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Evaluation of groundwater suitability for drinking, domestic and irrigational purposes: A case study of Makurdi metropolis and environs, Benue State, North Central Nigeria

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A study of groundwater samples from Makurdi metropolis and environs was carried out to assess its suitability for drinking, domestic and irrigational purposes. The chemistry of groundwater within the study area with respect to pH, total dissolved solids (TDS), NH_3^-, NO_3^-, Cl^-, Na^+, K^+, Ca^{2+}, Mg^{2+}, HCO_3^-, SO_4^-, Fe^{3+}, Cu^{2+}, Mn^{2+} and Zn^{2+} was used to determine its suitability for drinking. Some parts of the study area have elevated concentration of TDS, magnesium, nitrate, sulphate, copper, manganese and iron and which are considered unsafe for drinking and some domestic uses based on the standard organization of Nigeria (SON, 2007) and the World health organization (WHO, 2011) guideline concentration for drinking water. Sodium adsorption ratio (SAR), percentage sodium (Na%) and bicarbonate hazard have been studied to evaluate the suitability of the groundwater for irrigation purpose. This study show that groundwater within the area is safe for irrigation with respect to sodium adsorption ratio but a good number of the samples had high values of bicarbonate hazard and percentage sodium, and are unsuitable for irrigation.

Key words: Irrigation, groundwater, Makurdi metropolis, suitability.

INTRODUCTION

Groundwater is the largest source of fresh water in the world. It is of major importance to civilization, being the largest reserve of natural drinkable water that can be used by humans. Groundwater occurs in almost all geological formations and the natural filtering effect of these geologic materials often makes groundwater preferable to surface water for many purposes.

The chemical composition of groundwater is related to the soluble products of rock weathering, decomposition and dissolution of organic matter and changes over time (Raghunath, 2007). The chemical quality of groundwater depends on the characteristics of the soil and rocks through which it has percolated and also on its resident time in these rocks. Some constituents of groundwater are also derived from the atmosphere as rain takes some atmospheric gases and ions into solution. Others have resulted from anthropogenic sources such as agriculture, industrial and improper disposal of refuse and sewage

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which often results in groundwater pollution. Water pollution in Makurdi metropolis and environs results mainly from human activities which results in the deterioration of the physical, chemical and biological properties of water (Akuh, 2014). The population depends mostly on groundwater abstracted through hand-dug wells and boreholes as their source of domestic water supply, farmers in the rural areas also depend on groundwater from wells to irrigate their small farms during the dry season. For effective management of the available water resources, an evaluation of the quantity as well as the quality of water for various purposes has to be carried out. Irtwange and Sha'ato (2009) reported 0.22 mg/l TDS, 60 mg/l Cl^-, 28.81 mg/l SO_4^{2-}, 1.36 mg/l Zn^+ and 200 mg/l Na^{2+} for groundwater from a borehole located at a solid waste disposal site in Makurdi. Idoko (2010) reported iron concentration ranging from 0.03 to 2.38 mg/l for groundwater in Benue State during the rainy season and values ranging from 0.01 to 5.02 mg/l during the dry season. He attributed the elevated iron concentration to geology and confirmed higher concentration in areas with lateritic soil. Edet et al. (2011) reported concentrations of 6136.75 mg/l Na^+, 243.15 mg/l K^+, 390.58 mg/l Ca^{2+}, 70.80 mg/l Mg^{2+}, 10278.75 mg/l Cl^- and 406.05 mg/l HCO_3.

This study was conducted to determine the physico-chemical properties of groundwater in Makurdi metropolis and environs and evaluate its suitability for drinking, domestic and irrigational purposes.

The study area

Makurdi is located in Benue State, north central Nigeria. It is bounded by latitudes 8°30'00" to 8°41 '00"N and longitudes 7°40 '00" to 7°50' 00"E (Figure 1). It is located within the middle Benue Trough and covers an area of about 370 km^2. It is accessible by the Makurdi-Lafia road and intra state roads such as the Makurdi-Otukpo road, Makurdi-Gboko road as well as footpaths with many rural road networks linking the rural areas to Makurdi town. The annual rainfall depth ranges from about 1,200 to 1,500 mm with an average depth of about 1350 mm. Temperatures are generally very high during the day, particularly in March and April. Along the river valleys, these high temperatures together with high relative humidity produce debilitating weather conditions. Makurdi records average maximum and minimum daily temperatures of 35 and 21°C during the rainy season and 37 and 16°C during the dry season, respectively (Lower Benue River Basin Development Authority).

Geology and hydrogeology of the study area

Much of Benue State within which Makurdi is located falls within the intra cratonic sedimentary basin known as the Benue Trough which is believed to be structurally developed. The Benue Trough is a linear sedimentary basin which is filled with Cretaceous rocks whose ages range from Middle Albian to Maastrichtian. It is bounded on either side by granite and gneisses which make up the crystalline basement (Cratchley and Jones, 1965). Many others like Najime (2010), Obaje (1994) and Zaborski (1998) described the Benue Trough as a NE-SW trending intracratonic basin ranging between 150 km wide and 800 km long. Lithologies identified in the study area (Makurdi metropolis and environs) include: the Ezeaku shale, the Makurdi Formation, Awe formation, alluvial deposit and pockets of basalt.

The Ezeaku Formation consists of thick flaggy calcareous and non-calcareous shale, sandy or shally limestone and calcareous sandstones. It is reported to be 304.8 m thick in this region and ranges up to 609.6 m towards the south of the state (Offodile, 1989).

The Makurdi formation consists of a thick mass of current bedded coarse grained deposit described as the Makurdi Sandstone (Figure 2) Geological and mineral resources map of Benue State adopted from Nigerian Geological survey agency (NGSA) 2006. Akuh (2014) described this sandstone as well sorted, medium to coarse grained, grain supported and texturally immature subarkose with minor clay rim cement and 3 - 4% porosity. It is highly indurated and cemented mainly by quartz and iron oxide (Adanu, 1981). The Makurdi Sandstone is the most important aquifer in the middle Benue trough. This aquifer is almost impermeable in places; especially the western part of Makurdi metropolis where its compact and indurated nature makes it difficult for the inhabitants to sink hand dug wells into it as the wells are terminated when the sandstone is encountered. Where fractured or less indurated, the formation is usually less compacting, more permeable and has better prospect as an aquifer (Offodile, 2002). Adanu (1981) obtained hydraulic conductivity values of 0.132, 1.73, 3.5 and average porosities of 17.3, 27.8 and 31.3% for various samples of the Makurdi sandstone. These properties influence the rate at which this aquifer is recharged.

