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Hydrogeological Appraisal of parts of Jemaa Local Government Area, North-Central Kaduna State, Nigeria

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Abstract: The ground water potential quantity and quality of parts of Jema'a Local Government Area in the Basement Complex of southern part of Kaduna State have been investigated using surface geophysical, hydro-geological and hydro-chemical analysis. The results of the surface geophysical survey, using the resistivity techniques, Horizontal Electrical Profiling (HEP) and Vertical Electrical Sounding (VES) proved effective in locating and assessing the thickness of regolith aquifers. The HEP was used as a reconnaissance survey to select points for VES. Interpretation of the sounding curves obtained from the study area, suggests that the subsurface layering ranges from 3-4 layers. The estimation of aquifer potential from geo-electric sounding was carried out and the result was compared with a simple scheme presented for ranking of VES. The geometric mean of the weighing ranged from 2.5-10.5 with a modal class being 5.6-6.5. The results of the borehole yield using the above parameter showed a good correlation with actual drilling and pumping test data and a good degree of relationship with the geophysical appraisal. The result of the water quality analysis also shows that the water quality in the study area falls within the permissible limit of the World Health Organisation standard for drinking water. The tri-linear diagram revealed that the groundwater in the study area is more with the earth alkaline water with higher alkaline proportion predominantly rich in HCO_3^-.

Key words: Hydrogealogical, HEP, VES, layers, Nigeria

INTRODUCTION

Groundwater in most cases is free of pathogenic organism and need no purification (treatment) before usage, chemical and biological contamination of most groundwater is difficult compared to surface water, inadequacy of surface water in most places and underground water which has been stored by nature through many years of recharge is available and dependable than surface supplies hence can readily be tapped (Todd, 1980). Groundwater occurrence in the Basement complex system of Nigeria is variable and somewhat unpredictable. Success has been achieved in groundwater development in this terrain through a combination of geological, hydrogeological and geophysical survey.

Surface geophysical survey, using electrical method has been extensively used in the search for groundwater in the basement terrain with high success rate. The geophysical geological and hydrogeological methods were relied upon to achieve a meaningful success in groundwater development of the study area.

Groundwater being the most important natural resources available to man, its role as a supporter of life on earth, its also govern the economic industrial and agricultural growth of a nation (Todd, 1980) hence its requirement in sufficient quantity as well as accruable quality by humans lead to a healthy life. This therefore necessitate this study as most of the population in the study area live in the rural areas, where only surface water, which is invariably exposed to contamination has been in use.

The study is aimed at investigating the groundwater potential using resistivity prospecting techniques for proper location of good drilling sites for boreholes, examination of the aquifer system of the basement rocks in the study area, determination of the resistivity variation in the overburden and fracture units of the basement aquifer system and to asses the water bearing potentials of each unit. The study is also aimed at ascertaining the purity of the water through physio-chemical methods and qualitative characterization of the groundwater in the study area using trilinear method. The area understudy is located in the southern part of Kaduna State within the

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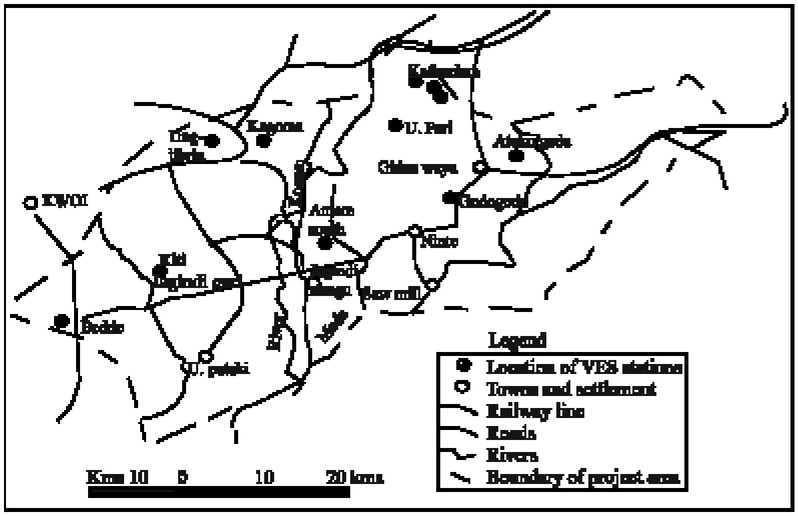

