Geoelectrical Survey for Groundwater Potential in Song and Environs NE, Nigeria

A. Yakubu and A. Nur*

Department of Geology, Modibbo Adama University of Technology, Yola, Nigeria

Abstract: Seventeen Vertical Electrical soundings (VES) using the Schlumberger configuration with current electrode spacing of AB/2 = 80m were carried out in Song and environs of Adamawa State of Nigeria to study the groundwater potential. Sixteen VES showed a three-layer earth model; while the remaining one has four-layer earth model. The average thickness of the first layer is 2m with a mean resistivity of 75.14Ωm; representing the top soil and clay material. The second layer has an average thickness of 12.09m with a mean resistivity of 50.0Ωm. This layer is unconsolidated and highly weathered/fractured basement. The average resistivity value of the third layer is 5150Ωm and represents the fresh basement. Water samples were collected from Seven Boreholes (BH) and four Hand-Dug wells (HDW). The overall assessment of the sampled water in the area indicates an average pH value of 5.8, mean temperature of 28.96°C, an average turbidity value of 0.453NTU, and with a mean conductivity value of 159.39μs/cm. The water is mostly acidic with a moderate temperature, and turbidity. Total hardness has an average value of 98.78mg/l indicating a moderately soft water quality. All the Hand-Dug wells in the study area have high concentration of Nitrate and total Coliform count of 50.93mg/l to 67.17mg/l and 12cfu/ml to 27cfu/ml respectively. The high value can be attributed to anthropogenic activities such as chemical fertilizer application and indiscriminate dumping of house hold solid waste in the area as well as animals and human faeces. The high concentration of total coliform count was also observed in BH4 because of the shallow depth. Apart from the HDW and BH4 that are of shallow depth, the groundwater is generally good for human as well as industrial and agricultural uses.

Keywords: Geo-electrical Survey, Song and environs, groundwater potentials and water quality.

1. INTRODUCTION

The study area is located between latitude 9°48' N and 9°52' N and longitude 12°35' E and 12°39' E in Song Local Government Area of Adamawa state, within 1:50, 000 topographical sheets 176 of Zummo NW, Nigeria (Figure **1**). The area is accessible by Trunk 'A' Yola – Gombi Federal road and is about 74km north of Yola and by several foot paths and Cattle routes traversing the area. The study area has a total land area of 53.58 km^2.

The area is highly rugged and generally undulating; the lowest elevation ranges from 300m to 330m, while the highest peak lies at about 2500m above mean sea level. The area is well drained by a network of streams whose courses are controlled largely by the geologic structures. Most streams have straight channels and flow N-S, NW-SE, or NE-SW. River Song a major river in the area and flows through the central part of the area (Figure **1**).

Water is one of the most valuable natural resources that are crucial to the existence of life, and therefore, an adequate supply of safe water for maintaining life and for achieving sustainable development is the impetus for groundwater exploration and evaluation [1]. Groundwater has become immensely important for human water supply in urban and rural areas in developed and developing nations alike [2].

The use of geophysics for both groundwater resource mapping and for water quality, evaluations has increased dramatically over the years. Direct current resistivity method is a common tool for surveying of groundwater in the crystalline rocks and has been successfully employed in groundwater exploration.

The electrical properties of rocks depend on the amount of water, conducting minerals and the resistivity varies with salinity and temperature. Olorunfemi and Fasuyi (1993)[3] adopted the electrical resistivity method to investigate the geo-electrical parameters and hydro-geologic characteristics of parts of basement complex terrain of Nigeria and identified five aquifer units. Other researchers (Olayinka, 1996[4]; Edet and Okereke, 1997[5]; and Nur and Ayuni 2011[6]; and Nur and Matazu, 2011)[7] have utilized resistivity methods as a tool for groundwater exploration in basement terrain where the occurrences of groundwater is due largely to the development of secondary porosity and permeability by weathering and/or fracturing of the parent rocks.

In this study; results of the seventeen (17) vertical electrical soundings (VES) carried out in Song town and environment have assisted in understanding of the groundwater systems of the area.

