Journal of Physics: Conference Series

PAPER • OPEN ACCESS

Understanding the interrelationship between electrical anisotropy and groundwater yield in a typical Basement Complex area

To cite this article: Oluseun Adetola Sanuade *et al* 2019 *J. Phys.: Conf. Ser.* **1299** 012067

Understanding the interrelationship between electrical anisotropy and groundwater yield in a typical Basement Complex area

Oluseun Adetola SANUADE[1]*, Kehinde David OYEYEMI[2], Joel Olayide AMOSUN[3], Jane Idowu FALOYO[4] , Tokunbo Sanmi FAGBEMIGUN[3], Abayomi Adesola OLAOJO[5]

[1]Geosciences Department, King Fahd University of Petroleum & Minerals, Dhahran, Saudi Arabia.
[2]Department of Industrial Physics, Covenant University, Ota, Ogun State, Nigeria
[3]Department of Geophysics, Federal University Oye-Ekiti, Ekiti State, Nigeria
[4]Department of Applied Geophysics, Federal University of Technology Akure, Nigeria.
[5]Department of Earth Sciences, Ajayi Crowther University, Oyo, Oyo State, Nigeria.

E-mail: sheunsky@gmail.com

Abstract.The rocks in the Basement Complexof southwestern Nigeria exhibit electrical anisotropy as a result of their heterogeneous nature caused by weathering, near-surface effects or presence of fractures. It is known that groundwater yield (Y) in a typical Basement Complex aquifers is related to its coefficient of anisotropy (λ). Therefore, it is essential to study the correlation between Y and λ in the basement complex. Ten (10) vertical electrical sounding (VES) points using Schlumberger array were studied in areas underlain by migmatite gneiss and quartzite rocks. The current electrode spacing (AB/2) varies from 1 m to a maximum spread length of 100 m. The quantitative interpretation of VES curves was done by using partial curve matching and computer assisted program called *WinResist* version 1.0 software. Dar Zarrouk parameters were estimated from the interpreted VES curves and thus coefficient of anisotropy (λ) was calculated from these parameters. Data on the groundwater yield at the VES points were also obtained. The results show that as λ increases, Y also increases with coefficient of correlation (R^2) of 0.86 and 0.79 for migmatite gneiss and quartzite rocks respectively. To further investigate the relationship between Y andλ, a regression analysis was performed. The regression analysis that was performed on the dataset shows that λ contributes significantly to the regression models of the two rocks. The relationship between Y and λ reveals that groundwater yield could be predicted from the values of λ in a given locality.
Keywords: Anisotropy, regression, groundwater yield, Dar Zarrouk.

