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Full Length Research Paper

Hydrochemical assessment of groundwater quality in the Chad Basin around Maiduguri, Nigeria

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The objective of this study was to investigate the impact of anthropogenic and natural sources of contamination on the groundwater quality of the upper unconfined aquifer system of the Chad Basin around Maiduguri. This has been determined by obtaining a total of 20 groundwater samples over a 4 months period in 2 different sites (Moduganari and Gwange) in Maiduguri. Groundwater samples were analysed for pH, EC, TDS, major cations (Na^+, Ca^{+2}, K^+, and Mg^{+2}), major anions (Cl^-, SO_4^{-2}, PO_4^{-2}, NO_3^-, CO_3^- and HCO_3^-). Results obtained showed that the water in site 1 is alkaline (pH 6.61 to 7.57), while that of site 2 ranged from slightly acidic to alkaline (pH 6.2 to 7.31). Concentration of all the cations and anions in both sites vary significantly ($p<0.05$) across all the samples. Sodium, calcium, potassium, and magnesium as well as carbonate and bicarbonate concentrations in the groundwater samples analysed is as a result of natural processes such as ion-exchange processes, silicate weathering and calcium carbonate dissolution. Nitrate, chloride, sulphate and phosphate indicate the impact of above ground anthropogenic activities on the groundwater. Water quality results for both sites showed that concentration of major ions significantly fall below the WHO standard limit. In total, 75% of the water samples is Calcium-Bicarbonate ($Ca\text{-}HCO_3$) type, while the remaining 25% are of sodium-bicarbonate ($Na\text{-}HCO_3$) type.

Key words: Groundwater quality, Maiduguri, contamination, major ions.

INTRODUCTION

Groundwater is the most reliable water supply source for domestic, agricultural and industrial use in Nigeria and other countries across the world. However, despite its reliability, this precious and vital resource is under increasing threats attributed to above ground anthropogenic activities related to uncontrolled urbanisation, incessant waste disposal and poor land use management. Also, the usefulness of groundwater to humans essentially depends on its chemical status, thus, assessment of groundwater quality is important for socio-economic development of most developing and developed countries of the world. Groundwater quality is an important factor in the context of sustainable water management, the integrity of underlying aquifers are mainly affected by pollution from above ground sources (Kumar et al., 2013) particularly solid waste disposal. Uncontrolled urban growth and its resultant effect, especially in developing nations like Nigeria, can adversely affect the quality of underlying groundwater if not properly controlled (Foster et al., 1998; Putra, 2008). Once groundwater is contaminated; its quality cannot be restored and it is very expensive, and difficult to clean it up (Ramakrishnaiah et al., 2009).

Urban population in Nigeria is growing rapidly, for

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example the total population of the country rose from 45.2 million in 1960 to about 168 million in 2013 (NPC, 2006), this trend indicates a change of 268% during the last 50 years. The current urban population is about 80 million (NPC, 2006), and are mostly concentrated in the marginal slum areas where access to sanitation and piped water is often limited. Wastes generated in these areas are incessantly disposed in open spaces and dumps. These wastes, over a period and the influence of climatic conditions, could leach down and pollute underlying groundwater. In Maiduguri, uncontrolled urbanisation has resulted in increased above ground anthropogenic activities such as incessant waste disposal, proliferation of pit latrines and routine agricultural activities. Large pressure from these above ground pollution sources, can considerably impact negatively on the underlying aquifers. Thus, there is an urgent need to investigate the current level of contamination that will help in developing a feasible and practical solution that will mitigate the impact of above ground activities on groundwater quality.

This study was therefore conceived to investigate the impact of anthropogenic and natural sources of contamination on the groundwater quality of the upper unconfined aquifer system of the Chad Basin around Maiduguri, and to ascertain whether the water in this system is within the acceptable limit for human consumption as set aside by World Health Organisation (WHO) (1993) or not. The findings are of relevance to water managers and scientists in Maiduguri and also in other developing countries in carrying out water quality related investigations.

POTENTIAL SOURCES OF POLLUTION IN MAIDUGURI

There are multitudes of anthropogenic and natural sources of contamination in Maiduguri metropolis which are likely to impact negatively on the groundwater system. These contaminants originate from both point and non-point sources across the city. The point-source emanates from domestic and municipal waste disposal sites; others are industrial effluent from the Maiduguri flour mill company, the Coca-Cola bottling plant, the Borno plastic company and the Borno Aluminium plant, as well as the Maiduguri water treatment plant etc. Also, in the informal settlement areas, the ever increasing utilisation of pit latrines is another major impediment. Impact from small businesses and other cottage industries such as dying, tanneries and local brick making cannot be overruled. Consequently, mechanical workshops and construction sites due to urban expansion are other potential sources of contamination. Non-point-sources of pollution in Maiduguri are largely from agricultural activities near the Alau Dam where extensive irrigation agriculture which involves intensive fertiliser application is practiced. Other presumed sources are the widespread commercial car wash centres, cattle markets and abattoirs.

The potential pathways taken by these contaminants to travel are mostly through the environment (Stuart et al., 2012). Direct pathways for municipal, agricultural and industrial pollutants are largely through the pore spaces and fractures that exists in the sedimentary formations of the area; where the contaminants infiltrate into the unsaturated zone and then to the saturated zone. In addition to this, the presumption that some of these pollutants may infiltrate into the upper aquifer of the study area is because of the unconfined nature of the upper aquifer system. Another important pathway is the hydraulic connectivity that exists between the River Ngadda and the upper aquifer system. In addition to this, other potential pathways results from improper drilling of wells or poor well development activities, abandoned old wells can also serve as conduit for direct vertical migration to depths closer to deep municipal aquifers. In many instances, solid wastes generated in the residential areas, local businesses and markets are dumped into the River Ngadda thereby threatening the groundwater system. Furthermore, treated effluents from the Maiduguri water treatment plant and domestic sewages are discharged into this River.

DESCRIPTION OF THE STUDY AREA

Maiduguri is the capital of Borno state located in north-eastern Nigeria (Figure 1). It lies on a vast sedimentary basin attaining an average elevation of 300 m above sea level. Moduganari and Gwange (Figure 2) are major areas with the highest population densities. Thus, above ground human activities such as waste generation and land use will impact negatively on the groundwater system of both areas if uncontrolled. The climate is semi-arid with three distinct seasons: a long hot dry season from April to May. Day time temperatures are in the range of 36 to 40°C and night time temperatures fall to 11 to 18°C. This is followed by a short rainy season from May to September with a daily minimum temperature of 24°C and a maximum of 34°C with relative humidity of 40 to n65% and annual rainfall from 560 to 600 mm. Finally, the cold (harmattan) season runs from October to March when temperatures fall to about 20°C and a dry dusty wind blows from the Sahara desert (Eugster and Maglione, 1979; Jaekel, 1984). The vegetation of the study area is Savannah woodland which is divided into two zones: Sudan Savannah to the south and Sahel Savannah to the north.

