Estimation of Aquifer Protective Capacity, Soil Corrosivity and Dar-Zarrouk Parameters in Kaura Area of Kaduna State, Nigeria

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***Abstract*—This study presents an estimation of aquifer protective capacity, soil corrosivity and Dar-Zarrouk parameters for Kaura area of Kaduna State in northern Nigeria. Electrical resistivity sounding data and borehole pumping test data obtained from 20 locations within the LGA were obtained and used for this study. The geoelectric data exhibited curve types generally consisting of H, HA, KH or K-A-H types from which five-layer lithology were delineated across the entire study area. Well yield varies from 16 – 400 litres/min, pumping rate ranges from 16 to 140 l/min, drawdown varies from 1 – 22m, while specific capacity ranged from 1 – 95 litres/min. The aquifer protective capacity characterization was based on values of longitudinal unit conductance of the overburden, and 35% of the locations showed good protective capacity, while the remaining 65% exhibited moderate protective capacity. From the soil corrosivity evaluation, the upper soil layers were classified as moderately corrosive at one location, four locations were marked as slightly corrosive, while the remaining locations were found to be practically non-corrosive. Based on thicknesses and resistivities of the overburden layers, Dar-Zarrouk parameters were determined. The reflection coefficient ranged from 0.29 to 0.92, resistivity contrast occurred between 0.35 and 25.38, while the coefficient of anisotropy ranged from 0.70 to 3.84 with mean value of 1.57. Values above 1.0 are generally considered high and they occurred more toward the western part of the area than the middle and eastern parts. Both the longitudinal unit conductance map and coefficient of anisotropy map were generated for the area.**

***Index Terms*—Aquifer Anisotropy, Dar-Zarrouk Parameters, Soil Corrosivity.**

I. Introduction

Groundwater refers to water occupying all the voids within a geologic stratum, which may be saturated or aerated, but the term is usually reserved for the subsurface water that occurs beneath the water table in soils and geologic formations that are fully saturated. Permeable geologic formations containing groundwater are termed aquifers if the formation has structures that permit appreciable water to move through them under ordinary field conditions [1].

Groundwater is particularly important for engineering works, geologic studies and water supply developments. The availability, quantity and exploitability of groundwater depend on the porosity and permeability of the aquifers. The exploration for groundwater has become increasingly important in Nigeria due to the ever increasing demand for water supplies due to population increases, especially where surface water supplies are either inadequate, or are being constantly degraded in quality due to continuous inflow of physical, chemical and biological, contaminants. If groundwater is to continue to play an important role in the development of the world's water-resource potential, then it will have to be protected from the increasing threat of subsurface contamination [2]. The over-exploitation and contamination of groundwater resources have put a lot of stress on the available groundwater resources globally. In many parts of the world, freshwater shortages have resulted from high increases in industrial development, urbanization and agricultural production, coupled with increasing potential sources of contamination and ubiquitous use and disposal of hazardous chemicals and other waste products without regards to the potential risk they pose to the hydrogeological system. The current hydrologic studies does not only include detecting new groundwater resources but also to protect them from contamination. The rate of groundwater contamination depends on permeability, porosity, and overburden thickness of geologic formations [3], [4].

A. *The Study Area, Geological and Hydrogeological Settings*

The study area is Kaura Local Government Area (LGA) located in the South eastern part of Kaduna State in the North central part of Nigeria (Figure 1). The headquarters of the LGA is in Kaura, and covers a total area of 485km², with a population of about 222,579 at the 2006 census. It is situated approximately between latitudes 9º 28.73'N and 9º 43.09'N, and between longitudes 8º 18.00'E and 8º 34.29'E.

The area is generally underlain by the Basement rocks of the Precambrian age, and the essential features of the Nigerian Basement complex as reviewed by [5] – [8] among others, revealed that there are three broad lithological groups, namely: the migmatite-gneiss complex, metasedimentary and metavolcanic rocks which form schist belts and appear to be dominantly restricted to the western half of the country, and the Older granites which intrude both the migmatite-gneiss complex and the schist belts. The migmatite-gneiss complex is composed of rock types including migmatites, gneisses of various origins and a series of metamorphosed basic and ultrabasic rocks represented by amphibolites and talc schist.