*Address correspondence to this author at the Department of Geology, Modibbo Adama University of Technology, Yola, Nigeria;
E-mail: anur07@gmail.com

E-ISSN: 2409-5710/15

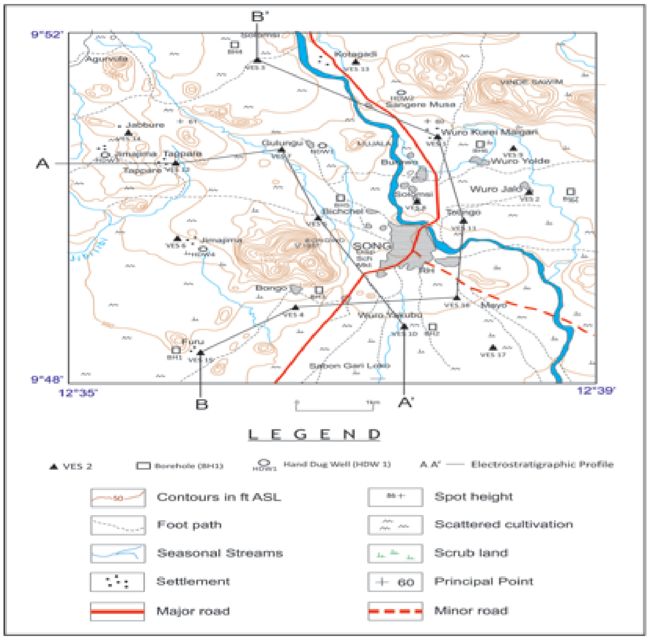

Figure 1: Topographic map of the study area. (Modified from)[14].

2. 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 overburden consisting of sands, clays and laterite. Lithologically, the major groups of rocks encountered within the area include gneisses, migmatites, and granites outcropping mainly as a range of hillocks and in some parts overlain by Tertiary alluvium. Gneisses are the dominant rocks and are highly intruded by a series of granite, pegmatite, and some basic intrusions (Figure **2**).

The gneissic rocks consist of varieties of predominantly granitic composition and textural variation. The rocks generally outcrop sandwiched between migmatites at the base of slope and granites on top. They exhibit variable color, due largely to the type and proportion of mafic or feldspar mineral content. The mafic minerals are mainly biotite and hornblende. In some sections, especially towards the base of hills, the rocks grade into migmatites gneisses. Petrologically therefore, the gneisses in Song area include; granite gneisses, transition gneisses, porphyroblastic (augen) gneisses, argentite and veined types [8].

Basalt flows are widespread in the study area and are part of the Cameroun Volcanic Line outcropping in Nigeria (Fitton, 1980, 1983)[9, 10]. The rocks are highly weathered leading to unconsolidated weathered overburden consisting of alluvium, sands, laterite, gravels and clays.

Generally, groundwater distribution in crystalline terrain varies from place to place due to the localized nature of the crystalline aquifers. The spatial variation of the aquifer parameters such as porosity, permeability, transmissivity and conductivity can be attributed to, among other causes, tectonic set-up and degree of weathering of near-surface rocks [11].

