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RESEARCH ARTICLE

Delineation of Groundwater Potentials in Alkaleri and Environs, North-Eastern Nigeria

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ABSTRACT

Water is a necessity in every day of our life. In our homes, offices, schools, hospitals, markets, industries, and even in our personal journey, there is always the need for continual water supply to meet our basic water needs. The research is aimed at delineating groundwater potentials in Alkaleri and environs. The geological field mapping was carried out and different rock types were identified in the study area, which consist of Precambrian basement rocks (Migmatite Gneiss, Hornblende Granite, and Bauchite), and the tertiary sedimentary rock of Kerri-Kerri formation. The vertical electrical sounding method was used to delineate the groundwater potentials in the research area. A total of 30 vertical electrical sounding points was randomly selected and surveyed. The electrode configuration used for the work was Schlumberger array. Fourteen curves were identified in the study area. The result revealed that the transverse resistance values vary from 78.5 Ωm^2 to 7984.9 Ωm^2 with an average value of 2180.534Ωm^2. The values of longitudinal conductance ranges from 0.002258 Ω to 0.74634037 Ω with an average of 0.1713455Ω. The transmissivity values range from 8.89 m^2/day to 467.2 m^2/day, average value of 100.3 m^2/day**.** The hydraulic conductivity values range from 0.9m/day to 29.6m/day with mean value of 8.3m/day. Aquifer characteristics revealed that transmissivity and hydraulic conductivity showed low potential.

1. INTRODUCTION

Water plays an important role in advancing civilization owing to the rapid growth in the world economy and civilization. According to National Groundwater Association (NGWA), groundwater makes up about 30% of the world's freshwater supply, which is estimated to be 2.78 million trillion gallons for the entire planet (NGWA 2023). The total volume of groundwater in the upper 2 km of the Earth's continental crust is approximately 22 million km^3, of which 0.1 to 5.0 million km^3 is less than 50 years old (Gleeson et al., 2016; Kwami et al., 2019; Ali et al., 2023). The need for development of water resources has become more urgent than ever before. The governments and organizations have already taken positive action to cope with the situation. The Bauchi State Government has undertaken various water supply projects throughout the state under the Bauchi State Rural Water Supply and Sanitation Agency (RUWASSA). Water is a necessity in every day of our life. In our homes, offices, schools, hospitals, markets, industries, and even in our personal journey, there is always the need for continual water supply to meet our basic water needs. The Federal Government of Nigeria took it upon itself to ensure that there is constant supply of potable water to her citizens and foreigners who are residing in Nigeria. The Federal Ministry of Water Resources arm of the Government has been doing a good job on behalf of the Federal Government to ensure regular water supply in the country. To achieve this enormous task, the Federal Ministry of Water Resources also does this in association with the state's arm of the Ministry of Water Resources, Federal and States constituted water Agencies, local Government arm of the Departments of Water Resources, Non-Governmental Organizations (NGO's), as well as the well to do private individuals, in their philanthropic gesture. Like any other government in any part of the world, the Nigerian Government has done well in water supply projects in the country. However, water supply projects, which are aimed at ensuring that potable water gets to all the parts of the country, have been facing a lot of setbacks. Vertical Electrical Sounding (VES) is a geophysical method used to look at the distribution of subsurface electrical resistivity. It entails putting current into the ground through electrodes and measuring the potential difference that results in order to determine the apparent resistivity of the ground at different depths (Sinaga et al., 2023). Groundwater exploration, mineral exploration, geotechnical investigations, and environmental studies are just a few of the uses for which VES data can be interpreted to offer information on the resistivity and thickness of subsurface layers (Asta and Prasetia 2020). Aliyu *et al.* (2016) carried out a research on Geoelectrical and Hydrogeochemical Characterization of the Basement Complex Aquifers in the area around the Abuja City Centre, Nigeria. The VES interpretation results revealed three (H and K-type), four (KH, HA and AA-type) and five (HKH-type) layers geoelectric models. The study concluded that the study area was characterized by both the weathered layer and partly weathered/fractured basement aquifers. The groundwater was also found to be generally potable. The study aims at delineating Groundwater Potentials in Alkaleri and Environs, North-Eastern Nigeria.

2. MATERIALS AND METHODS

2.1. Study Area

The study area is Alkaleri town and environs the area is located on the topographic map of Alkaleri South-west sheet 152 and lies between longitudes 10°10'0"E to 10°23'0"E latitudes 10°11'0"N to 10°21'0"N and covers an area of about 421.2 km^2 (Figure 1). It is accessible through the Bauchi Gombe road and characterized by numerous foot paths. The area of study is located within the Sudan savannah climatic belt of Nigeria. It is characterized by two distinct seasons: the dry season and the wet season. The dry season (harmattan) runs from October/November to March/April with little or no rainfall. The wet season is from April/May to October. The vegetation is dominated by shrubs, short grasses and scattered trees. The mean annual rainfall is between 1,000 and 1,200mm for Alkaleri where the study area is situated while the dry season is characterized by an arid wind or tropical continental air mass originating from the Sahara Desert. During the period, there is little cloud cover and the temperature ranges from 17 to 22 °C (BSADP 2022). The study area is mainly classified as a Sudan savannah region which is characterized by grasses, shrubs and trees with large trunks. The grasses dry and trees shed off their leaves during dry season and flourish again when the wet season returns.