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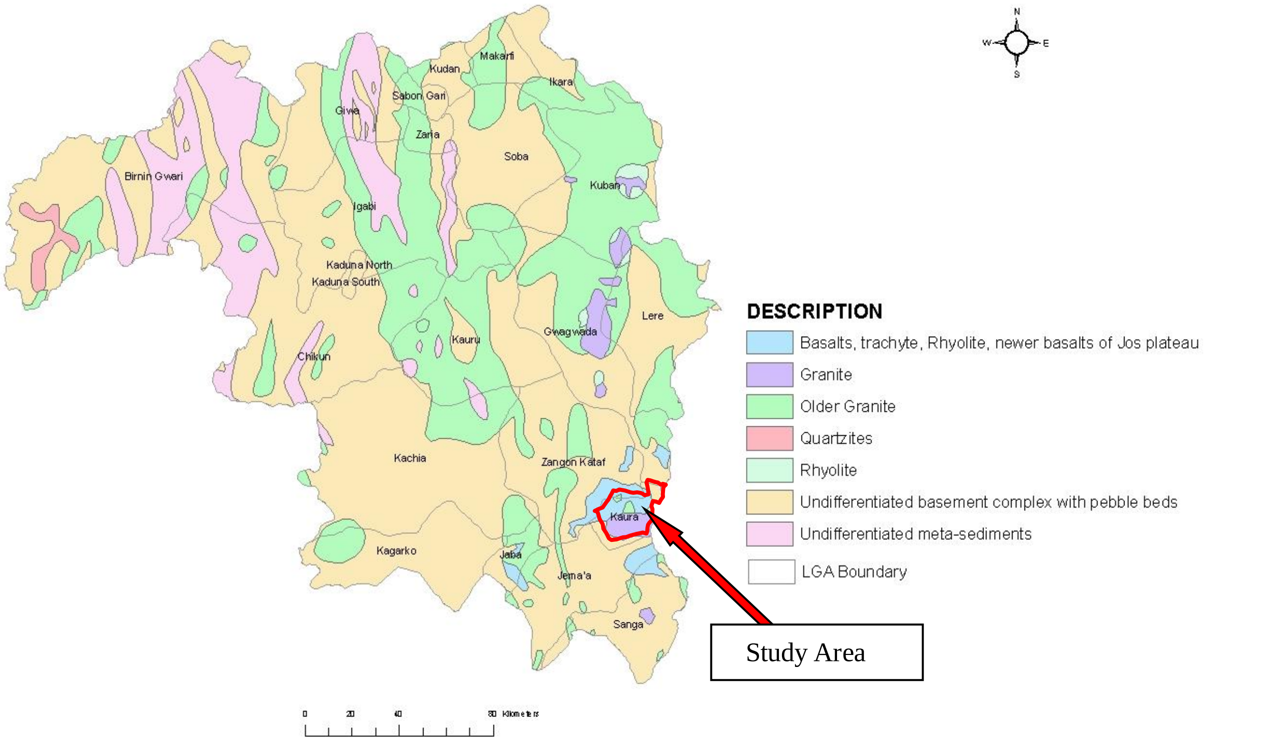

Fig.1: Geological Map of Kaduna State

The schist belts are mostly found in the N-S trend of Nigeria where each formation occupies a discrete belt separated from the others by the migmatite-gneiss complex. This region is considered the key area for the understanding of the relationships between the various rock units in the Nigerian Basement and the evolution of the Basement during the Upper Proterozoic times. The Older Granites include a wide spectrum of rock types from tonalites through granites to syenites and charnockitic rocks having Rb/Sr ages ranging between 750 and 450 m.y. reflecting the ages of emplacement [9].

The occurrence of groundwater resources in crystalline basement terrain depends immensely on the development of secondary permeability arising from weathering and fracturing of parent rocks and also to great extent on the fracture patterns [10]. Groundwater occurrence in the area could be grouped into three, namely the weathered/fractured Basement Complex, the Newer Basalts and the River Alluvium. The weathered granular sandy zone is composed of coarse-grained sands, made up of sands or gravels derived from the disintegrations of the crystalline rock. There are good prospects for groundwater production in the horizon of the intermediate zones with an average thickness of about 6 m [11]. The majority of hand-dug wells in the study area terminate in this part of the zone. The Newer Basalts occur in the vicinity of Kafanchan and Manchok along the western edge of the Jos Plateau, while zones of weathering and beds of alluvium also occur between individual basalt flows. The aquifer potential of the fluvio-volcanic sequence is good and yields of 370 to 500 m^3/day have been obtained [12].

