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Hydrogeological and hydrogeochemical evaluation of the groundwater potentials of Kaduna area, Central Nigeria

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ABSTRACT: An assessment of the groundwater potentials of Kaduna area, Central Nigeria, has been carried out using hydrogeological and hydrogeochemical characteristics. The investigations had led to a fairly good appraisal of the hydrogeological characteristics of the area of the basement complex terrain in Nigeria.

The basement complex as studied in the area has two main aquifer systems: the weathered overburden and the fractured crystalline rocks which are interconnected. Groundwater contour map showed the flow direction to be southwards and southeastward in the northern part of the area while the flow direction in the southern part is northwards toward River Kaduna. Analysis of the relationship between static water levels and depth of dug wells in the area gave a correlation of 0.89 with a regression coefficient of 0.79. While a correlation coefficient calculated for the variation of static water level with elevation of wells was -0.0479. The mean depth to water table was 4.03m with a standard deviation of 1.49 and a coefficient of variability of 37. The mean elevation of wells is 603.75m with a standard deviation of 27.54 and a coefficient of variability of only 4.5. Borehole yields in the area range from 30.24 to 207.36m^3/day with an average of 90.65m^3/day. Transmissivity values range from 0.38 to 47.4m^2/d with an average of 6.96m^2/d and specific capacity values range from 0.43 to 31.85m^3/day with an average of 6.13m^3/day/m. The depth to water level range from 1.1 to 16.63m with an average 6.51m while the overburden thickness range from 8.5 to 42.0m with an average of 23.4m.

Analysis of hydrogeological parameters from boreholes in the area revealed a correlation coefficient calculated for the variation of the overburden thickness with the transmissivity , specific capacity and yield as 0.083, -0.249, and -0.18 respectively with a regression coefficient of 0.0069, 0.062, and 0.032 respectively . The correlation coefficient calculated for the relationship between the transmissivity and the specific capacity was 0.78 and the regression coefficient 0.61. Chemical analysis of major ions for groundwater in the area indicates Sodium and Potassium ions and Bicarbonate ions were the dominant ions and hence the groundwater of the area is classified as Na-K and Bicarbonate water type.

Keywords: Groundwater, Kaduna, Transmissivity, Hydrogeological, Hydrogeochemical.

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Introduction

Groundwater is a very important water resource as throughout history it has been a major source of drinking water and even today, more than half of the world's population depends on groundwater for survival (UNESCO, 1992). Groundwater forms more than 98% of the available freshwater in the world's water supply exceeding the volume of surface water (Fetter, 1980). Shortages of groundwater in areas of excessive draught makes it imperative the importance of correct estimates and proper development, regulation and protection of supplies in order to ensure the continued availability of this key natural resource(Todd, 1980).

The area of study is located in northern Nigeria and lies between latitudes 10^0 25'N and 10^0 40' and longitudes $7^0$15' and 7^0 30'E (Fig.1). It covers a total area of about 716 sq km in the Guinea savannah region with two seasons – Wet season from March/April to October and Dry season from November to March. Mean monthly temperature range from 15^0 to 36^0, with average annual rainfall of 1270mm and mean annual relative humidity of 57%.

Regional Hydrogeological Setting

The basement complex consists of crystalline rocks of igneous and metamorphic suites with typically very low porosity (Davis, 1969). The occurrence of groundwater in the basement is enhanced by geologic processes of fracturing, faulting and weathering. Fractures could be developed by pressure relief, compressional and tensional forces caused by regional tectonic movements. Fracturing increases porosity of crystalline rocks by about 2-5% (Brace *et al*, 1966; Davis, 1969).