The topography of the area is characterized by a few hills reaching and elevation of 706 m above sea level in the north-western region, underlain by crystalline basement rocks. The lowest elevation in the area is 275 m above sea level and it is associated with stream channels in the north eastern region, underlain by the Tertiary Kerri-Kerri Formation (Figure 1).

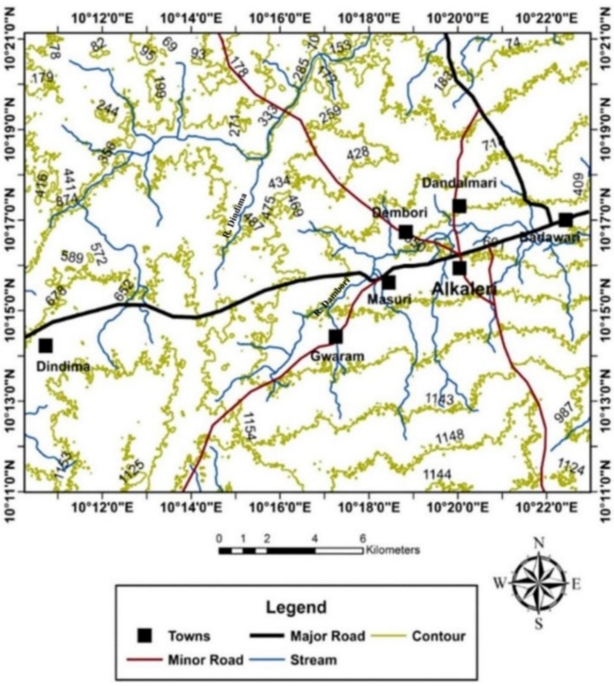

Figure 1: Topographic Map of the study area

Geological field mapping was carried out on scale 1:50,000 in order to collect samples, identify the field occurrences and structural relationship of all the rock types present in the study area. Fresh and unweathered rock samples were taken for hand specimen examination. During the mapping boundaries were demarcated between the Basement terrain (gneisses) and the sedimentary terrain (Kerri-Kerri formation). The vertical electrical sounding (VES) was used for depth investigation. A total of 30 VES points along 500 m length, was randomly selected and surveyed, with 60 electrodes spacing. The electrode configuration used for the work was Schlumberger array. The two outer current electrodes and the two inner potential electrodes were arranged along a line and symmetrical about their mid-point. For each reading, the current was sent into the ground through A and B which setup the measured potential difference between the potential electrodes M and N, the magnitude of the potential difference developed is a measure of the electrical resistance between probes. The resistance is in turn a function of the geometrical configuration of the electrodes and the electrical parameters of the ground (Dobrin 1976). The electrode separation (AB/2) varied from 1 to 100 m. The SAS 4000 Terrameter was positioned halfway between the potential electrodes M and N. The current electrodes A and B was connected to terminals C1 and C2 respectively, these cables were run in parallel adjacent to the SAS 4000 Terrameter and was arranged symmetrically with respect to the potential electrodes (ABEM 2010). The VES procedure was used in order to determine subsurface electrical condition by making use of the resistivity contrast of the subsurface. Structures that exist between fresh unproductive zone and weathered and/or fractured zones, i.e. the target zone are thick weathered and fractured zone or joints overlying the fresh basement rock which would provide favourable point for locating successful water borehole in the study area. The resistivity measuring equipment used for the survey was the ABEM SAS 400C terrameter. The instrument is equipped with current and potential cables of up to 500 m spread which connect the copper rods used as current and potential electrodes (ABEM 2010).

2.2. Determination of Dar-Zarrouk Parameters

Properties of aquifers such as transmissivity and hydraulic conductivity can be evaluated from surface resistivity measurements (Utom et al., 2012; Kwami et al., 2019; Ankidawa et al., 2023). The Dar-Zarrouk Parameters *S* and *T* are of direct use in aquifer protection studies and evaluation of hydrologic properties of aquifer. The relationship between aquifer transmissivity, and longitudinal conductance express as:

$$T = K\delta R = KS/\sigma \qquad (1)$$

Where T = aquifer transmissivity, K= hydraulic conductivity, σ = electrical conductivity (reciprocal of resistivity), `R = transverse resistance; S = longitudinal conductance. These were obtained from each VES Point.

Following the method by Heigold *et al.* (1979), hydraulic conductivity was determined using equation 2.

$$K = 386.40R_{rw}^{-0.93283} \qquad (2)$$

Where, K is the hydraulic conductivity m/day and R_{rw} is the aquifer resistivity ohm.m.

The aquifer transmissivity (T m^2/day) in the study area was estimated using equation 3.

$$T = k\ x\ h \qquad (3)$$

Where: K is the hydraulic conductivity (in m/day) and h is the layer thickness (in m). Offodile (1983) proposed a rating scale of aquifer potential based on their transmissivity values.

