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Application of Dar-Zarrouk Parameters for Groundwater Protective Potential within the Crystalline Basement Formation, Southwestern Nigeria

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Abstract

Dar-Zarrouk criteria were used to explore a study region in southwestern Nigeria that was covered by a crystalline groundwater basement complex to illustrate the possibility for groundwater protection. This was accomplished by determining if the research area's protective potentials were predominantly low, weak, moderate, or good. The study's protective potential was calculated using physical subsoil layer data such as apparent resistivity and layer thickness values. For vertical electrical probes, the Schlumberger electrode array arrangement was employed, and twenty probe locations were defined depending on the spread allowed and subsurface depth. The Dar-Zarrouk parameters revealed that there was 70% evidence of poor/weak groundwater protection potential within the study area, implying that the availability of profitable groundwater quality within the study area is envisaging a tragic development due to contaminating activities that could percolate from the topsoil to the subsoil in the near future. As a result, frequent assessment of adequate water quality development and standards is recommended within the environment for the safe use of groundwater resources.

Keywords: Geophysical investigation; Dar-Zarrouk parameters; Groundwater quality; Groundwater contamination; Leachate percolation.

Introduction

The natural phenomenon of water availability is a global concern because it is an essential and fundamental resource that sustains the course of the existence of humans within the environment. In addition, this type of water comprises groundwater such as wells, and boreholes and surface water such as springs, lakes, and rivers. Water availability can also inform precipitation that can then infiltrate the subsoil from the topsoil and run down to the groundwater table or be retained at the surface as puddles or standing water [1[reported that the accessibility of water sources is a dependable and proficient benefit to the environment for industrial activities, domestic purposes, and agricultural usage [2]. reported that groundwater and surface water are the major sources of water for industrial, household, and agricultural applications [3].

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reported that the study of groundwater is extremely important because it has a great impact on a healthy and favourably quality of life globally [4]. also places emphasis on the significance of groundwater for human uses as it is an enormous and prevalent commodity, and [5] reported the fundamental roles of groundwater because of its intensifying necessity. Decades ago, many establishments within the country have shifted to the use of groundwater because of a variety of setbacks, such as high demands due to population growth, the failure of dependability and continuous supply of pipe-borne water from the government and the relatively high cost of providing and maintaining surface water.

According to [6], groundwater is frequently used for drinking and irrigation. Consequently, groundwater is naturally guarded against migrating contaminants by existing subsurface structures, but in an environment where there are thin overburden; groundwater could be easily endangered by leachate contamination [7]. reported that leachate is generated from landfill sites and contains high levels of contaminants and is hazardous to humans and ecosystems [8]. Reveals that environmental assessment implementation is needed because it is a tool that envisages environmental problems. According to [9], one of the ten certified risks that the United Nations high-level board on threats has warned about is environmental downcast [10]. Reported that the investigation of groundwater is thoroughly crucial since the leachate contamination migrates to the subsoil from the topsoil and to the aquifer. Therefore, it is essential to carry out control groundwater quality estimation by assessing the protective potential of the study area so that the overburden nature can be understood. This can be achieved by employing the geophysical methods [11]. Emphatically reported that the geophysical method is used to investigate a large area of land cover, which is important in groundwater investigation [12]. Reported that the identification of groundwater potential has been assisted by the geophysical methods and this has contributed greatly to the planning of well/bore-hole drilling programmes in the environment.

Moreover [13], investigated the possibilities for employing vertical electrical ways to safeguard aquifers in the unit, including the near-ground refinery of Alberto Pasqualini in the Rio Grande do, Brazil, and concluded that regions designated as very excellent have good protection and pass visa [14]. Used a vertical electrical approach to categorize the overburden materials within Yenagoa, Southern part of Nigeria into weak, medium, and high aquifer protection [15]. Reports that the high clay content in the overburden thickness indicates a low groundwater potential, but improves the protective potential ratings using the vertical electrical probe method [16]. Reported that outcrops of geological formations also forms aquifers of good quality [17]. Completed a review to dissect potential groundwater regions to guarantee the accessibility of water for this city utilizing Dar-Zarrouk Parameters. Vertical Electrical Sounding (VES) estimations were utilized at eight focuses around the city of Pangkalpinang utilizing the Schlumberger exhibit setup. Dar-Zarrouk boundary was determined utilizing two boundaries of the geoelectric reversal results, i.e., resistivity and layer thickness. The outcomes revealed that the longitudinal conductance values shift from 0.097 to 0.307 mS. In view of this worth, the Northern piece of the review region has higher groundwater possible zone than the Southern part of the review region [18]. Carried out a pressure-driven properties of the water-bearing layer utilizing boundaries got from the Dar-Zarrouk condition and portrayed them into groundwater possible zones. The resistivity upsides of the endured and somewhat endured layers which make up the water-bearing layers were added and a normal was taken and utilized as the resistivity water-bearing arrangement in the calculation of Dar-Zarrouk boundaries in the Karlahi region. The upsides of resistivity of water-bearing development went from 18 to 4963 Ωm with a typical resistivity worth of 549 Ωm and the thickness of the water-bearing arrangement goes from 21 to 32 m with a typical thickness of 24.5 m. Conductivity values range from 0.000201 to 0.05509 (σ) while the longitudinal conductance range from 0.00483 to 1.2363 Ω-1, the cross over opposition goes from 407 to 123504.3 Ωm2.

