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Full Length Research Paper

Hydro-geophysical study of michika and environs, northeast Nigeria

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Thirty-five Schlumberger vertical electrical soundings (VES) of maximum electrode spread of AB/2 100 m were carried out in Michika and its environs to study the distribution of groundwater and the aquifer systems. Two distinctive curve types; H and KA were identified. The H- type curves account for 97.14% while the remaining 2.86 are KA curve type. The lithologic sequences to be penetrated during drilling of boreholes in the area were deduced from the analysis and interpretation of the resistivity data. Three main geo-electrostratigraphic layers were obtained from the analysis of the resistivity data, with average thicknesses of 2.28 m for the first layer; 22.56 m for the second layer. The mean resistivity values obtained are 551 ohm-m, 109 ohm-m, and 3131.78 ohm-m; and these represent top soil/laterite, weathered/fractured granite and fresh basement, respectively. Based on the resistivity data analysis and interpretation the possible locations were delineated for productive boreholes of depths between 2.58-53.62 m were drilled. The water quality analysis revealed the predominance of moderately acidic water with pH value of 4.7 to slightly alkali water with pH value of 7.9 indicating water that is soft and slightly hard with low concentration of dissolved chemical constituents. The results also indicate that the water is tasteless and is suitable for domestic purposes and well as industrial and agricultural except for few cases where high concentration of nitrates (NO_2, NO_3), iron (Fe) and magnesium were obtained.

Key words: Michika and its environs, geology, resistivity data interpretation and hydrogeology.

INTRODUCTION

The area falls within the basement complex of the north-east and covers about 188.5 km^2 and lies within longitudes of 13°19'E to 13°25'E and latitudes of 10°32'N to 10°41'N (Figure 1). Detailed geo-electrical study in Michika and its environs was carried out to delineate the resistivities and thicknesses of the subsurface layers and their hydro-geological implication. The area is bounded to the east by Republic of Cameroon, to the south by Mubi local government area of Adamawa State, to the west by Askira Uba local government area of Borno State and to the north by Madagali local government area. The area is hilly in the eastern part and relatively flat in the west, and despite the hilly nature of some parts of the area, there are good road networks, foot-paths and tracks. The objective of this study is to locate water bearing subsurface geological structures utilizing resistivity method and the water quality assessment for domestic use. The area is characterized by two climatic seasonal patterns; the wet seasons are between the months of May-October, while the dry seasons are between the months of November-April. The average annual rainfall is about 753.5 mm. Generally in the months of August and July the heaviest and also the greatest number of raining days are recorded.

During the raining season, the relative humidity of the study area is high, but with the onset of the dry season and tropical continental air mass with dry dust laden north-east trade wind, with the relative humidity falling to about 15% or less are experienced (Daral, 1991).

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Abbreviations: VES, Vertical electrical soundings; **DC**, direct current; **AC**, alternate current; **TDS**, total dissolved solid; **NO_2, NO_3** nitrates.

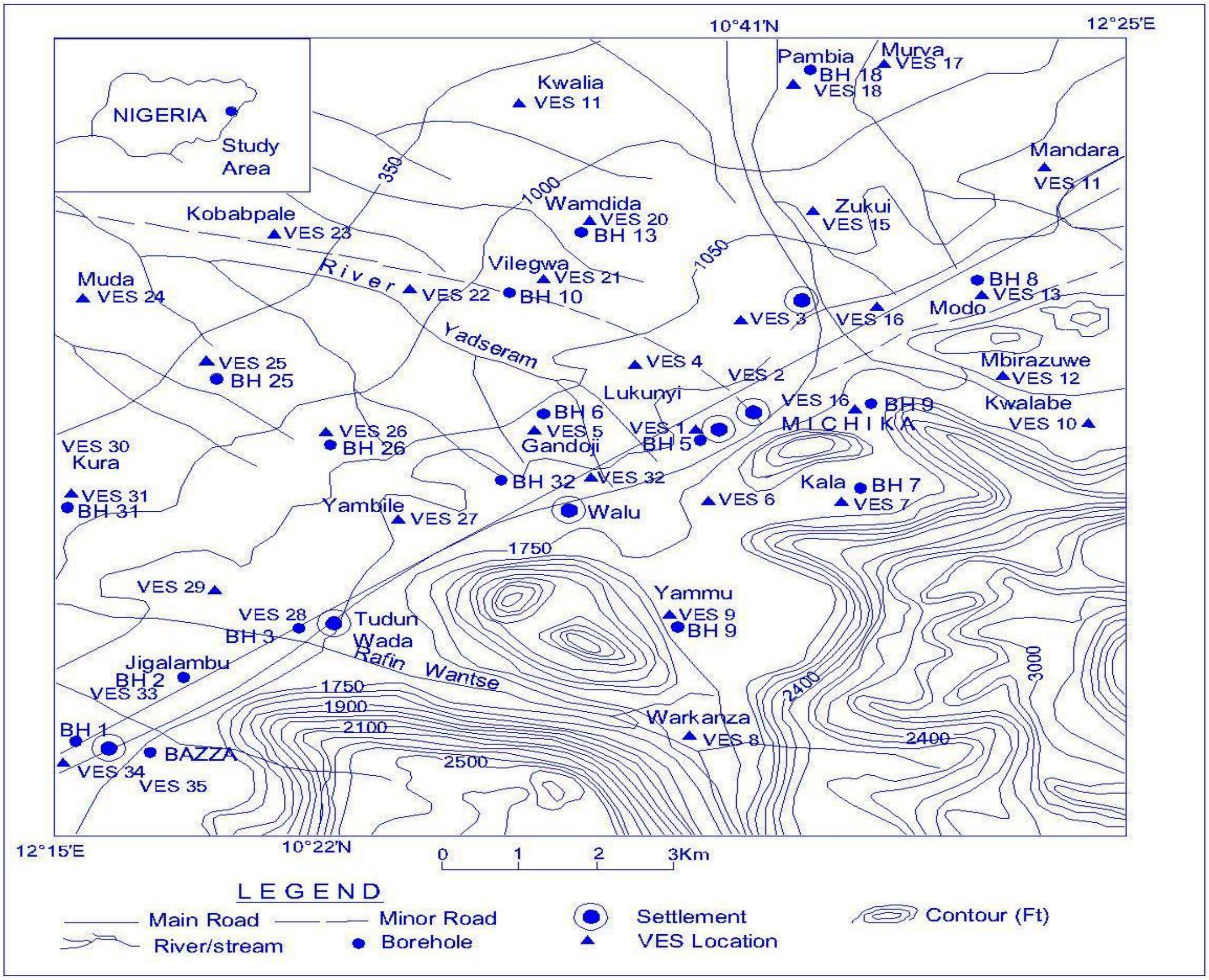

Figure 1. Topographic map of the study area (NGS, 1970).

Temperatures in the study area are extreme; both the diurnal and annual ranges of temperature are wide. Temperatures during this period range from 20 - 24°C, while at night, temperatures could be as low as 10°C at higher altitudes. Months of March to June experience increasing temperatures as the rainy season set in the daily maximum temperature may exceed 46°C. The coldest night of the year occur in the months of December and January during which air is often hazy and visibility is poor due to fine dust particles in the air (Harmattan). The study area is flat land with patches of granitic outcrops except in the in the south-eastern part of the study area where the elevation of the mountains attain over 2500 feet Figure 1. There are many rivers that originate from the mountains and generally flow towards west and northwest of the study area. Some of the rivers include River Rafin Wantse, Yedseram, and Rafin Nanda. The rocks aid in the formation of dendritic pattern of drainage network. The plain soils are alternating bands of light gravel and dark loamy to clay soils (Daral, 1991). The valleys that drained the rivers have alluvial flood plains comprising mainly of coarse quartzitic materials.