Fig. 1: Physical map of the study area showing recomended VES points drilled

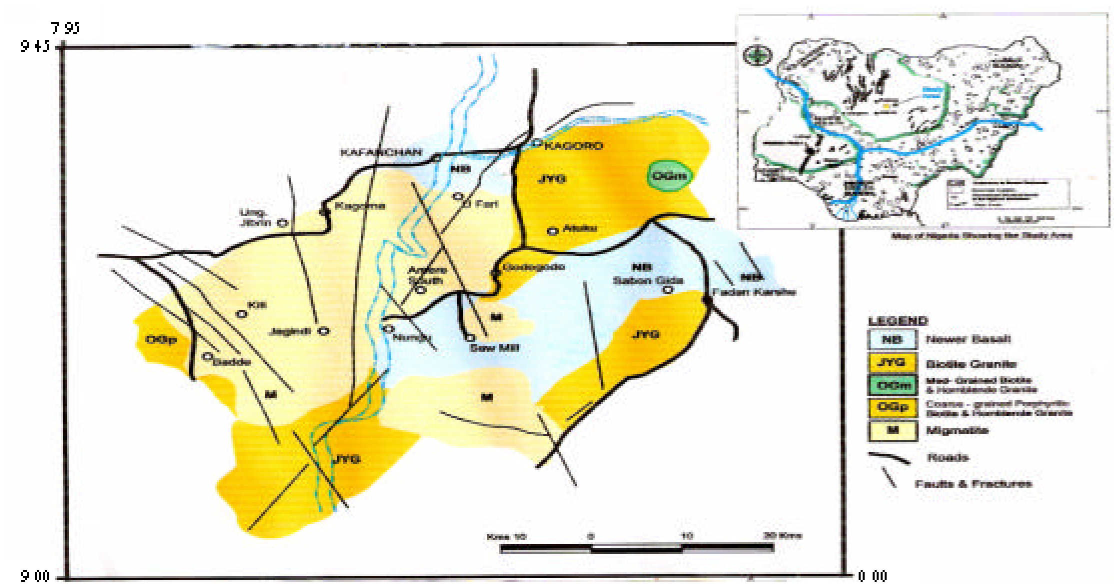

Fig. 2: Geological and structural map of the study area

Basement Complex rocks of North Central Nigeria. It lies between longitudes 8°0N and 8° 35N and between latitudes 9° 10'N and 9° 37'N (Fig. 1 and 2) it covers a total area of 140 km².

The area of study is underlain by the rock of Basement Complex of North-Central Nigeria consisting of migmatites granites gneisses granite, newer basalts laterite and alluvium. The migmatites exhibit a granoblastic texture and foliation and characterized with light and dark bands visible minerals includes quartz, biotite and plagioclase. Granites gneisses are found to be scattered all over the study area as low lying isolated exposures of height less than 1m, they are pinkish in colour with foliation and with quartz mineralization as veins. Minerals visible in hand specimen are notably quartz, feldspars.

Granite formed the dominant rock unit in the study area. Three types are identified in the area namely biotite granite, medium grained biotite granite and biotite hornblende granite. Newer basalt occurs as ridges in isolated exposures in the area, typical of tropical climatic belt. Alluvium stream channel contains deposit of alluvial sand derived from the area as a result of weathering of basement rocks. The range from fine to coarse grained sand, silts and clays. The unconsolidated gravels decomposed mainly of quartzite and laterites.

Some earlier workers in this area concentrated on the general geology of the area. Nahikhare (1971) and Okezie (1970) all identified granites, migmatites and gneisses as the dominant rocks in the area. Dupreez stated that groundwater could be extracted by open wells and boreholes located in the fracture systems in the fresh and the weathered parts of the Basement Complex and observed that generally the water has low mineralization.