The usefulness of the Makurdi Sandstone as a potential groundwater reservoir depends on its secondary permeability derived from weathering and fracturing (Offodile, 2002). It reported yields of 8.2 L/s from a borehole drilled into the Makurdi Sandstone at the Army cantonment, yields between 2.5 and 3.9 L/s were obtained in Aliade and 8.7 L/s from the borehole at the Lower Benue River Basin Estate. Recharge into the aquifer is both direct and indirect. Where the aquifer is uncovered and permeable, the recharge is direct from precipitation, by seepage and along fractures and joints. This is the case in Yaiko and Airport village, indirect recharge to this aquifer is by infiltration through weathered materials overlying the Sandstone aquifer (Adanu, 1981).

The Awe Formation was deposited as passage

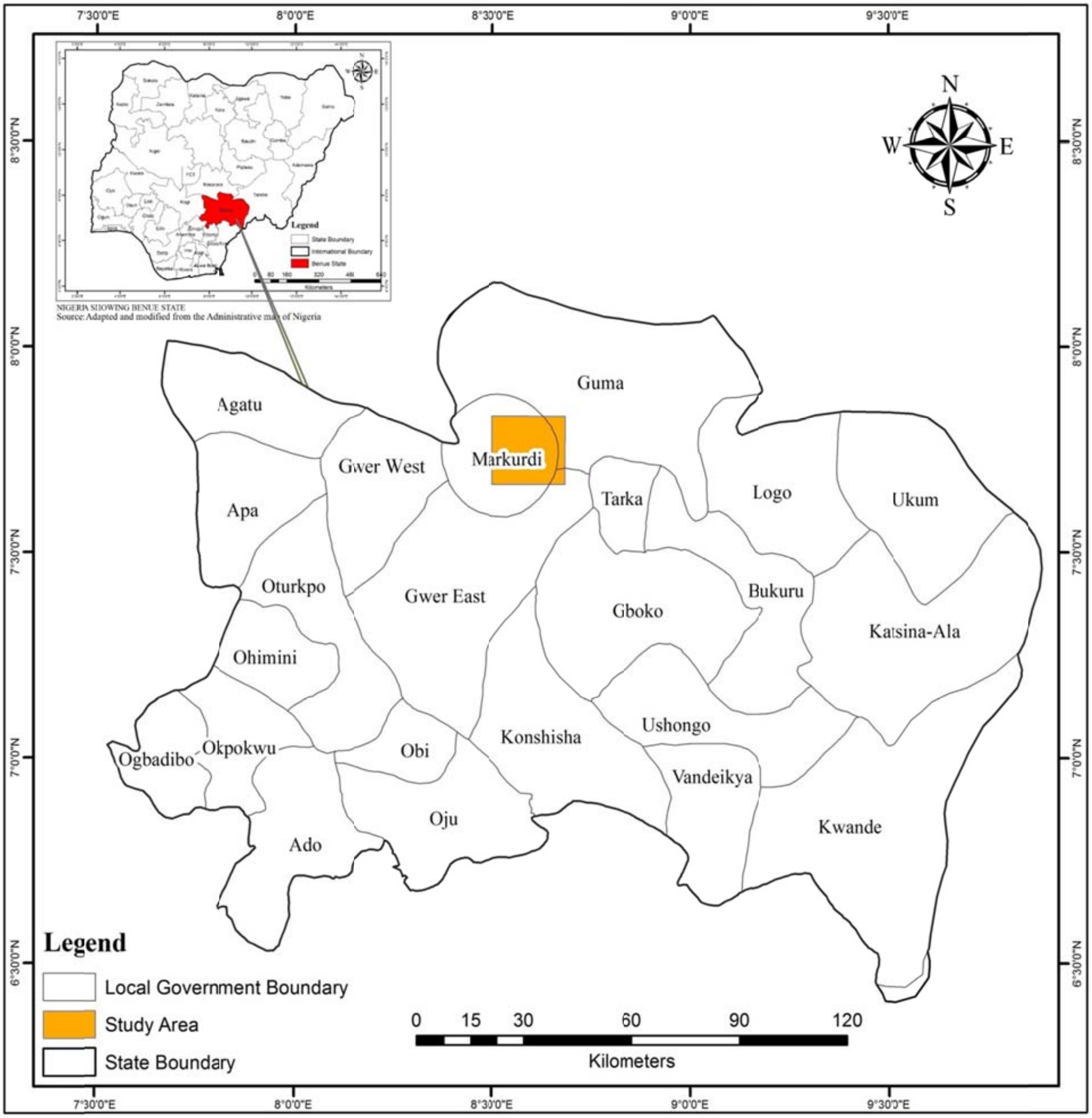

Figure 1. Map of Benue State showing the study area. Source: Adapted and modified from the admistrative map of Benue State State (2012).

(transitional) beds during the Late Albian-Early Cenomanian regression. This formation overlies the Asu River Group. Offodile (1976) estimated the thickness of the formation to be about 1000 m. The formation consists of flaggy, pale-colored medium to fine grained Sandstone with interbedded carbonaceous shale and clay (Offodile, 1976). The Sandstone beds, usually multi-layered appear highly porous and water yielding but the water from these aquiferous beds is contaminated by brines from the interbedded shales. The shale also confines the aquifer and present artesian to sub artesian situations (Offodile, 2002). A few boreholes drilled into this formation have produced good water yields, though often not potable due to the brine contamination.

The major flood plains of Benue State are those of Rivers Benue, Katsina Ala and other smaller rivers. Alluvial deposits, comprising an assortment of clays, sand, gravels and pebbles from these flood plains overlie the metamorphosed sediments and form the superficial geology.

The alluvium aquifer occurs along river and stream channels which are liable to seasonal flooding. It is the least extensive of all the aquifers. The thickness of the