GEOLOGY AND HYDROGEOLOGY OF THE STUDY AREA

The Chad Basin has been a structural depression since

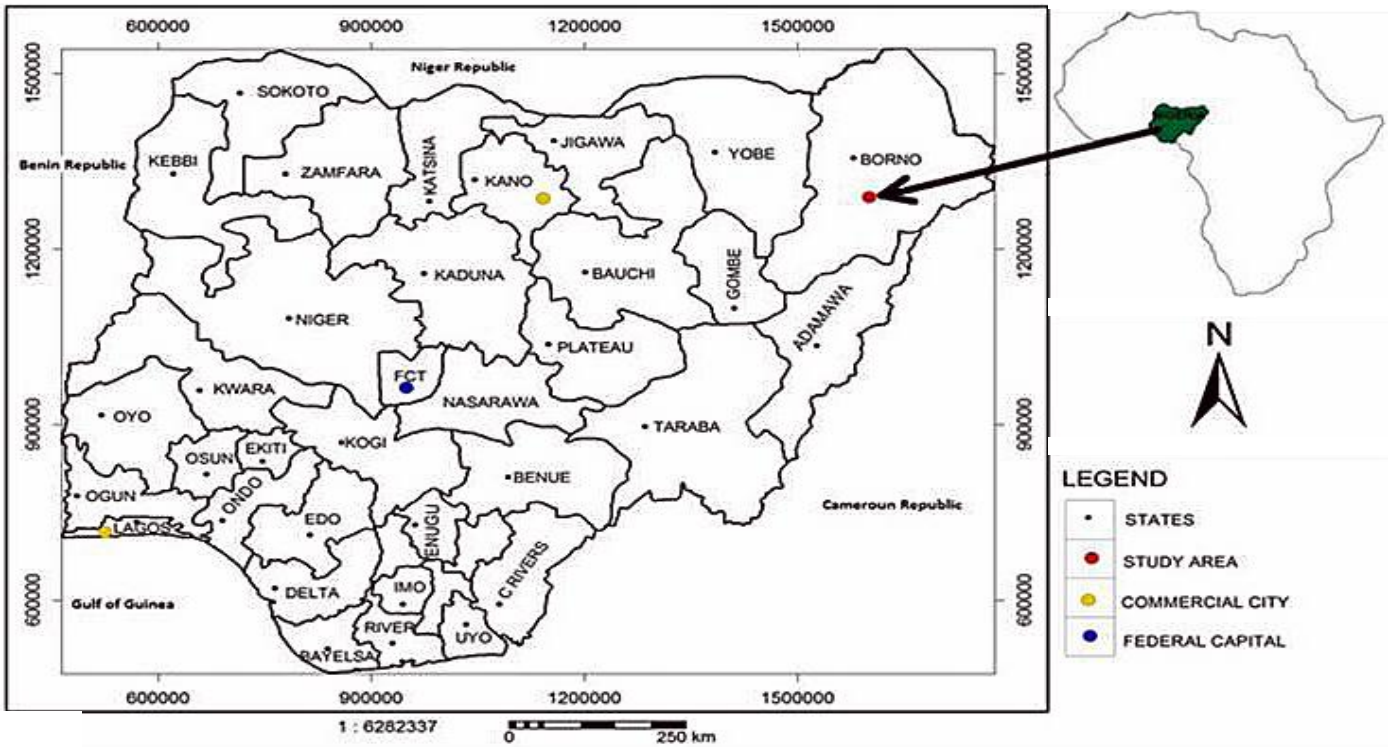

Figure 1. Map of Nigeria showing study area.

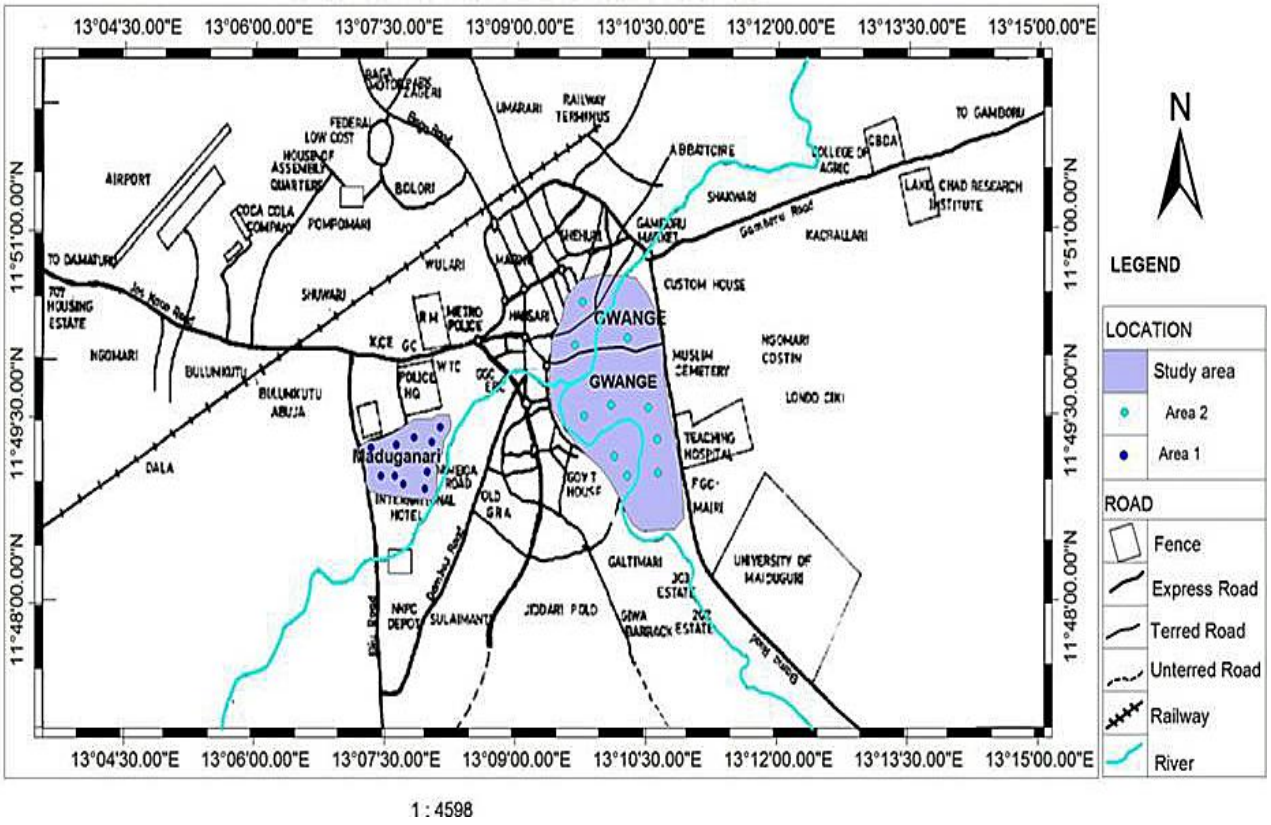

Figure 2. Map of Maiduguri showing study and sampling sites.

