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Full Length Research Paper

Groundwater Chemistry from Bama and Konduga Local Government Areas, Northeastern Nigeria

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Thirty groundwater samples were collected from boreholes in Bama and Konduga Local Government areas of Borno State, Northeastern Nigeria. The water was analyzed for pH, electrical conductivity, calcium, magnesium, sodium, potassium, bicarbonate, chloride and sulphate using standard procedures. The water quality parameters were compared with the World Health Organization (WHO) and Standard Organization of Nigeria (SON) recommended and permissible limits for domestic purposes. Statistical analyses show all the parameters to be positively skewed, with the exception of magnesium ions in the groundwater from Bama that extends towards negative values. Also magnesium in the groundwater from Konduga is normally distributed around its mean. Mean cation and anion concentration values in the groundwater from Bama are Na>Ca>Mg>K and HCO_3>Cl>SO_4 respectively and those from Konduga are Ca>Na>Mg>K and HCO_3>Cl>SO_4 respectively. Comparative results with WHO and SON standards give concentration values of all the samples within acceptable limits, except on three and two potassium parameters from Bama and Konduga water wells respectively that failed the tests. This by implication suggests the suitability of the water for domestic uses. The results also show no direct relationship between pH and potassium, sodium and sulphate ions and among potassium and bicarbonate ions from Bama water. This is also true for potassium and bicarbonate water from Konduga as their statistical correlation values are zero.

Keywords: boreholes, domestic uses, Groundwater, skew, statistical correlation

INTRODUCTION

Bama and Konduga areas lie within latitudes $11^{o}30'$ – $12^{o}00'$ N and longitudes $13^{o}00'$ – $14^{o}00'$ (Figure 1). It falls within Pleistocene Sediments of the Chad Formation in Northeastern Nigeria. The areas are characterized by a semi arid climate with two distinct seasons: a dry season from October to May and a wet season from June to September. Owing to insufficient rainfall, surface water is confined almost entirely to the channel of River Yedzaram, which flows only during peaks of rainy seasons. Drying up of the river channel during the long dry season has led different State Governments especially in the semi arid zones of Northern Nigeria to sink boreholes and wells so as to provide portable water to the different communities.

Where water occurs, its quality should meet domestic standards for portable water (Montgomery, 2000). Groundwater quality could nearly be as pure as rainfall or saltier than sea water (Olabaniyi and Owoyemi, 2004). Generally the quality of groundwater reflects that of the water which percolated to the water table, the distribution, solubility, exchange capacity and exchange selectivity of minerals contained in rocks or sediments present in the zone of saturation and the recorded time of the water within such zones (Hamil and Bell, 1986). Thus effort to

