ASSESSMENT OF ANTHROPOGENIC INFLUENCE ON QUALITY OF GROUNDWATER IN HAND-DUG WELLS IN PARTS OF MAKURDI METROPOLIS, NORTH CENTRAL NIGERIA

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ABSTRACT

Physico-chemical and bacteriological analysis of groundwater samples from 19 shallow hand-dug wells (approximately 10m deep) which constitutes a major source of water for domestic purposes was carried out to assess the quality in view of the proximity of the wells to open solid waste disposal sites and some uncased pit latrines. Results shows that the water is weakly acidic to alkaline (pH=5.7-7.3); moderately hard (Total Hardness = 60-140 mg/L) and low in total dissolved solids (TDS = 220-600 mg/L). Heavy metals occur in trace amounts (Fe^{2+} = 0.01- 0.06 mg/L, Zn^{2+} = 0.01-0.06 mg/L, Cu^{2+} = 0.001-0.010 mg/L, Pb^{2+} = 0.001-0.030 mg/L and Cd^{2+} = <0.01 mg/L). The plot of chemical analysis results on a Piper trilinear diagram shows that the water belongs to the bicarbonates facies. The sodium absorption ratio, SAR, is low (less than 10) implying that sodium hazard for irrigation is low. Correlation coefficients of the chemical constituents indicate common sources of most parameters. The work indicates that the groundwater is suitable for most domestic uses, irrigation, and most industrial purposes, but has the problem of bacteriological contamination. The high value of coliform count with a mean of 17 per 100 mg, shallow water table, unconfined aquifer and non-cased hand-dug wells will increase the risk of water borne diseases in future.

Keywords: Assessment, Anthropogenic Influence, Groundwater Quality, Makurdi Metropolis

INTRODUCTION

A dump is defined as, "a site used to dispose of solid wastes without environmental controls". Landfill is defined as a "facility in which solid waste from municipal and/or industrial sources is disposed; sanitary landfills are those that are operated in accordance with environmental protection standards (USEPA, 1988) where wastes are spread, compacted and covered with a layer of earth daily. Dumps and landfills are a threat to water quality when rainfall percolates through waste, leaching out a variety of substances such as metals, bacteria and other toxic materials. The leachate produced can eventually contaminate groundwater (Pedersen, 1997).

The availability and quality of groundwater in Makurdi, the capital town of the Central Nigerian State of Benue may be determined from a number of composite factors. The Public Water Works which hitherto supplied water to all parts of the town has become dysfunctional and moribund. Most residents of the town have adjusted to providing their own domestic supplies by use of shallow hand dug wells (approximately 10 m deep) which are often poorly completed. Individual residential plot of land is approximately 561 m^2 and is utilized to construct both water well and underground feacal holding tanks due to absence of a central municipal facility. The Makurdi Sandstone which is the main aquifer that supplies water into wells for abstraction, is highly indurated to the extent it is difficult to penetrate sing manual digging technique. Most hand-dug wells in the town are neither cased nor are they properly capped after completion. Also, the immediate surroundings of the wells are inadequately sequestered from unsanitary conditions. A more worrisome fact is that some of these wells are located near solid waste dump sites which lack any form of management, coupled with the nearness of household pit latrines used as permanent stores for human feaces and/or poorly engineered septic tanks. A possibility is that the water may be contaminated by substances like toxic chemicals, heavy metals and organic materials among others which are leached out of the waste. Once contaminated, a ground water system takes a long time to purify. A more serious problem is that the effects of some of these contaminants on the biosphere are cumulative or assiduous (Mills, 1975). Thus, by the time their effects manifest, a lot of harm which is often irreversible, would have been done. Since most people in the study area depend on shallow subsurface water sources for domestic and other purposes, it is necessary to continuously monitor the quality of groundwater in the area.

Studies have shown the adverse impacts of solid waste in dumpsites on ground water. Akoteyin *et al.* (2011) investigated groundwater contamination around landfill sites in a typical sub-urban settlement in Lagos, Nigeria and found that that leachate from the landfill have impacted adversely on the groundwater of the sampled area. The study showed that the concentration of lead and zinc exceeded the mean concentration of all the measured heavy metal parameters in about 90% of sampled waters based on the maximum permissible limit of WHO drinking water quality. Iron and copper were also found to exceed the mean concentration of all measured parameters in about 50% and 40% based on maximum permissible limits of WHO standards for drinking water quality.

The relationship between poor shallow water quality and distance from pollution sources has also been well documented (Aboho *et al.,* 2012, Akinyemi *et al.*, 2011, Akudo *et al.*, 2010, Longe, 2009). Also Rao and Shanataram (2003) investigated three landfill sites in Hyderebad, a major Indian city with a population of more than six million generating solid waste of about 2500 tones per day, found the groundwater at all sites were polluted and unfit for human consumption and domestic use, but could be used for irrigation only.

In an attempt to protect groundwater quality from adverse impacts from Municipal Solid waste, the US EPA (1991) adopted a "dry-tomb" approach for landfilling of Municipal Solid Waste which requires isolation of the wastes within a plastic sheeting and compacted-clay lined tombs, collection of leachate, monitoring of groundwater, collection and management of landfill gas, closure procedures and provision for funding of maintenance for 30 years after landfill closure. However, Lee and Jones-Lee (2005) have argued that these specifications are not adequate since plastic sheeting and compactedclay liners will eventually fail and allow generated leachate to pollute the groundwater. Thus it is essential to monitor water resources around these sites.

The purpose of this study is to determine the physico-chemical and bacteriological quality of groundwater from shallow hand-dug wells especially those near solid waste dump sites. This will help to evaluate the quality of the water against the current use among the inhabitants.

