JOURNAL GEOLOGICAL SOCIETY OF INDIA
Vol.82, October 2013, pp.413-420

Assessment of Groundwater Quality of Lokoja Basement Area, North-Central Nigeria

R. AYUBA[1], O. V. OMONONA[2] and O. S. ONWUKA[2]
[1]Department of Geology, Kogi State University, Anyigba, Nigeria
[2]Department of Geology, University of Nigeria, Nsukka, Nigeria
Email: omononavictor@yahoo.com

Abstract: The hydrochemical characteristics and quality of groundwater in Lokoja basement area have been evaluated based on different indices for assessing groundwater for drinking and irrigation purposes. Twenty groundwater samples were collected and analyzed for physicochemical parameters, major ions and heavy metals. The results revealed that the groundwater is slightly alkaline, with little variations in chemical composition. For example, electrical conductivity (EC) ranges from 242µS/cm to 1835µS/cm. The abundance of the major ions is in the order of Ca^{2+} >Na^{+}>Mg^{2+}>K^{+}> $Fe^{2+/3+}$ = HCO_3 >Cl^- >NO_3 >SO_4 >PO_4. Based on the hydrochemical data, four hydrochemical facies were identified namely, Ca-Mg-HCO_3, Na-K-HCO_3, Na-K-Cl-SO_4 and Ca-Mg-Cl-SO_4 and these facies depict groundwater recharge zone, transition flow zone, deep flow zone and mixed water zone respectively. Groundwater from the area is unsuitable for drinking and domestic purposes as some of the ions and heavy metals of health concerns are well above the stipulated guideline values. Irrigation water quality indicators (salinity, Na % and Mg %), reveal that the groundwater is unsuitable for irrigation purposes. Interpreted statistical analysis reveals that the groundwater chemical compositions are controlled predominantly by weathering of litho units of the basement rocks and by drainage from domestic wastes.

Keywords: Groundwater quality, Hydrochemical facies, Basement area, Lokoja, Nigeria.

INTRODUCTION

Groundwater is a key source of fresh drinking water essential to life over the globe. It is found in aquifers, which are rocks that have the capacity of both storing and transmitting groundwater, in significant quantities (Todd, 1980). Lokoja is a confluence town, where the river Niger from the Guinea Highlands in southeastern Guinea and the River Benue from the Adamawa Plateau of northern Cameron met. The economy of the city is heavily dependent on agricultural production (crop production and fish farming). Lokoja has witnessed an upsurge in infrastructural development and increase in human population since it became the capital of Kogi state in 1991. The city has a current population of 195, 261 inhabitants (2006 national census). Consequently, the water needs of the people have highly increased.

Notwithstanding the abundance of surface water in Lokoja, potable water supply has not been as effective as expected. Currently, the state water board supplies Lokoja and environs about 700, 000 gallons of water per day, against 10 million gallons needed per day (Abenemi, S. 2007). Water supply in Lokoja is a conjunctive use of both surface water and groundwater. Surface water in the study area is contaminated by diverse effluents emptied into the river Niger from industrial and domestic sources. This imposes a tedious task on the treatment and distribution of surface water for several needs in Lokoja.

Groundwater supply, however, has not augmented surface water supply adequately, because of the geology of the study area and poor siting of boreholes and wells. For example, the average thickness of the regolith over the fresh basement bedrock in Lokoja has been put at 20m (LRNBDA, 2003). Successive governments in Kogi State and the United Nation Children Education Fund (UNICEF)-Water and Environmental Sanitation (WES) project have provided a number of boreholes to ameliorate the water scarcity in Lokoja and environs. However, much attention has not been given to the quality of water that is being provided. Safe water supply especially when complemented by good sanitation and hygiene is an indispensable factor in the achievement of the Millennium Development Goals (MDGs).

This work is aimed at determining the groundwater hydrochemical characteristics and assessing their quality for agricultural and domestic uses.

0016-7622/2013-82-4-413/$ 1.00 © GEOL. SOC. INDIA

STUDY AREA

Lokoja, the confluence of river Niger and river Benue, is located between latitudes 7°45'N and 7°53'N and longitudes 6°39'E and 6°48'E (Fig.1). It is underlain by the basement complex. The town is strategically located and is accessible by good road network that links northern and southern and northern and western Nigeria. The area has low to moderate relief, with a few scattered laterite-capped hills of elevations ranging from 30 m – 400 m above sea level. It is drained by the Niger – Benue river system. The drainage system shows a dendritic pattern.

Lokoja is characterized by two distinct seasons namely, the rainy and dry seasons. The rainy season commences in April and lasts till October, while the dry season is from November to March. The annual average rainfall ranges between 1000mm and 1500mm while the mean annual humidity is about 70%. The annual average temperature is 27°C, with annual average sunshine hour of 6.7 per day. A high temperature of 33°C - 36°C is experienced in the area. Vegetation of the area is of the Guinea Savannah type, with denser (gallery) forests fringing some of the rivers (Federal Ministry of Aviation, 2007).