The occurrence of groundwater is limited to the

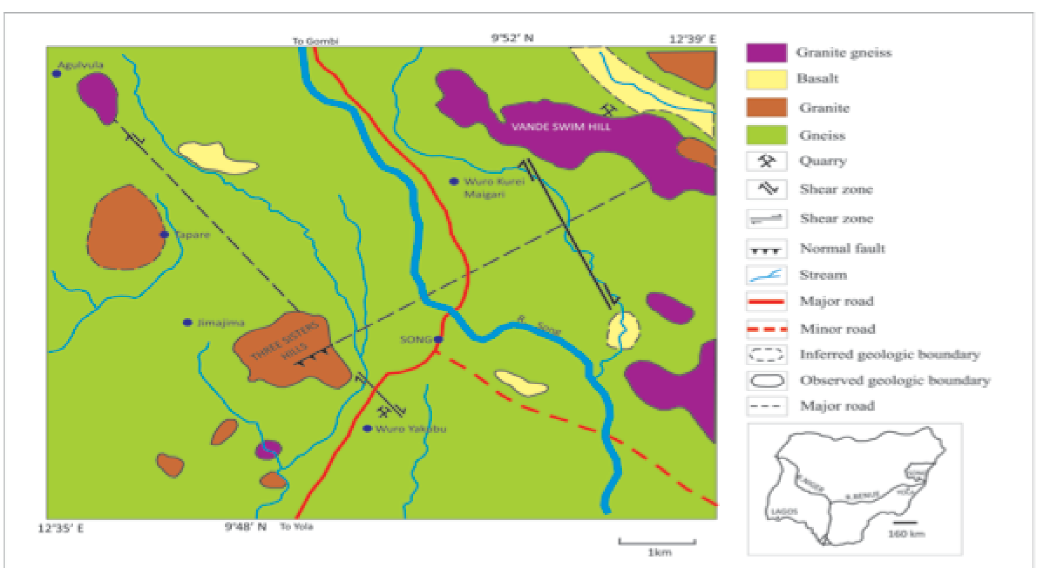

Figure 2: Geologic map of the study area (Modified from)[15].

weathered and fractured zones in the basement complex area. However, it is generally a poor source of groundwater [12]. These weathered zones must have appreciable lithologic thickness to be productive source of water. Sources of surface water supply to the study area are mainly the River Song and its major tributaries. The river takes it source from the mountains around the northern part and flow towards the southern part and water supply (Figure **1**). It is indeed essential to exploit the available groundwater resources for the communities of Song and its environs.

3. DATA COLLECTION, ANALYSIS AND RESULTS

The ABEM Signal Averaging System (SAS 1000) Terrameter was used for collection of seventeen Vertical Electrical soundings (VES) using the Schlumberger configuration with current electrode configuration was carried out in Song and environs of Adamawa State of Nigeria. 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 IX1-D software used for computer modelling. The results obtained were used as initial input into computer program, (IX1-D); where it was unsatisfactory the parameters were modified until a smooth layered model with a minimum percentage error is obtained. The computer output of the seventeen VES in the study area is presented in Table **1**. This result shows the details of the measured parameters such as thickness of layers, resistivity of layers, transverse resistance, longitudinal conductance and fitting error for all the sounded points.

4. ISO-RESISTIVITY MAPS

To understand the subsurface situation, resistivity values corresponding to AB/2 = 30m and AB/2 = 80m were contoured (Figures **3a**,**b**). In Figure **3a**, there are three anomalies, the major anomaly is located at the centre of the study area and has the highest resistivity value of 160 Ωm and covers an area of 35 km^2. The anomaly is elongated towards southeast of the study area. The second anomaly is located in the northeast of the area; the resistivity value is in the ranges between 60 Ωm to 30 Ωm and covers a Ωm area of 12 km^2 (Figure **3a**). The third anomaly which is the smallest is located in the south of the second anomaly and resistivity value is between 90 Ωm to 70 Ωm. the anomaly covers an area of 3.75 Km^2.

Figure **3b**, there are three anomalies, the major anomaly is located at the centre of the study area and has the highest resistivity value of 420 Ωm; while the lowest is 80 Ωm and covers an area of 36.5 km^2. The

Table 1: Summary of Results Obtained from the Computer Output of the 17 Ves in the Study Area