3. RESULTS AND DISCUSSION

3.1 Geology of the study Area

The study area is geologically underlain by four rock types; Migmatite Gneiss, Hornblende Granite, Bauchite and Kerri Sandstone (Oyawoye et al., 1972). The Migmatite Gneiss, (Basement complex) is the oldest of the four rock types; it is of the Pan African granites series. The Kerri-Kerri Sandstone which is part of the tertiary sedimentary rocks overlies uncomformably on the older granites (Oyawoye et al., 1972). The geological studies show that the oldest rock in the area is Migmatite Gneiss consisting of varieties of granitic rocks which covers almost 40% of the study area. The rocks were predominantly underly the areas of Kurwala, Kan'iyaka, Turiya and Shafan Fulani all in Northern and eastern part of the study area, and it also experienced the intrusion of Homblend Granite (Oyawoye et al., 1972). To the Far East it shared a boundary with Bauchite rocks while to the eastern and southern part of the study area it shared a boundary with Kerri-Kerri Formation that covered about 50% of the study area (Figure 2). This is proposed for a coarse plutonic fayalite-bearing rock which was first found in Bauchi Northern Nigeria (Oyawoye et al., 1972). It underlies about 10% of the study area which shared boundary with Hornblende Granite to the western part of the area (Figure 2). The Kerri–Kerri Formation is a continental sequence deposited on a wide range of conditions (alluvial, braided, and lacustrine) and lies unconformably on the Gombe Sandstone Formation. The formation lies within latitudes 9° 30' N to 11° 50' N and longitude 9° 50' E and 11° 30' in the Gongola arm of the Northern Benue Trough of Nigeria. The Formation was uncomformably overlies the basement rock in the study area and occupy almost half of the study area (Figure 2). However, it occupies the Eastern and Southern part of the study area and it doesn't experience any intrusion of the basement and any other rocks.

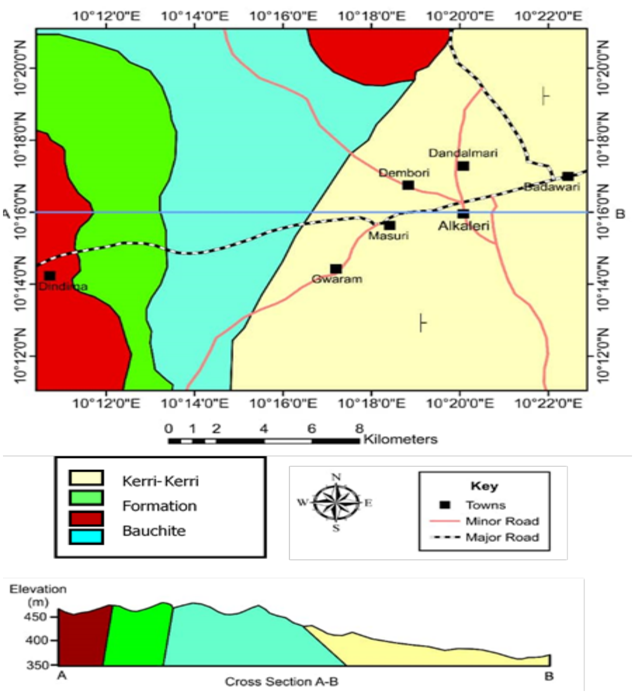

Figure 2: Geological Map of the study area

Figures 3 and 4 show rose diagrams for vein pattern on granite gneiss and homblend granite in the research area. A dyke and joint were observed in the study area during a field work. The dykes in the outcrop are not affected by weathering of the country rock in which they occur. They can be pronounced in the field because they look differently from the rock they penetrate. The dykes are found mainly in the northwestern part of the study area and trend mainly in the NW-SE direction. They range from 1m to 1.5m in thickness. Veins are tabular sheet-like mineral bodies which have intruded vertically into joints or fissures. The veins usually occur along fracture zones in form of mineralization due to the movement of molten materials that solidify along the fractures or faults (Ekwueme 2003). Quartz vein occur on the Homblend granite at Kurwala and trend in the NW-SE direction. Most of the veins follow direction of the joints which trend NW-SE.

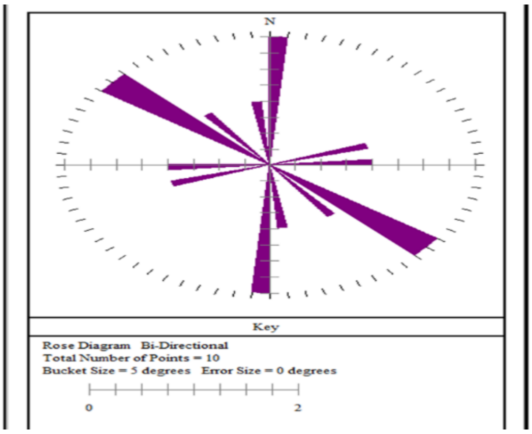

Figure 3: Rose diagram for vein pattern on granite gneiss

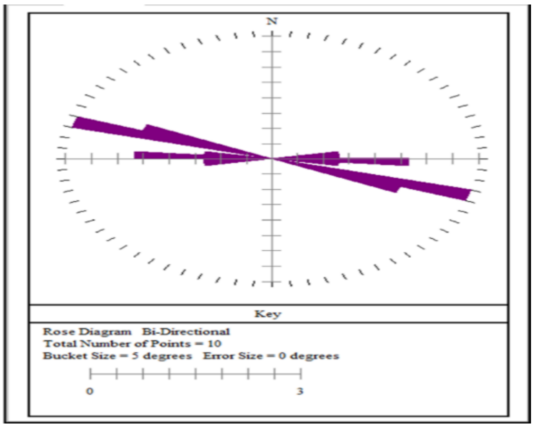

Figure 4: Rose diagram for vein pattern on homblend granite

3.2 Geo-Electrical Parameters

Table 1 shows the summary of interpreted data and aquifer system for each point in the study area. About 14 curves were identified in the study area (Table 1). The shape of the VES curve depends on the thickness of each layer, the number of layers in the subsurface and the resistivity of the layer. The geoelectric characteristic gives the respective layer resistivity values and thickness (Kwami et al., 2019; Seli et al., 2021; Ankidawa et al., 2023). The section gives a maximum of 6 layers with varying resistivity and thickness across each VES point. The aquifer type in the study area comprises mostly of fracture basement accounting for almost 24 VES locations, with 6 VES point medium to coarse grained Sandstone (Table 1). This inferred due to the high porosity and permeability characteristic of these lithological formation attributed to their resistivity values. Therefore, the aquifer system comprises the weathered and fractured basement in the North-Eastern and Central part of the study area while semi confined aquifer to the southern and North-eastern part of the area.