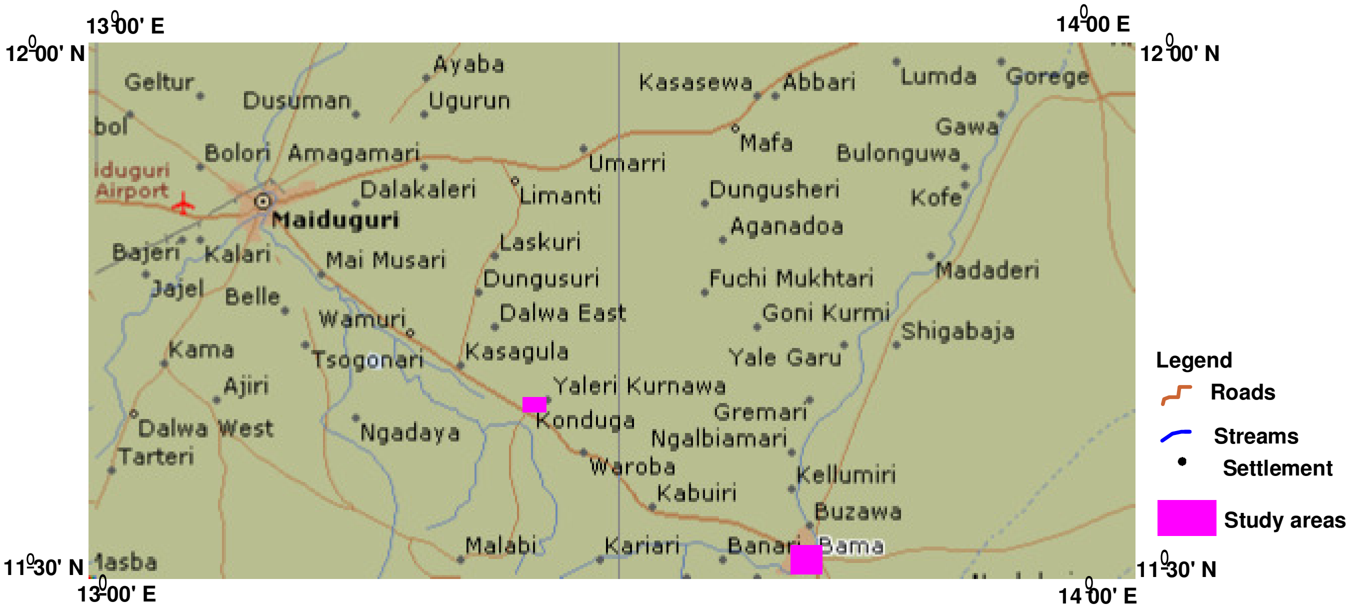

Figure 1 Location Map of the Study Area

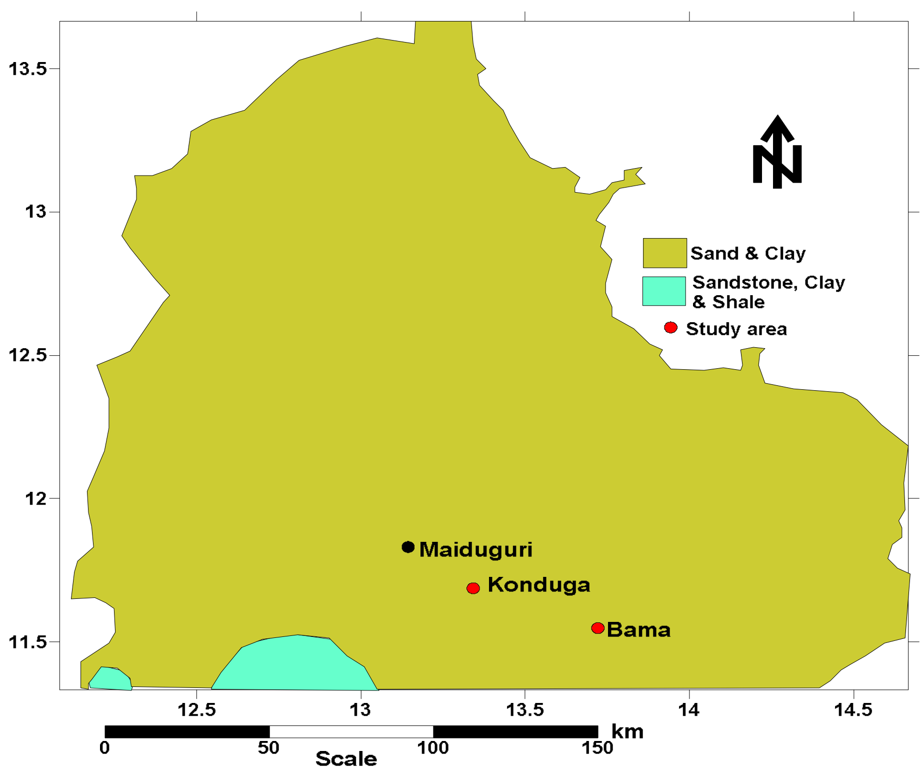

Figure 2 Part of Borno State, Nigeria showing area occupied by Chad Basin sediments

improve upon the quality of the water supply is paramount. The study is intended to determine the suitability or otherwise of the groundwater system for domestic functions, and to establish the relationship between same parameters of the water samples from the two localities.

