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HYDROGEOCHEMICAL ASSESSMENT OF GROUNDWATER IN KALTUNGO AND ENVIRONS, NORTHEASTERN NIGERIA.

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ABSTRACT

Analytical results indicate that groundwater samples from kaltungo and environs are polluted due to high concentrations of iron, fluoride, nitrate, and coliform bacteria. Iron concentrations range from 1.9 mg/l to 4.8 mg/l, fluoride values range from 0.6 mg/l to 1.9 mg/l, and nitrate concentrations range from 46.8 mg/l to 164 mg/l while coliform number counts range from nil to 80 number counts. The results further reveal that the water is generally good for agricultural uses. The SAR values range from 0.003 meq/l to 0.38 meq/l, RSC values range from -6.20 meq/l to 4.97 meq/l, EC values vary from 160 µS/cm to 790 µS/cm, and TDS ranges from 80 mg/l to 400.5 mg/l. However, the water may not be suitable for some industries due to high concentrations of iron, bicarbonate, and total hardness. Bicarbonate values range from 206 mg/l to 612 mg/l, and total hardness range from 73.4 mg/l to 163.7 mg/l. Piper trilinear plots classified the water into Ca-(Mg)-HCO_3 which belongs to the normal alkaline fresh water type. Based on Mg^{2+}/Ca^{2+} ratio, about 39% of water samples reveal water from silicate aquifer. Plots of logTDS against $Na^+/(Na^+ + Ca^{2+})$ reveal that the groundwater chemistry is influenced by evaporation, weathering induced dissolution, and dilution effects. The water would require treatment for human consumption and for industrial applications. It is recommended that regular groundwater quality monitoring will ensure groundwater quality protection and conservation.

KEY WORDS: Groundwater chemistry, silicate aquifer, alkaline fresh water, kaltungo area, polluted.

INTRODUCTION

Groundwater is considered the healthiest source of drinking water, but when contaminated, may lead to health problems (Aloa and Ige, 2003). The source of groundwater contamination could be natural through groundwater-rock interaction or through anthropogenic which involve human activities that can affect groundwater quality. Groundwater pollution which is man- made is worst than natural pollution as it eventually renders water less suitable for use than its original state (Abimbola et al., 2005). The study area is located between latitudes $9^0$48'00N to $9^0$50'38N and longitudes $11^0$16'00E to $11^0$19'45''E (Fig.1). It is accessible through the Bauchi-Gombe-Kaltungo and Numan-Cham-Kaltungo Federal Highway. The study area forms part of the Gongola arm of the Benue Trough. The area has a mean maximum temperature of 31^0C and average annual rainfall of 1550.7mm. The area is characterized by moderate to high relief which stands out within the general elevation, among which is the famous Tangale peak (Carter et al., 1963). The topography of the area rises from 402 metres to 702 metres above mean sea level. The area is drained by the River Kaltungo which flows from the north east towards the southwest.

The population of the area is about 183,000 (NPC, 2006), and the people are predominantly farmers, and they also rear cattle. The major sources of water supply in the area are surface waters including Rivers, streams ponds and groundwater which is obtained from hand-dug wells and boreholes. Most residents in the area use pit latrines and waste disposal is indiscriminately carried out. These practices could be responsible for the degradation of groundwater quality, and thus unsuitable for human consumption.

This study evaluates the influence of anthropogenic activities and geology on the groundwater quality of the study area and the peculiar use of the water for agricultural, industrial and domestic purposes.

GEOLOGY AND HYDROGEOLOGY OF THE AREA

The study area is located in the Upper Benue trough which has been variously described as intracontinental rift basin (Benkhelil, 1982; Ofoegbu, 1988 and Okereke, 1988). According to

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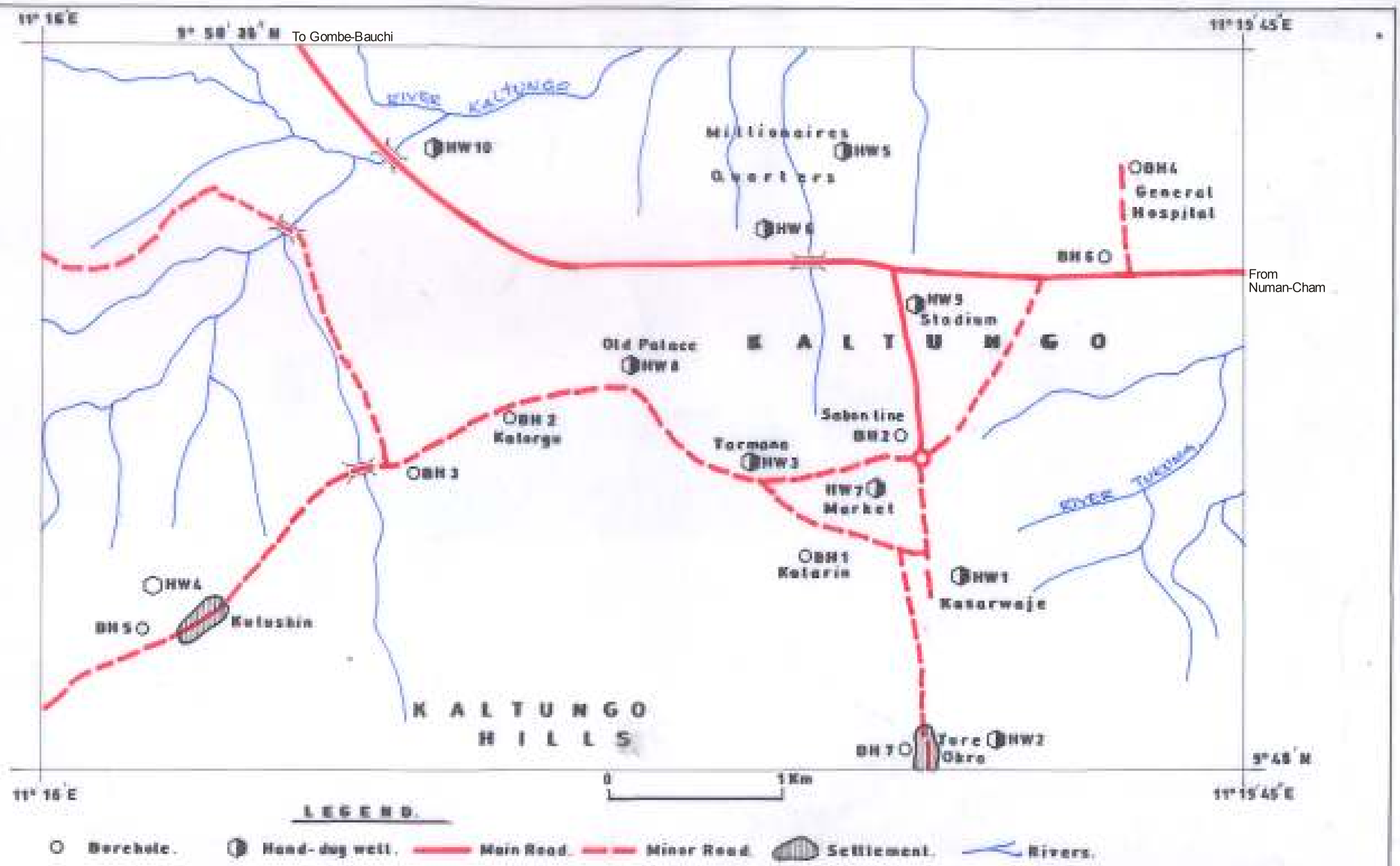

