HYDROCHEMICAL EVOLUTION OF GROUNDWATER IN JIMETA-YOLA AREA, NORTHEASTERN NIGERIA

J. M. ISHAKU

(Received 1 May 2010; Revision Accepted 17 August 2010)

ABSTRACT

Analytical results of thirty-seven water samples revealed that pH of the water samples ranged from acidic to alkaline throughout the sampling period. EC and TDS mean values were higher in the dry season in shallow aquifer and low in deep aquifer in the rainy season. This is an indication of the addition of leachable salts following the dissolution of waste materials in shallow aquifer. The low mean values of Ec and TDS in the case of deep aquifer is an indication of dilution effects due to recharging groundwater. The dominance of the cations in both seasons in shallow and deep aquifers was in the order of Na > Ca > K > Mg while the anions was in the order of Cl > HCO_3 > NO_3 > SO_4 in both seasons in shallow aquifer and in deep aquifer in rainy season, and the anions was in the order of HCO_3 > Cl>NO_3> SO_4 in the dry season in deep aquifer. The plots of log TDS against Na^+ /(Na^+ + Ca^{2+}) indicated that most sample points plot in the region of rock dominance and weathering zone suggesting precipitation induced chemical weathering along with dissolution of rock forming minerals. Piper plots of the groundwater samples in the dry season in shallow aquifer classified the water types into Na-SO_4-Cl, Ca-Mg-HCO_3, Ca-Mg-SO_4-Cl and Na-HCO_3 water types while the sample plots indicated Na-SO_4-Cl and Na-HCO_3 water types in shallow aquifer in the rainy season. The plots of the samples indicated Na-HCO_3, Ca-Mg-HCO_3, Na-SO_4-Cl and Ca-Mg-SO_4-Cl water types in deep aquifer in both seasons. Cation exchange, salinisation and mixing processes were the processes responsible for the chemical evolution of groundwater in the area. Organic decomposition, sewage effluent and house hold solid wastes were the major sources of nitrate in the area. It is recommended that controlled waste disposal practice should be encouraged while drilling of productive boreholes to deeper levels is also encouraged.

KEY WORDS: Chemical evolution. Ionic exchange. Weathering. Groundwater. Nigeria

INTRODUCTION

In water resources evaluation, it is becoming very important to determine the processes involved in the chemical evolution of groundwater (Narayanan et al., 1990). Groundwater chemistry may be modified through natural processes involving the dissolution of mineralogical constituents of rocks, and it has been established that geology has a role to play in the chemistry of subsurface water (Abimbola et al., 2002). Modification in groundwater chemistry may also result from anthropogenic activities. The overall effect is the pollution of groundwater resources which may ultimately affect the quality of the water in terms of its usefulness for domestic, industrial, and agricultural uses. The development of groundwater resources for water supply is a widespread practice in developing country like Nigeria. The rapid and unplanned expansion of cities in developing countries means that urban infrastructure and services lag behind population growth (Lawrence et al., 2000). Despite the importance of groundwater, little is known about the natural phenomenon that governs its chemical composition or anthropogenic factors that presently affect them (Garcia et al., 2001). Water supply to the people of the study area is obtained from treated surface water and groundwater from hand-dug wells and boreholes. The waste disposal practice is the open dump for solid waste, pit latrines and septic tank for human wastes (Yenika et al., 2003). Solid wastes are dumped on the land surface and are not evacuated for a

long time. When eventually removed, they are dumped along the banks of the River Benue, and low density residential areas. The rate of waste generation in Jimeta metropolis is about 0.90kg/day and is about 0.56kg/day in Yola town (Tanko and Anametemfiok, 2001). The indiscriminate waste disposal practices have major implications in terms of the degradation of groundwater quality and on its suitability as a source for human consumption. The quest for making easy money from water business has led to the proliferation of shallow boreholes where water has questionable character. The depths of these boreholes are less than 40 metres and tap water from the unconfined aquifer that is susceptible to pollution. As a result of the degradation of water quality in the area, workers such as Ishaku and Ezeigbo (2000), Ntekim and Bello (2001), Yenika et al., 2003), and Adekeye and Ishaku (2004) investigated the water quality (situations) in the area. The present paper intends to discuss the chemical evolution of groundwater in the area in order to understand the hydrogeochemical processes and mechanisms responsible for the groundwater chemical evolution in the area. Knowledge of geochemical evolution in this area could lead to improved understanding of hydrogeochemical systems, leading to sustainable development of water resources and effective management of groundwater resource.

The study involved the collection of groundwater samples which were analyzed for the chemical parameters. The chemical parameters were plotted on

---

J. M. Ishaku, Department of Geology, Federal University of Technology, Yola, Adamawa State, Nigeria

Piper (1944) diagrams based on the concentrations of the cations and anions to identify the different water types. The water types were studied to understand the geochemical processes responsible for the evolution of the water types. The chemical parameters were further plotted on Gibbs (1970) diagram to understand the processes and mechanisms responsible for the modification of the groundwater chemistry.

DESCRIPTION OF THE STUDY AREA

The study area is situated between latitudes $9^0 11$'N to $9^0 20$'N and longitudes $12^0 23$'E to $12^0 33$'E covering an estimated area of 305km^2 (Fig. 1). The area has a mean annual rainfall of
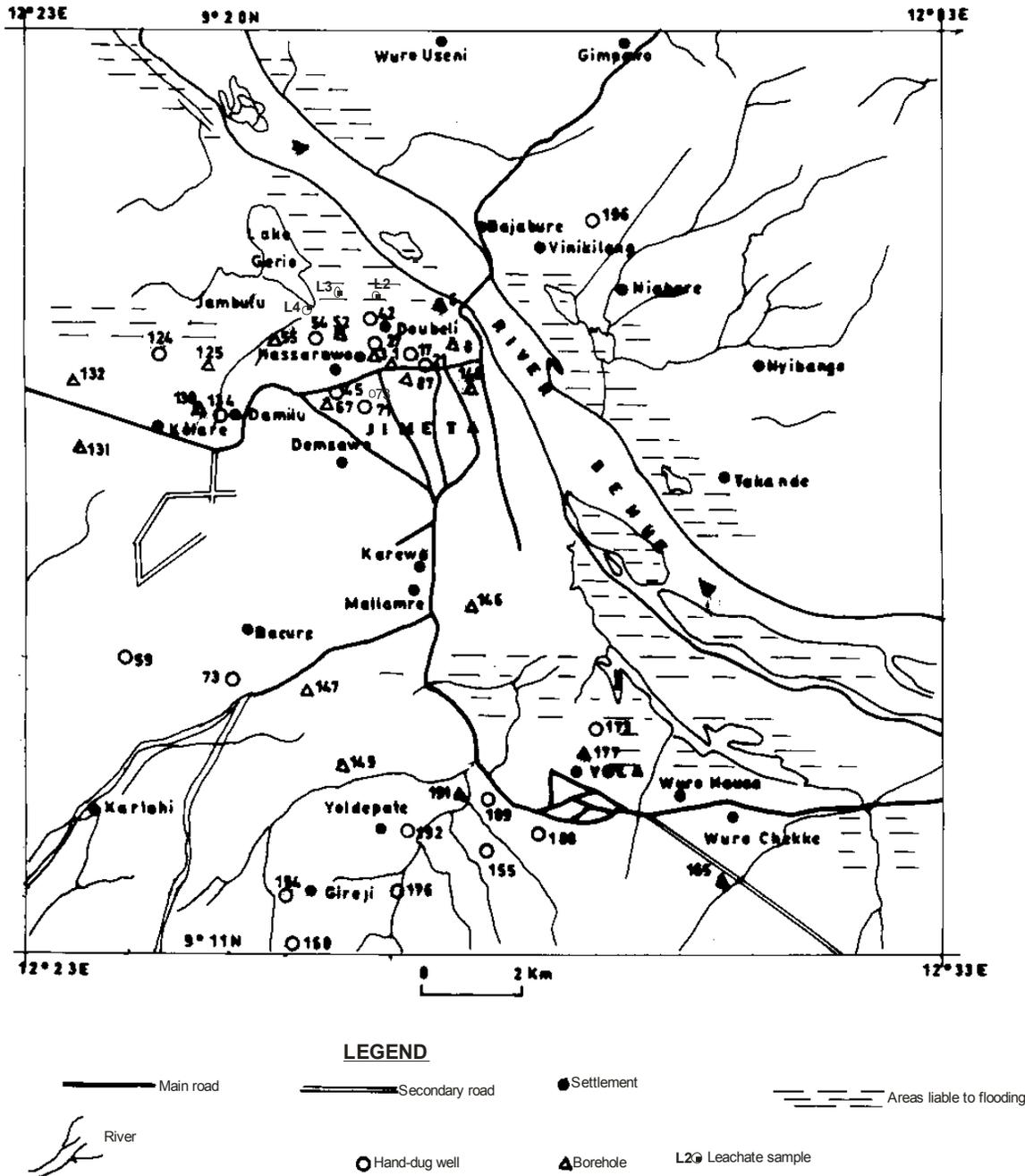

Fig. 1 Map of the study area showing sampling points

918.9 mm, and means monthly minimum temperature of 19^0C and maximum temperature of 37.9^0C. The mean monthly temperature is 28.5^0C (Ishaku, 2007). The mean monthly relative humidity in Yola varied from 26% in February to 76% in August with mean relative humidity at 52.8% (Ishaku, 1995). The area is characterized by broadly flat to gentle undulations (Ishaku, 1995). The area is largely drained by the River Benue, which is characterized by extensive flood plains along which occur lakes Geriyo and Njuwa (Adekeye

and Ishaku, 2004). Jimeta area is bordered by River Benue and lake Geriyo, and is dissected by a number of small streams (Ntekim and Bello, 2001), while Yola is bordered by lake Njuwa in the east. The major occupation of the people is agriculture while industries such as Nimafoam, Faro bottling Company and some other small-scale industries occur in the area. The population of the area is about 325,925 based on 2006 population census.