Weathering due to chemical decomposition and physical disintegration operates with greater efficiency in increasing rock porosity. Chemical weathering of crystalline rocks produces saprolite which has very high porosity and specific yield and acts as a reservoir, storing infiltrated water and releasing to wells that intersect fractures. Stewart (1964) reported that weathered crystalline rocks have porosities of between 30 and 60%. Oteze (1981) defined the aquifer system in the basement complex as dependent on the following factors viz; degree and nature of the fracturing in the rocks, degree and thickness of weathered profile and the absence of or presence in minimal amounts of clays at the weathered zone to allow infiltration of surface water. Wells located in geological faults or fracture zones give high yields due to high transmissivity values than surrounding areas (Greenbaum, 1985; Palacky *et al*, 1981).

The basement complex of Nigeria according to Oteze (1981) is reported to have aquifers with moderate yields to very prolific ones. The Igarra granites contain high fractures through which water is channeled into the local aquifer of the low lying weathered metasedimnetary rocks underlying Igarra town; initial yield obtained from a borehole in Tunfafia is comparable to good yields in sedimentary aquifers.; Other places with reported high yields include Ilorin $0.3m^3$/min, Mopa 0.46-$0.73m^3$/min, Osara $0.28m^3$/min and Talata Mafara $0.25m^3$/min (Oteze, 1981).

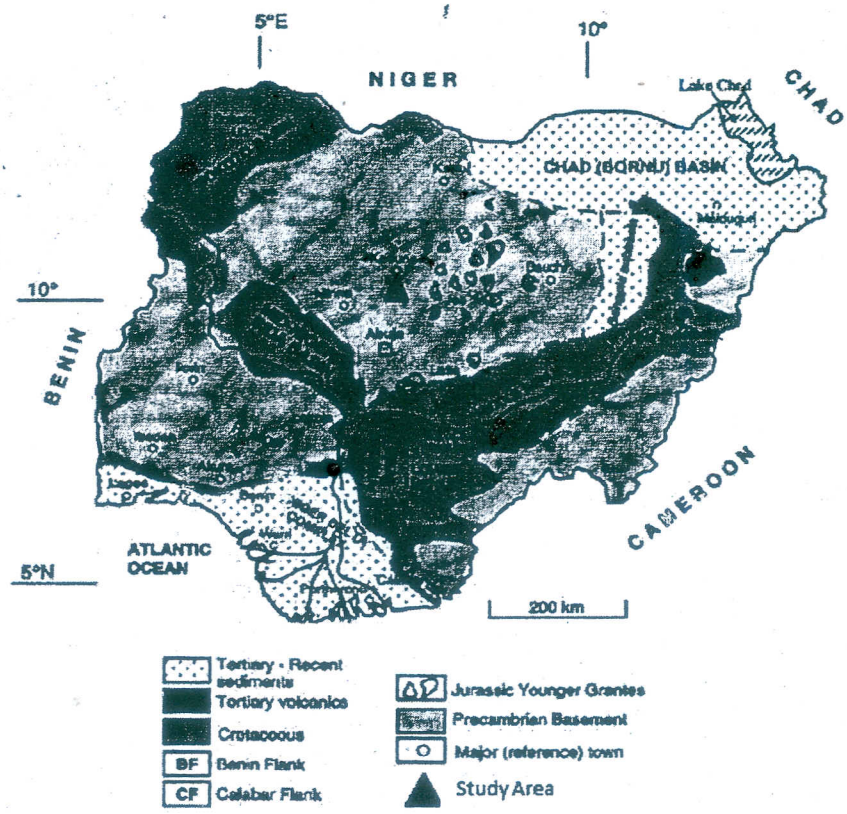


Fig 1: Geological Map of Nigeria (After Obaje and Abaa, 1996)

Local Hydrogeology

The area of study is essentially situated within the northern sector of the Nigerian basement complex and is characteristically underlain by the Granite-Gneisses, Porphyroblastic Gneisses, medium to coarse grained Granites, Porphyritic Granites and Quartzites (Eduvie 1991) (Fig. 2).