3.3 Delineation of Aquifer Systems

Aquifer systems in the study area were delineated through the results of the existing borehole lithologs and geoelectric logs of boreholes with some VES points as it shown in (Figure 5). The profile A-A’ line along NE-SW trends of the study area encountered borehole (BH 17) and 3 VES points (VES 19, 22 and 25) (Figure 6). The lithologic logs of the borehole were correlated with the inferred lithologies of the VES points. Layer 1 was encountered in all the geoelectric logs and the lithologic logs. It consists of top soil with resistivity values ranging from 76.8Ωm to 140.2Ωm with an average of 104.17Ωm and ranges in thickness from 1.5m to 7.3m with an average of 4.7m. It consists of weathered basement with resistivity values ranging from 33.2 Ωm to 273.5 Ωm with an average of 142.4Ωm and ranges in thickness from 8.4m to 11.2 m with an average of 9.93 m. Layer 3 is the fractured basement which is the aquiferous layer and it encountered in all the sections with resistivity values ranging from 150.6 Ωm to 640.4 Ωm and average of 409.1 Ωm. The thickness of the third layers is at infinite. The profile B-B’ (Figure 7) along NE-SW trends of the study area encountered borehole (BH 12) and 3 VES points (VES 2, 4 and 12). The lithologic log was correlated with the geoelectric logs of the VES points. Layer 1 was encountered in all the sections of the VES point and the lithologic log. It consists of top soil with resistivity value ranging from 145.4 Ωm to 824.6 with an average of 536.2 Ωm and ranges in thickness from 1.7 m to 4.5 m with an average of 3.06 m. Layer 2 was encountered in all the sections. It consists of weathered basement with resistivity values ranging from 71.8 Ωm to 301.2 Ωm with an average of 206.4 Ωm and ranges in thickness from 10.8m to 12.9m with an average of 11.63m. Third layer is the fractured basement and it encountered in all the sections with resistivity values ranging from 48.4 Ωm to 496.1 Ωm and average of 208.8 Ωm and ranges in thickness from 39.4 m to 41.6 m with an average of 41.6m. Layer 4 is the fresh basement and it was encountered in all the sections with resistivity values ranging from 19.2 Ωm to 816.8 Ωm and average of 424.1 Ωm. The thickness of the third layer is at infinite. In reference to the resistivity ranges obtained, it shows an indication of water bearing formations (Ighodalo and Japhet 2024).

Table 1: Geoelectric Parameters, lithologic delineation and aquifer type of the study area