The study area is underlain by the Albian-Aptian Bima Sandstone and recent river alluvium (Fig. 2). The Bima Sandstone is the oldest Formation in the Upper Benue Trough and overlies the Basement Complex uncomformably. The detailed description of the Bima Sandstone were provided by Carter et al (1963), Allix (1983)), Popoff et al (1986), Popoff (1988), and Guiraud (1990a, 1991a) into B1, B2 and B3 known as the Bima group. The outcrops of the Bima group belong to the Bima 2 and 3 in the Yola arm (Braide, 1992). The Bima sandstone (B2) varies from fine to coarse grained (Allix, 1983), and the deposits were regarded as of proximal braided river origin (Guirand, 1990a, 1990b, 1991a In Zaborski, 1998). The Bima Sandstone (B2) is widely distributed, and is characterized by trough and tabular cross-bedding. The sandstone ranges from 100-500 metres thick. The upper Bima Sandstone (B3) is fairly homogenous, relatively mature, and fine to coarse-grained sandstone, characterized by tabular cross-bedding, convolute bedding and overturned cross-bedding (Zaborski et al., 1997). The thickness ranged from 500-1500 metres. Lithologically, the Bima Sandstone consists of feldspathic sandstone, grits, pebble beds and clay intercalations in some places (Eduvie, 2000). Borehole litholgic logs in the area reveal the presence of lateritic soils, sandstones, clays, mudstone, siltstones and ironstones (Ishaku and Ezeigbo, 2000). The Bima Sandstone occurs in the southwestern, southeastern and northeastern parts of the study area (Fig. 2). The river alluvium (recent) belongs to the Quaternary age and is found along the main course of the Benue River, and extends towards the northeast and southern parts of the study area (Fig. 2). The river alluvium consists of poorly sorted sands, clays, siltstones and pebbly sand (Ishaku and Ezeigbo, 2000; Yenika et al., 2003). Borehole lithologic sections (Fig. 3) reveal unconfined and semi-confined aquifer systems. The unconfined aquifer ranges from 7m to 80m with an average of 43.5m while the semi-confined aquifer ranges from 4m to 73m with an average of 38.6m. Depths to water in the hand-dug wells range from 0.8m to 12.4m in the dry season, and it is 0.05m to 11.9m in the rainy season. Depths to water in boreholes range from 1.8m to 40.5m in the dry season, and ranges from 1.1m to 38.8m in the rainy season (Ishaku and Ezeigbo, 2008). The average hydraulic conductivity (K) for the aquifers is 1.63×10^{-6} m/s and average transmissivity (T) is 1.24×10^{-2} m^2/s (Ishaku, 1995). Figs. 4 and 5 showed no variation in the direction of groundwater flow between the dry season and rainy season. Regional groundwater flow occurs from the recharge area in the east around Dougirei and 80 housing units, and flows toward the southeast, southwest and northwest, respectively. Another zone occurs around the Federal University of Technology Quarters south of Yola town, and flows toward Wuro
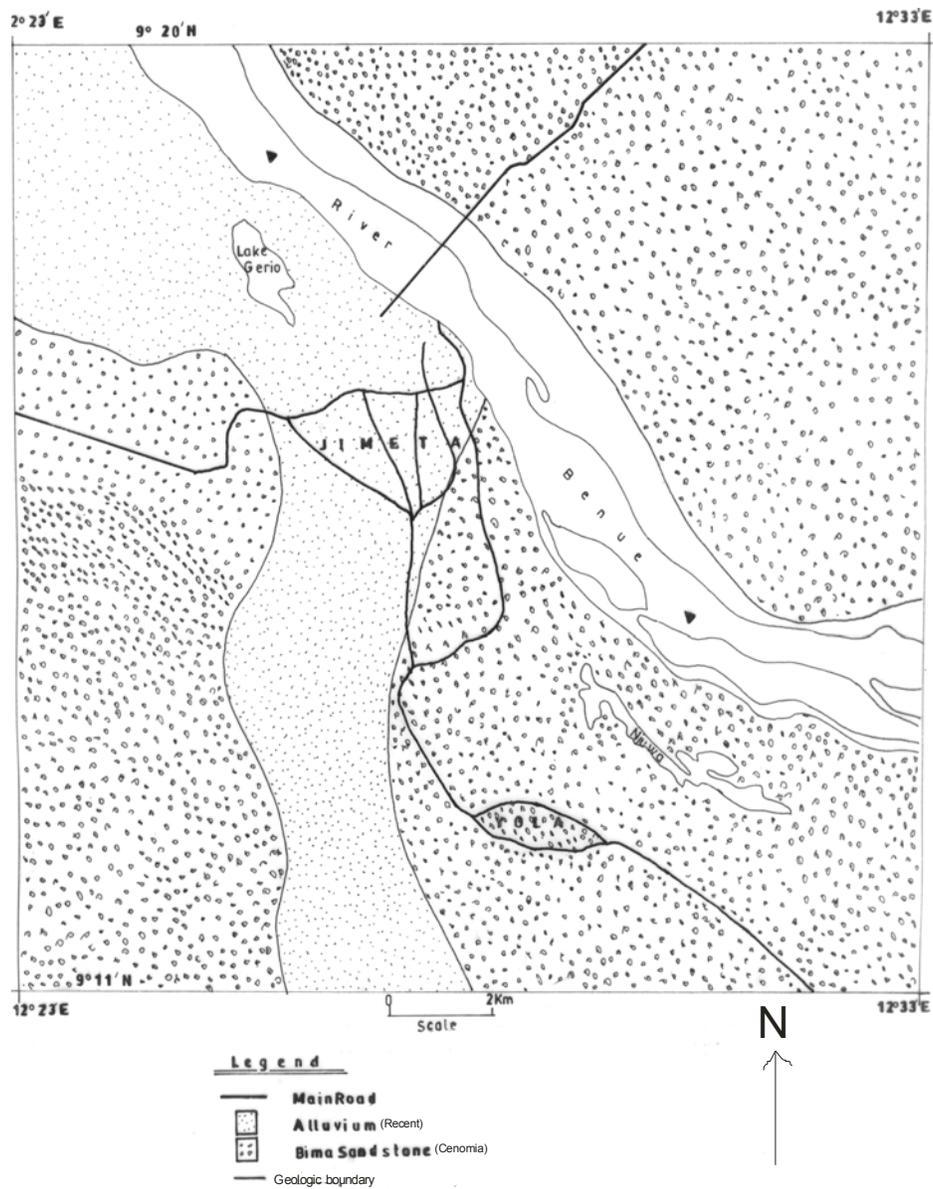
Fig.2.Geologic map of the study area
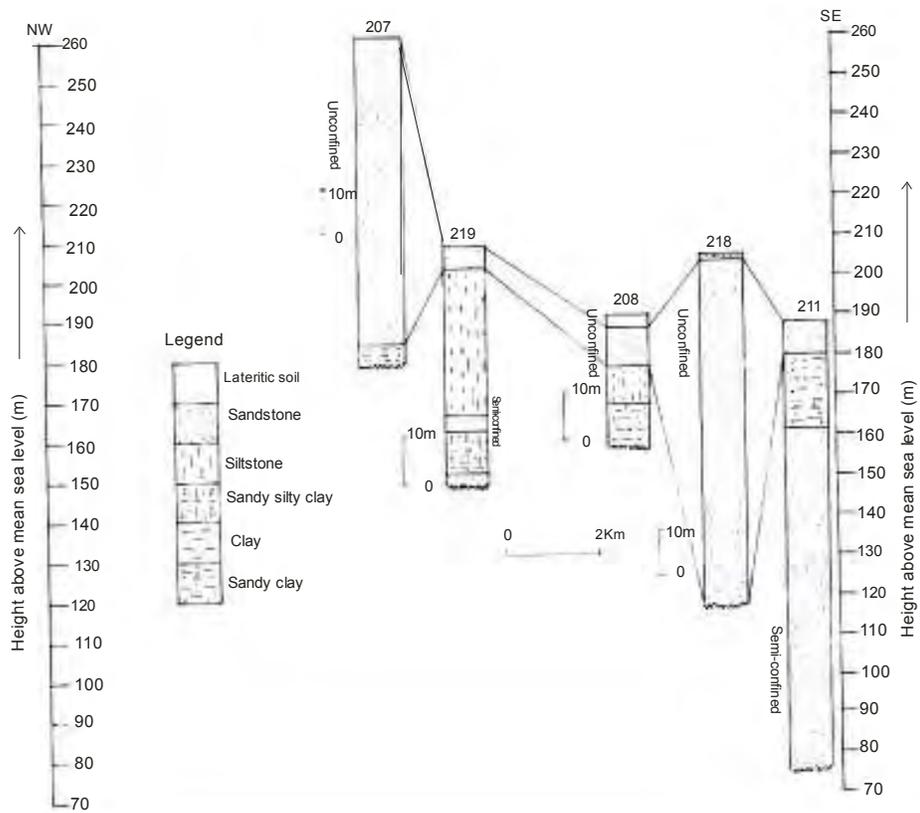
Fig. 3 Borehole lithologic section along NW- SE in the study area
(After Ishaku and Ezeigbo, 2008)
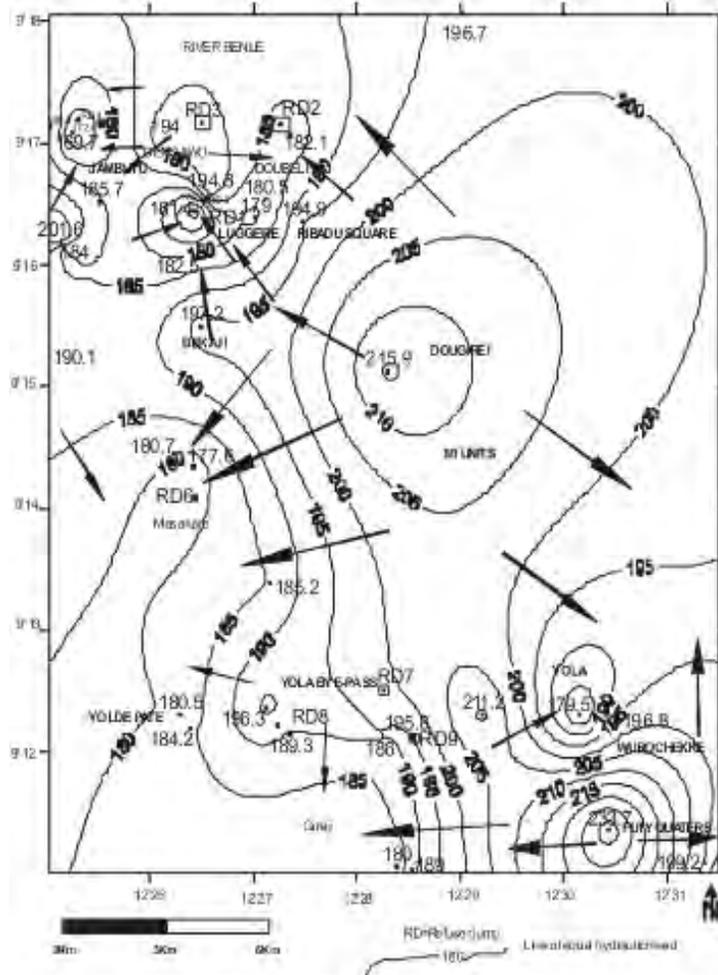
Table 4 HYDRAULIC HEAD DISTRIBUTION IN THE WET SEASON IN THE STUDY AREA Table 5 HYDRAULIC HEAD DISTRIBUTION IN THE DRY SEASON IN THE STUDY AREA
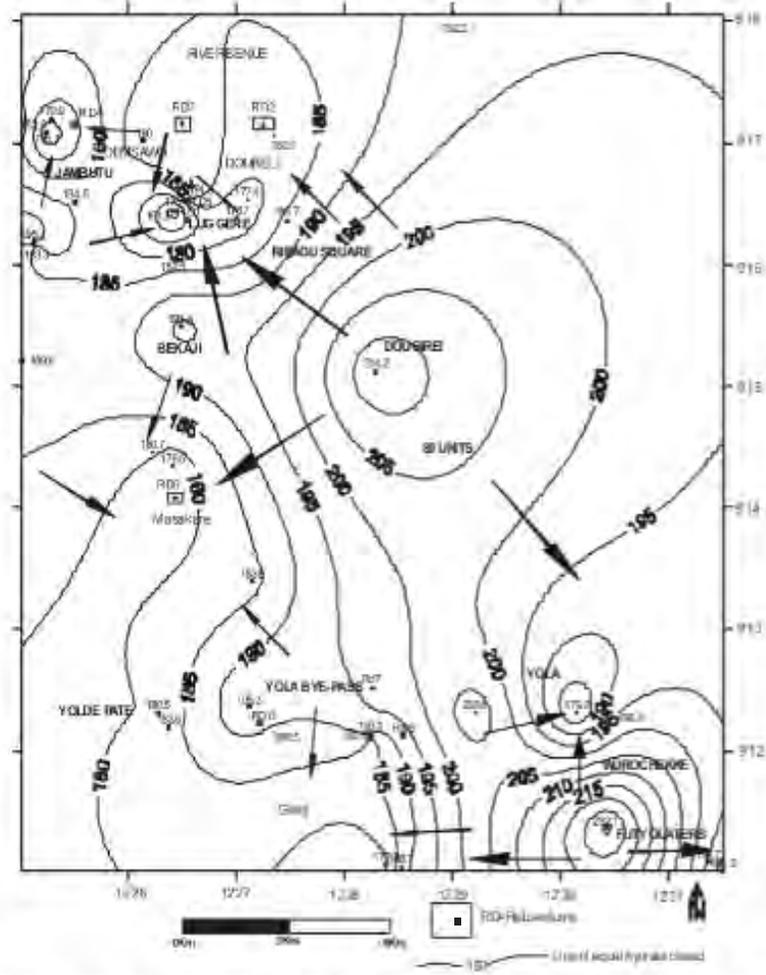
Chekke and Gireiji areas.The discharge areas cover Yolde Pate and Masakare areas, and some parts of Yola town in the east, and Luggere and Doubeli areas in Jimeta metropolis.