LOCAL GEOLOGY AND HYDROGEOLOGY

The study area is underlain by the basement rocks of Precambrian age, which comprise mainly of granite, gneisses and schists (Hockey and Sachi, 1986). The granite is coarsely porphyritic, with biotite and hornblende being the main ferromagnesian mineral. The gneisses are characterized by fairly regular banding in which predominantly light bands alternate with predominantly dark bands. Individual bands vary in thickness from a few millimeters to several centimeters. The schists include mica-schists, quartz-schists, and quartz-muscovite schist, in which quartz is usually dominant over muscovite. The quartz-muscovite schists are comparatively well exposed and form rounded hills or ridges due to resistant intercalated quartzite bands. The rocks are broadly oriented in the north-south direction and marked by a sub-parallel alignment of elongated and closely packed feldspar phenocrysts, mainly microcline and a corresponding preferred orientation of biotite mica and iron minerals. The geological map of Lokoja metropolis is presented in Fig.2.

Groundwater in the Lokoja area occurs in weathered and or weathered/fractured basement rocks and is recharged by precipitation and by river Niger. Two aquifer types have been delineated in the area: weathered layer aquifer and weathered/fracture aquifer. The Lokoja area is generally drained by rivers Niger, Benue and Meme. Aquifer parameter data of the study area are relatively sparse. Based on aquifer test data, the static water level varies between 1.5 m and 7.6 m; well depth is between 8.2 m and 21.8 m; and yield is between 70m^3/day and 130m^3/day (LRNBDA, 2003).

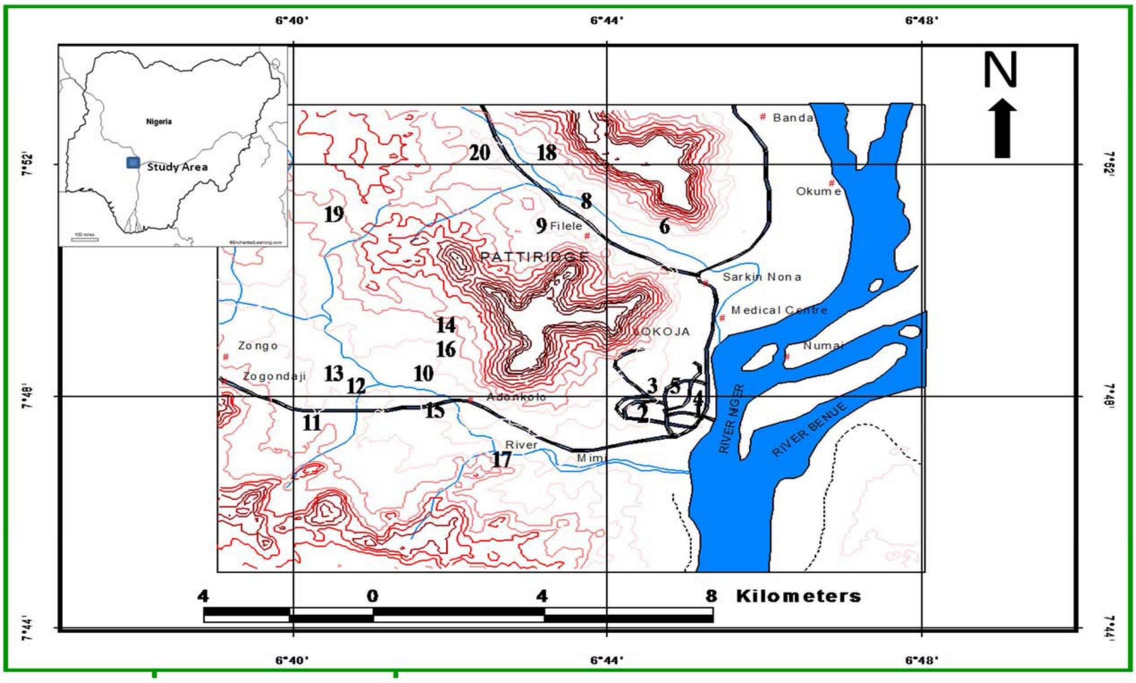

Fig.1. Location map of the study area showing sample collection points.

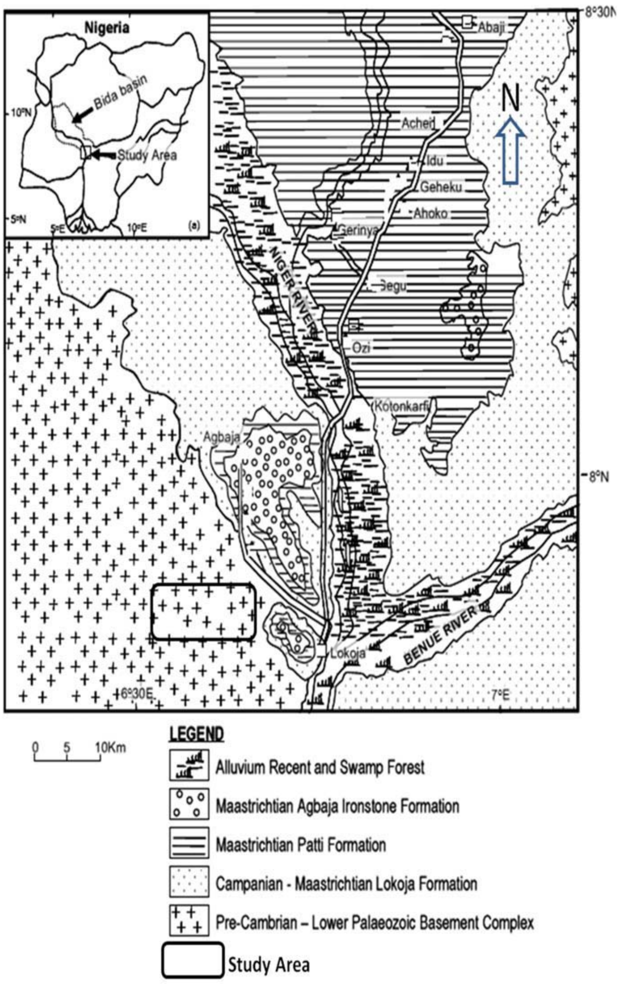

Fig.2. Geological map of the study area (*after* Agyinji, 1993).