S/N	Location	Coordinate	Elevation	Layer No.	Resistivity (0hm-m)	Thickness (m)	Inferred Lithology	Curve Type	Aquifer Type
1	Unguwan Ajiya	10⁰20'29''E 10⁰16'10''N	390	1	231.9	3.7	- Top Soil Clay	HA	Fractured Basement
				2	162.6	9.5	- Clay Sand		
				3	421.8	41.6	- Fractured Basement		
				4	745.3	-	- Fractured Basement		
2	Gwaram	10⁰15'12''E 10⁰16'40''N	345.7	1	145.4	4.5	- Top Soil Clay	HA	Fractured Basement
				2	71.8	11.2	- Clay Sand		
				3	496.1	41.5	- Fractured Basement		
				4	816.8	-	- Fractured Basement		
3	Kachichiya	10⁰19'57''E 10⁰16'40''N	378.2	1	156.94	6.0843	- Top Soil Sand	H	Fractured Basement
				2	67.653	25.308	- Weathered Basement		
				3	814.94	–	- Fractured Basement		
4	Sabongarin -Pali	10⁰20'8''E 10⁰15'53''N	420.8	1	824.6	1.7	- Top Soil Sand	QQ	Fractured Basement
				2	301.2	10.8	- Weathered Basement		
				3	48.4	41.6	- Fractured Basement		
				4	19.2	-	- Fractured Basement		
5	U/S/Shanu	10⁰21'46''E 10⁰17'48''N	378.8	1	924.1	1.9	- Top Soil Sand	Q	Fractured Basement
				2	299.5	11.1	- Weathered Basement		
				3	48.2	41.7	- Fractured Basement		
6	Gunchugun i	10⁰22'26''E 10⁰17'14''N	373.1	1	80.7	4.6	- Top Soil Sand	QHA	Medium Grain Sand
				2	15.7	9.5	- Clay Sand		
				3	10.4	18.7	- Weathered Basement		
				4	20.2	13.8	- Medium Grain Sand		
				5	57.8	-	- Fresh Basement		
7	Kan'iyaka	10⁰22'45''E 10⁰17'7''N	363.1	1	8.0	10	- Top Soil Clay	QH	Medium Grain Sand
				2	41.3	11.0	- Clay Sand		
				3	89.5	51.9	- Silty Sand		
				4	47.3	-	- Clay		
8	Maimadiri	10⁰22'16''E 10⁰16'54''N	356.2	1	46.4	4.2	- Sandy Top Soil	KH	Fractured Basement
				2	183.5	17.4	- Weathered Basement		
				3	38.9	43.5	- Fractured Basement		
				4	47.2	-	- Fresh Basement		
9	Unguwan Kudu	10⁰21'29''E 10⁰16'35''N	358.4	1	129.6	4.9	- Sandy Top Soil	KH	Fractured Basement
				2	654.5	12.2	- Weathered Basement		
				3	49.9	46.4	- Fractured Basement		
				4	126. 4	-	- Fresh Basement		
10	32 Junction	10⁰21'29''E 10⁰13'34''N	488.3	1	156.94	6.0843	- Top Soil Sand	H	Fractured Basement
				2	67.653	25.308	- Weathered Basement		
				3	814.94	–	- Fractured Basement		
11	Fanti	10⁰11'42''E 10⁰19'51''N	388.7	1	152.2	2.5	- Top Soil Clay	HA	Fractured Basement
				2	97.1	7.5	- Clay Sand		
				3	378.8	37.4	- Fractured Basement		
				4	726.1	-	- Fractured Basement		
12	Londo	10⁰20'46''E 10⁰16'4''N	378.6	1	638.6	3	- Sandy Top Soil	QA	Fractured Basement
				2	246.2	12.9	- Weathered Basement		
				3	81.9	39.4	- Fractured Basement		
				4	436.3	-	- Fresh Basement		
13	CPS Alkaleri	10⁰20'11''E 10⁰16'36''N	378.1	1	311.8	12.9	- Top Soil Sand	AKQH	Medium Grain sandstone
				2	501.9	9.1	- Clay Sand		
				3	942.3	29.5	- Loose sand		
				4	272.9	40.4	- Sandstone Intercalation		
				5	77.8	59.9	- Medium Grain Sandstone		
				6	238.1	-	- Sandstone		
14	Pali	10⁰20'6''E 10⁰16'22''N	388.1	1	28.7	1.6	- Top Soil Clay	KH	Fractured Basement
				2	218.7	7.9	- Clay Sand		
				3	49.3	58.7	- Fractured Basement		
				4	76.7	-	- Fractured Basement		
15	GGAC Alkaleri	10⁰20'17''E 10⁰15'32''N	410.4	1	29.1	0.7	- Sandy Top Soil	AHA	Fractured Basement
				2	219.4	7.5	- Clay Sand		
				3	86.7	33.7	- Weathered Basement		
				4	155.6	36.4	- Fractured Basement		
				5	159.6	-	- Fresh Basement		
16	Gagau	10⁰20'41''E 10⁰15'50''N	396.9	1	39.8	3	- Sandy Top Soil	HKH	Fractured Basement
				2	26.7	9	- Clay Sand		
				3	699.6	21.8	- Weathered Basement		

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				4	589.3	26.9	- Fractured Basement		
				5	834.7	-	- Fresh Basement		
17	Tarangadi	10°20’57’’E	399.5	1	316.2	14.6	- Clay Top Soil	AKQ	Medium
		10°15’39’’N		2	504.0	10.1	- Clay Sand		Grained
				3	947.2	30.5	- Reddish brown Sand		Sandstone
				4	279.8	41.8	- Kaoline		
				5	75.7	-	-Fresh Basement		
18	Federal	10°20’46’’E	423.7	1	130.27	5.8	- Top Soil Sand	H	Fractured
	Low Cost	10°15’14’’N		2	31.219	23.3	- Weathered Basement		Basement
				3	131.83	–	- Fractured Basement		
19	Kurwala	10°21’1’’E	426.2	1	76.8	5.3	- Top Soil Sand	A	Fractured
		10°14’17’’N		2	120.4	8.4	- Weathered Basement		Basement
				3	436.3	-	- Fresh Basement		
20	Balyari	10°19’37’’E	391.6	1	376.51	5.91	- Top Soil Sand	H	Fractured
		10°16’11’’N		2	68.385	21.9	- Weathered Basement		Basement
				3	226.1	–	- Fractured Basement		
21	Nainawa	10°19’4’’E	377.9	1	79.2	2.4	- Sandy Top Soil	QHA	Medium
		10°16’33’’N		2	15.7	5.0	- Clay Sand		Grained
				3	9.8	33.8	- Reddish brown Sand		Sandstone
				4	20.2	34.3	- Silty Sandstone		
				5	57.6	-	- Sandstone		
22	Gwaram	10°19’19’’E	388.7	1	140.2	7.3397	- Top Soil Sand	H	Fractured
	Sabuwa	10°16’19’’N		2	33.2	10.2	- Weathered Basement		Basement
				3	640.4	–	- Fractured Basement		
23	Mai’ari	10°19’56’’E	377.9	1	8.0	10	- Sandy Top Soil	QH	Fractured
		10°16’33’’N		2	41.3	11.0	- Clay Sand		Basement
				3	89.5	51.9	- Weathered Basement		
				4	47.3	-	- Fresh Basement		
24	Filu	10°12’11’’E	413.6	1	220.5	1.5	- Top Soil Clay	HA	Fractured
		10°13’16’’N		2	69.5	3.8	- Clay Sand		Basement
				3	518.4	23.7	- Fractured Basement		
				4	1152.1	-	- Fractured Basement		
25	Turiya	10°20’51’’E	373.8	1	95.5	5.1	- Laterite	Q	Fractured
		10°16’28’’N		2	273.5	11.2	- Weathered Basement		Basement
				3	150.6	-	- Fractured basement		
26	Arawa	10°20’53’’E	420.8	1	7.0	8	- Top Soil Clay	QH	Medium Grain
		10°18’51’’N		2	38.1	10.0	- Clay Sand		Sand
				3	83.7	44.7	- Silty Sand		
				4	41.2	-	- Clay		
27	Takai	10°19’58’’E	403.2	1	152.4	2.1	- Top Soil Clay	HA	Fractured
		10°15’44’’N		2	95.4	5.9	- Clay Sand		Basement
				3	334.6	29.7	- Fractured Basement		
				4	614.5	-	- Fractured Basement		
28	Wuroduwa	10°17’40’’E	414.4	1	32.9	2.1	- Top Soil Sand	KQ	Fractured
		10°15’50’’N		2	211.4	16.9	- Weathered Basement		Basement
				3	128.2	58.7	- Fractured Basement		
				4	131.7	-	- Fresh Basement		
29	Gokaru	10°18’26’’E	397	1	11.453	0.1822	- Top Soil Sand	KH	Fractured
		10°15’30’’N		2	102.5	3.9660	- Weathered Basement		Basement
				3	69.8	24.9654	- Fractured Basement		
				4	198.6	–	- Fractured Basement		
30	Tudu	10°12’26’’E	392.6	1	899.2	1.6	- Laterite	QQ	Fractured
		10°14’30’’N		2	301.7	9.6	- Weathered Basement		Basement
				3	41.1	40.3	- Fractured Basement		
				4	15.9	-	- Fractured Basement		