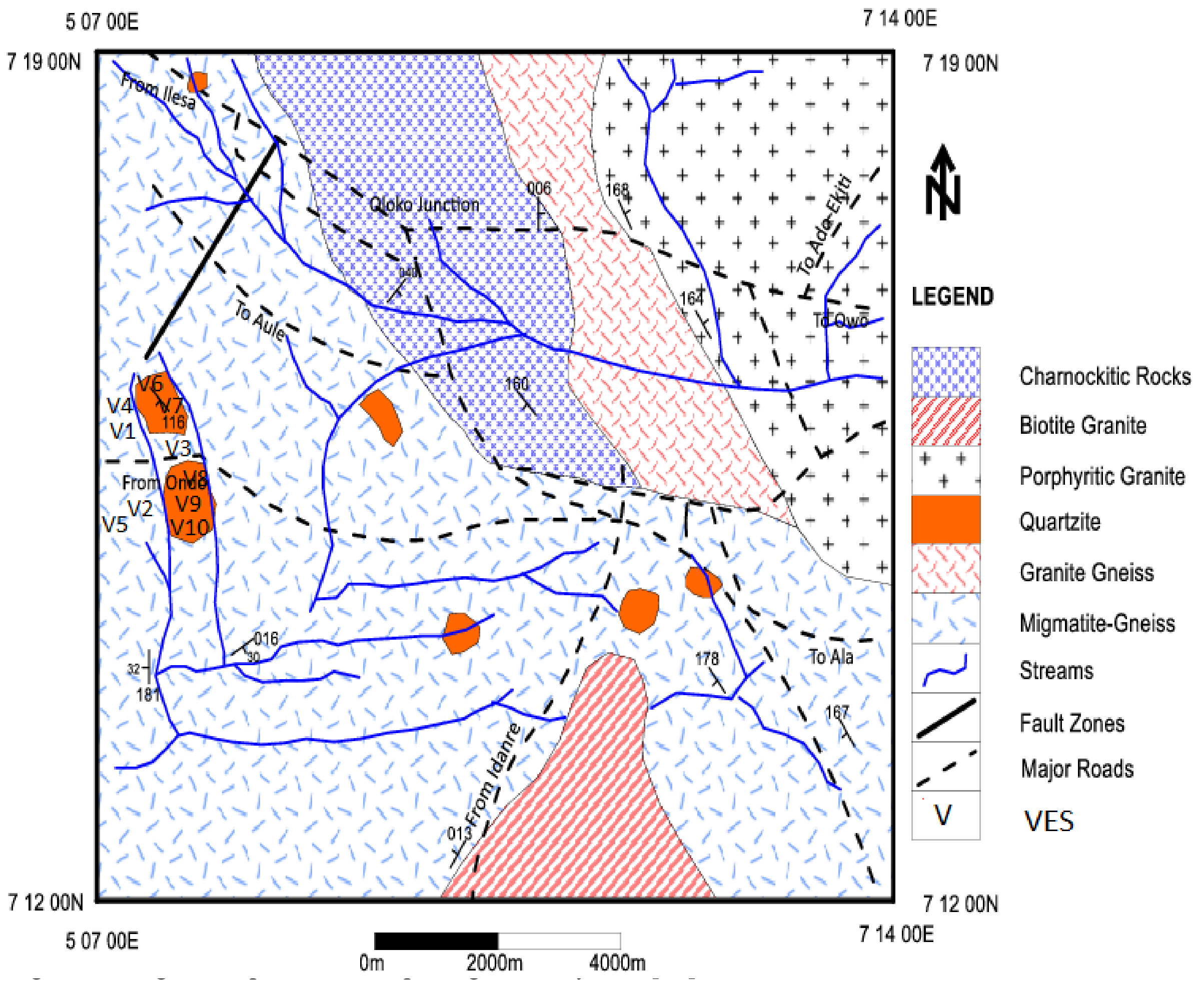
1. Introduction

The exploitation of groundwater in the Basement Complex rocks as an addition to surface water for both industrial and domestic uses is a common practice in areas that are made up of basement complex rocks. The principal aquifer unit in the Basement Complex are the saturated weathered or fractured zones [1-2], although the clayey/sand zone overlying the weathered zone might also have some significant amount of groundwater. However, the amount of groundwater that are accumulated in these fractured/weathered zones depends on effective porosity (ϕ_e) of the aquifer; where ϕ_e refers to both the primary (ϕ_p) and secondary porosities (ϕ_s) of the aquifer. The basement rocks are made up of very small ϕ_p, therefore the effective porosity of these rocks is mainly due to their ϕ_s [1]. The amount of groundwater accumulation (G_a) is therefore directly proportional the value of ϕ_e. Moreover, according to Archie [3], the permeability (K) of an aquifer is directly related to its ϕ_e, hence the groundwater yield (Y) is related to the amount of groundwater accumulation and K in a given aquifer.

Therefore, both G_a and K depend on porosity and thus, Y is indirectly proportional to ϕ_e[1]. Furthermore, it has been established that rocks in the Basement Complex exhibit anisotropy due to their heterogeneous nature [4-5]. The heterogeneous nature may be as a result of varying extent of weathering, near surface effects and existence of features such as faults, joints and foliation [5]. The presence of these features in basement rocks also create $\phi_s$and thus ϕ_e. Therefore, ϕ_e can be used to determine the coefficient of anisotropy (λ). Moreover, Y in a Basement Complex aquifers is a function of its λ[1;6].Several studies have used vertical electrical sounding (VES) to study the development and assessment of groundwater in the basement complex terrain of Nigeria [7-12].Therefore, this study aims at investigating the relationship between Y and λ; and develop a regression model between them in Basement Complex areas of southwestern Nigeria.

2. Description and geology of the study area

The area under study isBolorunduro in Akure, Ondo State, Nigeria and lies within longitude 5°07'00" to 5°08'04" E and latitude 7°14'02" to 7°15'10" (Fig. 1). The area is generally typified by uniformly high temperature, heavy and well distributed rainfall throughout the year with mean annual temperature of 24 to 27 °C. The rainfall in the area ranges between 1500 and 3500 mm per year having its peaks in July and September [13]. In term of geology, the area is part of the Precambrian Basement Complex rocks of southwestern Nigeria. The principal rock types in the study area are migmatite gneiss and quartzite (Fig. 1).