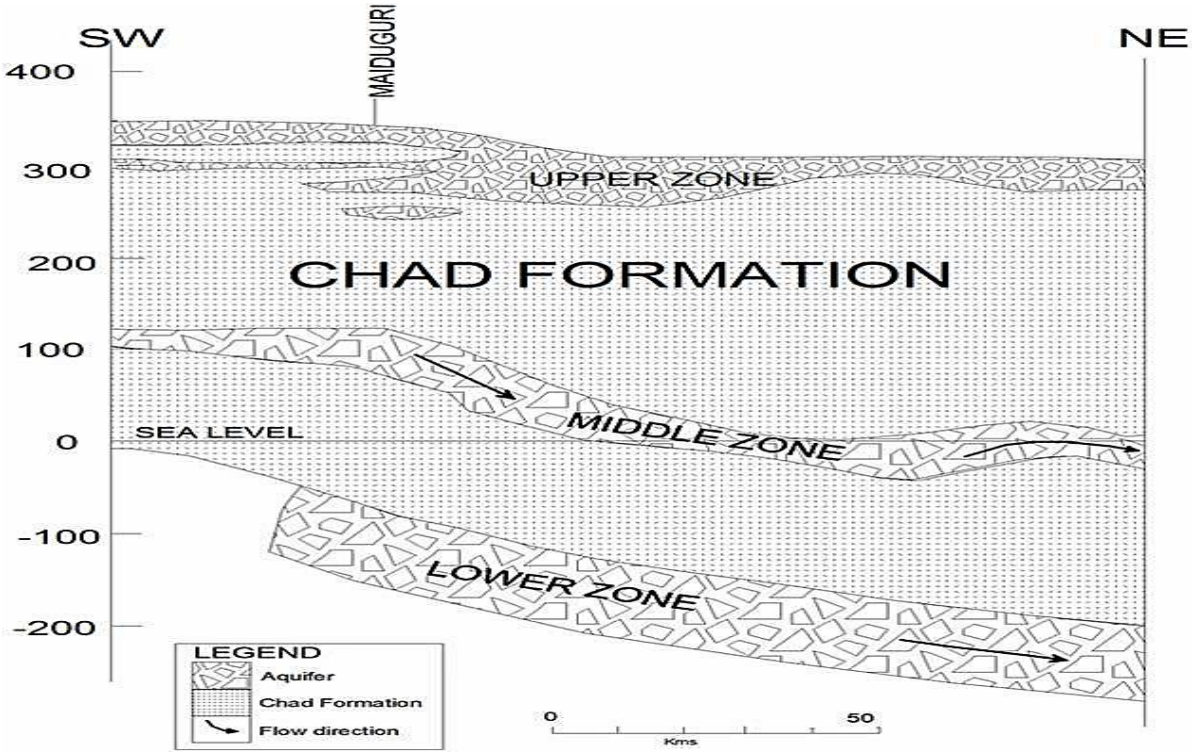

Figure 3. Cross section of the multi-layered aquifer system in Maiduguri.

early tertiary time and has been a locus of subsidence and sedimentation rather than erosion. According to Furon (1960) and Obaje (2009), the Chad Basin was a tectonic cross point between a NE to SW trending "Tibesti-Cameroon Trough" and the NW to SE trending "Air-Chad Trough" in which over 3600 m of sediments have been deposited. The crystalline basement complex outcrops in the eastern, south-eastern, south-western and the northern rims of the basin; its configuration beneath the sediments near the lake has the semblance of a horst and graben zone (Oteze and Fayose, 1988). The stratigraphy of the Chad Basin (Bornu sub-Basin) shows a depositional sequence from top to bottom which includes the younger Quaternary sediments, Plio-pleistocene Chad Formation, Turonian-Maastrichtian Fika shale, the late Cretaceous Gongila formation and the Albian Bima Formation (Maduabuchi et al., 2006). The Bima sand stone forms the deeper part of the aquifer series and rests unconformably on the basement complex rocks. Its thickness ranges from 300 to 2000 m and the depth between 2700 and 4600 m (Obaje, 2009). A pioneer investigation carried out by Barber and Jones (1960) revealed that the Chad formation reaches a thickness of at least 548 m at Maiduguri; in the central part of the basin the thickness may reach 600 to 700 m (Offodile, 1992). The Plio-pleistocene Chad Formation and the Quaternary sediments are the main sources of groundwater supply in the Maiduguri area.

The Chad formation dips gently east and northeast towards Lake Chad in conformity with the slope of the land surface. Except for a belt of alluvial deposits around the edge of the basin, the formation is of lacustrine origin and consists of thick beds of clay intercalated with irregular beds of sand, silt and sandy clay (Miller et al., 1968). As shown in Figure 3, Barber and Jones (1960) divided the Chad Formation into three water bearing zones designated upper, middle and lower aquifers (Miller et al., 1968; Odada et al., 2006; Adelana, 2006). The upper aquifer is a Quaternary alluvial fans and deltaic sediments of Lake Margin origin. The reservoir in this system is composed of interbedded sands, clays, silts and discontinuous sandy clay lenses which give aquifer characteristics ranging from unconfined, through semi-confined to confined types (Maduabuchi et al., 2006). It extends from the surface to an average depth of 60 m but locally to 180 m. The transmissivity of this aquifer system ranges from 0.6 to 8.3 m^2/day and the aquifer yield in Maiduguri is between 2.5 to 30 l/s (Akujieze et al., 2003). This aquifer is mainly used for domestic water supply (hand dug wells and shallow wells), vegetable growing and livestock watering (Maduabuchi, 2006). In Maiduguri, the likely sources of contaminants that may pose significant treat to groundwater quality range from pit latrines, municipal solid waste disposed in open dump sites, agricultural and industrial wastes.

Table 1. Results of physical parameters for site 1.

site 1	PH	EC	TDS	Temperature
BHM1	6.61±0.00	123±0.70	122±0.00	33±0.07
BHM2	7.57±0.01	179±1.00	142±0.57	32.3±0.39
BHM3	7.14±0.00	199±1.00	172±0.59	32.8±0.15
BHM4	7.34±0.01	148±1.53	164±0.58	32.7±0.15
BHM5	7.18±0.01	150±0.58	159±0.57	34.1±0.10
BHM6	7.22±0.01	167±1.00	145±1.00	34±0.16
BHM7	7.35±0.01	200±1.00	85±1.53	33.4±0.21
BHM8	7.02±0.01	187±1.73	175±0.57	34.1±0.10
BHM9	7.04±0.01	157±1.15	157±1.15	35.4±0.31
BHM10	7.07±0.00	188±1.00	147±0.57	34.3±0.20

Mean of samples in triplicate±STD.