MATERIALS AND METHODS

A total of thirty-seven water samples (18 from hand-dug wells, and 19 from boreholes) were collected during the dry season and rainy season (The monitoring was carried out at six months interval which coincided with the dry season and rainy season period in the area). Leachate samples were also collected beneath refuse dumps along the banks of the River Benue in both the dry season and rainy season according to the UNESCO/WHO/UNEP standards (Chilton, 1992). Locations of the monitoring wells were determined using the Global Positioning System (GPS). The field parameters such as pH, EC and TDS were determined in the field using the potable pH meter HANNA pH meter (Model HI 28129) and TDS/conductivity meter (HACH KIT) (Model 44600-00). The atomic absorption spectrophotometer (AAS) (model PYE UNICAM SP 9) was used for the analysis of calcium and magnesium while the flame photometer (Model 2655-90) was used for the analysis of sodium and potassium. Nitrate and sulphate were analyzed using spectrophotometer (Model DR/2000, USA). Bicarbonate was analyzed in the field during the sample collections using titrimetric method based on the Sexana (1990) method. Chloride was also analyzed by titrimetric method using the mercuric nitrate method. The sample containers were rinsed twice, before the samples were collected according to Barcelona et al (1985) method. The analyses were carried out at the Adamawa State Water Board Treatment Plant laboratory, Numan; Biotechnology laboratory, Federal University of Technology, Yola and also, Department of Chemistry Federal University of Technology, Yola.

RESULTS

The results of the physical and chemical parameters measured in the dry and rainy seasons are presented in Tables 1 and 2. The summary of the physical and chemical parameters for the dry and rainy season are presented in Tables 3, 4, 5 and 6.

Shallow aquifer

The results from Tables 3 and4 reveal that pH values ranged from 6.3 to 8.5 in the dry season, and from 5.4 to 8.3 in the rainy season with mean values of 7.4 and 7.3, respectively. EC values range from 260 to 1990 µS/cm in the dry season, and range from 290 to 2140 µS/cm in the rainy season with mean values of 1035.6 µS/cm and 1020.6 µS/cm, respectively. TDS values range from 130 to 1000 mg/l in the dry season and from 150 to 1070 mg/l in the rainy season with mean values of 551.7 mg/l and 511.7 mg/l, respectively. The results of the cations reveal that sodium range from 10 to 240 mg/l in the dry season, 90 to 420 mg/l in the rainy season, potassium range from 1.5 to 64 mg/l in the dry season, 5 to 72 mg/l in the rainy season, calcium range from 3 to 300.5 mg/l in the dry season, 15.2 to 88.4 mg/l in the rainy season, and magnesium range from 0.5 to 98 mg/l in the dry season, and values range from 3.6 to 26.8 mg/l in the rainy season. Among the cations, sodium reveal mean values of 90.4 mg/l in the dry season and 240.1 mg/l in the rainy season, potassium recorded mean values of 25.5 mg/l in the dry season and

Table 1 Field data of samples collected in dry season and Rainy season period

Proj. N0.	Latitude	Longitude	pH Dry season	Rainy season	Ec (µS/cm) Dry season	Rainy season	TDS (mg/l) Dry season	Rainy Season
Hw73	$9^0 16.38$	$12^0 27.02$	7.4	7.7	1090	2140	960	1070
Hw71	$9^0 16.38$	$12^0 26.55$	7.5	7.6	570	610	290	300
Hw17	$9^0 16.53$	$12^0 27.11$	7.6	7.1	1400	1060	700	530
Hw27	$9^0 17.07$	$12^0 26.44$	7.4	7.6	1740	1760	870	880
Hw42	$9^0 17.09$	$12^0 26.58$	8.5	7.8	1370	1640	690	820
Hw45	$9^0 17.03$	$12^0 26.35$	7.8	7.5	1650	1490	830	750
Hw54	$9^0 17.02$	$12^0 26.14$	8.3	7.3	1990	1050	1000	530
Hw59	$9^0 16.53$	$12^0 25.46$	7.7	7.4	1440	620	720	310
Hw116	$9^0 17.14$	$12^0 25.03$	7.6	8.2	590	1060	300	530
Hw192	$9^0 12.36$	$12^0 27.12$	6.3	7.1	310	500	310	250
Hw155	$9^0 12.14$	$12^0 27.55$	6.7	7.5	380	440	190	220
Hw176	$9^0 12.31$	$12^0 29.21$	6.5	6.5	1430	1300	720	650
Hw184	$9^0 12.23$	$12^0 29.32$	8.0	5.4	540	780	270	390
Hw160	$9^0 11.06$	$12^0 28.38$	6.3	7.1	260	290	130	150
Hw188	$9^0 12.12$	$12^0 28.25$	7.0	7.5	1500	1340	750	670
Hw189	$9^0 12.15$	$12^0 28.24$	7.8	7.1	1230	1010	620	510
Hw173	$9^0 13.09$	$12^0 29.15$	6.7	6.5	650	930	330	470
Hw134	$9^0 16.19$	$12^0 25.13$	7.9	8.3	500	350	250	180
BH1	$9^0 16.50$	$12^0 26.06$	6.4	6.2	290	270	150	140
BH87	$9^0 16.49$	$12^0 27.02$	8.0	8.0	380	390	190	200
BH3	$9^0 16.59$	$12^0 27.07$	6.4	6.1	1700	900	80	130
BH6	$9^0 17.11$	$12^0 27.28$	7.9	7.5	1790	1740	900	880
BH8	$9^0 17.10$	$12^0 27.34$	6.9	6.4	350	420	180	230
BH52	$9^0 16.59$	$12^0 26.19$	6.5	5.9	100	100	50	50
BH67	$9^0 16.36$	$12^0 26.13$	6.8	6.2	110	130	50	70
BH55	$9^0 17.07$	$12^0 25.53$	6.9	6.6	210	300	110	150

BH130	$9^0$16.16	$12^0$25.08	6.9	7.6	90	80	90	40
BH131	$9^0$15.34	$12^0$24.24	6.6	6.7	80	90	40	50
BH132	$9^0$16.21	$12^0$23.16	6.8	7.5	90	170	50	90
BH140	$9^0$16.35	$12^0$27.47	6.3	6.6	150	220	80	110
BH147	$9^0$13.42	$12^0$26.08	7.3	7.2	410	500	210	250
BH191	$9^0$12.37	$12^0$27.47	6.2	5.7	160	150	80	80
BH194	$9^0$12.41	$12^0$26.54	6.0	6.4	240	310	120	150
BH177	$9^0$12.23	$12^0$29.47	6.0	5.5	650	680	650	340
BH165	$9^0$11.37	$12^0$28.43	7.0	7.7	530	530	270	270
BH125	$9^0$17.20	$12^0$25.36	7.7	7.0	540	570	270	290
BH146	$9^0$14.19	$12^0$27.07	7.0	6.6	260	300	130	150

Table 2: Major ion and nitrate concentrations in groundwater of Jimeta-Yola area sampled in the dry and rainy season
Bdl= Below detection limit

Proj. N0.	Na+ mg/l(Mar.)	Sep	K+ mg/l(Mar)	Sep	Ca2+ Mg/l(Mar)	Sep	Mg2+ Mg/l(Mar)	Sep	Cl- Mg/l(Mar)	Sep	HCO3- Mg/l(Mar)	Sep	SO42- ,mg/l(Mar)	Sep	NO3- Mg/l(Mar)	Sep
Hw73	190	400	47	72	300.5	31	98	26.5	166.8	248.7	446.5	668.6	70	111	64.7	75.3
Hw71	50	160	18	21.5	71	53.2	3.6	13.5	59.6	67.4	168.4	168.4	36	7	36.3	69.1
Hw17	145	270	1.6	25	4	65.4	2.7	13	122.8	102.8	395.3	529.5	54	76	238.8	30.1
Hw27	180	420	44	44	82	88.4	9.2	26.8	180.4	244.6	219.6	678.3	20	117	89.9	149.7
Hw42	130	420	38	46.5	84	52	16	21	121.6	680	262.6	615.8	68	128	Bdl	71.3
Hw45	20	360	50	42	96	56.6	75	14	169.6	1490	319.6	378.4	20	82	81.5	94.3
Hw54	240	270	33	29	70	66.6	10	16	184.4	120.5	69.8	378.2	22	9	169.2	46.5
Hw59	110	141	26	17.5	71	60	16.2	5.6	147.6	46.1	378	302.8	68	31	27.5	25.7
Hw116	50	270	4	29.5	160	66.8	9.5	20	57.6	750	141.8	295.5	25	74	65.1	98.3
Hw192	30	140	1.5	6	5	47	4.8	12.7	265	325	51.2	141.5	27	32	88.5	57.6
Hw155	10	100	4	6	4	48	0.5	5.9	370	180	124.4	207.4	52	38	3.1	18.2
Hw176	95	260	56	50	90	62.5	31.6	26.8	1730	1265	83	153.7	74	82	93	224.1
Hw184	30	150	12	31	26	62.5	9.6	20	410	585	120	87.8	29	39	77.9	163
Hw160	22	90	2.8	5	3	15.2	5.2	3.6	200	145	68.3	90.3	14	12	49.6	39.4
Hw188	140	320	64	61	48	45	27.8	22	1510	1300	244	351.8	122	84	78.4	93
Hw189	96	230	23	28.5	88	75.8	14.2	17.6	1680	840	327	141.5	28	74	42.1	88.6
Hw173	60	200	24	54	34	52	10	20	975	882.5	153.7	158.6	42	57	9.3	136.4
Hw134	30	120	10	14	21	17.8	9.5	9	47.2	53.2	48.8	83	17	29	108.1	36.3
BH1	Bdl	50	1	8	9	31	2.4	9	240	35.5	58.6	92.7	8	10	43	21.7
BH87	10	50	3	6	37	19	8.8	7.5	Bdl	17.7	251.3	351.4	9	146	24.4	12.4
BH3	1	10	1.6	6	16	19	0.6	3.4	2.4	14.2	39	73.2	2	84	27	17.3
BH6	105	290	62	59	7	22.5	10	30.2	129.2	5375	461.2	780.8	30	25	101.9	86.8
BH8	10	91	6	12	58	38	8.8	16.8	23.8	335	41.5	109.8	8	20	56.7	55.8
BH52	1	10	4	5	7	11.8	0.8	0.3	6.4	21.3	39	48.8	7	114	34.1	22.1
BH67	1	10	22	4	2	25.5	0.7	2.8	4	14.2	41.5	61	3	22	18.2	26.6
BH55	5	70	2	11	2	26	0.8	7	8.4	24.8	56.1	163.5	8	126	34.1	44.3
BH130	8	5	5	4	5	6.2	5.4	16.2	2.8	25	29.3	48.8	6	9	27.9	26.1
BH131	25	14	6	3.5	1	3.4	2.3	Bdl	4	25	41.5	51.2	7	8	31	15.5
BH132	1	4	5	3.5	2	11.8	0.3	1.8	60	14.2	36.6	68.3	Bdl	9	44.3	27.9
BH140	1	20	24	10	16	25.6	5.4	8	2.8	14.2	30.5	175.7	10	48	29.2	4.9
BH147	40	170	8	2	2	26	4.8	14.6	90	14.2	302.6	517.3	Bdl	9	26.1	41.6
BH191	1	10	1.4	9	1	32	0.2	0.3	115	85	19.5	12.2	1	4	47.8	49.2
BH194	5	40	1.5	10	2	30	8	7.8	260	150	36.6	19.7	Bdl	2	77.1	51.4
BH177	16	70	19	25	37	38.5	10	19	42.2	460	24.4	12.2	9	7	85.5	191.3
BH165	95	Bdl	10	1	7	30	5.2	8.8	130	100	314.8	256.2	7	7	41.2	27
BH125	24	120	19	22	42	35	9.2	19.8	28.4	1137.5	563.6	202.5	18	8	58	43.8
BH146	30	80	6	4	5	31	6.8	12	150	14.2	151.3	217.2	4	15	26.6	13.3

Table 3 **Major ion and nitrate concentrations in groundwater in shallow aquifer of aquifer of Jimeta-Yola area sampled in the dry season**