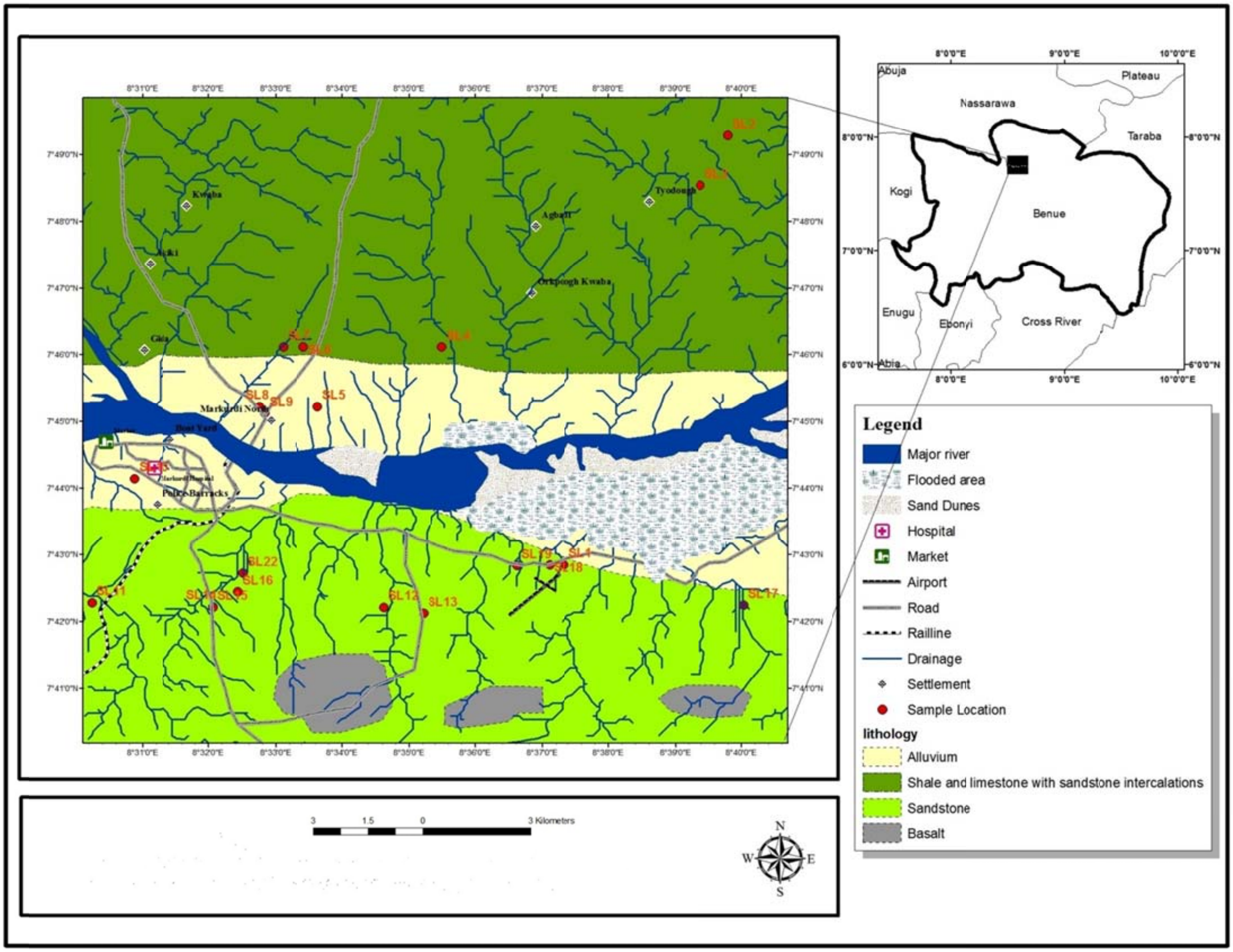

Figure 2. Geological map of Makurdi metropolis and environs adapted from Nigeria Geological Survey Agency (2006) Geological and Mineral Resources map.

aquifer ranges from 2 to 15 m, the thickest occur along the Benue River while the least thickness is along the stream channels (Adanu, 1981). It suggested watertable (unconfined) aquifer condition for the alluvium aquifer. Adanu (1981) also reported porosity and permeability coefficient for this aquifer as 37.5% and about 0.26 m/day respectively. The permeability and porosity value favors effective recharge into the aquifer. Recharge into this aquifer is mainly direct from annual precipitation and indirect recharge occurring when the river character is influent, thus supplying water to the alluvium aquifer (Adanu, 1981).

METHODOLOGY

Water samples were taken from four boreholes and 20 hand-dug wells at the peak of dry season (April, 2012) and stored in plastic sample bottles. The sample points are located as shown in Figure 2. The sample bottles were washed twice with the water to be sampled and filled to overflow, sealed tightly to avoid contamination with atmospheric gases. 500 ml of the sample was acidified to pH of 2 with concentrated nitric acid and another 500 ml non-acidified. A portion of the sampled water was acidified to keep the heavy elements in solution while in storage. *In situ* measurement of some physical parameters such as temperature, pH and total dissolved solids (TDS) was done. Chemical analysis of water samples was carried out at the Center for Energy Research and Training (CERT), Department of Water Resources Engineering Laboratory and Multipurpose Science Research Laboratory all in Ahmadu Bello University Zaria. Three analytical techniques were employed in determining the concentration of the chemical parameters of interest. These includes: photometric method (Zn, Fe, Cu, Mn2+, Cl, NH_3 and NO_3) using a Chemetric V – 2000 model multi – analyte photometer, atomic absorption spectrophotometry (Ca and Mg) titremetric techniques (HCO_3) and flame photometric method (Na and K). Values obtained were compared with maximum permissible limit set by the Standard Organization of Nigeria (SON, 2007) and

World Health Organization (WHO, 2011) to evaluate its suitability for drinking and domestic purpose.

The analytical data obtained were processed with aquachem 4.0 software for geochemical and statistical analysis. This software was used to plot Piper and Wilcox diagrams, deduce possible source of some chemical parameters and obtain correlation coefficient (Table 2) showing the relationship between the measured parameters. Basic statistical parameters such as minimum, maximum, mean, standard deviation and averages were also computed using aquachem 4.0 version software (Table 3).

Sodium adsorption ratio (SAR), percentage sodium (Na%) and bicarbonate hazard were used to evaluate the suitability of water for irrigation purpose. These parameters were determined using Equations 1, 2 and 3 respectively. Values obtained were compared with the classification of groundwater (Table 4).

RESULTS AND DISCUSSION

Physico-chemical parameters of groundwater

A summary of the physic-chemical analysis of the groundwater samples is presented in Table 1. pH values ranges from 2.90 to 7.26 with an average of 4.94 indicating acidic to slightly basic type of water. Only third (12.5%) of the 24 samples have values within the Standard Organization of Nigeria (2007) permissible range of 6.50 to 8.50 indicating that groundwater in most part of the study area is acidic. Total dissolved solids (TDS) ranges from 90 to 520 mg/l in boreholes and from 90 to 1250 mg/l in hand dug wells with an average of 489.55 mg/l. Chloride concentration ranges from 0.00 to 13.11 mg/l with an average of 2.92 mg/l. These values are far below the SON (2007) maximum permissible limit of 250.00 mg/l. No health-based guideline value is proposed for chloride concentration in drinking-water. Nitrate concentration ranges from 0.53 to 196.00 mg/l with an average of 42.61 mg/l. Four (16.7%) of the samples, SL7 and SL8 from North Bank, SL10 and SL11 from Wadata and George's quarters respectively have elevated concentrations of 107, 196, 96 and 117 mg/l, respectively above the maximum permissible limit of 50 mg/l (Table 1). Elevated nitrate concentration in groundwater has resulted from agricultural activities (for example, excess application of nitrogenous fertilizers and manures), from waste water disposal and oxidation of nitrogenous waste products in human and animal excreta. Results show a range of 0.34 to 3.20 mg/l with an average of 1.06 mg/l for ammonia concentration in groundwater within Makurdi metropolis (Table 1).