3. Methodology

3.1 Geophysical investigation

Vertical electrical sounding (VES) data, using Schlumberger array, wereacquired with a Campus Ohmega resistivity meter. Ten (10) VES points were studied with electrode spacing (AB/2) of current ranging from 1 to 100 m. Five (5) of the VES sites were located in area that is composed of migmatite gneiss rock while the other five were located within quartzite rocksin Bolorunduro and its environs. The quantitative interpretation of VES curves were done by using partial curve matching and computer assisted program using *WinResist* version 1.0 software.

3.2 Coefficient of anisotropy (λ) determination

Anisotropic coefficient could be estimated from geoelectric parameters: layer resistivity (ρ) and thickness (h) [9]. Both h and ρ were obtained from quantitative interpretation of VES data.
The longitudinal conductance (S) can be calculated using equation 1 [15]:

$$S = \sum_{i=1}^{n} \frac{h_i}{\rho_i} \qquad (1)$$

where n is the number of layers, h_i is the layer's thickness and ρ_i is the layer's resistivity.

Also, transverse resistance (T) in a geoelectric section could be calculated using equation 2.

$$T = \sum_{i=1}^{n} h_i \rho_i \qquad (2)$$

Moreover, longitudinal resistivity (ρ_l) can be estimated using the relation in equation 3:

$$\rho_l = \frac{H}{S} \qquad (3)$$

where H is the addition of thicknesses in the rock unit.
Likewise transverse resistivity (ρ_t) can be calculated using equation 4.

$$\rho_t = \frac{T}{H} \qquad (4)$$

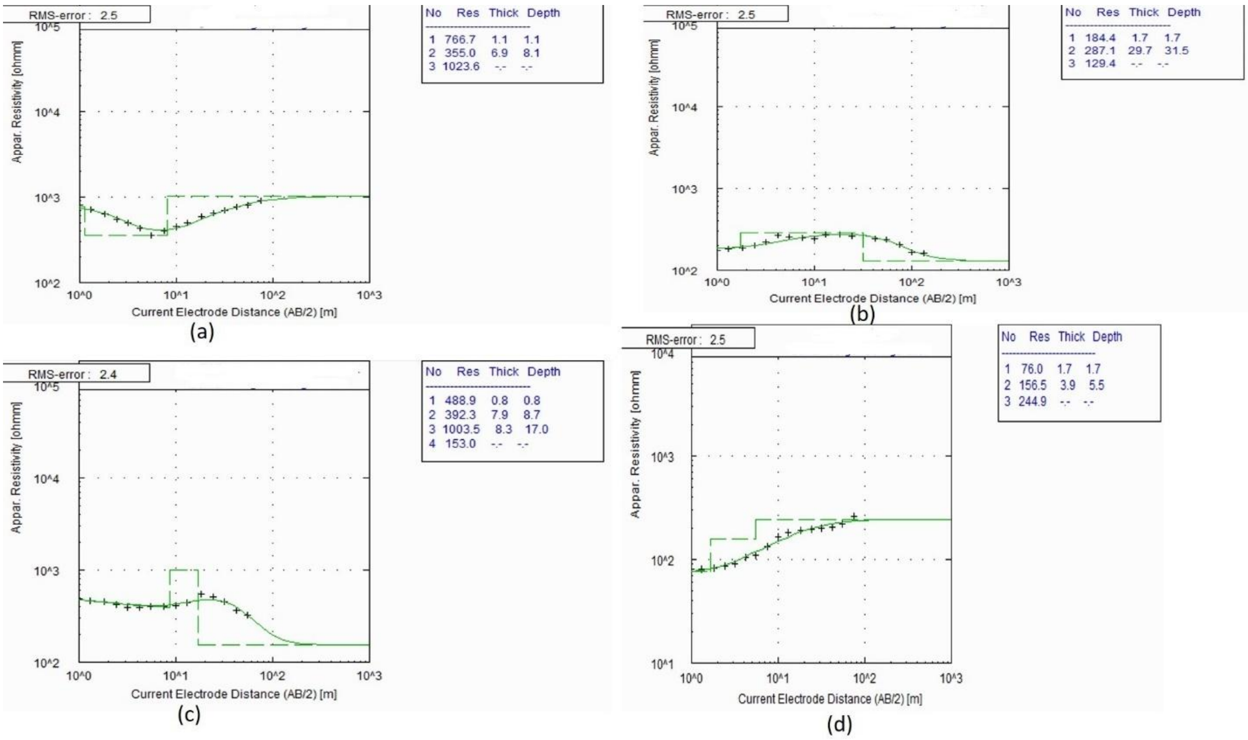
Therefore, the coefficient of anisotropy (λ) can be determined using equation 5.