The water powered conductivity and transmissivity values range from 0.14 to 25.87 m/day and 3.28 to 580.4 m2/day separately. The longitudinal conductance values in Karlahi region uncovered poor to great with a typical longitudinal conductance esteem that is moderate. High cross over opposition values are situated in the focal and southern piece of Karlahi region while low qualities are situated in the eastern part. The spatial dissemination guide of transmissivity in the space uncovered moderate to high transmissivity values in the north focal part and unimportant to low transmissivity in southern part, outrageous northeastern part. The groundwater likely guide of Karlahi region shows irrelevant to powerless potential groundwater zones in SW and SE, moderate possible in the key to northern piece of Karlahi region [19]. Utilized Dar Zarrouk (D-Z) Parameters like the Total Transverse Unit Resistance, T (Ωm2) and Total Longitudinal Unit Conductance, S (Ω-1) to propose ideal areas for penetrating of boreholes in the review region. To achieve this reason, 50

Schlumberger Vertical Electrical Sounding (VES) bends with greatest flow anode dividing of AB/2 = 681 m were deciphered. Consequently, the spring boundaries data assessed from the (VES) bends were utilized to plan form guides of T (Ωm2), S (Ω-1), spring thickness h (m), spring resistivity ρ (Ωm), and Water Table Depth (WTD). The Northern part of the location, which shows low qualities for T (Ωm2), h (m), and ρ (Ωm) proposes low efficiency for the aquiferous zones. The scarcity of water in these parts of the review region can be made sense of to be because of the prevailing geography. The high S, values at the Uburu and Okposi areas in this locale recommend the presence of saline spring. This study would be pertinent to the advancement of powerful ground water plot and for future hydrogeological examinations nearby.

When measuring groundwater potential [12], further stressed that the vertical electrical approach is ideally suited to studying the resistivity and thickness of the subsoil layer. The electrical resistivity technique was used for this study because it provides broad insights into the formation of subsoil layers. As a result, the research's goal was to establish groundwater quality by determining if the primary study area's groundwater protection potential was low, poor, medium, or outstanding. The Dar-Zarrouk parameter was used to calculate the apparent resistivity and thickness of vertical electrical sounding (VES) data. Figure 1 shows the twenty VES locations that were probed from the research region.