STUDY AREA DESCRIPTION

Makurdi, the capital of Benue State is located between longitudes $8^0$20 and 8^0 40 E and latitudes 7^0 40 and 7^0 50 N (Fig.1). The town lies

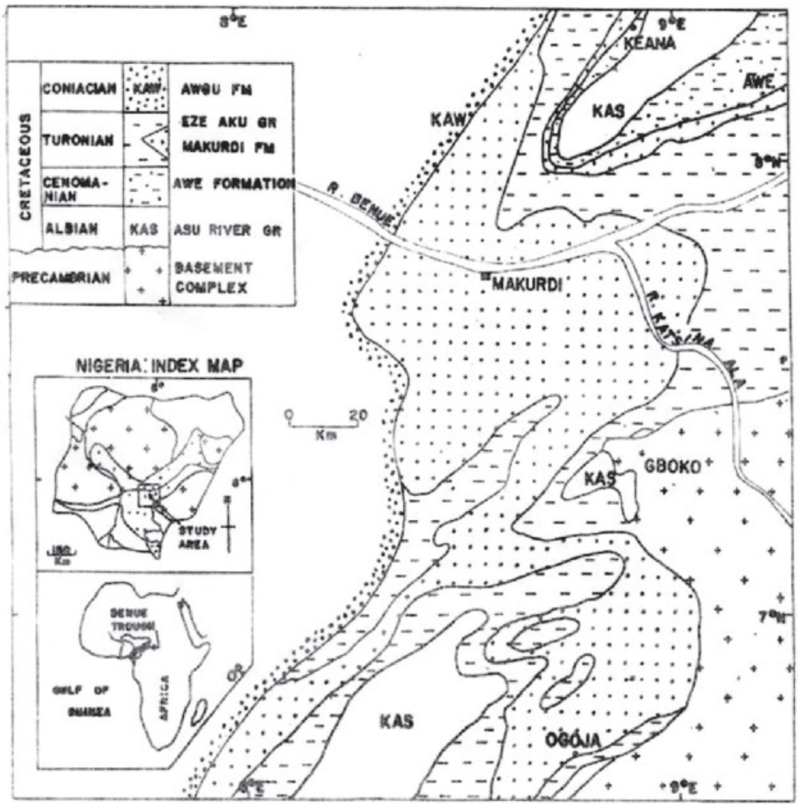

Fig.1: Geological Map of the Middle Benue Trough Showing Makurdi Formation (after Nwajide and Hoque, 1984.)

approximately 200 m above sea level and is drained mainly by River Benue and some of its small seasonal tributaries. The terrain is flat to gently undulating, sloping generally towards River Benue which divides the town into two halves. Vegetation in the study area is the Sudan savannah type characterized by tall grasses and short trees. The vegetation is sustained by the tropical climate which is characterized by alternate hot, rainy season (April to October) and cool, dry season (November to March). The annual total rainfall in the area ranges from 1000-1400 mm with a mean of 1,200 mm. Relative humidity values are above 60% and mean annual temperature is 29^0C (Iloeje, 1981). Knowledge of the general geology of Benue area is obtained from the works of Reyment (1965), Grant (1971) and Obaje *et al.* (1994) while the local geology is elucidated by Nwajide and Hoque (1984) as summarized in Fig. 2. Also aspects of the hydrogeology of Makurdi area have been generally discussed by Offodile (2002). Geologically, the study area is part of the Middle Benue Trough. The stratigraphc succession in the Middle Benue Trough (Obaje *et al.,* 1994) begins with Asu River Group consisting of Arufu, Uomba and Gboko Formations. These are overlain by the Cenomanian Keana and Awe Formations and the Cenomanian-Turonian Ezeaku Formation consisting essentially of shales, which is in turn succeeded by the Awgu Formation. Folding and uplift of the sediments were the dominant tectonic activities during the Santonian after which the CampanianMaastrichtian Lafia Formation terminated sedimentation during the Cretaceous in the area succeeded in the Tertiary by widespread volcanic activities. Locally, Makurdi and its environs are underlain mostly by the Turonian Makurdi Sandstone which comprise poorly sorted feldspathic fluvio-deltaic sandstones, basal conglomerates, silts, mudstones and clay lenses. Recent superficial deposits comprise mainly sands, clays and gravels as well as colluvium which cover most of the flood plains of River Benue. The semi-confined Makurdi Sandstone which is the main aquifer that supplies most of the water is indurated especially in most of the western parts of the town to the extent that manual digging of hand-dug wells is always terminated within it due to the difficulty of breaking the rocks. Water tables are encountered at various depths, varying between 1 and 10 m, but may occur less than 0.5 m in some areas especially during the rainy season. The sampling locations share similar characteristics with respect to waste composition and relative positions of the wells and latrines. All

