.4m and 3.5m. The second layer is diagnosed to be lateritic soil, resistivity values vary from 12.7-1194.5Ωm. Thickness of this layer ranges from 2-8m-16.2m. Location 28 has the highest thickness and located towards the central part of the study area. Highly weathered formation is observed in VES location 31, 33, 44 and 58. The resistivity of this layer ranges between 35.7-1144.7Ωm while the respective thicknesses ranged between 3.9-21.1m. A moderately weathered basement is also observed in location 21, 31, 33, 44, 58 with resistivity values and thickness ranged as 54.3-963.0Ωm and 6.6.6-37.1m respectively. Fresh basement has very high resistivity values ranging from 113.9-9873.0Ωm.

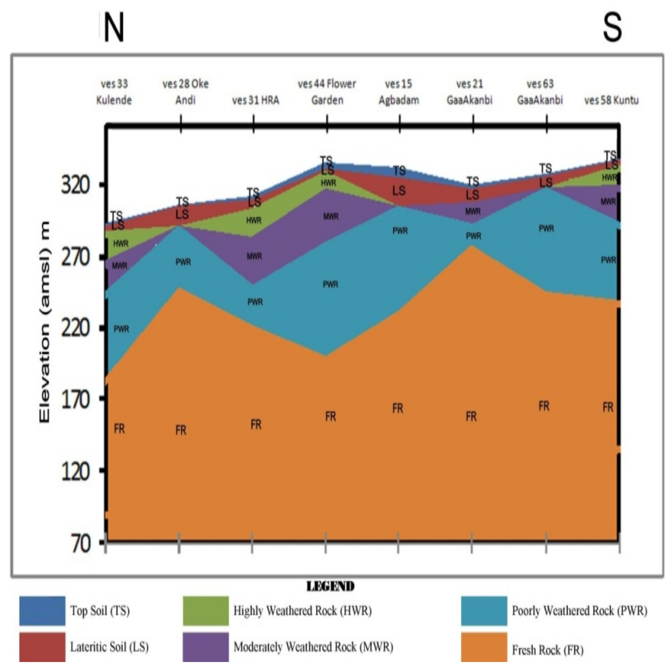


Figure 4 Geo-electric section of Ilorin metropolis along N-S directions

4.1.3. Geo-electric Section W-E Direction

Figure 5 is the geo-electric section generated along W-E transverse direction and comprises of VES location 75, 29, 30, 95, 44, 82 and 6. The top soil is characterized by resistivity values between 14.0 and 4106.5Ωm and thickness values between 0.4m and 3.5m. The second layer is delineated to be lateritic soil, having resistivity values varying from 20.9 to 1194.5Ωm. Thickness of this layer ranges from 1.5m-10.0m.A highly weathered formation is at location 95, 44 and 6 with varying thicknesses ranging between 12.5 and 37.1m while the resistivity values ranged between 57.0 and 283.6. Subsequence to this is the formation considered to a moderately weathered basement observable at location 95, 44, 82 and 6. It has a resistivity values ranged between 129.2 and 283.6 Ohms-m and thickness of 37.1 and 42.4m. A poorly weathered rock and fresh basement cut across the VES points within this transverse. Their respective resistivity values and thickness are; 222.-497.3 Ohms-m with thickness between 19.0-80.5m. The resistivity of fresh basement ranged between 120.9-2969.7Ohms-m while the thickness tends to infinity.