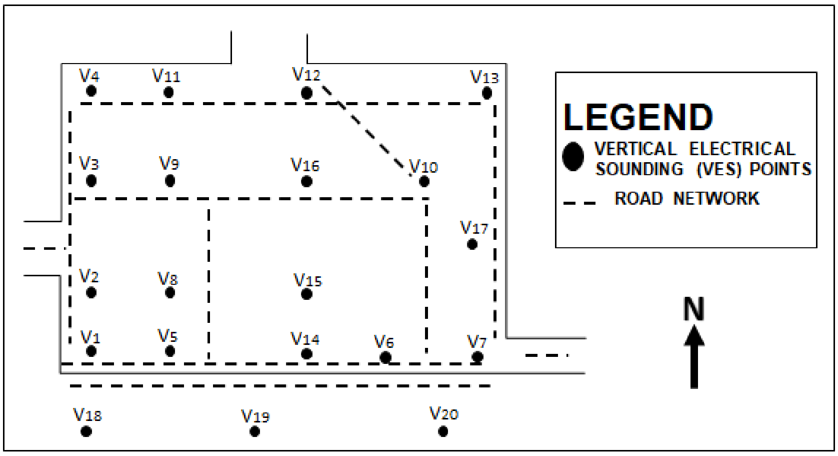

Figure 1. The distribution of Vertical Electrical Sounding

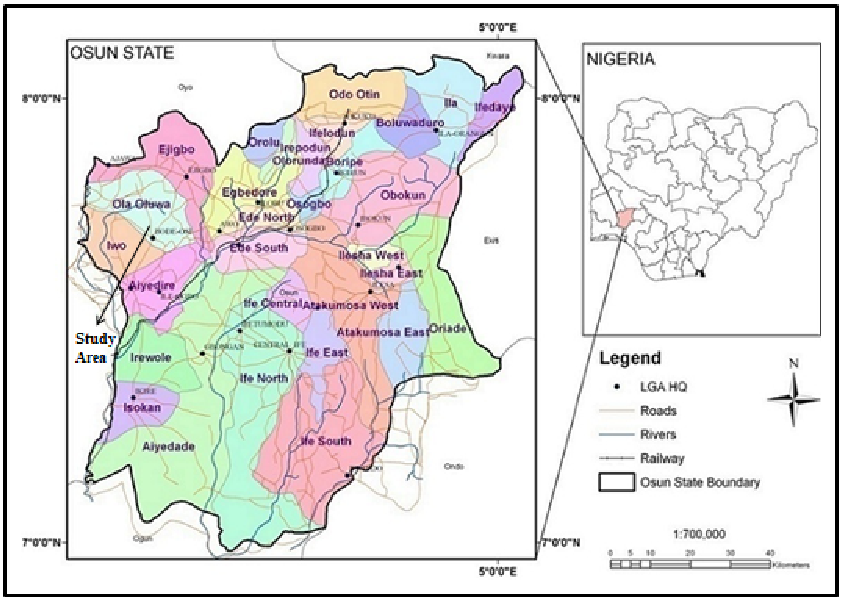

Figure 2. Shows the Study area

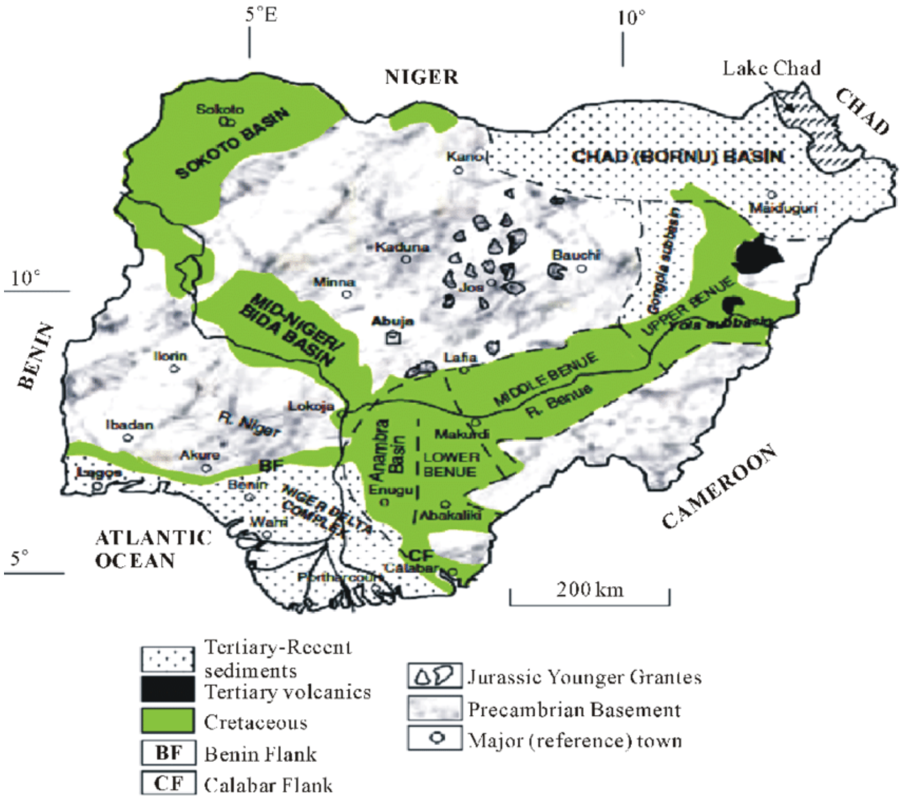

Figure 3. Map of Nigeria showing the major Geological Components [20[

The Geological Setting Study Area

The research region, Awgbagba, is located at coordinates of latitude 07° 42" to 07° 4" 20' N and longitude 04° 55" to 04° 22" E (Figure 2). Within the research region, the tropical rain pattern that covers southern Nigeria is seen, with two different seasons: the rainy season, which occurs between March and October, and the dry season, which occurs between November and February.

The study area soil formation constitutes the Precambrian Basement Complex of Southwestern Nigeria (Figure 3) with diverse divisions in the Pan–African (i.e old) granitoids. The main rock type found in the research region are quartzo-syenite.

Materials and Methods

For the geophysical research, the Terrameter, also known as a resistivity meter, was used. This was used to test the depth sounding in the research region. The aim of resistivity measurement is based on the estimation of the resistivity of the subsurface variation by undertaking measurements on the surface of the ground. In addition, estimating the possibility of the true resistivity is also known since the subsurface is inhomogeneous. The resistivity measurement is typically conducted by the use of two electrodes that are usually inserted into the ground surface. One of the pairs of electrode called the current electrode is denoted as (C1 and C2) and the other pair called the potential electrode is denoted as (P1 and P2) as shown in Figure 4.

For the field survey inquiry, the Schlumberger electrode configuration was adopted, with a maximum half–width of the current electrode spatial distribution (AB/2) ranging from 65 m to 260 m. The depth to the subterranean basement determines the distribution and the spread allowed with two electrode pairs placed along a set straight line [21]. The geoelectrical soundings acquired from the field survey were automatically interpreted using the WinGLink program (WinGLink software, 2008).

Figure 4. Shows the position of current/potential electrodes

Table 1. The Aquifer Protective Potential (APP) [26]

Raking	>10	5–10	0.2–4.9	0.1–0.19	< 0.1
Observation	Excellent	Very Good	Moderate	Weak	Poor

The curve fit of the theoretical curve and the auxiliary curve yielded resistivity values and associated thicknesses of inhomogeneous layers [22), [23) advanced computational modeling algorithm called WinResist [24), where the resulting geoelectrical characteristics were adjusted using to achieve a low RMS. By deducing the Dar-Zarrouk parameters from the apparent resistivity of the observed layer and its thickness, the groundwater protection potential is calculated.

Electrical Resistivity Theoretical Background

The theoretical basis for the resistivity method is Ohm's law as reported by [25]. The instrument used in the field survey is called Resistivity meter or Terrameter. In addition, Terrameter is a solid-state electronic meter used to measure the resistivity of liquids, slurries or semi-solids, which has a resistivity ranging from 0.01 to 10 Ωm. When conducting the field survey, the Terrameter usually provides a resistance value and this is inferred from the relationship between the current I and the potential V from the electrode readings i.e

$$R = \frac{V_r}{I_r} \quad (1)$$

Where V_r is the voltage (V) recorded from the potential electrodes and I_r is the current (I) recorded from the current electrode. Subsequently, the apparent resistivity $\rho a = K\frac{V_r}{I_r}$ (2)

Where K is the geometry factor, which is determined by the electrode spacing on the field. As a result,

$$\rho a = KR \quad (3)$$

Dar-Zarrouk Theoretical Background

The Dar-Zarrouk characteristics' layer resistivity structure and thickness have a considerable and ongoing usage value in aquifer safety measures [26, 27]. Reported that both the variables, models, and theories generated out of Dar-Zarrouk parameters are of vital significance in the development of vertical electrical sounding interpretation, according to [21]. Moreover, the combination of thickness and resistivity has good advantages because it can be done to evaluate the transmission, storage of aquifers and protection of groundwater [26, 28]. Also reported that the Dar-Zarrouk parameters are best estimated from the resistivity and thickness of the subsurface measurement and the Dar-Zarrouk parameter, according to [29], provides practical and dependable findings for investigating basement aquifer formations.