Sulphate concentration in groundwater within the study area ranges from 5.00 to 500.00 mg/l with an average of 28.25 mg/l. Only two (4.5%) of the samples analyzed had sulphate concentration above SON (2007) maximum permissible limit of 100 mg/l. Sulphate in groundwater within the study area as deduced from the aquachem software is from pyrite oxidation. Other sources of sulphate in groundwater includes; atmospheric precipitation and from the solution of sulphate minerals in sedimentary rocks (Davis and Dewiest, 1966). Most part of the study area (about 95.5%) contains groundwater considered safe with respect to its sodium concentration. One location however, SL 8 at North Bank has elevated sulphate concentration (150 mg/l) and is therefore unsafe for drinking and domestic use. Sodium concentration ranges from 10.70 to 36 mg/l with an average of 17.24 mg/l. All samples analyzed had concentrations below SON (2007) maximum permissible limit of 200 mg/l. The source of sodium in groundwater in the study area has been traced to weathering of albite and ion exchange. Magnesium concentration in groundwater within the studied area ranges from 5.68 to 74.20 mg/l with an average of 23.32 mg/l. All the samples analyzed had concentration above SON (2007) permissible limit of 0.20 mg/l.

Guideline values have not been established for bicarbonate, potassium and calcium. Bicarbonate concentration in groundwater within the study area ranges from 90.90 to 1525.50 mg/l with an average of 555.97 mg/l and is derived from carbondioxide in the atmosphere, carbondioxide in the soil and dissolution of carbonate rocks. Potassium concentration ranges from about 1.80 to 94.50 mg/l with an average of 23.46 mg/l and calcium ranges from 2.78 mg/l to 144.74 mg/l with an average of 41.98 mg/l. Potassium results from weathering of orthoclase and microcline. The abundance of potassium and sodium is about the same but potassium is commonly less than one tenth of sodium in natural water because many potassium minerals have higher resistance to weathering (Davis and Dewiest, 1966). Calcium on the other hand, has resulted from the contact of water with sedimentary rocks of marine origin such as calcite, aragonite, dolomite and gypsum.

Concentration of iron (Fe^{3+}) ranges from 0.00 to 0.47 mg/l in boreholes and 0.00 to 0.86 mg/l in hand dug wells with an average of 0.27 mg/l. 15 (62.5%) of the samples analyzed were within the SON (2007) permissible limit of 0.30 mg/l and nine (37.5%) samples had elevated iron concentration above the permissible limit. At concentrations above 0.30 mg/l, iron stains laundry and plumbing fixtures. There is usually no noticeable taste at iron concentrations below 0.30 mg/l, although turbidity and colour may develop (WHO, 2011). Sources of iron in groundwater could be from atmospheric absorption, leaching of the products of rock weathering especially pyrite, the use of galvanized hand pump (Idoko, 2010). Water from most part of the study area is safe for drinking and other domestic uses. Some parts of the study like Wurukum, Mu village, Kanshio, North bank and Airport however have iron in concentrations that make them unsafe for the uses earlier mentioned.

Manganese concentration ranges from 0.00 to 0.16 mg/l in boreholes and 0.00 to 2.43 mg/l in hand dug wells with an average of 0.48 mg/l. 18 (75%) of the samples show elevated manganese concentration above the SON (2007) maximum permissible limit of 0.20 mg/l while five (25%) of the samples had values below this limit.

Table 1. Results of water analysis from Makurdi metropolis and environs.

S/N	ID	TDS (mg/l)	PH	Temp (°C)	Fe^{3+}	Cu^{2+}	Mn^{2+}	Zn^{2+}	NH_3^-	Cl^-	NO_3^-	Na^+	K^+	Ca^{2+}	Mg^{2+}	HCO_3^-	SO_4^{2-}
1	SL 1	130	5.65	29.5	0.47	0.11	2.43	0.22	0.54	0.97	0.53	11.6	2.5	3.18	22.1	90.9	5
2	SL 2	260	7	31.3	0.1	0.18	0.53	0	1.03	1.37	16	13.3	2.1	31.68	12.53	525.2	15
3	SL 3	400	3.1	30.3	0	0.11	0.39	0.02	1.39	0	15	12.3	3	42.33	36.49	858.5	40
4	SL 4	360	7.26	29.1	0.02	0.15	0.31	0.1	0.76	0.34	0.63	12.8	3	29.58	5.68	401.25	10
5	SL 5	320	4	28.6	0.27	0.09	0.36	0.1	0.82	1.75	32	16.7	18.6	8.16	74.2	232.3	25
6	SL 6	260	4.41	31.4	0.29	0.18	0.19	0.13	0.61	0	32	14	45.4	9.92	22.66	313.1	15
7	SL 7	850	2.24	32.2	0.38	0.01	0.28	0.09	0.86	9.28	107	20.9	51.1	41.5	9.71	700.65	5
8	SL 8	1230	4.34	30.4	0.27	1.93	0.26	0.12	3.2	13.11	150	36	2.99	94.5	7.43	1525.5	105
9	SL 9	90	4	30.5	0.47	0.11	0.53	0.16	0.53	1.39	16	10.5	4.7	18.45	10.99	171.7	15
10	SL 10	1190	5.82	29.4	0.2	0.87	0.49	0.12	2.8	11.29	96	35.5	66.5	49.59	9	550.30	6.5
11	SL 11	1250	6.44	29.9	0.25	0.9	0.54	0.09	0.34	10.76	117	36	64	36.25	15.43	450	50
12	SL 12	240	7.01	28.3	0	0.2	0.93	0.08	0.49	0	17	11.8	17.4	15.27	9.93	255	30
13	SL 13	330	5.8	31.2	0	0.14	1.28	0.06	0.89	0	33	10.7	8.3	4.39	7.09	200	25
14	SL 14	450	7.17	32.3	0.11	0.09	0.5	0.03	0.96	0.3	36	17.8	33.2	2.78	24.27	565.6	40
15	SL 15	170	4.33	32.3	0.35	0.29	0.66	0.11	1.11	0	26	10.4	7.3	32.86	38.59	181.8	15
16	SL 16	810	5.01	32.6	0.18	0.39	0.09	0.13	2.34	5.61	21.3	25.7	53.5	14.12	9.77	757.5	80
17	SL 17	180	4.18	29.6	0.86	0.28	0.24	0.16	0.5	0	38	12.1	1.8	25.19	21.86	131.3	5
18	SL 18	90	3.33	29.8	0.11	0.1	0	0.07	0.96	0	26	10.5	2.2	144.74	24.21	111.1	5
19	SL 19	520	5.91	31.7	0.37	0.27	0	0.11	0.83	0.39	18	20	2.5	119.71	22.98	505	20
20	SL 20	630	2.95	29.1	0.22	0.08	0	0.18	0.79	1.91	49	19.4	4.2	169.74	44.5	505	40
21	SL 21	520	5.88	30.4	0.58	0.35	0.13	0.07	0.61	0.88	16	13	2.3	10.63	39.54	767.6	10
22	SL 22	490	2.9	30.4	0.43	0.23	0	0.15	0.9	4.84	29	19.3	28	110.43	44.08	343.4	15
23	SL 23	130	4.18	28.1	0.13	0.13	0	0.06	0.37	1.09	28	11.7	3				
24	SL 24	520	5.88	30.4	0.66	0.97	1.29	0.14	1.58	0.98	21	13.1	2.8				
	Background	180			0	0.09	0	0.02	0.5	0		10.7	1.8	2.78	21.86	131.3	40
	SON MPL	500	6.5 -8.5		0.3	1	0.2	3		250	50	200			0.2		100

Units: mg/l except for pH and temperature (Temp): SON MPL: Standard organization of Nigeria Maximum permissible limit.