Chemical parameter	Minimum	Maximum	Mean	Std. Deviation
pH	6.30	8.50	7.3889	.66411
EC	260.00	1990.00	1035.5556	556.19741
TDS	130.00	1000.00	551.6667	287.65277
Sodium	10.00	240.00	90.4444	68.17212
Potassium	1.50	64.00	25.4944	20.44253
Calcium	3.00	300.50	69.8611	71.33801
Magnesium	.50	98.00	19.6333	25.90701
Chloride	47.20	1730.00	466.5333	580.43460
Bicarbonate	48.80	446.50	201.2222	128.07792
Sulphate	14.00	122.00	43.7778	28.11647
Nitrate	3.10	238.80	77.8235	57.35108

Table 4 **Major ion and nitrate concentrations in groundwater in shallow sampled in the rainy season Jimeta-Yola area**

Chemical parameters	Minimum	Maximum	Mean	Std. Deviation
pH	5.40	8.30	7.2889	.66765
EC	290.00	2140.00	1020.5556	518.74818
TDS	150.00	1070.00	511.6667	259.05371
Sodium	90.00	420.00	240.0556	110.29398
Potassium	5.00	72.00	32.3611	19.55972
Calcium	15.20	88.40	53.6556	18.49611
Magnesium	3.60	26.80	16.3333	7.26053
Chloride	46.10	1490.00	518.1000	475.60960
Bicarbonate	83.00	678.30	301.7278	202.90878
Sulphate	7.00	128.00	60.1111	37.49492
Nitrate	18.20	224.10	84.2722	54.66640

Table 5 **Major ion and nitrate concentrations in groundwater in deep aquifer of Jimeta-Yola area sampled in the dry season**

Chemical parameters	Minimum	Maximum	Mean	Std. Deviation
pH	6.00	8.00	6.8211	.58460
EC	80.00	1790.00	427.8947	493.93633
TDS	40.00	900.00	194.7368	220.18599
Sodium	1.00	105.00	21.0556	31.00943
potassium	1.00	62.00	10.8684	14.41535
Calcium	1.00	58.00	13.5789	16.95522
Magnesium	0.20	10.00	4.7632	3.65456
Chloride	2.40	260.00	72.1889	82.50996
Bicarbonate	19.50	563.60	133.6263	164.65943
Sulphate	1.00	30.00	8.5625	6.91827
Nitrate	18.20	101.90	43.9000	22.79861

Table 6 **Major ion and nitrate concentrations in groundwater in deep aquifer of Jimeta-Yola area sampled in the rainy season**

Chemical parameter	Minimum	Maximum	Mean	Std. Deviation
pH	5.50	8.00	6.7053	.71761
EC	80.00	1740.00	413.1579	389.53038
TDS	40.00	880.00	193.1579	187.91407
Sodium	4.00	290.00	61.8889	72.99225
Potassium	1.00	59.00	10.7895	13.25531
Calcium	3.40	38.50	24.3316	10.17377
Magnesium	0.30	30.20	10.2944	7.93618
Chloride	14.20	5375.00	414.5789	1231.24925
Bicarbonate	12.20	780.80	171.7105	196.41384
Sulphate	2.00	146.00	35.4211	45.96655
Nitrate	4.90	191.30	41.0000	41.31743

32.4 mg/l in the rainy season while calcium and magnesium reveal mean values of 69.9 mg/l and 19.6 mg/l in the dry season, and mean values of 53.7 mg/l and 16.3 mg/l in the rainy season, respectively. The results of the anions reveal that chloride concentrations range from 47.2 to 1730 mg/l in the dry season and 46.1 to 1490 mg/l in the rainy season with mean values of 466.5 mg/l and 518.1 mg/l, respectively. Bicarbonate concentrations range from 48.8 to 446.5 mg/l in the dry season and from 83 to 678.3 mg/l in the rainy season, and mean values of 201.2 mg/l and 301.7 mg/l, respectively. Sulphate recorded values ranging from 14 to 122 mg/l in the dry season and 7 to 128 mg/l in the rainy season with mean values of 43.8 mg/l and 60.1 mg/l, respectively. Nitrate values range from 3.1 to 238.8mg/l in the dry season and 18.2 to 224.1 mg/l in the rainy season with mean values of 77.8 mg/l and 84.3 mg/l, respectively.

Deep aquifer

The results from Tables 5 and 6 reveal that pH values ranged from 6 to 8 in the dry season, and from 5.5 to 8 in the rainy season with mean values of 6.8 and 6.7, respectively. EC values range from 80 to 1790 µS/cm in the dry season, and range from 80 to 1740 µS/cm in the rainy season with mean values of 427.9 µS/cm and 413.2 µS/cm, respectively. TDS values range from 40 to 900 mg/l in the dry season and from 40 to 880 mg/l in the rainy season with mean values of 194.7 mg/l and 193.2 mg/l, respectively. The results of the cations reveal that sodium range from 1 to 105 mg/l in the dry season, 4 to 290 mg/l in the rainy season, potassium range from 1 to 62 mg/l in the dry season, 1 to 59 mg/l in the rainy season, calcium range from 1 to 58 mg/l in the dry season, 3.4 to 38.5 mg/l in the rainy season, and magnesium range from 0.2 to 10 mg/l in the dry season, and values range from 0.3 to 30.2 mg/l in the rainy season. Among the cations, sodium reveal mean values of 21.1 mg/l in the dry season and 61.9 mg/l in the rainy season, potassium recorded mean values of 10.9 mg/l in the dry season and 10.8 mg/l in the rainy season while calcium and magnesium reveal mean values of 13.6 mg/l and 4.8 mg/l in the dry season, and mean values of 24.3 mg/l and 10.3 mg/l in the rainy season, respectively.

The results of the anions reveal that chloride range from 2.4 mg/l to 260 mg/l in the dry season and from 14.2 mg/l to 5375 mg/l in the rainy season with mean values of 72.2 mg/l and 414.6 mg/l, respectively. Bicarbonate and sulphate values range from 19.5 mg/l to 563.6 mg/l and 1 mg/l to 30 mg/l in the dry season with mean values of 133.6 mg/l and 8.6 mg/l, respectively. While in the rainy season, bicarbonate and sulphate concentrations vary from 12.2 mg/l to 780.8 mg/l and from 2 mg/l to 146 mg/l with mean values of 171.7 mg/l and 35.4 mg/l, respectively. Nitrate concentrations vary from18.2 mg/l to 101.9 mg/l in the dry season and from 4.9 mg/l to 191.3 mg/l in the rainy season with mean values of 43.9mg/l and 41 mg/l, respectively.

The dominance of cations in the dry season and rainy season in shallow aquifer was in the order of Na > Ca > K > Mg while the dominace of the anions was in the order of Cl > HCO_3 > NO_3 > SO_4.   The dominance of the cations in the dry season in deep aquifer was in the order of Na > Ca > K > Mg while the anions was in the order of HCO_3 > Cl > NO_3 > SO_4. In the rainy season, the dominance of the cations was in the order Na>Ca > K > Mg while the anions was in the order of Cl > HCO_3 > NO_3 > SO_4.

DISCUSSIONS

In the shallow aquifer, the pH values range from acidic to alkaline throughout the sampling period in the shallow aquifer. The acidity of the groundwater could be attributed to the presence of dissolved Carbondioxide, which is derived from organic decomposition. The mean EC value is higher in the dry season which could be due to the addition of some salts following the dissolution of waste materials at shallow depth. TDS reveal high mean value in the dry season which suggests addition of leachable salts following the dissolution of waste materials. Sodium and potassium recorded higher mean values in the rainy season. Calcium and magnesium however recorded higher mean values in the dry season. This could be attributed to cation exchange on clay minerals in which sodium replaced calcium and magnesium leading to the enrichment of sodium. From the results presented for the anions, and nitrate, it was evident that there was increase in chloride, bicarbonate, sulphate, and nitrate in the groundwater during the rainy season. The higher mean concentrations of sodium, chloride and sulphate in the rainy season can promote increase in salinity of the shallow aquifer. The source of sodium, chloride and sulphate could have resulted from the leaching of soluble salts from waste materials and soil zone. Bicarbonate can result from organic decomposition in the soil zone.

In the deep aquifer, the pH values range from acidic to alkaline throughout the sampling period similar to what was obtained in the shallow aquifer. The acidity could be due to percolation of acidic water from the shallow aquifer. In the deep aquifer, from the mean results presented, EC and TDS reveal high mean values in the dry season which could be attributed to the addition of salts through the prevailing anthropogenic activities. The low mean values of Ec and TDS in the rainy season could be attributed to dilution effect from the recharging groundwater. The mean values of the cations suggest that sodium, calcium and magnesium recorded higher mean values in the rainy season. This could be attributed to the dissolution of mineralogical constituents. While potassium did not reveal significant change in both the dry and rainy season periods which could be attributed to its high absorption on soil particles. The anions mean values suggest that chloride, bicarbonate and sulphate revealed higher mean vlues in the rainy season. Chloride and sulphate could have resulted from the leaching of soluble salts from waste materials and soil zone. The source of bicarbonate could result from organic decomposition in the soil zone and percolation of acidic water from recharged groundwater. The low mean values of nitrate in both seasons could be attributed to denitrification process due to the action of anaerobic bacteria and dilution effects.

Sources of ions

The plot of log TDS agaist $Na^+/(Na^+ + Ca^{2+})$ (Figs.6, 7, 8 and 9) for the dry and rainy season in shallow and deep aquifers reveal that most samples fall

in the rock dominance and weathering zones suggesting precipitation induced chemical weathering along with dissolution of rock forming minerals. However, some points plotted outside the diagram which according to Ogunbajo (2003) reflects water characteristics of tropical regions of Africa and South America. Evaporation greatly increases the concentrations of ions formed by chemical weathering, leading to higher salinity (Rao, 2006). As a result, the water samples move from the zone of rock-dominance towards the zone of evaporation-dominance. Anthropogenic activities (indiscriminate waste disposal practice) also influence the evaporation by
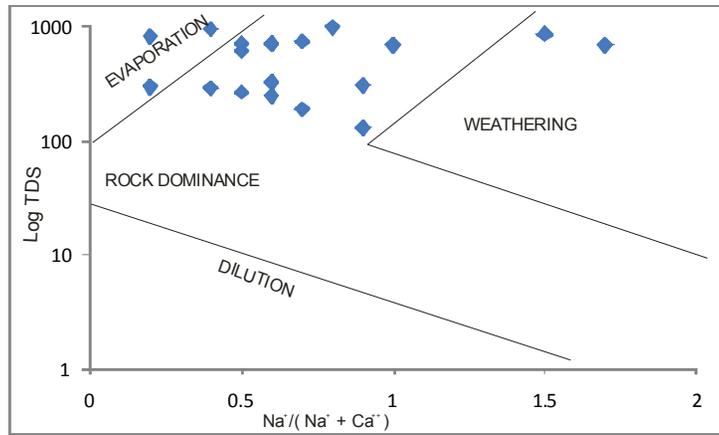
Fig. 6 Plot of logTDS versus Na$^+$/(Na$^+$+Ca^{++}) for dry season in shallow aquifer
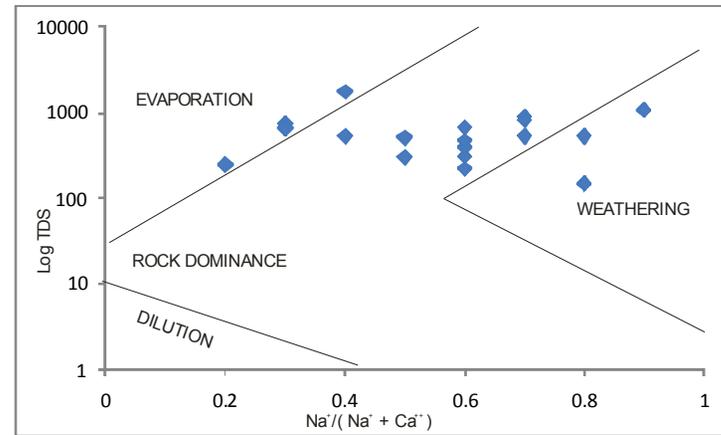
Fig. 7 Plot of log TDS versus Na$^+$/(Na$^+$ + Ca^{++}) for rainy season in shallow aquifer
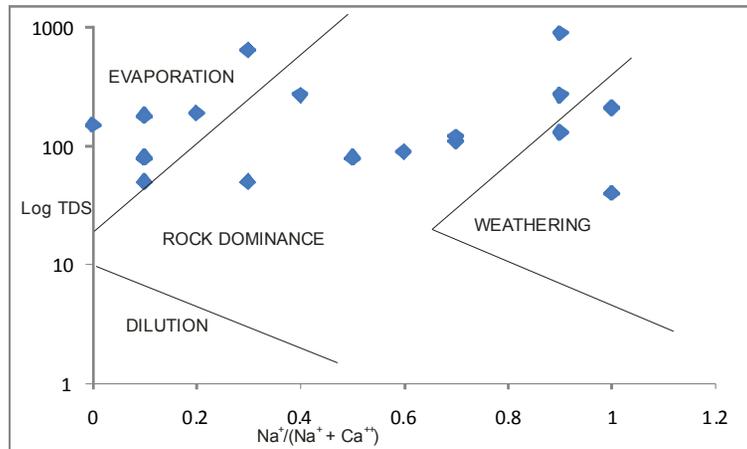
Fig. 8 Plot of logTDS versus Na$^+$/(Na$^+$+Ca^{++}) for dry season in deep aquifer
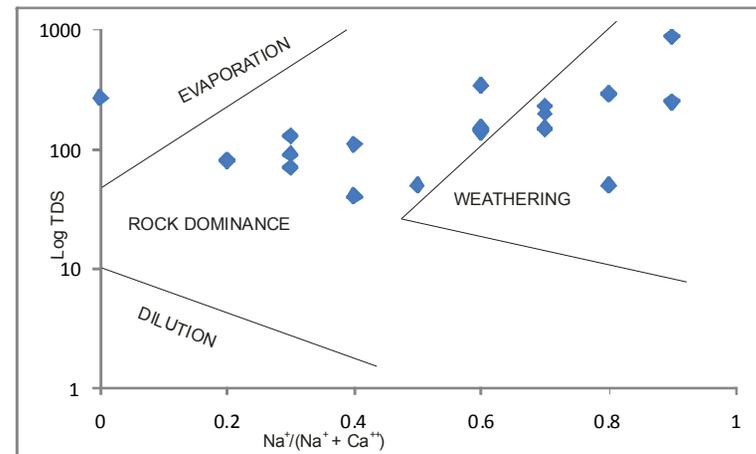
Fig.9 Plot of log TDS versus Na$^+$/(Na$^+$ + Ca^{++}) for rainy season in deep aquifer