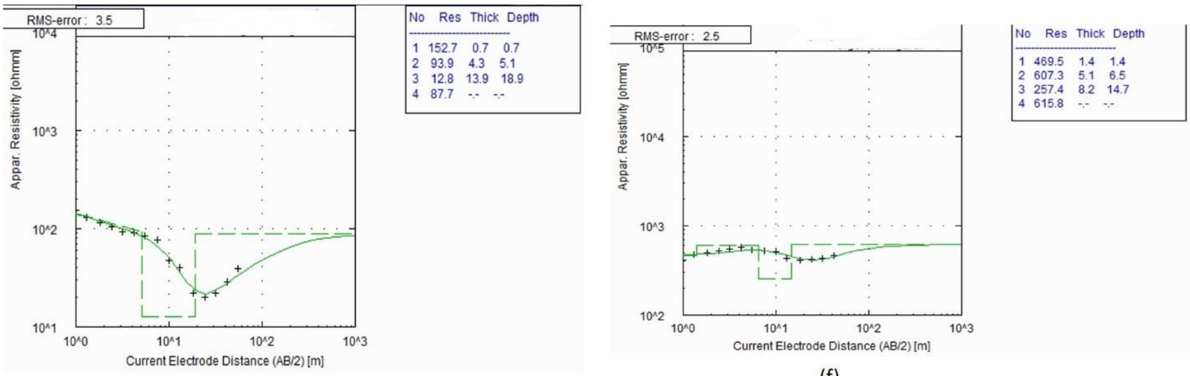
$$\lambda = \sqrt{\frac{\rho_t}{\rho_l}} = \frac{\sqrt{TS}}{H} \qquad (5)$$

In this study, λ refers to the overburden anisotropic coefficient. The groundwater yield at the location of the borehole within the VES location was also obtained.

4. Results and Discussion

The typical curve types identifiedin the study area are shown in Fig. 2a-f. Table 1 also shows the interpretation of VES data. The geophysical interpretation reveals that the area is made up of three to four lithology which are top soil, weathered basement (clayey), compacted lateritic clay and fractured basement with variable resistivities and thicknesses as seen in Table 1. The hydrogeological interpretation from the VES datausing the resistivity values and thicknessesshows that the area under study is composed of fairly good aquifer potential to good aquifer potential[16].





(e) (f)

Fig. 2: Typical curve types in the study area (a) H-type (b) K-type (c) HK-type (d) A-type (e) QH-type (f) KH-type.

Table 1. Summary of the geophysical interpretation

VES	Rock Type	Curve Type	Layer	Resistivity (Ohm-m)	Thickness (m)	Depth (m)	Lithology	Hydrogeological Significance
1	Migmatite Gneiss	H	1	230	0.7	0.7	Topsoil	-
			2	83	4.2	4.9	Weathered basement (clayey)	Fairly good aquifer potential
			3	523	-	-	Fractured basement	Good aquifer potential
2	Migmatite Gneiss	H	1	236	1.0	1.0	Topsoil	-
			2	44	8.3	9.3	Weathered basement (clayey)	Fairly good aquifer potential
			3	684	-	-	Fractured basement	Good aquifer potential
3	Migmatite Gneiss	H	1	63	0.7	0.7	Topsoil	-
			2	21	5.2	5.9	Weathered basement (clayey)	Fairly good aquifer potential
			3	261	-	-	Fractured basement	Good aquifer potential
4	Migmatite Gneiss	H	1	260	1.4	1.4	Topsoil	-
			2	64	7.7	9.1	Weathered basement (clayey)	Fairly good aquifer potential
			3	744	-	-	Fractured basement	Good aquifer potential
5	Migmatite Gneiss	H	1	767	1.1	1.1	Topsoil	-
			2	355	6.9	8.0	Weathered basement	Fairly good aquifer potential
			3	1023	-	-	Partially	Fairly good