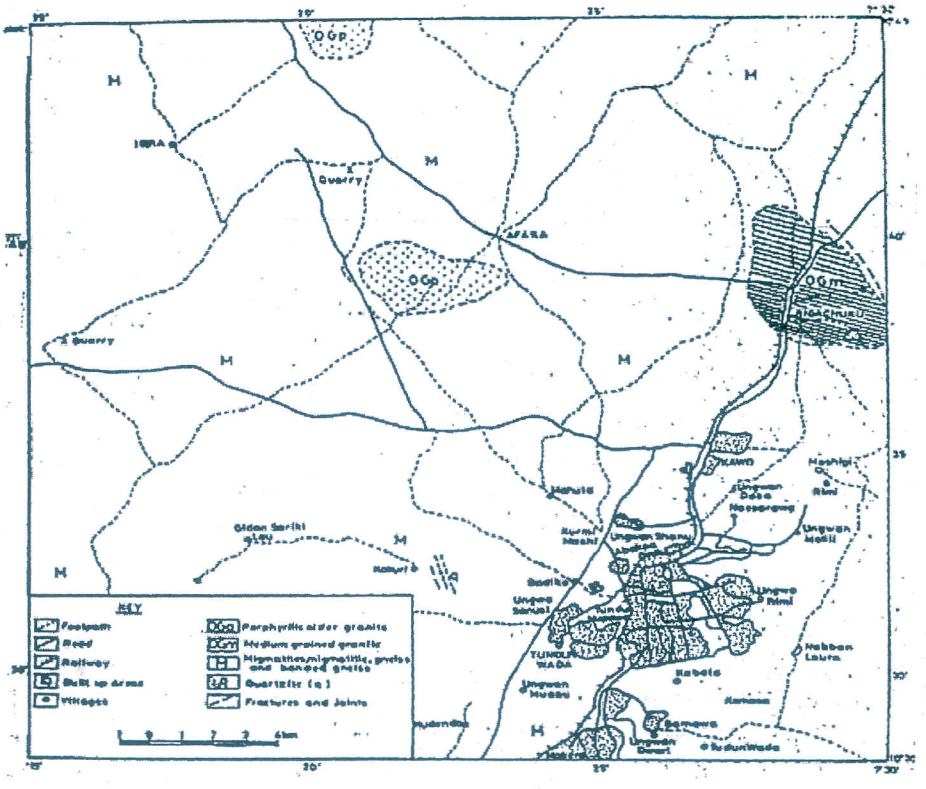


Fig 2: Geological Map of Kaduna Area (Eduvie *et al.* 1999)

Essentially, two aquiferous units are delineated in the study area- The weathered overburden and the fractured crystalline rocks which are generally interconnected.

The Weathered Overburden: The weathered overburden is represented by a mantle of in situ weathering products of varying thicknesses. It is quite variable and highly weathered, degrading to a material containing high percentage of kaolinite. This stage of weathering is found in the topmost part of the zone, extensive and has significant storage potential. At greater depth beneath the kaolinite, the degradation has similar lithologic characteristics with clayey grit and the joints and fractures s in the layer tend to be open (Mogekwu, 1987).The intermediate zone is more productive at the base where the rock fragments are coarser in size and have not been subjected to extensive weathering processes. (Offodile,1983; Jones, 1985; Egboka, 1988)

Th[illegible]ictured basement: The fractured basement represents the more prolific aquifer system in the area. Groundwater occurs in fissures, joints and fractures, which have been developed through the geologic processes of fracturing, faulting and weathering. It constitutes the most prolific aquifer system in the crystalline rocks the world over (Oteze, 1981). The capacity of this zone to hold and transmit water depends on the extent,

pattern, size openness and continuity of the fractures and the degree to which the fractures are connected hydraulically (Stewart, 1964; Oteze, 1981)

Materials and Methods

Water samples were obtained from thirty hand dug wells and water depth measurements from eighty wells. Water level contour map (Fig 3) was produced from water level measurements which was statistically analysed together with hydraulic parameters from available data. Hydrogeochemical study of the area was investigated using analysis of major anions and cations carried out on thirty selected water samples from dug wells by Atomic Absorption Spectroscopy and Volumetric analysis.