In many communities of the world groundwater abstraction is from weathered fractured zones through wells/boreholes are sited (Clark, 1985; Olasehinde *et al.*, 1998). Eduvie *et al.* (1999) stated that the possibility of rock fracturing in the basement area of parts of Kaduna at a depth greater than 60 m is very rare. Mbonu (1988) also carried out a study of the hydrogeology of basement rocks North-Central Nigeria. He reported that 91% of sampled water points both surface and groundwater sources have nitrates concentration less than 45 mg L^{-1}. Hazell *et al.* (1992) stated that the crystalline basement exposures of Northern Nigeria has areas of deeply weathered regoliths estimated at 10-30 m which constitute useful aquifers separated by larger areas of relatively barren shallow regolith.

Clark (1985) and Jones (1985) observed that deeply weathered sites and fracture zones could be identified from aerial photograph. This is however restricted to a regional study. A location error of less than 1.0-5.0m can make a large difference between a productive borehole and an abortive one due to the great variability and unpredictability of the nature of the basement aquifer , for this reason, a ground geophysical survey is often very necessary upon which this research work is based.

Weathered/fractured occur within the weathered residual overburden (regolith) and the fractured bedrock (Clark, 1985; Offodile, 1992; Chilton and Smith-Carrington, 1984). The main source of groundwater is the weathered zone and or fractured basement, otherwise, they are sterile as it concerns storage and transmission of groundwater Mbonu (1988). These weathered products have often been referred to as sappolites (Jones, 1985).

MATERIALS AND METHODS

Geophysical traverses where made in the field after acquisition of physical and geological maps of the area of study. Reconnaissance survey was used to select points for sounding. Compilation of data from resistivity survey investigation and interpretation of data were done using 1Xid and 1Win×P software. Recommendations for drilling were then made and examinations of drill cuttings during the drilling were carried out. Other information collected include depth of each formation penetrated, rate of penetration, identification of the various rock units, pumping test analysis and collection of water samples from each of the boreholes for chemical parameters analysis while the physical parameters were analyzed on site. The results were further subjected to qualitative analysis to determine the water characteristics in the study area.

RESULTS AND DISCUSSION

A total of 20 vertical electrical sounding points were carried out based on 2-3 traverses per each station that were conducted in the area using resistivity profiling dipole dipole spread of 20 m throughout (Fig. 3).

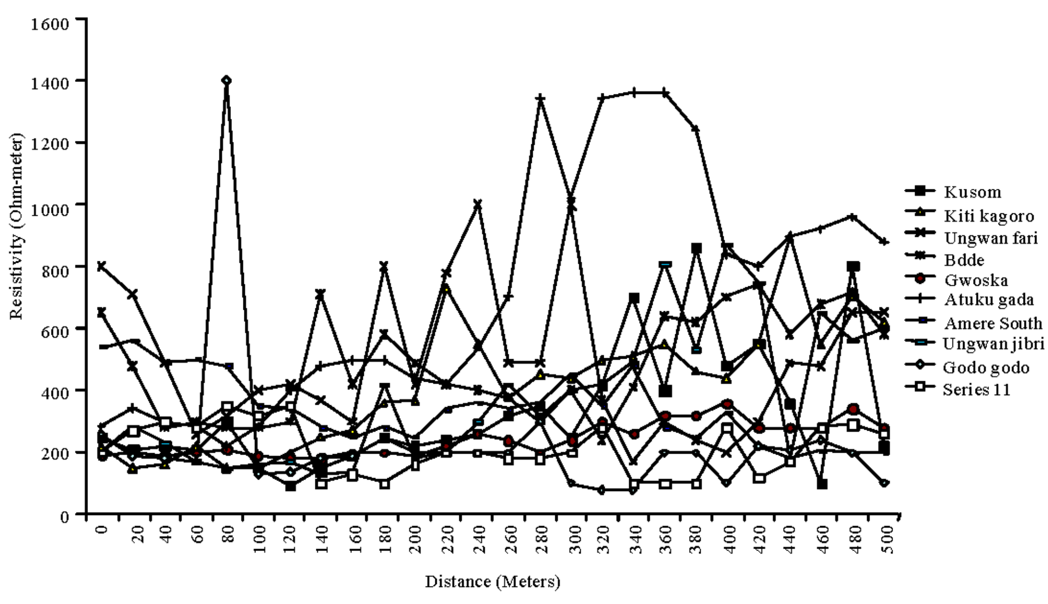

Fig. 3: Reconnaissance Geo-electric profilling using dipole-dipole method AB/2 = 20 m

