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On the Application of Coefficient of Anisotropy as an Index of Groundwater Potential in a Typical Basement Complex of Ado Ekiti, Southwest, Nigeria

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

This paper examines the application of the Dar Zarrouk parameter, the Coefficient of Anisotropy to Groundwater Potential Evaluation in a typical Basement Complex Terrain of Ado-Ekiti Southwest, Nigeria. A regional Geoelectric Depth sounding was carried out across the metropolis using the Schlumberger electrode array. Resistivity-depth image in terms of layer thickness and resistivity was used to compute the Coefficients of Anisotropy for the VES locations occupied. Thematic maps of the geoelectric parameters were generated using the Concept of Geographical Information System (GIS). Comparative Map Analysis revealed that a range of 1.3 to 1.6 Anisotropy values was observed across the zones characterized by thick overburden, Weathered Basement Thickness in excess of 25m, low weathered basement resistivity, fractured bedrock and basement depressions in the study area. Anisotropy values ranging from 1.8 to 2.8 were observed across the basement ridges and zones characterized by thin overburden, Weathered Basement Thickness of generally less than 15m and Weathered Basement resistivity greater than 1500 Ω-m with least groundwater potential. The regions of Anisotropy values ranging from 1.3 to 1.6 are demarcated as high groundwater potential zones. Areas characterized by higher Anisotropy values can be associated with low porosity and permeability with less hydro geological appeal.

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Keywords: Anisotropy; basement; groundwater potential; index; overburden.

1. INTRODUCTION

In hard rock terrains, the weathered basement zone and fractured basement are known to give the highest groundwater yield. Geoelectric variables often considered for groundwater potential estimation include Overburden thickness, weathered basement/saprolite resistivity and the fractured bedrock resistivity [1,2,3]. Structural Mapping in regional geoelectric surveys are thus presented as the Isopach map of overburden, weathered basement Map and the bedrock resistivity map Bedrock Relief Map. These maps present structural trends which permit categorization of the study area into groundwater potential zones. For instance, series of basement ridges and depressions delineated on the Bedrock Relief Map and Isopach map of overburden are indicative of poor groundwater potential zones and good groundwater potential zones respectively. Fairly low bedrock resistivity confirms the presence of fractures and an enhanced groundwater potential of the aquifer. The combination of the thicknesses and resistivities of the geoelectric layers into single variable; the Dar-Zarouk parameter of Coefficient of Anisotropy should offer an Index of Groundwater Potential [4,5].

2. GEOLOGY

The ancient town of Ado-Ekiti falls within the basement complex of south-western Nigeria. The geology is thus dominated by the crystalline rocks of the basement (Fig.1 (a)). The rock sequence in the area includes Pegmatite and