Evaluation of Hydrogeological Parameters

Parameters such as static water level, depth, elevation of wells, overburden thickness, yield, specific capacity and transmissivity, were statistically analysed to find out the interrelationship among them.

Table 1: Summary of water yielding characteristics

Parameters		
Yield	min	30.24
(m3/d)	max	207.36
	average	90.65
Specific Capacity	min	0.43
(m3/d/m)	max	31.85
	average	6.13
Transmissivity	min	0.38
(m2/d)	max	47.40
	average	6.96
Depth to Water(m)	min	1.10
	max	16.63
	average	6.51
Overburden Thickness		
(m)	min	8.50
	max	42.00
	average	23.40

(Eduvie *et al*, 1999)

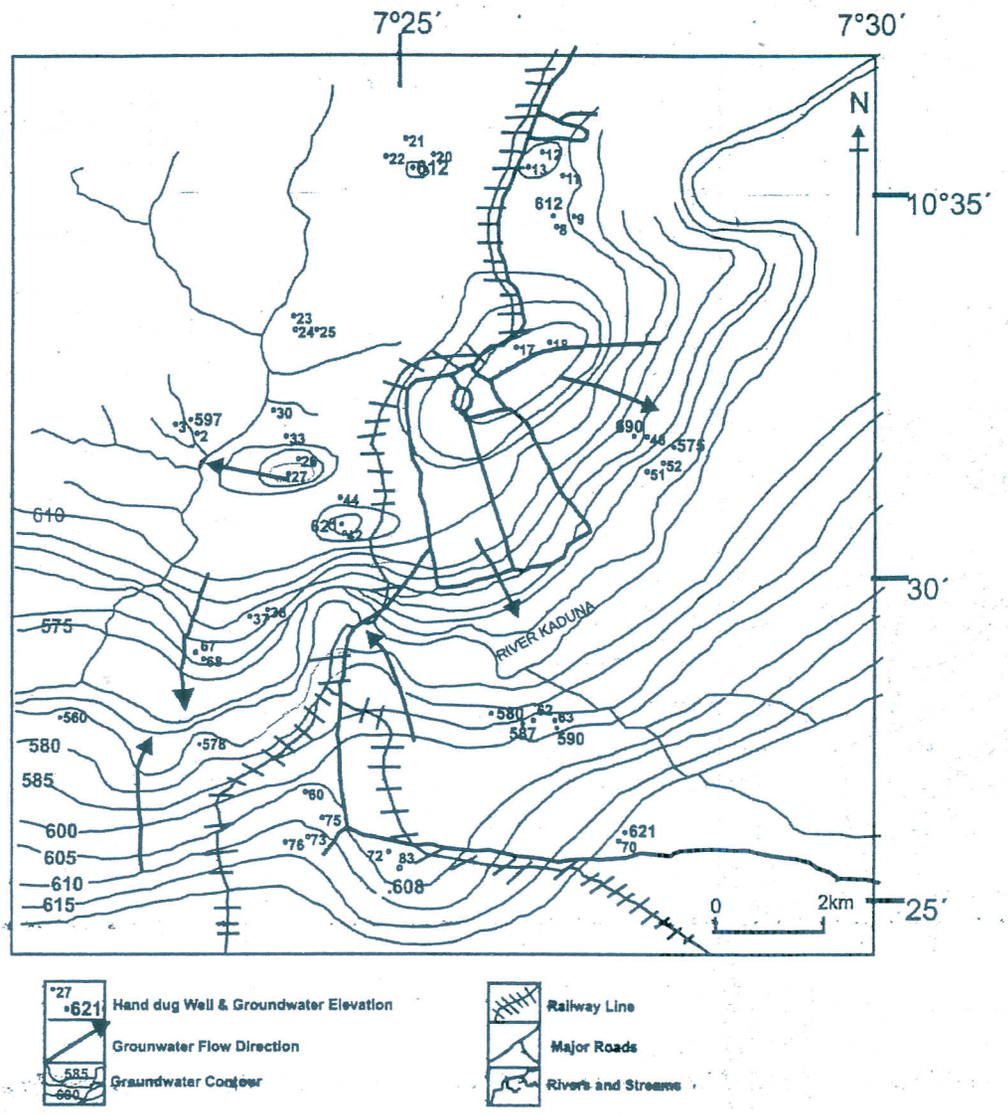


Fig 3:Groundwater Contour Map of Kaduna Area

the static water level in not dependent on the thickness of the overburden. The equation of regression derived is S=5.36-0.057D and regression coefficient 0.0204.

Thus it is observed from the foregoing, that the overburden thickness has no effect on the yield or specific capacity i.e. an increased in depth improves neither the yield of boreholes nor the specific capacity. Consequently, the water yielding ability of the basement aquifers may not be related to the thickness of the overburden at the point of drilling.

Hydrogeochemistry

A total of thirty hand dug wells were sampled for chemical analysis of the ions using Atomic Absorption Spectroscopy and Volumetric analysis. The characterization of the water shows that sodium ion concentration in the water samples range from 1.6 to 18 mg/l; potassium ions 1.8 to 19mg/l; calcium ion 0.57 to 18mg/l and magnesium ions 0.1 to 9.4mg/l. for the anions , the following concentrations were obtained: chloride ion range from 1.2 to 24 mg/l; sulphate ions 2.5 to 16mg/l and bicarbonate ions 15 to 112mg/l. the ionic concentration of the major anions and cations are generally below the standard limits set by the World Health Organization.