B. Dar-Zarrouk Parameters

The concept of Dar-Zarrouk parameters were first introduced to explain the problem of non-uniqueness in the interpretation of electrical resistivity depth sounding curves. Dar-Zarrouk and other geoelectric parameters can be used to recognize and differentiate areas of fresh groundwater aquifers from those of saline groundwater. Empirical relationships have been established between aquifer hydraulic properties and aquifer electrical properties since both properties are related to the pore space structure and heterogeneity [13] and [14]. Therefore, the application of geophysical methods in combination with pumping tests provide a cost-effective and efficient alternative for estimating aquifer parameters. This is especially significant because pumping test methods only provide data for a small section of the aquifer, whereas inverted geoelectrical models can be useful in the hydraulic modeling of an aquifer by using analytical relationship between them.

For a sequence of n horizontal, homogeneous and isotropic layers of resistivity ρ_i and thickness h_i, the Dar-Zarrouk parameters, basically the longitudinal conductance, S (measured in mhos) and transverse resistance, T (expressed in ohm-m^2) can be defined respectively with the following equations:

$$S = \sum_{i=1}^{n} \frac{h_i}{\rho_i} = \frac{h_1}{\rho_1} + \frac{h_2}{\rho_2} + \frac{h_3}{\rho_3} \ldots\ldots\ldots\ldots + \frac{h_n}{\rho_n} \quad (1)$$

$$T = \sum_{i=1}^{n} h_i\,\rho_i = h_1\,\rho_1 + h_2\,\rho_2 + h_3\,\rho_3 \ldots\ldots\ldots\ldots + h_n\,\rho_n \quad (2)$$

Where $i = 1, 2, 3 \ldots\ldots n$

Taking the total thickness of the layers in the geoelectric section considered to be H, then the average longitudinal resistivity ρ_L can be written as:

$$\rho_L = \frac{H}{S} = \sum_{i=1}^{n} \frac{h_i}{S_i} = \frac{\sum_{i=1}^{n} h_i}{\sum_{i=1}^{n} h_i / \rho_i} \quad (3)$$

While the average transverse resistivity ρ_t is expressed as:

$$\rho_t = \frac{T}{H} = \sum_{i=1}^{n} \frac{h_i \, \rho_i}{h_i} = \frac{\sum_{i=1}^{n} h_i \, \rho_i}{\sum_{i=1}^{n} h_i} \quad (4)$$

Considering the entire section to be anisotropic with reference to electrical resistivity, the coefficient of anisotropy can then be written as:

$$\lambda = \sqrt{\frac{\rho_t}{\rho_L}} \quad (5)$$

Using the relationship adopted by [15], the reflection coefficient, R_C, and the resistivity contrast, F_C of the fresh basement rock of the study area can be computed with the following relationships:

$$R_C = \frac{\rho_n - \rho_{n-1}}{\rho_n + \rho_{n-1}} \quad (6)$$

$$F_C = \frac{\rho_n}{\rho_{n-1}} \quad (7)$$

Where ρ_n is the resistivity of the n^{th} layer and ρ_{n-1} is the resistivity of the layer overlying the n^{th} layer.

C. Aquifer Protective Capacity and Soil Corrosivity

Water inflow into the earth goes through filtration because the earth acts as a natural filter to percolating fluid. The ability of the earth to retard or accelerate and filter percolating fluid is a measure of its protective capacity [16]. In unconsolidated geologic units with relatively permeable materials such as sand, gravel, or fractured rock, leachate migration may percolate to cause groundwater contamination which may render the soil corrosive and form a polluting plume over such areas. Continuous transport by groundwater flow will cause the zone of contamination to greatly expand in such areas [2].

The corrosive nature of such influents may cause pipeline leakage, rupture or explosion such as to constitute serious hazards to the environment, assets, and even human lives. The use of geophysics, especially the electrical resistivity method, for both groundwater resource mapping and for water quality evaluation has increased dramatically due to the rapid advances in microprocessors and associated numerical modelling solutions. Overburden protective capacity has been defined [17] as the ratio of the overburden thickness to its resistivity. The higher the overburden longitudinal conductance, the higher its protective capacity. Included among recent researches on the use of electrical resistivity method for the study of aquifer protective capacity and soil corrosivity in Nigeria include [18], [19] and [20] among others.

The main thrust of this paper is to estimate aquifer protective capacity, soil corrosivity and Dar-Zarrouk parameters in Kaura local government area of Kaduna State, northern Nigeria. Commonly used methods for characterizing protective layers include test hole drilling and log analysis, which provide data on thickness and/or lateral extent of the protective layer. Such investigations have the disadvantages that they can be labour-intensive and expensive, in addition to covering limited areas. Interpreted electrical resistivity sounding data have been used in this study to evaluate the aquifer protective capacity, soil corrosivity of overburden units and Dar-Zarrouk parameters, such as longitudinal conductance, reflection coefficient, resistivity contrast and coefficient of anisotropy. The result of this study will provide a lead into identifying areas prone to groundwater contamination by leachates, as well as areas with high groundwater potentials.