							fractured basement	aquifer potential
6	Quartzite	K	1	184	1.7	1.7	Topsoil	-
			2	287	29.7	31.4	Lateritic clay	Poor aquifer potential
			3	129	-	-	Completely weathered basement	Good aquifer potential
7	Quartzite	HK	1	489	0.8	0.8	Topsoil	-
			2	392	7.9	8.7	Lateritic clay	Poor aquifer potential
			3	1004	8.3	17.0	Partially weathered basement	Fairly good aquifer potential
			4	153	-	-	Completely weathered basement	Good aquifer potential
8	Quartzite	A	1	76	1.7	1.7	Topsoil	-
			2	157	3.9	5.6	Compacted lateritic clay	Poor aquifer potential
			3	245	-	-	Completely weathered basement	Good aquifer potential
9	Quartzite	QH	1	153	0.7	0.7	Topsoil	-
			2	94	4.3	5.0	Lateritic clay	Poor aquifer potential
			3	13	13.9	18.9	Completely weathered basement (clayey)	Fairly good aquifer potential
			4	88	-	-	Fractured basement	Good aquifer potential
10	Quartzite	KH	1	470	1.4	1.4	Topsoil	-
			2	607	5.1	6.5	Compacted lateritic clay	Poor aquifer potential
			3	257	8.2	14.7	Weathered basement	Fairly good aquifer potential
			4	616	-	-	Fractured basement	Good aquifer potential

Table 2 shows the results of the Dar Zarrouk parameters, coefficient of anisotropy and groundwater yield. The table shows that λ values for the two rock types are greater than 1 which is typical of Basememt Complex rocks [1]. Coefficient of anisotropy ranges from 1.02 to 1.16 for migmatite gneiss, while that of quartzite ranges from 1.00 to 1.48.

Table 2. Result of Dar Zarrouk parameters, anisotropic coefficient and groundwater yield

Location	Rock type	S (mhos)	T (Ωm^2)	H (m)	ρ_l (Ωm)	ρ_t (Ωm)	λ	Y (l/s)
1	Migmatite Gneiss	0.05358	510.3	4.9	91.45203	104.1429	1.067131792	0.50
2	Migmatite Gneiss	0.1933	600.47	9.3	48.11174	64.56667	1.158453579	0.67
3	Migmatite Gneiss	0.25759	153.68	5.9	22.90462	26.04746	1.066402523	0.58
4	Migmatite Gneiss	0.12589	855.47	9.1	72.28533	94.00769	1.140398445	0.62
5	Migmatite Gneiss	0.02087	3292.87	8.1	388.1169	406.5272	1.023442619	0.48
6	Quartzite	0.112667	8840.35	31.5	279.585	280.646	1.001895766	0.60
7	Quartzite	0.030045	11819.34	17	565.8179	695.2553	1.108495146	0.68
8	Quartzite	0.047289	739.55	5.5	116.3061	134.4636	1.075229439	0.73
9	Quartzite	1.1363	688.58	18.9	16.63293	36.4328	1.480000634	0.82
10	Quartzite	0.04324	5865.21	14.7	339.963	398.9939	1.083346267	0.68

Figs. 3 and 4 show the plots of Y against λ for the two rock types in the area respectively. The figures show that Y increase with an increase in λ for the two rock types[1; 17]as well ascorrelation coefficients (R^2) of 0.86 for migmatite gneiss rock and 0.79 for quartzite rock. The relatively high R^2 obtained between Y and λ for both rock types indicate that the extent of heterogeneity of the overburden has influence on the groundwater yield.