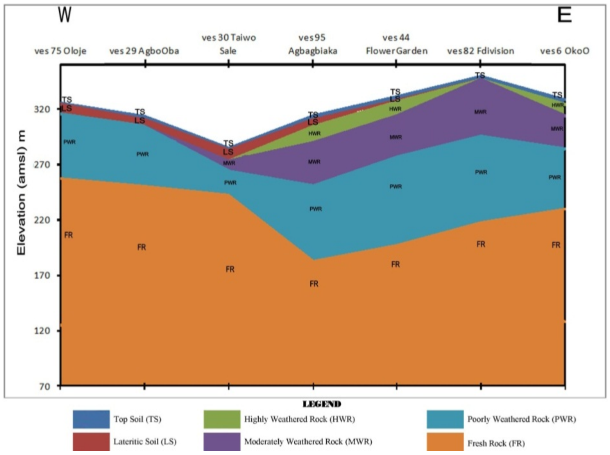


Figure 5 Geo-electric section of Ilorin Metropolis along W-E direction

4.1.4 Geo-electric Section NE-SW

Figure 6 is a geo-electric section drawn through VES transverse locations NE-SW comprises of VES location 87, 46, 28, 34, 19, 53, 42 and 79.The top soil in these locations is relatively thin and is characterized by resistivity values between 19.4-400.9Ωm and thickness values between 0.9m and 4.8m. The second layer is delineated to be lateritic soil, having resistivity values varying from 19.4-127.0hm-m. Thickness of this layer ranges from 2.9-24.7m. A highly weathered formation is at location 46, 53, 42 and 79 with varying thicknesses ranging between 12.6-15.9m while the resistivity values ranged between 55.1-122.7Ωm. A poorly weathered rock basement also cut across the VES points within this transverse. The resistivity values and thickness are 44.6-1662.5 Ohms-m and 30.6-44.6m. The resistivity of fresh basement ranged between 1522.5Ohms-m while the thickness tends to infinity.

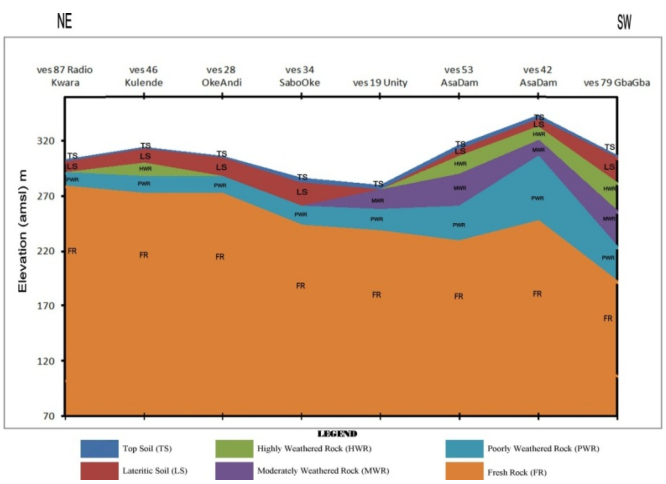


Figure 6 Geo-electric section of Ilorin Metropolis along NE-SW direction

4.2 Geo-electric parameters

The following geo-electric parameters were inferred from the sequential layer resistivities and corresponding thickness:

i. Transverse Resistance (T)
ii. Longitudinal Conductance (S)
iii. Coefficient of Anisotropy (λ).
iv. Reflection Coefficient (r)

This is imperative to help in reduction of uncertainty in differentiating the potential and non-potential ground water zone.

4.2.1 Coefficient of Anisotropy (λ)

Coefficient of Anisotropy has similar functional form to permeability anisotropy which implies that a higher coefficient of anisotropy implies a higher permeability. Literature suggest that an higher permeability anisotropy is associated with a higher groundwater flow [17]. Thus a higher coefficient of anisotropy implies higher permeability. Higher permeability anisotropy implies higher groundwater flow. The Coefficient of anisotropy (ʎ) values in the area varies between 4.8 and 1.02 (Figure 7.). This is classified into areas of low, medium and high groundwater potential. Locations with the value greater than >1.88 is considered to be high. Locations whose values ranges between 1.28 and 1.87 are classified to be medium while those with values ranging between 1.02 and 1.27 are considered to be low. High values of coefficient of anisotropy are observable in locations such as Sango, Akerebiata, Agba dam, Tanke-Bubu, Post office areas. Places such as Balogun, F-division, Gbagba etc. shows low values of coefficient of anisotropy while those considered to be medium are found in locations such as Biada, Basin, kwara hotel, Oke-odo etc.