II. Materials And Methods

The geophysical data and well hydraulic parameters for 20 boreholes across the LGA were obtained from the Kaduna State Ministry of Water Resources. The aquifer protective capacity characterization was based on the values of the longitudinal unit conductance of the overburden rock units in the area. Soil corrosivity was evaluated by comparing the resistivity value of the first layer at each VES point in the study area with the standard corrosivity rating. Based on the values of thicknesses and resistivities of the overburden layers, Dar-Zarrouk parameters of the study area, namely, longitudinal conductance, reflection coefficient, resistivity contrast, longitudinal resistivity, transverse resistivity and coefficient of electrical anisotropy of 20 locations across the study area were determined.

III. Results And Discussion

Vertical electrical sounding data were obtained and interpreted in terms of layer resistivities and depths. The curve types were generally H, HA, KH and K-A-H types. Generally, five-layer lithology was delineated across the entire study area, comprising top soil to lateritic clay 0 - 4m thick and resistivity of 150 – 900 Ωm, silty to sandy clay occurring at a depth range of 3 – 7m and resistivity between 23 – 250 Ωm, sandy to gravelly sandstone layer with resistivity range of 200 – 1000 Ωm at depths between 5 - 16m, weathered to fractured basement occurring between 9 – 26m depth with resistivity range of 700 – 4500 Ωm all overlying the fresh basement.

Using the inferred layer resistivities and thicknesses at each location, longitudinal conductance values were determined by using equation (1) and these values were used as criteria for the aquifer protective capacity rating with reference to the range of values provided in Table I.

TABLE I: AQUIFER PROTECTIVE CAPACITY RATING (*After: [21] and [4]*)

Longitudinal Conductance (mhos)	Protective Capacity Rating
Greater than 10	Excellent
5 – 10	Very Good
0.7 – 4.9	Good
0.2 – 0.69	Moderate
0.1 – 0.19	Weak
Less than 0.1	Poor

The longitudinal unit conductance values obtained from the 20 locations investigated within the study area ranged from 0.201 at Sofio Kpak-I to 1.492 mhos at Aduwa Gida-II, and the values have been used to generate the longitudinal unit conductance map presented in Figure 2. The map showed that the longitudinal unit conductance varies systematically from the highest values at the western part of the area to lower values at the eastern side. The results obtained revealed that 7 (or 35%) of the locations have good protective capacity based on the numerical values of longitudinal conductance determined for each point, while the remaining 13 (or 65%) locations exhibited moderate protective capacity. The moderate to good aquifer protective capacity obtained across the entire study area coincided with zones of appreciable overburden thicknesses with clayey columns that are sufficiently thick enough to protect the aquifer in the area from surface polluting fluid. The summary of this result is presented in Table III.

The soil corrosivity in the study area was determined by using the first layer resistivity at each location and comparing with the classification shown in Table II.

TABLE II. SOIL RESISTIVITY CLASSIFICATION IN TERMS OF CORROSIVITY *(After: [22])*

Soil resistivity (Ω-m)	**Soil corrosivity**
< 10	Very strongly corrosive (VSC)
10 to 60	Moderately corrosive (MC)
60 to 180	Slightly corrosive (SC)
>180	Practically noncorrosive (PNC)

The results obtained suggest that the soil in the study area is moderately corrosive at only one location, Rafin Gora, slightly corrosive at four locations, namely Malagum, Sofi Kpak-I, Sofio Kpak-II and Aduwa Gida-II, while the remaining 15 (or 75%) of the locations are classified as practically noncorrosive. The result is summarized in Table III.

In addition, pumping test results indicated that well yield in the area varies from 16 – 400 litres/min, pumping rate ranges from 16 l/min at Madakiya to 140 l/min at Sofio Kpak-II, drawdown varies from as low as 1m at Mahuta-I to as much as 22m at Tsokowai, while specific capacity ranged from 1 – 95 litres/min.

Dar-Zarrouk parameters were evaluated based on the overburden layer thicknesses and resistivities in order to unravel the subsurface groundwater potential of the area. Parameters evaluated are the average longitudinal resistivity, average transverse resistivity, coefficient of electrical anisotropy, reflection coefficient and the resistivity contrast of the 20 locations across the study area by using equations (3), (4), (5), (6) and (7) respectively. The computed values of various formation parameters are presented in Table IV. The reflection coefficient is a measure of the density variation between layers of the formation in an area. It could also indicate the degree of fracture in the aquifer. Areas of low reflection coefficient value have high water potentials. The results obtained from the study area showed that the reflection coefficient (R_c) values ranged from 0.29 at Malagum to 0.92 at Ungwan Afong and Randiyam with an average value of 0.61.