Table 2. Results of physical parameters for site 2.

site 2	PH	EC	TDS	Temperature
BHG1	6.2±0.05	180±1.00	132±1.00	28±0.05
BHG2	6.1±0.15	213±2.08	176±0.57	30±0.05
BHG3	6.7±0.05	167±0.57	140±2.50	29±0.57
BHG4	7.3±0.15	179±2.00	163±1.73	31±0.00`
BHG5	7.2±0.05	200±0.57	181±0.57	27±0.28
BHG6	6.6±0.11	165±0.57	128±2.00	32±0.28
BHG7	7±0.11	97±1.00	103±1.00	30±0.00
BHG8	7.1±1.09	113±0.57	110±1.00	29±0.05
BHG9	7.04±0.00	110±1.52	117±1.52	27±0.11
BHG10	6.8±0.15	134±0.57	134±0.57	26±0.05

Mean of samples in triplicate±STD.

The pathways by which contaminants travel from the source includes spaces, poorly developed or abandoned wells, and fractures in the unconsolidated geologic material of the Chad Basin through which it flows into the aquifer and the receptors are the environment, people and animals drinking water from the aquifer.

MATERIALS AND METHODS

Water samples were collected from boreholes (tube wells); a total of 20 shallow tubewells, 10 each in Moduganari (site 1) and Gwange (site 2) areas respectively. Prior to collection of the water samples, the 2 L polyethylene containers used to store the samples were first washed with de-ionised water, and then three times with the sample water in order to avoid any contamination. Then, the water samples were collected from the boreholes after 5 to 10 min of pumping to ensure that the samples were true representative from the aquifer. The collected samples were then stored in an ice-packed cooler for analysis within 24 h. Field parameters such as pH, EC, TDS and Temperature were measured in the field due to their unstable nature. The pH and temperature of the water sample was measured with a digital HANNA pH-meter (Model HI 98129). EC and TDS were measured with a portable conductivity, TDS and salinity meter (Model EC400 Ex Stik II). The water samples were analysed chemically using spectrophotometer (Model, 2010, USA), atomic absorption spectrophotometer (AAS) (PYE UNICAM SP-9) and titrimetric method according to APHA (1998).

Statistical test was carried out for testing the difference in concentration of ions across the boreholes using analysis of variance (ANOVA), using Tukey method in Minitab™16 statistical software (MINITAB©, USA). Means of ions that do not share a same superscript letter (a to j) within a row are significantly different ($p < 0.05$), based on grouping information of Tukey method at 95% simultaneous confidence interval.

RESULTS AND DISCUSSION

The results in Tables 1 and 2 show physical parameters measurement for site 1 (Moduganari) and site 2 (Gwange) areas, respectively. The values indicate that pH in site 1 ranges from 6.61 to 7.57 with an average of 7.76. In site 2, the results show that the pH varies from 6.2 to 7.31 with an average of 6.81. This distribution of pH suggests that the groundwater in site 1 is alkaline while that of site 2 is acidic-alkaline in nature. Both mean

Table 3. Chemical parameters mean values with standard deviation for boreholes in site 1.

Parameter	BHM1	BHM2	BHM3	BHM4	BHM5	BHM6	BHM7	BHM8	BHM9	BHM10
Na	19.6^{c}±0.61	21.3^{b}±0.87	18.3^{de}±0.15	21.5^{b}±0.11	16.2^{f}±0.15	18.6^{cd}±0.01	25.2^{a}±0.20	17.3^{e}±0.30	10.5^{g}±0.10	19.22^{cd}±0.01
K	14.3^{d}±0.15	13±^{e}0.55	17.2^{a}±0.58	15^{c}±0.06	12.5^{e}±0.10	7.22^{h}±0.00	16.5^{b}±0.06	15.3^{c}±0.10	8.66^{g}±0.01	11.3^{f}±0.00
Ca	21.8^{d}±0.06	19.6^{f}±0.15	20.5^{e}±0.06	22^{c}±0.02	18^{h}±0.10	24.8^{b}±0.20	19^{g}±0.06	28.5^{a}±0.06	22.3^{c}±0.05	20.6^{e}±0.00
Mg	11.2^{de}±0.06	12.4^{c}±0.05	9.6^{g}±0.15	11.5^{d}±0.05	10^{f}±0.05	6.6^{h}±0.0.06	12.8^{b}±0.06	9.7^{g}±0.10	14.6^{a}±0.25	11^{e}±0.06
Cl	16^{a}±0.05	4^{d}±0.10	12^{b}±1.00	10^{c}±0.05	9.1^{c}±0.05	3.2^{de}±0.05	2^{e}±0.06	10^{c}±0.20	3^{de}±1.00	2.2^{e}±0.06
SO_4	0.3^{f}±0.05	0.07^{h}±0.00	1.58^{c}±0.03	0.17^{gh}±0.05	3.1^{b}±0.06	0.5^{e}±0.10	0.24^{fg}±0.06	5.47^{a}±0.04	0.32^{fg}±0.10	1.25^{d}±0.00
PO_4	0.12^{h}±0.00	0.23^{g}±0.00	0.46^{e}±0.02	0.67^{c}±0.05	0.78^{b}±0.06	0.89^{a}±0.00	0.34^{f}±0.06	0.45^{e}±0.01	0.54^{d}±0.00	0.77^{b}±0.01
NO_3	12.6^{de}±0.10	10.8^{f}±0.70	17.7^{c}±0.35	23.5^{b}±0.05	10.5^{f}±0.06	13^{d}±0.06	25.2^{a}±0.35	11.3^{ef}±0.30	17.2^{c}±0.20	18^{c}±1.00
CO_3	180^{a}±1.00	132^{c}±2.00	132^{c}±1.00	181^{a}±0.05	156^{b}±1.00	132^{c}±0.06	157^{b}±0.60	84^{e}±2.00	73.2^{f}±1.00	97.63^{d}±0.06
HCO_3	183^{b}±0.04	164.7^{h}±0.60	250.2^{c}±0.85	195.3^{f}±0.35	244.1^{d}±0.10	219.7^{e}±0.75	268.5^{b}±0.25	299^{a}±4.00	168^{h}±3.00	264^{b}±1.00

Results are mean of triplicates±SD. Results on the same row followed by different superscript letter (a-h) indicate significant difference ($p \leq 0.05$) by ANOVA using Tukey grouping test.