Concentration above 0.1 mg/l causes undesirable taste in beverages, stains sanitary wares and laundry (WHO, 2011) and neurological disorder (SON, 2007). Health-based value for manganese according to the World Health Organization is placed at 0.40 mg/l. Manganese present in groundwater is usually absorbed from the atmos-phere or leached from products of rock weathering.

Copper in water supply usually arises from the corrosive action of water leaching copper from copper pipes in buildings (WHO, 2011). This corrosive action of water is often accelerated by high levels of dissolved oxygen in water. The analysis reveals concentration of 0.09 to 1.93 mg/l with an average of 0.31 mg/l for samples analyzed. At concentration above 5 mg/l copper imparts colour and an undesirable bitter taste to

Table 2. Correlation matrix for measured parameters

	pH	Na	Mg	Ca	Cl	K	SO_4^{2-}	TDS	Temp	Fe^{3+}	Mn	Cu	Zn	NO_3^-	HCO_3^-	NH_3
pH	1	0.05	-0.41	-0.42	-0.26	-0.03	-0.01	0.02	0.3	-0.33	0.27	0.09	-0.16	-0.18	0.1	-0.07
Na		1	-0.22	0.03	0.9	0.87	0.59	0.96	-0.16	-0.24	-0.19	0.78	0.1	0.81	0.78	0.63
Mg			1	0.26	-0.37	-0.32	-0.17	-0.25	-0.18	0.18	-0.1	-0.27	0.02	-0.25	-0.36	-0.25
Ca				1	-0.1	-0.24	-0.18	0.01	-0.13	-0.15	-0.24	-0.16	0.22	-0.07	-0.13	-0.09
Cl					1	0.93	0.51	0.9	0.02	-0.05	-0.17	0.77	-0.07	0.9	0.8	0.63
K						1	0.64	0.83	-0.05	-0.23	-0.26	0.74	-0.12	0.84	0.72	0.65
SO_4^{2-}							1	0.57	0.02	-0.23	-0.21	0.76	-0.01	0.64	0.58	0.65
TDS								1	0.15	-0.21	-0.25	0.74	0.01	0.82	0.88	0.61
Temp									1	-0.08	0.15	-0.06	-0.11	-0.12	-0.15	-0.17
Fe^{3+}										1	0.09	-0.03	0.37	-0.07	-0.3	-0.31
Mn											1	-0.12	0.43	-0.2	-0.36	-0.29
Cu												1	0.12	0.83	0.71	0.71
Zn													1	0.01	-0.18	0.03
NO_3^-														1	0.73	0.56
HCO_3^-															1	0.71

Table 3. Statistical summary of measured parameters.

Parameter	Min	Max	Mean	St. Dev.	Dev. Coef
TDS (mg/l)	90	1250	489.545	362.931	74.136
pH	2.24	7.26	4.942	1.538	31.126
TEMP (°C)	28.6	32.6	30.571	1.194	3.906
Fe^{3+} (mg/l)	0	0.86	0.27	0.213	79.152
Mn^{2+} (mg/l)	0	2.43	0.477	0.549	115.096
Cu^{2+} (mg/l)	0	1.93	0.307	0.433	140.963
Zn^{2+} (mg/l)	0	0.22	0.099	0.057	57.532
Ca^{2+} (mg/l)	2.78	169.74	46.136	48.969	106.139
K^+ (mg/l)	1.8	66.5	19.3	22.48	116.481
Mg^{2+} (mg/l)	5.68	74.2	23.32	16.98	72.814
Na^+ (mg/l)	10.4	36	17.741	8.424	47.483
Cl^- (mg/l)	0	13.11	2.918	4.262	146.068
$HCO3^-$ (mg/l)	90.9	858.5	409.973	232.618	56.74
SO_4^{2-} (mg/l)	5	105	26.205	25.481	97.24
NH_3^- (mg/l)	0.34	3.2	1.057	0.751	71.076
NO_3^- (mg/l)	0.53	150	40.521	39.799	98.218

Min: minimum, Max: maximum, St. Dev.: standard deviation, Dev. Coef: deviation coefficient.

water (WHO, 2011). Maximum permissible limit of copper concentration in water for drinking and domestic uses by SON (2007) is set at 1.00 mg/l; consumption of water with concentration above this value causes gastro-intestinal disorder. All except one (SL 8 at North Bank) of the samples analyzed had concentration below the permissible limit. With an exception of the immediate area around SL 8 at North Bank, groundwater in Makurdi metropolis is considered safe for drinking and domestic uses with respect to its copper concentration. All samples analyzed had zinc concentration below the SON (2007) permissible limit of 3.00 mg/l with concentration ranging from 0.00 to 0.18 mg/l with an average of 0.09 mg/l.

Statistical analysis

The correlation coefficient reveals some relevant hydrochemical relationships, the content of TDS have high positive correlation with Na^+, Cl^-, K^+ and SO_4^{2-} with correlation coefficients of 0.96, 0.90, 0.62 and 0.56 respectively (Table 2). This positive correlation indicates that the ions are derived from the same source. In a similar way, there exists positive correlation between Cl^- – Na^+ (0.90), K^+ – Na^+ (0.63), K^+ – Cl^- (0.63), NO_3 – NH_3 (0.5), NO_3 – Cl (0.92) and Na – Cl (0.90). The high positive correlation (0.90) between Na^+ and Cl^- may represent influence from salty water.

On the other hand, there are negative relationships between Mg – Na, Mg – K, K – Ca, SO_4 – Mg and HCO_3^- - Mg. These relationships could indicate ion exchange process between the groundwater and soil minerals.

Hydrochemical facies

From the Piper plot (Figure 3), an evaluation of the hydrochemistry of groundwater in Makurdi metropolis was done. The groundwater samples fall in the fields of Mg – Na – HCO_3, Mg-K-HCO_3, K – HCO_3 – SO_4, Mg-Ca-HCO_3, Mg-HCO3 and Ca - Mg - HCO_3 in order of increasing dominance.

Table 4. Calculated values of bicarbonate hazard, percentage sodium and sodium adsorption ratio for groundwater in Makurdi metropolis and environs.