Similarly, low values of resistivity contrast (F_c) indicate high groundwater potentials. The values of resistivity contrast in this work ranged from as low as 0.35 to 25.38, indicating good groundwater potentials.

The coefficient of anisotropy (λ) depicts the true variation of the anisotropic flow characteristics of a rock formation. High values of coefficient of anisotropy suggests that the fracture system must have extended in all the directions with different degrees of fracturing, which may encourage good water-holding capacity from different directions of the fracture(s) within the rock with resultant higher porosity. On the other hand, low values of coefficient of anisotropy may arise from uni-directional fracture which will restrict inflow and may not produce good yield of water. In this study, the values of coefficient of anisotropy obtained ranged from 0.70 at Malagum to 3.84 at Madakiya with an average value of 1.57. Values of λ above 1.0 are generally considered to be high, and the higher values occurred more toward the western part of the LGA than at the middle and eastern parts. Anisotropic flow conditions often occur due to the nature of sedimentation and pressure of overlying material which causes flat-shaped sediment that produces flow channels parallel to the bedding plane, with good porosity and high permeability occurring more in one direction than the other. Lower values occurred at the central and western parts, possibly indicating a condition favourable to isotropic flow in which permeability at a considered point is independent of direction of flow. Figure 3 shows the variation in the coefficient of anisotropy across Kaura LGA.

IV. CONCLUSION

An estimation of aquifer protective capacity, soil corrosivity and Dar-Zarrouk parameters has been carried out in Kaura area of Kaduna State, Nigeria using electrical resistivity sounding data and borehole pumping test data obtained from 20 locations within the LGA to assist in identifying areas prone to groundwater contamination by leachates, as well as areas with high groundwater potentials. The geoelectric data provided the basis for five-layer delineation of lithologic succession across the entire study area. Moderate to good aquifer protective capacity was obtained, which showed that the overburden thicknesses are sufficiently thick enough to protect the aquifer from surface polluting fluids. The upper soil layers were classified as moderately corrosive at only one location, while the remaining areas were found to be either slightly corrosive or practically non-corrosive. The reflection coefficients and resistivity contrasts suggested high groundwater potentials. The coefficient of anisotropy gave high average value of 1.57, towards the western part of the LGA and as low as 0.70 towards the middle and eastern parts. High values of coefficient of anisotropy suggest good water-holding capacity with resultant higher porosity. Maps of distribution of longitudinal conductance and the variation in the coefficient of anisotropy were generated for the study area.