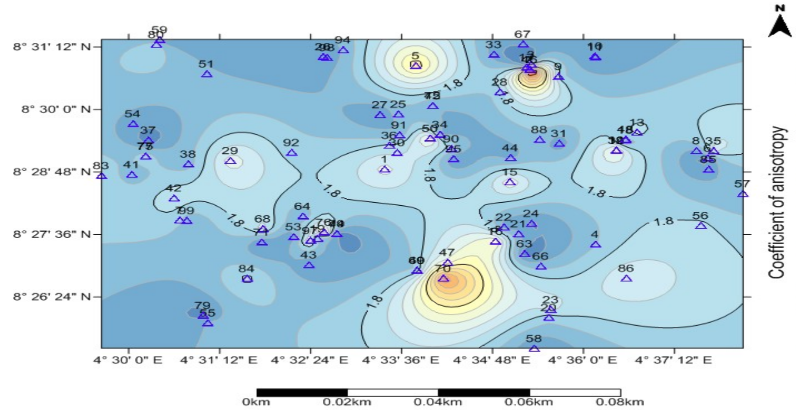


Figure 7 Contour Map of Coefficient of Anisotropy for the Study Area

4.2.2 Total Transverse Unit Resistance (T)

The total transverse unit resistance (T) is also employed to delineate areas of prominent groundwater potential. The transmissivity of an aquifer is directly proportional to transverse resistance and higher value of T reflects higher transmittivity values of the auriferous zones [18][19],[20][21][22]. Transverse resistance is the product of thickness and resistivity of a geo-electrical layer. The geo-electric parameters like Transverse Resistance (T) has been extensively used in identifying the ground water potential zones combined with the values of Longitudinal Conductance (S)[23][24][24]. Ayolabi, (2005) stated that the coefficient of anisotropy of the overburden material can be determined with the Transverse Resistance and Longitudinal Conductance Singh, (2003) has observed that the Transverse Resistance (T) is used to demarcate with better resolution of thin layers of both resistive and conductive properties [25]

Figure 8 shows the contour map of the total transverse unit resistance. Generally increasing T values is indicative of an increase in thickness of the resistive material [26][27], [28]. Higher aquifer transmissivity zones can be located by higher T value. The values of transverse resistivity are given in table 4.4. In the present study, the T values range between 297740.8 and 510 Ωm^2.The highest values of the total transverse unit resistance are observed around the northwestern and north eastern parts of the study area while the lowest value is obtainable in the southern and central parts. Transverse resistance within the study area has been classified into areas of low, medium and high groundwater potential. Location with T values >34,000 is classified to be high, those between 3,680 and 33,918 to be medium while those ranging between 510 and 3,677.5 are classified to be low. Places such as Sabo-oke, Agbooba, Kulende, Geri-alimi, hasvalues of T greater than 34000. Those within medium were obtainable in places like Oke-Andi, Okesunna, HRA, Niger etc. Low values of T are obatainable in Gbagba, Tanke-Iledu, Adewole areas.

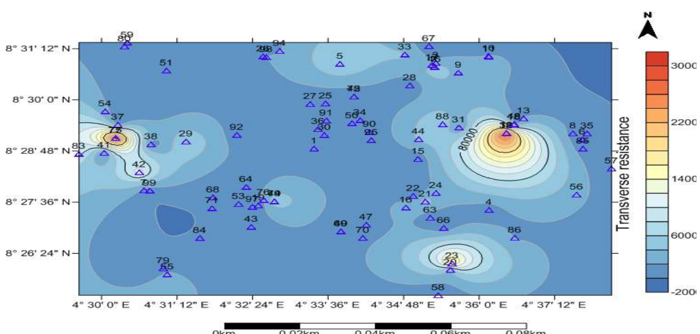


Figure 8 Contour Map of Transverse Resistance for the Study Area

4.2.3 Total longitudinal unit conductance (S)

The total longitudinal unit conductance values have been utilized severally in the evaluation of overburden protective capacities over hydrogeologic structures [29][30][31]. Longitudinal unit conductance values within the study area range between 2.157 and 0.07mhos. The Contour map of longitudinal unit conductance of the study area is shown figure 9. It is observed that 90% of the study area has a very high longitudinal unit conductance which implies a very high aquifer protective capacity. Meanwhile, the southeastern area has low values of longitudinal unit conductance. The study area is also divided into area of Low, Medium and high longitudinal conductance. Area with longitudinal conductance value between 0.007and 0.331 is classified to be low; area between 0.332 and 1.293 is classified to be medium while area with value greater than 1.293 is classified to be high aquifer protective capacity.

