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INVESTIGATION OF AQUIFER PROTECTIVE CAPACITY FOR GROUNDWATER EXPLORATION USING DAR ZARROUK PARAMETERS IN FEDERAL POLYTECHNIC MUBI ADAMAWA STATE NORTH EASTERN NIGERIA

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Abstract

This research was conducted to investigate aquifer protective capacity for groundwater exploration using Darzarrok parameters in the Federal Polytechnic Mubi, Adamawa State, Northeastern Nigeria, in order to determine aquifer thickness (H), aquifer resistivity (r), Conductivity d =1/r, longitudinal conductance (S = dh), and transverse resistivity (R = hr) of each VES point; to determine transmissivity (Tr = kh) and diagnostic parameters (Dp = Tr/R) of each VES point; and to classify protective capacity ratings of vertical electrical soundings (VES) points into moderate, weak, good, and poor. The data obtained in the field were subjected to qualitative and quantitative analysis that reveals the numbers of layers and the resistivity values of each Vertical Electrical Sounding (VES). Dar Zarrouk parameters of each VES point were analyzed and determined. The protective capacity rating of VES points VES A, VES B, VES C, VES D, VES E, and VES F was Moderate, Weak, Good, Moderate, Moderate, and Good. VES points A, B, C, D,

Keywords: Aquifer, Protective Capacity Rating, Vertical Electrical Sounding (VES), Dar Zarrouk Parameters, Resistivity and Groundwater

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and E were promising for groundwater exploration (hand dug well), while VES point B is not promising for groundwater exploration. For future research, there is a need to employ an integrated geophysical survey within the study area to detect the hidden targets of promising groundwater potential zones.

Introduction

Groundwater is one of the major sources of water for human existence on the surface of the earth; this water can be found beneath the earth's surface. Exploration of groundwater helps man to meet his demand for water utilization for many purposes, such as drinking, cooking, agricultural activities, industrial and other domestic activities (Maiti et al., 2012).

In searching for groundwater, geophysicists, geologists, and other geoscientists make use of different geophysical techniques in carrying out surveys to locate the potential zone for groundwater exploration where the borehole can be located and drilled for the purpose of water supply for human needs. The Schlumberger Techniques (Vertical Electrical Soundings) method has been used in the past to locate viable points for groundwater exploration (Simon et al., 2022; Yakubu & Nur, 2025; Abel et al., 2023; Chinyem & Ovwamuedo, 2024; Abel et al., 2023; Esonanjor et al., 2023; Bahri & Zulfiah, 2023).

The electrical resistivity method (vertical electrical soundings) is mostly used in geophysics to obtain field data (geo-electric data).Dar Zarrouk parameters has be employed to obtain more information about aquifer of some areas from previous research, Dar Zarrouk parameters consist of the following: Aquifer Resistivity r (Ωm), Aquifer Thickness h (m), Conductivity d = 1/r $(\Omega m)^{-1}$, Transverse Resistivity R = hr $(\Omega m)^2$, Diagnostic Parameters DP DP= Tr/R (m/(Ω)) (Ankidawa & Seli, 2018; Kwami et al., 2019 ; Ankidawa, Ishaku & Hassan, 2018; Seli, Ankidawa & Ishaku, 2021; Simon et al., 2022; Okolo, Emechata & Madu, 2024; Iduma, Abam & Uko, 2016; Nyembwe et al., 2024; Bello, 2025; Bahri et al., 2024 ; Chinyem & Ovwamuedo, 2024).

Simon et al. (2022) evaluated groundwater potential using Dar Zarrouk Parameters in Mapeo and Environs, Northeastern Nigeria, using a Schlumberger array to survey thirty-five Vertical Electrical Soundings (VES). The geoelectric layers of the area were revealed through the analysis of the Vertical Electrical Sounding (VES) obtained. Then, a second analysis of the Dar Zarrouk parameters was performed. The longitudinal conductance and transverse resistance values range from 0.0842 Ω to 1.5926 Ω, with the average value of 0.5767 Ω, and from 1107.235 to 8910.410 Ωm^2, with the average value of 4167.902 Ωm^2, respectively. From the research on the aquifer properties, empirical formulas according to the size of the grains were used to ascertain hydraulic conductivity ranges from 1.01 x

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10^{-9} to 9.82 x 10^{-6} m^2/day with an average of 2.176 x 10^{-3} m^2/day, and hydraulic conductivity determined from geophysical techniques ranges from 1.833 m^2/day to 17.525 m^2/day with an average value of 289.113 m^2/day. Finally, groundwater potential zones were determined based on transmissivity values and classified the area into low, moderate, and high potentials.