Location description	Sample ID	Bicarbonate hazard (meq/l)	SAR	Na%	EC (µS/cm)
Air Port 1	SL 1	0	0.51	22.45	91
Orowa Village	SL 2	5.99	0.51	17.26	182
Miande Akpu Village	SL 3	8.96	0.33	7.18	280
Antsa Village	SL 4	10.31	0.56	24.89	252
University Of Agriculture Road	SL 5	0	0.40	11.38	224
North Bank 2	SL 6	2.77	0.56	41.69	182
North Bank 3	SL 7	12.52	0.76	40.62	595
North Bank 4	SL 8	24.24	2.54	104.49	861
North Bank 5	SL 9	0.99	0.48	24.92	63
Wadata	SL 10	17.98	1.22	45.18	833
Wadata 2	SL 11	11.82	1.26	46.15	875
Georges Qtrs	SL 12	3.39	0.58	40.31	168
Nyon Village	SL 13	6.65	0.73	63.99	231
Welfare Qtrs	SL 14	7.14	0.75	42.53	315
Kanshio	SL 15	0	0.29	8.77	119
Wurukum	SL 16	10.91	1.29	66.48	567
Mu Village	SL 17	0	0.43	13.00	126
Airport 2	SL 18	0	0.21	2.77	63
Airport 3	SL 19	0.41	0.44	5.71	364
Ikyaan Village	SL 20	0	0.34	3.44	441
Wurukum 2	SL 21	8.79	0.41	10.66	364
Wurukum 3	SL 22	0	0.39	10.37	343

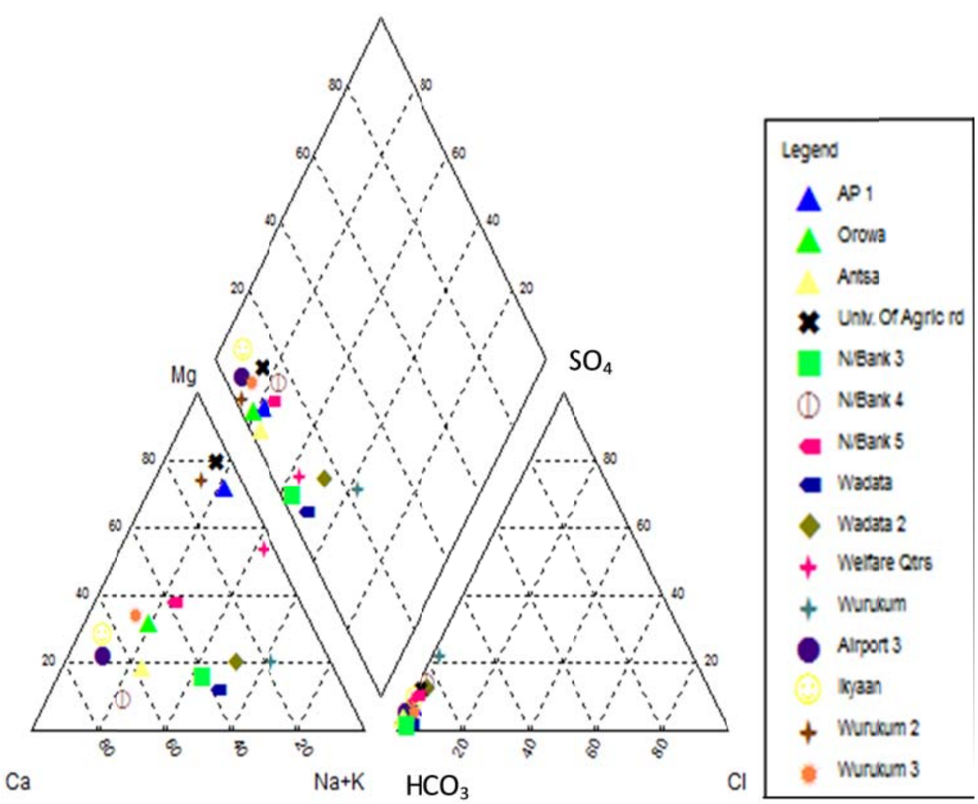

Figure 3. Piper diagram of groundwater in Makurdi metropolis and environs.

Table 5. Classification of groundwater based on Na%, SAR and bicarbonate hazard (source: Tabue et al., 2012).

Parameters	Range (meq/l)	Class
Na%	>200	Above max permissible limit
	20 – 40	Good
	<20	Excellent
SAR	20 - 40	Good
	40 - 60	Permissible
	60 - 80	Doubtful
	>80	Unsuitable
Bicarbonate hazard	0.00 – 1.25	Safe
	1.25 – 2.50	Marginal
	>2.50	Unsuitable

Suitability of groundwater for irrigational purposes

The quality of water used for irrigation purpose is of great importance for crop productivity, soil maintenance and environmental protection (Tabue et al., 2012). The quality of groundwater as earlier explained is influenced by the mineral composition of the aquifers within which water is stored as well as the residence time in these aquifers.

Percent sodium (Na%)

The percentage sodium was calculated using the expression:

$$Na\% = \left(\frac{Na^{+} + K^{+}}{Ca^{2+} + Mg^{2+} + Na^{+} + K^{+}}\right) \times 100 \quad (1)$$

Within the study area, Na% varies from 3.44 to 104.50% (Table 4) and are less than the maximum allowable limit of 200% (Table 5). Three (14 %) of the samples fall within the class of 20 to 40 Na% and are considered good for irrigation. Nine samples (41 %) have percentage sodium values above the 20 to 40% class but are still below the maximum permissible limit of 200. Ten (45%) have Na% less than 20% and are considered excellent for irrigation (Table 5).

Higher Na% observed in groundwater from nine locations which constitutes 41% of the study area indicates the dominance of ion exchange and weathering from lithological units of the study area (Tabue et al., 2012). Groundwater with relatively high Na% values above 40 occurs around North bank, Wadata, George's quarters, Nyon, welfare quarters and Wurukum. When the concentration of sodium is high in water, sodium tends to be absorbed by clay particles displacing magnesium and calcium. This exchange of sodium for calcium and magnesium reduces soil permeability and results in soil with poor internal drainage. A larger proportion (59 %) of groundwater within the study area is considered safe for irrigation.

Sodium adsorption ratio (SAR)

This was calculated using the expression (SAR) = ………………… (2)

SAR for samples within the study area varies from 0.21 to 2.54. The groundwater according to the classification in Table 4 is of excellent quality with respect to sodium adsorption ratio. If water used for irrigation has high Na^{+} and low Ca^{2+}, the ion exchange complex may become saturated with Na^{+} which destroys the soil structure due to dispersion of clay particles and reduces plant growth (Tabue et al., 2012). High Na^{+} and low Ca^{2+} in water used for irrigation results in ion exchange complex which becomes saturated with Na^{+} as a result of clay particle dispersion. This causes the destruction of the soil structure and consequently reduces plant growth.

The Wilcox diagram (Figure 4) also shows that all samples analyzed fall within the S1C1, S1C2 and S1C3 regions. This indicates water of good quality for irrigation.

High Na^{+} and low Ca^{2+} in water used for irrigation results in ion exchange complex which becomes saturated with Na^{+} as a result of clay particle dispersion. This causes the destruction of the soil structure and consequently reduces plant growth.