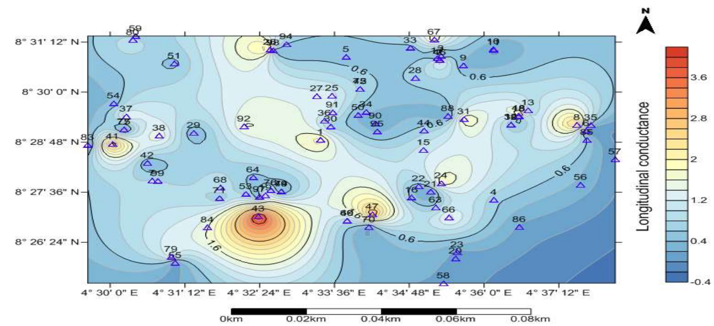


Figure 9 Contour Map of Longitudinal Unity Conductance for the Study Area

4.2.4 Reflection coefficient

Groundwater assessment within the crystalline basement focuses on complementary, interconnectivity of overburden and the fractured basement rock. However, resistivity values are not sufficient in adequately describing fractured basement rock and corresponding areas of promising groundwater yield. Hence, various geo-electric parameters such as reflection coefficient are employed to compliment efforts at groundwater potential delineation. Reflection coefficient are able to better reflect the degree of fracturing in the underlying basement. In the basement complex a low reflection coefficient (<0.8) and/or thick overburden depicts a good aquiferous zone [32]. Within the study area, the values of reflection coefficient ranged between 0.91and 0.02. The western and central portions of the study area reflect a thick overburden and fractured basement. Areas of high, medium and low groundwater potential were also identified and classified. Locations with (r) greater than 0.8 is considered to be low, those ranged between 0.14 and 0.79 are classified to be medium while those less than 0.15 are classified as high (Figure 10.). However, locations with (r) less than 0.15 are Gaa-Imam, Post- Office, Kwara Hotel, OKe-fomo etc. Those with values between 0.14 and 0.79 are observable in places like, Post Office, Alagbado, Gaa-Akanbi, HRA. Values greater than 0.8 were obtained in locations such as Mandate, Niger-edun, TankeIledu, Yidi-road area. These are considered to be of low/non groundwater potential.

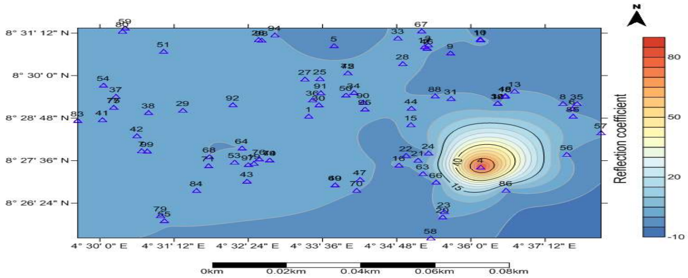


Figure 10 Contour Map of Reflection Coefficient for the Study Area

6. Conclusion

Evaluating groundwater potential in the crystalline basement complex is technically challenging due to the complex nature of rocks, tectonic activities that have affected them and the localized nature of aquifers within the crystalline complex. Characteristics of aquifers in parts of Ilorin municipality have been assessed in order to unravel the subsurface geology using various indices. Three to six geo-electric sections were delineated. The dominant curve type within the study area is H-type which is considered to have a three successive layers with resistivities ρ1, ρ2, ρ3 and a central low value (ρ1>ρ2<ρ3. The values of transverse resistance (T) range between 297740.8 and 510 Ωm^2. The highest values of the total transverse unit resistance are observed around the northwestern and north eastern parts of the study area while the lowest value is obtainable in the southern and central parts. Longitudinal unit conductance values within the study area range between 2.157 and 0.07mhos. It is observed that 90% of the study area has a very high longitudinal unit conductance which implies a good aquifer protective capacity. The Coefficient of anisotropy (ʎ) values in the area varies between 3.8 and 1.02. A high value of coefficient of anisotropy is observed around central areas of the study area. This area is considered to be a good groundwater potential area. Reflection Coefficient(r)shows the degree of fracturing. Reflection coefficient values ranged between 0.91 and 0.02. The western and central part reflected thick overburden and fractured basement. Areas of high, medium and low groundwater potentials have been delineated. Ilorin is considered to be of medium or moderate in terms of groundwater potential.