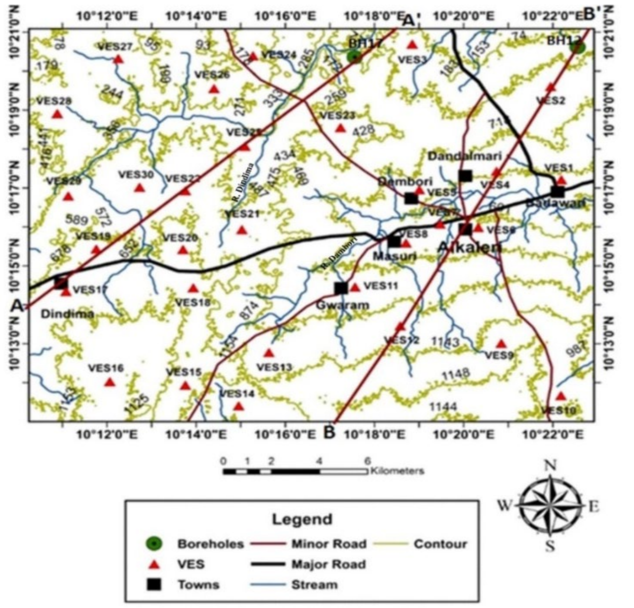

Figure 5: Map of the study area showing profile lines on VES Points and Boreholes Points

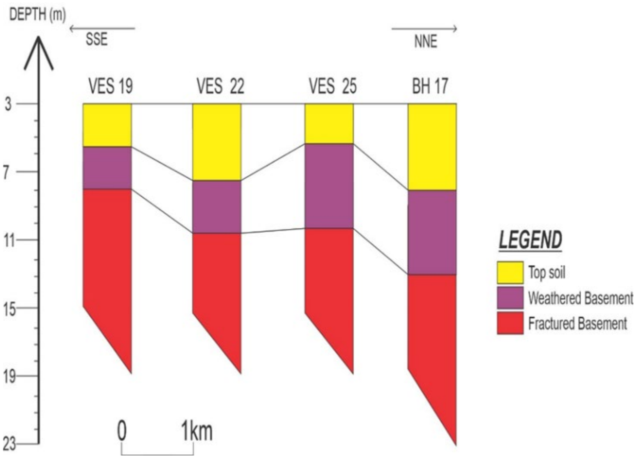

Figure 6: Correlation of geoelectric and lithologic sections along A-A[1]

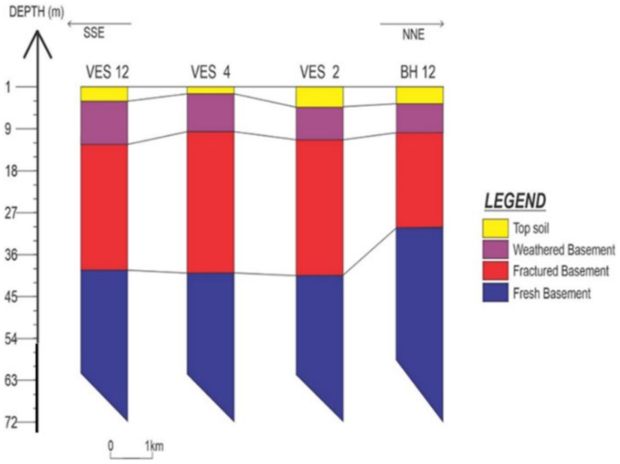

Figure 7: Correlation of geoelectric and lithologic sections along B-B[1]