Bicarbonate hazard

Bicarbonate hazard means excess of bicarbonate over calcium and magnesium, all expressed in milliequivalent per liter. Water with bicarbonate hazard greater than 1.25 meq/l should not be used for irrigation except on very sandy, highly permeable soils or with some soil chemical amendments such as the application of gypsum. Bicarbonate hazard was computed using the expression

$$HCO_3^{-} - (Ca^{2+} + Mg^{2+}) \quad (3)$$

Only nine (41%) of the samples analyzed (SL 1, SL 5, SL 9, SL 15, SL 18, SL 19 and SL 20) fall within the class of samples considered safe (0.00 to 1.25 meq/l) for irrigation in terms of bicarbonate hazard. Groundwater from other locations should not be used for irrigation purpose except on soils that are sandy, permeable or with some chemical amendments as they are considered unsuitable (Table 4).

Conclusions

Groundwater is of immense importance to both rural and urban dwellers of developing nations. The groundwater of the study area is acidic to slightly basic in nature.

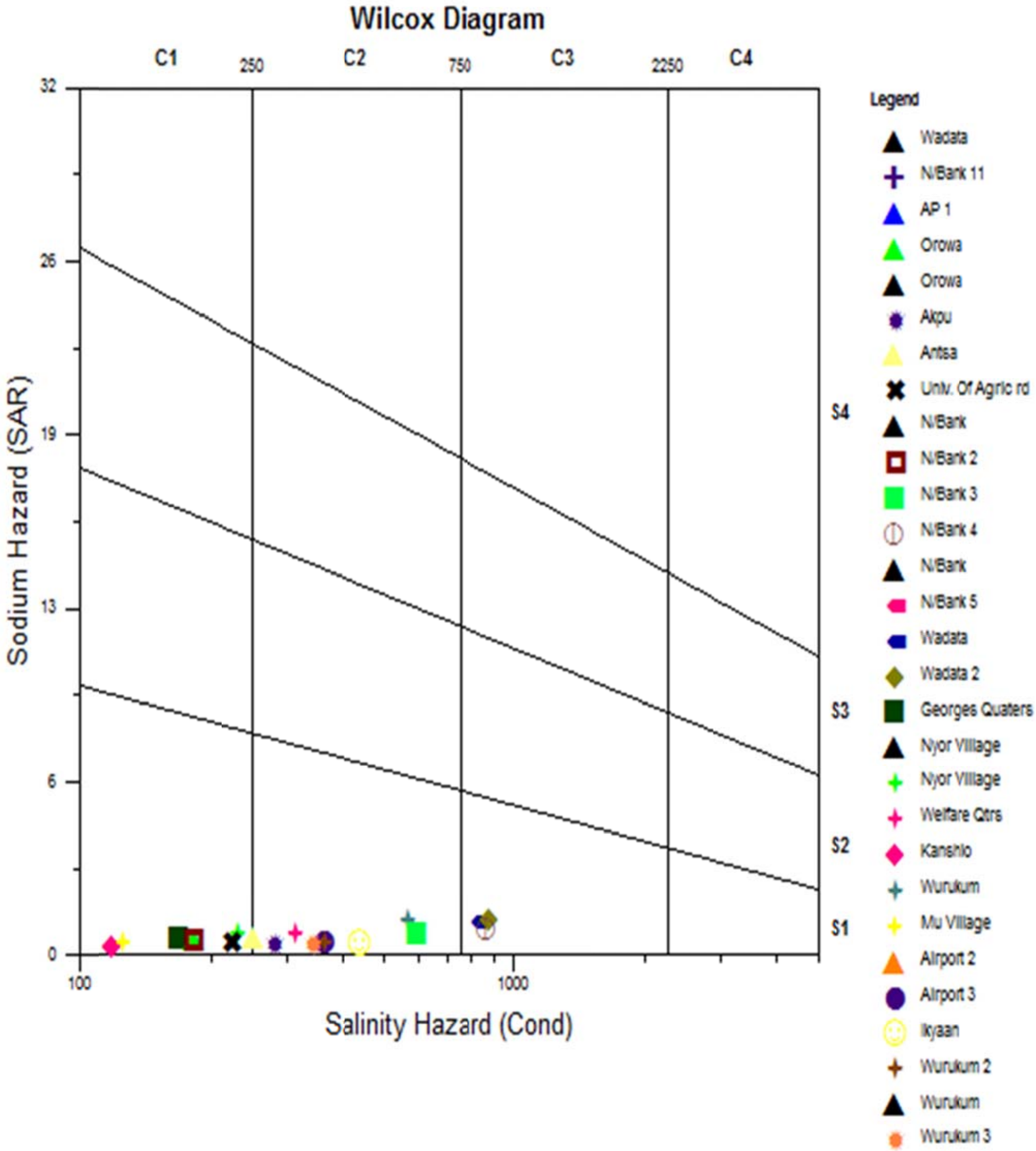

Figure 4. Wilcox diagram of groundwater in Makurdi metropolis and environs.

Groundwater in Makurdi metropolis and environs has been evaluated for its chemical composition and suitability for drinking and irrigation purposes.

The abundance of chemical concentrations in groundwater within the study area is in order of Ca > Mg > Na > K for the cations and HCO_3^- > SO_4^{2-} > NO_3^- > Cl^- for the anions. Groundwater in some parts of the study area have elevated TDS, magnesium, sulphate, nitrate, copper, manganese and iron concentrations above the SON (2007) maximum permissible limit for drinking water and considered unsafe for drinking with respect to these parameters (Figure 5). The acidic nature of groundwater