Fig. 1 Map of the study area showing sampling points and Access road

Ntekim and Orazulike (2004) that the present tectonic setting of the area is influenced by the late Cretaceous intense compressional earth movements dominated by series of long and narrow simple fold structures. They went further to state that large scale faulting occurred after the faulting events and resulted in grabens. The reactivation of the major basement faults is responsible for the sinistral faults in Kaltungo, Teli-Wuyo and Gombe areas. Bassey (2000 and 2005) identified the Chibok lineaments which align N50^{0}E to be similar to the trend of the Kaltungo fault zone and the Wuyo-Gubrunde lineaments. Bassey (2006) also reported a Chibok NE-SW trending lineaments which are intrabasement extension of the Benue trough lineaments traceable to Kaltungo inlier through Wuyo-Gubrunde-Shani fault zones. The area is underlain by the basement complex rocks which include porphyritic and biotite granite (Fig.2). The porphyritic granite underlies most parts of the study area while the biotite granite underlies the southern portion of the study area. The biotite granite underlies a small portion of the northern part of the study area. The porphyritic and biotite granites belong to the older granite of the Nigerian basement complex. The porphyritic granites are coarse to very coarse grained with large white or pink prismatic phenocrysts of microcline while the biotite granite have granular texture with wide range of grain sizes (Rahman, 1976, Van Breeman, et al., 1977). Groundwater occurs in the weathered portion of the basement rock as well as fractures in the basement rocks.

Borehole lithologic sections (Fig.3) revealed fracture aquifer which range from 12 m to 24m. Boreholes in the area generally have average depth of 30m while hand-dug wells have depths ranging from 3m to 6m. The fracture aquifer yields range from 3.3l/s to 16.7l/s (Gombe State Rural Water Supply, 2003).

METHODOLOGY

This study involves the collection of Eighteen (18) water samples from the different water sources in February, 2007) (Fig.1). Eight (8) water samples were collected from boreholes while Ten (10) water samples were collected from hand-dug wells. The water samples were collected in one-litre containers which were rinsed with the samples to be collected according to Barcelona et al (1985) method. Water samples were collected from the discharge of existi

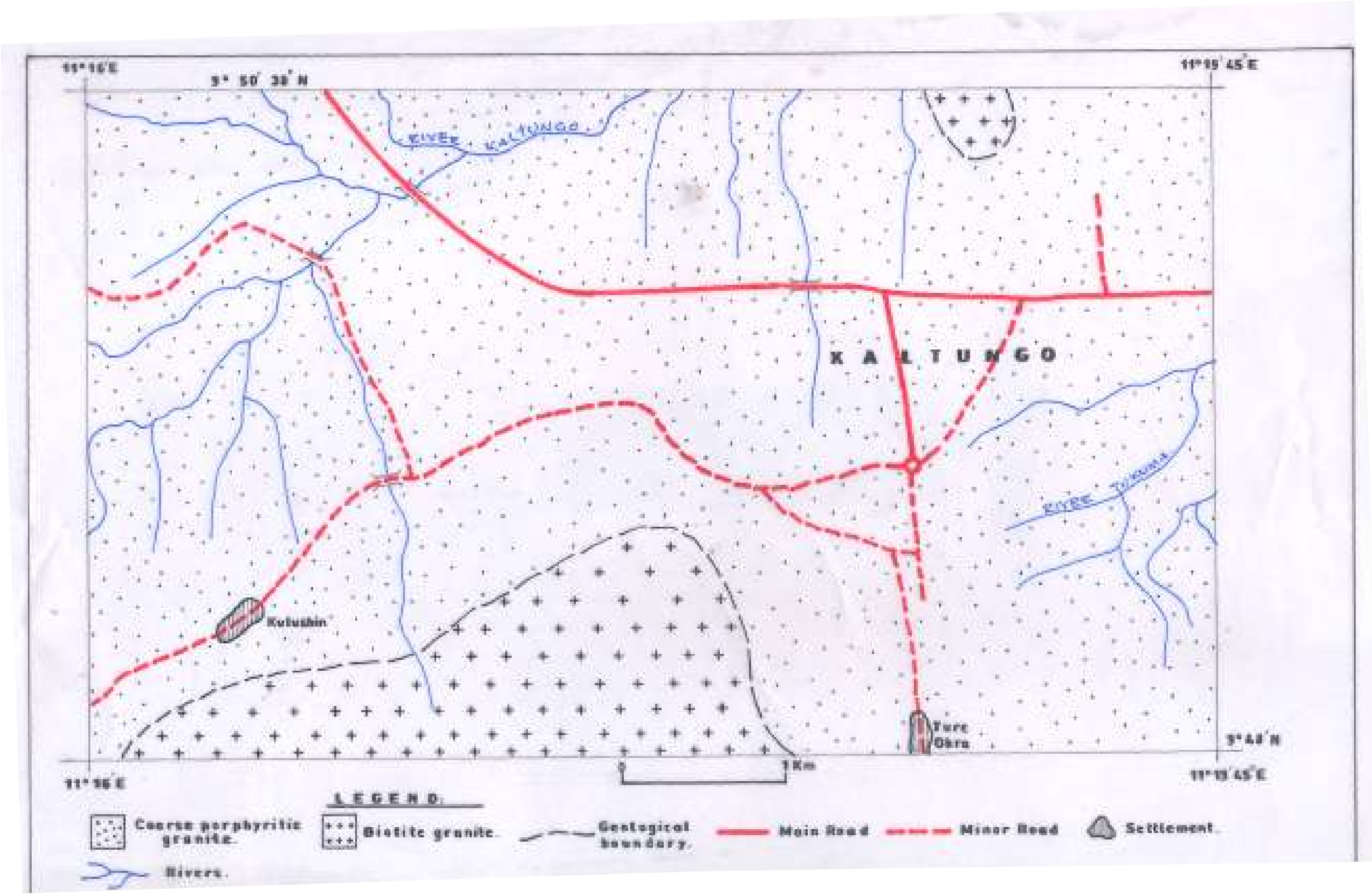

Fig. 2 Geologic Map of the study area
(Nigerian Geological Survey Agency, 2006)