increasing Na^+ and Cl^-, and thus TDS. Semi-arid climate also tends to evaporation-dominance groundwater systems (Rao, 2006). The evaporation-dominance groundwater in the study area is strongly linked to the semi-arid condition of the study area.

HYDROGEOCHEMICAL FACIES

The dominant mineral in the Bima Sandstone and river alluvium are feldspars, quartz, and clay minerals. The plots of the chemical data on the Piper (1944) trilinear diagram (Fig. 10, 11, 12 and 13) were used to identify the different water types characterizing the dry season and rainy season in both the shallow and deep aquifers.

Ground water types
Shallow aquifer

The chemical data plotted on Piper-trilinear diagram based on the major cation and anion identified four water types in the dry season and two water types in the rainy season.

Na-(SO_4)-Cl

This is the dominant water type characterizing the dry season and rainy season period in the shallow aquifer. It constitutes about 66.67% in the rainy season and 38.89% in the dry season period. This water type is designated as 3 on the diamond shape, and the dominant cation is sodium while the dominant anion is chloride. The water type could be as a result of pollution in the area which is connected with anthropogenic activities. For example, Fig. 14 in the dry season reveals a major sodium plume occurring between RD4 and Jambutu area having sodium concentration of 240 mg/l.

Jambutu area is characterized by uncontrolled waste disposal practice where house hold solid wastes are dumped on the street and in some cases wastes are also use as infill materials in pot holes and most residents use pit latrines. Sodium plume having concentration of 180 mg/l also occurs around RD3 dumpsite. Looking at Fig. 5 for instance, groundwater flow occurs away from RD3 towards RD4, Jambutu and Doubelli areas. RD3 therefore is responsible for the high sodium concentration. The sodium plume of 190 mg/l occurs in Jambutu Street which is located in the most densely populated area of Jimeta metropolis where most residents use pit latrines and waste water generation is high. Another indication of the contribution of sodium from waste materials can also be observed in the southeastern portion of the study area where a plume having sodium concentration of 140 mg/l occurs down gradient of RD9 dumpsite. In the rainy season, Fig. 15 reveals a major sodium plume having concentration of 420 mg/l around RD3 decreasing down gradient to concentrations of 360 mg/l and 270 mg/l respectively. Another plume having concentration of 400 mg/l occurs in Jambutu Street. Adjacent to this, a minor plume of 270 mg/l occurs which is located in Yelwa Street bordering the major drainage network that empties waste water into the Benue River. In the southeastern part of the study area, a plume of sodium having
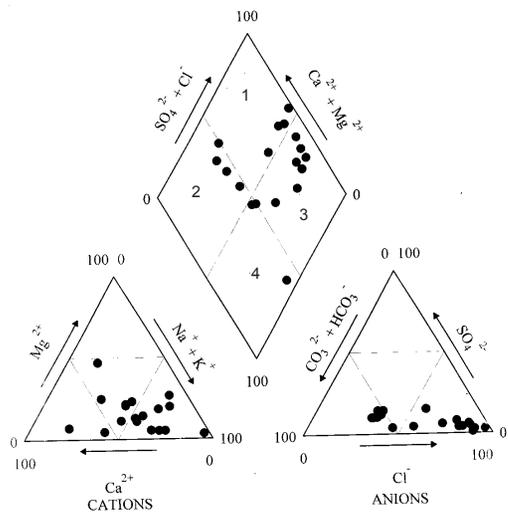
Fig. 10 Piper plots of groundwater samples for the shallow aquifer in the dry season
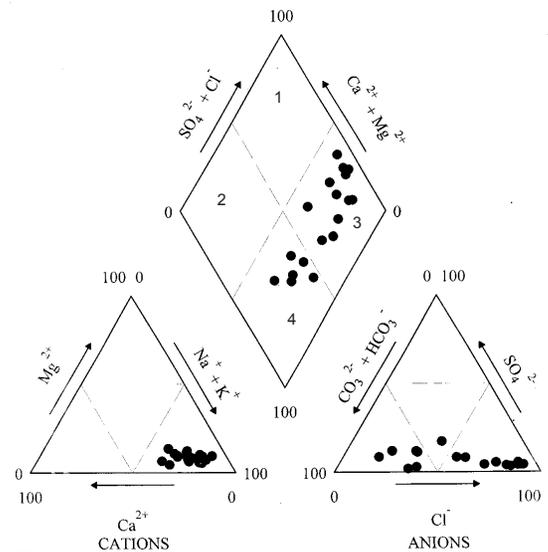
Fig. 11 Piper plots of groundwater samples for the shallow aquifer in the rainy season
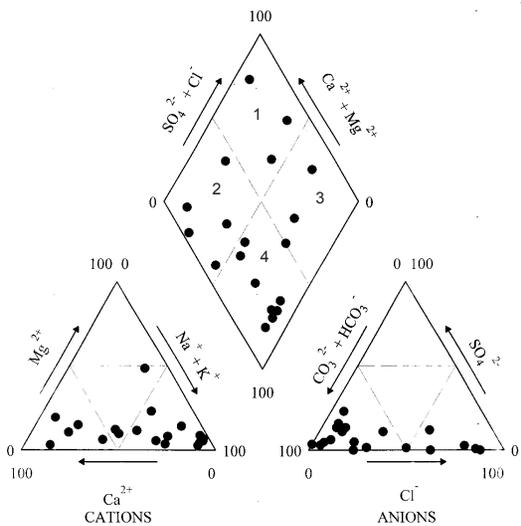
Fig. 12 Piper plots of groundwater samples for the deep aquifer in the dry season
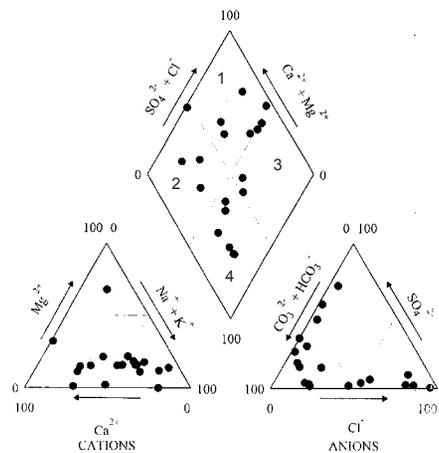
Fig. 13 Piper plots of groundwater samples for the deep aquifer in the rainy season
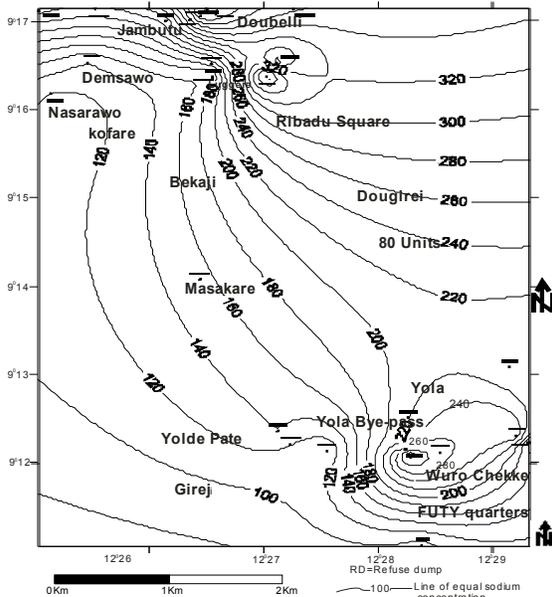
Fig. 14 Distribution of sodium in shallow aquifer in the rainy season
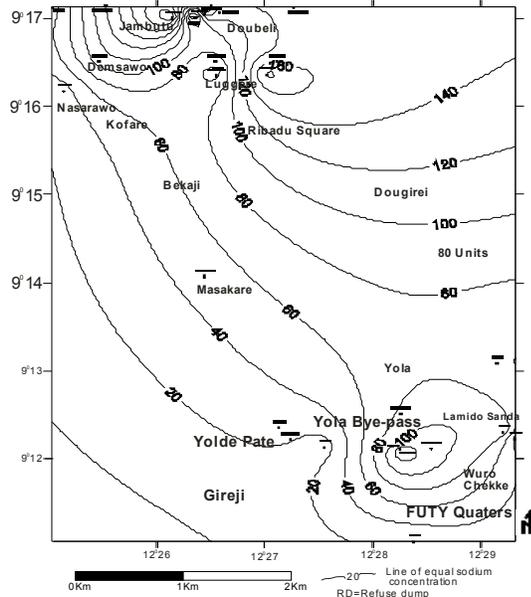
Fig. 15 Distribution of sodium in shallow aquifer in the dry season
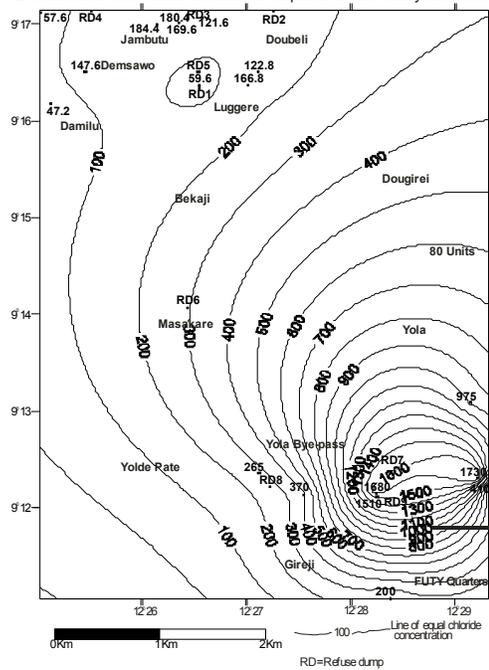
Fig. 16 Distribution of chloride in shallow aquifer in the dry season   Fig.17 Distribution of chloride in shallow aquifer in the rainy season
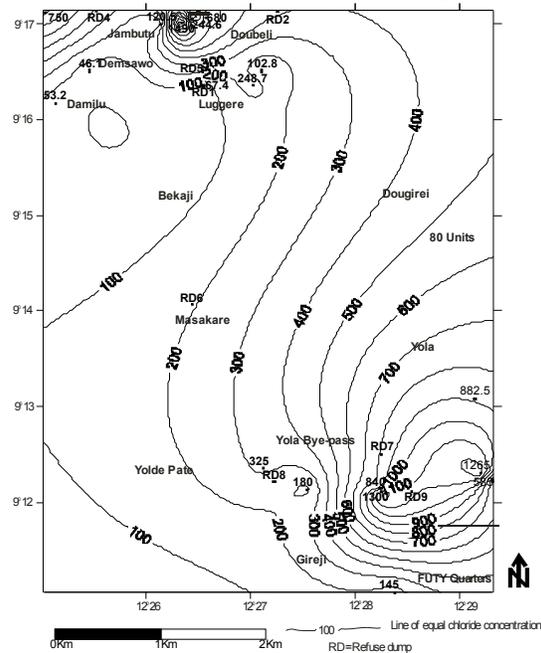
concentration of 320 mg/l occurs down gradient of the dumpsite RD9. This is also a clear indication of anthropogenic impact on the water quality.