Estimation of the Dar-Zarrouk Parameters

The longitudinal conductance is indicated as S and the transverse resistance is denoted as T when estimating Dar-Zarrouk parameters. Longitudinal conductance is a major contributor to resistivity sounding, according to [27). However, if the subsurface structure is made up of N and the thickness is provided as $h_1, h_2, \dots, h_n$ with resistivity$\rho_1, \rho_2, \dots, \rho_n$, the thickness is given as $H = \sum_{i=1}^{N} h_i$ (4)

Therefore, longitudinal conductance $S = \frac{h_1}{\rho_1} + \frac{h_2}{\rho_2} + \dots + \frac{h_n}{\rho_n} = \sum_{i=1}^{N} \frac{h_i}{\rho_i}$ (5)

And transverse resistance $T = \rho_1 h_1 + \rho_2 h_2 + \dots + \rho_n h_n = \sum_{i=1}^{N} \rho_i h_i$ (6)

[26) and [27) reported that the protective potential secure and reply on longitudinal conductance and transverse resistance of the acquired values. The clay material at the overburden usually acts as a protective covering for aquifer formation according to [15] and [26]. Table 1 shows the rating of the aquifer protective potential as reported by [26].

Results and Discussion

Quantitative and qualitative interpretations were used to examine the possibility of groundwater protection in the research region. This comprises the Dar-Zarrouk parameter computation as well as the visual interpretation of tables and graphs.

The Vertical Electrical Sounding

The resistivity (ρ) and thickness (h) data acquired from the vertical electrical sounding are summarized below (Table 2). According to the Table 2, four layers made up the research area such as the topsoil, the clayey layer, the weathered layer, and the fractured/fresh basement. As shown in Figure 5, there exists the intercalation of clay (brown color) formation within the weathered layer across VES (1, 2, 3, 5, 6, 19) with resistivity between (44. 0 – 101.5 Ωm) [22) and depth between (14.6 – 64.7 m) respectively. As reported by [30], clay formation below a thin topsoil always act as a slight protection for groundwater when contaminants migrate from the topsoil to the subsoil.

Consequently, since the topsoil within the study area have comparatively thin overburden thickness; the

Table 2. The acquired Resistivity and Thickness summary

VES	ρ_1	h_1	ρ_2	h_2	ρ_3	h_3
1	219.50	0.70	129.10	7.20	77.90	6.70
2	230.60	0.70	360.30	5.00	76.00	25.40
3	273.00	1.70	85.30	16.10	219.80	46.90
4	108.80	0.60	320.30	2.30	145.40	16.30
5	169.60	7.30	101.10	13.40	71.80	8.40
6	309.20	1.10	223.00	1.10	75.80	32.50
7	376.80	0.70	181.80	2.30	270.00	16.00
8	2259.90	0.60	815.10	1.00	168.80	14.70
9	434.40	0.70	101.50	9.30	177.40	5.10
10	1606.00	0.70	716.60	10.50	893.30	13.90
11	100.20	1.40	336.80	1.20	334.30	3.80
12	621.40	0.60	250.90	17.90	280.60	7.30
13	269.20	1.10	375.60	2.10	358.50	1.40
14	88.50	0.60	196.80	2.30	1058.80	13.30
15	1380.70	2.10	478.20	0.90	93.60	16.50
16	2169.90	1.10	494.50	3.50	58.60	34.60
17	4401.10	0.50	1451.70	0.80	1496.00	0.60
18	1699.80	0.90	434.10	0.70	313.70	2.10
19	161.10	0.70	44.00	10.30	255.70	40.70
20	1375.10	2.20	715.90	0.40	97.00	14.70

NOTE. The resistivity (ρ) is measured in (Ωm) and the thickness (h) is measured in (m)

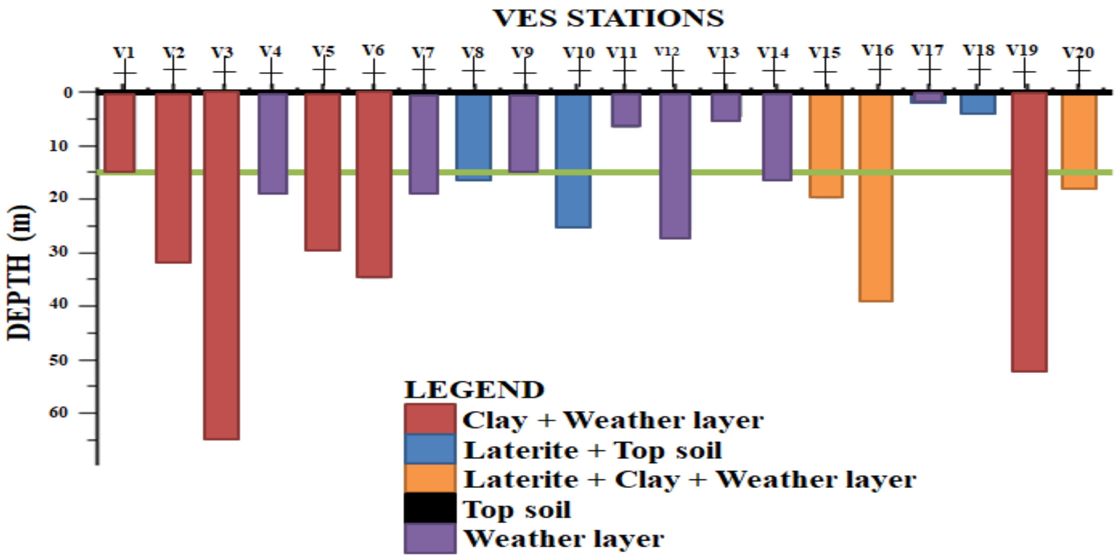

Figure 5. Showing the Geological formations present within the study area

groundwater especially in fractured crystalline basement with resistivity (89.3 – 616.5 Ωm) is given protection by geological barriers. It was also observed that laterite which represent an outcrop and clay are within the weathered layer (yellow colour) as shown in VES [15, 16, 20] with resistivity (17.4 – 39.1 Ωm) [22]. Thus, to have a substantial groundwater protective potential, there must be a barrier such as silt and clay having sufficient thickness but low hydraulic conductivity.