Geology of the Chad Basin

A geological map of part of Borno State showing the study areas is shown in Figure 2. The area is underlain by sediments of the Chad Formation. The oldest sediment in the basin is the Bima Formation which was deposited unconformably on the Precambrian Basement complex (Barber, 1965). The Chad Formation which is the youngest sediments is a variable sequence that includes quaternary sediments of lacustrine origin. The formation consists essentially of argillaceous sequence in which persistent arenaceous horizons occur. Towards the centre of the basin, lacustrine clays prevailed in the sequence but near the margins fluviatile sands, grits and gravel become more important.

The Chad Formation is overlain by recent alluvial deposits. Sands with variable grain size and colour is the main sediment of the formation. The sediments were deposited by turbulent current and are poorly sorted. Fluviatile sediments deposited at low velocity are characterized by finer grains. Deposition of the Chad Formation occurred after regression of the sea southward at the end of Cretaceous time. Data information from wells and boreholes revealed three distinct zones of sandy sediments separated by clay deposits (Barber and Jones, 1960). The lithology varies both laterally and vertically. The sandy sediments were thought to have been laid down as Lake Margin deposits or as alluvial fans and deltas. The presence of diatomite indicates that extreme conditions of low sedimentation persisted for long periods in some parts of the formation when the sea transgressed.

Hydrogeology of the Chad Basin

Within the Chad Formation three zones of sandy sediments (aquifers) separated by clay deposits are recognized. These are known as the Lower, Middle and Upper aquifer zones. The Lower aquifer occurs at depths of 420 – 650 m. Geophysical and borehole data indicate the presence of the aquifer beyond Maiduguri. Recharge to this aquifer is believed to be far from Maiduguri area. The Middle aquifer is widely spread and is the best developed confined aquifer in the Nigerian sector of the Chad Basin. Its surface area is in excess of 50,000 km^2 and the depth ranges from about 200 - 350 m. Its lithology consists mainly of sands and gravels with silts and clays intercalations. Recharge to the aquifer occurs by horizontal inflow around the ridge of rocky areas fringing the Chad Basin and by vertical percolation from the Bama Ridge area. Around Maiduguri the Upper aquifer consists of three aquifer systems, referred to as A, B, and C (Bumba, et al, 1991; Alkali, 1995). They occur at depths of 10 – 40 m, 40 – 70 m and 78 – 99 m in the same order. Recharge into this aquifer system occurs through vertical infiltration of rainfall as well as seepage along rivers and streams.

MATERIALS AND METHODS

Thirty groundwater samples were collected and analyzed for their physico-chemical parameters. The samples were collected in clean polythene bottles. The bottles were tightly sealed and labeled in the field.

Physico-chemical analysis of the water samples were carried out for pH, electrical conductivity (EC), sodium, potassium, calcium, magnesium, bicarbonate, chloride and sulphate according to standard methods for examination of water and wastewater of American Public Health Association (APHA, 1992). The pH and EC of the water samples were determined with a Combo pH/EC meter. Sodium, potassium, calcium and magnesium ions were determined using Perkin Elmer Analyst 400 Atomic Absorption Spectrometer (AAS). The anions of sulphate were experimentally determined by Lamda 35 Ultraviolet Visible Spectrometer and amount of chloride and bicarbonate ions were determined by titration.

RESULTS AND DISCUSSION

Physico-chemical parameters of the water samples from Bama and Konduga are reported in Tables 1 and 2 respectively. Statistical analyses of the parameters are shown in Tables 3 and 4 respectively. The experimental results were compared with the recommended and permissible limits provided by World Health Organisation (WHO, 2004) and Standard Organization of Nigeria (SON, 2007) for domestic functions.