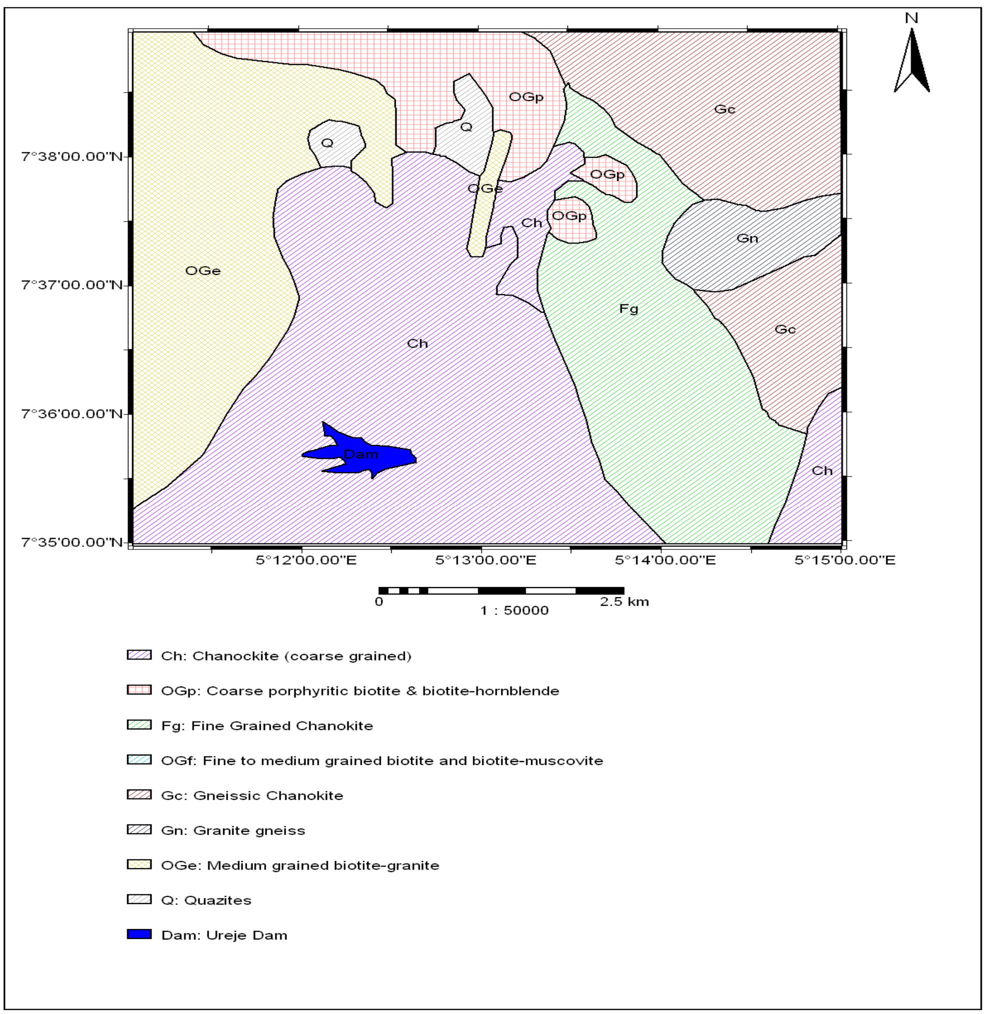

Fig. 1(a). Geological map of Ado Ekiti (after Geological Map of Akure Sheet 56)

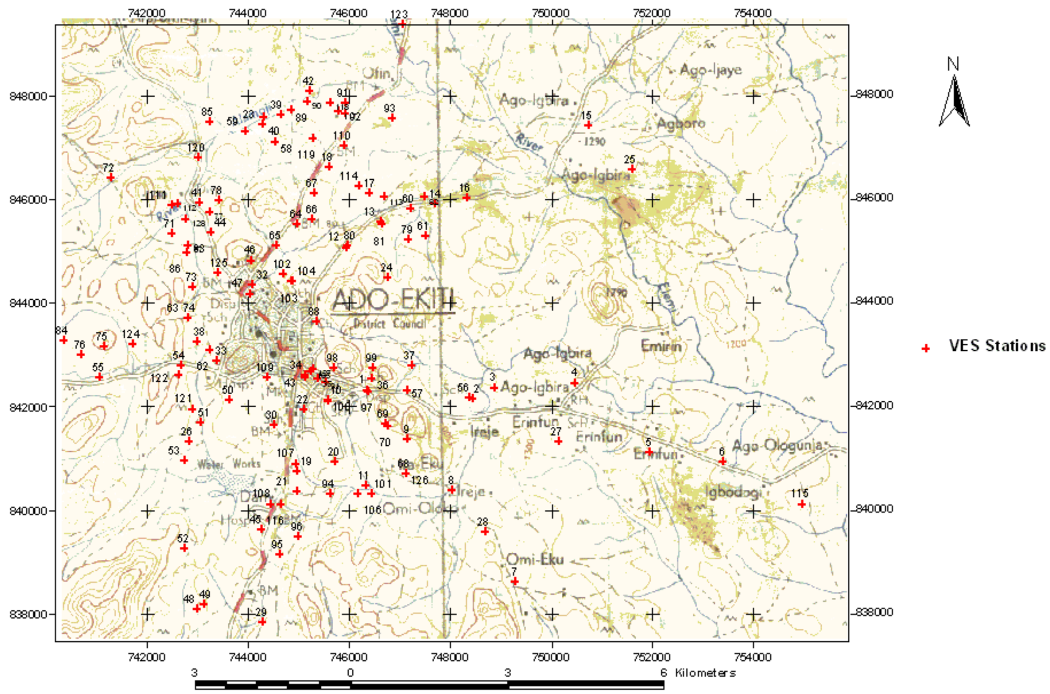

Fig. 1(b). The map of Ado-Ekiti showing the VES stations

Aplites, Granitite rocks, Charnockitic rocks, quartzite series, Gneisses and Migmatites. The rocks generally trend toward north-south in direction. The granitic rocks occupy the western and north central parts of the area, the charnockitics rocks are found in the central and eastern parts of the area while the gneisses and migmatites occur in the eastern part. The quartzite occurrences are located in the western and central portion as elongated bodies within the granitic and coarse grained charnockitic rocks. Ado-Ekiti, Southwest Nigeria is drained by River Ireje, Elemi, Omisanjana and Awedele Stream (Fig.1 (b)). They flow into River Ose and River Owena and empty into the Atlantic Ocean [6,7].