Table 1: Geophysical parameters of the study area as deduced from ves curves interpretation

Location	Lat.	Long.	1st Layer App. Res. (Ωm)	1st Layer Thickness (m)	2nd Layer App. Res. (Ωm)	2nd Layer Thickness (m)	3rd Layer App. Res. (Ωm)	3rd Layer Thickness (m)	4th Layer App. Res. (Ωm)	4th Layer Thickness (m)	Estimated depth to basement (m)	Recommended depth of drilling
Kusom	9.3	9.9	60	7	680	8	190	13	1666	>13	26	20-35m
Tudun wada	9.31'	8.13'	1000	7	30	13	40	10	1366	>10	28	30-35m
Kiti	9.22'	8.11	300	0.45	1000	1.5	100	15	1748	>15	16	25-30m
Ungwan fari	9.34'	8.18	450	8	45	22	50	10	1540	>10	40	40-45m
Bedde	9.19'	8.4'	200	1.9	65	14.1	200	11	1742	>11	26	30-35m
Goska	9.32'	8.21'	500	2.5	5000	5.5	80	22	1000	>22	29	30-35m
Atuku gada	9.29	8.28'	300	4	50	11	200	10	737	>10	25	30-35m
Amere south	9.24'	8.15'	500	8.5	290	1.5	75	10	1617	>10	20	25-30
Angwan jibrin	9.32'	8.9'	90	2.5	2000	9.5	200	18	315	>18	30	30-35m
Godo-godo	9.24	8.22'	550	1.6	200	18.4	50	22	1656	>22	32	32-35m

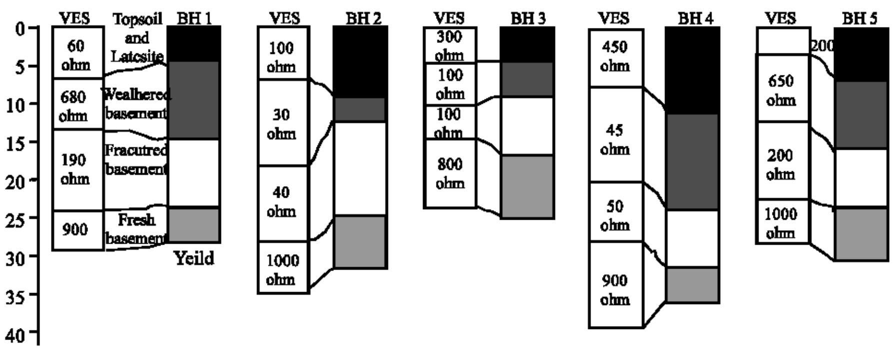

Fig. 4: A comparism of VES interpectation result with geologic section

illustrating points selected for the vertical electrical sounding. Interpretations of the sounding curves suggest that the subsurface layers are basically four (Table 1). The resistivity values of the first layer varies from 60-100 Ωm grouped as top laterite soil, the second layer resistivity generaly varies from 30-500 Ωm consisting of sandy-clay, claying sand with intercalation of silts/clays and laterite in some places. The third layer resistivity values ranged between 40-200 Ωm, which corresponds to the weathered regolith transition zone called saprolite and the fresh basement rocks (Jones, 1985). The bedrock which occurs as either the third or fourth layer in different parts of the study area has relatively high resistivity values ranging from 300 Ωm and above.

The depths to bedrock obtained from the vertical electrical soundings are in agreement within 10% with that indicated by drilling results. This difference could be due to human error of interpretation of actual depth to basement and during drilling due to the effectiveness of the drilling bit contamination by drilling mud and possible irregular bedrock topography. The depth to basement ranged between 20-49 m (Table 1). Another factor that could be advanced for the small difference between the depths to bedrock estimated during geophysical investigations and actual borehole drilling results is the fact that sounding may have been affected by lateral variation in resistivity, which cannot necessarily be identified from the data for a single sounding. Often times too, during drilling compressed air drilling may be introduced to create artificial reservoir.

Furthermore, the sounding provided an estimate of an average borehole depth for the area, while a borehole provides essentially a point value. These therefore could cause some discrepancies of the depth of weathering varies rapidly. A good degree of correlation was however observed of the Selected Vertical Electrical Sounding (VES) points obtained from (Table 1) and borehole logs are presented in (Fig. 4 and 5).