S/N	VES Number	Thickness of layers (meters)			Resistivity of layers (Ωm)				Traverse Resistance (Ωm^2)			Longitudinal Conductance (Siemens)			Elevation (meters)			Fitting error (%)
		h_1	h_2	h_3	ρ_1	ρ_2	ρ_3	ρ_4	T_1	T_2	T_3	S_1	S_2	S_3	E_1	E_2	E_3	
1	VES 1	2.79	18.30	-	13.82	17.87	5587	-	38.55	325.23	-	0.2018	1.0184	-	-2.79	-21.04	-	0.29
2	VES 2	0.83	5.86	-	146.51	19.80	177.06	-	121.6	116.02	-	0.0056	0.2959		-0.83	-6.60	-	0.29
3	VES 3	2.80	22.80	-	14.98	30.16	5822	-	41.94	687.6	-	0.1869	0.7559	-	-2.80	-25.68	-	0.25
4	VES 4	0.23	15.95	-	3.77	23.43	3455	-	0.867	373.7	-	0.0610	0.6807	-	-0.23	-16.18	-	0.53
5	VES 5	2.73	46.37	-	84.94	37.67	4165	-	231.8	1746.75	-	0.03214	1.2309	-	-2.73	-49.10	-	0.49
6	VES 6	3.01	10.30	-	161	24.3	163		482.5	269.7	-	0.0181	0.4567	-	-3.01	-13.31	-	0.73
7	VES 7	0.62	10.58	-	270.81	58.07	9988	-	167.9	614.38	-	0.0022	0.1821	-	-0.62	11.20	-	0.60
8	VES 8	3.93	3.17	-	59.94	9.75	6683	-	235.5	30.91	-	0.0655	0.3251	-	-3.93	-7.10	-	0.88
9	VES 9	1.48	17.31	-	111.71	12.54	6077	-	15.48	14.16	-	0.0582	1.4935	-	-1.48	-18.79	-	0.76
10	VES 10	1.00	6.36	-	129.87	6.77	4345	-	129.7	43.12	-	0.0077	0.9380	-	-1.00	-7.36	-	0.49
11	VES 11	4.70	1.78	-	13.99	24.02	9230	-	65.75	523.15	-	0.3359	0.9067	-	-4.70	-6.48		0.59
12	VES 12	1.95	20.89	-	92.54	28.12	5513	-	180.5	587.43	-	0.0210	0.7428	-	-1.95	-22.84	-	0.24
13	VES 13	0.63	3.59	-	126.38	6.98	9236	-	79.61	25.05	-	0.0049	0.5143		-0.63	-4.22	-	0.53
14	VES 14	3.39	4.81	-	4.43	7.08	9353	-	15.02	34.05	-	0.7652	0.6793	-	-3.39	-8.20	-	0.10
15	VES 15	2.85	1.91	-	6.73	50.63	82.27	-	19.18	96.70	-	0.4234	0.0377	-	-2.85	-4.76	-	0.58
16	VES 16	0.49	14.10	-	9.14	57.54	7671	-	4.47	811.3	-	0.0536	0.2450	-	-0.49	-14.59	-	0.28
17	VES 17	0.58	1.60	9.48	26.91	435.3	11.51	2886	15.61	696.64	109.11	0.0215	0.0036	0.8236	-0.58	-2.18	-11.66	0.40
	Mean	2.00	12.09	9.48	75.14	50.00	5150.52	2886	108.5	411.52	109.11	0.1332	0.6180	0.8236	-2.00	-12.77	-11.66	0.47

VES: Vertical Electrical Sounding.

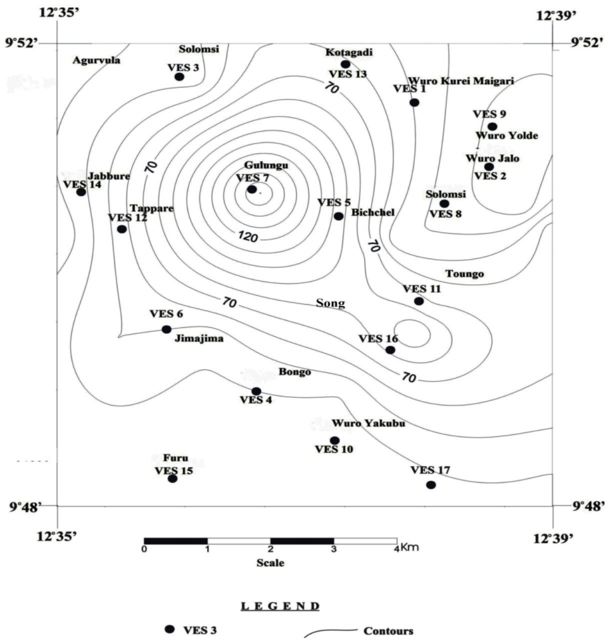

Figure 3a: Iso-resistivity map of AB/2 = 30m. (Contour Interval = 10 Ωm).

anomaly is elongated towards southeast of the study area. The second anomaly is located in the northeast of the area; the resistivity value is in the ranges between 240 Ωm to 60 Ωm and covers an area of 27.15 km^2 (Figure **3b**). The third anomaly which is the smallest is located in the south of the second anomaly and resistivity value is between 120 Ωm to 60 Ωm; the area covered the third anomaly is 6.859 Km^2.