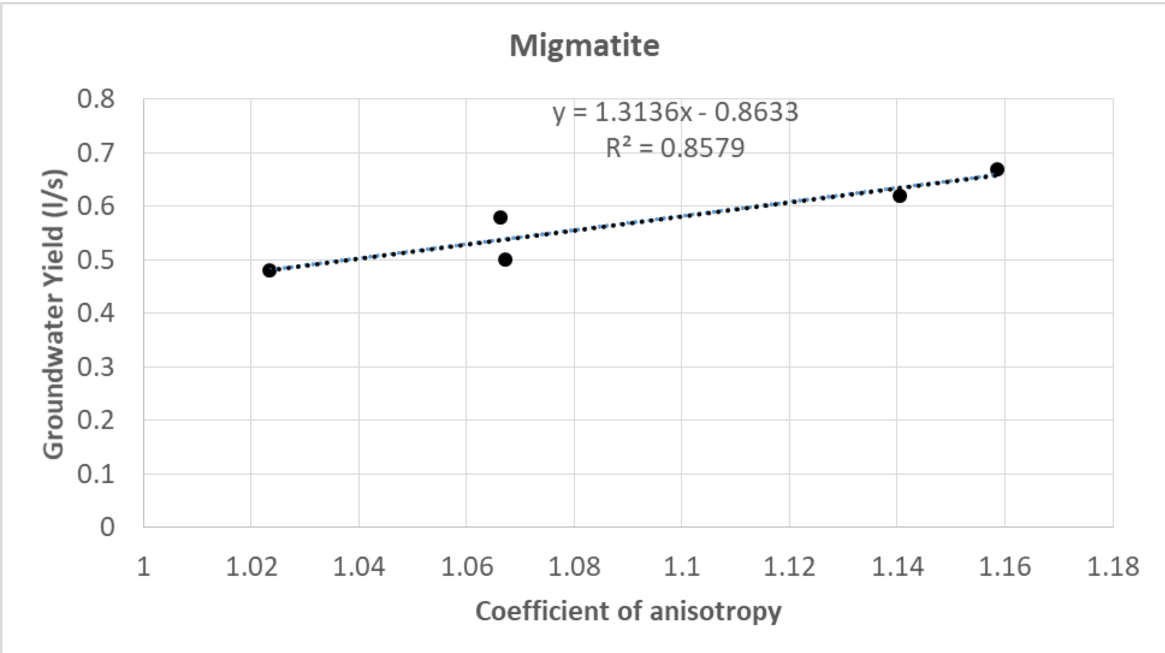


Fig. 3: Plot of groundwater yield against the coefficient of anisotropy for migmatite gneiss rock

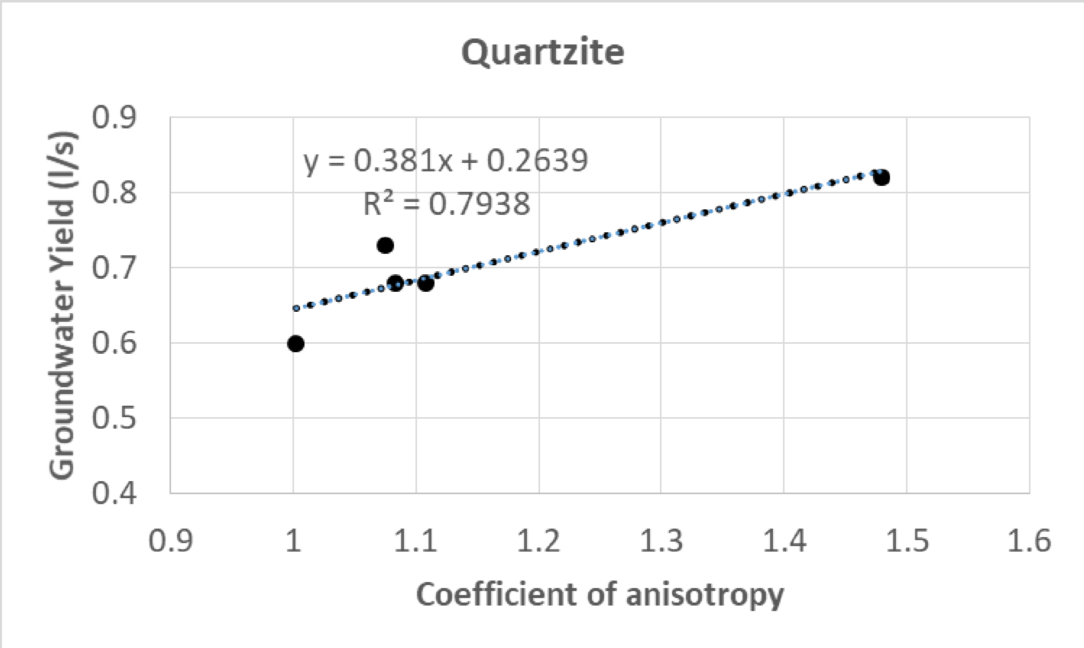


Fig. 4: Plot of groundwater yield against the coefficient of anisotropy for quartzite rock.

To further investigate the relationship between Y and λ, a regression analysis was done using *Minitab 17* software at 5% level of significance. Given a model as shown in equation 6 [18]:

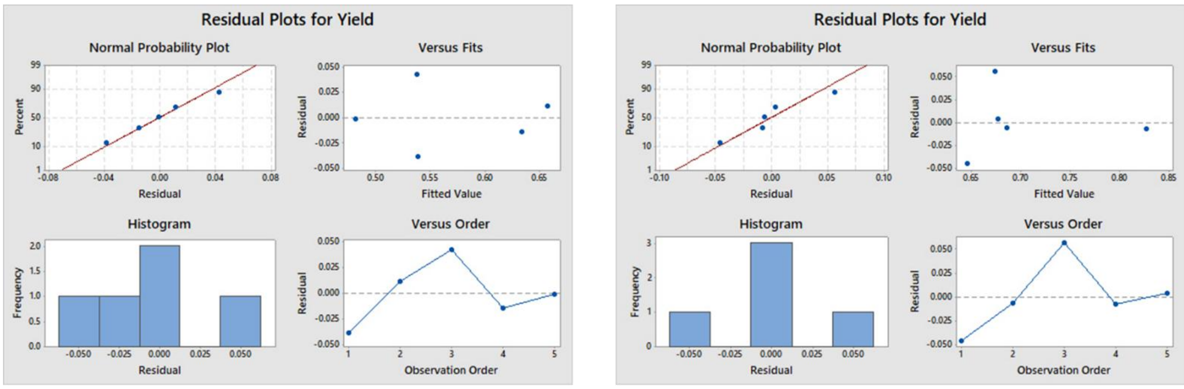
$$Z = \beta_0 + \beta_1 X + \in \quad (6)$$