3. MATERIALS AND METHODS

Vertical Electrical Sounding (VES) was carried out using the Schlumberger Array with maximum electrode separation (AB/2) of 100 m. The spread was extended to 300m at some stations based on well inventory data. ABEM Terrameter, SAS 300B with ABEM 2000 Booster was used for the geoelectric data acquisition. A total of 127VES points were occupied. The VES data were interpreted by partial curve matching and computer - iterations techniques using RESIST Version 1.0 [8].

The geoelectric parameters of layer thickness and resistivity were obtained and applied for the computation of the Overburden Coefficient of Anisotropy [9,10].

The coordinates (latitudes, longitudes) and elevations above mean sea level of the VES points were obtained with a GARMIN 12 Channel Global Positioning System (GPS) unit. The location of each sounding station was recorded in Universal Traverse Mercator (UTM) coordinates. This geo - referencing permitted the application of Software for generation of maps amongst other features.

The processed geoelectric and GPS data were fed into an electronic database which was subjected to thorough data-checking exercises. Mapping and Statistical software were utilized to produce thematic maps relevant to groundwater potential evaluation and the Coefficient of Anisotropy Map. Detailed Analysis of these maps was done including Comparative analysis.

4. RESULTS AND DISCUSSION

The observed Resistivity Sounding Curves are classified into geoelectric type curves as summarized in Table 1. They include A, AA, H, HA, HK, K, KH, Q, QH and combinations with maximum of six geoelectric layers. The predominant type curves are the H-type, KH-type and HA-type with percentage occurrence of 18.11%, 15.75% and 14.17% respectively.

The statistical summary of the geoelectric parameters is presented in Table 2 to provide an initial discussion of the results. Coverage maps, Figs. 2 – 8, indicate the regional dispersion of the parameters and provide basis for comparative map analysis.

4.1 The Isopach Map of Overburden

Fig. 2 shows the isopach map of overburden of the study area produced with a Contour Interval of 5m. The overburden encompasses all materials above the presumably fresh bedrock. The Overburden Thickness varies from 1.0 to 79.9m with a mean of 25.24±16.66m. The map shows the regional variations in depth to the top of bedrock at each of the VES stations.

The contour pattern is characterized by isolated closures typical of discontinuous basement aquifer system [9]. Closed contour curves of maximum depth- to- bedrock are indicative of basement depression zones which are Groundwater Collecting Centres or Groundwater Convergent Zones. These zones offer the highest potential for groundwater. Conversely, zones with relatively thin overburden indicating basement highs/ridges are the groundwater radiating zones or groundwater divergent zones with the least groundwater potential. Basement depressions occur in the Western, Southwestern and Central parts of the area. The basement highs/ridges are seen along Northern/Central/South Central portions and Northwestern/Northeastern/Southeastern flanks. Areas with thick overburden cover and less percentage of clay in which the intergranular flow has either dominant or important role are known to have high groundwater potential particularly in the basement complex area [11,12].

Table 1. Resistivity sounding curves in the study area

Characteristics	Curve types	No. of layers	No. of occurrence	% occurrence
$\rho_1<\rho_2$	2 Layers	2	2	1.57
$\rho_1<\rho_2<\rho_3$	A	3	4	3.15
$\ell1<\ell2<\ell3<\ell4$	AA	4	2	1.57
$\rho_1>\rho_2<\rho_3$	H	3	23	18.11
$\rho_1>\rho_2<\rho_3<\rho_4$	HA	4	18	14.17
$\rho_1>\rho_2>\rho_3<\rho_4$	QH	4	6	4.72
$\ell1>\ell2>\ell3<\ell4<\ell5$	QHA	5	2	1.57
$\rho_1<\rho_2>\rho_3$	K	3	6	4.72
$\rho_1<\rho_2>\rho_3<\rho_4$	KH	4	20	15.75
$\rho_1>\rho_2<\rho_3>\rho_4$	HK	4	9	7.09
$\rho_1>\rho_2<\rho_3>\rho_4<\rho_5$	HKH	5	11	8.66
$\ell1>\ell2>\ell3$	Q	3	2	1.57
$\ell1<\ell2<\ell3>\ell4$	AK	4	2	1.57
$\ell1<\ell2>\ell3>\ell4$	KQ	4	1	0.79
$\ell1>\ell2<\ell3<\ell4>\ell5$	HAK	5	1	0.79
$\rho_1>\rho_2<\rho_3>\rho_4>\rho_5$	HKQ	5	2	1.57
$\rho_1<\rho_2>\rho_3>\rho_4<\rho_5$	KQH	5	3	2.36
$\ell_1<\ell_2>\ell_3<\ell_4<\ell_5$	KHA	5	4	3.15
$\rho_1<\rho_2>\rho_3<\rho_4>\rho_5$	KHK	5	4	3.15
$\ell_1<\ell_2<\ell_3>\ell_4<\ell_5$	AKH	5	1	0.79
$\ell1>\ell2<\ell3<\ell4<\ell5$	HAA	5	1	0.79
$\rho_1<\rho_2>\rho_3<\rho_4>\rho_5<\rho_6$	KHKH	6	1	0.79
$\ell_1<\ell_2>\ell_3<\ell_4<\ell_5<\ell_6$	KHAA	6	1	0.79
$\ell1>\ell2<\ell3>\ell4<\ell5<\ell6$	HKHA	6	1	0.79
			127	100%