pH values are within the WHO tolerable limit. The alkalinity and acidity of the pH values in both sites may be due to the presence of dissolved carbon dioxide and organic acids (fulvic and humic acids) in the groundwater, which are derived from the decay and subsequent leaching of plant materials (Langmuir, 1997). Waters with pH values above 10 are exceptional and may reflect contamination by strong base such as NaOH and $(CaOH)_2$. The ranges for desirable limit of pH of water prescribed for drinking purpose by World Health Organisation (WHO) (1984) are 6.5 to 8.5 while that of EEC (Lloyd and Heathcote, 1985) is 6.5 to 9.0. A low pH can cause corrosion of water carrying metal pipes, thereby releasing toxic metals such as zinc, lead, cadmium, copper etc. (Trivedy and Goyal, 1986). EC and TDS values as shown in Table 1 for site 1 ranged from 123 to 200 µS/cm, and 85 to 175 mg/L. Their mean values are 169.8 µS/cm and 146.8 mg/l, respectively. Also in site 2, the EC values range from 97 to 213 µS/cm, with a mean value of 168 µS/cm; the TDS vary from 103 to 181 mg/L with a mean value of 138 mg/L.

The mean EC and TDS values for both sites are well within WHO acceptable limit. The relatively low value for EC and TDS in both sites signifies lower residence time of ground water within the Chad formation. Also, the occurrence of low EC values indicates low degree of mineralisation and input from the agricultural activities up stream of both sites, consequently, the water quality is good, and thus, it is safe for drinking and domestic purposes. Furthermore, the low TDS values found for both sites can be attributed to the continuous recharge of the groundwater from rainfall, which causes significant dilution. Such situations are usually found in shallow unconfined aquifers (Kumar, 2010). Consequently, the low TDS values also suggest that inputs of salts from the anthropogenic sources of pollution in both sites are minimal. Respective minimum and maximum temperatures obtained for site 1 vary from 32.3 to 35.4°C, with a mean value of 33.6°C. The temperatures recorded for site 2 vary from 26 to 32°C, with an average of 28.9°C. As shown in Tables 1 and 2, all the water samples collected from the two sites were found to have temperatures higher than the natural background levels of 22 to 29°C for waters in the tropics (Stumn and Morgan, 1981). While cool waters are generally more potable for drinking purposes, waters with temperature above the normal human body temperature are usually preferred in the tropics, though not totally objected. However, high temperature conditions may not be desirable for water samples as it encourages the growth of micro-organisms, which have the potentials of altering the odour, taste and colour of the water.

Metal corrosion problems are also associated with high temperature especially when the pH of the water happens to be skewed to extreme. Temperatures obtained for both sites correspond with previous studies across the Basin (Goni, 1996; Kolo et al., 2009). Tables 3 and 4 show the major ions concentration in mg/L for the

Table 4. Chemical parameters mean values with standard deviation for boreholes in site 2.

Parameter	BHG1	BHG2	BHG3	BHG4	BHG5	BHG6	BHG7	BHG8	BHG9	BHG10
Na	4.2^{g}±0.44	13.5^{e}±0.27	17.6^{c}±0.26	11.3^{f}±2.14	15.4^{d}±0.48	28.11^{a}±1.25	23^{b}±0.96	16.31^{d}±0.61	11.53^{f}±0.50	12.86^{e}±0.46
K	8.03^{ef}±0.11	12.2^{c}±0.42	18.2^{a}±0.15	7.4^{f}±0.49	10.4^{d}±0.40	4.94^{h}±1.09	14.99^{b}±0.28	14.5^{b}±0.39	8.3^{e}±0.35	6.04^{g}±0.05
Ca	10.5^{cd}±0.45	21.03^{b}±1.07	23^{b}±0.42	13.1^{c}±0.10	19.6^{b}±0.39	7.65^{d}±1.39	22.4^{b}±0.59	26^{a}±3.75	21.1^{b}±0.07	10.7^{cd}±0.60
Mg	9.5^{h}±0.55	10.8^{e}±0.02	11.2^{d}±0.03	7.31^{i}±0.42	9.77^{g}±0.05	13^{c}±0.16	10.1^{f}±0.02	10.2^{f}±0.03	13.9^{b}±0.09	15.1^{a}±0.90
Cl	6.4^{g}±1.47	7.5^{f}±0.45	10.12^{d}±0.07	13.7^{b}±0.47	6.2^{g}±0.15	12.9^{c}±0.59	14.8^{a}±0.56	8.9^{e}±0.06	4.95^{h}±0.16	8.6^{g}±1.03
SO_4	0.51^{c}±0.04	0.12^{f}±0.02	2.14^{c}±0.02	1.32^{d}±0.49	4.2^{b}±0.04	2.6^{c}±0.53	0.53^{ef}±0.06	7.3^{a}±0.06	0.91^{de}±0.09	2.14^{c}±0.04
PO_4	0.36^{d}±0.02	0.29^{e}±0.02	0.42^{de}±0.01	0.98^{b}±0.15	0.78^{c}±0.02	2.6^{a}±0.56	0.48^{d}±0.03	0.54^{d}±0.01	0.81^{c}±0.02	0.92^{bc}±0.02
NO_3	12.5^{d}±0.84	12^{d}±0.14	10.9^{e}±0.13	17.9^{c}±0.06	21^{b}±0.11	8.11^{f}±0.76	13.3^{d}±0.24	25.3^{a}±0.89	12.2^{d}±0.30	12.9^{d}±0.02
CO_3	91^{f}±2.00	142^{d}±1.52	137^{d}±1.52	72.7^{f}±1.52	140^{d}±1.00	158^{c}±1.00	178^{a}±2.51	163^{b}±3.05	94.3^{e}±1.52	75.1^{f}±1.50
HCO_3	119^{j}±0.53	160^{g}±0.80	230^{c}±0.58	176^{i}±1.73	191^{d}±2.08	242^{b}±0.70	219^{e}±0.49	293^{a}±2.51	172^{f}±1.00	217^{h}±1.00

Results are mean of triplicates±SD. Results on the same row followed by different superscript letter (a-h) indicate significant difference ($p \leq 0.05$) by ANOVA using Tukey grouping test.

boreholes in sites 1 and 2 respectively in Maiduguri metropolis. The major cations show that the Alkaline and Alkali metals are dominant in all the groundwater samples of both sites; in site 1, Na^{+} recorded highest and lowest mean values (25.2 and 10.5 mg/L) in BHM7 and BHM9 respectively; in site 2, Na^{++} recorded highest mean value (28.11 mg/L) in BHG6 and lowest (4.2 mg/L) in BHG1. This uneven distribution indicates that concentration of sodium in all the samples of both sites are significantly different ($p<0.05$) across the boreholes. Highest and lowest concentration of 28.5 and 18 mg/L was obtained in BHM8 and BHM5 for Ca^{++} in site 1. Similarly, in site 2, highest and lowest mean concentrations of calcium (26 and 7.65 mg/L) were recorded in BHG8 and BHG6 respectively, the results of both sites indicates that their concentration are significantly different ($p<0.05$) in each case. Also, in site 1, highest and lowest mean concentrations of 17.2 and 7.22 mg/L were separately recorded for K^{+} in BHM3 and BHM6. In site 2, the highest mean value of 18.2 mg/l was obtained for K^{+} in BHG3, while the lowest concentration of 4.94 mg/L was recorded in BHG6. Thus, the trend of concentration in both sites showed significance difference.