where Z is the response variable (groundwater yield), X is the explanatory variable (coefficient of anisotropy), $\in$ is the residual error, β_0 is the slope and β_1 is the intercept which vary from rock to rocks and depending on the composition and nature of the near surface processes. The purpose of the statistical study is to establish whether there is a linear relationship between the response variable (groundwater yield)and an explanatory variable (coefficient of anisotropy) so as to affirm the relationship given in Figs. 3 and 4[1; 16]. The hypothesis used for the statistical analysis is given thus:

Null hypothesis (H_0): $\beta = 0$ (7a)

Alternate hypothesis (H_1): $\beta \neq 0$ (7b)

Fig. 5a and b show the residual plots for the statistical analysis. From the figure, the normal probability plot in the form of Anderson Darling test reveals that the response variable for the parameters considered are normal. The histograms also show normality. The plot for the residual versus fit affirmed the homogeneity of the variance as no patterned plot was observed. The plots for the residual versus order show the independent relationship that exist between points as no particular trend was developed.



(a) (b)

Fig. 5: Residual plots for yield (a) Migmatite gneiss (b) Quartzite

The two-way analysis of variance (ANOVA) table in Table 3 for migmatite gneiss rock shows that p-value (0.024) is less than the level of significance (0.05), hence the null hypothesis is rejected and we can conclude that coefficient of anisotropy contributes significantly to the model (groundwater yield). Likewise for quartzite rock (Table 4), the p-value (0.043) is less than the level of significance (0.05), and the null hypothesis would also be rejected thereby concluding that coefficient of anisotropy contributes significantly to the model (groundwater yield). The R^2 for the model are 81.06% and 79.4% respectively for migmatite gneiss and quartzite rocks.

Table 3. Regression Analysis: Yield versus coefficient of anisotropy for migmatite gneiss rock

ANOVA					
Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**
Regression	1	0.021963	0.021963	18.12	0.024
Coefficient of anisotropy	1	0.021963	0.021963	18.12	0.024
Error	3	0.003637	0.001212		
Total	4	0.025600			
Summary of Model					
S	R^2	R^2 (adjusted)	R^2 (predicted)		
0.0348169	85.79%	81.06%	72.42%		

DF is the degree of freedom, Adj SS is the adjusted sum of squares and Adj MS is adjusted mean square

Table 4. Regression Analysis: Yield versus coefficient of anisotropy for quartzite rock

ANOVA					
Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**
Regression	1	0.020703	0.020703	11.55	0.043
Coefficient of anisotropy	1	0.020703	0.020703	11.55	0.043
Error	3	0.005377	0.001792		
Total	4	0.026080			
Summary OF Model					
S	R^2	R^2 (adjusted)	R^2 (predicted)		

0.0423368	79.38%	72.51%	71.45%

Therefore, the regression models for migmatite gneiss and quartzite rocks are given by equations 8 and 9 respectively

$$Yield = -0.863 + 1.314\, coefficient\ of\ anisotropy \quad (8)$$

$$Yield = 0.264 + 0.381\, coefficient\ of\ anisotropy \quad (9)$$

The relatively high prediction R^2 of 72% and 71% respectively for migmatite gneiss and quartzite rocks respectively indicate that the regressions models in equations 8 and 9 are reliable.

5. Conclusions

An increase in the overburden coefficient of anisotropy also leads to increase in Y in the Basement Complex rocks of southwestern Nigeria. The interrelationship between these two factors (groundwater yield and coefficient of anisotropy) could be estimated by a linear equation as determined by regression analysis for the two rock types investigated. The regression equations could be applied for rocks with similar characteristics as the ones in the study area. An overlap was observed in the values of coefficient of anisotropy for both migmatite gneiss and quartzite rocks, although quartzite rock has a relatively higher mean value. Therefore, it is possible to employ λ to differentiate lithology broadly especially in areas where the geology is known. This study is in agreement with the study conducted by Olorunfemi et al. [1]

Acknowledgments
The authors thank KFUPM for the provision of valuable software.