Comparative results from the two sites in Tables 5 and 6 show three potassium water well parameters from Bama and two potassium water well parameters from Konduga above the recommended limits.

pH Parameters

Recommended pH standards values given by WHO (2004) and SON (2007) for drinking water are 6.5 - 8.5. Where there is no alternative source, water with pH values from 6.5 - 9.2 may be accepted (Singh et al, 2012).

The pH values for Bama and Konduga water samples areas range from 6.09 - 6.99 and 6.08 - 7.26 respectively. Their respective averages are 6.47 and 6.58 while the standard deviations are ±0.29 and ±0.42 respectively.

Electrical Conductivity Parameters

Electrical conductivity (EC) measurements are used as indications of total quantities of soluble salts. The quantities of salts which pass into solution in groundwater depend on its amounts and water into which it dissolved. The electrical conductivity values of Bama and Konduga water samples range from 111.00 - 846.00 mS and 112.00 - 785.00 mS respectively. Their averages and standard deviation are 356.27 mS and 346.53 mS;

Table 1 Physicochemical Composition of Bama Groundwater

Sample No.	pH	EC	Na^+	K^+	Ca^{2+}	Mg^{2+}	HCO_3^-	Cl^-	SO_4^{2-}
BM 01	6.99	407.00	67.45	12.60	4.34	16.30	136.40	18.00	0.28
BM 02	6.88	373.00	23.65	9.40	20.60	5.40	109.80	24.00	1.09
BM 03	6.37	846.00	33.45	2.44	23.50	3.70	74.00	34.00	31.00
BM 04	6.15	678.00	45.01	6.40	16.30	21.50	122.00	90.00	0.00
BM 05	6.40	156.00	19.44	3.66	57.80	16.00	168.00	78.00	4.57
BM 06	6.68	389.00	42.66	5.43	8.59	14.00	73.20	24.00	0.27
BM 07	6.27	380.00	37.08	8.04	5.78	2.90	85.40	26.00	0.30
BM 08	6.22	251.00	20.54	1.44	6.70	17.50	97.60	23.00	0.92
BM 09	6.79	332.00	45.90	4.03	1.20	15.80	122.00	26.00	16.09
BM 10	6.69	111.00	32.65	5.33	1.56	13.60	97.50	20.00	2.99
BM 11	6.28	326.00	78.41	6.44	5.00	1.26	136.48	28.00	2.23
BM 12	6.18	169.00	43.61	**15.60**	2.34	5.04	163.48	34.00	2.39
BM 13	6.69	372.00	85.60	**13.70**	8.48	12.60	61.32	24.00	6.01
BM 14	6.40	334.00	22.40	6.50	8.49	12.50	103.21	26.00	0.04
BM 15	6.09	220.00	65.73	**16.20**	20.50	5.40	73.20	28.00	7.95

Above WHO (2004) and SON (2007) recommended and/or permissible limits in red.

Table 2 Physicochemical Composition of Konduga Groundwater

Sample No.	pH	EC	Na^+	K^+	Ca^{++}	Mg^{++}	HCO_3^-	Cl^-	SO_4^{2-}
KG 01	6.08	112	8.2	5	47.1	11.3	173	22	82.52
KG 02	6.22	408	12.6	5	17.47	9.84	27	18	6.33
KG 03	6.09	332	15	4	38.24	2.69	102	34.1	7.26
KG 04	6.33	331	28	**12.3**	72.72	3.49	85.4	96	49.26
KG 05	6.44	216	7.9	2.3	25.89	11.4	109.8	22	7.48
KG 06	6.72	271	17.2	1.2	18.8	9.62	28.61	26	6.33
KG 07	7.02	223	7.9	3.4	18.98	1.47	265.2	24	1.38
KG 08	7.09	214	72.8	**12.4**	33.15	3.62	97.6	88	49.81
KG 09	7.25	301	17	2.6	33.96	1.2	102.3	24	8.62
KG 10	6.88	343	7.9	6.7	35.02	1.25	89.63	24.2	2.02
KG 11	6.55	656	18.4	1.06	34.19	2.16	101.2	30	8.61
KG 12	6.29	785	7.8	8	29.69	8.22	115.2	18.4	4.32
KG 13	6.18	711	11.4	1.72	20.13	10.2	97.2	23.4	4.15
KG 14	6.12	144	12.5	6.2	51.03	6.81	140.1	44	5.44
KG 15	7.12	166	12.5	2.6	4.8	11.4	73.2	16	3.46

Above WHO (2004) and SON (2007) recommended limits in bold red.