Estimation of aquifer potential from geoelectric sounding: To serve as the basis for a preliminary estimate of aquifer potential a simple schemes (Olayinka, 1996) are shown from (Table 2-4) were used. These entailed consideration of the depth to bedrock, the saprolite resistivity and the bed rock resistivity, obtained from inversion of the sounding data. The weighing factors have been assigned to the depth of the overbuden ranging from a minimum of 2.5 for thickness less than 10 m to a maximum of 10 for thickness exceeding 30 m (Table 2).

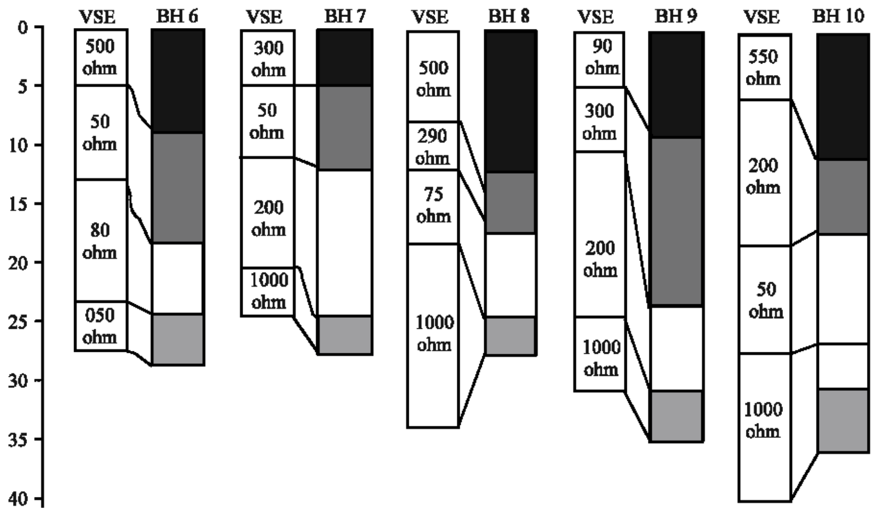

Fig. 5: A comparism of VES interpectation result with geologic section and borehole logs

Table 2: Aquifer potential as function of the depth to bedrock

Depth to bedrock (m)	Weighing factor
<10	2-5
10-20	5.0
20-30	7-5
>30	10

Source (Olayinka, 1996)

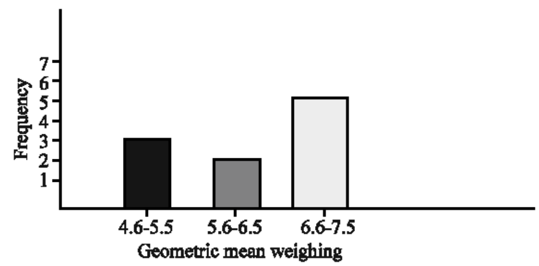

Fig. 6: Frequency distribution of geometric mean weighing of geoelectric data

The low resistivity of the order of less than 20 Ωm for the regolith is often indicative of a clayey regolith (Olayinka and Olurunfemi, 1992; Barkers, 1992) Carithers and Smith which reduces the permeability (Table 3) gives the summary of the optimum aquifer potential associated with the saprolite resistivity.

If the bedrock has a relatively low resistivity this could suggest a high aquifer potential due to the expected high fraction permeability. The maximum weight factor 10 is thus assigned to the bed rock (weathered bedrock) that is less than 750 Ωm (Table 4). The frequency distribution of geometric mean weighing factor from the three geo-electric parameters for the study area is presented in (Fig. 6). The geophysical parameter from VES and pumping test results for the study area are shown in Table 5.

The geometric weighted mean varies between 2.5 and 7.5 with the model class being 6.6 to 7.5. It is expected that the low geometric weighted means represented possible low yield while the higher weighted mean could be attributed to higher aquifer potential. The results of the yield of boreholes using the above parameters (Table 2-4) showed some correlation when all criteria are used. It was observed however, that wells located in malific areas and quartzite vein have better yields than wells located in finer grained equivalents. Consequently a total reliance in the three selected criteria may not be very correct, when exposure of this nature occur. In general the location of a thick overburden is very important parameter. This is due to the fact that the regolith facilitates the ingress of water into the overburden and so transforms the ordinary permeable and impervious granite and gneisses into sources of abundant groundwater reserves.