The area is underlain by crystalline basement complex, where the occurrence of groundwater is due largely to the development of secondary porosity and permeability by weathering and/or fracturing of the parent rocks. Acworth (1987), Olorunfemi and Fasuyi (1993), Edet and Okereke (1997), Nur and Ayuni (2004), Nur and Kujir (2006), Olasehinde (1989) and Olayinka (1996) have utilized resistivity methods as a tool for groundwater exploration in basement areas. Experience throughout the world has shown that the rate of failure of boreholes is usually highest in the basement complex terrain. Geophysical surveys of the subsurface for aquifers can be very important in the basement complex where groundwater occurrence is erratic.

The vertical electrical soundings (VES) method adopted is considered suitable for the subsurface investi-

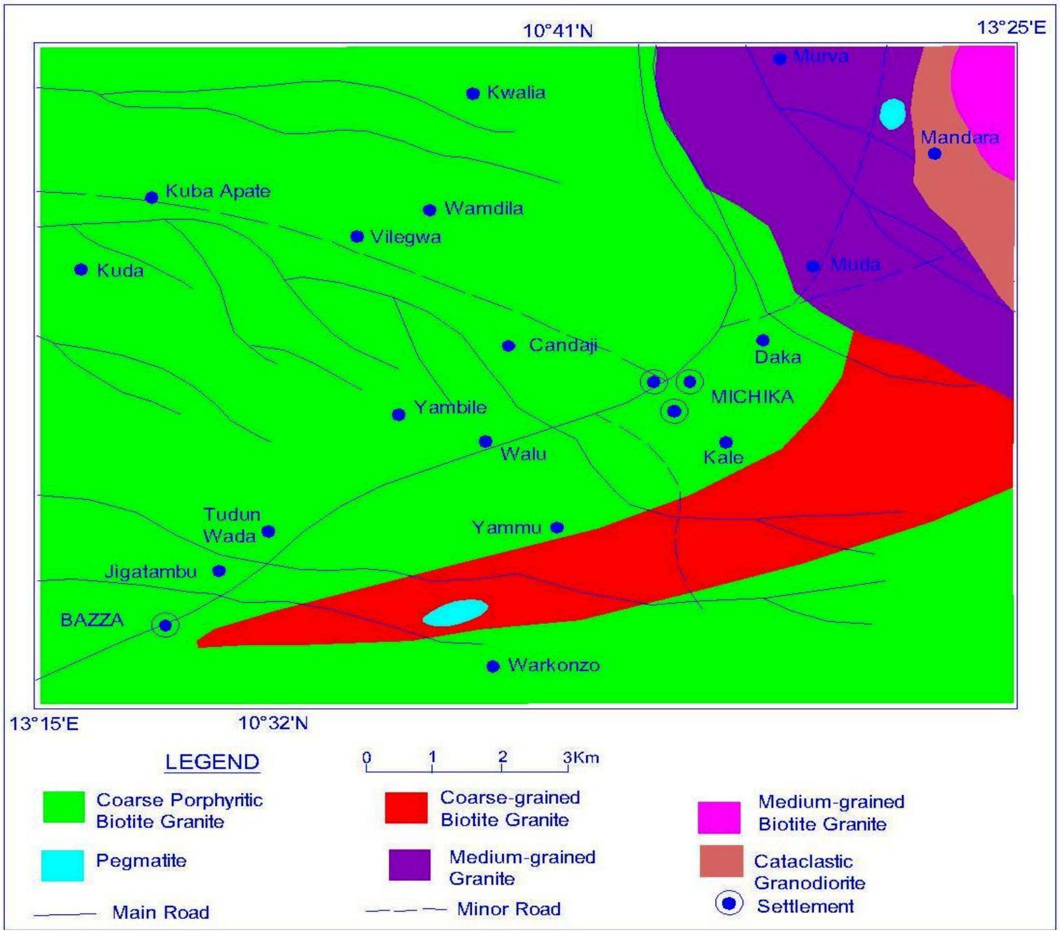

Figure 2. Geological map of the study area (after Adamu, 1991).

gation of geologic environments in basement areas. Abrupt lateral changes in the lithology and electrical properties brought about by steeply dipping beds, fracture and fault zones or highly variable thickness of weathered bed, rock materials can make interpretation of VES admittedly very difficult in this type of geological setting. Therefore the ability of the layer to conduct electricity depends largely on the type and nature of the materials within the subsurface, thus most rocks conduct electricity by electrolytic rather than electronic processes. It therefore follows that porosity is the major control of resistivity of rocks, and that resistivities generally increase as porosity decreases. This work therefore seeks to address among other things the shortages of drinking water in Michika and its environs by means of identifying suitable locations for borehole drilling.

GEOLOGY AND HYDROGEOLOGY OF THE AREA

The area is located within the eastern province of the basement complex of north-eastern Nigeria, and most rocks belong to the older granites of the Pan African Orogeny. The granitic rocks have undergone complete weathering leading to unconsolidated weathered overburden consisting of sands, clays and laterite. According to Carter et al. (1963), the basement complex of the eastern province is divided into the Mandara mountain, Alantika mountain, Shebshi mountain and the Adamawa Massif. Islam et al. (1989) showed that Mylonite occupies a narrow shear zone trending north-south in Liga, Disa and Limakara which are located in the northern part. However, the southern part of the area is predominantly occupied by granites ranging from fine-coarse grained, pegmatite's, granodiorites and biotite granite (Figure 2). At Kwalia, Michika, Kura, Watu, Jigalambu and Bazza areas, granites covers these places extensively. There are also thick deposits of alluvium as exposed along a stream channel cutting through the sediments (Adamu, 1991).

Coarse porphyritic biotite granite is predominantly scattered as small outcrops in the Northwest, western and southern part of the study area. The essential minerals found in these rocks are feldspar, quartz and biotite while associated accessory minerals include iron-oxide and sphene. The medium grained granite occurs at the eastern part of the study area around Moda as intrusive bodies characterized by numerous bodies of mafic minerals, veins of quartz and pegmatites. Fine grained granite occurs as massive equip-granular with the mineral components found in them as quartz, biotite (Adamu, 1991). These rocks are located at the top right corner of the study area (Figure 2). Cataclastic granodiorites is a massive dark grey or light black coloured plutonic rock with patches of feldspar and quartz magacryst are found in the northeast and southern part of the study area. The plain and along the river banks there are gravels, coarse sands, loamy and clay soils with the grain size of the soil decreasing with increasing of the distance from the mountains/hills. The soil of the hilly areas and its immediate vicinity are coarse, stony and while those of the plains or flat area are alternating bands of light gravel with dark, medium texture sandy and loamy soil (Ray, 1991).

Groundwater in general originate as surface water, but their occurrence and distribution are controlled by geologic factors such as lithology, texture of the rock and climatic factors such as rainfall. Sources of surface water supply to the study area are River Yedseram and its major tributaries; and it is the only perennial river around the area and takes it source from the mountains around the southern part, and flow from the south around Bazza towards the north.