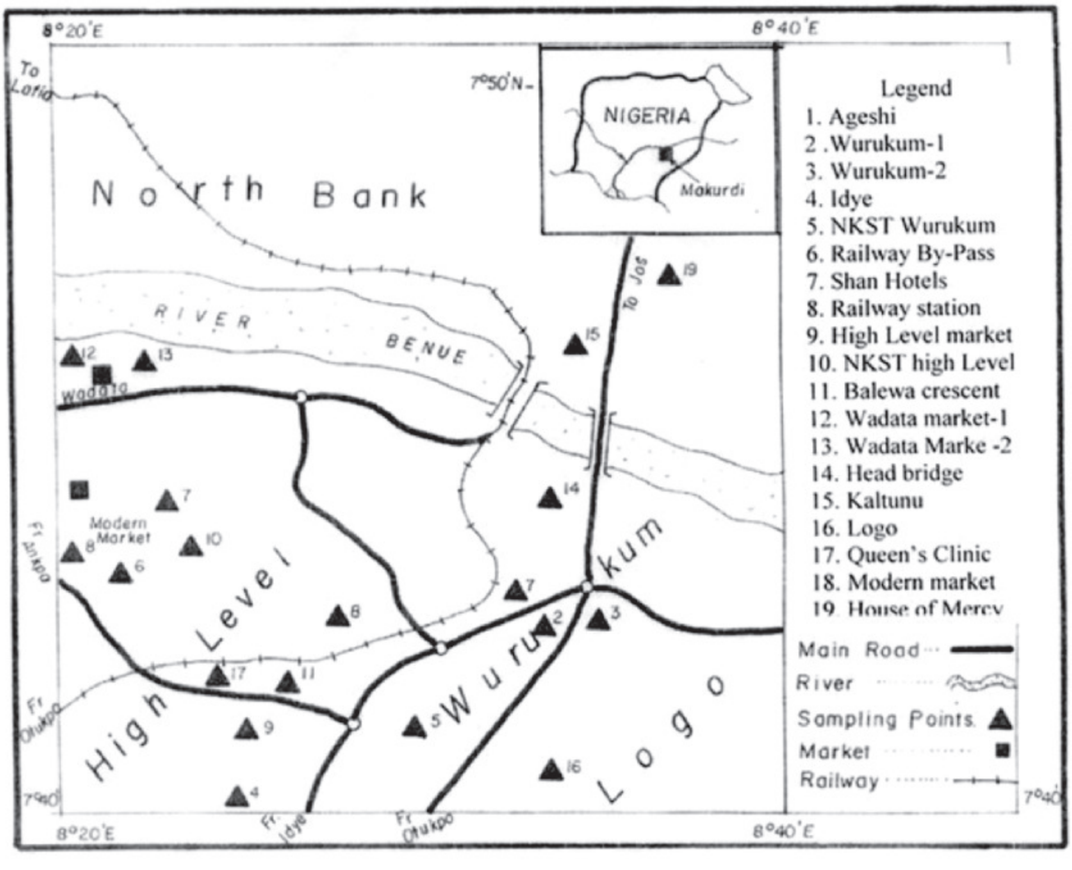

Fig 2: Map of Study Area Showing the Sample Locations

the hand-dug wells chosen for this study were uncased. The average depth was 10m. Generally, solid wastes at the dumpsites, which are located between approximately 30 and 60 metres away from the study wells, are similar in composition, consisting paper, plastics, broken bottles, putrescibles, metal scraps, textiles, disused household items, dry battery cells, agricultural and human wastes etc. Also, the pit latrines and the wells are located at opposite ends of the residential plots of land which are about 33 m long.

MATERIALS AND METHODS OF STUDY

Groundwater samples were collected by using plastic bailers from 19 hand-dug wells in different parts of the study area and stored in 200 ml plastic bottles. The sampling points are shown in Fig. 2. The bottles were first washed with deionized water, and then several times with the sample water before collection in order to avoid any contamination. Plastic bottles for bacteriological analysis samples were sterilized and capped. Temperature, pH and electric conductivity were determined in the field using mercury filled thermometer, a Mark electronic switchgear conductivity meter and pH meter respectively.

After sampling, the lids of the bottles were immediately replaced to minimize contamination and escape of gases. The samples were then stored in an ice-packed cooler for analysis within 24 hours. Analyses for cations: K^+, Na^+, Ca^{2+}, Mg^{2+}, and heavy metals, Fe Mn, Pb, Cd,Cu and Zn were carried out using computerized Atomic Absorption Spectrophotometer (AAS) model 210 in the Soil Science Laboratory of the University of Agriculture, Makurdi. The anions; $NO_{3,}$ SO_4^{2-}, HCO_3^-, $C1^-$ and hardness were determined by standard titration methods. Total Dissolved Solid (TDS) was determined by gravimetric method. The membrane filter technique, which centres only on total coliform count, was employed for bacteriological analysis (Fawole and Oso, 1998). Sodium Absorption Ratio, SAR, was evaluated to

Table 1:Physicochemical and Bacteriological Parameters of the Water Samples

S/N	Sample Location	Approx. distance from dumpsite (m)	Temp (°C)	pH	TDS	Cond. (αs/cm)	Hardness	HCO_3^-	Cl^-	NO_3^-	SO_4^{2+}	K^+	Na^+	Ca^{2+}	Mg^{2+}	SAR (meq/l)	Coliform per 100m1
1	Ageshi Transport Garage	40	26	7.3	260	180	140	600	10	0.08	60	1.50	50	190	100	0.73	20.0
2	Wurukum Market-1	65	28	6.8	310	200	190	540	15	0.06	20	3.00	50	250	40	0.78	40.0
3	Wurukum Market-2	20	26	6.5	400	300	60	720	6	0.08	50	10.0	50	300	70	0.68	30.0
4	Idye	30	27	5.8	220	140	75	290	3	0.02	60	6.70	30	300	40	0.43	2.00
5	NKST Wurukum	45	27	5.7	600	260	140	300	20	1.00	100	7.00	50	196	40	0.85	50.0
6	Railway By-Pass	45	28	6.7	530	280	65	200	16	0.04	60	2.50	20	270	10	0.33	25.0
7	Shan Hotels	40	26	6.4	360	160	95	800	9	2.00	50	3.00	10	280	80	0.14	1.00
8	Railway Station	30	26	5.8	280	250	85	800	8	3.0.0	60	4.00	26	130	70	0.46	20.0
9	High Level Market	35	28	7.1	320	290	70	800	10	2.00	50	4.00	50	96	80	0.91	10.0
10	NKST High Level	45	27	6.2	510	190	130	340	30	2.50	70	9.00	35	120	30	0.75	1.00
11	Balewa Crescent	30	28	6.3	480	310	110	280	6	4.50	40	8.00	40	300	20	0.60	2.00
12	Wadata Market-1	33	26	6.0	340	300	80	310	7	0.08	45	5.00	45	294	10	0.70	4.00
13	Wadata Market-2	40	28	6.1	290	200	100	440	4	0.06	55	6.00	10	260	40	0.15	5.00
14	Head Bridge	38	26	6.7	516	210	120	500	4	0.05	60	6.00	15	210	10	0.27	30.0
15	Kaltunu	30	27	5.9	580	300	115	360	8	0.07	70	7.00	30	196	30	0.53	4.00
16	Logo	40	26	6.8	420	310	95	740	10	5.00	40	8.00	20	200	80	0.30	30.0
17	Queen's Clinic	55	28	6.4	260	280	90	600	18	2.50	30	1.50	30	261	80	0.42	20.0
18	Modern Market.	50	28	7.0	380	170	110	310	21	0.03	90	3.50	10	300	90	0.13	20.0
19	House of Mercy	35	27	6.8	570	150	60	680	17	0.05	20	10.00	50	135	100	0.80	15.0
	Minimum	30	26	5.7	220	140	60	200	3.0	0.02	20	1.50	10	96	10	0.13	1.00
	Maximum	65	28	7.3	600	310	140	800	30	5.00	100	10.00	50	300	100	0.91	50.0
	Mean		27	6.0	401	236	96	516	11.7	1.20	54	5.60	33	226	54	0.51	17.2
	NSDWQ (2007)			6.5-8.5	500			NS	250	50	100						
	WHO (2008) Limits			5.7 - 7.3	1000	1400	500		250	50	400			500			1.00