A correlation of the surface measured geo-electrical data with drilling results suggest that for a weathered basement aquifer to be water bearing its resistivity should be within a moderate range of 50-150 Ωm for the study area. A comparism of all the apparent resistivity range (Table 1) for all the layers shown that the weathered saprolith transition zone which is the third layer with resistivity range of 40-200 Ωm and a depth range of 15-38 m is the major water bearing formation in the area. Using the above parameters however, (Olayinka and Olurunfemi, 1992) stated that the most promising site for the drilling of a water supply borehole may not necessarily coincide with the thick development saprolite, this become evident after considering other geoelectrical parameter which influence the resistivity of the saprolite

Table 3: Aquifer Potential as a function of Saprolite resistivity

Saprolite resistivity Ωm	Aquifer characteristics	Weighing factor
<20	Clay with limited potential	7.5
21-100	Optimum weathering and ground water potential	10.0
101-150	Medium Conditions and potential	7.5
151-300	Little weathering and poor potentials	5.0
>300	Negligible potential	2.5

Source: (Olayinka, 1996)

Table 4: Aquifer Potential as function of fractured bedrock resistivity

Saprolite resistivity Ωm	Aquifer Characteristics.	Weighing factor
150	High fracture permeability as a result of weathering high aquifer potential	10.0
750-1500	Reduced influence of weathering medium aquifer potential	7.5
1500-3000	Fairly low effect of weathering, low aquifer potential	
<3000	Little or no weathering of bedrock negligible potential	2.5

Source (Olayinka, 1996)

Table 5: Geophysical parameter from VES and pumping test result of the study area

S/N	Location	Lat.	Long.	Depth to Basement	Saprolite	Resistivity	Fractured bedrock weight	Geometric mean yield L/M
1.	Kusom	9.31'	9.9'	2.5	2.5	10.0	5.0	36
2.	Gbosob (T/wada)	9.13'	8.13'	2.5	10.0	10.0	7.5	20
3.	Kiti Kagoma	9.22'	8.11'	2.5	10.0	10.0	7.5	45
4.	Ungwan Fari	9.34'	8.18'	2.5	10.0	2.5	5.0	16
5.	Bedde	9.19'	8.4'	2.5	10.0	10.0	7.5	120
6.	Gwoska	9.32'	8.21'	2.0	10.0	10.0	7.5	50
7.	Atuku Gada	9.29'	8.28'	2.5	7.5	7.5	5.8	20
8.	Amere South	9.24'	8.15'	2.5	10.0	2.5	5.0	20
9.	Angwan Jibrin	9.32'	8.9'	2.5	5.0	10.0	5.8	10
10.	Godogodo	9.24'	8.22'	2.5	10.0	10.0	7.5	50

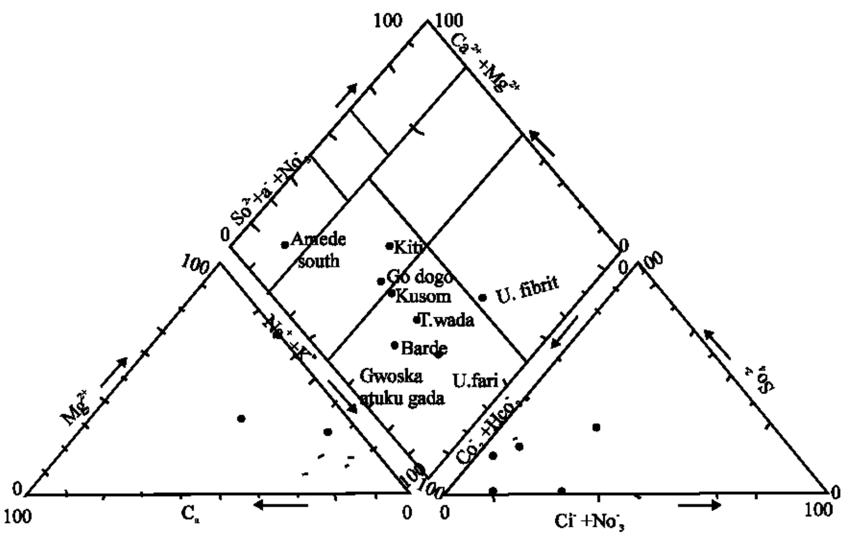

Fig. 7: Trilinear diagram of the study area

as well as that of the bedrock. The pumping test results of the ten boreholes are shown in Table 5 with varying good yields in the study area.