Table 2. Descriptive statistics of geo-electric and Dar Zarrouk parameters

Geo-electric parameters	Range	Minimum	Maximum	Mean	Std. deviation
Overburden Thickness(m)	78.9	1.0	79.9	25.238	16.6599
Bedrock Resistivity (Ohms-m)	99963.1	35.9	99999.0	12622.428	29981.5616
Weathered Basement Resistivity(Ohms-m)	5710.5	6.5	5717.0	340.321	699.8642
Weathered Basement thickness (m)	53.0	.2	53.2	17.783	12.4029
elevation (m)	106	367	473	419.56	20.281
bedrock relief	137.4	321.6	459.0	394.321	24.1300
second layer resistivity (ohms - m)	5195.2	4.8	5200.0	300.515	631.0476
Coefficient of Anisotropy(λ)	2.463	.339	2.802	1.34035	.407403

4.2 The Weathered Basement/Fractured Basement Layer

Fig.3 shows that the weathered basement layer is thickest around the Southern/South Western portions with isolated portions along the Western/North Western portions of the study area. As the weathered basement layer is believed to be the major aquifer, the said regions offer high groundwater potential. The Weathered Basement Resistivity Distribution Map of the study area, Fig. 4, discriminated between high water - bearing weathered basement zones and the low water - bearing ones. It also indicated the variations in the degree of weathering/saturation across the study area. Occurrences of low resistivity values are indicative of high degree of weathering. At such points the weathered basement layer is saturated with water [13].

4.3 Bedrock Resistivity Map

The bedrock in the area of study was observed to be variably fractured (Fig. 5). The fractured nature of the rocks in some parts of the survey area is displayed by their low bedrock resistivity values. The resistivity value of the bedrock often exceeds 1000Ωm and where the bedrock is fractured/sheared and saturated with fresh water, the resistivity often reduces below 1000Ωm. The presence of the fractures and hence water contained within the fissures are responsible for the fairly low bedrock resistivity [13,14].