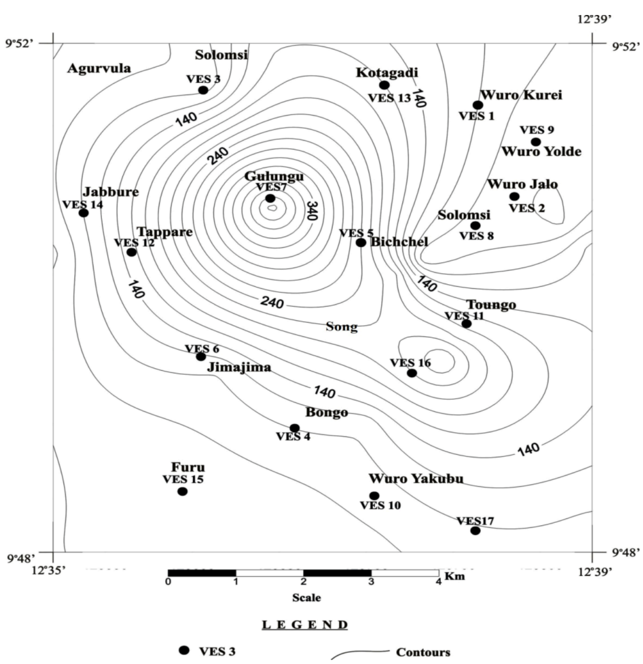

Figure 3b: Iso-resistivity map of AB/2 = 80m. (Contour interval= 20Ωm).

5. GEOELECTRO-STRATIGRAPHIC SECTIONS

Geo-electrostratigraphic sections A-A' shown in Figure **4** has three layers and is 6.9 km long. The first layer is the top soil; the layer has its lowest resistivity value of 85Ωm and highest with a resistivity value of 270Ωm. The thickness of the layer varies between 0.62m and 2.73m. The second layer is highly weathered basement; the resistivity varies between 6.77Ωm and 58 Ω; while the thickness of the second layer is from 6.36m and 46.37m. The resistivity of third layer is between 4165Ωm and 9988Ωm and represents fresh basement rocks.

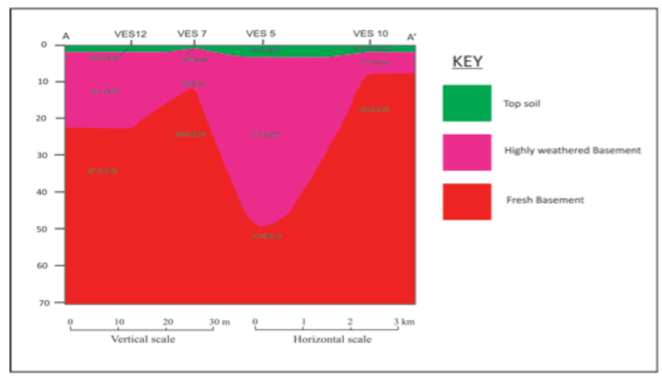

Figure 4: Geo-electro stratigraphic section of profile A-A'.

Geo-electrostratigraphic sections B-B' shown in Figure **5** has three layers; the first layer is the top soil and the resistivity of the layer is in between 3.77Ωm and 14.9Ωm; while the thickness of the layer is 0.23m and 4.7m. The second layer is highly weathered basement; the resistivity varies between 23.4Ωm and 57Ω; while the thickness of the second layer is from 1.78m and 22.8m. The resistivity of third layer is between 82Ωm and 5822Ωm and represents fresh basement rocks.

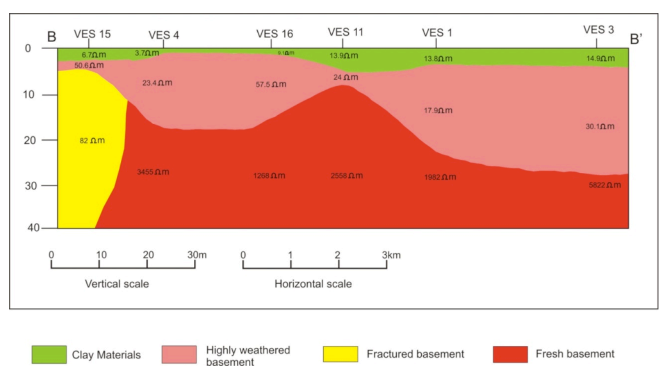

Figure 5: Geo-electrostratigraphic section of profile B-B'.

The conditions for accumulation of groundwater include thick layer of unconsolidated and highly weathered/fractured basement rock. From the qualitative and quantitative interpretations of the analyzed data the second layer is the potential aquiferous zones in the study area and should be target areas for drilling purposes. Areas with minute thickness of the second layer were identified.