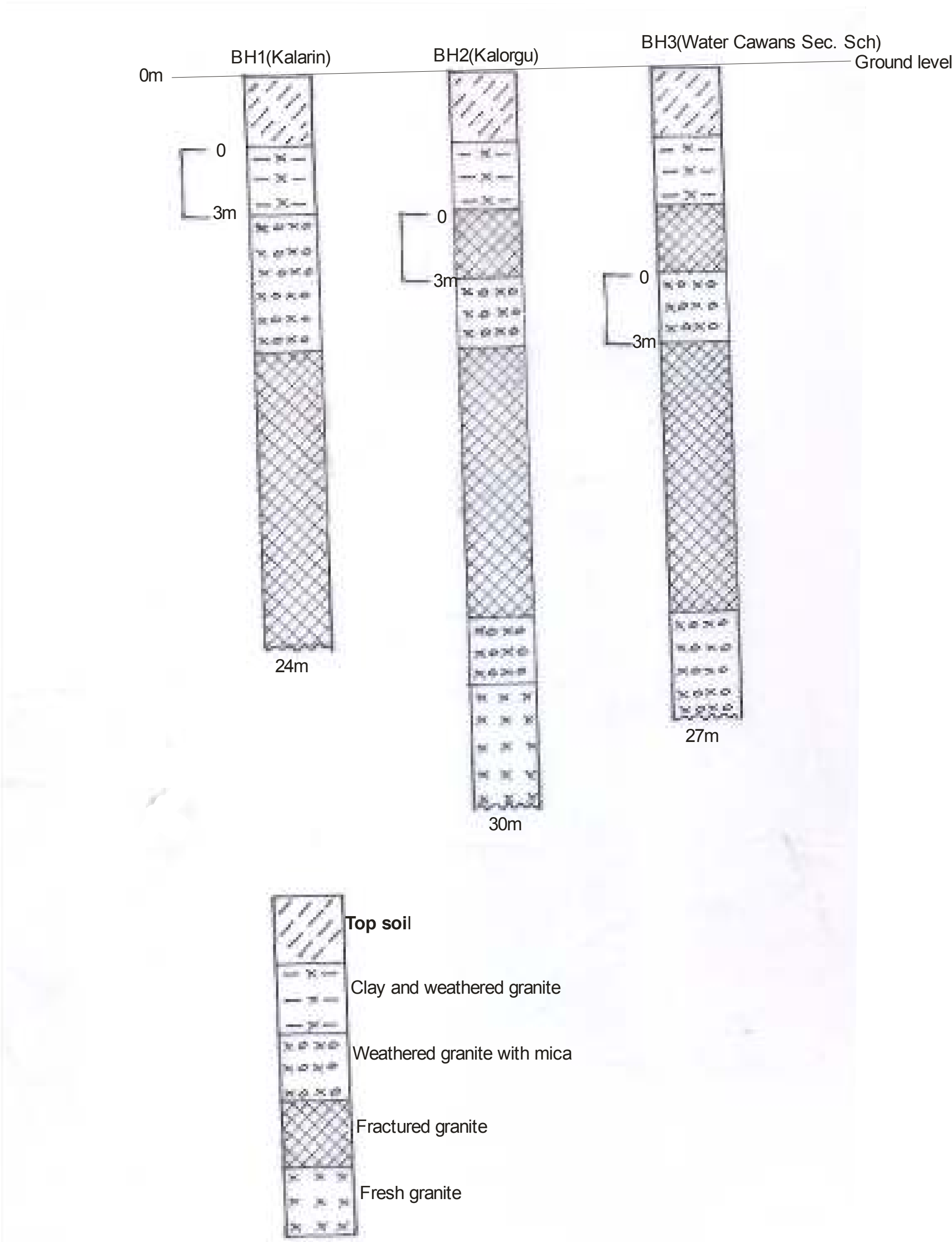

Fig. 3 Lithologic sections of some boreholes in the study area

hand-dug wells and boreholes according to Chilton (1992) method. Field parameters such as Temperature, pH, Conductivity (EC), and Total Dissolved Solids (TDS) were measured in the field using TDS/Conductivity meter (HACH KIT) (Model 44600-00) while pH was measured using HANNA pH meter (Model HI 28129). The samples were analyzed chemically using HACH Spectrophotometer (Model DR/2000, USA) and titrimetric method using digital titrator (HACH) (Model 16-19-01). The samples for bacteriological analysis were carried out within 24 hours using the membrane filtration method employing the use of membrane assemblage (Vacuum pump, Asbestos pad, Bukner flask and membrane funnel) and Leica Quebec Dark field colony counter. The bacteriological analysis was carried out according to WHO (1985).

RESULTS AND DISCUSSION

Results

The results of the physical, chemical and bacteriological characteristics of the water are presented in Table1.

Water quality for domestic uses

Table 1 revealed that pH of the borehole water samples range from 7.4 to 8.1, and values range from 6.9 to 8.2 in the hand-dug wells. The electrical conductivity values of the samples from boreholes range from 204µS/cm to 650µS/cm, values from the hand-dug wells vary from 160µS/cm to 790µS/cm. The values of the chemical parameters revealed that the total dissolved solids (TDS) from the boreholes range from 122mg/l to 346mg/l, and from 80mg/l to 400mg/l in the hand-dug wells. The values of the total hardness range from 73.4mg/l to 103.4mg/l in the borehole samples, and from 70.8mg/l to 162.9mg/l in the hand-dug well samples. The values of the major cations revealed that calcium concentrations from boreholes range from 37.5mg/l to 70.2mg/l, and 20.6mg/l to 111.7mg/l in the hand-dug wells. Potassium values range from 2.2mg/l to 8.6mg/l in boreholes, and 3mg/l to 8.1mg/l in the hand-dug wells. Sodium values range from 0.1mg/l to 6.4mg/l in boreholes, and 0.3mg/l to 7.2mg/l in the hand-dug wells. Magnesium concentrations range from 22.8mg/l to 51.3mg/l in the borehole samples, and values vary from 35.9mg/l to 88.5mg/l in the hand-dug wells. The values of the

Table 1 Results of Chemical and Bacteriological Analyses from Boreholes and Hand-dug wells