Table 3 Statistical Analysis of Water Quality Parameters From Bama

Parameter	pH	EC	Na^+	K^+	Ca^{2+}	Mg^{2+}	HCO_3^-	Cl^-	SO_4^{2-}
Minimum	6.09	111.00	19.44	1.44	1.20	1.26	61.32	18.00	0.00
Maximum	6.99	846.00	85.60	16.20	57.80	21.50	168.00	90.00	31.00
Mean	6.47	356.27	44.24	7.81	12.75	10.90	108.24	33.53	5.08
Standard Deviation	0.29	191.81	21.15	4.70	14.43	6.33	32.95	21.05	8.35
Skewness	0.41	1.38	0.72	0.64	2.41	-0.12	0.43	2.26	2.55

±191.81 mS and ±208.97 mS respectively.

Though neither WHO (2004) nor SON (2007) provided recommended value for this parameter, however all values are below permissible limits for these organizations.

Total Hardness (Calcium and Magnesium) Parameters

Calcium and magnesium play significant roles in water as their presence in large quantity contribute greatly to the

Table 4 Statistical Analysis of Water Quality Parameters from Konduga

Parameter	pH	EC	Na^+	K^+	Ca^{2+}	Mg^{2+}	HCO_3^-	Cl^-	SO_4^{2-}
Minimum	6.08	112.00	7.80	1.06	4.80	1.20	27.00	16.00	1.38
Maximum	7.25	785.00	72.80	12.40	72.72	11.43	265.20	96.02	82.52
Mean	6.56	347.53	17.14	4.97	32.08	6.31	107.16	34.01	16.47
Standard Deviation	0.42	208.97	16.35	3.63	16.44	4.14	56.87	24.58	24.01
Skewness	0.41	1.14	3.19	1.11	0.88	0.00	1.44	2.08	2.04

Table 5 Comparison of Bama Groundwater with WHO (2004) and SON (2007) Standards

Parameter	Min	Max	Mean	Standard Deviation	WHO (2004)		SON (2007)	
					Recommended	Permissible	Recommended	Permissible
pH	6.09	6.99	6.47	0.29	6.5	8.5	5.5	8.5
EC	111.00	846.00	356.27	191.81	-	1480	-	1000
Na^+	19.44	85.60	44.24	21.15	150	200	150	200
K^+	1.44	16.20	7.81	4.70	10	15	-	-
Ca^{2+}	1.20	57.86	12.75	14.43	75	200	75	200
Mg^{2+}	1.26	21.50	10.90	6.33	39	150	20	150
HCO_3^-	61.32	168.00	108.24	32.95	500	1000	-	-
Cl^-	18.00	90.00	33.53	21.05	200	500	250	600
SO_4^{2-}	0.00	31.00	5.08	8.35	150	250	100	200

Table 6 Comparison of Konduga Groundwater with WHO (2004) and SON (2007) Standards

Parameter	Min	Max	Mean	Standard Deviation	WHO (2004)		SON (2007)	
					Recommended	Permissible	Recommended	Permissible
pH	6.08	7.25	6,56	0.42	6.5	8.5	5.5	8.5
EC	112.00	785.00	347.53	208.97	-	1480	-	1000
Na^+	7.80	72.80	17.14	16.35	150	200	150	200
K^+	1.06	12.40	4.97	3.63	10	15	-	-
Ca^{2+}	4.80	72.72	32.08	16.44	75	200	75	200
Mg^{2+}	1.20	11.43	6.31	4.14	39	150	20	150
HCO_3^-	27.00	265.20	107.16	56.87	500	1000	-	-
Cl^-	16.00	96.02	34.01	24.58	200	500	250	600
SO_4^{2-}	1.38	82.52	24.01	3.39	150	250	100	200

hardness of the water. WHO (2004) recommends ions concentration values of 75 mg/l and 39 mg/l for calcium and magnesium ions respectively, while acceptable limits by SON (2007) are 75 mg/l and 20 mg/l respectively for the same cations. In situations where these requirements are not met, WHO (2004) and SON (2007) permitted maximum concentration values of 200 mg/l and 150 mg/l for calcium and magnesium respectively.