Additionally, the concentration of magnesium also varied across the boreholes in both sites. In site 1, the highest concentration is 14.6 mg/l in BHM9, while the lowest is to 6.6 mg/l in BHM6. Furthermore, in site 2, magnesium recorded highest mean concentration of 15.1 mg/L in BHG10 and lowest concentration of 7.31 mg/L in BHG4 as shown in Table 4. This result suggests that natural processes occurring within the geological formations; such as ion-exchange processes, silicate weathering and calcium carbonate dissolution are responsible for the concentration of most of the cations in the groundwater of the study area (Lakshmanan et al., 2003). Calcium, sodium, potassium and magnesium are among the general elements essential for human health and metabolism and should be available in normal drinking water. However, if one or more of these elements occur in the water above certain limits, the water may become intolerable to consumers and even become hazardous to their health. These cations are present in tolerable amounts in the groundwater of both sites; and they derive their source from the natural sources of contamination across the basin.

The potential factors governing the concentration of the cations can be attributed to the continuous chemical weathering of plagioclase and orthoclase feldspars, and Hornblende found in abundance in the Mandara Mountains (North-eastern basement complex) which lies about 100 miles East of Maiduguri, where they are weathered, transported and subsequently deposited as aquifer materials. Also, the Chad Basin contains bulk sedimentary rock series as; Continental Intecalaire arenaceous, marine limestones, continental sandstones derived from pre-existing country rocks, and lacustrine or

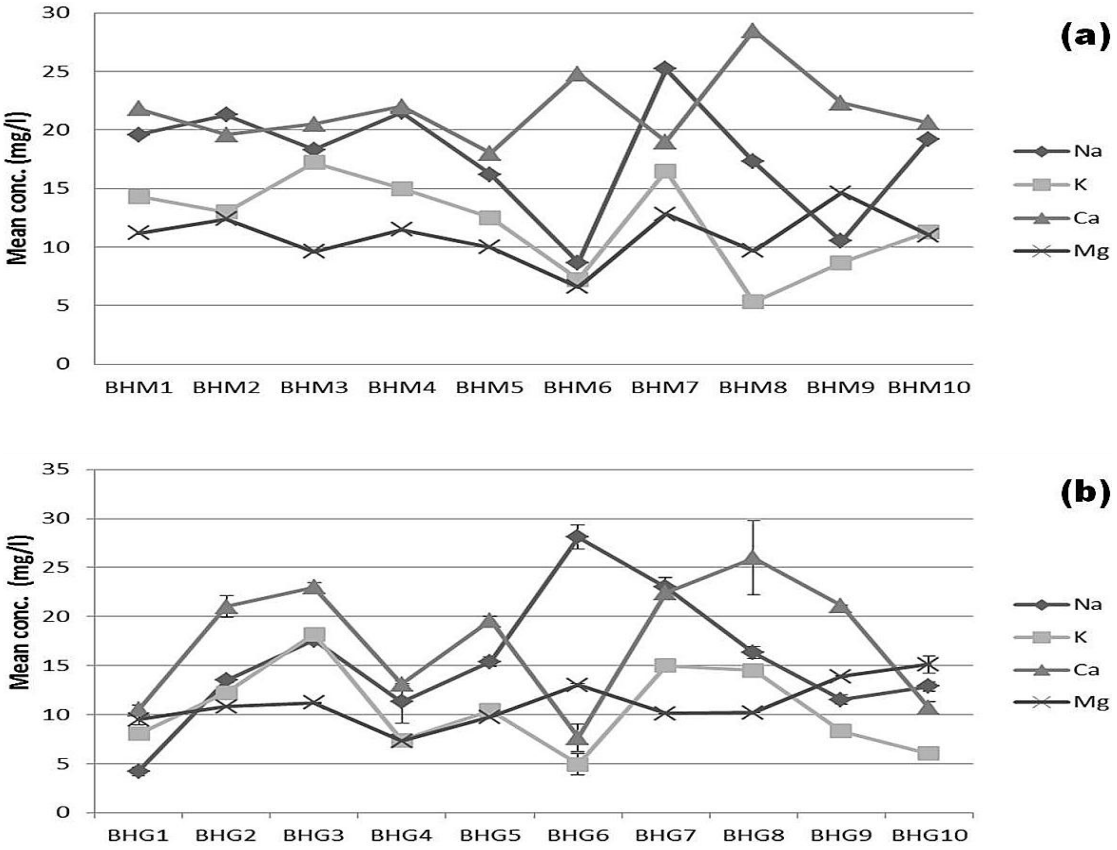

Figure 4. Concentration of major cations in boreholes of site 1 (a) and site 2(b).

deltaic sandstones as well as mineral assemblages derived from sedimentary, igneous and metamorphic rocks. Thus, the concentration of the entire four ions aforementioned can be said to be derived from these sources and they are constantly involved in cation exchange processes and interaction with the aquifer material (Mercado, 1985). Concentration of each of the cations in the two sites as shown in Figure 4a and b, falls far below the tolerable limit as set aside by the World Health Organisation (1993). Thus, this signifies that they, poses neither physiological nor aesthetic problem to their usage, thus the groundwater quality is good for drinking and other domestic use. The dominance of the cations in site 1, except for 2 boreholes where sodium is dominating is in the order of Ca>Na>Mg>K, while for the anions is HCO_3>CO_3>NO_3>Cl>SO_4. Thus, 80% of the water type is calcium-bicarbonate (Ca-HCO_3) while the remaining 20% is sodium-bicarbonate (Na-HCO_3); also in site 2, 70% of the water samples are calcium-bicarbonate (Ca-HCO_3) type and the remaining 30% is of sodium-bicarbonate (Na-HCO_3) type.