DATA COLLECTION ANALYSIS

Thirty-five Schlumberger VES were carried out using ABEM SAS 1000 Terrameter and a current of 12 volts universal direct current/alternate current (DC/AC) frequency of 5 HZ. The field work was carried out in the month of May 2006. The apparent resistivity values obtained from the field indicated three layers earth model. The two distinctive curve types identified in the study area were H and KA type.

The apparent resistivities obtained from the fieldwork were plotted on a log-log graph paper; partial curve matching technique was used in the initial stage of the analysis to obtain the resistivities and thicknesses, which were used as the initial input into a computer program for modelling. Details of the model parameters and the mathematical formulae used can be obtained in Mbonu et al. (1991) and Nur et al. (2001). During the analysis, existing borehole information was incorporated and results obtained are summarized and presented in Table 1, while Figures 3 and 4 show contoured maps of AB/2= 10 and 50, respectively.

To understand better the geo-electrostratographic characteristics of the subsurface profile AA' was traced and presented in Figure 5. From the available data of the thirteen boreholes in the study area the groundwater flow direction was established and presented in Figure 6.

The following methods were used in analyzing the water samples. The thermometer was used for measuring the temperature of the water at site, digital pH meter which was used for measuring the pH value. The water samples were taken freshly from the boreholes and the sensitive end of the meter is dipped into the water, holding it until the reading is stable, the pH value is then read. Other analytical tools include the total dissolved solid (TDS) meter, where the sensitive end of the probe is dipped into the water sample and the TDS value is read directly. The conductivity meter was used for the measurement of the conductivity of the water sample, while the DR 2400 Spectrophotometer was used in the analysis of the elements. The result of the analysis of the water samples collected from the thirteen boreholes in the area is presented in Table 2.

DISCUSSION OF RESULT

The study area is characterized by lower resistivity values which could be attributed to clayed materials, unconsolidated weathered overburden and highly weathered/fractured basement. To understand the subsurface resistivity values corresponding to AB/2 = 10 m and AB/2 = 50 m were contoured (Figures 3 and 4). In Figure 3, five distinctive anomalies were identified at the north, northeast, south and south western part of the area. The anomalous zone at the northern part of the area depict a resistivity value of 300 Ohms-m that decreases outward to a lower resistivity value of 100 Ohms-m. This anomaly can be seen at Kwalia, Wamdida, Vilegwa and kopable areas, respectively and measures 10.4 km in length and 3.6 km in width while trending in north-north west direction. The second anomaly which covers the eastern part of the area can be observed at Daka, Kafa, Kwatabe, Mbirazuwe and Moda. Resistivity values here ranges between 100 Ohms-m to as high as 900 Ohms-m at Kwatabe. The anomaly measures 6.2 km in length and 6.1 km in width and trend east-southwest. The third anomaly which covers the southern part of the area is 6.5 km in length and 4.9 km in width with resistivity values of 600 Ohms-m at Wakanza that decreases outward to 100 Ohms-m around Yammu. This anomaly has trend north-south. Another anomalous zone can be observed around Bazza, Jigalambu, Tudun Wada and Yambile areas respectively. This anomaly trends northeast-southwest and measures 9.5 km in length and 1.7 km in width, the resistivity values are between 200 Ohms-m to 100 Ohms-m. Other areas exhibit lower resistivity values and can be readily seen in Figure 3.

In Figure 4, six anomalous zones were observed. The first anomaly which trend north-south and covers Kopable, Kwalia, Wamdida and Vilegwa areas, respectively; the resistivity values range between 500 Ohm-m at Kwalia to as lower as 100 Ohm-m around Wamdida

Table 1. Summary of results from computer modeling for the 35 VES in the area.

Location	Thickness of layers (meters)		Resistivity of layers (Ohms-meter)			Layer resistance (Ohms)		Long. conductance (Siemens)		Elevations (meters)			Fitting error (%)
	H1	H2	P1	P2	P3	R1	R2	∂1	∂2	E1	E2	E3	
VES 1	1.43	52.86	582.7	46.08	5485.	835.1	2436.	0.00246	1.14	-1.43	-54.29	-54.29	1.23
VES 2	1.64	15.40	415	46.99	659.1	682.9	723.9	0.00396	0.327	-1.64	-17.05	-17.05	3.34
VES 3	1.00	10.41	190.7	21.86	513.8	191.2	227.7	0.00526	0.476	-1.00	-11.41	-11.41	2.93
VES 4	1.60	30.27	842.6	83.67	1290.	1351.4	2532.	0.00190	0.361	-1.60	-31.87	-31.87	2.63
VES 5	1.46	53.62	214.6	78.55	1641.	314.4	4212.	0.00682	0.682	-1.46	-55.08	-55.08	2.78
VES 6	1.66	9.63	332.9	48.36	2247.	555.4	465.9	0.00501	0.199	-1.66	-11.30	-11.30	2.21
VES 7	0.59	8.69	455.2	67.84	1154.	272.6	589.9	0.00132	0.012	-0.598	-9.29	-9.29	0.99
VES 8	0.76	18.72	371.5	108.1	1559.	282.7	2024.	0.00205	0.173	-0.761	-19.48	-19.48	2.57
VES 9	6.37	4.50	822.3	238.1	1721.	5240.6	1072.	0.00775	0.018	-6.37	-10.87	-10.48	1.42
VES 10	7.05	19.00	1247.8	208.5	1250.	8799	3963.	0.00565	0.091	-7.05	-26.05	-26.05	2.76
VES 11	2.11	10.83	349.7	167.5	504.9	738.8	1815	0.00604	0.064	-2.11	-12.94	-12.94	1.83
VES 12	1.89	5.30	511	174.3	2498.	967.4	925.1	0.00370	0.030	-1.89	-7.20	-7.20	1.43
VES 13	0.98	8.27	363.5	160.6	1430.	357.4	1329	0.00270	0.051	-0.983	-9.25	-9.25	1.76
VES 14	2.56	17.34	789.7	96.14	1437.	2021.8	1667.	0.00324	0.180	-2.56	-19.90	-19.90	2.66
VES 15	5.59	32.77	411.8	60.53	9241	2305.5	1984	0.0135	0.541	-5.59	-38.37	-38.37	3.64
VES 16	3.27	23.61	942.3	174.1	2475	3087.7	4114.	0.00348	0.135	-3.27	-26.89	-26.89	1.65
VES 17	1.55	32.00	1262.3	204.2	1349.	1963.2	6536.	0.00123	0.156	-1.55	-33.55	-33.55	2.78
VES 18	1.82	43.00	514.6	135	9388	940.7	5805	0.00355	0.318	-1.82	-44.82	-44.82	1.94
VES 19	2.12	17.11	644	319.3	844.2	1407.7	5465.	0.00319	0.053	-2.12	-19.23	-19.23	0.94
VES 20	1.98	18.00	975.5	72.67	2135.	1931.6	1308.	0.00203	0.247	-1.98	-19.98	-19.98	1.42
VES 21	1.99	33.92	556.2	153.1	2465.	1109	5195.	0.00358	0.221	-1.99	-35.91	-35.91	1.23
VES 22	1.31	45.00	443.5	216.5	3973.	582.1	9744.	0.00296	0.207	-1.31	-46.31	-46.31	1.06
VES 23	4.23	14.81	406.9	156.3	1438	1722.4	2317	0.0104	0.094	-4.23	-19.05	-19.05	1.52
VES 24	1.69	16.92	715.1	83.76	2200.	1209.4	1418	0.00236	0.202	-1.69	-18.61	-18.61	2.56
VES 25	3.35	18.15	192.2	117.3	8770.	645.5	8585.	0.0174	0.623	-3.35	-20.50	-20.50	1.38
VES 26	2.46	15.34	437.7	52.44	1332.	1078.8	804.8	0.00563	0.292	-2.46	-17.81	-17.81	2.48
VES 27	3.97	36.67	350.5	49.05	4846	1392.9	1799.	0.0113	0.747	-3.97	-40.65	-40.65	4.47
VES 28	1.03	41.00	525.6	61.10	4018.	544.7	2505.	0.00197	0.671	-1.03	-42.04	-42.04	2.16
VES 29	1.13	27.12	505.3	83.43	16898	571	2263.	0.00224	0.325	-1.13	-28.25	-28.25	2.30
VES 30	2.04	2.58	473.6	21.72	778.4	969.4	56.13	0.00432	0.118	-2.04	-4.63	-4.63	2.09
VES 31	1.31	19.88	627.9	19.60	2449.	823.4	389.7	0.00209	1.01	-1.31	-21.19	-21.19	2.65
VES 32	1.64	24.09	475.2	32.74	3358.	781.2	788.8	0.00346	0.735	-1.64	-25.73	-25.73	4.12
VES 33	2.78	17.38	467	177.4	1476.	1302.3	2041.	0.00597	0.148	-2.78	-20.17	-20.17	1.49