Geoelectric Section

From Figure 1, the twenty (20) VES stations were grouped into five (5) geoelectric profiles (a - e) according to how suitable they can be positioned on a straight line to understand the image of the subsurface. The results of the interpreted VES curves as shown from Table 2 were used to draw a 2D geoelectric sections Figure (6a – e) along profile A with VES point (18, 1, 2, 3, 4), profile B with VES point [4, 11, 12, 13), profile C with VES point (20, 7, 17, 13), profile D with VES point [18, 19, 20] , and profile E with VES point [14, 15, 16, 12]. This revealed the vertical and lateral distribution of the layer resistivities within the capacity of the subsurface in the investigated area. One of the major significance of 2D geoelectric section is that, it helps to understand visibly where there are groundwater protective potential within the subsurface of the sounding locations, which can be signified by geological materials such as laterite and clay formation.

Profile A

The geoelectric section of Profile A, (Figure 6a) shows that the area is divided into six (6) regions namely: laterite, topsoil, weathered layer, clayey layer, fractured basement and fresh basement. The area revealed both thin and thick overburden. The area revealed that groundwater availability is visible within the Profile across VES 18, 1, 2 and 3, due to the presence of fractured basement. In addition, the best zones form groundwater yield is the zone within weathered/fractured basement with visibility of thick overburden [3]. This can be revealed as VES 1 and VES 2 with depth greater than 15 m. However, due to the presence of geological materials such as laterite and clay, there is a slight protective potential across VES 18, 1, and 2. VES 3 also revealed a clayey formation but