MATERIALS AND METHODS

A total of twenty groundwater samples were collected in one-liter plastic containers in February 2009. Thirteen samples were collected from boreholes while the remaining seven were taken from dug wells. Sensitive parameters such as pH, temperature and electrical conductivity (EC) were determined in the field. Standard laboratory methods were used for the determination of other biological, physical and chemical characteristics of the groundwater. Total bacteria and faecal coliform counts were determined by using the Millipore filtration method. The pH was determined by using a Hach portable pH/ISE meter. The meter was calibrated with buffers pH 4.0 and 9.0 prior to measurement. EC, total dissolved solids (TDS) and temperature were determined by WTW conductivity meter calibrated with KCl solution. Colour, turbidity and total suspended solids (TSS) were determined by Hach DR/2000 spectrophotometer. Total Hardness (TH) was determined by Hach digital titrator. 0.8M EDTA titration cartridge was selected and titrated against the water samples. 2 ml of hardness buffer (pH 10.01) was introduced to a 50 ml sample and this was followed by CalVver 2 calcium indicator. The mixture was titrated from pink to a blue end point.

Calcium Hardness (CaH) was also determined by Hach digital titrator. 0.8M EDTA titration cartridge was selected and titrated against the water samples. 2ml of 8N potassium hydroxide standard solution was introduced to a 50ml sample and the mixture was titrated from pink to a light blue end point. Magnesium Hardness (MgH) was determined by finding the difference between TH and CaH. TH as mg/l$CaCO_3$ = MgH mg/l - CaH mg/l. $CaCO_3$ Alkalinities (HCO_3^- CO_3^{2-} and OH^-) were determined by titrimetric analytical method employing standard HCl solution. 100ml of the samples were titrated with standard HCl using phenolphalein and bromocresol green indicator. Chloride (Cl) was determined by the argentomentry titrimetric method, employing standard silver nitrate solution. 50ml of water samples were titrated with standard $AgNO_3$ solution using potassium chromate indicator. The mixture was titrated from yellow to dirty brownish colour. Trace metals, such as Pb, Cr, Cd and Mn, were determined by digital bulk 205 atomic absorption spectrophotometer (AAS). $S0_4^{2-}$, NO_3^-, Fe and PO_4^{3-} were all determined by Hach DR/2000 spectrophotometer.

Statistical analysis was carried out using the software package, GenStat Discovery Edition 3. The two statistical tests that were carried out are correlation matrix and principal component analysis. Hydrochemical plots were drawn using the Aquachem 2011.1 software while the irrigation parameters (sodium adsorption ratio, sodium percentage and magnesium hazard) were determined using AqQA version 1.1.1 [1.1.5.1] software.

RESULTS AND DISCUSSION

Groundwater Chemistry

The summary of the results of the analysis of the hydrochemical parameters is presented in Table 1. It can be observed from the table that the pH in all the groundwater samples ranged from 7.8 to 8.8, with a mean of 8.39 indicating an alkaline condition. The pH values are all within the prescribed WHO (1993) limits of 6.5 to 8.5 for potable water. Table 1 also shows that the total hardness varied between 120mg/l and 5239mg/l, with a mean of 499mg/l, indicating that the groundwater in the study area is hard. TDS varied from 157.04 to 1192.49mg/l, with a mean of 443.42mg/l. TDS in 3 of the 20 groundwater samples are above the stipulated guideline limit of 500mg/l for drinking water purposes. Groundwater containing TDS (>1000mg/l)