Table 1. Contd

VES 34	1.86	10.09	381.9	68.14	1484.	712.4	682.3	0.00488	0.146	-1.86	-11.96	-11.96	0.95
VES 35	1.59	35.50	451.5	74.13	7294.	721.3	2632.2	0.00354	0.478	-1.59	-37.10	-37.10	2.29
Mean value	2.28	22.56	550.56	109.11	3131.	1383.2	2583.	0.00476	0.322	-2.28	-24.82	-24.82	2.16

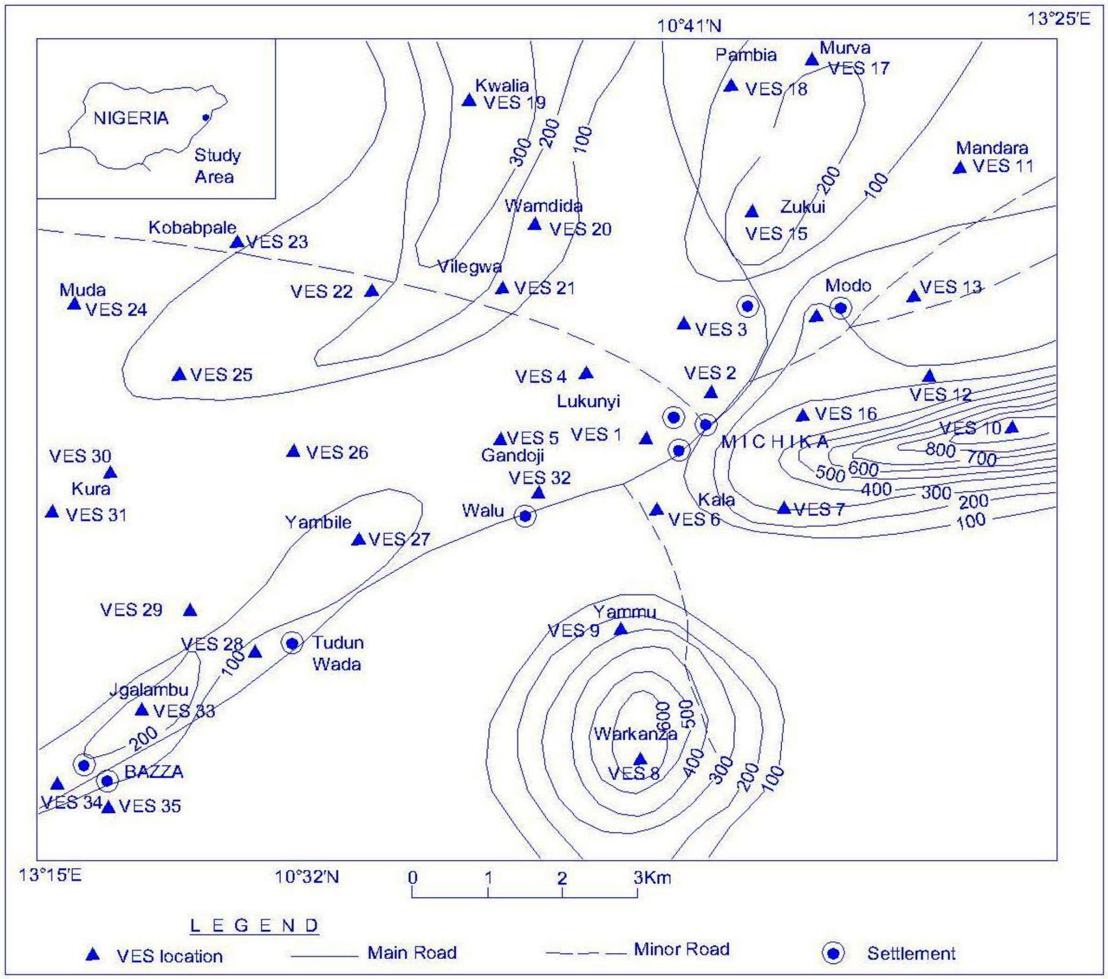

Figure 3. Contour map AB/2=10 m.

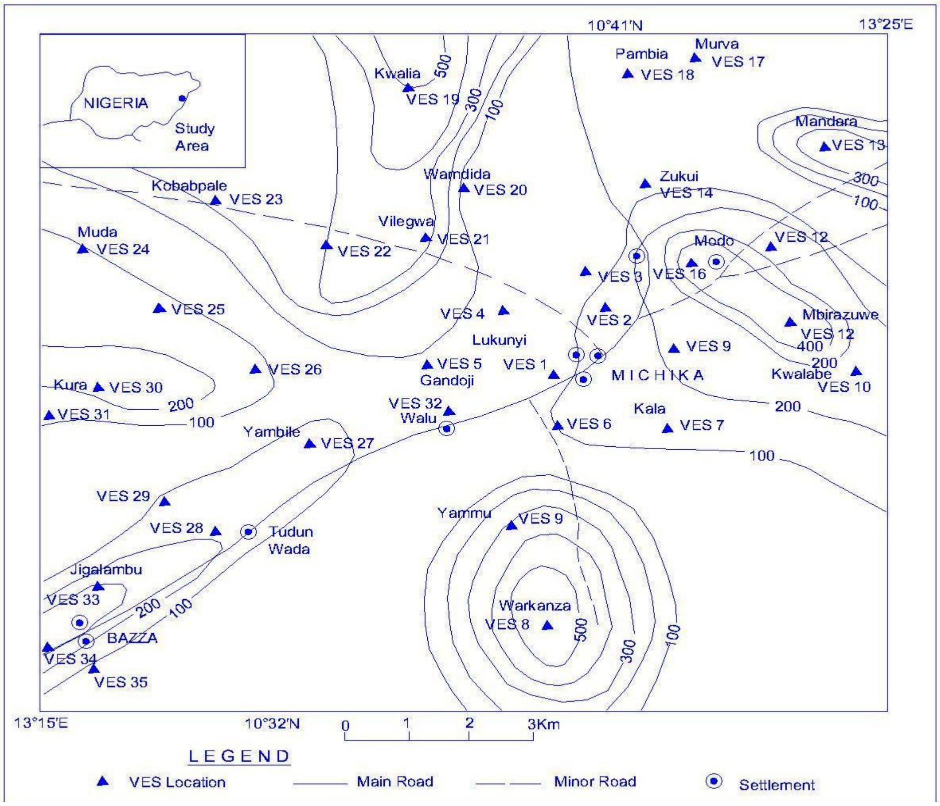

Figure 4. Contour map AB/2=50 m.