The groundwater system from Bama has calcium concentration levels from 1.20 - 57.80 mg/l, while those from Konduga ranges from 4.80 - 72.72 mg/l. Magnesium ions concentration from Bama range from 1.26 - 21.50 mg/l and from Konduga, the range is from 1.20 - 11.43 mg/l. An average concentration of calcium ions from Bama is 12.75 mg/l and from Konduga is 32.08 mg/l. The magnesium samples from Bama and Konduga have mean concentration values of 10.90 mg/l and 6.31 mg/l respectively. Calculated standard deviation of the samples from Bama and Konduga amounts to ±14.43 mg/l and ±16.44 mg/l for calcium and ±6.33 mg/l and ±4.14 mg/l for magnesium respectively. The results in Tables 5 and 6 indicate the concentration of the cations within WHO (2004) and SON (2007) limits.

Sodium Parameters

Sodium ion concentration in excess of 150 mg/l makes the water unsuitable for domestic activity and causes severe health problems. Experimental concentration values of sodium ions range from 19.44 - 85.60 mg/l and from 7.80 – 72.80 mg/l in the water samples from Bama and Konduga respectively. The average concentration levels are 44.24 mg/l and 17.14 mg/l respectively in that order. Standard deviation of ±21.15 mg/l was obtained from Bama while Konduga gave standard deviation of ±16.35 mg/l.

Table 7 Correlation Coefficients of Water Quality Parameters from Bama

	pH	EC	Na^+	K^+	Ca^{2+}	Mg^{2+}	HCO_3^-	Cl^-	SO_4^{2-}
pH	1.00								
EC	-0.03	1.00							
Na^+	0.09	0.06	1.00						
K^+	0.00	-0.25	0.58	1.00					
Ca^{2+}	-0.17	0.04	-0.34	-0.19	1.00				
Mg^{2+}	0.24	-0.02	-0.18	-0.31	0.08	1.00			
HCO_3^{2-}	-0.05	-0.32	-0.16	0.00	0.25	0.13	1.00		
Cl^-	-0.41	0.24	-0.21	-0.21	0.64	0.39	0.43	1.00	
SO_4^{2-}	-0.01	0.52	0.00	-0.25	0.18	-0.25	-0.25	-0.03	1.00

Table 8 Correlation Coefficients of Water Quality Parameters from Konduga

	pH	EC	Na^+	K^+	Ca^{2+}	Mg^{2+}	HCO_3^-	Cl^-	SO_4^{2-}
pH	1.00								
EC	-0.27	1.00							
Na^+	0.33	-0.15	1.00						
K^+	-0.04	-0.10	0.61	1.00					
Ca^{2+}	-0.39	-0.12	0.19	0.60	1.00				
Mg^{2+}	-0.39	-0.05	-0.27	-0.26	-0.36	1.00			
HCO_3^-	0.05	-0.21	-0.18	0.00	0.14	-0.27	1.00		
Cl^-	0.03	-0.18	0.78	0.80	0.66	-0.36	-0.06	1.00	
SO_4^{2-}	-0.18	-0.35	0.42	0.52	0.56	0.10	0.16	0.51	1.00

Potassium Parameters

Concentration of potassium ions in the groundwater system is from 1.44 – 16.60 mg/l and 1.06 - 12.40 mg/l for Bama and Konduga respectively. Average values of 7.81 mg/l and standard deviation of $\pm$4.70 mg/l were obtained from Bama. The average concentration and standard deviation of 4.97 mg/l and ±3.63 mg/l respectively were obtained from Konduga.