.16 reveals a major chloride plume in the southeastern part of the study area during the dry season period. The plume having concentration 1730 mg/l extends towards the areas covering RD7 and RD9 which is an indication of the contribution of chloride from the dumpsites. Other dumpsites such as RD2, RD4, RD6 and RD8 also show high chloride concentrations relative to the surrounding areas. In the rainy season, Fig. 17 reveals a major chloride plume having concentration of 1490 mg/l occurring down gradient of RD3, while the surrounding areas reveal decrease in concentrations of 680 mg/l,

244.6 mg/l and 120.5 mg/l, respectively. This clearly indicates the source of chloride to be from RD3. Another chloride plume occurs in the southeastern part of the study area having chloride concentration of 1300 mg/l down gradient of RD9. This is also a clear indication that the source of chloride is from RD9.

The dominance of Na-SO$_4$-Cl groundwater type during the rainy season period generally indicates a strong anthropogenic influence on the shallow aquifer. The sources of this water type could be associated with the dissolution of leachable salts from waste materials and soil zone. These leachable salts percolate into the subsurface due to high rate of recharge.

Na-HCO$_3$

This water constitutes about 33.33% of the water type in the rainy season and 16.67% of the water type in the dry season, and is designated as 4 on the diamond shape. The $Na-HCO_3$ is referred to as alkaline water and is usually called exchange water due to evolution through cation exchange process (Loehnert, 1970 and 1973). The presence of clay minerals (as cation exchanger) in the rock types in the study area coupled with low flow velocity promoted longer residence time which facilitated the cation exchange process as indicated by the equation according to Nton et al (2007) as

$\frac{1}{2}Ca^{2+}$ - HCO_3 + Na^+ -X →$\frac{1}{2}Ca-X_2$ + $-HCO_3^-$ (X=clay mineral as cation exchange site)………………(4)
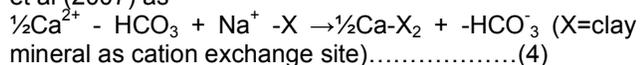
The replacement of Ca by Na through cation exchange results in the formation of $Na-HCO_3$ water (Adams et al., 2001). The dominance of this water type in the rainy season is a strong indication that cation exchange is the main process controlling groundwater chemistry in this season as it affects the shallow aquifer. Excess Na^+ in the water provided by the leachable salts and clay minerals has replaced the available Ca from the recharged $Ca-Mg-HCO_3$ water through the cation exchange process leading to the evolution of $Na-HCO_3$ water type.

Ca-Mg-HCO$_3$

The $Ca-Mg-HCO_3$ facies represents alkaline water type where the chemical properties of the water are dominated by alkaline earths and weak acid (Karanth, 1987). This water type constitutes about 22.22% of the water type in the dry season, and is designated as 2 on the diamond shape. The water is regarded as recently recharged water and its sources are related to atmospheric precipitation and dissolution of silicate minerals. The Ca and Mg could be released from silicate minerals by weathering due to the action of weak carbonic acid. Bicarbonate could result from the interaction between organic matters, nitrate, iron and hydrogensulphide through the following equations according to Lawrence (2000) as follows:

$5CH_2O$ + $2NO_3^-$ → $2N_2$+ 2 HCO_3 + CO_2 + $3H_2O$…………………………………………………..(1)

CH_2O + $3Fe(OH)_3$ → HCO_3^- + Fe^{2+} + $4OH^-$ + $3H_2O$…………………………………………………..(2)

$2CH_2O$ + SO_4^{2-} → H_2S + HCO_3^-…………………………………………………(3)
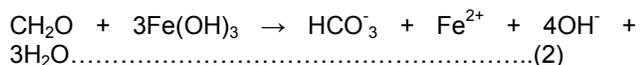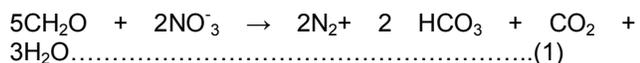
Ca-Mg-SO$_4$-Cl

Calcium and chloride represent the dominant cation and anion in this water type. The water type constitutes about 22.22% of the water type in the dry season, and is designated as 1 on the diamond shape. The water is characterized by intermediate composition which evolved between $Ca-Mg-HCO_3$ recharged water and $Na-SO_4-Cl$ water type. The intermediate composition of this water type therefore is a result of hydrogeochemical processes that occur between the two end groundwater types. At higher salinities, the process of reverse cation exchange may create Ca-Mg-SO_4-Cl water due to the removal of Na out solution for bound Ca (Adams et al., 2001). Alternatively; Ca-Mg-

SO_4-Cl could also be a result of the mixing process between "younger" fresher water with more saline water.

Deep aquifer

Distribution of groundwater samples on the Piper- trilinear diagram identifies four water types in both the dry season and rainy season in the deep aquifer. There is no signicant change in the hydrogechemical facies noticed between the dry season and rainy season in deep aquifer during the study period, which indicates that most of the major ions are natural in origin.

Na-HCO$_3$

The $Na-HCO_3$ water type constitutes about 42.11% of the water type in the dry season and 31.58% of the water type in the rainy season. The dominance of $Na-HCO_3$ in both seasons is an indication of the strong influence of cation exchange process in controlling the groundwater chemistry in the deep aquifer. Cation exchange is an important geochemical process taking place in aquifers and responsible for modifying groundwater quality (El-fiky, 2010). The source of sodium in this water type could be due to the dissolution of sodium rich montmorillonite. The dominace of this water type in both seasons is an indication that the source of sodium and bicarbonate are natural in origin. The dissolution of sodium rich montmorillonite is accomplished through the following equation;

$NaASi_3O_8$ + H_2CO_3 + $\frac{9}{2}H_2O$ →Na^+ + HCO_3^-+ $2H_4SiO_4$ + $\frac{1}{2}Al_2Si_2O_5(OH)_4$
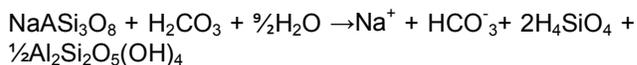
Bicarbonate could be derived from the contribution of CO2-charged rainstorms and weathering process.

Ca-Mg-HCO$_3$

The $Ca-Mg-HCO3$ water type constitutes about 26.32% of the water composition in the dry season and 21.05% in the rainy season. The composition of this water type reveal no significant change in both seasons, which is an indication of common source derived from the weathering process following the dissolution of silicate minerals by weak carbonic acid.

Ca-Mg-SO$_4$-Cl

This water type constitutes about 26.32% of the water type in the rainy season and 15.79% of the water type in the dry season, and is controlled by mixing and cation exchange processes resulting from water of saline characteristics (Na-SO_4-Cl). The dominance of this water type in the rainy season implies the dissolution of leachable salts from the waste materials and percolated by high rate of recharged water. Increase in salinity promotes reverse cation exchange resulting in the evolution of Ca-Mg-SO_4-Cl water type. Equally, this water type can also result from simple mixing where the recharged $Ca-Mg-HCO_3$ mixes with $Na-SO_4-Cl$. Such an evolutionary pattern indicates that the groundwater chemistry was controlled by simple mixing process between two end members as well as by cation exchange (Vengosh et al., 1991; Appelo & Postma, 2005; Aris et al., 2009).

Na-SO$_4$-Cl

This water type constitutes about 21.05% of the water type in the rainy season and 15.79% of the water

type in the dry season with the dominant anions represented by Na and Cl. The high percentage in the rainy season is a result of high rate of dissolution of leachable salts from waste materials and soil zone. The evolution of this water type is related to anthropogenic activities due to indiscriminate waste disposal practice. For example, in the dry season Fig. 18 reveals a major sodium plume having concentration of 105 mg/l around the dumpsites (RD2 and RD3). This concentration decreases down gradient to less than 100 mg/l. Another plume having concentration of 95 mg/l occurs around FUTY quarters in the southern corner of the study area. This plume could have resulted from the dissolution of sodium rich montmorillonite. The direction of groundwater flow is away from RD9 as indicated by Figs. 4 and 5.

A minor plume having concentration of 40 mg/l occurs between Baccure and Masakare, and is located in the discharge area as indicated by Figs. 4 and 5. The localized plume could be due to the dissolution of sodium rich montmorillonite. In the rainy season, Fig. 19 reveals a sodium plume having concentration of 290 mg/l down gradient of RD2 and decreases to 91 mg/l down gradient around the Doubeli area. Fig. 19 also reveals a sodium plume having a concentration of 170 mg/l in the central part of the study area. This plume occurs in the discharge area as reveal by Figs. 4 and 5. The source of sodium could be from the inflow of contaminated groundwater and dissolution of sodium rich montmorillonite.