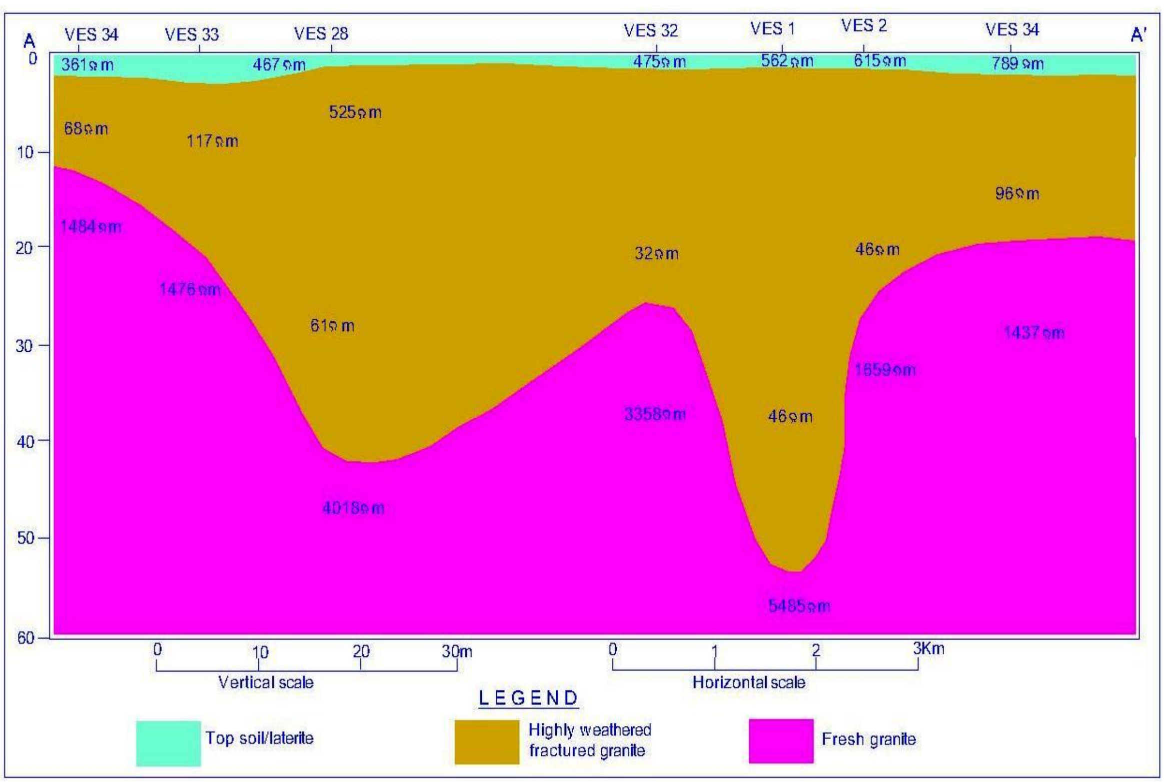

Figure 5. Geo-electrostratigraphic section AA' of the study area.

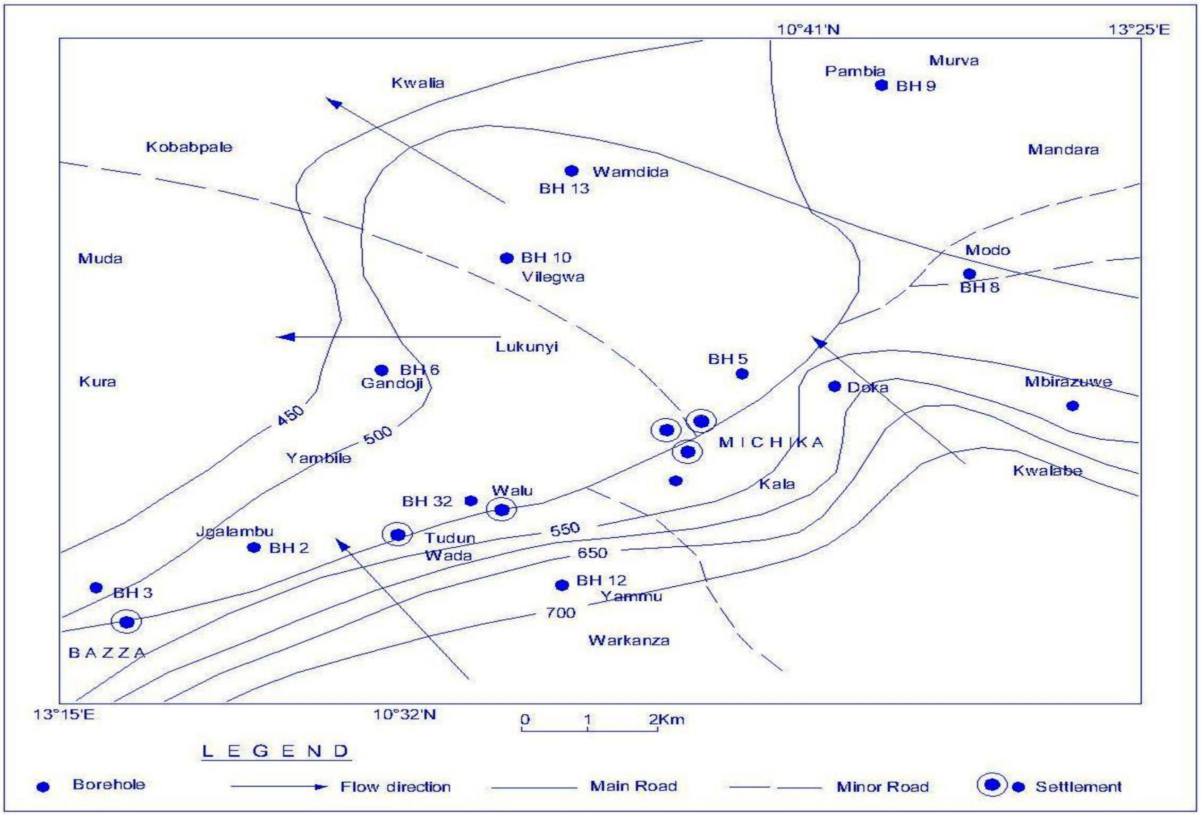

Figure 6. Groundwater flow direction.