Table 1. Summary of results of physiochemical parameters

Site no.	Source	pH	Temp*	EC#	TDS	TH	SO_4	Cl	HCO_3	NO_3	PO_4	Ca	Mg	Na	K	Fe	Cd	Cr	Mn	As	Pb
1	BH	8.7	30.8	599	389.61	282	2	34	160	10.56	0.13	172.8	24.42	40.095	12.117	0.07	0.004	0.003	0.01	0.009	0.006
2	BH	8.8	32.1	601	390.57	222	12	40	120	13.20	0.21	75.2	80.3	49.788	10.856	0.06	0.000	0.000	0.04	0.007	0.000
3	HDW	8.4	32.3	599	389.81	260	10	38	100	9.68	0.18	44.8	19.53	41.051	12.093	0.05	0.000	0.006	0.04	0.006	0.000
4	BH	8.3	32.5	1383	899.47	352	98	126	100	34.76	0.40	73.6	16.60	43.113	15.147	0.26	0.008	0.017	0.03	0.010	0.009
5	HDW	8.0	31.4	339	220.17	198	10	28	100	17.16	0.50	42.4	22.46	41.051	19.332	0.17	0.013	0.125	0.20	0.011	0.018
6	HDW	7.9	32.2	500	325.14	268	5	52	80	37.84	0.12	76.0	19.04	48.916	17.149	0.06	0.015	0.145	0.01	0.011	0.022
7	BH	8.7	31.3	242	157.04	240	8	38	45	25.52	0.12	74.4	38.09	37.675	13.093	0.16	0.005	0.022	0.05	0.008	0.017
8	BH	8.7	31.8	569	370.11	264	15	50	90	7.04	0.30	72.8	20.02	41.115	10.941	0.06	0.001	0.035	0.00	0.009	0.008
9	BH	8.7	31.1	331	215.09	122	2	16	5	101.20	0.36	32.8	9.76	44.316	17.315	0.06	0.000	0.042	0.03	0.006	0.013
10	BH	8.6	34.4	385	250.45	213	0	16	45	7.48	0.72	62.8	13.67	31.151	11.932	0.07	0.000	0.004	0.00	0.006	0.000
11	BH	7.9	32.0	601	390.46	306	18	46	190	9.68	0.46	81.6	24.91	62.133	21.881	0.10	0.001	0.117	0.00	0.008	0.008
12	BH	8.8	33.3	503	327.08	264	5	10	100	13.64	0.38	72.0	20.51	51.095	16.743	0.05	0.014	0.205	0.06	0.010	0.023
13	BH	8.6	33.5	623	405.15	304	10	36	125	21.44	0.46	100.0	13.19	44.638	12.986	0.00	0.003	0.115	0.01	0.007	0.019
14	BH	7.9	33.8	1835	1192.49	600	75	209	321	115.72	0.19	160.8	50.79	191.572	55.117	0.13	0.000	0.043	0.01	0.007	0.008
15	HDW	8.8	32.4	576	374.60	332	0	18	0	16.28	0.53	69.6	38.58	54.162	83.786	0.24	0.001	0.056	0.20	0.008	0.014
16	BH	8.6	30.3	533	402.16	295	16	86	100	33.53	0.16	60.2	24.16	46.301	16.376	0.18	0.018	0.000	0.04	0.009	0.000
17	HDW	8.2	31.2	385	237.26	120	0	18	47	16.05	0.16	73.2	23.08	27.617	12.102	0.20	0.006	0.023	0.04	0.003	0.014
18	HDW	7.8	33.0	622	376.13	122	0	61	83	20.63	0.37	52.1	20.71	42.317	11.652	0.08	0.004	0.019	0.00	0.000	0.010
19	BH	8.1	29.9	596	380.73	198	3	53	126	11.24	0.43	41.19	33.86	88.187	12.716	0.27	0.000	0.015	0.05	0.012	0.040
20	HDW	8.3	30.7	1164	712.15	277	53	148	112	83.19	0.11	82.0	36.07	46.581	23.861	0.01	0.003	0.190	0.20	0.008	0.010

* measured in °C; #µS/cm; other parameters are measured in mg/l

may cause laxative and constipation effects. The anions are in the order of HCO_3 >Cl^- >NO_3 >SO_4 >PO_4, the cations Ca^{2+} >Na^+>Mg^{2+}>K^+>$Fe2^{+/3+}$, and the heavy metals $Cr^{3+/6+}$ > Mn^{2+} > Pb^{2+} > As^+.

Statistical Analysis

Correlation matrix and principal component analysis tests were carried out on the geochemical data. Correlation coefficient is used to establish the relationships between two parameters. It helps to know how one parameter predicts the other. The correlation matrix for TDS, major ions and heavy metals is presented in Table 2 and significant correlation between parameters were taken at values equal to or greater than 0.5. From the table, HCO_3^-, Cl^-, Ca^{2+}, NO_3, Na^+ and SO_4 appear to be the main contributors of the groundwater TDS because of their high correlation coefficients with TDS. SO_4 shows a very strong correlation (0.886) with Cl^- indicating that the two anions are derived from the same source. HCO_3^--Ca^{2+}, HCO_3^--Cl^-, NO_3^-- Cl^-, Na^+-Cl^-, Na^+-HCO_3^- and SO_4^{2-}-HCO_3^- are also the more significant correlation pairs.

Principal component analysis (PCA) is currently used in environmental impact studies. It aids in reducing the complexity of large-scale geochemical data sets and thereby identifying the common underlying processes (Davis, 1973 and 1986). In this study, 15 variables (parameters) in 20 groundwater samples were used for the principal component analysis and four principal components (PCs) were extracted

Table 2. Correlation coefficient matrix of water quality parameters (n = 20)

	As^+	Ca^{2+}	Cd^+	Cl^-	Cr^{3+}	TDS	Fe^{2+}	HCO_3^-	K^+	Mg^{2+}	Mn^{2+}	NO_3^-	Na^+	PO_4^-	Pb^{2+}	SO_4^{2-}
As^+	**1.000**															
Ca^{2+}	0.052	**1.000**														
Cd^+	0.360	-0.116	**1.000**													
Cl^-	0.064	0.431	0.373	**1.000**												
Cr^{3+}	0.322	0.042	0.361	0.039	**1.000**											
TDS	0.076	**0.522**	-0.142	**0.925**	0.027	**1.000**										
Fe^{2+}	0.249	0.182	0.135	0.086	0.376	0.105	**1.000**									
HCO_3^-	0.148	**0.669**	0.114	**0.671**	0.082	**0.705**	**0.106**	**1.000**								
K^+	0.053	0.232	0.172	0.263	0.109	0.370	0.318	0.100	**1.000**							
Mg^{2+}	0.341	0.251	0.266	0.290	0.159	0.277	0.098	0.334	0.290	**1.000**						
Mn^{2+}	0.258	0.228	0.138	0.023	0.408	0.023	0.230	0.259	0.482	0.194	**1.000**					
NO_3^-	0.073	0.225	0.100	**0.664**	0.166	**0.575**	0.128	0.301	0.314	0.107	0.096	**1.000**				
Na^+	0.089	0.479	0.228	**0.688**	0.010	**0.720**	0.168	**0.776**	0.487	0.404	0.106	**0.572**	**1.000**			
PO_4^-	0.018	0.336	0.2088	0.344	0.037	0.180	0.162	0.219	0.166	0.307	0.080	0.298	0.114	**1.000**		
Pb^{2+}	0.416	0.196	0.150	0.161	0.384	0.173	0.311	0.086	0.017	0.135	0.178	0.042	0.126	0.135	**1.000**	
SO_4^{2-}	0.184	0.324	0.008	**0.886**	0.057	**0.897**	0.196	**0.506**	0.186	0.156	0.042	**0.514**	0.464	0.152	0.186	**1.000**