The potential viable areas for groundwater development in the area include; Woro Kurei, Maigari, WuroJalo, Sangaya, Bongo, Bichchel, Jima Jima, WuroYolde, Tappare, Sabon-gariLoko and Furu respectively because of the considerable thickness of the weathered/fractured basement.

6. WATER QUALITY ANALYSIS

Eleven water samples were collected from seven boreholes and four hand dug wells in a one liter capacity properly washed plastic bottles. Boreholes were pumped for few minutes to allow steady flow before samples were collected. The results of the analysis of water samples collected from seven Boreholes and four Hand Dug Wells presented in Table **2** was used in the evaluation of groundwater water quality for drinking and domestic use in Song and environs. The total dissolve solid in the area vary from 68mg/l to 137.83mg/l; this result is permissible compared with the [13] standard of up to 500mg/l as the permissible value for drinking. Mg^{2+} concentrations vary from 30.01mg/l to 71mg/l this value is within the permissible range of 200mg/l while concentration of CO_3^- vary from 0.0mg/l to 3.40mg/l, it has a mean value of 1.43mg/l, all these values falls within the permissible range for drinking water. HCO_3^- concentration varies from 20mg/l to 466mg/l with a mean value of 374.18mg/l. The SO_4^{2-} concentration range from 16.11mg/l to 36.17mg/l with a mean value of 23.91mg/l, this low concentration of sulfate is permissible for drinking water.

The SO_4^{2-} concentration in the analyzed sample is probably derived from oxidation of sulfate in the igneous rocks. Cl^- concentration in the area also shows concentration values which vary from 27.01mg/l to 80.01mg/l, these values are permissible for drinking compared with the standard of 250mg/l. High concentrations of chloride give a salty taste to water and beverages. Taste thresholds for the chloride anion depend on the associated cations and are in the range of 200–300mg/l for sodium, potassium and calcium chloride. The probable source of chloride in the study area could be attributed to anthropogenic activities. Fe^{2+} concentration in the study area ranges from 0.006mg/l to 0.227mg/l this value is within the permissible range of 0.3mg/l. Na^+ concentration in the study area shows a very low concentration values which vary from 0.12mg/l to 4.83mg/l. K^+ concentration in the study area ranges from 5.81mg/l to 9.30mg/l with a mean value of 7.29mg/l (Table **2**).

The hydro-geochemical results in the area shows that BH4, HDW1, HDW2, HDW3 and HDW4 have anomalous NO_3^- concentration levels of 56.10mg/l, 50.93mg/l, 67.17mg/l, 62.0mg/l and 58.9mg/l respectively the concentration of NO_3^- in these wells are in excess when compared with the standard of 50mg/l for drinking water (Table **2**); this may be attributed to anthropogenic activities such as application of chemical fertilizer to boast plant growth and indiscriminate waste disposal practices.

The statistics of the physical, chemical and biological parameters for the seven boreholes indicates moderately acidic condition with a mean pH value of 6.09. Electrical Conductivity, Total Dissolved Solids, Turbidity, Total hardness and Total Coliform count reveal mean values of139.9µs/cm, 89.92, 0.354NTU, 95.21, 4cfu/ml respectively. All the analyzed cations and anions reveal ranges and mean values within the set limit [13].

Results from Hand-Dug Wells indicate an acidic condition with a mean pH value of 5.58.Electrical Conductivity, Total Dissolved Solids, Turbidity, Total hardness and Total Coliform count reveal mean values of 191µs/cm; 124.99; 0.695NTU; 106.56; 19cfu/ml respectively. The analyzed cations reveal ranges and mean values within the set limit (Table **2**). Apart from anomalous nitrate concentration in all the Hand-Dug Wells all the anions are within the set limit for human and domestic uses. Based on the mean values of the chemical parameters, the cations were in order of abundance as $Ca^{2+} > Mg^{2+} > K^+ > Na^+ > Fe^{2+} > Mn^{2+} > Cu^{2+}$ while the anions reveal order of abundance as $HCO_3^- > Cl^- > NO_3^- > SO_4^{2-} > CO_3^- > F^-$. TDS indicates concentration occurring very low which suggest that the groundwater in the area is characterized by low degree of mineralization.