Bicarbonate Parameters

Recommended limit for bicarbonate in drinking water is 500 mg/l; beyond which the taste of water becomes unpleasant. However in the absence of an alternative source, a bicarbonate value up to 1000 mg/l is permissible.

The values of bicarbonate in the water samples are between 61.32 - 168.00 mg/l for the water from Bama and between 27.00 - 265.20 mg/l for Konduga. The respective mean of the water from Bama and Konduga are 108.24 mg/l and 107.16 mg/l while their standard deviations are ±32.95 mg/l and ±56.87 mg/l in the same order.

Chloride Parameters

In most cases chloride is readily leached. Maximum recommended limit of chloride ions in portable water is 200 mg/l by WHO (2004) and 250 mg/l by SON (2007). These values may be extended to 500 mg/l by WHO (2004) and 600 mg/l by SON (2007) permissible standards.

Chloride concentrations in the groundwater samples from Bama and Konduga vary from 18.00 - 90.00 mg/l and from 16.00 - 96.02 mg/l respectively. The mean values of 33.53 mg/l and standard deviation of ±21.05 mg/l were obtained from Bama water. The values 34.01 mg/l and ±24.58 mg/l are the respective mean and standard deviation from Konduga water.

Sulphate Parameters

WHO (2004) recommended and permitted values of 150 mg/l and 250 mg/l respectively for sulphate concentration in water. In Nigeria situation values of 100 mg/l and 200 mg/l are the recommended and permissible limits respectively. Sulphate content higher than the permissible limit is unacceptable for domestic purpose as it is likely to cause gastro-intestinal irritation particularly when magnesium and sodium are also present in the groundwater system. Water containing sulphate beyond 1,000 mg/l has purgative effects. Sulphate undergoes transformation to sulphur and sulphur oxides depending upon the redox potential of the water.

In the groundwater, sulphate from Bama water ranges from 0.00 - 31.00 mg/l and those from Konduga water ranges from 1.38 – 82.52 mg/l. The average concentration of 5.08 mg/l and standard deviation of

±8.35 mg/l were calculated from Bama water, while Konduga water yielded average value of 16.47 mg/l and standard deviation of ±24.01 mg/l. Mean cation and anion concentrations of the groundwater from Bama are in sequence of Na>Ca>Mg>K and HCO_3>Cl>SO_4 respectively and from Konduga are in order of Ca>Na>Mg>K and HCO_3>Cl>SO_4 respectively.

Statistical analyses indicate all the parameters extending towards positive values. Disparities from these results are magnesium parameters of the groundwater from Bama and Konduga where they extend towards negative values and normally distributed respectively around their means.

Correlation Analysis

Correlation coefficient which is a measure of the extent to which two measurements vary is defined by the equation:

$$r = \frac{\Sigma XY}{\sqrt{(\Sigma X2 + \Sigma Y2)}}$$

This tool is used to examine each pair of the parameter, so as to determine whether they tend to move together. The correlation matrix of the water samples are reported in Tables 7 and 8 for Bama and Konduga respectively.

In Table 7 the correlation coefficient of pH parameter is positive with sodium and magnesium parameters, but has no common relationship with potassium parameter. Electrical conductivity shows its large values associating with large values of sodium, calcium, chloride and sulphate parameters. Sodium correlation coefficient large values associate positively with large values of potassium, pH and electrical conductivity parameters. No any relationship exists between sodium and sulphate parameters. Potassium ions associate positively with sodium ions only and do not have any relationship with pH and bicarbonate ions. Calcium ions correlate positively with all but pH and sodium ions where the correlation matrix results are negative. Positive correlation exists between magnesium, bicarbonate, chloride, pH and electrical conductivity parameters. Bicarbonate correlates positively with chloride and calcium and exhibits no common relationship with potassium. Chloride exhibits positive correlation with electrical conductivity, calcium, magnesium and bicarbonate. Large values of sulphate ions tend to associate positively with large values of electrical conductivity and calcium, but have no common relationship with sodium.