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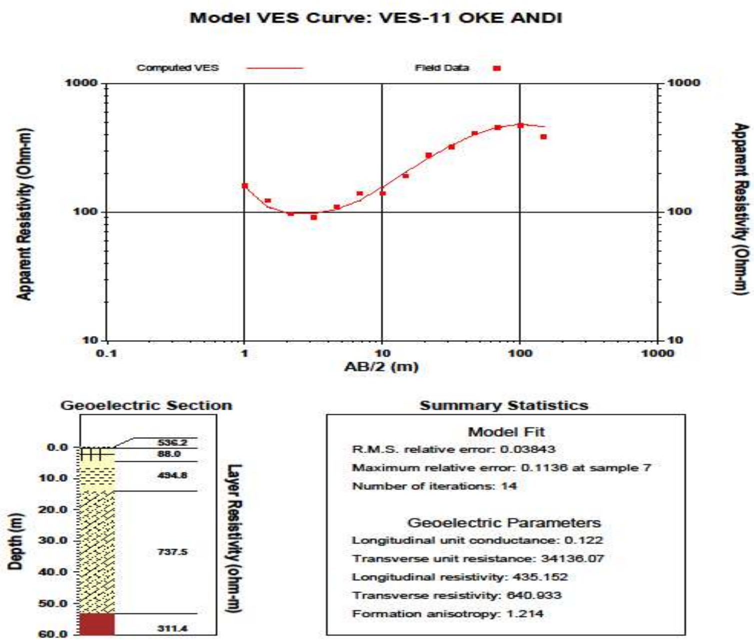
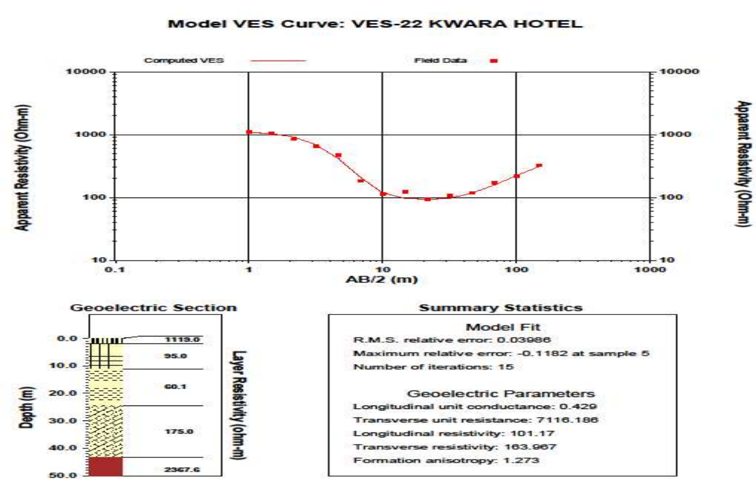
APPENDIX



(a)



(b)

Appendix 1 a & b Typical VES Curve within the study area

Table 1 Modelled hydro geophysical data interpretation

VES No	No of layers	Thickness (m)	Depth (m)	Resistivity (Ohms-m)	Inferred lithologies
22	1	1.89	1.89	1103.6	Top soil
	2	9.40	11.20	99.4	Lateritic soil
	3	19.87	31.15	79.4	Highly weathered
	4	61.30	92.46	720.2	Medium weathered
	5	∞	∞	454.0	Fresh basement
75					
	1	0.42	0.42	3503.2	Top soil
	2	9.12	9.53	294.0	Lateritic soil
	3	50.35	67.78	3536.4	Medium weathered
		∞	∞	732.5	Fresh basement
95					
	1	4.21	4.21	258.5	top soil
	2	5.40	9.60	728.8	Lateritic soil
	3	14.69	24.30	73.7	Highly weathered
	4	38.82	63.11	563.8	Medium weathered
	5	68.65	131.71	94.5	Poorly weathered
	6	∞	∞		Fresh basement
28					
	1	1.72	1.72	269.9	top soil
	2	16.15	17.87	29.2	Lateritic clay
	3	15.89	33.77	243.7	Medium weathered
	4	∞	∞	1336.3	Fresh basement
29					
	1	2.90	2.90	90.9	Lateritic
	2	5.61	8.50	20.9	Lateritic clay
	3	54.62	63.12	1120.3	Poorly weathered
	4	∞	∞	502.9	Fresh basement
83					
	1	3.17	3.17	1120.3	Lateritic
	2	5.74	8.92	95.6	Medium weathered
	3	35.60	44.54	2292.3	Poorly weathered
	4	∞	∞	149.1	Fresh basement