Table 3. Factor loadings of each variance

Parameter (n=15)	PC 1	PC 2	PC 3	PC 4
As	-0.04629	**0.43980**	-0.14476	-0.33535
Ca	-0.27767	-0.15391	-0.15886	-0.05140
Cd	0.08387	0.32538	-0.33415	-0.20549
Cl	**-0.40961**	0.02078	-0.06929	-0.01836
Cr	-0.01532	0.39471	-0.43222	0.38422
Fe	-0.03414	0.26274	**0.48069**	**-0.48737**
HCO_3	**-0.35693**	-0.09234	-0.21026	-0.18190
K	-0.19771	0.22783	0.41116	0.30019
Mg	-0.18908	-0.03415	0.34801	0.06663
Mn	0.00421	**0.45262**	0.25522	0.39947
NO_3	-0.29338	0.04714	-0.07522	0.32994
Na	**-0.38235**	0.03220	0.07821	-0.07580
Pb	0.06416	0.42156	-0.04063	-0.20537
SO_4	**-0.35602**	0.06573	-0.0.7430	-0.10725
TDS	**-0.42327**	-0.00020	-0.03208	-0.04091
Latent Roots	5.008	2.375	1.710	1.364
Percentage variation	33.39	15.83	11.40	9.10

which explains 69.72% of the total sample variance. The numbers of significant PCs for interpretation were selected on the basis of the Kaisier criterion with Eigen value higher than one and a total explained percentage of variation equal to or greater than 70%. Table 3 shows the factor loadings, the latent roots, Eigen value and the percentage of variation of each PC. The selection of parameters in each PC was based on their latent roots; the first PC has a latent root of 5.008, the second 2.375, the third 1.710 and the fourth 1.364. Five parameters were considered to be highly varied for PC 1; two for PC 2; and one each for PC 3 and PC 4 respectively.

The first PC (PC1) explains 33.39 % of the total sample variance and has loading for Cl^-, HCO_3, Na^+, SO_4 and TDS. Chloride (Cl^-) is thought to be released from the leaching of upper soil layers, which receive waste water and sewage from domestic activities. HCO_3 source may be due to action of CO_3 upon the basic material of soils and granitic rocks. Na^+ concentration in groundwater indicates weathering of plagioclase bearing rocks and SO_4 source could be attributed to anthropogenic activities (domestic waste waters). Because of the high correlation coefficients of Cl^-, HCO_3, Na^+ and SO_4, 0.95, 0.705, 0.72 and 0.897 respectively with TDS, they are assumed to be the dominant dissolved ions in the groundwater of the area. PC1 therefore could be said to reflect the influence of weathering, leaching of host rocks and anthropogenic activities.

The second PC (PC2), which describes 15.83 % of the total variance, has high loading for As^+ and Mn^{2+}. Both As^+ and Mn^{2+} are thought to be released from weathering of bedrock materials (mica, biotite and amphibole hornblende); and the association of these elements in PC2 reveals contamination of groundwater by heavy metals. PC3 and PC4 account for 11.40 % and 9.10 % respectively of the total variance of the data set and both have high loading for $Fe^{2+, 3+}$. Iron is thought to be released by weathering of ferromagnesian micas and amphiboles of the basement rocks. These PCs reflect concentration of iron in groundwater.

The PC scores are presented in Table 4 and it shows the loadings of the four PCs (PC1, PC2, PC3 and PC4) on each of the groundwater samples. PCs with scores of 1.0 and higher are considered significant controlling processes. PC1 has high loading on samples 4, 5, 7, 9, 10, 12, 14, 17, 18 and 20; this indicates that these samples are controlled by weathering of host rocks and domestic wastes. PC2 has high loadings on samples 1, 2, 3, 5, 6, 10, 12, 15, 18, 19 and 20 which reveals that the samples' chemistry is predominantly controlled by heavy metal contamination. PC3 and PC 4 have high loadings on samples 2, 4, 9, 6, 12, 13, 15, 16, 19 and 20, suggesting the influence of dissolution of iron and its concentration in groundwater.

Hydrochemical Facies

Piper plot (Piper, 1953) is used to infer hydrochemical facies of groundwater. The piper plot (Fig.3) reveals four hydrochemical facies ($Ca\text{-}Mg\text{-}HCO_3$, $Na\text{-}K\text{-}HCO_3$, $Na\text{-}K\text{-}Cl\text{-}SO_4$ and $Ca\text{-}Mg\text{-}Cl\text{-}SO_4$), with the $Ca\text{-}Mg\text{-}HCO_3$ as the predominant facies type.