Sample Location	Proj. N0.	Temp. ^{o}C	pH	Cond. µS/cm	TDS mg/l	Total Hardness mg/l	Ca^{2+} mg/l	K^{+} mg/l	Na^{+} mg/l	Fe^{2+} mg/l	Mg^{2+} mg/l	Cu^{2+} mg/l	SO_4^{2-} mg/l	NO^{-}_{3} mg/l	F mg/l	HCO_3^{-} mg/l	Cl^{-} mg/l	CO^{-}_{3} mg/l	Coliform Count/ 100ml	SAR	RSC
Kalarin	BH1	28.8	7.4	230	122.0	82.7	40.6	4.3	2.1	2.9	42.1	0.4	25.2	46.8	1.7	366	120.0	7.5	30	0.05	0.76
Kalorgu	BH2	28.7	7.5	260	144.5	85.4	62.6	3.3	3.0	4.7	22.8	0.2	9.0	90.4	1.5	366	85.1	Bdl	7	0.08	1.00
Water Cavans Sec. Sch.	BH3	28.6	7.7	320	204.0	96.6	45.3	7.0	2.2	3.9	51.3	0.7	22.6	78.6	1.4	427	100.3	2.9	25	0.06	0.62
General Hospital	BH4	29.0	8.1	409	264.0	84.4	47.3	2.2	5.2	2.6	37.2	1.6	32.0	96.8	1.9	301	185.1	2.6	Nil	0.14	-0.4
Kulushin Clinic	BH5	28.7	7.5	208	170.0	91.0	59.0	5.8	5.1	3.2	40.0	0.5	22.0	79.0	1.6	355	10.3	2.1	3	0.13	-0.37
Sch. of Health Tech.	BH6	28.9	8.0	406	245.5	73.4	43.7	5.0	3.9	2.9	29.6	1.0	29.1	86.2	1.2	345	59.3	Bdl	80	0.11	1.04
NDP Sec. Okra	BH7	28.6	7.7	204	126.0	76.3	37.5	8.6	0.1	4.8	48.0	0.2	20.0	92.6	1.4	206	32.9	2.4	22	0.002	-2.36
Cross Sabon Layi	BH8	28.8	7.7	650	346.0	103.4	70.2	6.2	6.4	3.2	30.2	0.3	27.0	53.4	1.6	427	90.2	Bdl	Nil	0.16	1.02
Kasar Waje	HW1	28.8	8.0	610	316.0	161.0	111.7	5.2	2.0	2.7	59.3	0.4	34.0	98.0	ND	305	210.0	6.2	58	0.04	-5.24
Okra	HW2	28.7	7.8	160	80.0	70.8	20.6	3.0	5.1	4.0	50.1	0.1	7.0	120.4	1.6	612	20.8	2.3	42	0.14	4.96
Termana	HW3	28.6	7.5	380	223.0	146.8	74.8	7.7	2.7	3.0	72.0	0.1	22.0	121.2	1.5	206	56.7	2.3	40	0.05	-6.19
Kulushin	HW4	28.9	7.5	280	176.0	107.1	58.5	4.6	2.3	3.2	48.7	1.0	24.0	108.6	0.6	355	14.3	Bdl	24	0.05	-1.1
Millionaire's Quarters A	HW5	28.9	11.1	790	400.5	162.9	101.7	8.0	5.2	2.6	61.2	0.5	10.0	164.0	1.9	365	38.0	Bdl	2	0.10	-4.12
Millionaire's Quarters B	HW6	29.0	8.0	480	261.5	163.7	75.2	3.8	3.3	2.6	88.5	1.0	34.0	113.0	1.7	305	28.1	5.2	32	0.07	-5.86
Kaltungo Market	HW7	28.5	7.4	610	305.0	127.4	81.0	4.8	7.2	3.0	46.4	0.1	20.1	130.0	0.6	355	97.3	Bdl	60	0.16	-2.04
Old Palace	HW8	28.8	8.2	300	195.5	141.3	65.1	8.1	0.3	1.9	76.6	0.4	18.0	116.7	1.8	310	65.2	2.4	75	0.005	-4.47
Obasanjo Stadium	HW9	28.5	6.9	300	187.0	74.5	38.6	6.6	6.8	4.0	35.9	0.2	28.5	128.2	1.0	206	30.0	4.6	42	0.19	-1.35
Kwarin Kasar Waje	HW10	30.5	7.8	380	220.0	138.6	82.5	3.1	2.4	2.9	56.1	0.8	32.3	140.0	1.8	355	88.1	Bdl	80	0.05	-2.91
WHO, 1993		variable	6.5-9	1500	1000	500	200	200	200	0.3	150	1.5	400	45	1.3	600	500		0-3		

ND= Not determined, Bdl= Below detection limit major anions revealed that sulphate values from the borehole samples vary from 9mg/l to 32mg/l, and from 7mg/l to 34mg/l in the hand-dug wells. Bicarbonate values range from 206mg/l to 427mg/l in boreholes, and 206mg/l to 612mg/l in the hand-dug wells. Chloride concentrations vary from 10.3mg/l to 186.1mg/l in boreholes, and values range from 14.3mg/l to 210mg/l in the hand-dug wells. The values of carbonate range from 0mg/l to 7.5mg/l in boreholes, and from 0mg/l to 6.2mg/l in the hand-dug wells. Values of iron concentrations vary from 2.6mg/l to 4.8mg/l in boreholes, and 1.9mg/l to 4mg/l in the hand-dug wells. The values of copper in boreholes range from 0.2mg/l to 1.6mg/l, and 0.1mg/l to 1.0mg/l in the hand-dug wells. The values of Flouride range from 1.2mg/l to 1.9mg/l in boreholes, and values vary from 0.6mg/l to 1.9mg/l in hand-dug wells. The colliform bacteria from the borehole samples range from nil to 80 number counts per 100mls, and from 2 to 80 number counts in the hand-dug wells. Nitrate concentrations vary from 46.8mg/l to 96.8mg/l in borehole samples, and 98mg/l to 164mg/l in the hand-dug wells.

Water quality for Agriculture

The criteria adopted for the evaluation of water quality for agricultural practices include SAR, RSC and Salinity hazard. From Table1, the Sodium Adsorption Ratio (SAR) values range from 0.003meq/l to 0.38meq/l, and Residual Sodium Carbonate (RSC) values range from -6.20meq/l to 4.97meq/l. The Salinity hazard is expressed as Elecrical conductivity (EC) and total dissolves solids (TDS). The EC values range from 160mg/l to 790mg/l, and TDS vary from 80mg/l to 400.5mg/l.

Water quality for industrial activities

The criteria for the evaluation of water quality for industrial applications revealed that iron concentrations range from 1.9mg/l to 4.8mg/l, sodium range from 0.1mg/l to 7.2mg/l, sulphate values vary from 7mg/l to 34mg/l. The concentrations of bicarbonate range from 206mg/l to 612mg/l, Chlorides range from10.3mg/l to 210mg/l while total hardness, fluoride, and pH values range from 70.8mg/l to 163.7mg/l, 0.6mg/l to 1.9mg/l, and 6.9 to 8.2 respectively.

Discussion

The physical, chemical and bacteriological parameters for the evaluation of water quality revealed that all the P^H values from the different water sources are below the maximum limit of World Health Organization (WHO). The electrical conductivity (EC) values are also below the WHO recommended limits. All the values of the total dissolved solids (TDS) are also below the WHO maximum permissible limits. The values of total hardness are also below the recommended limits. All the values of the major cations and anions also fall below the WHO maximum permissible limits. However one sample (Hw 2) revealed high concentration of bicarbonate value of 612mg/l which is above the maximum permissible limit of 600mg/l. The values of copper from the different water sources are below the recommended limit of WHO, one sample (BH4) however recorded a value of 1.6 mg/l which is above the recommended limit. Iron concentrations are all above the recommended limit. Iron concentration values are all above the recommended limit of WHO of 0.3mg/l. High iron concentration has taste problem and can precipitates and stains if in excess. Fluoride values range from 0.6mg/l to 1.9mg/l, most samples revealed concentrations above the recommended limit of 1mg/l. A concentration value of 0.6mg/l is regarded as the permissible limit, and 1.3mg/l is the permissible limit maximum in drinking water in many countries (WHO, 1984). Beyond 1.5ppm excessive fluoride in drinking water has been reported to cause mottling teeth. Concentrations above 4ppm may affect teeth structure (Hem, 1959). Fluoride at concentration levels of 3-6ppm can cause skeletal flourosis (WHO, 1984). Based on the above various effects of fluoride concentrations in drinking water, the people in the area are likely to suffer from mottling of teeth. High fluoride concentrations in drinking water in the area could be from the mineralogical dissolutions of fluorite minerals associated with the rock types in the area. The values of total hardness are all below the recommended limit of 500mg/l. According to Mc Carty, 1967, hardness values between 0-75mg/l is classified as soft water, 75-150mg/l as moderately hard, 150-300mg/l as hard and greater than 300mg/l as very hard. The water in the area therefore ranges from soft to hard water. Nitrate concentration values revealed high concentrations above the recommended limit of 45mg/l of WHO. High nitrate concentration is known to cause an increase in risk of babies developing infant methaemoglobinaemia, a disease commonly known as ‘blue baby’ syndrome (Canter, 1996; Jana and Kent, 2009). Other health hazards due to high nitrate concentrations include hypertension, congenital malformations and spontaneous abortions (Spalding and Exner, 1993). Bowman (1994) stated that increased concentration of nitrate often cause blood disorders. Nitrate pollution in the area could be due to shallow nature of hand-dug wells and boreholes, indiscriminate waste disposal practices, use of manure and chemical fertilizers on farm lands. Nitrate is produced from nitrogen following the equation describing the process below