Seli, Ankidawa, and Ishaku (2021) carried out research on Dar Zarrouk Parameters for delineating groundwater potentials in Ganye and environs, Adamawa State, Northeastern Nigeria. Fourteen (14) Vertical Electrical Soundings (VES) were sounded on the study area and analyzed; geo-electric units were obtained. Furthermore, Dar Zarrouk parameters were analyzed. The aquifer conductivity within the study area ranges between 0.00871 and 0.032032 Ω^{-1} with a near value of 0.019493 Ω^{-1}. From the revealed result, the aquifer longitudinal ranges from 0.22246 to 0.759252, having the mean value of 0.432846. Transverse resistance is 627.8721 to 1857.282 Ωm^2 with an average value of 1235.854 Ωm^2. The aquifer hydraulic conductivity value ranges between 6.9314 and 15.562 m/day with a mean value of 9.738 m/day, while the transmissivity across the study area ranges between 114.2152 and 378.774 m^2/day with a mean value of 216.0487 m^2/day.

Ankidawa, Ishaku, and Hassan (2018) estimated aquifer transmissivity using the Dar Zarrouk parameter derived from resistivity soundings on the floodplain of River Dadin Kowa, Sombé State, Northeastern Nigeria. Geoelectric layers of the area under study were determined from the analysis of the Vertical Electrical Soundings (VES) obtained. The aquifer hydraulic characteristics revealed the transverse resistance R range between 436.8 Ωm^2 and 77.3240 Ωm^2, with a mean value of 111963.71 Ωm^2. The Longitudinal conductance was from 0.0026 to 1.1792, with an average value of 0.26348. From the other parameters obtained, such as hydraulic conductivity value ranging between 0.16 m/day and 29.79 m/day with a mean value of 5.597 m/day, the transmissivity value was 16 m^2/day to 834.1 m^2/day with an average value of 128.86 m^2/day. The Dar Zarrouk parameter was used to obtain a transmissivity value that revealed low to high aquifer potential.

Ankidawa and Seli (2018) worked on Dar Zarrouk parameters for delineating groundwater potential zones in the Geriyo irrigation floodplain of the River Benue, Adamawa State, Northeastern Nigeria. Geoelectric layers were obtained from the Vertical Electric Soundings (VES). The aquifer hydraulic characteristics indicated the transverse resistance, R, ranged between 2,626.70 Ωm^2 and 241,252.39 Ωm^2 with a mean value of 45,172.17 Ωm^2. The longitudinal conductance, S, obtained was 0.001-0.221 with a coverage value of 0.036. Hydraulic conductivity values range from 0.21 m/day to 29.06 m/day across the floodplain with a mean value of 11.22 m/day, and transmissivity values range from 1.68 m^2/day to 808.16 m^2/day with an average value of 214.07 m^2/day. From the research the hydraulic

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head shows that the water levels in the floodplain were higher than the river and recharged the river.

Tantasso (2005) recently carried out research on geoelectric surveys for groundwater potential zones in Federal Polytechnic Mubi, Mubi, Adamawa State, Northeastern Nigeria. Dar Zarrouk Parameters analysis revealed values of the following: Aquifer resistivity, transmissivity, diagnostic parameter, aquifer thickness, longitudinal conductance, transverse resistivity, and longitudinal conductivity ratings of VES points 1-6 were not promising for groundwater exploration.

Kwami, Mukkafa, Haruna, and Ankidwa (2019) carried out research on the delineation of aquifer potential zones using hydraulic parameters in Gombe and environs, northeastern Nigeria. The study was basically underlined by basement complex rocks represented by diorites and granites and Cretaceous sedimentary rocks represented by the Bima, Yolde, Fika, and Gombe formations. Thirty-two (32) vertical electrical soundings (VES) were carried out in the area using the Schlumberger array method with the ABEM (SAS) terameter for data acquisition. The result of the interpretation shows four to six geo-electric layers. Four groundwater potential zones were delineated, including medium-grain sandstone, clay sand, and shale sand.