Hardness as $Ca(HCO_3)_2$ Temp = temperature TDS = Total dissolved Solids Cond = Conductivity SAR = Sodium absorption Ratio All units are in mg/L unless stated assess the suitability of the waters for irrigation because backyard garden crops are routinely watered from these sources by the inhabitants. The suitability of the water for domestic purposes was determined by comparing the concentrations of the constituents with SON (2007) and WHO (2008) drinking water standards. Also, a non parametric, 2 tailed correlation analysis at 5% alpha level of significance was carried out according to the procedure described by Akujieze and Oteze (2007) to understand the relationship and variation of ionic content of water and some pollution indicators.

RESULTS AND DISCUSSIONS

Hydrochemistry and Water Quality

Results of the physicochemical and bacteriological characteristics of the ground water are shown in Table 1. The average temperature of groundwater within the study area is 27°C. The pH value range from 5.7 to 7.3 with a mean of 6.02, indicating that the groundwater is weakly acidic to alkaline. pH values below 6 were recorded in Idye (pH 5.8), Wurukum (pH 5.7) and Kaltunu (pH5.9). The values obtained in this study however, fall within the range of pH of 5.5 to 9.0 of natural waters (Hems, 1985). According to Cox (1995), the presence of slightly acidic waters is probably due to the leaching of organic acids from decaying vegetation and/or soil, hydrolysis of ferruginized Makurdi sandstones or dissolution of CO_2 from the atmosphere to form carbonic acid. Also, Hems (1985) explained that weak acids normally tend to buffer solutions to lower pH changes. This implies that the weakly acidic to alkaline groundwater in the study area has the capability to reduce any pH within natural values of 5.5 to 9.0. Moreso the dissolution of calcareous lenses or intercalations in the Makurdi Sandstones could neutralize any acidity and maintain the pH within natural levels.

The total dissolved solid (TDS) and electrical conductivity values range from 220 to 600 mg/L and 140 to 310 αs/cm with mean values of 401 mg/L and 235.7 αs/cm respectively. These values are far below the WHO (2008) limits of 1000 mg/L and 1400 αs/cm respectively. Electrical conductivity measures the degree of salinity in water, which greatly affects taste and thus has a significant impact on the user's acceptance of the water (Langeneggar, 1990). On the basis of these two parameters, the groundwater in this area is suitable for domestic and other purposes. The conductivity values of the groundwater also indicate that it is suitable for irrigation.

A diagram summarizing the cation chemistry is shown in Fig.3. Among the heavy metals, Fe and Mn concentration range from 0.01 to 0.06 mg/L and 0.01 to 0.08 mg/L with mean values of 0.12 mg/L and 0.04 mg/L respectively (Table 2). These