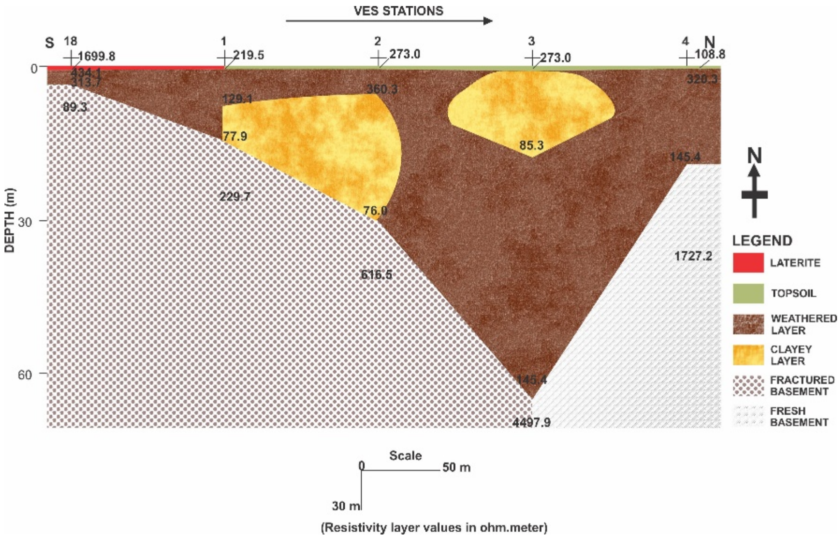

Figure 6a. Geoelectric Section along Profile A

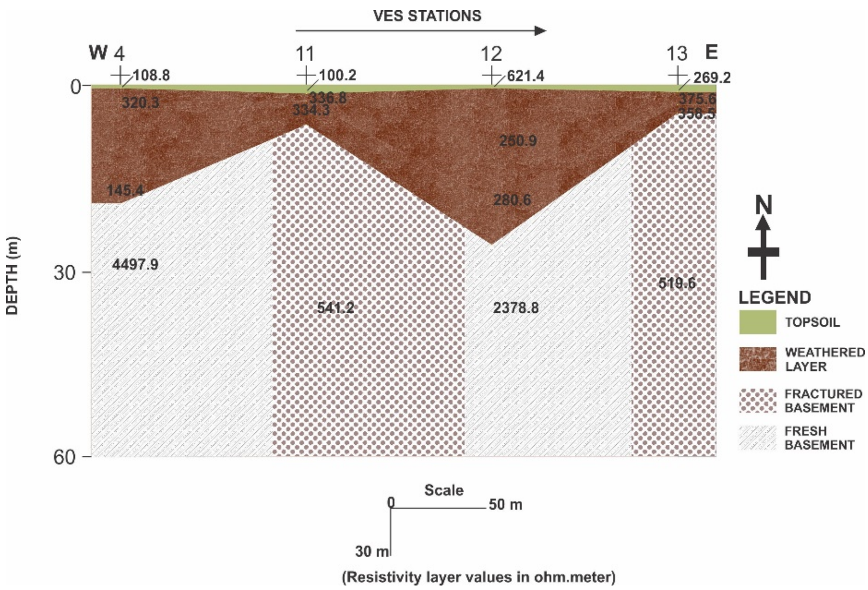

Figure 6b. Geoelectric Section along Profile B

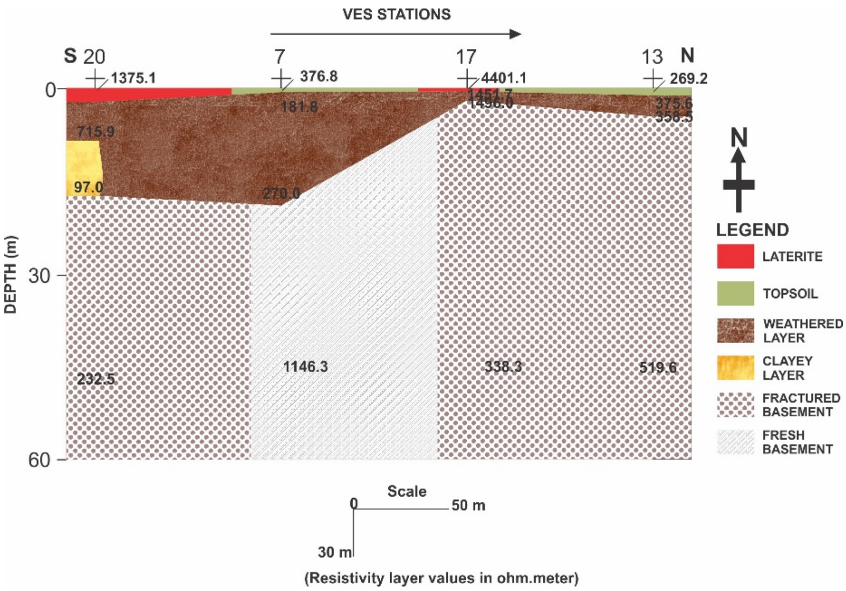

Figure 6c. Geoelectric Section along Profile C

however it is underlain by partially fracture/fresh basement, which is not favorable for groundwater prospects.

Profile B

The geoelectric section of Profile B, (Figure 6b) shows that the area is divided into four (4) regions namely: topsoil, weathered layer, fractured basement and fresh basement. The area revealed both thin and thick overburden. Groundwater availability is not visible within the Profile since the area is not majorly composed of thick overburden/fractured basement. Also, there is no indication of geological protective potential across the profile.

Profile C

The geoelectric section of Profile C, (Figure 6c) shows that the area is divided into six (6) regions namely: Laterite, topsoil, weathered layer, clayey layer, fractured basement and fresh basement. The area revealed both thin and thick overburden. The area revealed that groundwater availability is visible within the Profile across VES 20 due to the presence of weathered/fractured basement with thick overburden. However, due to the presence of geological materials such as laterite and clay, there is a highly protective potential across VES 20.

Profile D

The geoelectric section of Profile D, (Figure 6d) shows that the area is divided into five (5) regions namely: Laterite, topsoil, weathered layer, clayey layer, and fractured basement. The area revealed both thin and thick overburden. The thick overburden is reveal from the V shape which extended slightly from VES 18 across VES 20. The area revealed that groundwater availability is visible within the Profile across VES 19 and 20, due to the presence weathered/fractured basement with predominantly thick overburden. However, due to the presence of geological materials such as clay VES 19, there is a slight protective potential, while VES 20 also revealed the presence of laterite and clayey formation with prospect of groundwater, therefore, this area exhibit a high protective potential.

Profile E

The geoelectric section of Profile E, (Figure 6e) shows that the area is divided into six (6) regions namely: Laterite, topsoil, weathered layer, clayey layer, fractured basement and fresh basement. The area revealed both thin and thick overburden. The area revealed that groundwater availability is visible within the Profile across VES 15 and 16, due to the presence of weathered/fractured basement with thick overburden. However, due to the presence of geological materials such as laterite and clay, there is a highly protective potential across VES 15 and 16.

Dar-Zarrouk parameters

The Dar-Zarrouk parameters were derived using equations (5) and (6), with the longitudinal conductance