In some other parts of the world, Vertical Electric Soundings (VES) were also employed to investigate, delineate, and assess groundwater potential zones. Bahri and Zulfiah (2023) investigated groundwater quality using Vertical Electrical Soundings (VES) and Dar Zarrouk Parameters in Leihitu, Maluku, Indonesia. According to the research outcome, Dar Zarrouk Parameters, Longitudinal Conductance (S) range from 0.0278 to 5.1213 mho and were classified as moderate to good protective capacity.

This research was an attempt to investigate aquifer protective capacity for groundwater exploration using Dar Zarrouk parameters in Federal Polytechnic Mubi, Adamawa State, Northeastern Nigeria, with the following objectives:

(i) To determine aquifer thickness H, aquifer resistivity (r), conductivity d = 1/r, longitudinal conductance S = dh, and transverse resistivity R = hr of each VES point

(ii) To determine transmissivity Tr = kh and diagnostic parameters Dp = Tr/R of each VES point

(iii) To classify protective capacity ratings of Vertical Electrical Soundings (VES) points into moderate, weak, good, and poor.

Geology and Hydrogeology of the area

Mubi belongs to the Hawal Massif's Precambrian Basement Complex, which is located in the northeastern portion of Nigeria's eastern Basement Complex. According to Obiefuna

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(1997), it is precisely situated in the areas that stretch into Adamawa State's northern regions. Pervasive migmatization, extensive granite plutonism, and high-grade metamorphic rocks are characteristics of the rocks found in the Hawal Basement (Ferre et al., 1996). Gneiss, granite gneiss, granite, dolerite, aplite, and pegmatite are among the minor rocks (Obiefuna, 1997; Adekeye and Ntekim, 2004; Patrick, 2005; Bassey and Valdon, 2011).

Overlying some areas of the Basement Complex in Mubi are alluvial deposits that may have formed as a result of the basement complex weathering in situ or upward (Obiefuna, 1997). Additionally, some regions are distinguished by reddish to brownish laterite overburden that covers the bedrock along the Yedzaram River. This overburden has a thickness of 5 to 25 meters. According to Adebayo (2004) and Obiefuna (1997), the area's most common geological features are quartz feldspar veins, folds, shear zones, and older granite with dolerite and pegmatite dykes.

Two extremely localized aquifer systems, which are typical of groundwater occurrence in the crystalline basement area, define Mubi. These aquifer types are the unconsolidated weathered overburden aquifer and the fractured basement aquifer, which is primarily composed of migmatite granite. According to research by Obiefuna (1997), tap water from the unconsolidated weathered overburden was discovered in all hand-dug wells.

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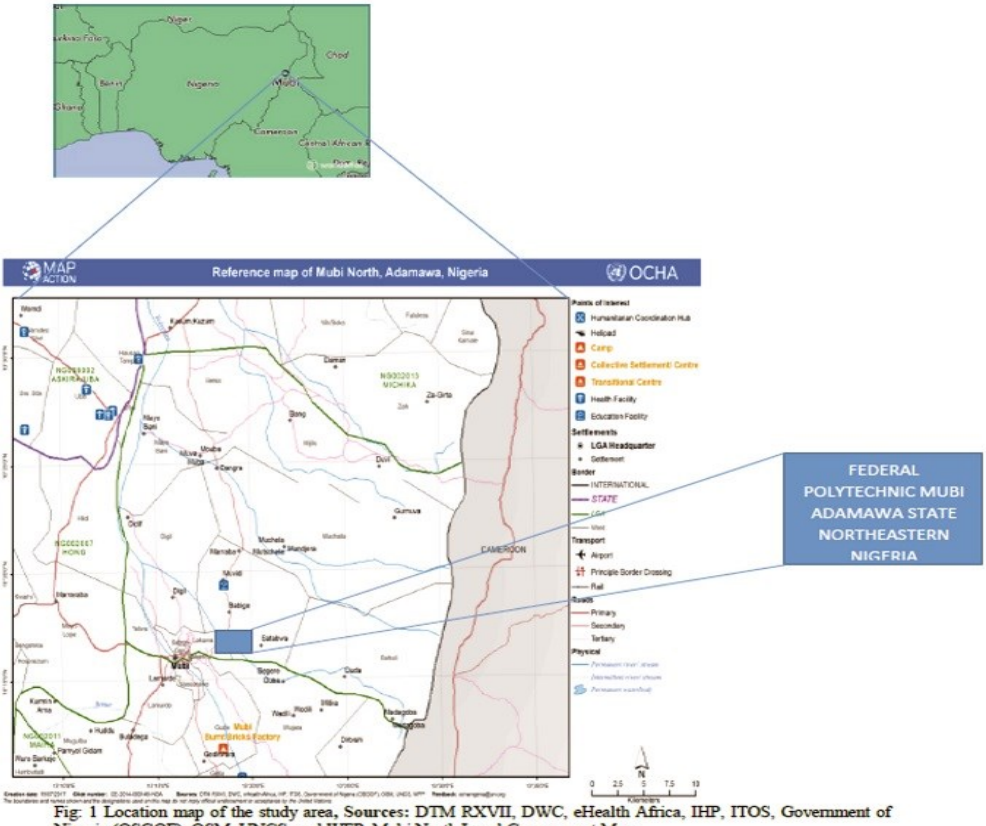