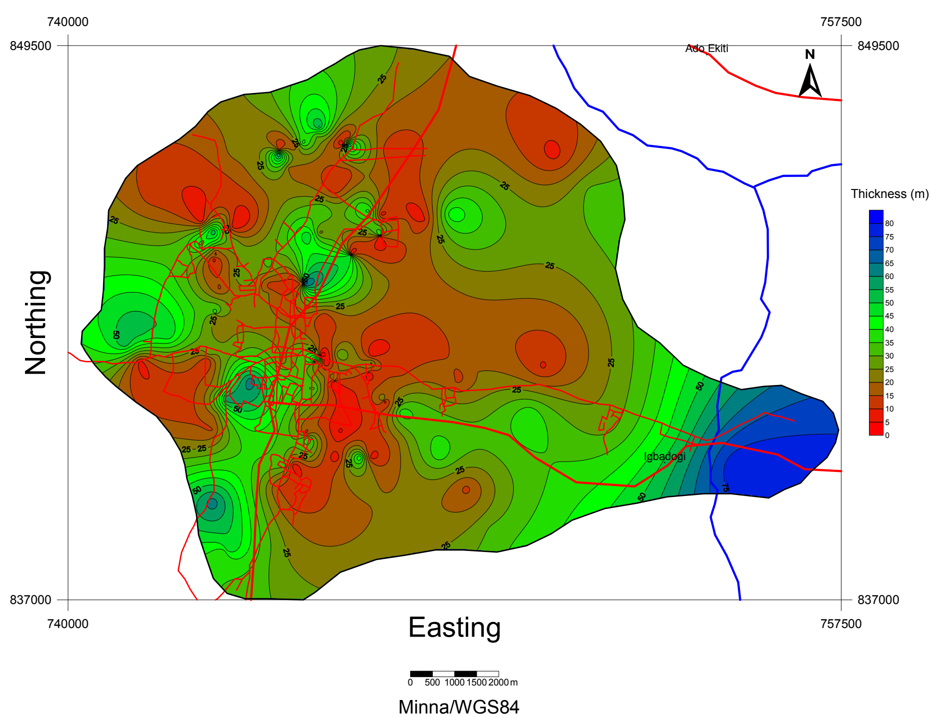

Fig. 2. Isopach map of the overburden

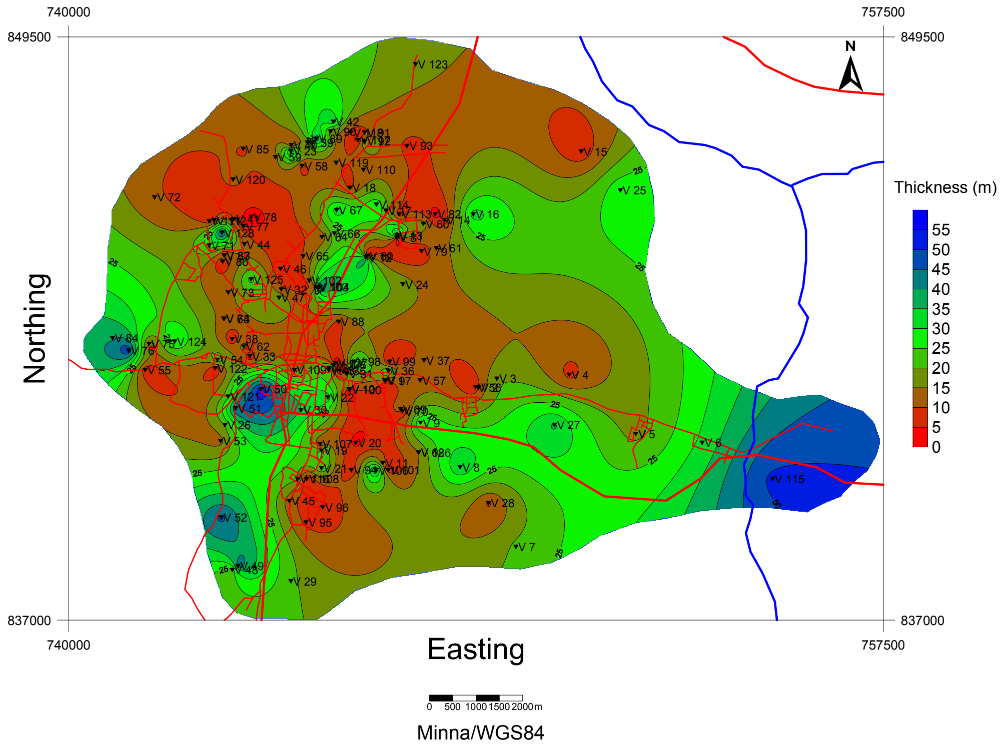

Fig. 3. Weathered basement thickness map

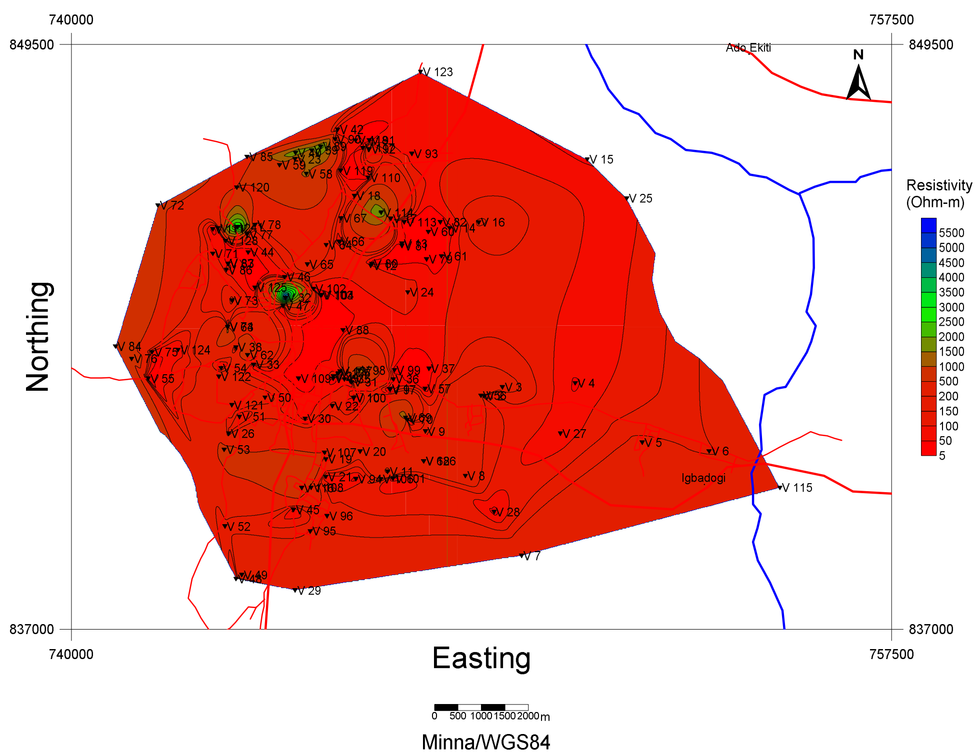

Fig. 4. Weathered basement resistivity map

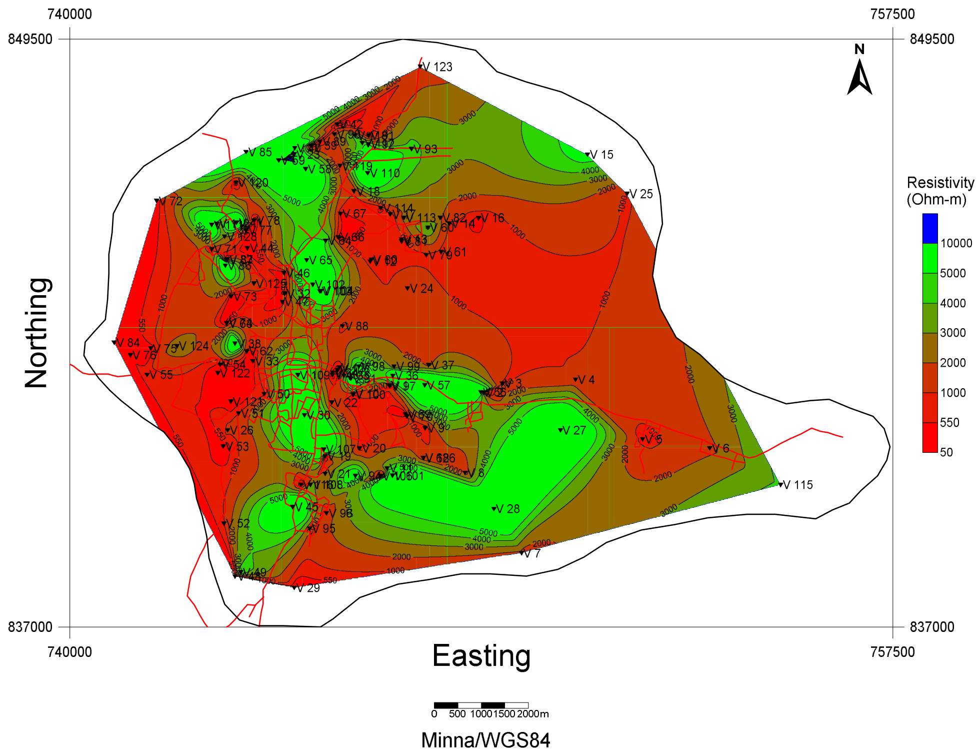

Fig. 5. Bedrock resistivity map

4.4 The Bedrock Relief Map

The Bedrock Relief Map (Fig. 6) delineated a series of bedrock ridges and depressions within the surveyed area. The bedrock ridges are the basement highs showing relatively thin overburden cover while the depressions are characterized by thick overburden and low resistivity values. The depression zones in the basement terrain serve as groundwater collecting troughs especially water dispersed from the bedrock crests [12,15,16].

4.5 Coefficient of Anisotropy Map and Comparative Analysis

Fig. 7 shows the contour map of Coefficient of Anisotropy with values varying from 0.34 to 2.80 across the study area. This result agrees with [4] and [5]. Super-positioning of Fig. 7, in turn, on Figs. 2 - 6 gave a categorization of the observed values across the zones of high and poor groundwater potential.

An average Anisotropy value of 1.4 was observed across the eastern flank and other Zones of high Overburden Thickness. Anisotropy values of 2 and above were observed across the regions of decreasing Overburden Thickness values. Anisotropy value of over 2.6 was recorded across the basement ridge/high delineated along the Northwestern axis as a region of low groundwater potential on the account of thin overburden.