$CH_2O\ (NH_3) + O_2 = NH_4^+ + HCO_3$…………………….. (1)
(Ammonification)
$NH_4 + 2O_2 = NO_3^- + 2H^+ + H_2O$………………………… (2)

The coliform number counts range from nil to 80 coliform number counts revealed that most samples exceeded the recommended limit of WHO of 3 number counts with the exception of BH4, BH5, BH8, and Hw5 are within the recommended limit. High coliform number counts in the area could be from indiscriminate waste disposal practices, and sewage effluent following the use of pit latrines by most residents. The SAR values range from 0.003 to 0.38meq/l, indicating that the water can be used on all classes of soils (Table 2). The RSC values which vary from -6.20 to 4.97 meq/l, revealed that about 67% of the samples fall within the most desirable class (Table 2). EC values range from 160µS/cm to 790 µS/cm, all values revealed that the water in the area has no salinity problem, except sample Hw5 revealed a value of 790 µS/cm which is higher than the critical value (Table 2). Parameters used in the evaluation of water quality for industrial applications revealed that all the concentration values of iron exceeded 0.2mg/l, and therefore the water in the area may not be suitable for some industries (Table 3). According to Todd, 1980, more than 65mg/l of sodium is known to cause problems in ice manufacture. Consequently, the values of sodium from the water sources are below the above standard limit. The water in the study area is good for industrial use as far as sodium is concern. Also, the values of sulphate suggest water of good quality, and can be used for industrial

Table 2 CRITERIA FOR EVALUATING WATER QUALITY FOR AGRICULTURAL PRACTICE

CRITERIA	CLASS (meq/l)	QUALITY
SAR (Mandel and Shiftan, 1981)	0-10	Use for all soil types
	10-18	Preferably used on coarse textured soil
	18-26	May produce harmful effect, good soil management is essential
	26-100	unsatisfactory
RSC (California Fertilizer Committee, 1975)	<0.00	Most desirable
	0.00-1.25	Probably safe
	1.25-2.25	Use on appropriate soils or apply soil amendment
	>2.25	Trouble is imminent
Ec (California Fertilizer Committee, 1975)	<0.75µS/cm	No salinity problem
	0.75-3 µS/cm	Increasing problem may be expected
	>3 µS/cm	May cause severe problems except restricted to only salt tolerant crops

SAR= Sodium Adsorption Ratio
RSC= Residual Sodium carbonate
Ec= Electrical conductivity

SOURCE: Mandel and Shiftan, 1981 and California Fertilizer Committee, 1975

SAR= Sodium Adsorption Ratio, **RSC=** Residual Sodium Carbonate, **Ec**= Electrical conductivity

Table 3 PARAMETERS USED IN THE EVALUATION OF WATER FOR INDUSRIAL USE

PARAMETERS	CONCENTRATION LIMITS	QUALITY
Iron	>0.2 mg/l	Objectionable for most industries
Sodium	>65 mg/l	Can cause problem in ice manufacture
Sulphate	>250 mg/l	Not suitable for carbonated beverages
Bicarbonate	30-250 mg/l	Suitable for brewing, carbonated beverages, food canning and freezing, food processing
Chloride	<100 mg/l	Suitable for textile processing, paper manufacture, and synthetic rubber manufacture
	<250 mg/l	Suitable for food processing
Total dissolved solids	<300 mg/l	Suitable for dyeing and manufacture of plastics, pulp paper, rayon
Fluoride	0.2-2.4 mg/l	Suitable for brewing, carbonated beverages, food canning and freezing, food equipment washing, and food processing
pH	6-8.3	Suitable for brewing, confectionery, food canning and freezing, Rayon manufacture, and taining
Hardness	0-50 mg/l	Suitable for textile
	10-250 mg/l	Food processing
	50-500 mg/l	Taining
	200-250 mg/l	Carbonated beverages

(**Source:** Todd, 1980)

activities. Bicarbonate values revealed that the water quality may not be suitable for some industries (Table 3) as most of the values (83%) exceeded the recommended limit. The values of chloride revealed that the water quality is suitable for some industries as 78% of the values are within the recommended limit of good quality water for industrial use. The values of total dissolved solids, fluorides, and pH also revealed water of good quality for industrial use. The concentration values of total hardness revealed that the water may not be suitable for the textile industries, but may be suitable for taining, carbonated beverages and food processing.

CHARACTERIZATION OF THE GROUNDWATER

Plots of chemical data on piper Trilinear (1944) (Fig. 4) revealed that the water can be classified into Ca-(Mg)-HCO_3^- which belongs to the normal alkaline fresh water type. According to Amadi (1987) that this water type is typical of the Nigerian basement complex terrain with limited mixing perhaps reflecting a primary stage of evolution of its ground water system. The bicarbonate could have resulted from the reaction of carbonate ion in groundwater with hydrogen ion as explained below;

$H^+ + CO_3 = HCO_3^-$.. (3)

Bicarbonate ion in groundwater could also be enriched through the biodegradation of organics in the presence of urea and nitrogenous wastes by de-nitrification (Akujieze and Oteze, 2007) as illustrated below;

$2CH_2O + 4NO_3 = 2N_2 (g) + 5HCO_3 + H+ + 2H_2O$…………………………… (4)

The Ca and Mg resulted from the leaching of plagioclase feldspars which are essential minerals in rocks (Adeyemi et al., 2003). Tijani (1994) reported that the Ca-(Mg)-HCO_3 type of chemical composition is due to the dissolution of silicate minerals in the bed rock and aluminosilicates in the weathered regolith. The Mg^{2+}/Ca^{2+}ratio vary from 0.3 to 2.4 with an average of 0.9. According to Hem (1989) that Mg^{2+}/Ca^{2+}ratios exceeding 0.9 indicate waters from silicate aquifers. Consequently, 39% of the samples revealed water from silicate aquifers