Fig: 1 Location map of the study area, Sources: DTM RXVII, DWC, eHealth Africa, IHP, ITOS, Government of Nigeria (OSGOF), OSM, UNCS, and WFP. Mubi North Local Government Map.

Materials and Method

Electrodes (both current and potential), reels of connecting wires, a battery, a hammer, and an ABEM SAS1000 Terameter are the materials used in this study. For this study, the Vertical Electrical Sounding (VES) method was used on the study area since it provides a means of exploring groundwater and is a tool for analyzing the Dar Zarrouk Parameter. A maximum electrode spread of 100 meters was used for five vertical electrical soundings. This was accomplished by using the Schlumberger electrode arrangement as shown in Figure 2.

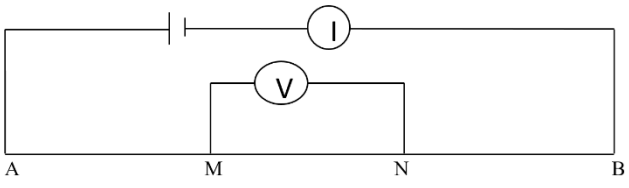


Fig 2: Schlumberger Configuration.

The process measures the resulting potential difference in the subsurface using two current electrodes and two potential electrodes. For every sounding, the tetrameter shows the average digital value of the subsurface's apparent resistivity.

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Result Interpretation

In order to predict the vertical changes of subsurface resistivity at various depths, the Interpex IX1D resistivity program was used to analyze the VES data using one-dimensional (1D) inversion. A standard geo-soft format for entering apparent resistivity data is provided by this software. Additionally, it smoothes the field curve by using a filtering technique that moves vertical curve segments and corrects single points. To determine the true state of the ground, this package may translate the apparent resistivity values as a function of electrode spacing that were obtained as field data into values of true resistivity as a function of layer depth. Using the VES interpretation results, second-order Dar-zarrouk parameters were calculated and analyzed.

Table 1: Dar Zarrouk Parameter Obtained from the Iterated Field Data

S/N	Aquifer Resistivity ρ	Aquifer Thickness H	Conductivity $\delta = 1/\rho$	Longitudinal Conductance $S=\delta h$	Transverse Resistivity $R=h\rho$	Transmissivity $T_r=kh$	Diagnostic Parameters $D_P= T_r/R$
VES A	2.0	0.5	0.500000	0.250000	1.000000	5	5.000000
VES B	1.2	0.5	0.833333	0.416666	0.600000	5	8.333333
VES C	0.4	0.6	2.500000	1.500000	0.240000	6	25.00000
VES D	12	15.1	0.083333	1.258328	181.2000	151	0.834254
VES E	0.8	0.3	1.250000	0.375000	0.240000	3	12.50000
VES F	0.3	0.6	3.333333	1.999999	0.180000	6	33.33333

Table 2: VES point of Layers, Resistivity, thickness and S = Ration of thickness and resistivity.