The result of the quality water analysis indicates two major sources of chemical constituents interpreted as the effects of rock-water interaction, leading to silicate weathering and the effects of anthropogenic activities, such as application of chemical fertilizers, and indiscriminate dumping of house hold solid wastes in the area as well as human and animal faeces.

Table 2: Result of Physio-Chemical (mg/l) and Microbiological (cfu/ml) Analysis of Water Sample from Seven BH and Four HDW in Song and Environs

S/N	BH/ HDW	pH	EC (μs/cm)	Turb-idity (NTU)	TDS	Total Hardness	K^+	Ca^{2+}	Cu^{2+}	Na^+	Mg^{2+}	Fe^{2+}	Mn^{2+}	$C0_3^{2-}$	$HC0_3^{-2}$	F	$N0_3^{2-}$	Cl^-	$S0_4^{2-}$	Total Coliform count
1	BH1	4.88	149.8	0.075	95.67	89.010	5.81	43.41	0.000	2.73	39.88	0.183	0.007	0.00	466	0.078	36.27	42.03	17.92	2.00
2	BH2	6.0	148.1	0.015	92.18	131.72	6.93	66.83	0.000	3.00	68.13	0.006	0.00	1.00	376	0.108	39.00	37.26	27.62	7.00
3	BH3	5.88	152.0	0.150	97.19	111.71	5.97	58.99	0.000	2.17	49.68	0.062	0.009	1.40	366	0.170	27.62	43.66	19.66	2.00
4	BH4	5.53	166.0	0.009	103.11	142.11	7.17	75.21	0.012	2.11	71.00	0.017	0.001	0.00	423	0.012	56.10	30.11	28.11	5.00
5	BH5	6.32	137.3	0.117	89.66	120.92	6.17	60.03	0.000	2.10	63.17	0.071	0.002	3.40	417	0.093	22.93	47.77	21.83	4.00
6	BH6	6.93	103	0.905	68	54.62	6.10	27.06	0.002	0.12	30.01	0.016	0.004	0.00	201	0.83	16.07	27.01	24.04	0.00
7	BH7	5.91	133.0	0.930	89.38	10.220	6.00	59.00	0.014	2.20	50.06	0.121	0.023	0.00	348	0.120	32.16	47.00	16.11	6.00
8	HDW1	5.27	190.0	1.007	121.79	101.62	8.77	52.17	0.003	4.83	55.21	0.227	0.011	2.70	316	0.103	50.93	61.62	18.24	12.0
9	HDW2	4.98	198.8	0.910	127.38	127.81	9.11	59.87	0.000	4.16	61.01	0.152	0.014	3.10	400	0.570	67.17	80.01	23.01	21.0
10	HDW3	6.17	201.7	0.205	137.83	87.670	9.30	43.92	0.010	4.22	39.82	0.103	0.024	2.20	411	1.003	62.00	59.81	36.17	16.0
11	HDW4	5.93	173.6	0.660	112.98	109.17	8.93	61.03	0.001	3.90	57.82	0.137	0.021	2.00	392	0.42	58.90	71.21	30.37	27.0
	Mean	5.8	159.39	0.453	103.19	98.78	7.29	55.22	0.004	2.86	53.25	0.099	0.010	1.43	374.18	0.318	42.65	49.77	23.91	10.2
	WHO 2011	6.5-8.5	0-1000	0-5	0- 500	0-150	0-200	0-200	0- 2	0- 50	0-200	0-0.3	0-0.4	0-120	1-1000	0 – 1.5	0-50	1-250	0-100	1-10

BH: Borehole; HDW: Hand-Dug Well; EC: Electrical Conductivity; TDS: Total Dissolved Solid.

CONCLUSIONS

The information gathered from qualitative and quantitative interpretation of the seventeen Vertical Electrical Soundings in the study area revealed that most of the curves in the study area are the H-type curve constituting of 52.94% and the A-type curve which constitutes 41.17% describing three earth models with only one curve depicting a four layered earth model. The qualitative and quantitative interpretation of the seventeen vertical electrical sounding (VES) has helped in delineating the depth to the basement in the study area. The average thickness of the first layer is 2meters with a mean resistivity of 75.14Ωm; and represents the top soil and clay. The second layer has an average thickness of 12.09m with a mean resistivity of 50.0Ωm. The layer is unconsolidated and highly weathered/fractured basement. The average resistivity value of the third layer is 5150Ωm and represents the fresh basement.