Chemistry of the groundwater in the study area: Ten water samples from the boreholes were collected for chemical analysis, at the National Water Resources Institute Kaduna, the results of the physio-chemical analyses are shown in (Table 6) with (WHO, 2004) standard. The qualitative analysis (Fig. 7) revealed that the groundwater characteristics in the study area are more of earth alkaline water deduced from (Table 6). The temperature of the water samples range from 22-31°C with an average value of 27°C. The ph of the water analyzed ranges from 5.85-7.60 which are within the recommended level (WHO, 2004). The major cation and anion results

Table 6: Summary of hydrogeochemical analysis (All values in mgL)

Location	PH	Na^+	K^+	Mg^{2+}	Ca^{2+}	H_{CO3}	Cl	SO_4^{2-}	No^{3-}	Fe^{2+}
Kusom	7.4	28.50	7.04	16.29	0.98	16.00	1.53	4.5	0.00	0.00
Gbosob (T/Wada)	7.2	12.87	5.10	3.53	2.00	9.15	4.15	0.05	0.00	0.12
Kiti Kagoma	6.8	2.8	1.56	1.58	2.2	16.47	0.17	9.13	0.00	0.03
Ungwan Fari	7.2	3.45	1.95	0.36	0.58	24.18	2.62	6.21	0.28	0.00
Bedde	7.0	34.66	2.55	10.25	1.12	32.67	1.62	5.11	0.2	0.00
Gwoska	7.8	2.59	0.60	0.37	0.60	13.40	0.07	0.07	0.00	0.01
Atiku Gada	7.8	8.74	1.95	0.61	3.00	63.45	0.00	0.8	0.00	0.17
Amere South	7.0	1.61	8.21	21.89	1.80	12.80	1.78	0.04	0.11	0.04
Angwan Jibril	7.2	7.19	9.6	1.42	1.25	9.19	5.07	4.75	0.05	0.15
Godogodo	7.8	3.50	2.40	2.92	0.26	25.63	11.34	0.00	0.07	0.2
WHO(2004) MCLG	7.85		200.00	50.00	75.00	100.00	200.00	20.00	45.00	0.1
MCL	6.5			150.00	200.00	500.00	600.00	400.00	50.00	1.0

MCLG: Maximum contaminant level Goal (non enforceable), MCL: Maximum contaminant level (enforceable)

falls within the WHO (2004) acceptable limit for standard for drinking and domestic water.

CONCLUSION

The result of the study shows a good groundwater potential and the groundwater development in the study area is mostly within the weathered overburden and fractured bedrock (basement), hence its importance must not be ignored. The result of the geophysical investigations estimation of aquifer potential was carried out and the result was compared with a simple scheme presented for ranking it Olayinka (1996). The geometric mean of the weighing ranged from 2.5-10.5 with a modal class being 5.6-6.5. The results of the boreholes yield using the above parameter showed a good correlation with actual drilling and pumping test data and a good degree of relationship with the geophysical appraisal.

The result of the physio-chemical analysis of the ten samples of water from the ten boreholes drilled falls within the permissible standard of drinking and domestic water (WHO, 2004). The qualitative analysis revealed that the ground water in the study area is more of earth alkaline water.

A systematic hydrogeological mapping of the whole area should be encouraged and continued until all parts of Kaduna and the Nation at large are hydro-geologically mapped. This will compliment the Federal Government efforts in total hydrogeological mapping of the country.

Furthermore, as the quality of water in terms of major and minor constituents are within acceptable and safe standard for drinking a potent danger in the presence of bacteriological and toxic trace elements should not be overlooked, hence the need for occasional bacteriological and trace elements analysis in the water in the study area is therefore recommended.

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