area and has a length of 9.2 km. The second anomalous zone trends north-northeast and covers places around Moda, Daka, Kafa, Mbirazuwe, and Kwatabe, respectively. Resistivity values are in the range of 300 Ohm-m around Kwatabe to 100 Ohm-m around Kafa (Figure 4). The anomaly measures 7.9 km in length and 7.6 km in width. Other anomalies can be seen at the southern part of the area and trend in the north-south direction covering places like Yammu and Wakanza. This anomaly has a length of 6.9 km and a width of 4.8 km. Resistivity values here are increases from 100 Ohm-m to as high as 500 Ohm-m at Wakanza. The fourth anomalies can be observed at the south west and western part of the area. The south west anomaly covers Bazza, Jigalambu, Tudun Wada, and Yambile localities. This anomaly trend in the northeast-southwest direction and measures 8.9 km × 2.2 km; the resistivity values here are from 300 Ohm-m around Bazza to 100 Ohm-m at Yambile (Figure 4). Minutes anomalies can be observed at the western part of the area. This anomaly trend in the west-southeast direction and covers places around Kura and Kuda. It measures 4.5 km × 4.4 km with resistivity values that ranges between 200 Ohm-m to 100 Ohm-m. Other areas exhibit relatively low resistivity values that were not contoured.

The computer modelling revealed H and KA curve types and the overall assessment of the quantitative analysis, the average thickness for the first layer is 2.28 m with a mean resistivity value of 551 Ohm-m. These layers depict the top lateritic soil with clay mixture. The second layers have an average thickness of 22.56 m, mean resistivity value of 109 Ohm-m. These layers can be said to be the unconsolidated weathered/fractured granite. The third layer which is the last layer in sequence represents the fresh basement and has an average resistivity value of 3132 Ohm-m. The obtained result was used to infer the lithologic sequence anticipated to be penetrated while drilling at each of the VES points. The upper most layer which is the first layer has a thickness ranging between 0.59-7.05 m and a resistivity which varies between 191-1262 Ohm-m. The first layer overlies the second layer with a thickness of between 2.58-53.62 m and a resistivity in the range of between 22-319 Ohm-m. The third layer has a resistivity in the range of 505-16898 Ohm-m and underlies the second layer. The first layer is a superficial layer of top lateritic soil. The second layer is a layer of unconsolidated weathered overburden and fractured granite while the third layer is considering being the fresh basement rocks (Table 2 and Figures 3 and 4).

Profile AA' (Figure 5) passes through VES (34, 33, 28, 32, 1, 2, and 20). The first layer represent topsoil/laterite

Table 2. Result of physiochemical analysis (mg) obtained from thirteen boreholes in the study area.

S/N	Location	pH	TDS	Ca^{2+}	Mg^{2+}	Na^{2+}	K^{+}	$S0_4$	C1-	$HC0_{-3}$	$C0_3$	$N0_2$	$N0_3$	$P0_4$	F^{-}	Fe^{2+}	Mn^{2+}	NaC1
1	BAZZA (BH34)	6.7	76	8.1	3.2	0.03	38.2	8.8	3.1	63	0.00	0.00	0.00	0.21	0.04	0.37	0.03	0.00
2	JIGALAMBU (BH33)	6.3	18	1.46	1.08	31.6	22	29.8	4.5	60	1.2	1.01	3.2	0.66	0.31	0.57	0.001	0.00
3	TUDUN WADA (BH28)	6.1	36	2.83	3.96	0.05	20.0	6.00	1.4	53	0.00	0.00	0.00	0.09	0.00	0.6	0.03	0.00
4	WATU (BH32)	6.6	35	40	10.72	1.7	36.9	13	1.5	230	2.1	0.00	0.06	0.37	0.23	0.4	0.08	0.00
5	MICHIKA (BH1)	6.4	43	5.7	0.68	0.02	28.9	3.04	1.8	72	6.2	0.00	0.07	0.31	0.4	0.16	0.03	0.00
6	GANDAJI (BH5)	7.8	140	50.06	10.6	1.1	1.8	9.0	2.8	76	0.00	1.8	6.3	0.04	0.00	0.18	0.03	1.00
7	KAFA (BH7)	7.6	130	58	18	30.5	4.1	23.5	7.4	332	6.2	8.9	22.7	0.08	0.006	0.04	0.003	0.00
8	MODA (BH13)	7.3	147	60	27.8	30.02	89.2	16.03	6.8	302	5.2	7.3	30.0	8.02	0.21	0.04	0.00	1.00
9	DAKA (BH16)	6.6	120	33.5	16.5	3.8	0.06	2.4	13	110.6	1.1	0.7	15.2	0.8	0.22	0.06	0.001	0.00
10	VILAGWA (BH21)	4.7	126.5	55.7	20.09	0.07	2.10	6.3	20	255	2.1	3.7	12.00	1.00	0.03	0.045	0.00	0.00
11	PAMBULA (BH19)	6.0	36	4.3	1.32	0.14	3.00	4.00	1.35	23	0.00	0.00	0.06	0.00	0.00	0.09	0.002	0.00
12	YAMMU (BH8)	7.9	125	40	11.96	1.93	44.6	10.0	3.4	246	1.4	0.00	0.096	0.06	0.03	0.40	0.20	1.00
13	WAMDIDA (BH20)	6.3	136	32.5	27.6	6.6	3.05	19.6	37	110	2.00	9.23	10.05	1.02	0.11	0.007	0.00	0.00
	MEAN VALUE	6.6	89.88	30.16	11.81	6.19	22.61	11.65	8.0	148.6	2.15	2.51	7.67	0.97	0.122	0.228	0.03	0.23
	WHO (2006)	6.5-8.5	0-500	0-250	0-0.2	0-200	0-200	0.100	0-300	0-1000	0-120	0-0.2	0-0.5	0-10	0-1.5	0-0.3	0-0.2	2.00

with a thickness that ranges between 1.03-2.76 m and resistivity of 381-789 Ohm-m. The second layer which is highly weathered and fractured has a thickness that ranges between 10.06- 52.86 m and resistivity that ranging between 32-117 Ohm-m. The last layer which represent the fresh basement has a resistivity that ranges between 1437-5485 Ohm-m. The favourable conditions for accumulation of groundwater include thick layer of alluvium to weathered and fractured basement rock. The groundwater potentials of the area were therefore inferred from analysis and interpretation the resistivity data. The second layer which contains some alluvium deposit (weathered overburden) and weathered to fractured basement complex rock was considered as the water bearing layer in the area.

WATER QUALITY ANALYSIS

The result of the analysis of water samples collected from the thirteen boreholes presented in Table 2 indicate that the pH value ranges from 6.0 (moderately acidic) at Pambula to 7.9 (slightly acidic) at Yammu. Water samples from Bazza, Jigalambu, Tudun Wada, Watu, Michika, Daka, Vilegwa Pambua and Wamdida exhibit acidic conditions with values of 6.7-6.3. Boreholes at Gandayi, Kafa, Moda, and Yammu exhibit alkalinity with values of 7.8, 7.6, 7.3, and 7.9. The study area shows a mean pH value of 6.6 indicating an acidic solution; however, water samples from Jigalambu, Tudun Wada, Michika, Vilegwa, Pambua, and Wamdida fall short of the standard specify by W.H.O (2006). Water entering the groundwater flow system usually passes through the recharge zones which occur within the biologically active soil zone. Properties of groundwater evaluated in a physical analysis include temperature, colour, turbidity, odour, and taste. In a physical analysis of groundwater, temperature is reported in degrees Celsius. The temperatures obtained from the area are moderate ranging from 29°C at Yammu to 36°C at Wamdida. Temperature mean value obtained here is 31.5°C which is ambient and falls within the recommended standard for drinking water. The colour of water in the area ranges from 0.03 hazen unit at Watu to 2.0 hazen unit at Pambula. The average colour value as observed in the area is 0.91 hazen set value of water coloration (Table 2).