Among the anions, preference is given to nitrate, chloride, sulphate and phosphate because their concentration in the groundwater will signifies the influence of above ground anthropogenic activities. The result in Tables 3 and 4 shows the concentration of nitrate across the boreholes of sites 1 and 2. In site 1, nitrate is having varied concentration which ranged from 25.2 mg/l in BHM7 to 10.5 mg/l in BHM5. Similarly in site 2, nitrate recorded highest and lowest concentrations of 25.3 and 8.11 mg/L in BHG8 and BHG6 respectively. In both sites, the concentration of nitrate varied across the boreholes ($p<0.05$). The source of nitrate in the study area can be linked to the widespread anthropogenic point-source pollution sources such as the widespread open dumpsites, pit latrines, and the uncontrolled domestic wastewaters emanating from the cluster of informal residents in both Moduganari and Gwange areas, as well as agricultural inputs from upstream manure application in farm lands. Nolan et al. (2002), Squillace et al. (2002) and Singleton et al. (2005) estimate that nitrate concentration in the range of 13 to 18 mg/l are considered to indicate anthropogenic input. Hence, the average concentrations as reported in this study (15.9 mg/L and14.64) for sites 1 and 2 respectively fall within this bracket as shown in Table 5, but fall below the limit set aside by WHO (1993).

In site 1, the variation in concentration of nitrate as shown

Table 5. Summary of parameters used in assessing impact of anthropogenic activities on groundwater.

Field measurement	Nitrate	Chloride	Sulphate	Phosphate	pH	EC
Total no. of samples	20	20	20	20	20	20
WHO guideline (mg/L)	50	250	250	5	6.5-9.2	500
Maximum Conc. Site1	25.2	11.6	5.47	0.89	7.57	200
Maximum Conc. Site2	25.3	14.8	7.3	2.6	7.3	213
Minimum Conc. Site 1	10.5	2	0.07	0.12	6.61	123
Minimum Conc. Site 2	8.11	4.95	0.12	0.29	6.1	97
Average Site 1	15.98	7.15	1.3	0.53	7.15	169.8
Average Site 2	14.64	9.41	2.18	1.63	6.6	155.8

Values of all parameters are in mg/l except for pH, EC is measured in µS/cm. A total of 10 samples each where obtained for sites 1 and 2.

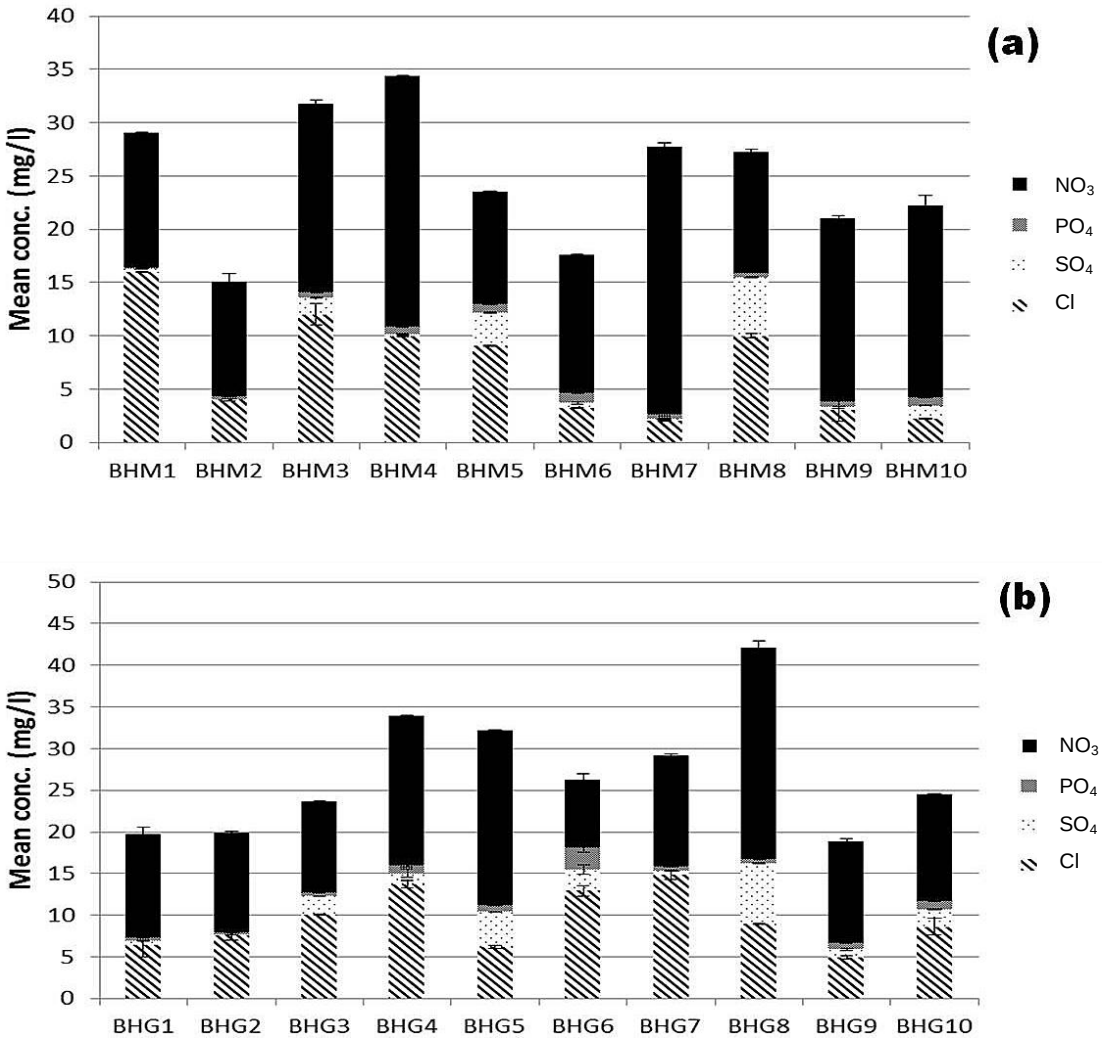

Figure 5. Concentrations of major cations in boreholes of site 1 (a) and site 2(b).

in Figure 5a, is due to the location of the largest dumpsite in the south-eastern part of the area, while the borehole (BHM5) furthest away from the dumpsite is having minimal concentration, thus, this showed significant

difference in their concentration. Hence, the dumpsites have potentials to impact groundwater negatively. This is also true for site 2, where elevated NO_3 concentration as shown in Figure 5b was highest in the borehole (BHG8) located in the western part of the area, and the lowest concentration was found in the northern part which receives less impact. These differences can be related to the dissimilarity of anthropogenic activities in the two locations; the former location receives high nitrate because it very close to the river Ngadda Bank where huge amount of solid wastes are disposed, also it receives high organic load from the closely packed adjacent residential areas that highly utilise pit latrines. Elevated concentration (> 50 mg/L) of nitrate in waters is an indication that the waters are at the risk of pollution (Atabey, 2005). The levels of nitrate in waters are of particular importance for use in drinking water. Studies have shown that high nitrate in water can lead to blue baby syndrome or infantile methemoglobinaemia (WHO, 1984; Price, 1996), cancer (WHO, 1984; Uslu and Turkman, 1987), urinary tract diseases (Wasik et al., 2001; Polat et al., 2007). Furthermore, Bowman (1994) suggests that increased concentration of nitrate often cause blood disorders. Also, Adelana et al (2003) have suggested that chronic exposure to high levels of nitrate in drinking water may have adverse effects on the cardiovascular system.