Discussion

From the analysis of the correlation between the static water level and the elevation of dug wells, a very low value of -0.0479 suggests that the static water level at any location in the area of study is hardly affected by the elevation. A strong positive relationship is indicated between the static water level and depth of dug wells from the calculated coefficient of correlation, which is 0.89. Thus it could be said that an increase in depth of wells, positively affects the static water levels in dug wells in the area of study.

The values of hydrogeological parameters such as yield, specific capacity and transmissivity are characteristic of basement aquifers. The varying quantities in yield of boreholes in the area reflect the effect of varied degree of fracturing and weathering of the basement rocks in the area. The values of specific capacity, which give a better indication of aquifer performance than yield , were generally less than $10m^3/d/m$. This supports the view that specific capacity of wells in the basement aquifers are generally low (Chilton and Smith-Carrington, 1984).

The correlation coefficient calculated for the variation of the overburden thickness with the Transmissivity, Specific Capacity and Yield were very low. Thus it is reasonable to assume that the overburden thickness does not play any significant role in determining the yield/specific capacity, in other words the productivity of the basement aquifer in Kaduna area. Rather, the hydraulic characteristics are suggestive of more important impact on the aquifer performance arising from the degree and extent of both fracturing and weathering of the crystalline basement rocks. However, the Transmissivity was observed to have a strong positive relationship with the specific yield.