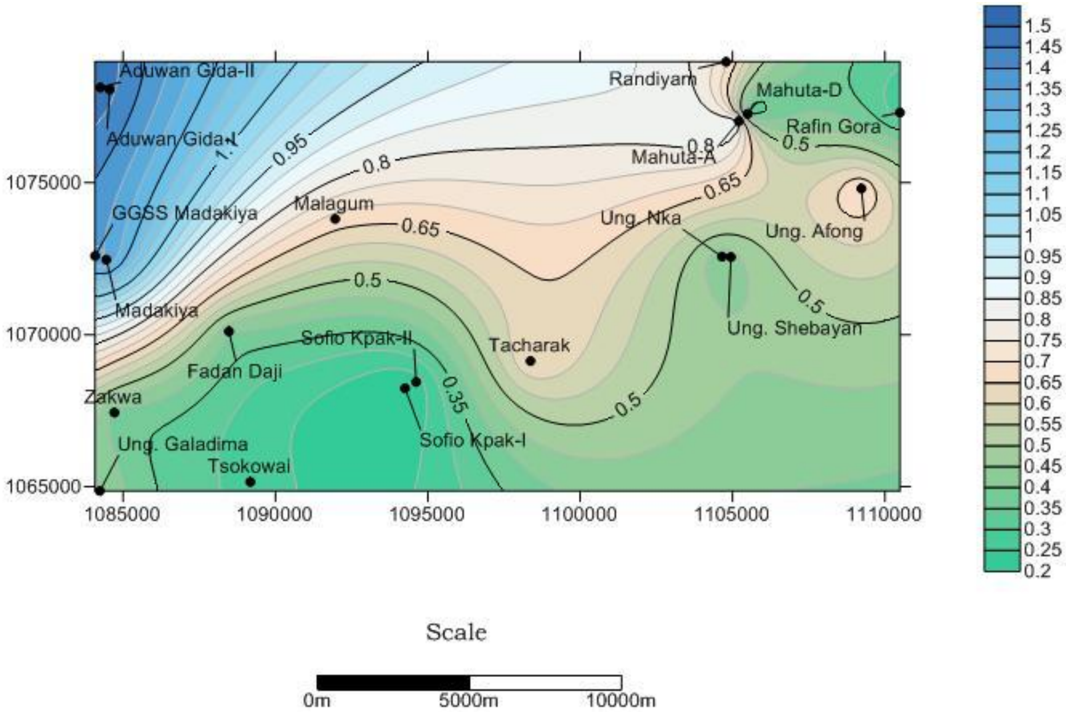

Fig. 2: Map of Distribution of Longitudinal Conductance in the Study Area

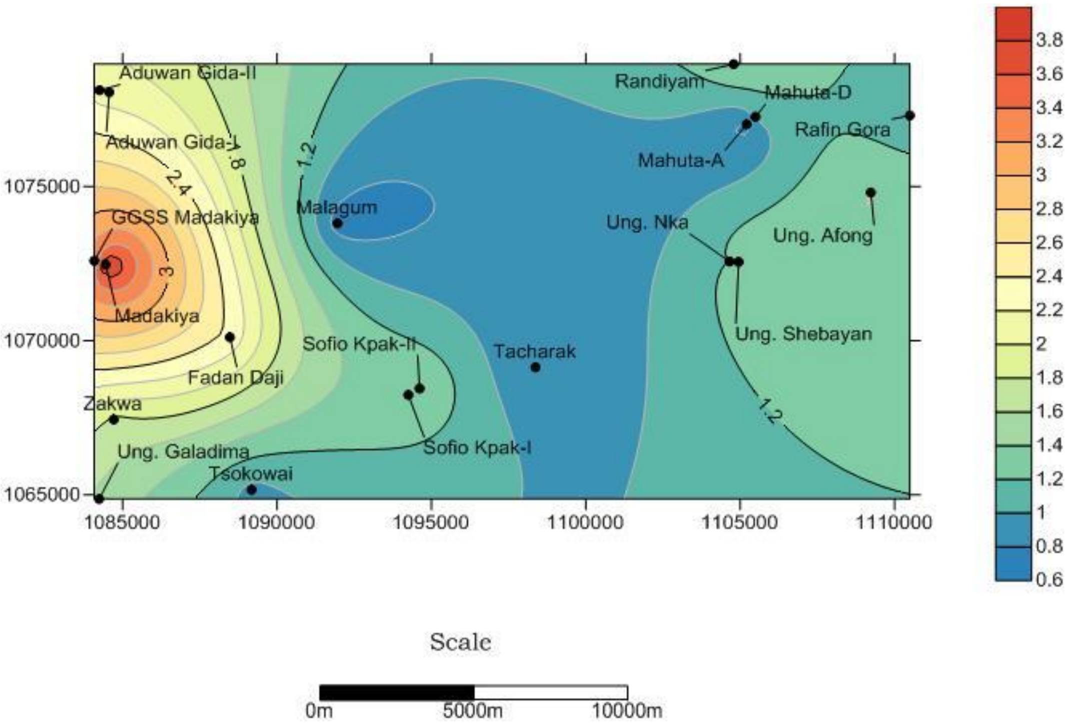

Fig. 3: Coefficient of Anisotropy Map

TABLE III. SUMMARY OF THE LONGITUDINAL CONDUCTANCE, AQUIFER PROTECTIVE CAPACITY AND SOIL CORROSIVITY

	Location	**Layer**	**Resistivity**	**Thickness**	**Depth**	$S=\sum_{i=1}^{n}\frac{h_i}{\rho_i}$	**Long. Cond. of Protective Layers**	**Aquifer Protect. Cap.**	**Soil Corrosivity**
			Ω-m	m	m	mhos	mhos		
		1	500	2	2	0.0040			
		2	90	5	7	0.0556			Practically
1		3	30	10	17	0.3333	0.653	Moderate	Noncorrosive
		4	200	52	69	0.2600			
	Tacharak	5	5000						
2	Tsokowai	1	400	0.4	0.4	0.0010			
		2	700	2	2.4	0.0029			Practically
		3	100	6	8.4	0.0600	0.289	Moderate	Noncorrosive
		4	200	45	53.4	0.2250			
		5	2000						
3	Raf. Gora	1	55	2.5	2.5	0.0455			
		2	180	6	8.5	0.0333			Moderately
		3	150	7	15.5	0.0467	0.268	Moderate	Corrosive
		4	280	40	55.5	0.1429			
		5	3000						
4	Gujeni	1	300	0.5	0.5	0.0017			
		2	500	2.2	2.7	0.0044			Practically
		3	65	7	9.7	0.1077	0.203	Moderate	Noncorrosive
		4	450	40	49.7	0.0889			
		5	9999						
5	Malagum	1	150	6	6	0.0400			
		2	75	12	18	0.1600			Slightly
		3	120	25	43	0.2083	0.681	Moderate	Corrosive
		4	220	60	123	0.2727			
		5	9999						
6	Zakwa	1	900	0.4	0.4	0.0004			
		2	2000	2	2.4	0.0010			Practically
		3	23	6.5	8.9	0.2826	0.380	Moderate	noncorrosive
		4	250	24	32.9	0.0960			
		5	2200						
7	S/Kpak-I	1	120	0.5	0.5	0.0042			
		2	107	1.7	2.2	0.0159			Slightly
		3	108	8	10.2	0.0741	0.201	Moderate	corrosive
		4	300	32	42.2	0.1067			
		5	3000						
8	S/ Kpak-II	1	150	0.5	0.5	0.0033			
		2	500	2.3	2.8	0.0046			Slightly
		3	60	8	10.8	0.1333	0.227	Moderate	corrosive
		4	350	30	40.8	0.0857			