Likewise, in site 1, chloride recorded highest concentration of 16 mg/L in BHM1 and lowest of 2 mg/L in BHM7. In site 2, highest and lowest concentrations for Cl were recorded in BHG9 and BHG4 as shown in Table 4 thereby making the concentration of the samples to be significantly different ($p<0.05$) across the two sites. Chloride ions might be introduced to ground water from the widespread domestic sewage and waste water flowing uncontrollably in gutters of the informal settlements of sites 1 and 2 or as atmospheric inputs from rainfall recharge. The latter assumption was validated by a previous study carried out by Edmunds et al. (1999), where they measured chloride concentration of 2.1 mg/l in the present day rainfall of the area. Also, Edmunds and Street-Perrott (1996) and Gaye and Edmunds (1996) have analysed the rainfall chemistry in this region and estimated concentration of chloride as 1.28 and 0.61 mg/l for dry and wet seasons, respectively. Hence, taking these analyses into consideration, it is the opinion of this author that significant amounts of chloride were derived from residential sewage, agricultural activities in the adjacent farm lands and atmospheric input in the study area. The moderate level of chloride in all the samples of sites 1 and 2 suggests that anthropogenic input from sewage is moderate, and also due to the furthest distance of this inland aquifer from the coastal zone where chloride concentration is very high. Mean concentration of chloride for both sites fall below the WHO permissible limit of 250 mg/L.

Water with chloride in excess of drinking water standard can be used for irrigation and some types of livestock can drink water that has chloride concentrations as high as 4,000 mg/L. Also, in site 1 of the study area, sulphate has highest and lowest concentration of 5.47 and 0.07 mg/L in BHM8 and BHM2 respectively, while phosphorous recorded highest concentration of 0.89 mg/l in BHM6 of the same site and lowest concentration of 0.12 mg/L in BHM1. Similarly in site 2, sulphate has highest mean concentration of 7.3 mg/L in BHG8, and BHG2 has the lowest sulphate concentration of 0.12 mg/L; also in the same site, phosphorus has highest concentration of 2.6 mg/L and lowest of 0.29 mg/L in BHG6 and BHG2, respectively. Thus, the concentration of both sulphate and phosphorous varied and hence concentrations are significantly different ($p<0.05$). Sulphate occurs naturally in geological materials, in igneous rocks, sulphur occurs mostly as metallic sulphides, and is fairly distributed in the various rock types. In arid sedimentary basins, the highest abundance is in gypsum and anhydrite (Helvoort et al., 2009). The main anthropogenic sources of sulphate in groundwater of the study area can be attributed to application of agrochemicals, the mining of gypsum in the western part of the Basin and contemporary acid rain (Quevauviller et al., 2009). However, in the study area, Goni et al. (2001) have analysed the rainfall geochemistry of the region, and posits that sulphate in the region is derived from atmospheric mixing of aerosols, and from ash of burnt forests.

Consequently, the low levels of sulphate in both sites could be as a result of the removal of sulphate from the water by bacteria (Freeze and Cherry, 1979).

Concentration of sulphate levels is low in both sites as shown in Tables 3 and 4 and they all fall below the World Health Organisation (WHO) (2011) recommended limit. Anthropogenic sources of phosphate in the study area include human sewage, agricultural run-off from crops, sewage from animal feedlots, and the routine use of non-biodegradable detergents. As a result of the monotonous agricultural activities up stream of both sites especially near the Lake Alau Dam and Biu/Damboa Road, phosphates derived from the application of fertiliser in these areas are continuously added to soil and leaches to underlying aquifers gradually. Long-term over-application of manure and chemical fertiliser contributes to phosphorus movement into the groundwater system, resulting in a significant contamination of the groundwater resource (Domagalski and Johnson, 2012). Higher concentration of phosphorus in receiving waters bodies especially surface water, can lead to eutrophication, which in turn, will lead to depletion of oxygen which may have effect on aquatic fauna and flora (Corell, 1998; Wolfe and Patz, 2002).

Lastly, bicarbonate concentrations in both sites vary considerably, in site 1 the concentration vary between 299 and 164 mg/L in BHM8 and BHM2 respectively; in site 2 it varies from 293 mg/L in BHG8 and 119 mg/L in

BHG1. Also, the concentration carbonate in sites 1 and 2 vary significantly as shown in Tables 3 and 4. Hence, all the samples are significantly different ($p<0.05$). The bicarbonate and carbonate ions in the groundwater samples of both sites originate from the solution of $CaCO_3$ in groundwater made by acid dissolving CO_2 gas from the atmosphere and soil. Also, their concentration can be linked to the dissolution and ion exchange processes occurring within the huge limestone deposit sources in the south-western part of the Basin. Bicarbonate reduces the acidity of dietary components such as protein. Many oral hydration solutions contain bicarbonate showing the usefulness of bicarbonate to control water absorption in patients at risk of dehydration (Kessler and Hesse, 2000).

Conclusions

This study has investigated the impact of above ground anthropogenic and natural sources of pollution and their impact on the groundwater system (upper unconfined aquifer) of the Chad Basin in Maiduguri. Results obtained showed that the water in site 1 is alkaline (pH 6.61 to 7.57), while that of site 2 ranged from slightly acidic to alkaline (pH 6.2 to 7.31). Natural sources of contamination and process such as ion-exchange, silicate weathering and calcium carbonate dissolution across the Basin are responsible for the concentration of sodium, calcium, potassium, and magnesium as well as carbonate and bicarbonate concentrations in the groundwater samples analysed. The study have also evaluated and identified above ground anthropogenic activities such as the ever increasing utilisation of pit latrines, incessant domestic and municipal waste disposal, agricultural and industrial activities as the major sources of nitrate, chloride, sulphate and phosphate and they have potential impact on the groundwater quality. However, their impact is not significant currently, but if not controlled it will be a future problem. Also, the water quality results for both sites showed that concentration of major ions significantly fall below the WHO standard limit. Thus, the groundwater quality is very good for drinking and other domestic use. Lastly, 75% of the water samples are calcium-bicarbonate ($Ca\text{-}HCO_3$) type, while the remaining 25% are of sodium-bicarbonate ($Na\text{-}HCO_3$) type.

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