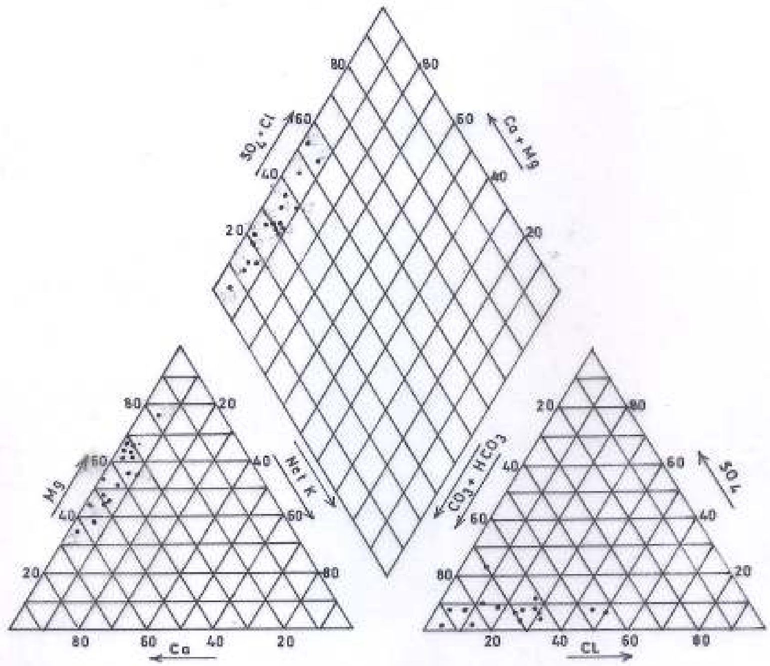

Fig. 4 Trilinear plots of some chemical data in the study area

From the plot of the logTDS values versus the ratios of $Na^+/(Na^++Ca^{2+})$ (Table 4) on the Gibbs (1970) diagram (Fig.5), revealed that evaporation, weathering, and dilution could be responsible for the chemical behavior of the groundwater under different conditions. From Fig.5, the sample points cut across the evaporation, weathering, and dilution fields which are an indication that the chemistry of the groundwater in the area is a function of evaporation, weathering induced dissolution and dilution effects.

Using a Pearson correlation analysis (Table 5) reveal a strong positive correlation between conductivity and TDS (r=0.98), TH and Ca (r=0.88), TH and Mg (r=0.78), TDS and Ca (r=0.76), TDS and TH (r=0.63), SO_4 and Cu (r=0.54), and NO_3 and TH (r=0.51). These strong positive correlations are indications that the chemical parameters have a common source. Positive correlation also exists between Ec and pH (r=0.60), TDS and pH (r=0.58), and NO_3 and pH (r=0.46). This positive correlation between pH and the chemical parameters is an indication that they have influence on each other. The strong positive correlation of TDS with other parameters is a clear indication that these parameters contributed to the overall TDS. The strong correlation between TDS and conductivity is an approximate relationship for most natural water (Richard, 1954). Total hardness reflects the contributions of calcium and magnesium. The strong positive correlations between TH and Ca, and TH and Mg show that the total hardness of the water is caused primarily by Ca and Mg (Ariyo et al., 2005). The scatter plots of some positively correlated parameters are shown in Fig. 6. Negative correlation of some parameters such as Fe and TH (r= -0.62), Fe and TDS (r= -0.54), Fe and Ca (r= -0.50), Fe and Mg (r= -0.50), and Fe and Ec (r= -0.48) (Table 6), suggest that these parameters are not from the same sources and could probably be explained that these parameters have no influence on each other. The scatter plots of some negatively correlated parameters are shown in Fig. 7.

Regression analysis is a predictive model that predicts for the dependent variable whenever there is a change in independent variable. Regression model has the linear equation in the form of;

Table 4 Values of Mg/Ca and Na/(Na + Ca) ratios

Sample Location	Project N0.	Mg/Ca	Na/(Na + Ca)	logTDS
Kalarin	BH1	1.0	0.05	2.1
Kalorgu	BH2	0.3	0.05	2.2
Water cawans Sec. Sch.	BH3	1.1	0.05	2.3
General Hospital	BH4	0.8	0.10	2.4
Kulushin Clinic	BH5	0.7	0.08	2.2
Sch. of Health Tech.	BH6	0.7	0.08	2.4
NDP Sec. Okra	BH7	1.3	0.003	2.1
Cross Sabon Layi	BH8	0.4	0.08	2.5
Kasar Waje	HW1	0.5	0.02	2.5
Okra	HW2	2.4	0.20	1.9
Termana	HW3	1.0	0.03	2.3
Kulushin	HW4	0.8	0.04	2.2
Millinaire's Quarters A	HW5	0.6	0.05	2.6
Millinaire's Quarters B	HW6	1.2	0.04	2.4
Kaltungo Market	HW7	0.6	0.08	2.5
Old Palace	HW8	1.2	0.004	2.3
Obasanjo Stadium	HW9	0.9	0.1	2.3
Kwarin Kasar Waje	HW10	0.7	0.03	2.3
Average		0.9	0.06	

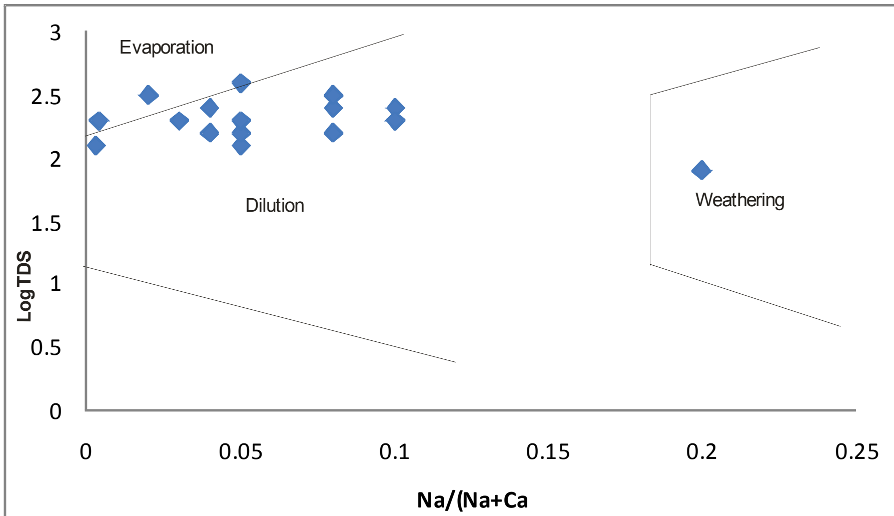

Fig. 5 Plot of logTDS versus Na/(Na+Ca) ratio

Table **5** Correlation between some hydrochemical parameters

Variable	Correlation coefficient
Conductivity and TDS	0.98
TH and calcium	0.88
TH and magnesium	0.78
Conductivity and calcium	0.78
TDS and calcium	0.76
TDS and TH	0.63
Ec and pH	0.60
TDS and pH	0.58
Sulphate and copper	0.54
Nitrate and TH	0.51
Nitrate and pH	0.50