References

[1] Olorunfemi MO,Olarewaju VO,Alade O(1991)On the electrical anisotropy and groundwater yield in a Basement Complex area of S.W. Nigeria. Journal of African Earth Sciences12 (3): 467-472.
[2] Fashae OA, Tijani MN, Talabi AO, Adedeji OI (2014) Delineation of groundwater potential zones in the crystalline basement terrain of SW-Nigeria: an integrated GIS and remote sensing approach. Applied Water Science 4 (1): 19–38.
[3] Archie GE(1942)The electrical resistivity log as an aid in determining some reservoir characteristics. Trans AIME, 1445:54-62.
[4] Olasehinde PI, Bayewu OO(2011) Evaluation of electrical resistivity anisotropy in geological mapping: A case study of Odo Ara, West Central Nigeria. African Journal of Environmental Science and Technology 5(7): 553-566.
[5] Bayewu OO, Mosuro GO, Oloruntola MO(2013)The evaluation of anisotropic properties of parts of Ijebu-Igbo, southwestern, Nigeria, using azimuthal resistivity survey (ARS) method. 13th International Congress of the Brazilian Geophysical Society held in Rio de Janeiro, Brazil, August 26-29: 1-5.
[6] Kumar D, Rai SN, Thiagarajan S, Kumari YR (2014) Evaluation of heterogeneous aquifers in hard rocks from resistivity sounding data in parts of Kalmeshwar Taluk of Nagpur District, India. Current Science 107(7):1137-1145.
[7] Joshua EO, Odeyemi OO, Fawehinmi OO (2011) Geoelectric investigation of the groundwater potential of Moniya area, Ibadan. Journal of geology and mining research 3(3): 54-62.

[8] Lateef TA (2012) Geophysical investigation for groundwater using electrical resistivity method- A case study of Annunciation grammar school, IkereLga, Ekiti State, Southwestern Nigeria. IOSR Journal of Applied Physics 2(1): 1-6.

[9] Asiwaju-Bello YA, Ololade JO (2013) Groundwater potential of Basement aquifers in part of Southwestern Nigeria. American International Journal of Contemporary research 3(3):124-141.

[10] Oladunjoye HT, Odunaike RK, Ounsola P, Olaleye OA (2013). Evaluation of groundwater potential using electrical resistivity method in Okenugbo area, Ago-Iwoye, Southwestern Nigeria. International Journal of Advances in Engineering Sciences and Applied Mathematics 4(5): 22-30.

[11] Bayewu OO, Oloruntola MO, Mosuro GO, Laniyan TA, Ariyo SO, Fatoba JO (2017) Geophysical evaluation of groundwater potential in part of Southwestern Basement Complex terrain of Nigeria. Applied Water Science 7(8): 4615-4632.

[12] Bayowa OG, Fashola AK, Adegoke AB, Agesin AA, Oyeniyi SA (2018) Geophysical investigation for groundwater potential around LadokeAkintola University of Technology Campus, Ogbomoso, Southwestern, Nigeria. Journal of Earth Science & Climatic Change 9(8): 1-10.

[13] Yusuf GA, Akinrinade OJ, Ojo JS(2015)Anengineering site characterization using geophysical methods: a case study from Akure, southwestern Nigeria. Journal of Earth Sciences and Geotechnical Engineering 5(4): 57-77.

[14] Owoyemi FB (1996) A geological-geophysical investigation of rain-induced erosional features in Akure metropolis. Unpublished. M.Tech Thesis, Federal University of Technology: Akure, Nigeria, pp. 11-18.

[15] Zohdy AAR, Eaton GP. Mabey DR(1974) Application of surface geophysics to groundwater investigation. In: *Techniques of Water ResourcesInvestigations of the United States Geological Survey*. Book 2, Chapter DI, 22-24.

[16] Oladunjoye MA, Jekayinfa S (2015) Efficacy of Hummel (Modified Schlumberger) Arrays of Vertical Electrical Sounding in groundwater Exploration: Case study of parts of Ibadan Metropolis, southwestern Nigeria. International Journal of Geophysics 2015: 1-24, doi.10.1155/2015/612303.

[17] OlorunfemiMO, Olorunniwo, MA(1985)Geoelectric parameters and aquifer characteristics of some parts of southwestern Nigeria. GeologiaApplicataIndrogeologia 20(1): 99–109.

[18] Montgomery DC (2013) Design and analysis of experiments, eighth ed. international student version. John Wiley & Sons.