According to Keller and Frischnecht [17], occurrence of compact rock at shallow depth increases the coefficient of anisotropy. Areas characterized by high Anisotropy values can be associated with low porosity and permeability. Hence, the areas are of less hydro-geological appeal. Conversely, relatively lower Anisotropy values are suggestive of zones of high porosity and permeability occasioned by fracturing at some depth.

A range of 1.3 to 1.6 Anisotropy values were observed across the depressions in the study area with a range of 1.8 to 2.8 Anisotropy values observed across the bedrock ridges with increase in value reflecting the compactness of the basement rock and its shallow occurrence.

Anisotropic values ranging from 1.2 to 1.6 were observed across water-bearing zones which are characterized by Weathered Basement

Thickness in excess of 25m. Anisotropic values ranging from 1.8 to 2.8 were observed across zones characterized by Weathered Basement Thickness generally less than 15m.A range of Anisotropy values of 1.2 to 1.6 were observed across the "low weathered basement resistivity zones" while a range of Anisotropy values of 1.8 to 2.8 were observed across the areas of Weathered Basement resistivity greater than 1000/1500 Ω-m with least groundwater potential.

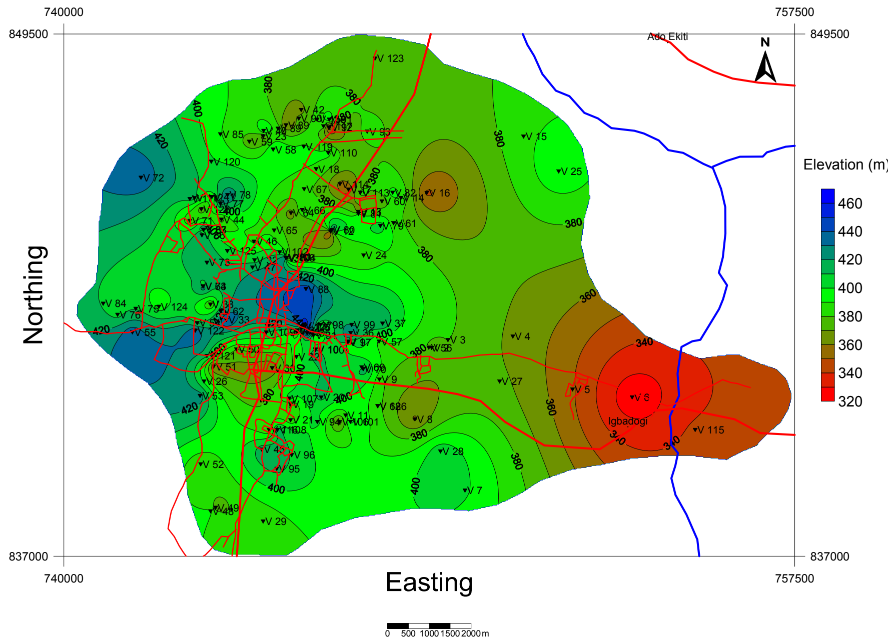

Fig. 6. Bedrock Relief map

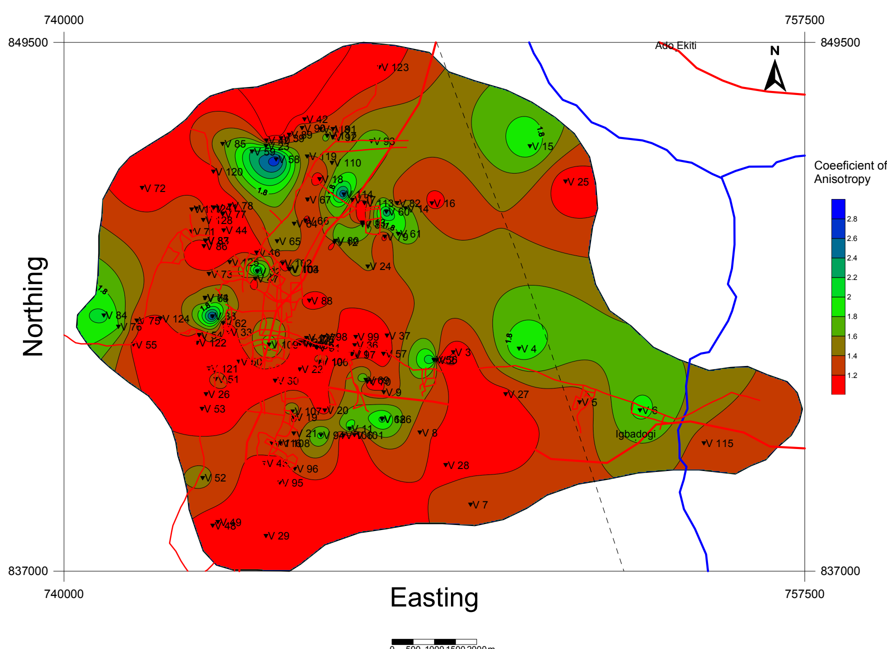

Fig. 7. Coefficient of anisotropy map

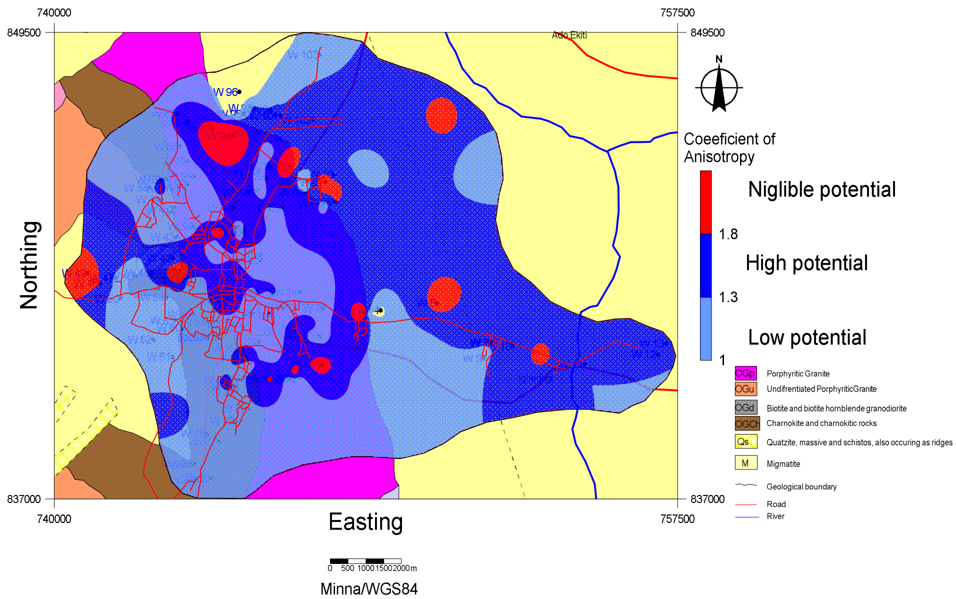

Fig. 8. Coefficient of anisotropy rating and groundwater potential zones

The Comparative study of the Bedrock resistivity Map and the Anisotropy map revealed that regions of high anisotropy values from (λ > 2.00) correlates with regions characterized by high Bedrock resistivity values (ρ > 2000 Ωm). This inference is supported by the fact that the influence of weathering reduces with increasing value of resistivity. The range of values 1.3 to 1.6 was recorded across regions of bedrock resistivity values of below 1000 Ωm.