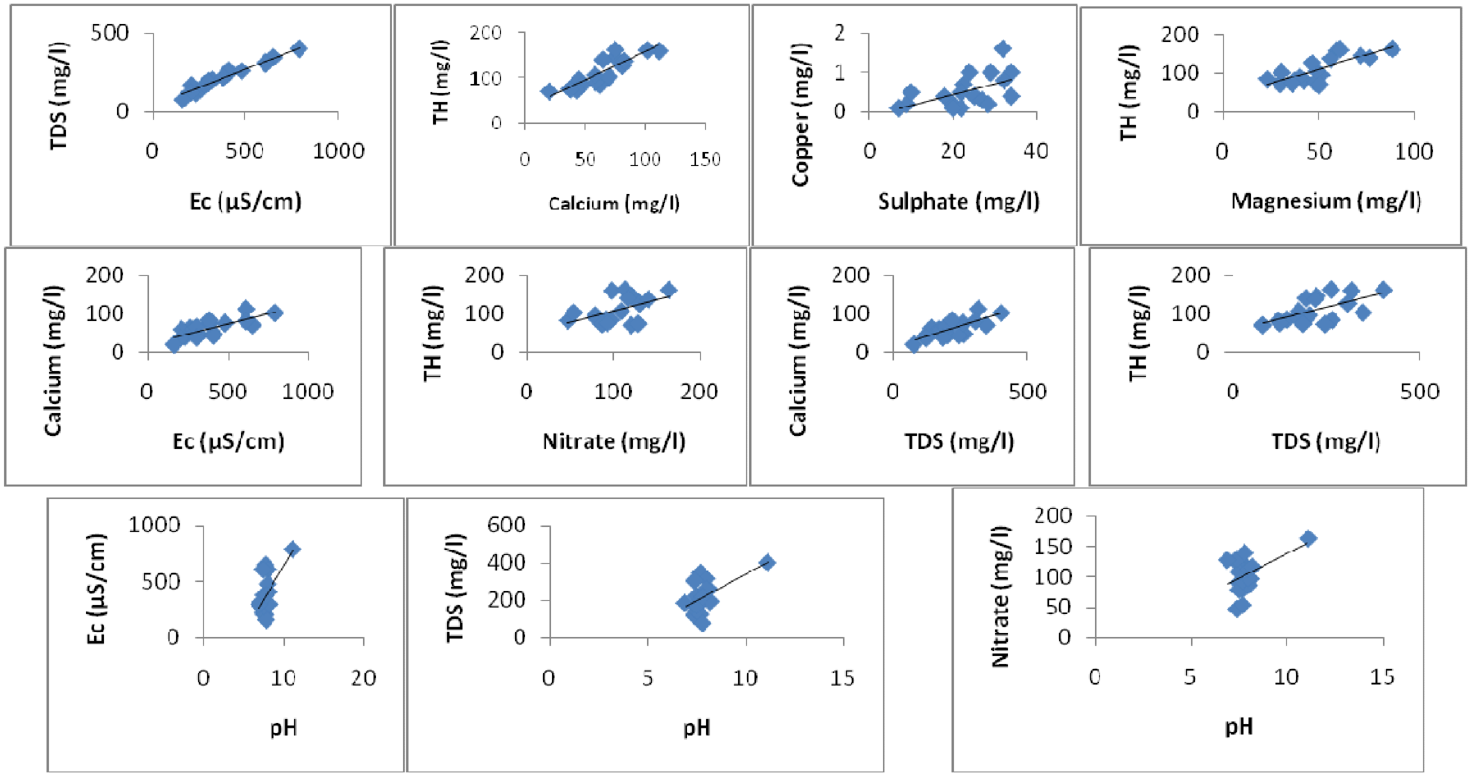

Fig. 6 Depicts positive correlation between some chemical parameters.

Table 6 Correlation of some hydrochemical parameter

Variable	Correlation coefficient
Fe and TH	-0.62
Fe and TDS	-0.54
Fe and Ca	-0.50
Fe and Mg	-0.50
Fe and Ec	-0.48

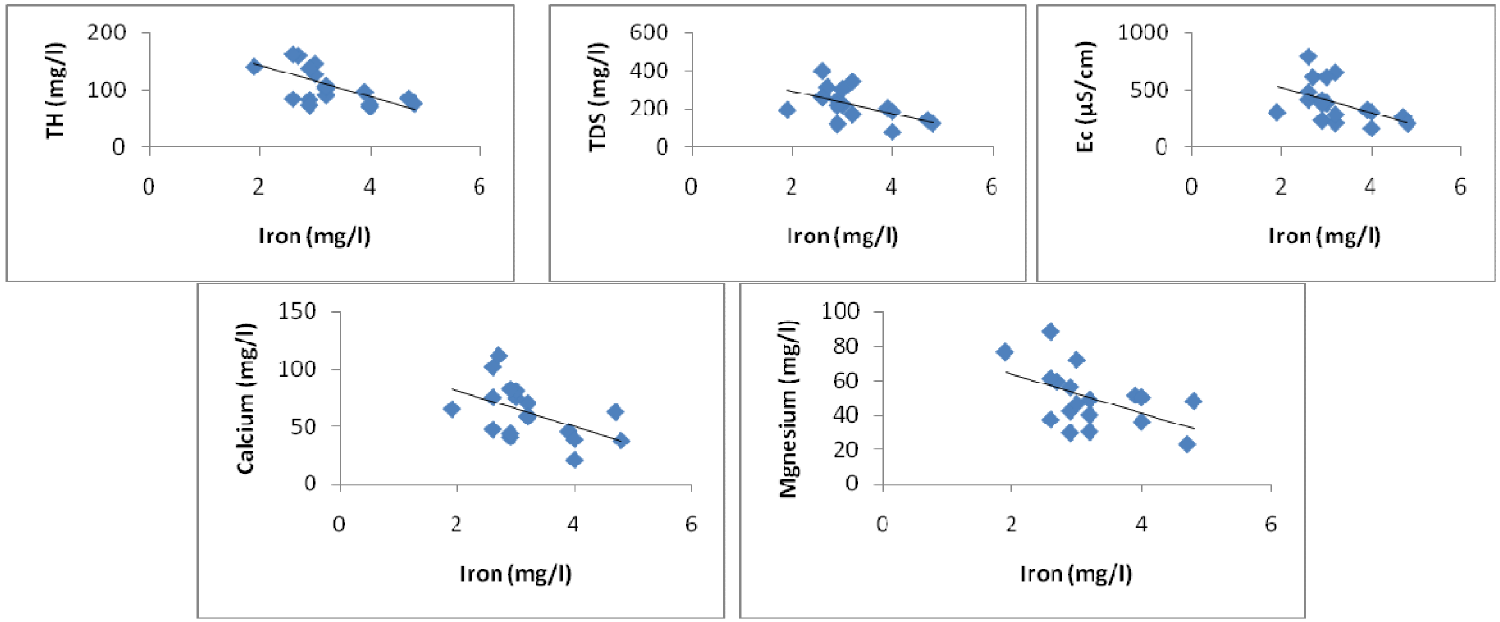

Fig. 7 Depicts negative correlation between some chemical parameters.

$\hat{Y} = a + bx$ ……………………………………………………………………………………………. (5)
The above equation is linear regression equation while the equation below is linear multiple regression equation.
$\hat{Y} = a+b_1x_1+ b_2x_2+ b_3x_3+ b_4x_4 \ldots\ldots b_nx_n$ (Multiple regression)……….. (6)
Where,
a= constant, b= slope or rate of change of the independent variable x. based on the regression analysis, estimates of the linear and multiple regression equations developed for the study area are as follows;
TDS= 41.985+ 0.463Ec………………………………………………. (7)
TH= 0.307+ 0.985Ca+Mg…………………………………………. (8)
TDS= 53.693+ 2.706Ca…………………………………………………. (9)
SO_4= 17.438+ 10.833Cu…………………………………………….. (10)
NO_3= 56.023+ 0.440TH…………………….......................... (11)
TDS= -200.228-11.81CO_3+ 8.022K+ 0.686Ca+ 7.241Na+ 0.294NO_3+ 0.139HCO_3+ 0.419Cl+ 6.817SO_4+ 1.109Mg…………………………………………………………………… (12)
For example in equation (12) the x_1= CO_3, x_2= K, x_3= Ca, x_4= Na, x_5= NO_3, x_6= HCO_3, x_7= Cl, x_8= SO_4 and x_9= Mg
Table 7 shows the results of the regression analysis between TDS and conductivity (R=0.95), TDS and Ca (R=0.58), SO_4 and Cu (R=0.29), and NO_3 and TH (R=0.26). The R Square values used in the model explain how good a regression model is or how well data points fit in to the regression model. The results of R Square values suggest a common origin for the chemical parameters. The R Square between SO_4 and Cu, and NO_3^- and TH indicated weak relationships, but it also shows that the parameters could have resulted from a common source. Total hardness of the water in the area could be influenced by organic decomposition such as domestic effluent or sewage effluent. Multiple regression analysis between TDS and the major ions revealed R Square of 1.00 (Table 7). This relationship explains the contributions of the ions to the overall mineralization of the groundwater in the area. Multiple regressions between TH, Ca and Mg revealed R Square of 0.99 which further confirms that the hardness of water is dependent on Ca and Mg. Calcium may be released from feldspars, amphiboles, and pyroxenes, Mg may also be released from the above minerals or even clay minerals (Nton et al., 2007). TDS, TH, sulphate, and copper could be influenced by waste disposal practices. Fig. 8 shows the linear regression curves of some chemical parameters. The correlation and regression analyses revealed that the dissolved geochemical constituents in groundwater in the area could have been derived from similar sources.