Fig. 20 reveals a chloride plume having concentration of 260 mg/l, occurring in the densely populated area of Yolde Pate. This high concentration could be due to the indiscriminate waste disposal practice following the use of pit latrines by most residents and uncontrolled house hold solid wastes. Another
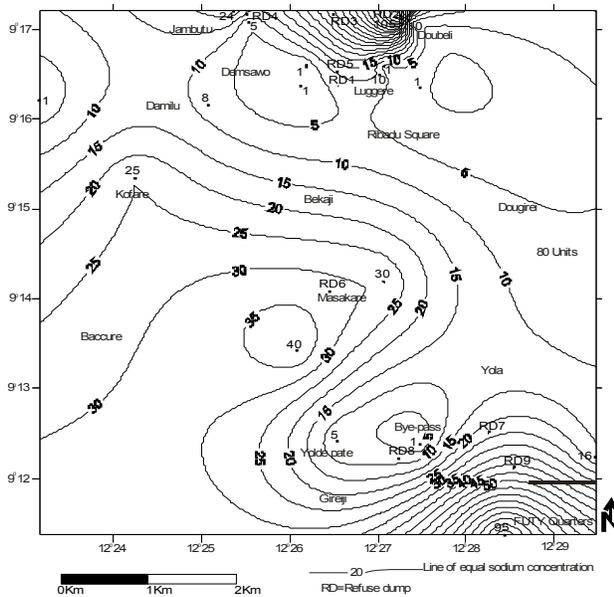
Fig. 18 Distribution of sodium in deep aquifer in the dry seson
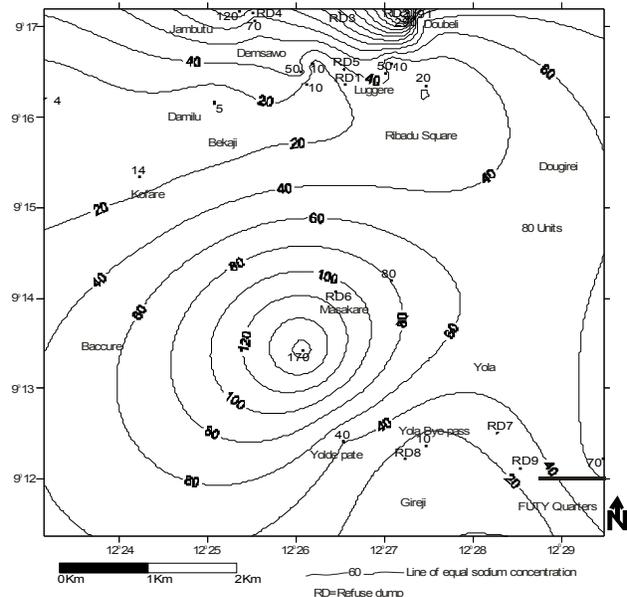
Fig. 19 Distribution of sodium in deep aquifer in the rainy season
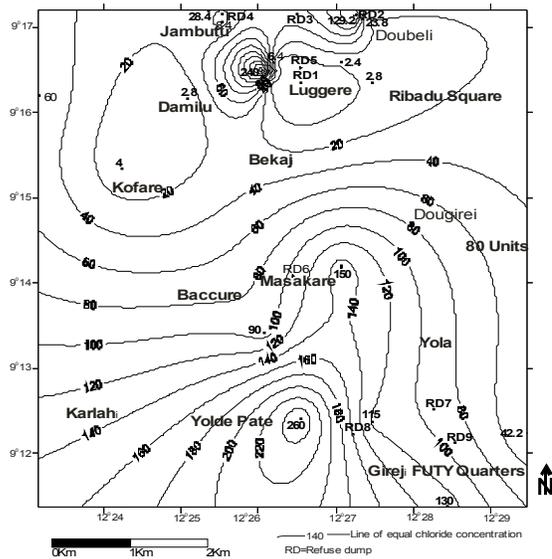
Fig.20 Distribution of chloride in deep aquifer in the dry season   Fig. 21 Distribution of chloride in deep aquifer in the rainy season
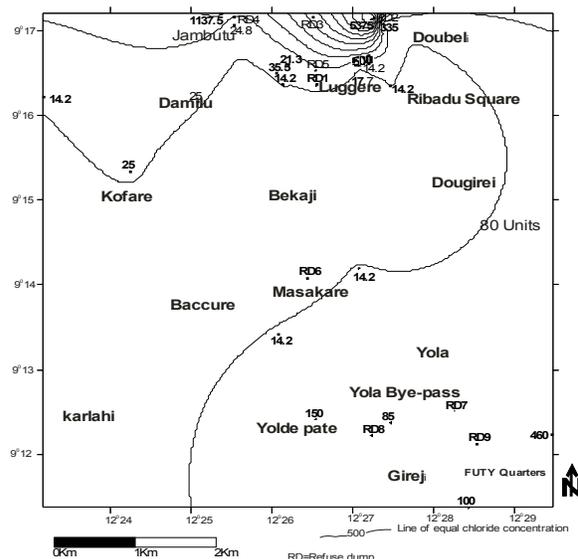
plume having concentration of 240 mg/l occurs along the major drainage network; hence the high chloride concentration is strongly associated with waste materials in the drainage. A minor chloride plume of 129.2 mg/l occurs around RD2 which is a result of leachates from the dumpsite. In the rainy season, Fig. 21 reveals a major chloride plume having a concentration of 5375 mg/l down gradient of RD2 and decreases to 335 mg/l down gradient. This is a clear indication of the impact of RD2 on groundwater quality. Fig. 21 further reveals a chloride plume having concentration of 1137.5 mg/l located in Jambutu area. This high chloride concentration is strongly associated with the indiscriminate waste disposal practice in Jambutu area. The salinization of this aquifer is due to hydraulic contact with the shallow aquifer. The change between Ca-Mg-SO$_4$-Cl water typeand Na-SO$_4$-Cl water type shows that cation exchange process was controlled by salinization process of the aquifer which act simultaneously due to the inflow of water of saline characteristics from the shallow aquifer. The salinization of this aquifer has negative impacts on the local population in terms of taste and acceptability for use. It is now clear that regional flow recharges the deep aquifer with saline water. This source of water contributes to improving the water quantity; however, it worsens the quality of the water for human consumption. It can be deduced from the fore going that cation exchange, salinisation and mixing processes are responsible for the chemical evolution of groundwater in the area.

The use nitrate as pollution indicator

Nitrate concentrations monitored along side with the chemical parameters in the dry and rainy seasons (Table 2) indicated that the highest concentrations were 238.8 mg/l and 224.1 mg/l in the hand-dug wells (Hw 42 and Hw 176), and the lowest concentrations were observed in hand-dug well Hw 155 and borehole BH 140 as 3.1 mg/l and 4.9 mg/l, respectively. The high concentrations were observed in hand-dug wells located in the densely populated areas of Jimeta metropolis and Yola town. The high concentrations of nitrate were observed in the hand-dug wells during the dry season period. The lowest value of nitrate concentrations of 18.2 mg/l in the hand-dug wells occurred in Hw 155 which is located outside the densely populated area of Yola town. The highest nitrate concentration was recorded in hand-dug well Hw 176 as 224.1 mg/l; this well is located in Lamido Sanda area in the densely populated area of Yola town. In the dry season, the lowest value recorded was 3.1 mg/l (Hw 155), and the highest value of 238.8 mg/l was recorded in hand-dug well Hw 17 located in the densely populated area of Jimeta metropolis. In boreholes during the rainy season, the highest concentration recorded was 191.3 mg/l in BH 177 located in the densely populated area of Yola town, and the lowest concentration of 4.9 mg/l was obtained in borehole BH 140 located outside the densely populated area of Jimeta metropolis.

The relatively high nitrate concentrations obtained during the sampling periods indicate groundwater degradation by nitrate. The high nitrate concentration is linked to the indiscriminate waste disposal practice in the area, for example, house hold solid wastes are dumped along the banks of the Benue River. Leachates samples were collected during the sampling period at the disposal sites along the banks of the Benue River. The results indicate that during the dry season period, only one sample was collected and a value of 294.1 mg/l was obtained. In the rainy season, two samples were collected and results reveal values of 21.7 mg/l and 343.7 mg/l, respectively. The low value of 21.7 mg/l could be due to denitrification and dilution processes at the sampling point. The low nitrate concentrations in the hand-dug wells and boreholes in the inner areas of the metropolis are likely to reflect areas that are located in the recharge zone.

Figs. 22 and 23 reveal nitrate distribution in shallow aquifer in the dry season and rainy season. In the dry season, Fig. 22 reveals a major nitrate plume having concentration of 238.8 mg/l which is located at the Yelwa Primary School Mosque. In the rainy season period, this plume was reduced to a concentration of 30.1 mg/l (Fig.23). The low concentration could be attributed to dilution or denitrifcation process. The high concentration in this plume could be due to contaminated groundwater derived from drainage network which borders the area and contaminated groundwater derived from sewage in the metropolis. Fig. 22 indicates a nitrate plume in Jambutu area having a concentration of 169.2 mg/l in the dry season period. The plume was reduced to a concentration of 46.5 mg/l in the rainy season (Fig. 23). The low concentration could be due to dilution and denitrification process while the high concentration is strongly linked to contaminated groundwater derived from sewage and leachates from house hold solid wastes. Fig. 22 reveals nitrate concentrations of 89.9 mg/l down gradient of RD3 which decreases to a concentration of 81.5 mg/l in the dry season. In Fig. 23, a plume having concentration of 149.7 mg/l occurs down gradient of RD3 which was reduced to a concentration of 94.3 mg/l and 71.3 mg/l respectively in the rainy season. These high concentrations of nitrate are strongly linked to leachates from RD3 dumpsite following the dissolution of waste materials in the rainy season period. Between RD1 and RD5, a low concentration of nitrate was recorded in the dry season period (Fig. 22) of 36.3 mg/l. This concentration was increased to 69.1 mg/l in the rainy season period (Fig. 23). This clearly demonstrates the influence of house hold solid wastes on the degradation of groundwater quality by nitrate. In the southeastern part of the study area, Fig. 22 reveals a nitrate plume having a concentration of 93 mg/l. This was increased to 224.1 mg/l in the rainy season period (Fig. 23). Figs. 4 and 5 indicate that this plume occurs in the discharge area, and the high concentration is attributed to in flow of contaminated groundwater. In the dry season period, Fig. 22 indicate nitrate concentrations of 42.1 mg/l and 78.4 mg/l down gradient of RD7 and RD9 while a nitrate plume having concentration of 88.5 mg/l occurs around RD8. The nitrate concentrations down gradient of RD7 and RD9 were increased to 88.6 mg/l and 93 mg/l respectively (Fig. 23). This clearly demonstrates that the source of nitrate is from the dumps. At RD8 (Fig. 23), nitrate concentration was reduced to 57.6 mg/l against 88.5 mg/l recorded in the dry season. This low concentration could be due to dilution or denitrifcation process. Figs. 24 and 25 show the distribution of nitrate

in deep aquifer in the dry and rainy season periods. Fig.24 shows nitrate plume having concentration of 101.9 mg/l around RD2 and decreases to a concentration of 56.7 mg/l. In Fig. 25 in the rainy season, the plume decreases in concentration to 86.8 mg/l and decreases to 55.8 mg/l down gradient during the rainy season period. This low concentration compared to the concentrations in the dry season is an indication of dilution effect and dinitrification process. The development of the plume is a result of the leachates produced from RD2. Fig.24 also shows a plume having a concentration of 77.1 mg/l in Yolde Pate

area in the dry season period and decreases to a concentration of 51.4 mg/l in the rainy season period (Fig. 25). This could be attributed to dilution and denitrification process. The development of the nitrate plume is as a result of poor waste disposal practice in the area. Another nitrate plume having a concentration of 85.5 mg/l occurs in the southeastern part of the study area. This plume is located in Garwa/Yerima Street in Yola town, and is located in the discharge area as indicated by Figs. 4 and 5. This plume increases in concentration to
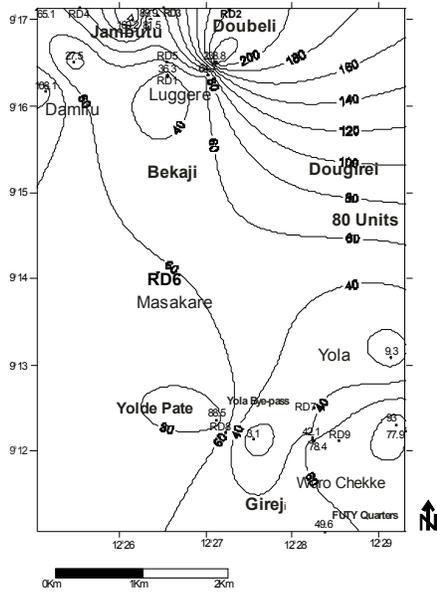
Fig.22 Distribution of nitrate in shallow aquifer in the dry season
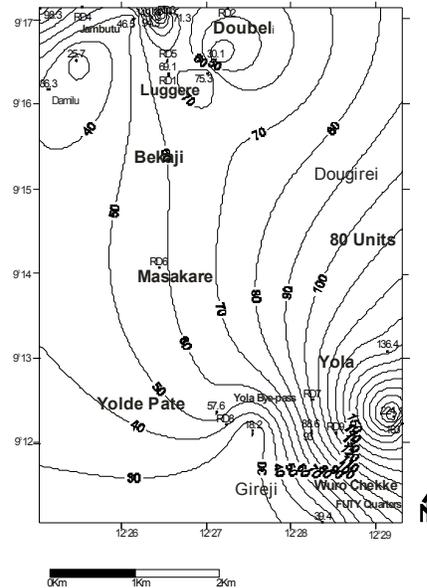
Fig. 23 Distribution of nitrate in shallow aquifer in the rainy season
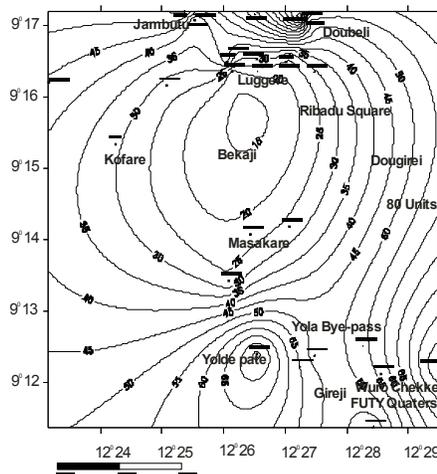
Fig. 24 Distribution of nitrate in deep aquifer in the dry season
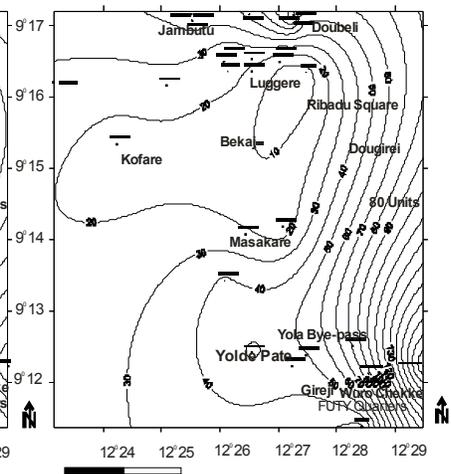
Fig.25 Distribution of nitrate in deep aquifer in the rainy season

191.3 mg/l in the rainy season (Fig. 25). The high concentration is attributed to inflow of contaminated groundwater derived from leachates associated with house hold solid wastes and sewage effluent as most residents in the area use pit latrines.