Ca-Mg-HCO_3 Facies

This facies is described as earth alkaline water and it constitute about 70% of the total facies types in the area. It

Table 4. Principal scores

Sample site	PC 1	PC 2	PC 3	PC 4
1	-0.212	**-1.549**	-0.815	-0.854
2	-0.253	**-1.812**	**1.349**	0.300
3	0.987	**-1.679**	0.205	0.371
4	**-2.236**	0.675	0.007	**-2.046**
5	**1.351**	**2.909**	-0.094	0.112
6	0.752	**1.573**	**-2.007**	-0.263
7	**1.226**	0.103	0.769	-0.493
8	0.722	-0.979	-0.460	-0.403
9	**1.406**	-0.558	0.051	**1.515**
10	**1.869**	**-1.939**	0.197	0.163
11	-0.360	-0.558	-0.663	-0.144
12	**1.206**	**2.000**	**-2.066**	0.293
13	0.474	-0.467	**-1.687**	0.454
14	**-8.188**	-0.692	0.277	0.065
15	0.394	**2.181**	**3.713**	**1.522**
16	0.154	0.243	-0.191	**-1.178**
17	**1.803**	-0.721	0.862	-0.289
19	**1.069**	**-2.078**	0.190	0.574
19	0.230	**1.819**	**1.361**	**-2.446**
20	**-2.391**	**1.500**	**-0.998**	**2.749**

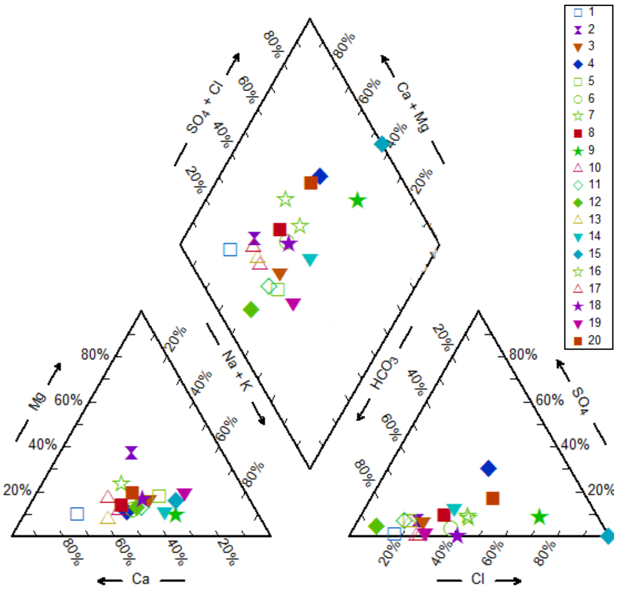

Fig.3. Piper diagram.

is typical of the Nigerian basement complex environment with little or no mixing (Amadi, 1987 and Nton et al. 2007). It reflects the earliest phase of evolution of groundwater system and depicts groundwater of recharge zone. Tijani (1994) and Nton et al. (2007) reported that the chemical composition of this facies is due to the dissolution of silicate minerals (feldspar) in the bedrock and aluminosilicate (andalusite) in the weathered regolith.

Na-K-HCO$_3$ Facies

This facies constitutes about 10% of the total facies types. It is an alkaline water type and is usually referred to as exchange water because of the geochemical evolution through exchange processes (Loehnert, 1970 and 1973; and Nton et al. 2007). The presence of appreciable amount of clay material (as cation exchanger) in the overburden unit and the apparently high residence time of flow promoted the active cation exchange and reaction, as represented in equation (1):

$$\frac{1}{2}Ca^{2+}\text{-}HCO_3 + Na\text{-}X \rightarrow \frac{1}{2}Ca^{2+}\text{-}X_2 + NaHCO_3$$

(X-clay materials as cation exchanger) (1)

Ca-Mg-Cl-SO$_4$ Facies

The facies falls within the alkaline earth water and constitutes about 10% of the water types. It is typical of the Nigerian basement complex areas with limited groundwater mixing (Amadi, 1987; Nton et al. 2007). Sulphate and chloride are constituents of atmospheric precipitation (Davies and Dewiest, 1966), hence this facies is influenced by precipitation as well as dissolution of silicate minerals in the bedrock and aluminosilicate minerals in the weathered regolith (Tijani, 1994 and Nton et al., 2007) which releases the Ca^{2+} and Mg^{2+}.

Na-K-Cl-SO$_4$ Facies

This facies constitutes about 10% of the facies types. The occurrence of $Cl^-$and SO_4 reveals that this facies is influenced by precipitation, and Na and K which are released from the weathering of plagioclase from the bedrock.

Groundwater Quality for Drinking Purposes

Table 5 presents a comparison of the results of the physiochemical analysis of groundwater of the study area with the standard guideline values recommended by the World Health organization (WHO, 1993) for drinking water purposes. It is observed from the Table that 15% of the samples show TDS values above the guideline value of 500mg/l while 15%, 40%, 50%, 35% and 15% of the samples are contaminated by heavy metals As^+, Pb^{2+}, Cd^{2+}, Cr^{3+} and Mn^{2+} respectively. Also, 100% and 35% of the groundwater samples have total hardness and NO_3 concentrations respectively above the stipulated guideline values. All the groundwater samples, however, have $Cl^{\%}$, SO^{2-}_4 and $Fe^{2+/3+}$ concentrations below guideline values for drinking water.