Fig. 8 shows the Groundwater Potential Index based on the Coefficient of anisotropy. The Map offers a combination of the thickness and resistivity of the geoelectric layers into single variable as provided for by the Dar-Zarouk parameters [10].

These results follow the trends observed by many researchers [3,4,5,9,12]. Olorunfemi and Olorunniwo [4] reported Anisotropy coefficients of overburden columns of productive boreholes and wells varying from 1.39 to 1.66 across the basement complex of the Southwest, Nigeria. These values fall within the middle range of the observed values of between 1.0 and 3.0. Rao et al. [5] obtained values of anisotropy ranging from 0.3 to 2.0 in the hard rock terrain of Eastern Ghats, Andhra Pradesh and used the Anisotropy values to delineate probable permeable zones. The authors considered Areas with 1.0 and less than 1.5 anisotropy values and ranked the zones high for groundwater development with characteristic high porosity and permeability. Anisotropy value of more than 2 indicated the hard porphyritic granite gneiss and garnet biotite gneiss terrain of the basin. These rock types are amongst the suite of rocks constituting the Geology of Ado-Ekiti.

5. CONCLUSION

The study revealed that a range of 1.3 to 1.6 Anisotropy values correspond to the zones characterized by thick overburden, Weathered Basement Thickness in excess of 25m, low weathered basement resistivity, fractured bedrock and basement depressions in the study area. Anisotropy values ranging from 1.8 to 2.8 were observed across the basement ridges and zones characterized by thin overburden, Weathered Basement Thickness of generally less than 15 m and Weathered Basement resistivity greater than 1500 Ω-m with least groundwater potential.

The regions of Anisotropy values ranging from 1.3 to 1.6 are demarcated as high groundwater potential zones. Areas characterized by higher Anisotropy values can be associated with low porosity and permeability with less hydro-geological appeal.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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