Measurement of turbidity is often based on the length of a light path through the water which just causes the image of a flame of a standard candle to disappear. Turbidity values in the area are from 0.06 in Bazza, 0.25 at Jigalambu, 0.52 at Tudun Wada, 0.15 at Watu, 0.025 at Michika, 0.05 at Gandu, 1.5 at Kafa, 0.35 at Moda, 2.2 at Daka, 0.55 at Vilagwa, 1.25 at Pambula, 3.00 at Yammu, and 1.25 at Wamdida, while the average turbidity value is 0.86 and fall within the set value (Table 2). Analysis carried out reveals that the conductivity value ranges from 27 Ohms at Jigalambu, 53.5 Ohms at Watu to 204 ohms at Wamdida, 210 Ohms at Gandaji, and 222 Ohms at Moda respectively. The mean conductively value here is 135.6 ohms which falls with the recommended limit. TDS is concentration of dissolved minerals in water and is an indication of the suitability of water for much type of uses. Total dissolved solids in the study area ranges from 18 mg/L at Jigalambu, to 147 mg/L at Moda which is moderate and falls within standard, hence the water is desirable (Table 2).

Calcium concentration in the area ranges from 1.46 mg/L at Jigalambu, to 60 mg/L at Moda. Other places that have low concentration of calcium are, Bazza (8.1 mg/L), Tudun Wada (2.83 mg/L), Michika (5.7 mg/L), and Pambua (4.3 mg/L) respectively. Magnesium has a concentration level that range from 0.68 mg/L at Michika, 1.08 mg/L at Jigalambu, 1.32 mg/L at Pambula, 3.2 mg/L at Bazza, 3.96 mg/L at Tudun Wada, to 20.09 mg/L at Vilegwa, and 27.8 mg/L at Moda respectively. Calcium and magnesium combine with bicarbonate, carbonate, sulphate, and silica to form heat-retarding, pipe clogging scale in boilers. Sodium concentration has values as low as 0.02 mg/L at Michika, 0.03 mg/L at Bazza, 0.05 mg/L at Tudun Wada, 0.07 mg/L at Vilagwa, 0.14 mg/L at Pambula, 1.1 mg/L at Gandaji, 1.7 mg/L at Watu, and 1.73 mg/L at Yammu to 30.5 Mg/L at Kafa, and 31.6 mg/L at Jigalambu, respectively (Table 2). Sodium concentration here falls within the standard set by W.H.O (2006); hence the water is permissible for consumption. In the area sulphate concentration levels ranges from 2.4 mg/L at Daka, 3.04 at Michika, 4.00 mg/L at Pambula, 6.00 mg/L at Tudun Wada to 19.6 mg/L at Wamdida, 23.5 mg/L at Kafa to 29.8 mg/L at Jigalambu. These results are within the desirable values. The general low concentration of sulphate may be due to the absence of sulphate bearing minerals such as pyrite, anhydrate, gypsum etc, within the soil zone that bounders the aquifer. Sulphate combines with calcium to form an adherent, heat retarding scale and more than 250 g/ is objectionable in water in some industries. Potassium concentration ranges from 0.06 mg/L at Daka, 1.8 mg/L at Gandaji, 2.10 mg/L at Vilegwa, 3.00 mg/L at Pambula, 3.05 mg/L at Wamdida, and 4.1 mg/L at Kafa to 20.00 mg/L at Tudun Wada, 22 mg/L at Jigalambu, 28.91 mg/L at Michika, 36.9 mg/L at Watu, 38.2 mg/L at Bazza, 44.6 mg/L at Yammu to 89.2 mg/L at Moda, respectively (Table 2). When compared to the WHO (2006) standard the concentration level of potassium in the water is low.

Chloride concentration in the area ranges from 1.35 mg/L at Pambula, 1.4 mg/L at Tudun Wada, 1.5 mg/L at Watu, 1.8 mg/L at Michika, 2.8 mg/L at Gandaji, 3.1 mg/L at Bazza, 3.4 mg/L at Yammu to 7.4 mg/L at Kafa, 13 mg/L at Daka, and 37 mg/L at Wamdida with a mean value of 8.00 mg/L. Chloride concentration values fall within WHO (2006) standard. The bicarbonate value ranges from 23 mg/L at Pambula, 53 mg/L at Tudun Wada, 60 mg/L at Jigalambu, 63 mg/L at Bazza, 72 mg/L at Michika, and 76 mg/L at Gandaji to 230 mg/L at Watu, 246 mg/L at Yammu, 255 mg/L at Vilagwa, 302 mg/L at Moda, and 332 mg/L at Kafa. The mean bicarbonate concentration value is 148 mg/L. Carbonate concentration levels ranges from 0.00 mg/L at Bazza, Tudun Wada, Gandaji, and Pambula to 1.1 mg/L at Daka, 1.2 mg/L at Jigalambu, 1.4 mg/L at Yammu, 2.00 mg/L at Wamdida, 2.1 mg/L at Watu and Vilagwa to 5.2 mg/L at Moda, and 6.2 mg/L at Michika and Kafa, respectively. The nitrate (NO_2) concentration range from 0.00 mg/L at Bazza, Tudun Wada, Watu, Michika, Pambula, and Yammu to 1.01 mg/L at Jigalambu, 0.7 mg/L at Daka, 1.8 mg/L at Gandaji, to 3.70 mg/L at Vilagwa, 7.3 mg/L at Moda, 8.9 mg/L at Kafa, and 9.23 mg/L at Wamdida with a mean concentration value of 2.51 mg/L. Nitrate (NO_2) concentration is high in some of the areas sampled when compared to (WHO, 2006) standard. Nitrate (NO_3) concentration in the study area ranges from 0.00 mg/L at Bazza, and Tudun Wada to 30.01 mg/L at Moda. NO_2 concentration here is low, except at Moda, Kafa, and Daka where high values of 30.01 mg/L, 22.7 mg/L, and 15.2 mg/L for these boreholes were recorded and this may be due to fertilizer application (nitrogen, phosphate, and potassium) to boast plant growth. Hence water from Jigalambu, Daka, Gandaji and Vilegwa should be treated before use. The phosphate (PO_4^-) concentration ranges from 0.00 mg/L at Pambula, 0.04 mg/L at Gandu, 0.06 mg/L at Yammu, 0.09 mg/L at Tudun Wada, 0.28 mg/L at Kafa, 0.21 mg/L at Bazza, and 0.31 mg/L at Michika to 1.00 mg/L at Vilagwa, 1.02 Mg/L at Wamdida, and 8.02 mg/L at Moda respectively (Table 2).