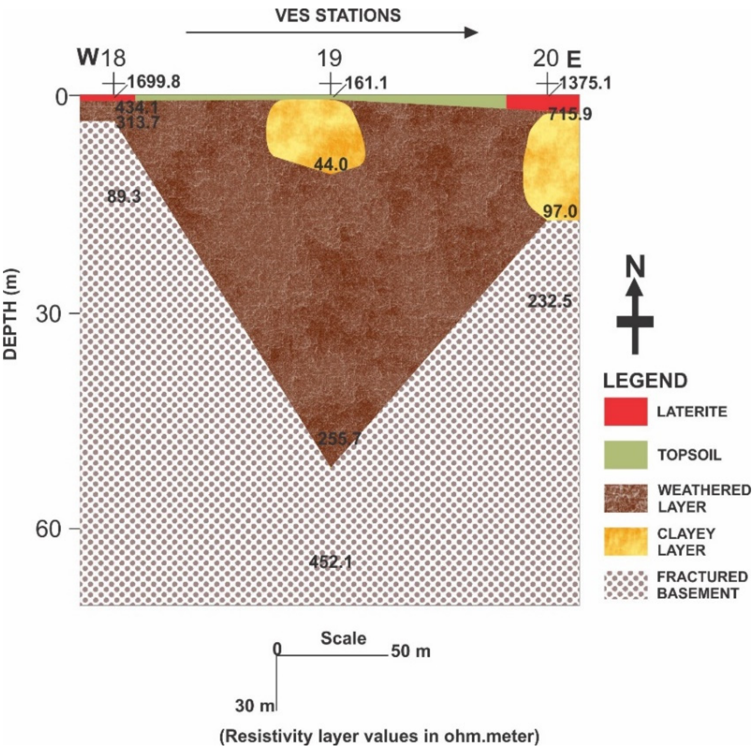

Figure 6d. Geoelectric Section along Profile D

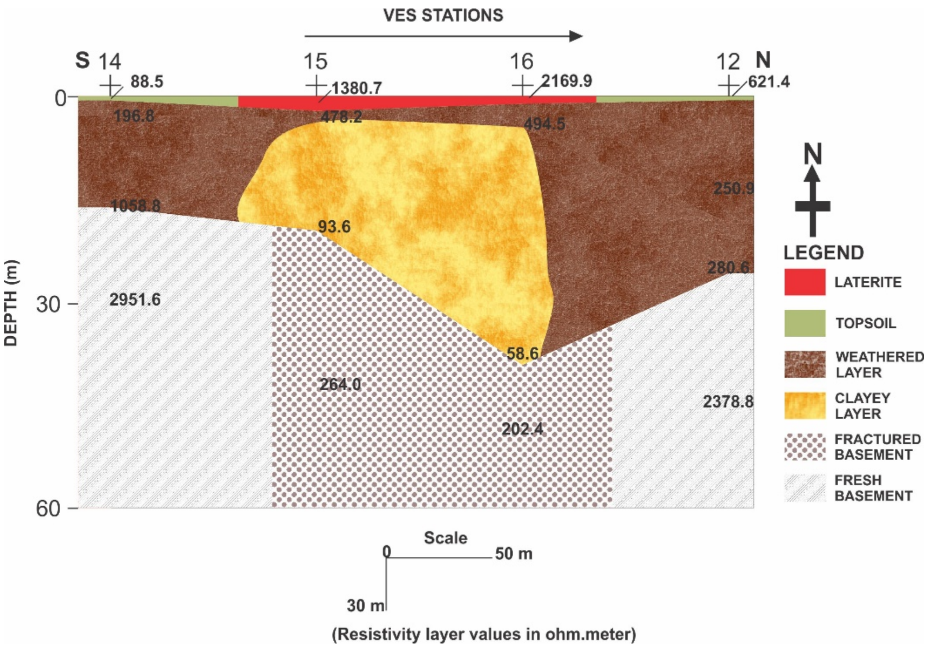

Figure 6e. Geoelectric Section along Profile E

(Lc) and transverse resistance (Tr) taken from Table 2. According to [26], an aquifer's capacity to protect itself is directly proportionate to the thickness and resistivity of the inhomogeneous subsurface formation. As a result, the magnitude to which the groundwater has been shielded from the vertical filtering of some probable

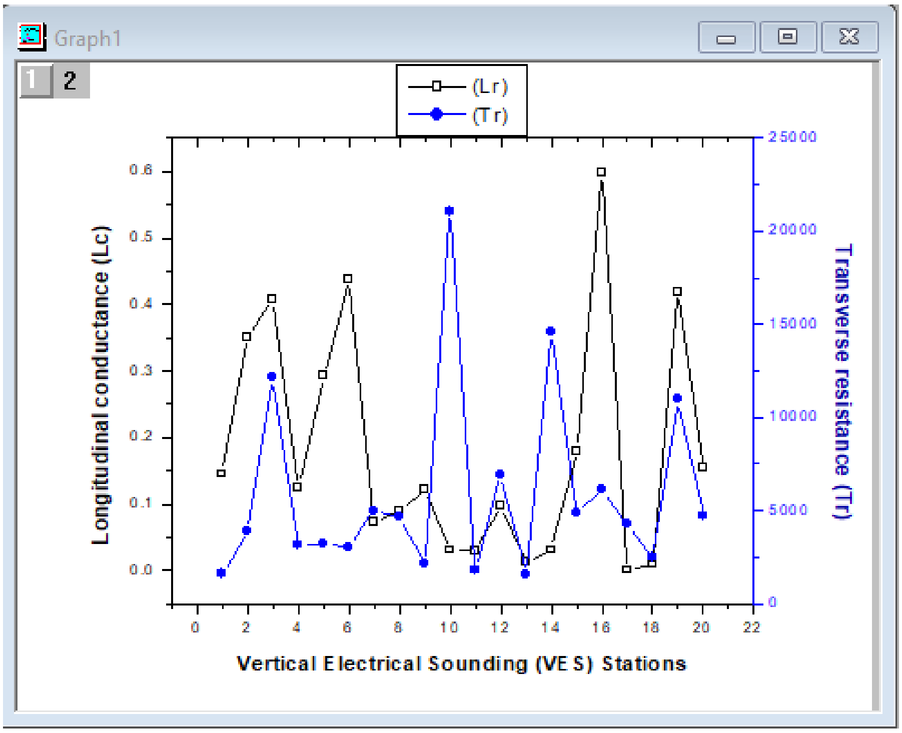

Figure 7. Shows the Lc and Tr of VES stations

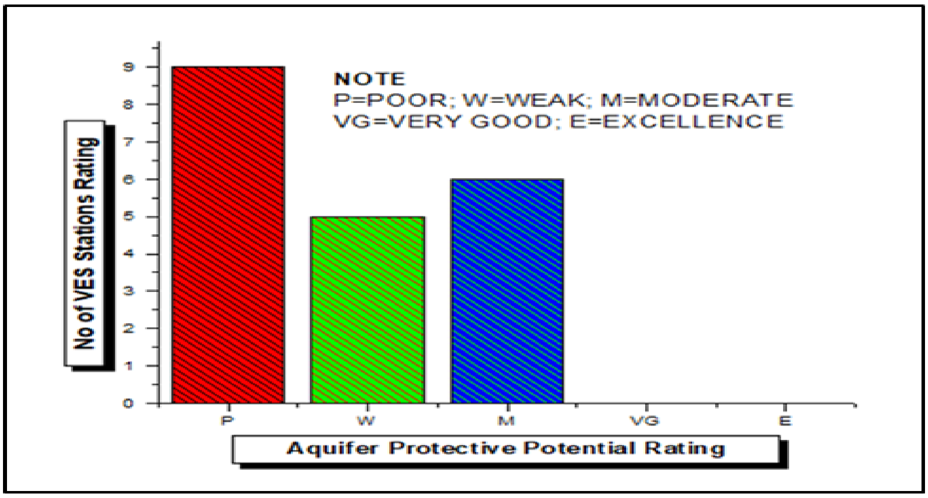

Figure 8. Shows the number of VES Station with the APP Rating

pollutants may be explained. Because the Earth's surface works as a natural filter for percolating fluid, as proposed by [31], the Lc and Tr values of the 20 VES soundings have been utilized to estimate the subsurface's protective capacity, as shown in Figure 7. The Lc unit values found in the research region ranges between 0.0011 and 0.5980 mhos.