Groundwater Quality for Irrigation Purposes

The summary of the results of the irrigation water quality parameters is shown in Table 6.

Sodium Adsorption Ratio (SAR) and Electrical conductivity (EC)

Table 5. Groundwater quality

Water quality index	Range of values measured (mg/l)	Mean (mg/l)	WHO (1993) guideline value (mg/l)	No. of samples above the stipulated value
TDS	157-1192.49	420.28	500	3
Total hardness	120-600	261.95	100	20
Cl	10-209	56.15	250	0
NO_3	7.04-115.72	30.29	25	7
SO_4	0-98	17.10	250	0
Fe	0.00-0.27	0.11	0.3	0
As	0.000-0.012	0.00775	0.010	3
Pb	0.000-0.040	0.01195	0.010	8
Cd	0.000-0.018	0.00518	0.003	10
Cr	0.000-0.205	0.06305	0.050	7
Mn	0.00-0.20	0.05546	0.100	3

The sodium adsorption ration (SAR) parameter evaluates the sodium hazard in relation to calcium and magnesium concentrations. SAR values ranged from 0.827 to 4.056. Values greater than 2.0 indicate groundwater is unsuitable for irrigation purposes (Vasanthaviger et al. 2010). Only groundwater samples 9, 14 and 19 with SAR values of 2.080, 4.056 and 3.551 respectively are unsuitable as sources of water for irrigation. According to the U. S. Salinity diagram classification of irrigation water (USLL, 1954), the ground waters fall in the field of C1-S1, C2-S1 and C3-S1 (Fig.4) indicating a low to high salinity hazard and low sodium (alkalinity) hazard.

Sodium Percentage (Na %)

Sodium in soils is considered vital for determining groundwater suitability for irrigation purposes because sodium reacts with soil to reduce its permeability and support little or no growth (Vasanthaviger et al. 2010). Sodium salts in soil, besides affecting the growth of plants directly, also affect soil structure, permeability and aeration which directly affect plant growth (Singh et al. 2008). The Na % in the area ranged from 18.883% to 64.068%. Na % greater than 35% in groundwater is unsuitable for irrigation (Vasanthaviger et al. 2010). Groundwater samples 1, 7, 10 and 13 with Na % of 18.883%, 32.898%, 33.839% and 30.849% respectively are suitable for irrigation purposes. The plot of Na % against EC (Wilcox, 1955 diagram) shows that the ground waters are of excellent to doubtful quality (Fig.5).

Table 6. Irrigation water quality parameters

Site no.	Source	SAR	Na %	Mg hazard (%)
1	BH	0.827	18.883	12.38
2	BH	1.457	35.638	51.64
3	HDW	1.631	46.648	30.36
4	BH	1.358	37.267	18.40
5	HDW	1.665	49.778	34.63
6	HDW	1.514	39.390	20.03
7	BH	1.155	32.898	33.86
8	BH	1.297	35.261	21.57
9	BH	2.080	37.995	22.93
10	BH	1.063	33.839	17.88
11	BH	1.848	43.273	23.39
12	BH	1.620	41.340	22.17
13	BH	1.216	30.849	11.65
14	BH	4.056	53.578	24.00
15	HDW	1.711	54.276	35.66
16	BH	1.591	43.176	28.64
17	HDW	1.180	33.608	21.52
18	HDW	1.564	43.639	28.44
19	BH	3.551	64.068	45.12
20	HDW	1.367	37.531	30.55

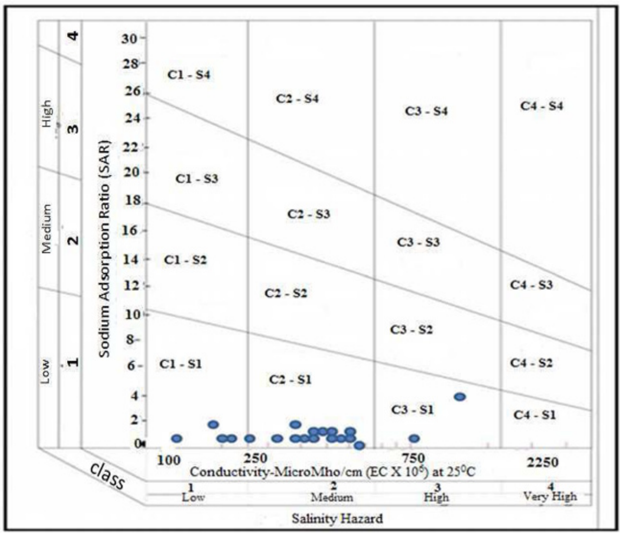

Fig.4. U.S. Salinity Classification of Groundwater for Irrigation (USLL, 1954) for the Study Area

Magnesium Hazard (MH) %

Magnesium hazard defines the relationship between magnesium and calcium concentration in groundwater. MH ranged from 11.65% to 51.64%. MH greater than 50% is considered harmful and unsuitable for irrigation purposes (Kacmaz and Nakoman, 2010). Only groundwater sample number 2 with magnesium hazard 51.64% is unsuitable for irrigation usage.

