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

Isaac O. Olaniyan

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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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 Olde 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 fluvo-volcanic sequence is good and yields of 370 to 500 m³/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 \( \rho_i \) and thickness \( h_i \), the Dar-Zarrouk parameters, basically the longitudinal conductance, \( S \) (measured in mhos) and transverse resistance, \( T \) (expressed in ohm-m²) can be defined respectively with the following equations:

\[
S = \frac{\sum_{i=1}^{n} h_i \rho_i}{\rho_1 + \frac{h_2}{\rho_2} + \frac{h_3}{\rho_3} + \ldots + \frac{h_n}{\rho_n}}
\]

\[
T = \sum_{i=1}^{n} h_i \rho_i = h_1 \rho_1 + h_2 \rho_2 + h_3 \rho_3 + \ldots + h_n \rho_n
\]

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 \( \rho_L \) can be written as:
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 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

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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.

| 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 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 Aduwu Gida-II, while the remaining 15 (or 75%) of the locations are classified as practically noncorrosive. The result is summarized in Table III.

| 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) |

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 (R₀) 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 (F₀) 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.
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.
### Table III. Summary of the Longitudinal Conductance, Aquifer Protective Capacity and Soil Corrosivity

| Location   | Layer | Resistivity | Thickness  | Depth | Long. Cond. of Protective Layers | Aquifer Protect. Cap. | Soil Corrosivity |
|------------|-------|-------------|------------|-------|----------------------------------|---------------------|------------------|
|            |       | Ω·m         | m          | m     | s = Σ (di / ρi)                 |                     |                  |
| Tacharak   | 1     | 500         | 2          | 2     | 0.0040                           |                     |                  |
|            | 2     | 90          | 5          | 7     | 0.0556                           | Practically         |                  |
|            | 3     | 30          | 10         | 17    | 0.3333                           | 0.653               | Moderate         |
|            | 4     | 200         | 52         | 69    | 0.2600                           |                     | Noncorrosive     |
|            | 5     | 5000        |            |       |                                  |                     |                  |
| 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         |
|            | 4     | 200         | 45         | 53.4  | 0.2250                           |                     | Noncorrosive     |
|            | 5     | 2000        |            |       |                                  |                     |                  |
| 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         |
|            | 4     | 280         | 40         | 55.5  | 0.1429                           |                     | Corrosive        |
|            | 5     | 3000        |            |       |                                  |                     |                  |
| Gujeni     | 1     | 300         | 0.5        | 0.5   | 0.017                            |                     |                  |
|            | 2     | 500         | 2.2        | 2.7   | 0.0044                           | Practically         |                  |
|            | 3     | 65          | 7          | 9.7   | 0.1077                           | 0.203               | Moderate         |
|            | 4     | 450         | 40         | 49.7  | 0.0889                           |                     | Noncorrosive     |
|            | 5     | 9999        |            |       |                                  |                     |                  |
| Malagum    | 1     | 150         | 6          | 6     | 0.0400                           |                     |                  |
|            | 2     | 75          | 12         | 18    | 0.1600                           | Slightly            |                  |
|            | 3     | 120         | 25         | 43    | 0.2083                           | 0.681               | Moderate         |
|            | 4     | 220         | 60         | 123   | 0.2727                           |                     | Corrosive        |
|            | 5     | 9999        |            |       |                                  |                     |                  |
| 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         |
|            | 4     | 250         | 24         | 32.9  | 0.0960                           |                     | noncorrosive     |
|            | 5     | 2200        |            |       |                                  |                     |                  |
| 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         |
|            | 4     | 300         | 32         | 42.2  | 0.1067                           |                     | corrosive        |
|            | 5     | 3000        |            |       |                                  |                     |                  |
| 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         |
|            | 4     | 350         | 30         | 40.8  | 0.0857                           |                     | corrosive        |
|            | 5     | 3200        |            |       |                                  |                     |                  |
| 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         |
|            | 4     | 220         | 18         | 34.9  | 0.0818                           |                     | noncorrosive     |
|   |   |   |   |   |
|---|---|---|---|---|
| 5 | 3000 |   |   |   |
| 10 Mahuta-D | 1 | 250 | 1.4 | 1.4 | 0.0056 |
|   | 2 | 50  | 2.5 | 3.9 | 0.0500 |
|   | 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 |
|   | 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 |
|   | 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 |
|   | 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 |
|   | 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 |
|   | 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 |
|   | 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 |
|   | 3 | 308  | 11 | 12.1 | 0.0357 | 1.356 Good noncorrosive |
|   | 4 | 32   | 42.2 | 54.3 | 1.3188 |
|   | 5 | 1016 |   |   |   |
| 18 Ung. Afong | 1 | 400 | 4.5 | 4.5 | 0.0113 |
|   | 2 | 80   | 9 | 13.5 | 0.1125 |
|   | 3 | 33   | 18 | 31.5 | 0.5455 | 0.707 Good noncorrosive |
|   | 4 | 800  | 30 | 61.5 | 0.0375 |
|   | 5 | 4800 |   |   |   |
| 19 Ung Shebayan | 1 | 550 | 4 | 4 | 0.0073 |
|   | 2 | 150  | 8.5 | 12.5 | 0.0567 |
|   | 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 |
|   |   | 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 |
|   |   | 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 |
|   |   | 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 |
|   |   | 3 | 350 | 20 | 41 | 0.0571 | 1.492 |
|   |   |   |   |   |   | Good | corrosoive |
|   |   | 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 |
|   |   | 3 | 308 | 11 | 12.1 | 0.0557 | 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 |
|   |   | 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 |
|   |   | 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 |
|   |   | 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 |
|   |   | 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 |

**Notes:**
- Practically
- Slightly
- Moderately noncorrosive
- Good noncorrosive
- Practically
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 |
|-----|--------------|----------------|--------------|-------------------|-----------------|--------------|-------------------|---------------------|
| 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   | Malagurn     | 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  | Adowa GidaI  | 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  | Adowa 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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