The groundwater potentials of the area from analysis and interpretation of the resistivity data is therefore the second layer which is the unconsolidated and highly weathered/fractured basement rock. Results of analyses of seven boreholes and four hand dug wells revealed that the groundwater in Song and environs is moderately acidic with a mean pH value of 5.8mg/l. The overall total hardness average of 98.72mg/l was observed and thus, the water can be classified as moderately soft. The level of total dissolve solid in the groundwater is low with a mean value of 103.19mg/l indicating low mineralization in the area. All the Hand-Dug wells in the study area have high concentration of nitrate and total coliform count of 50.93mg/l to 67.17mg/l and 12cfu/ml to 27cfu/ml respectively. This high value may be attributed to anthropogenic activities such as chemical fertilizer application and indiscriminate dumping of house hold solid wastes in the area as well as animals and human faeces. The high concentration of total coliform count was also observed in BH4 because of the shallow depth. The groundwater in the study area is generally good for human as well as industrial and agricultural uses.

REFERENCES

[1] Topfer K. Editorial comments on freshwater. Our Planet 1998; 9(4): 3.

[2] Omosuyi GO. Geoelectric assessment of groundwater prospect and vulnerability of overburden aquifers at Idanre, South Western Nigeria; Ozean Journal of Applied Sciences 2010; 3(1): 19-28.

[3] Olorunfemi MO and Fasuyi, SA. Aquifer types and the geo-electric/hydrogeologic characteristics of part of the Central basement terrain of Nigeria (Niger State). J Afr Earth Sci 1993; 16: 317-403. http://dx.doi.org/10.1016/0899-5362(93)90051-Q

[4] Olayinka AI. Non uniqueness in the interpretation of bedrock resistivity from sounding curves and hydrological implications. J Nig Assoc Hydro Geol 1996; 7(1 and 2): 49-55.

[5] Edet AE and Okereke CS. Assessment of hydrogeologic conditions in basement aquifers of the Precambrian Oban massif, southeastern Nigeria. Journal of applied Geophysics 1997; 36: 195-204. http://dx.doi.org/10.1016/S0926-9851(96)00049-3

[6] Nur A and Ayuni KN. Hydro-geophysical study of Michika and environs, northeast Nigeria. International Journal of the Physical Sciences 2011; 6(34): 7816-7827.

[7] Nur A and Matazu HI. Hydrogeo-electrical Investigation of Fufore and its Environs of Adamawa State, North-eastern Nigeria. International Journal of Earth Sciences and Engineering (IJEE), Hyderabad, India 2011; 04 (5): 796-806.

[8] Adekeye JD and Ntekim EE. The geology of Song area in southern Hawal massif, N.E Nigeria. Zuma jour Pure and Applied Sci 2004; 6(2): 145-157.

[9] Fitton JG. Benue Trough and Cameroun line. A migrating Rift system in West Africa; Earth and planetary Sci. Letters 1980; 51: 473-138. http://dx.doi.org/10.1016/0012-821X(80)90261-7

[10] Fitton JG. Active versus passive continental rifting; evidence from West Africa rift system. Tectonophysics 1983; 94: 473-481. http://dx.doi.org/10.1016/0040-1951(83)90030-6

[11] Barker R, Rao TV and Thangarajan M. Delineation of contaminant zone through electrical imaging technique. Curr Sci 2001; 81(3): 277-283.

[12] Todd DK. Groundwater hydrogeology.2nd edition John Wiley and sons. New York 1980: 535.

[13] WHO. Guidelines for Drinking Water Quality, 4th ed. World Health Organization, Geneva 2011.

[14] Federal Survey Nigeria. Topographical map of Zummo (Sheets 176, NW) Nigeria, 1968.

[15] Bassey NE. Structural geological mapping and interpretation of landsat and aeromagnetic data over parts of hawal basement complex, northeast nigeria. Doctoral Thesis Abubakar Tafawa Balewa University Bauchi 2006.

Received on 27-05-2015 Accepted on 05-07-2015 Published on 30-06-2015

DOI: http://dx.doi.org/10.15377/2409-5710.2015.02.01.3