The Figure 8 depicts the number of VES stations as well as the APP rating, which allows the region to be split into three protective potential zones: poor, weak, and moderate.

Moderate protective potential zones have a Lc value of 0.2–0.69, weak protective potential zones have a Lc value of 0.1–0.29, and poor protective potential zones have a Lc value of less than 0.1. In the research region, there were nine (9) zones with low potential protection,

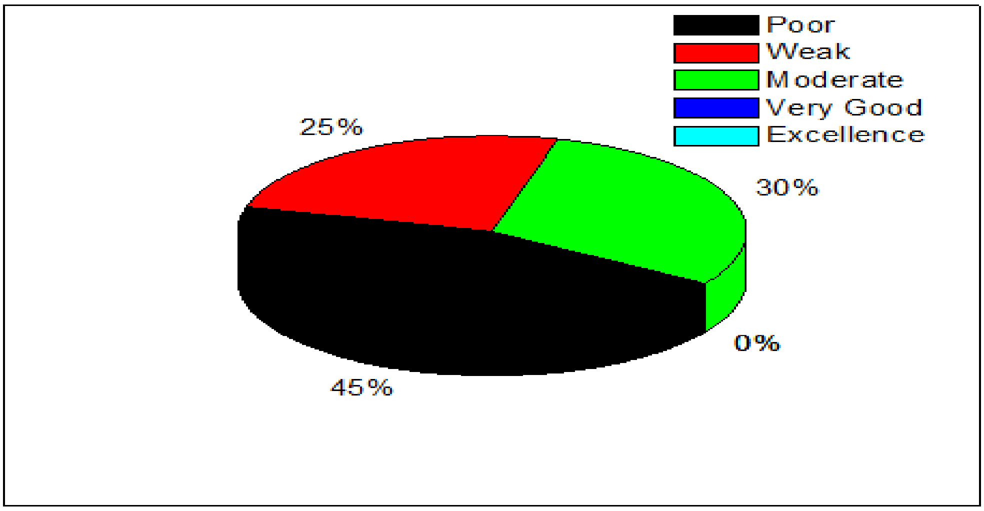

Figure 9. Shows the percentage distribution of the APP of the study area

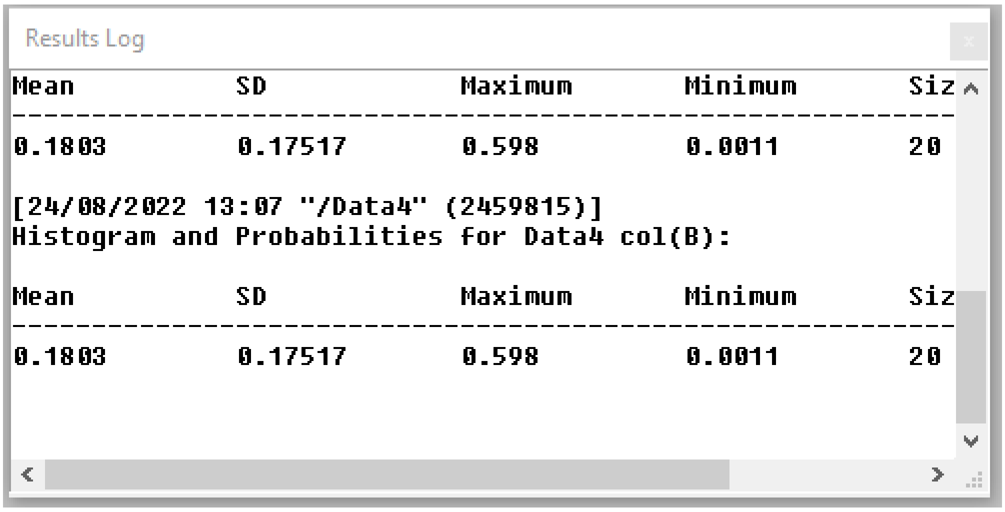

Figure 10. Showing the Probability Distribution of Lc

five (5) zones with weak potential protection, and six (6) zones with moderate potential protection. This showed why contamination of the aquiferous formation within the research regions might occur as a result of the topsoil's migration to the subsurface formation. According to the results, the protective potential is typically low over the research region and geographically poor across the study region.

The moderate zones which are also located near the zones of poor/weak tend to be having a harmful influence and effect on the groundwater prospect. Figure 9 shows the percentage potential protection of the research study; showing that 45 percent have poor protection potential, 25 percent have weak protection potential, and also, 30 percent have moderate protection potential. The research region is majorly constituted with poor and weak overburden protection potential, with 70 percent being inside the poor and weak zones and 30% falling within the moderate zones.

The mean probability is revealed to be 0.1803 and the standard deviation is revealed to be 0.17517 (Figure 10). As a result, determining the area's groundwater protection potential is usually considered poor [26].

Conclusion

Dar-Zarrouk parameters and the resistivity approach have shown to be crucial in groundwater protection research because they provide a convenient, substantial, and reliable solution for assessing groundwater's protective potential. Because of the low groundwater protective potential and the relatively thin overburden thickness of the topsoil, simple pollutant filtering might occur, according to the study's results. On the other hand, the presence of geologic barriers like as clay and laterite may provide some protection to groundwater over time.

The study has produced trustworthy data on deep groundwater environmental parameters that are important for industrial, commercial, and residential development. As a result, groundwater quality programs should be done frequently in the environment for successful groundwater development, and preliminary geophysical investigations should be encouraged to analyze water quality for environmental objectives.

This work has shown that the geoelectrical sounding method may be utilized successfully to estimate the hydraulic characteristics of an aquifer as well as to explore groundwater resources. By enabling a more thoughtful selection of the well sites, it can significantly minimize the quantity of test drilling necessary.

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