Table 2: Concentration of Major Cations and Anions in Mg/l

Sample No	Na^+	K^+	Ca^{2+}	Mg^{2+}	Cl^-	SO_4^{2-}	HCO_3^-
2	4.00	5.70	6.00	3.00	2.60	6.00	30.00
5	21.20	4.20	3.40	0.15	7.00	3.00	56.00
8	12.20	4.20	2.00	0.88	10.40	7.00	19.00
10	8.20	11.70	4.00	1.20	6.80	5.04	112.00
14	10.00	5.00	18.00	3.50	24.00	16.00	32.00
15	5.60	5.50	1.98	0.97	5.00	7.50	20.00
18	4.20	6.10	1.75	1.30	10.10	8.20	27.00
22	7.20	12.21	9.10	1.87	1.50	4.89	68.00
23	9.80	2.60	1.20	1.12	1.20	7.50	30.00
26	11.00	2.40	0.95	1.14	1.48	8.00	26.00
31	4.50	5.20	0.61	0.70	1.40	1.20	22.00
34	6.00	2.80	20.00	1.00	2.90	5.00	70.00
37	8.90	13.40	5.70	1.86	1.72	6.00	68.00
40	7.20	12.50	6.10	2.10	1.80	5.70	65.00
42	8.60	8.70	12.00	0.80	5.20	6.00	70.00
43	7.50	8.20	11.00	0.91	6.10	5.91	67.00
44	5.90	2.70	3.40	0.10	8.60	4.80	17.00
48	15.00	16.00	4.00	1.50	18.00	6.30	58.00
51	18.00	19.00	3.80	1.20	17.00	7.00	72.00
57	2.90	5.82	5.43	2.30	2.70	5.20	25.00
59	9.50	4.40	0.57	0.12	7.80	2.50	15.00
62	7.20	11.20	6.37	1.23	4.00	6.00	41.00
66	1.60	2.60	0.60	1.10	2.13	3.00	15.00
67	2.80	3.28	2.93	9.54	1.76	3.04	20.10
69	2.80	3.27	2.89	9.46	1.67	3.14	22.00
72	4.60	6.20	1.60	1.34	6.21	4.00	20.00
74	7.20	11.20	6.37	1.24	4.10	6.20	44.00
75	6.40	5.60	4.12	0.82	6.10	7.30	16.00
81	9.80	4.10	1.00	2.10	7.60	8.50	33.00
84	3.60	1.80	7.20	0.18	2.65	7.00	23.00

Hydrogeochemical facies established for the ground waters in the Kaduna area is classified based on the dominant ions as Na-K and Bicarbonate type water. The Na-K and HCO_3 being the dominant ions from the Piper (1944) and Durov Diagrams (Fig. 4 & 5). It is suggested that this is as a result of high weathering of feldspathic minerals in the area. The hydrochemical facies is a function of the lithology, solution kinetics and flow patterns of the aquifers (Back, 1960; 1966).