		5	3200						
9	Fadan Daji	1	300	2.4	2.4	0.0080			
		2	25	4.5	6.9	0.1800			Practically
		3	75	10	16.9	0.1333	0.403	Moderate	noncorrosive
		4	220	18	34.9	0.0818			

		5	3000						
10	Mahuta-D	1	250	1.4	1.4	0.0056			
		2	50	2.5	3.9	0.0500			Practically
		3	35	6	9.9	0.1714	0.297	Moderate	noncorrosive
		4	575	40	49.9	0.0696			
		5	1780						
11	U/Afong	1	400	4.5	4.5	0.0113			
		2	80	9	13.5	0.1125			Practically
		3	33	18	31.5	0.5455	0.707	Good	noncorrosive
		4	800	30	61.5	0.0375			
		5	4800						
12	U/Shebaya	1	550	4	4	0.0073			
		2	150	8.5	12.5	0.0567			Practically
		3	50	15	27.5	0.3000	0.434	Moderate	noncorrosive
		4	430	30	57.5	0.0698			
		5	9999						
13	Ung. Nka	1	400	2	2	0.0050			
		2	120	7	9	0.0583			Practically
		3	65	20	29	0.3077	0.415	Moderate	noncorrosive
		4	800	35	64	0.0438			
		5	1200						
14	Mahuta-A	1	370	1.5	1.5	0.0041			
		2	151	3.5	5	0.0232			Practically
		3	35	23	28	0.6571	0.852	Good	noncorrosive
		4	340	57	85	0.1676			
		5	5000						
15	Randiyam	1	280	1.6	1.6	0.0057			
		2	77	9.3	10.9	0.1208			Practically
		3	29	16	26.9	0.5517	0.719	Good	noncorrosive
		4	736	30	56.9	0.0408			
		5	5000						
16	A/Gida II	1	125	8	8	0.0640			
		2	50	13	21	0.2600			Slightly
		3	350	20	41	0.0571	1.492	Good	corrosive
		4	27	30	71	1.1111			
		5	1018						
17	Madakiya	1	490	0.3	0.3	0.0006			
		2	890	0.8	1.1	0.0009			Practically
		3	308	11	12.1	0.0357	1.356	Good	noncorrosive
		4	32	42.2	54.3	1.3188			
		5	1016						
11	Ung. Afong	1	400	4.5	4.5	0.0113			
		2	80	9	13.5	0.1125			Practically
		3	33	18	31.5	0.5455	0.707	Good	noncorrosive
		4	800	30	61.5	0.0375			
		5	4800						
12	Ung Shebayan	1	550	4	4	0.0073			
		2	150	8.5	12.5	0.0567			Practically
		3	50	15	27.5	0.3000	0.434	Moderate	noncorrosive