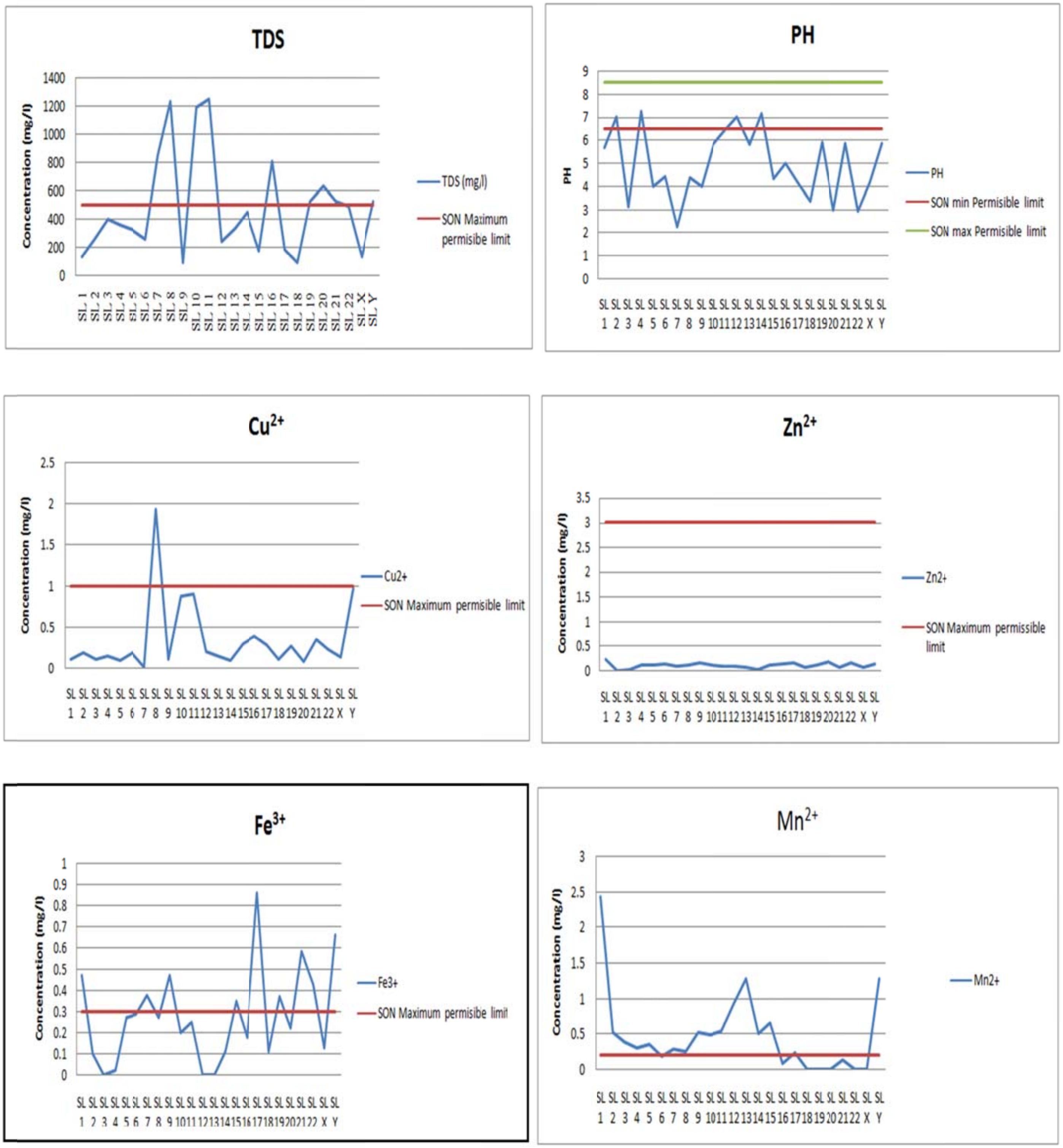

Figure 5. Plots of concentrations of measured parameters and Standard Organization of Nigeria's 2007 permissible limits.

in the study area has also impaired its quality. Northbank and Wadata areas are identified to be areas where groundwater is polluted the most and this is attributed to the poor sanitary conditions in these areas.

Groundwater within the study area is safe for irrigation with respect to its sodium adsorption ratio but a large portion of it has high percentage sodium and bicarbonate hazard and should not be used for irrigation except on

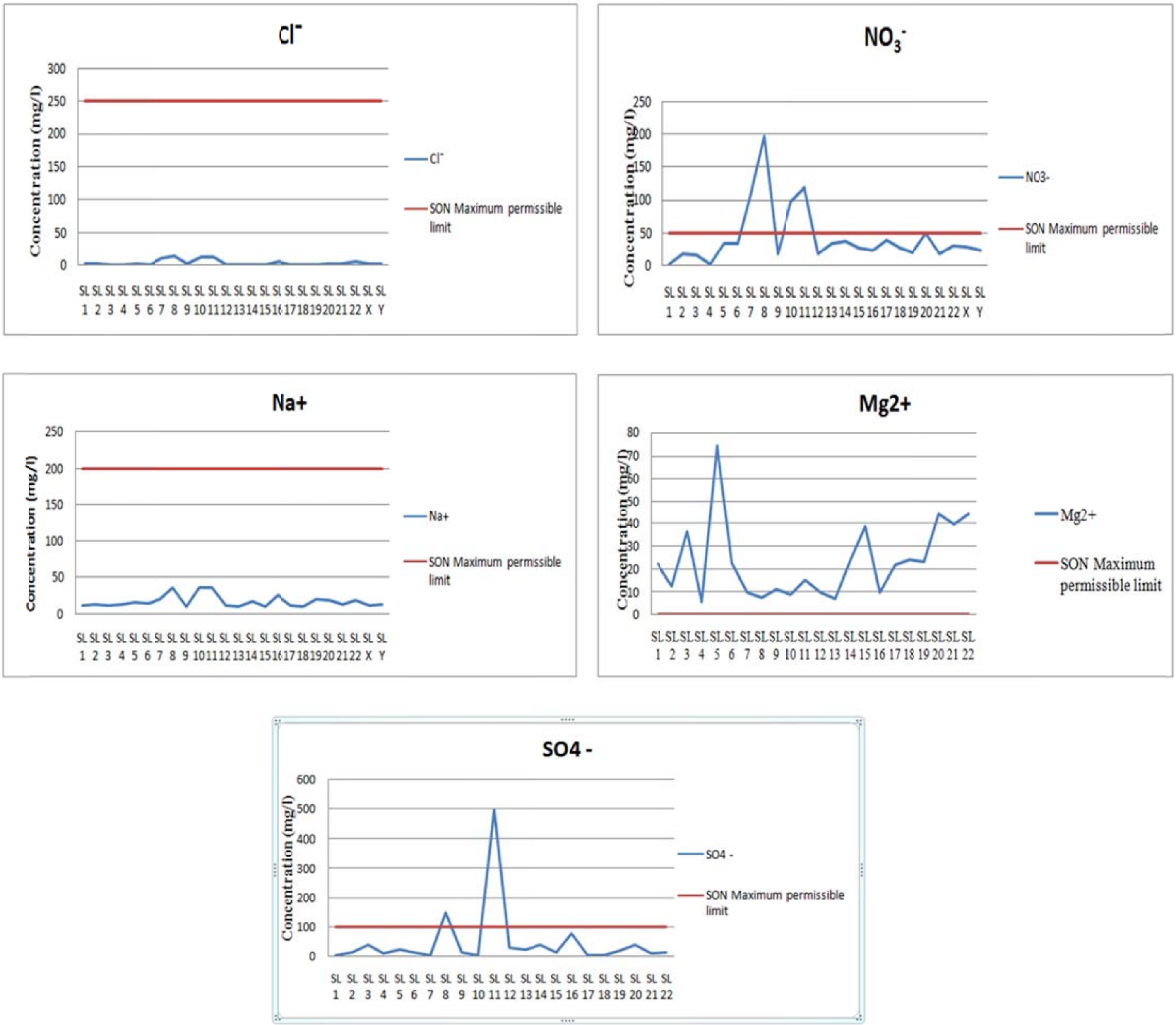

Figure 5. Contd.

very porous and permeable soils or when used with some chemical soil amendments.

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