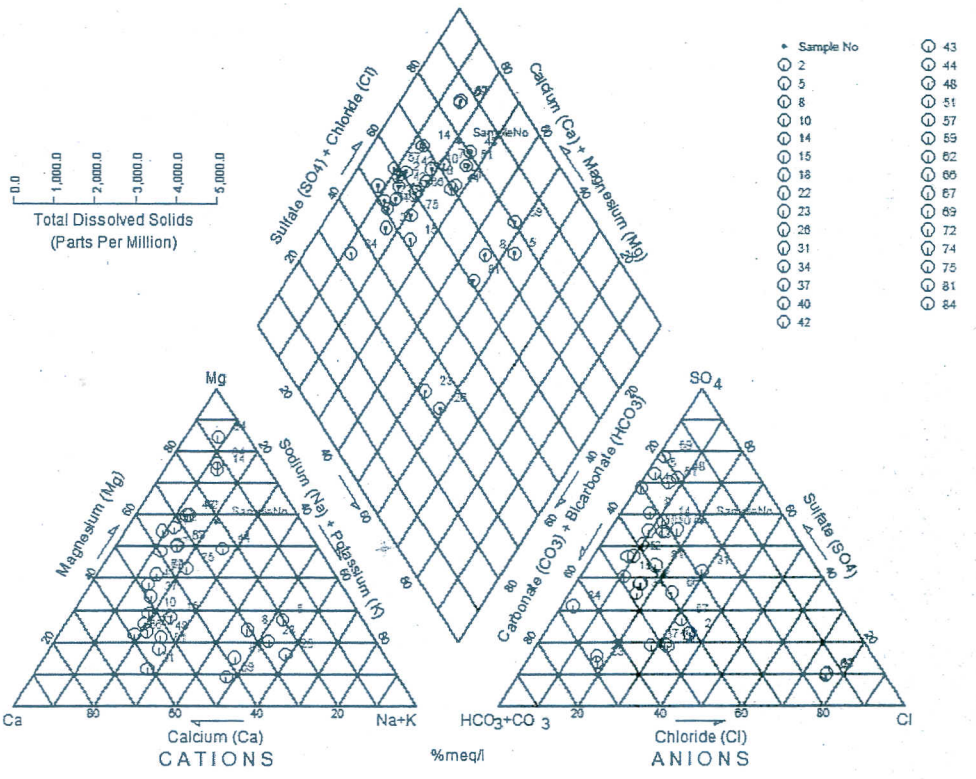


Fig.4: Piper diagram of water analysis from Hand dug wells in Kaduna area indicating their hydrochemical affinities.

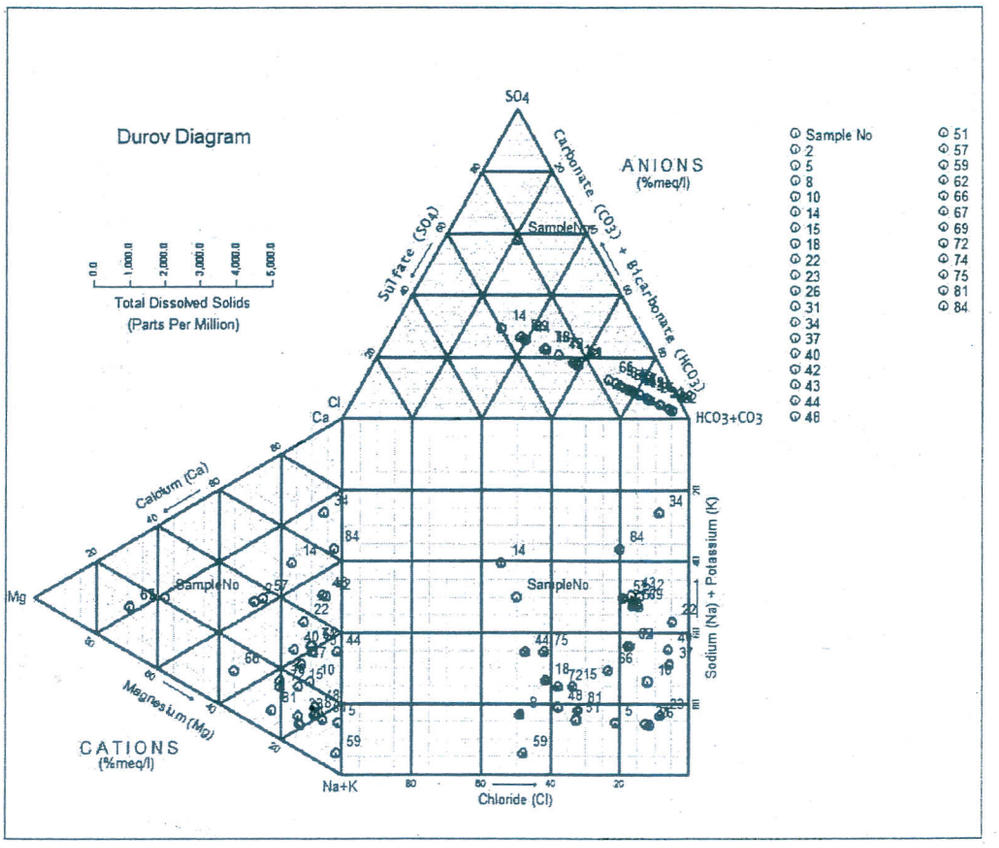


Fig.5: Durov diagram of water analysis from Hand dug wells in Kaduna area indicating their geochemical affinities

Significant differences between well variations in the compositions of the groundwaters were observed. The well to well variations are inferred to be the result of the degree of interaction between groundwaters and basement rock weathered by a given groundwater, and/or variations in groundwater redox conditions. (Mueller *et al* 2000).

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