Table 7 Regression analysis of some hydrochemical parameters

Variable		
Dependent	Independent	R Square
TDS	Cond.	0.95
TH	Ca and Mg	0.99
TDS	Ca	0.58
SO_4	Cu	0.29
NO_3	TH	0.26
TDS	CO_3, K, Ca, Na, NO_3, HCO_3, Cl, SO_4, Mg	1.00

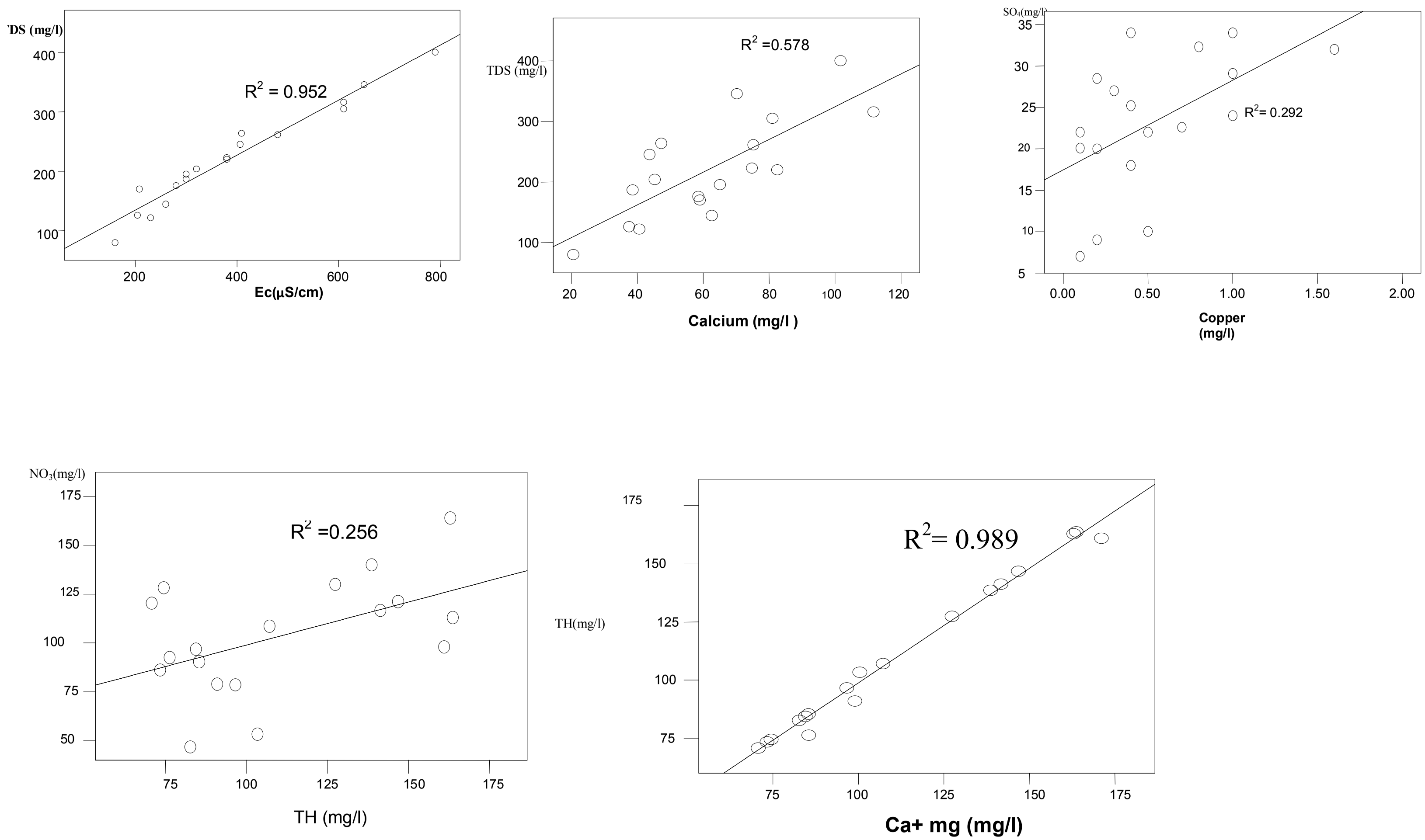

Fig.8 Regression curves of some chemical parameters in the study area.

CONCLUSIONS

The following conclusions can be drawn from this study:

1. The study area is underlain by the basement complex rocks which consist of the porphyritic and biotite granites. The porphyritic granites are coarse to very coarse grained in texture with large white or pinkish prismatic phenocrysts of microcline. The biotite granites have granular texture with wide range of textures.
2. Borehole lithologic logs revealed fractured aquifer system which range from 12m to 24m in thickness. Borehole yields range from 3.3l/s to 16.7l/s.
3. The results of 18 water samples collected from the hand-dug wells and boreholes revealed that the groundwater is polluted due to high concentrations of iron, fluoride, nitrate, and coliform bacteria. The results further revealed that the water is generally good for agricultural practices but may not be suitable for some industries.
4. Plots of chemical data on trilinear diagram revealed that the water in the area is of Ca-(mg)-HCO_3 which belongs to the normal alkaline fresh water type.
5. Based on Mg^{2+}/Ca^{2+} ratio, about 39% of the water samples reveal water from the silicate aquifer. The plot of logTDS against $Na^{+}/(Na^{+}+Ca^{2+})$ ratio indicated that the groundwater chemistry in the area is controlled by evaporation, weathering induced dissolution and dilution effects.
6. Correlation and regression analyses on chemical data revealed that the parameters could be from similar source.
7. Groundwater quality in the area is controlled by the geology and anthropogenic activities.
8. The water quality is unfit for human consumption due to bacteriological pollution, and high concentrations of iron, fluoride, and nitrate. The water would require treatment to be used for domestic and industrial purposes in the area.
9. High groundwater velocities in fractures and thin overburden materials could be responsible for the wide range of groundwater quality deterioration in the area. It is recommended that regular water quality monitoring will ensure groundwater quality protection and conservation.

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