3.4 Interpretation of Dar Zarrouk Parameters

Aquifer parameters such as transmissivity, hydraulic conductivity, longitudinal conductance, and transverse resistance were determined from the VES interpretation results using Dar Zarrouk Parameters (Table 2). The transverse resistance in the study area varies from 78.5 Ωm^2 to 7984.9 Ωm^2 with an average value of 2180.534 Ωm^2. Thus, indicating very low ground water development class (Ezeh 2012). Ezeh (2012) went further to state that values of transverse resistance of less than 200,000 Ωm^2 may not indicate absence of aquifer but may imply inadequate aquifer thickness or high mixed aquifer materials with finer sediments. The values of the longitudinal conductance were used to evaluate the protective capacity of the aquifer using Table 2. Values of longitudinal conductance in the study area showed in Table 2 revealed that only VES 18 point have good protective capacity, VES 3, VES 6, VES 7, VES8, VES10, VES 16, VES 20, VES 21, VES 22, VES 23 and VES 26, have Moderate Protective capacity, VES 1, VES 2, VES 4, VES 5, VES 9, VES 11, VES 12, VES 13, VES 14, VES 15, VES 17, VES 19, VES 24, VES 25, VES 27, VES 28, VES 29 and VES 30 have poor protective capacity, (Table 3). Most of the VES points in the study area have values of moderate to poor protective capacity, thus indicating that the aquifers are not protected. This is a good indication that wells located at these points are susceptible to contamination.

3.5 Transmissivity and Hydraulic Conductivity

The transmissivity of the aquiferous layer in the study area was calculated and presented in Table 4. The transmissivity values range from 8.89 m^2/day to 467.2 m^2/day, the average value being 100.3 m^2/day**.** The Variation of the transmissivity values in the study area was interpreted using the classification in table 2. It was observed that 56.67% of the VES points show Low Potentials, 43.3% show Moderate Potentials (Table 4). Transmissivity values calculated from pumping test data of the study area ranges from 1.18m^2/day to 27.67 m^2/day with average value of 11.81 m^2/day indicate Low potential (Table 4). The variation in tranmissivity values was due to inherent in geophysics. The hydraulic conductivity values of the area range from 0.9 m/day to 29.6m/day with mean value of 8.3m/day, is higher than values obtained from pumping test. The result of hydraulic conductivity calculated from the pumping test data of the study area gives values ranging from 0.34 to 3.59 m/day with an average of 1.055 m/day. The variation in hydraulic conductivity was also due to inherent in geophysics.

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Table 2: Aquifer parameters of the study area (Dar Zarrouk parameter)

S/N	Location	Resistivity (0hm-m)	Thickness (m)	Aquifer Conductivity	Longitudinal Conductance (Ω)	Transverse Resistance (Ωm²)	Hydraulic Conductivity (m/day)	Transmissivity (m²/day)
1	Unguwan Ajiya	231.9	3.7	0.0043	0.015955	858.03	2.40222	8.889
2	Gwaram	496.1	11.2	0.002015	0.002258	5556.32	1.18176	13.2358
3	Kachichiya	67.653	25.308	0.01478	0.374085	1712.162	7.5804	191.844
4	Sabongarin-Pali	301.2	10.8	0.00332	0.0358566	3252.96	1.88229	20.32873
5	U/S/Shanu	299.5	11.1	0.0033389	0.0370618	3324.45	1.892256	21.00404
6	Gunchuguni	15.7	9.5	0.06369	0.605096	149.15	29.611884	281.3129
7	Kan'iyaka	41.3	11	0.024213	0.2663439	454.3	12.012418	132.1366
8	Maimadiri	183.5	43.5	0.0054496	0.2370572	7982.25	2.988474	129.9986
9	Unguwan Kudu	654.5	12.2	0.00152788	0.0186402	7984.9	0.9125824	11.133506
10	32 Junction	67.653	25.308	0.01478131	0.3740854	1712.162	7.5803706	191.844019
11	Fanti	97.1	7.5	0.01029866	0.0772399	728.25	5.4112724	40.5845436
12	Londo	246.2	12.9	0.00406173	0.0523964	3175.98	2.2718093	29.3063409
13	CPS Alkaleri	501.9	9.1	0.0019924	0.0181311	4567.29	1.1690158	10.6380437
14	Pali	218.7	7.9	0.0045724	0.03612254	1727.73	2.53720744	20.0439387
15	GGAC Alkaleri	219.4	7.5	0.00455788	0.034184138	1645.5	2.52965537	18.9724153
16	Gagau	26.7	9	0.03745318	0.33707865	240.3	18.0444902	162.4004122
17	Tarangadi	504	10.1	0.0019841	0.02003968	5090.4	1.16447143	11.7611615
18	Federal Low Cost	31.219	23.3	0.03203177	0.74634037	727.4027	15.595462	363.37426
19	Kurwala	120.4	8.4	0.00830565	0.06976744	1011.36	4.42757893	37.191663
20	Balyari	68.385	21.9	0.014623089	0.32024566	1497.6315	7.50465249	164.3518896
21	Nainawa	15.7	5	0.063694267	0.31847134	78.5	29.6118844	148.059422
22	Gwaram Sabuwa	33.2	10.2	0.030120481	0.30722891	338.64	14.72562983	150.2014243
23	Mai'ari	41.3	11	0.024213075	0.26634383	454.3	12.01241786	132.1365964
24	Filu	69.5	3.8	0.014388489	0.054676258	264.1	7.392280409	28.09066556
25	Turiya	273.5	11.2	0.003656307	0.040950639	3063.2	2.059539904	23.06684693
26	Arawa	38.1	10	0.026246719	0.26246719	381	12.95098716	129.5098716
27	Takai	95.4	5.9	0.010482181	0.061844864	562.86	5.501169258	32.45689862
28	Wuroduwa	211.4	16.9	0.004730368	0.079943236	3572.66	27.64569823	467.2123
29	Gokaru	102.5	3.96	0.009756097	0.038634146	405.9	5.144860154	20.37364621
30	Tudu	301.7	9.6	0.003314551	0.031819688	2896.32	1.879381213	18.04205964
	Minimum	15.7	3.7	0.0015279	0.002258	78.5	0.9125824	8.889
	Maximum	654.5	43.5	0.0636943	0.74634037	7984.9	29.6118844	467.2123
	Average	185.8437	12.29253	0.01493	0.1713455	2180.534	8.25413729	100.3167198