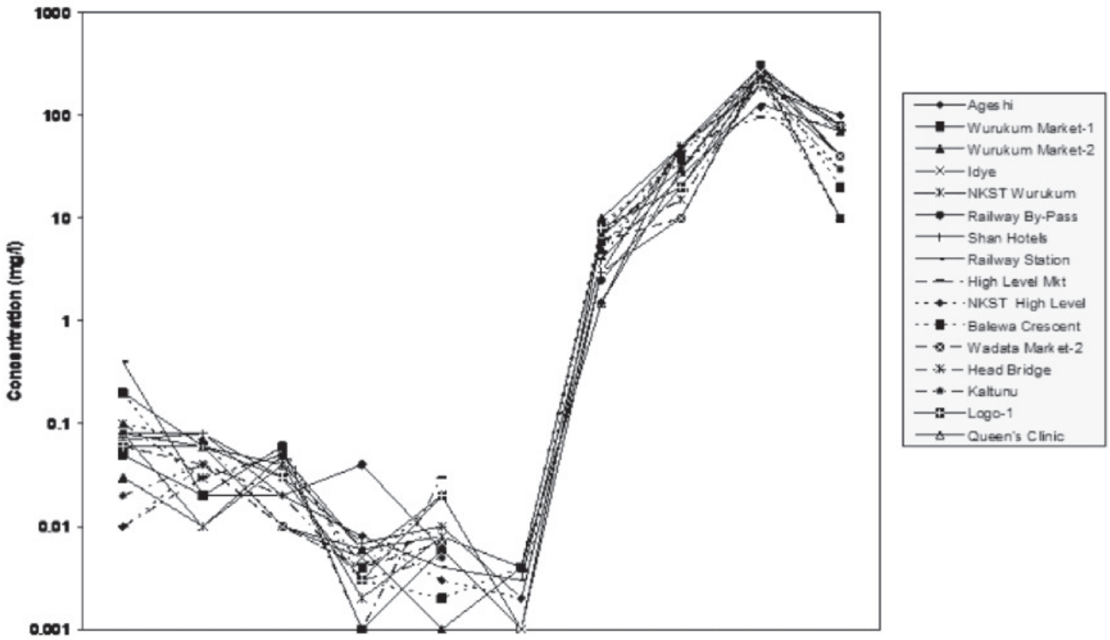

Fig 3. Diagram Summarizing the Cation Chemistry of the Groundwater

Table 2: Concentration of Heavy Metals in the Water Samples

S/N	Sample Location	Fe	Mn	Zn^{2+}	Cu^{2+}	Pb^{2+}
1	Ageshi Transport Garage	0.20	0.06	0.01	0.006	0.008
2	Wurukum Market-1	0.05	0.02	0.06	0.001	0.006
3	Wurukum Market-2	0.03	0.01	0.05	0.006	0.001
4	Idye	0.06	0.06	0.01	0.005	0.020
5	NKST Wurukum	0.08	0.01	0.04	0.002	0.008
6	Railway By-Pass	0.08	0.08	0.02	0.04	0.006
7	Shan Hotels	0.07	0.08	0.03	0.007	0.010
8	Railway Station	0.40	0.02	0.02	0.008	0.004
9	High Level Market	0.01	0.03	0.05	0.001	0.030
10	NKST High Level	0.01	0.04	0.02	0.008	0.003
11	Balewa Crescent	0.20	0.02	0.06	0.003	0.002
12	Wadata Market-1	0.10	0.07	0.01	0.004	0.020
13	Wadata Market-2	0.06	0.04	0.01	0.004	0.007
14	Head Bridge	0.10	0.03	0.05	0.004	0.010
15	Kaltunu	0.02	0.04	0.02	0.003	0.005
16	Logo	0.06	0.06	0.03	0.003	0.020
17	Queen's Clinic	0.08	0.06	0.04	0.006	0.001
18	Modern Market.	0.01	0.02	0.06	0.001	0.030
19	House of Mercy	0.40	0.05	0.01	0.010	0.006
	Minimum	0.06	0.01	0.01	0.001	0.001
	Maximum	0.40	0.08	0.06	0.010	0.030
	Mean	0.12	0.04	0.03	0.04	0.010
	NSDWQ (2007)	0.30	0.20	3.00	1.00	0.01
	WHO (2008) Limits	0.30	0.05	5.00	0.05	0.05

Table 3: Quality Classification of Water for Irrigation (Langeneggar, 1990)

Water Class	Sodium (mg/1)	Specific Conductance (αs/cm)	SAR
Excellent	<20	<250	0-10
Good	20-40	250-750	10-18
Permissible	41-60	750-2000	18-26
Doubtful	61-80	2000-3000	26-30
Unsuitable	>80	<3000	
This Study	10-50	140-310	0.13-0.91

are all within WHO (2008) recommended limits of 0.3 mg/L and 0.5 mg/L respectively. Fe and Mn in natural water are usually found in the form of soluble ferrous and manganese bicarbonates respectively (Hems, 1985). Upon aeration, the ferrous iron is oxidized to ferric state while manganese bicarbonate changes to insoluble manganese hydroxides and are precipitated. The low values of these parameters therefore indicate that the high water table in the study area (0.5 to 5 m) is within the zone of aeration where these elements are insoluble. The concentration of zinc, lead, copper and cadmium occur in trace amounts. The low level of concentration of heavy metals in groundwater correlates well with its acidic to alkaline nature. Under such condition

Table 4: Correlation Coefficient (r) Matrix of Groundwater Chemistry in Makurdi Area.

	pH	TDS	Cond	Hrdn	HCO_3	Cl	NO_3	SO_4	Fe	Mn	Zn	Cu	Pb	Cd	K	Na	Ca	Mg
pH	1.000																	
TDS	-0.100	1.000																
Cond	-0.139	0.206	1.000															
Hrdn	0.067	0.044	-0.199	1.000														
HCO_3	0.340	-0.325	-0.008	-0.204	1.000													
Cl	0.142	0.341	-0.173	0.278	-0.197	1.000												
NO_3	-0.060	-0.013	0.408	-0.041	0.299	0.071	1.000											
SO_4	-0.294	0.269	-0.066	0.146	-0.437	0.222	-0.186	1.000										
Fe	0.235	0.244	-0.248	-0.146	0.069	-0.026	-0.063	-0.441	1.000									
Mn	0.095	-0.174	-0.142	-0.329	-0.020	-0.064	-0.025	-0.265	0.187	1.000								
Zn	0.314	0.091	0.248	0.311	0.067	0.103	0.211	-0.004	-0.263	-0.614	1.000							
Cu	0.085	0.247	0.066	-0.371	-0.246	0.173	-0.155	-0.011	0.119	0.485	-0.314	1.000						
Pb	0.298	-0.258	-0.099	-0.176	0.005	-0.075	-0.056	0.222	-0.254	0.095	0.109	-0.263	1.000					
Cd	-0.136	0.434	0.817	-0.211	-0.094	0.145	0.556	0.245	0.469	-0.333	0.336	-0.083	-0.275	1.000				
K	-0.296	0.530	0.098	-0.217	-0.067	-0.024	0.127	-0.003	0.222	-0.339	-0.060	-0.193	-0.175	0.013	1.000			
Na	0.084	0.066	0.207	0.123	0.088	0.125	-0.095	-0.244	0.336	-0.290	0.059	-0.186	-0.150	0.060	0.219	1.000		
Ca	-0.128	-0.227	0.028	-0.053	-0.408	-0.319	-0.214	-0.035	-0.115	0.165	0.201	0.073	0.005	-0.044	-0.145	-0.282	1.000	
Mg	0.487	-0.332	-0.284	-0.170	0.694	0.155	0.136	-0.160	0.229	0.012	0.008	-0.243	0.201	0.133	-0.147	0.096	-0.264	1.000

Cond = conductivityHrdn = hardnes

metals are insoluble and tend to deposit in the solid phase. This is particularly true of Fe and Mn which are deposited as hydrous ferric and manganese oxides respectively. These oxides have large adsorption capacity for metal ions thereby decreasing the mobility of heavy metals and enhancing their concentration in the soil. (Hems, 1985).

Calcium and Magnesium concentrations range from 96 to 300 mg/L and 101 to 100mg/L with average values of 26 mg/L and 54 mg/L respectively. The limits for these parameters in drinking water are 500 mg/L and 150 mg/L respectively. Based on these results, the groundwater is suitable for domestic and most industrial processes except for boiler feed water, which requires less than 0.01 mg/L for these parameters (Cox, 1995). The values of Potassium and Sodium range from 1.5 to 10 mg/L and 10 to 50 mg/L with mean values of 5.6 mg/L and 33mg/L respectively. These sodium values are below the limiting values of 200 mg/L set by WHO (2008). Sodium is considered as a major factor governing the choice of water for irrigation because of its deleterious effect on plants. In this study, the sodium absorption ratio (SAR) is extremely low (less than 1). As shown in Table 3, water with sodium content of less than 60mg/L and SAR of 0-26 is permissible for irrigation. The ground water from the study area is therefore suitable for irrigation based on these parameters. When the TDS was plotted against $Na/(Na^{+}Ca)$ ratio of Gibbs (1970) diagram (Fig. 4), majority of the samples plotted in the region which indicates that the chemistry of the waters is modified by evaporation and dilution. These are partly influenced by seasons (in this case, dry season) and anthropogenic factors. Overall, the chemistry of the waters represent the allomorphic phase of sediment modification (phase of ion exchange with clays, micas and feldspars) marked by mineral replacement such as quartz, chert, clay or feldspars by carbonates, feldspars by clays, aragonite and calcite, (Nwajide and Hoque, 1984.) Mg^{2+} and Ca^{2+}, and K^{+} are most probably lithogenic. They owe their source to the dissolution of minerals, such as micas and feldspars that have these elements in their structures as illustrated in the equation below:

$$\underset{\text{(K-feldspar)}}{KAlSi_3O_8} + \underset{\text{(carbonic acid)}}{2H^{+} + 2HCO_3)} + \underset{\text{(water)}}{H_2O} \longrightarrow \underset{\text{(clay residue)}}{Al_2Si_2O_5(OH)_4} + \underset{\text{(soluble products).}}{2K^{+} + 2HCO_3^{-} + 4SiO_2}$$

The concentrations of the anions (HCO_3^{-}, $C1^{-}$, NO_3^{-} and SO_4^{2-}) are summarized in Fig.5. The values of the anions are all within WHO (2008) standards for domestic, industrial and agricultural purposes. Bicarbonates values in the samples range from 200 to 800 mg/L. No limits is given for this parameter in drinking water by WHO (2008). The concentration of HCO_3^{-} in the water system of the study area owes its origin probably to CO_2 from the atmosphere and/ or produced by the biota of the groundwater system (Tijani, 1994). The super saturation with CO_2 could also be responsible for the weak acidity of the water system.

The concentration of Cl lies between 3 to 30mg/L with a mean value of 12 mg/L. The low values indicate that the ground water in this area is fresh. WHO (2008) stipulates 200mg/L as the limit of Cl in drinking water primarily for reasons of taste. The limit for most industrial processes is also 200mg/L (Cox, 1995). The concentrations of NO_3 and SO_4^{2-} in the groundwater samples range from 0.02 to 5mg/L and 20 to 100mg/L with average values of 1.2mg/L and 54mg/L respectively. These values are all within the permissible limits stipulated by WHO (2008). Nitrate may occur naturally, or be present due to the use of nitrate-based fertilizers, discharge of wastewater, septic tank leachate, or concentrated animal feeding operations. Sulfate may occur naturally or may be caused by human activities such as agriculture, mining, or other activities (Kaown *et al,* 2007, Whelan and Poulson, 2009). Although many non-point source contaminants such as sulfate and total dissolved solids are not regulated for drinking water use, their presence in groundwater can cause significant service problems for water providers and other water users. Good management of septic tanks and proper application of fertilizer are necessary to maintain the low levels of these parameters.

Although the study area is underlain by Makurdi Sandstone which is the main aquifer unit in the area, Nwajide and Hoque (2004) described it as comprising poorly sorted feldspathic fluvio-deltaic sandstones, basal conglomerates, silts,

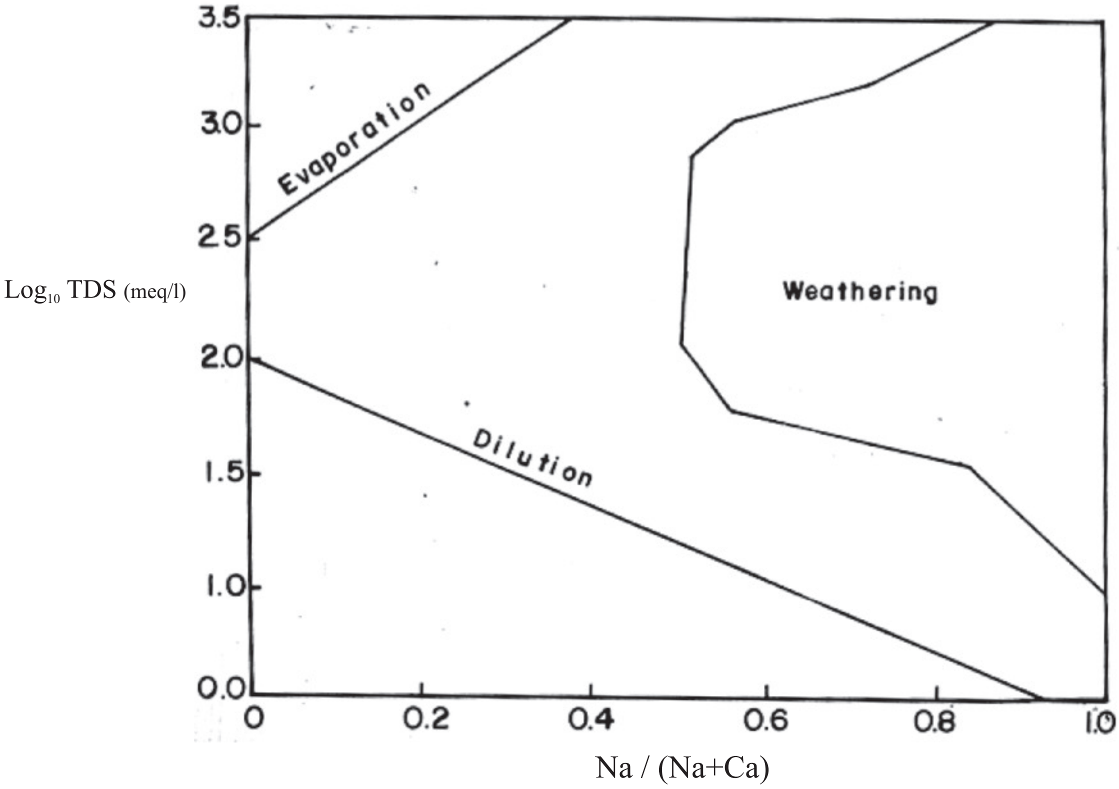

Fig.4 Plot of TDs Against the Na/(Na+Ca) Ratio (After Gibbs, 1970)