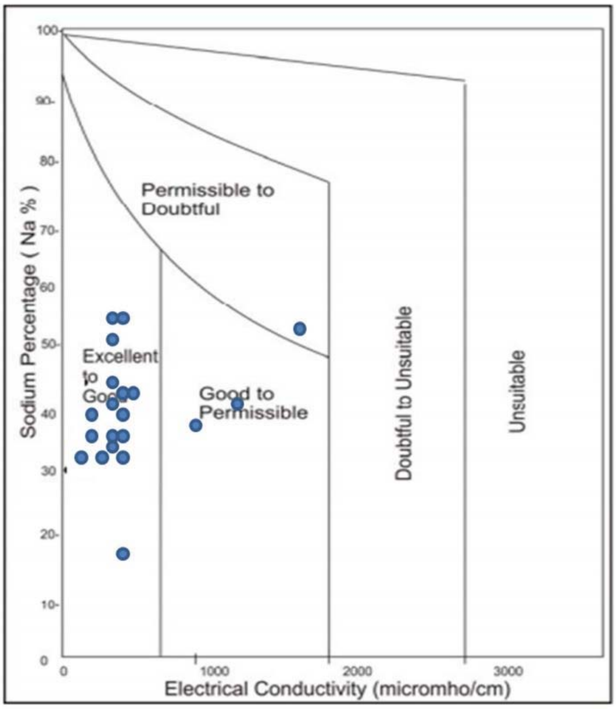

Fig.5. Wilcox (1955) diagram for the study area.

CONCLUSIONS

The chemical composition of the groundwater of the study area is strongly influenced by the effective weathering of igneous and metamorphic rocks underlying the study area, along with anthropogenic activities like domestic wastes, automobile emission and phosphate fertilizers in the urban environment. The water is generally hard and contaminated by heavy metals and ions of health concerns, making it unsuitable for drinking and for use for domestic purposes. 30%, 70% and 10% of the groundwater samples fall within the low, medium and high salinity hazard respectively while Wilcox classification showed that the groundwater ranged from doubtful to excellent for irrigation uses.

References

Abenemi, S. (2007) Greater Lokoja Water Supply Scheme. Ministry of Water Resources and Rural Development, Kogi State.

Amadi, U.M.P. (1987) Mixing phenomenon in groundwater systems and its relevance in water quality assessment in Nigeria. *In:* Klwugon (Ed.), paper presented at the 2nd annual symposium of Nigeria Water and Sanitation Association 17:1-17.31

Davies, S.N. and Dewiest, R.J.M. (1966) Hydrogeology John Wiley and Sons New York 436p.

Davis, J.C. (1986) Statistics and data analysis in geology. 2nd edition Wiley, New York.

Davis, J.C. (1973) Statistics and Data Analysis in Geology. Wiley, New York

Federal Ministry of Aviation (2007) Weather Reports.

Hockey, R.D. and Sachi, R. (1986) The Geology of Lokoja-Auchi Area. Geol. Surv. Nigeria Bull. no.39.

Kacmaz, H. and Nakoman, M.E. (2010) Hydrochemical characteristics of shallow groundwater aquifer containing Uranyl phosphate minerals in the Koprubasi (Manisa) area, Turkey. Environ. Earth Sci., v.59, pp.449-457.

LNRBDA (Lower River Niger Basin Development Authority) 2003. Report of borehole drilling operations at some locations in Lokoja Local Government Area of Kogi State. Messers John Solomon and Partners consulting Engineers, Fate-Ilorin, Kwara State, 126p.

Lohnert, E.P. (1970). Grundwasserchemismus und Kationentaush in Norddeutschen Flachland Z.dt geol. Ges. Sonderheft. Hydrogeochem 139-159 Hanover.

Lohnert, E.P. (1973). Austauskhwaesser in H. Schneider (Hrsg) Die Grunwassererschiessung 2nd Edition, 138-144 vulkan verlag. Essen

Nton, M.E., Adejumo, S.A. and Elueze, A.A. (2007) Hydrogeochemical assessment of surface and groundwater quality in Agbowo-Orogun area of Ibadan Southwestern Nigeria. Global Jour. Geol. Sci., v.5(1&2), pp.13-24.

Piper, A.M. (1953) A graphic procedure I the geo-chemical interpretationof wayer analysis. USGS Groundwater note no.12.

Singh, A.K., Mondal, G.C., Kumar, S., Singh, T.B., Tewary, B.K. and Sinha, A. (2008) Major ion chemistry, weathering processes and water quality assessment in upper catchment of Damodar River basin, India. Environ. Geol., v.54, pp.745-758.

Tijani, M.N. (1994) Hydrological Assessment of Groundwater in Moro Area, Kwara State, Nigeria. Environmental Geology 24: 194-202.

Todd, D.K. (1980) Groundwater Hydrology. John Wiley and Sons.

USSL (1954). Diagnosis and improvement of saline and alkali soils. USDA Agr. Handbook No. 60, Washington DC.

Vasanthavigar, M., Srinivasamoorthy, K., Vijayaragavan, K., Rajiv-Ganthi, R., Chidambaram, S., Anandhan, P., Manivannan, R. and Vasudevan, S. (2010) Application of water quality index for groundwater quality assessment: Thirumanimuttar sub-basin, Tamil Nadu, India. Environmental Monitoring Assessment.

WHO (1993) Guidelines for drinking water quality (2nd ed., Vol. 1, p.188). Recommendations, Geneva: World Health Organization

Wilcox, L.V. (1955) The quality of irrigation use. Vol. 40, U.S. Department of Agriculture Technology Bulletins 962, Washington DC.

(Received: 20 April 2012; Revised form accepted: 20 August 2012)