S/N	Layers	Resistivity(ρ)	Thickness(h)	Longitudinal unit conductance (S). $S=\sum_{h}/\rho$	Longitudinal conductivity of protecting layers= Average of S	Protective Capacity Rating
VES A	1	25	4.7	0.18800	0.21900	Moderate
	2	2	0.5	0.25000		
	3	15000	-	-		
VES B	1	70	6.3	0.09000	0.11833	Weak
	2	1.2	0.5	0.41666		
	3	13,0000	-	-		
VES C	1	180	1.8	0.01000	0.75500	Good
	2	0.4	0.6	1.50000		
	3	14000	-	-		
VES D	1	500	0.9	0.00180	0.63006	Moderate
	2	12	15.1	1.25833		
	3	1000000	-	-		
VES E	1	70	6.2	0.08857		

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	2	0.8	0.3	0.37500	0.23178	Moderate
	3	15000	-	-		
VES F	1	150	3.0	0.00200		
	2	0.3	0.6	2.00000	1.00100	Good
	3	16000	-	-		

Table 3: Showing Aquifer protective Capacity Rating (Olusegun et al., 2016)

Rating	Remarks
Greater than10	Excellent
5 to 10	Very Good
0.2 to 4.9	Moderate
0.1 to 0.19	Weak
Less than 0.1	Poor

Discussion of Result

VES A has aquifer resistivity of 2.0, aquifer thickness (H) of 0.5, Conductivity (S) $\delta = 1/\rho$ of 0.500000, Longitudinal Conductance $S=\delta h$ of 0.250000, Transverse resistivity $R=h\rho$ of 1.000000, Transmissivity $T_r = kh$ of 5 and Diagnostic parameter Dr = Tr/R of 5.000000.

VES B has aquifer resistivity of 1.2, aquifer thickness (H) of 0.5, Conductivity (S) $\delta = 1/\rho$ of 0.833333, Longitudinal Conductance $S=\delta h$ of 0.416666, Transverse resistivity $R=h\rho$ of 0.600000, Transmissivity $T_r = kh$ of 5 and Diagnostic parameter Dr = Tr/R of 8.333333.

VES C has aquifer resistivity of 0.4, aquifer thickness (H) of 0.6, Conductivity (S) $\delta = 1/\rho$ of 2.500000, Longitudinal Conductance $S=\delta h$ of 1.500000, Transverse resistivity $R=h\rho$ of 0.420000, Transmissivity $T_r = kh$ of 6 and Diagnostic parameter Dr = Tr/R of 25.00000.

VES D has aquifer resistivity of 12, aquifer thickness (H) of 15.1, Conductivity (S) $\delta = 1/\rho$ of 0.083333, Longitudinal Conductance $S=\delta h$ of 1.258528, Transverse resistivity $R=h\rho$ of 181.2000, Transmissivity $T_r = kh$ of 151 and Diagnostic parameter Dr = Tr/R of 0.834254.

VES E has aquifer resistivity of 0.8, aquifer thickness (H) of 0.3, Conductivity (S) $\delta = 1/\rho$ of 1.250000, Longitudinal Conductance $S=\delta h$ of 0.375000, Transverse resistivity $R=h\rho$ of 0.240000, Transmissivity $T_r = kh$ of 3 and Diagnostic parameter Dr = Tr/R of 12.50000.

VES F has aquifer resistivity of 0.3, aquifer thickness (H) of 0.6, Conductivity (S) $\delta = 1/\rho$ of 3.333333, Longitudinal Conductance $S=\delta h$ of 1.999999, Transverse resistivity $R=h\rho$ of 0.180000, Transmissivity $T_r = kh$ of 6 and Diagnostic parameter Dr = Tr/R of 33.33333.

In table 2

VES A Shows that the longitudinal conductivity of property layer of S is 0.21900

VES B Shows that the longitudinal conductivity of property layer of S is 0.11833

VES C Shows that the longitudinal conductivity of property layer of S is 0.75500

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VES D Shows that the longitudinal conductivity of property layer of S is 0.63006
VES E Shows that the longitudinal conductivity of property layer of S is 0.23178
VES F Shows that the longitudinal conductivity of property layer of S is 1.00100

Conclusion

Research was conducted to investigate aquifer potential zones for groundwater exploration within the study area. From the result analysis and outcome the aquifer thickness of VES A, VES B, VES C, VES ,D VES E, VES F were 0.5, 0.5, 0.6, 15.1, 0.3 and 0.6 respectively and the capacity ratings VES A, VES B, VES C, VES ,D VES E, VES F were Moderate, Weak, Good, Moderate, Moderate and Good respectively.

Recommendations

Therefore VES point A, B, C, D and E were promising for groundwater exploration while VES point B is not promising for groundwater exploration. For future research, there is need to employed integrated geophysical survey within the study area to detect the hidden targets for groundwater exploration.

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