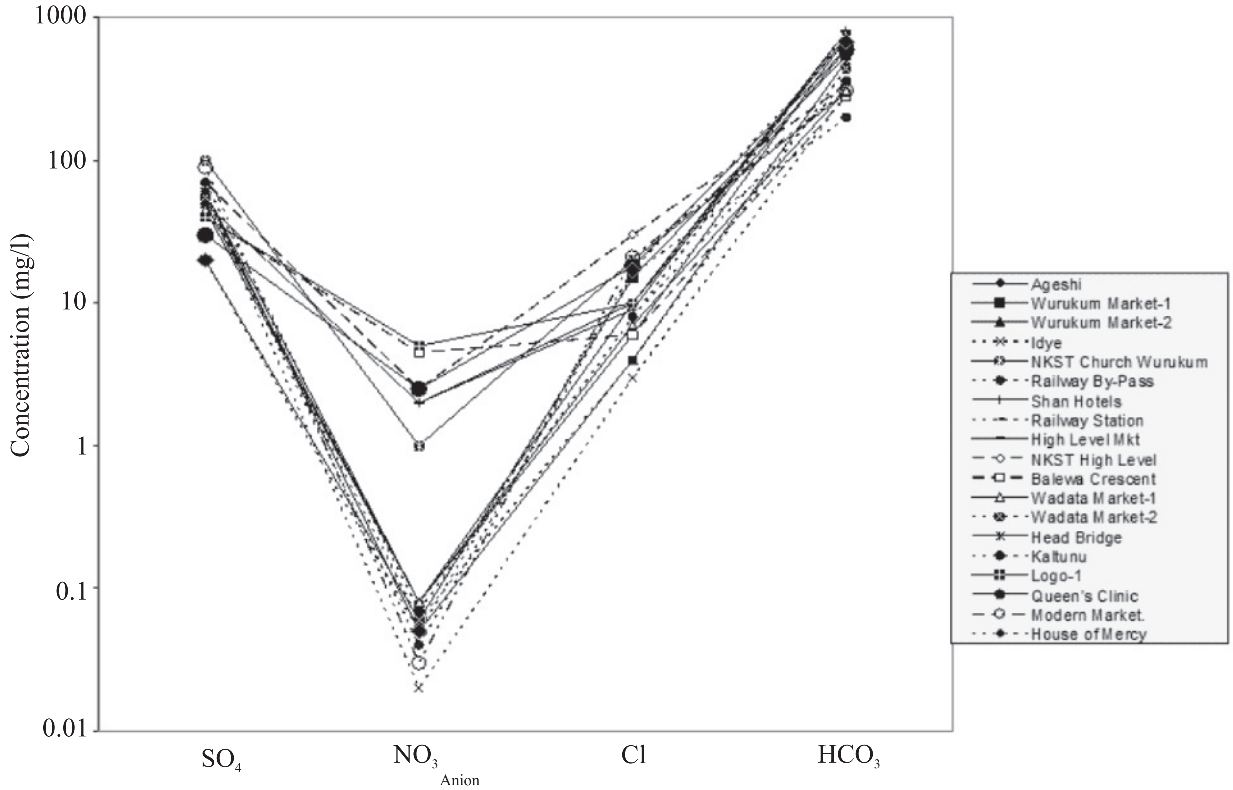

Fig. 5 Diagram Summarizing the Anion Chemistry of the Groundwater

mudstones and clay lenses, and is frequently indurated . In the upper 10 m from the ground surface which is the average depth of hand dug wells in the area, clay is a significant component of the cemented sandstone which adds stability to the well bore, but reduces permeability thus preventing the ingress of harmful materials from the adjacent latrines and dumpsite. Thus the anthropogenic factors have not affected the groundwater quality as much as expected.

The hardness values in the study area range from 60 to 140 mg/L with a mean value of 96 mg/L. According to Durfor and Becker (1964), hardness range of 0-75 mg/L indicates soft water, 75-150 mg/L indicates moderately hard water and >150 mg/L indicates hard water. The water is therefore moderately hard. The hardness is caused mainly by Ca^{2+} which may have been released from the calcareous Makurdi Sandstone. The hardness is therefore an impediment to laundry because the water will not lather easily with soap, and may form scum on clothes and scales on kettles and boilers. The water could be treated to remove the hardness by boiling or adding soda lime.

Comparatively, the highest values of cations and anions are calcium (mean = 226mg/L) and HCO_{3-} (mean = 513 mg/L) respectively. Elueze *et al.* (2004) obtained similar results in groundwater's in Ilesha area of Southwestern Nigeria, and explained that according to David and Dewiest (1966), the abundance of calcium in the earth's crust and its high mobility in the hydrosphere makes it very common in underground waters. Tijani (1994) explained that the source of HCO_3^- can be attributed to CO_2^- recharge.

Hydrochemical Facies

From the piper's trilinear diagram (Piper, 1944) of the concentrations of the major cations and anions in groundwater samples (Fig.6), the hydrochemical facies has been delineated as