Table 3: Protective capacity rating of aquifers in the study area

S/N	Location	Longitudinal Conductance (Ω)	Protective Capacity Rating (Oladapo and Akintorinwa, 2007)
1	Unguwan Ajiya	0.015955	Poor
2	Gwaram	0.002258	Poor
3	Kachichiya	0.374085	Moderate
4	Sabongarin-Pali	0.0358566	Poor
5	U/S/Shanu	0.0370618	Poor
6	Gunchuguni	0.605096	Moderate
7	Kan'iyaka	0.2663439	Moderate
8	Maimadiri	0.2370572	Moderate
9	Unguwan Kudu	0.0186402	Poor
10	32 Junction	0.3740854	Moderate
11	Fanti	0.0772399	Poor
12	Londo	0.0523964	Poor
13	CPS Alkaleri	0.0181311	Poor
14	Pali	0.03612254	Poor
15	GGAC Alkaleri	0.034184138	Poor
16	Gagau	0.33707865	Moderate
17	Tarangadi	0.02003968	Poor
18	Federal Low Cost	0.74634037	Good
19	Kurwala	0.06976744	Poor
20	Balyari	0.32024566	Moderate
21	Nainawa	0.31847134	Moderate
22	Gwaram Sabuwa	0.30722891	Moderate
23	Mai'ari	0.26634383	Moderate
24	Filu	0.054676258	Poor
25	Turiya	0.040950639	Poor
26	Arawa	0.26246719	Moderate
27	Takai	0.061844864	Poor
28	Wuroduwa	0.079943236	Poor
29	Gokaru	0.038634146	Poor
30	Tudu	0.031819688	Poor

Table 4: Inferred aquifer potential rating using transmissivity values

S/N	VES Locations	Transmissivity (m^2/day)	Aquifer Potentials
1	Unguwan Ajiya	8.889	Low potential
2	Gwaram	13.2358	Low potential
3	Kachichiya	191.844	Moderate potential
4	Sabongarin-Pali	20.32873	Low potential
5	U/S/Shanu	21.00404	Low potential
6	Gunchuguni	281.3129	Moderate potential
7	Kan'iyaka	132.1366	Moderate potential
8	Maimadiri	129.9986	Moderate potential
9	Unguwan Kudu	11.133506	Low potential
10	32 Junction	191.844019	Moderate potential
11	Fanti	40.5845436	Low potential
12	Londo	29.3063409	Low potential
13	CPS Alkaleri	10.6380437	Low potential
14	Pali	20.0439387	Low potential
15	GGAC Alkaleri	18.9724153	Low potential
16	Gagau	162.4004122	Moderate potential
17	Tarangadi	11.7611615	Low potential
18	Federal Low Cost	363.37426	Moderate potential
19	Kurwala	37.191663	Low potential
20	Balyari	164.3518896	Moderate potential
21	Nainawa	148.059422	Moderate potential
22	Gwaram Sabuwa	150.2014243	Moderate potential
23	Mai'ari	132.1365964	Moderate potential
24	Filu	28.09066556	Low potential
25	Turiya	23.06684693	Low potential
26	Arawa	129.5098716	Moderate potential
27	Takai	32.45689862	Low potential
28	Wuroduwa	467.2123	Moderate potential
29	Gokaru	20.37364621	Low potential
30	Tudu	18.04205964	Low potential

3.5 Transmissivity and Hydraulic Conductivity

The transmissivity of the aquiferous layer in the study area was calculated and presented in Table 4. The transmissivity values range from 8.89 m^2/day to 467.2 m^2/day, the average value being 100.3 m^2/day**.** The Variation of the transmissivity values in the study area was interpreted using the classification in table 2. It was observed that 56.67% of the VES points show Low Potentials, 43.3% show Moderate Potentials (Table 4). Transmissivity values calculated from pumping test data of the study area ranges from 1.18m^2/day to 27.67 m^2/day with average value of 11.81 m^2/day indicate Low potential (Table 4). The variation in tranmissivity values was due to inherent in geophysics. The hydraulic conductivity values of the area range from 0.9 m/day to 29.6m/day with mean value of 8.3m/day, is higher than values obtained from pumping test. The result of hydraulic conductivity calculated from the pumping test data of the study area gives values ranging from 0.34 to 3.59 m/day with an average of 1.055 m/day. The variation in hydraulic conductivity was also due to inherent in geophysics.

4. CONCLUSION

Groundwater potentials investigation using ABEM SAS 400C terrameter was successfully carried out in sedimentary terrain of Alkaleri and Environs. That study area is underlain by the Precambrian Basement Complex rocks (Migmatite gneiss, Hornblende Granite, and Bauchite) and Kerri-Kerri Formation. The result revealed that the major aquifers were weathered/fractured basement aquifer types and semi-confined aquifers in the eastern part of the study area. Aquifer characteristics revealed that transmissivity and hydraulic conductivity showed low potential.

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