From the fore going, it can be deduced that organic decomposition, sewage effluent and household solid wastes are responsible for the high nitrate concentrations in groundwater in the area. Dilution and denitrification processes are responsible for the low concentration of nitrate in groundwater in the area. Correlation analysis between NO3 and chemical parameters reveal positive correlation between nitrate, Mg, K, and Cl which is an indication of a common source resulting from anthropogenic activities. For example, in shallow aquifer during the rainy season period, there was positive correlation between NO_3, Mg, Cl and K as 0.761, 0.613 and 0.556. In the deep aquifer during the dry season, NO_3 and Cl correlated positively with a correlation coefficient of 0.557. In the rainy season NO_3 correlated positively with K and Mg as 0.569 and 0.506.

CONCLUSIONS.

The following conclusions can be drawn from this study as follows:

1. Analytical results reveal that pH ranged from acidic to alkaline throughout the sampling period.
2. EC and TDS mean values were higher in shallow aquifer in the rainy season and lower in deep aquifer, which was attributed to addition of leachable salts following the dissolution of waste materials and dilution effects due to recharging groundwater in the case of deep aquifer.
3. The dominant cations in shallow aquifer was in the order of Na > Ca > K > Mg and anions was in the order of Cl > HCO_3> NO_3 > SO_4 in both seasons.
4. The dominant cations in deep aquifer was in the order of Na > Ca > K > Mg and anions was in the order of HCO_3 > Cl > NO_3 > SO_4 in the dry season while in the rainy season, the dominant cations was in the order of Na > Ca > K > Mg and anions in the order of Cl > HCO_3 > NO_3 > SO_4.
5. The plots of log TDS against $Na^+/(Na^+ + Ca^{2+})$ indicated that most sample points plot in the region of rock dominance and weathering zone suggesting precipitation induced chemical weathering along with dissolution of rock forming minerals.
6. Piper trilinear diagram for the shallow aquifer in the dry season classified the water types into: $Na-SO_4-Cl$, $Ca-Mg-HCO_3$, $Ca-Mg-SO_4-Cl$ and $Na-HCO_3$, and $Na-SO_4-Cl$ and $Na-HCO_3$ in the rainy season. The deep aquifer revealed $Na-HCO_3$, $Ca-Mg-HCO_3$, $Na-SO_4-Cl$ and $Ca-Mg-SO_4-Cl$ in both seasons which is an indication that the major ions are natural in origin.
7. Cation exchange, salinisation and mixing processes are the factors responsible for the chemical evolution of groundwater in the area.
8. Organic decomposition, sewage effluent and house hold solid wastes are the major sources of nitrate in the area while dilution and denitrification process are factors responsible for the natural attenuation of nitrate in groundwater in the area.
9. It is recommended that controlled wastes disposal practice should be encouraged and drilling of productive borehole to deeper levels is also encouraged.

REFERENCES

Abimbola, A. F., Adukoya, A. M. and Olatunji, A. S., 2002. Influence of bed rock on the hydrogeochemical characteristics of groundwater in northern part of Ibadan metropolis, SW Nigeria. WATER RESOURCES-Journal of the Nigerian Association of Hydrogeologists (NAH) 13, pp1-6.

Adams, S., Titus, R., Pietersen, K., Tredoux, G. and Harris, C., 2001. Hydrochemical characteristics of aquifers near Sutherland in the Western Karoo, South Africa. Journal of hydrology 241, pp91-103.

Adekeye, J. I. D. and Ishaku, J. M., 2004. Groundwater contamination in shallow aquifers of Jimeta metropolis, Adamawa State, N.E. Nigeria. Zuma Journal of Pure and Applied Sciences 6, (1): pp150-159.

Allix, P., 1983. Environments me'sozoïques de la partie nord-orientale du fosse de la Bénoué (Nigeria). Stratigraphie, sédimentologie, evolution géodynamique. Trav. Lab. Sci. Terre, St. Jérôme, Marseille (B), 21, 1-200.

Appelo, C. A. J. and Postma, D., 2005. Geochemistry, Groundwater and pollution. 2nd ed. Rotterdam: A.A. Balkema.

Aris, A. Z., Abdullah, M.H., Kim, K. W and Praveena, S. M., 2009. Hydrochemical changes in a small tropical island's Aquifer. Manukan Island, Sabah, Malaysia. Environmental Geology 56(8): 1721-1732.

Barcelona, M. J., Gibb, J. P., Helfrich, J. A. and Garske, E. E., 1985. Practical guide for groundwater sampling. ISWS contract 374. IIlinois State Water Survey Campaign, 94p.

Braide, S. P., 1992. Studies on the Sedimentation and Tectonics of the Yola arm of the Benue Trough. Facies Architecture and their Tectonic significance. J. Min. Geo. 28, (1): pp23-31.

Carter, J. D., Barber, W. and Tait, E. A., 1963. The Geology of parts of Adamawa, Bauchi and

Borno Provinces in Norteastern Nigeria. Geol. Surv. Of Nig. Bull. (30):.

Census, 2006. Population of the Federal Republic of Nigeria. Adamawa State Statistical Tables. National Population Commission Final Results of population Census of Nigeria.

Chilton, J., 1992. Groundwater. Water Quality Assessment-A guide to use; sediments and water in environmental monitoring, 2nd ed. UNESCO/WHO/UNEP.

Eduvie, M. O., 2000. Groundwater Assessment and Development in the Bima Sandstone: A cases study of Yola-Jimeta area. WATER RESOURCES-Journal of the Nigerian Association of Hydrogeologists (NAH) II, pp31-38.

El-fiky, A. A., 2010. Hydrogeochemical characteristics and Evolution of Groundwater at the Ras Sudr-Abu Zenima Area, Southwest Sinai, Egypt. JKAU: Earth Sci, 21, (1): pp: 79-109.

Garcia, M. G., M.dei, V. Hilgo and Blesa, M. A., 2001. Geochemistry in the alluvial plain of Tucuma'n province, Argentina. Hydrogeology Journal 9:597-610.

Gibbs, R. J., 1970. Mechanism Controlling World Water Chemistry. Science:1088-1090.

Guiraud, M., 1990a. Mécanime de formation du basin sur décrochements multiples de la Haute-Bénoué (Nigeria): faciés et géometrie des corps sédimentares. Mém. Habilitation, Univ. Montpellier, 445p.

Guiraud, M., 1991a. Mécanisme de formation du basin crétacé sur décrochements multiples de la Haute-Bénoué (Nigeria). Bull. Centres Rech. Explor.-Prod. Elf-Aquitaine. 15, 11-67.

Ishaku, J. M., 1995. The hydrogeology of Yola area and Environs in the Upper Benue River Basin. MSc. Thesis (unpublished). Department of Geology, University of Nigeria, Nsukka.

Ishaku, J. M. and Ezeigbo, H. I., 2000. Water quality of Yola, northern Nigeria. WATER RESOURCES-Journal of the Nigerian Association of Hydrogeologists (NAH) 1, pp39-48.

Ishaku, J. M. and Ezeigbo, H. I., 2008. Groundwater quality monitoring in Jimeta-Yola area, northeastern Nigeria. Paper presented at the conference of the Nigerian Association of Hydrogeologists (NAH), Ibadan.

Karanth, K. R., 1987. Groundwater Assessment Development and Management, Tata Mc Graw-Hill, New Delhi, 720p.

Lawrence, A. R., Goody, D. C., Kanatharana, P., Meesilp, W. and Ramnarong, V., 2000. Groundwater evolution beneath Hat Yai, a rapidly developing city in Thailand. Hydrogeology Journal, 8: pp564-575.

Lohnert, E. P., 1970. Grundwassersch hemismus und Kationentaush im norddeutschen Flachland Z dt geol. Ges., Sonderheft. Hydrgeol. Hydrogeochem., 139-159. Hannover.

Lohnert, E. P., 1973. Austauschwaesser. In: Schzcider (Hrsq) Die Grundwassererschliessung. 2nd Edition, 138-144 Vulkan Verlag. Essen.

Narayanan, N. V., Reena, T. and Beena, T., 1990. Chemical evolution of groundwater in a hard rock terraine of parts of Tinneveli District, south India. The Hydrological Basis for Water Resources Management. Proceedings of the Beijin Symposium, October 1990. IAHS publ. no. 197.

Ntekim, E. E. and Bello, H., 2001. Evaluation of heavy metal contents of soils and well water around Jimeta bridge, Yola, northeastern Nigeria. J.Min. Geol. 37, (2): pp103-111.

Nton, M. E., Adejumo, S. A. and Elueze, A. A., 2007. Hydrochemical Assessment of Surface Water and Groundwater Quality in Agbowo-Orogun area of Ibadan Southwestern Nigeria. Global Journal of Geological Sciences. 5, (1& 2): pp13-23.

Ogunbajo, M. I., 2003. Hydrogeochemical evaluation of water sources in Mokwa local gonernment area of Niger State in relation to its geology and anthropogenic influence. WATER RESOURCES-Journal of the Nigerial Association of Hydrogeologists (NAH) 14, pp53-59.

Piper, A. M., 1944. A graphic procedure in Geochemical interpretation of Water Analysis. Trans. Amer. Geophs. Union. 25, pp914-923.

Popoff, M., 1988. Du Gondwana ă ľ Atĺantique sud: les connexions du fosse de la Bénoué avec les basins du Nord Est brësilion jusqúá Í ouverture du golfe de Guinée au Crétacé inferior. J.Afr. Earth Sci., 7, 409-431.

Popoff, M., Wiedmann, J. and De Klasz, I., 1986. The Upper Cretaceous and Gongila and Pindiga Formations, northern Nigeria: Subdivisions, age, stratigraphic correlations and paleogeographic Implications. Eclogae geol. Helv., 79, 343-363.

Rao, N. S., 2006. Seasonal variation of groundwater quality in a part of Guntur District, Andhra Pradesh, india. Environ Geol. 49: 413-429.

Sexana, M. M., 1990. Environment: Water analysis, soil and air. 2nd ed. Agro Botanical Publishers (India), 188p.

Tanko, J. and Anemetemfiok, V., 2001. Optimization and processes of solid wastes coolection,

transportation and disposal in Yola, Adamawa Stste. Technical report. Department of Civil Engineering, Federal University of Technology, Yola.

Vengosh, A., Starinsky, A., Melloul, A., Fink, M. and Erlich, S., 1991. Salinization of the coastal aquifer water by Ca-chloride olutions at the interphase zone, along the coastal Plain of Israel. Report 20/1991. Hydrological Service of Israel

World Health Organization, 1993. International Standards for drinking Water Quality. Vol.1. Geneva.

Yenika, M.E., Uma, K.O. and Obiefuna, G. I., 2003. A case study of shallow aquifer in Jimeta-Yola metropolis, northeastern Nigeria. WATER RESOURCES-Journal of the Nigerian Association of Hydrogeologsts (NAH) 14, pp84-91.

Zaborski, P., Ugodulunwa, F., Idornigie, A., Nnbo, P. and Ibe, K., 1997. Stratigraphy and Structure of the Cretaceous Gongla Basin, Northeast Nigeria. Elf exploration production, F-64018 Pau.

Zaborski,P. A review of the Cretaceous system in Nigeria. Africa Geoscience Review, 5, (4): Pp385-483.