In the area, fluoride concentration ranges from 0.00 mg/L at Tudun Wada, Gandaji, and Pambua to 0.006 mg/L at Kafa, 0.03 mg/L at Vilagwa, and Yammu, 0.04 mg/L at Bazza to 0.31 mg/L at Jigalambu,0.23 mg/L at Watu to 0.4 mg/L at Michika (Table 2). However, the result falls within the permissible limit set by WHO (2006). The effect of usability of water with fluoride is that fluoride concentration of between 0.6 mg/Land 1.7 mg/L in drinking water has a beneficial effect on the structure and resistance to decay of children teeth. Fluoride in excess of 1.5 mg/L in some areas causes “mottled enamel” in children’s teeth. Fluoride in excess of 6.0 mg/L causes pronounced mottling and disfiguration of teeth. Iron concentration in the study area ranges from 0.007 mg/L at Wamdida, 0.04 mg/L at Kafa, and Moda, 0.06 mg/L and 0.09 mg/L at Daka and Pambula, 0.045 mg/L at Vilegwa, 0.16 mg/L and 0.18 mg/L at Michika and Gandaji, respectively (Table 2). However, water samples obtained from Bazza (0.37 mg/L), Jigalambu (0.57 mg/L), Tudun Wada (0.6 mg/L), Watu and Yammu (0.40 mg/L) indicate excessive presence of iron constituents. The water in these areas should be treated before use. An overall average value obtained from the analyzed water shows a value of 0.228 mg/L which is desirable. Manganese estimation from the analyzed water samples indicate that the values are within the recommended W.H.O (2006) limit with concentration ranging from 0.03 mg/L at Bazza, 0.001 mg/L at Jigalambu, and Daka, 0.08 mg/L at Watu, 0.03 mg/L at Tudun Wada, Michika and Gandaji, 0.00 mg/L at Moda, Vilagwa and Wamdida, 0.003 mg/L at Kafa, 0.002 mg/L at Pambula and 0.20 mg/L at Yammu (Table 2). Overall assessments indicate an average value of 0.03 mg/L which is permissible. Copper concentration values ranges from 0.00 mg/L at Bazza to 0.001 mg/L at Watu with an average value 0.00007 mg/L.

Total hardness results from the presence of divalent metallic cations, of which calcium and magnesium are the most abundant in groundwater. These ions react with soap to form precipitates and with certain anions present in the water to form scale. Total hardness concentration in the analyzed water samples has values ranging from 16 mg/L at Jigalambu, 27 mg/L at Bazza, 28 mg/L at Michika, 31.4 mg/L at Pambula, 32 Mg/L at Tudun Wada, 33 mg/L at Gandaji, 89 mg/L at Wamdida, 90 mg/L at Kafa, 93.5 mg/L at Yammu, 100 mg/L at Moda, 142 mg/L at Watu and 169 mg/L at Daka (Table 2). The water in the area is thus generally soft at Bazza, Jigalambu, Tudun Wada, Michika, Gandaji, and Pambula, and moderately soft at Kafa, Wamdida, Yammu, and Vilegwa, slightly hard at Watu, and moderately hard at Daka. Overall average of (74.76 mg/L) was obtained and thus, the water can be classified as moderately soft. The sodium chloride (NaCl) for the water analyzed reveals that the salinity of water from the area is generally low with values ranging from 0.00 mg/L at Bazza, Jigalambu, Tudun Wada, Michika, Watu, Kafa, Daka, Vilegwa, Pambula, and Yammu to 1.00 mg/L at Gandaji and Wamdida. The average value of 0.28 mg/L was observed which indicate that the concentration of sodium chloride falls within the permissible limit set by WHO (2006).

An overall assessment of the sampled water in the area indicate an average pH value of 6.6, a mean temperature of 31.50°C, mean colour value of 0.91 hazen unit, and an average turbidity value of 0.86 with a mean conductivity value of 135.6 ohms. This shows that the water is mostly acidic with a moderate temperature, colour and turbidity. Furthermore, the analysis reveals a mean TDS value of 89.88 mg/L, average calcium value of 30.16 mg/L, and mean magnesium value of 11.81 mg/L. Sodium has an average value of 6.19 mg/L, potassium is 22.61 mg/L, sulphate has an average value of 11.65 mg/L, while chloride has a mean value of 8.00 mg/L. further studies shows that bicarbonate has an average value of 148.6 mg/L carbonate is 2.15 mg/L, and nitrate has a mean value of 2.51 mg/L, this indicate that the water is desirable (Table 2). However, nitrate (NO_3) should be treated before use as it values falls above the standard set by WHO (2006), phosphate, fluoride, iron, manganese, and copper has averaging values of 7.67 mg/L, 0.97 mg/L, 0.122 mg/L, 0.228 mg/L, 0.03 mg/L, and 0.00007 mg/L, respectively. Total hardness and sodium chloride has average value 74.76 mg/L and 0.23 mg/L. However, the chemical compositions of the groundwater in the area indicate that apart from magnesium, nitrate (NO_2 and NO_3) iron (Fe), and total hardness in some areas, the water is generally good for various purposes. The present study indicates that the quality of groundwater is good for most purposes. This is true base on the fact that most of the analyzed chemical constituents' falls within the recommended concentration limit set by WHO (2006).

Many workers such as Mayboom (1966), Toth (1966) and Brassington (1988), among others gave six indicators of recharge and discharge zones on the basis of field observation hydro-geometric trends, topography, piezometric patterns, hydro-geochemical trends, and the use of environmental isotopes, soil and land surface features. In the study area, the topography and the piezometric patterns were used to delineate the recharge and discharge areas as well as hydraulic head. To understand the nature of groundwater flow systems the hydraulic head map of the study area was produced (Figure 6). Two groundwater flow system were recognized in the areas, and are the local flows system occurring in the hand-dug wells and the regional flows system observed in the weathered/fractured basement aquifer penetrated by boreholes. Flow is from areas of higher elevation around the Southeast to areas of lower elevation around the Northwest/west of the study area.

The groundwater flow directions in the study are is therefore largely topographically controlled.

CONCLUSIONS

Thirty-five VES were carried out in Michika and its environs of Adamawa State in order locate boreholes for portable water. Most of the curves in the study area are the H-type (97.14%) describing three earth models. The area is generally characterized by lower resistivity values. Water samples collected from thirteen selected boreholes. Resistivity values here ranges as from 50 Ohm-m to as high as 500 ohm-m as decipher from the iso-maps. Hence three distinctive geo-electric layers were identified in the study area with an average thickness that ranges from 0.59-7.05 m and resistivity values of 192-1262 ohm-m for the first layer. The second layer has thickness ranging between 2.58-53.62 m and resistivity of between 20-319 Ohm-m. The third layer is the fresh basement and has a resistivity value in the ranging from 505-16898 Ohm-m. It was therefore considered from the resistivity values that the second layer which is weathered and/or fractured basement rocks to be the aquiferous layers in the study area and was target for drilling the boreholes.

Thirteen boreholes with mean depth of 25 m were drilled in the study area. Water samples analysis revealed an average pH value of 6.6 indicating an acidic condition, mean TDS value of 89.88 mg/L, indicating that the water is desirable, average turbidity value of 0.86, and a mean concentration level of Calcium carbonate of 74.76 mg/L. The mean phosphate value is in the range of 0.00 mg/L – 0.02 mg/L while Nitrate concentration is between 0.00 mg/L at Bazza and Tudun Wada to 30.01 mg/L at Moda. This result shows that most of the dissolved chemical constituents are within the limit set by the world health organization. Hence the water quality in the study area is good for human as well as industrial and agricultural uses.

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