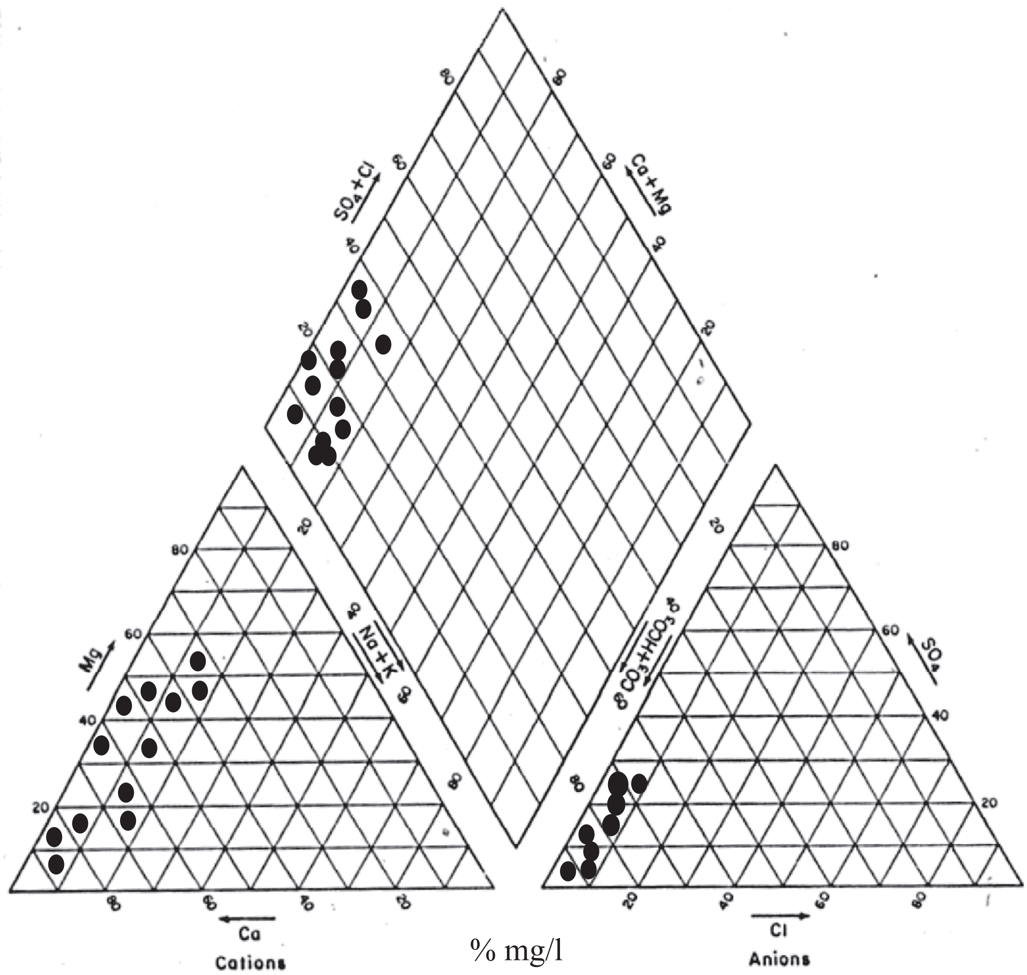

Fig.6: Piper's Trilinear Plots of the Major Ion Chemistry of the Groundwater

calcium-magnesium-bicarbonate (Ca-Mg-HCO_3-). This water type falls within the normal alkaline group, according to Fartirk and Langguth (1967) classification (in Elueze *et al.,* 2004). This indicates that the groundwater in the study area is fresh, it comes from a shallow depth or it has a low residence time. The observation is in agreement with Tijani's (1994) explanation that the dissolution of silica minerals in the bedrock may also have contributed to the chemical composition of the groundwater.

Correlation Analysis

The correlation coefficient matrix produced from the correlation analysis of the ionic content of the water is shown in Table 4. A correlation coefficient (r) of +1 indicates that two variables are perfectly related in a positive linear sense, but r = -1 indicates a negative linear correlation. However no relationship between 2 variables exists if r = 0. Thus two variables having a positive correlation coefficient infers that they have a common source, while negative correlation coefficient indicates different source.

For example in this study, Zinc has a weak positive correlation with rare earth metals, (Ca: r = 0.201; Na: r = 0.059 and Mg: r = 0.008) which indicates that they have a common source, although its negative correlation with K (r = -0.060) shows a different source. Other than Fe (r = 0.119) with which it has a positive correlation factor, Cu shows negative correlation with sulphate (r = -0.011 and Pb (r = -0.263) indicating different sources. Also Cl correlates negatively with Fe and K (r = -0.026, and -0.024 respectively) but positively with Zn and Cu (r = 0.103 and 0.173 respectively) just as Ca does with Mn (r = 0.165), Zn (r = 0.201) Cu, (r = 0.073) and Pb (r = 0.005). However, nitrate correlates positively with phosphate, but negatively with Pb and and Mg

Bacteriological Quality

The coliform count of groundwater samples ranges from 1 to 50 coliform count per 100 ml. The values are higher than the permissible count of 1 per 100 ml recommended by WHO (2008). This implies that bacteriological contamination of groundwater is a major problem in this area. The water table in this area is so shallow (0.5m-5.0m) that pit latrines occasionally intersect the water table where the Makurdi Sandstone is not indurated thereby increasing the risk of contamination of the groundwater with faecal materials. Where the hand-dug wells are not cased this may allow for the direct ingress of bacteriologically contaminated surface water bodies, especially sewage effluents and leachates from garbage dumps (Bouwer, 1978). Residents commonly use the same bucket to bail water from the wells as well as for laundry and for flushing the toilets after use. The tardy, often wet surroundings of the uncased and uncovered wells due to frequent use by large households and surrounding neighbours and the multi purpose use of the bailing buckets could quite easily introduce foreign matters including bacteria into the water. The major diseases that could arise from bacteriological contamination of the groundwater include typhoid, diarrhea and cholera. Zenone *et al.* (1975) have shown that differences in local geohydrologic conditions can influence groundwater quality. At present, the high rate of discharge of refuse at sites that are not engineered for this purpose, the unconfined nature of the aquifer, the high water table and rate of recharge of aquifer by rainfall in the area indicates that the groundwater is prone to contamination in the future when the buffering or purifying capacity of the soil and groundwater is overloaded. Under such condition, the soil will release back the pollutants into the groundwater. Thus the deleterious impact of refuse dumps on the quality of groundwater within Makurdi metropolis could occur in the future.

CONCLUSIONS

The present investigation suggests that the shallow aquifer from which hand dug wells in Makurdi metropolis tap its water is the Makurdi Sandstone. The results of the physico-chemical parameters reveal that the groundwater is safe for most domestic uses when treated for pH and total hardness. It is also suitable for irrigation and for most industrial purposes. This implies that groundwater in the sampled areas have not been affected by the solid wastes at the nearby dump sites as shown by the low concentration of heavy metals. This may be attributed to the induration of the Makurdi Sandstones which is the aquifer material. However, water in some of the boreholes is contaminated with coliform organisms. The sources may be from the poorly constructed pit latrines and poor sanitary practices. The relevant local authorities should strengthen the campaign for cleanliness of the environment, proper location and construction of pit latrines, and best practice on refuse and sewage disposal by the inhabitants. Specifically, the closure and conversion of the open dumps and selection of some to operate as secured landfill is recommended provided this is determined by a constraint mapping exercise which requires that the sites do not fall within exclusion areas for landfills.

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