		4	430	30	57.5	0.0698			
		5	9999						
13	Ung. Nka	1	400	2	2	0.0050			
		2	120	7	9	0.0583			Practically
		3	65	20	29	0.3077	0.415	Moderate	noncorrosive
		4	800	35	64	0.0438			
		5	1200						
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		2	151	3.5	5	0.0232			Practically
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		5	5000						
15	Randiyam	1	280	1.6	1.6	0.0057			
		2	77	9.3	10.9	0.1208			Practically
		3	29	16	26.9	0.5517	0.719	Good	noncorrosive
		4	736	30	56.9	0.0408			
		5	5000						
16	Aduwa Gida II	1	125	8	8	0.0640			
		2	50	13	21	0.2600			Slightly
		3	350	20	41	0.0571	1.492	Good	corrosive
		4	27	30	71	1.1111			
		5	1018						
17	Madakiya	1	490	0.3	0.3	0.0006			
		2	890	0.8	1.1	0.0009			Practically
		3	308	11	12.1	0.0357	1.356	Good	noncorrosive
		4	32	42.2	54.3	1.3188			
		5	1016						
18	GSS Madakiya	1	380	1.4	1.4	0.0037			
		2	42	6	7.4	0.1429			Practically
		3	114	13.3	20.7	0.1167	1.329	Good	noncorrosive
		4	32	34.1	54.8	1.0656			
		5	1018						
19	Aduwa Gida I	1	275	3	3	0.0109			
		2	70	8.9	11.9	0.1271			Practically
		3	301	20	31.9	0.0664	1.460	Good	noncorrosive
		4	29	36.4	68.3	1.2552			
		5	1018						
20	U/ Galadima	1	850	2	2	0.0024			
		2	2100	4	6	0.0019			Practically
		3	23	8	14	0.3478	0.452	Moderate	noncorrosive
		4	270	27	41	0.1000			
		5	2300						
18	GSS Madakiya	1	380	1.4	1.4	0.0037			
		2	42	6	7.4	0.1429			Practically
		3	114	13.3	20.7	0.1167	1.329	Good	noncorrosive
		4	32	34.1	54.8	1.0656			
		5	1018						
19	Aduwa Gida I	1	275	3	3	0.0109			

		2	70	8.9	11.9	0.1271			Practically
		3	301	20	31.9	0.0664	1.460	Good	noncorrosive
		4	29	36.4	68.3	1.2552			
		5	1018						
20	U/ Galadima	1	850	2	2	0.0024			
		2	2100	4	6	0.0019			Practically
		3	23	8	14	0.3478	0.452	Moderate	noncorrosive
		4	270	27	41	0.1000			
		5	2300						

TABLE IV: COMPUTATION OF DAR-ZARROUK PARAMETERS

S/N	Location	Aquifer Thick.	Aquifer Res.	Reflection Coeff.	Resist. Contrast	Long. Resist.	Transverse Resist.	Coeff. of Anisotropy
		h (m)	*ρ* (Ωm)	*Rc*	*Fc*	*ρL* (Ωm)	*ρt* (Ωm)	*λ*
1	Tacharak	52	200	0.74	6.67	439.13	290.00	0.81
2	Tsokowai	45	200	0.33	2.00	380.02	335.11	0.94
3	Rafin Gora	40	280	0.30	1.87	337.79	377.00	1.06
4	Gujeni	40	450	0.75	6.92	337.79	377.00	1.06
5	Malagum	60	220	0.29	1.83	506.69	251.33	0.70
6	Zakwa	24	250	0.83	10.87	202.68	628.33	1.76
7	Sofio Kpak-I	32	300	0.47	2.78	270.23	471.25	1.32
8	Sofio Kpak-II	30	350	0.71	5.83	253.34	502.67	1.41
9	Fadan Daji	18	220	0.49	2.93	152.01	837.78	2.35
10	Mahuta-D	40	700	0.89	16.43	337.79	377.00	1.06
11	Ung. Afong	30	800	0.92	24.24	253.34	502.67	1.41
12	Ung.Shebayan	30	430	0.79	8.60	253.34	502.67	1.41
13	Ung. Nka	35	800	0.85	12.31	295.57	430.86	1.21
14	Mahuta-A	57	340	0.81	9.71	481.35	264.56	0.74
15	Randiyam	30	736	0.92	25.38	253.34	502.67	1.41
16	Aduwa GidaII	20	350	0.75	7.00	168.90	754.00	2.11
17	Madakiya	11	308	-0.49	0.35	92.89	1370.91	3.84
18	GS Madakiya	13.3	114	0.46	2.71	112.32	1133.83	3.18
19	Aduwa Gida I	20	301	0.62	0.48	168.90	754.00	2.11
20	Ung.Galadima	27	270	0.84	11.74	228.01	558.52	1.57

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