Large values of pH in Table 8 tend to associate positively with large values of sodium and chloride. The coefficient matrix between electrical conductivity and other parameters suggests that its smaller values tend to associate negatively with large values of such parameters. Sodium associates positively with potassium, calcium, chloride, sulphate and pH parameters. Potassium associates positively with calcium, chloride, sulphate and sodium but shows no common relationship with bicarbonate. Calcium tends to associate positively with bicarbonate, chloride, sulphate, sodium and potassium. Statistical correlation of the groundwater data shows positive correlation between magnesium and sulphate. Large values of bicarbonate ions tend to associate positively with large values of sulphate, pH and calcium but its correlation matrix with potassium tends to be unrelated. Positive relationship exists between chloride, sulphate, pH, sodium, potassium and calcium. Large values of sulphate tend to associate positively with large values of all parameters except those of pH and electrical conductivity where negative relationship exist.

CONCLUSION

The chemistry of fifteen boreholes' water samples each from Bama and Konduga Local Government areas were obtained. The water was analyzed for pH, electrical conductivity, sodium, potassium, calcium, magnesium, bicarbonate, chloride and sulphate using established standard procedures. The results show majority of the water samples from the two sites to be positively skewed. Groundwater from Bama has mean cation concentration values in the order of Na>Ca>Mg>K and mean anion concentration values in the order of HCO_3>Cl>SO_4. The magnitude of the mean concentration of the cations and anions from Konduga water are Na>Ca>Mg>K and HCO_3>Cl>SO_4 respectively. Concentration values of all but few potassium ions in the water fit perfectly well within international and local recommended and permissible standards. The results thus favour suitability of the water for domestic purposes. No correlation relationship exists between pH and potassium, sodium and sulphate; and potassium and bicarbonate as their respectively correlation coefficients are zero. It is suggested that the water wells with the potassium parameters that are above the standard recommended and/or permissible limits be checked for accuracy of the analysis and/or sources of the anomalies, so as to offer necessary remedial measures to the communities living around such areas.

REFERENCES

Alkali SC (1995): Resistivity measurement of the upper aquifer system around Lake Alau area. Water Resource Journal of the National Association of Hydrogeologists. 6:(1, 2): 26-30.

American Public Health Association (1992): Standard methods for analysis of water and waste water. American Public Health Association, Inc, Washington DC.

Barber W (1965): Pressure water in the Chad Formation of Borno and Dikwa emirates, North East Nigeria. Geological Survey of Nigeria, Bulletin. 35: 138.

Barber W, Jones DG (1960): The geology and hydrogeology of Maiduguri. Geological Survey of Nigeria, Records, 20.

Bumba J, Kida, HI, Bunu Z (1991): Exploitation of groundwater in the Chad Formation – Maiduguri as a case study. In: Arid zone hydrology and water resources. Edited by Gadzama NM, Adeniji FA, Richards WS, Thambyahphillay GGR. University of Maiduguri press, Maiduguri. 89 – 97.
Hamil L, Bell FG (1986): Groundwater resources development. Butterwork, London.
Montgomery CW (2000): Environmental geology. McGraw-Hill companies, Inc, NY, 546.
Olabaniyi SOB, Owoyemi FB (2004): Quality of water in the Deltaic plain sand aquifer of Warri and environs, Delta State, Nigeria. Water Resources Journal of the Nigerian Association of Hydrogeologist. 15:38 – 45.
Singh S, Singh P, Kumar R, Saharan S (2012): Groundwater quality analysis of Safidon and Julana blocks of District Jind, Haryana, India. Journal of Water Resources and Protection. 4:39 – 47.
Standard Organization of Nigeria (2007): Nigeria standards for drinking water quality. 17.
World Health Organisation (2004): Guidelines for drinking water quality. International standards for drinking water, 1. Geneva. 130.