British Journal of Applied Science & Technology
2(2): 146-172, 2012

SCIENCEDOMAIN ***international***
www.sciencedomain.org

Assessment of the Chemical Quality of Potable Water Sources in Abuja, Nigeria

Muhammad M. Alhassan[1] and Fanan Ujoh[1*]

[1]Department of Geography & Environmental Management, University of Abuja, Nigeria.

Authors' contributions

Author MMA collected water samples for laboratory analysis and also designed the study, in addition to providing overall direction for the work. Author FU managed the literature review, performed the statistical analysis, and wrote the first draft of the manuscript. All Authors read and approved the final manuscript before submission.

Research Article

Received 20th January 2012
Accepted 13th May 2012
Online Ready 29th May 2012

ABSTRACT

Aims: To determine the level of some chemical parameters in samples of 5 potable water sources namely, tap, borehole, open well, sachet water, and bottled water. To further compare results with WHO (2011) standards to ascertain safety of water sources within the study area.
Study Design: Collection and analysis of samples from potable water sources.
Place and Duration of Study: 16 settlements within the Abuja Municipal Area Council (AMAC) constitute the study area. Sample collection took place during the dry season months of January – March 2011 to avoid the possibility of contamination of some water sources from runoff.
Methodology: Stratified random sampling technique was adopted for sample collection from 16 settlements; one each from four identified categories of settlement within the study area. For data analysis, mean, standard deviation and minimum and maximum values were computed for every chemical parameter for each sampling location.
Results: The results reveal that pH, NO_3, Cu, Al, TOT-N and Fe are not limiting factors to the quality of drinking water in the study area; the levels of Cd, Bicarbonate, NH_4-N, Mn, Zn, As, Cr and Pb concentration in water samples are above the safety limit set by the WHO (2011); pH, SO_4, NO_3^-, TOT-P and HCO_3^-, Cl in open well samples have slightly higher values than in samples of the other four sources of potable water. Borehole and sachet water samples have slightly higher SO_4 values; bottled and tap water samples have

**Corresponding author: E-mail: fananujoh@yahoo.com;*

the highest values of HCO_3^-, among others. Increasing anthropogenic activities that result in pollution are attributed to these levels of water contamination at the study area.
Conclusion: There is need for Nigeria's National Agency for Food and Drug Administration and Control (NAFDAC) to focus on promoting the safety of potable water, most especially the sachet and bottle water sources; periodic, unannounced inspections should be conducted on facilities producing sachet and bottled water to ensure that standards are highly maintained. Lastly, efficient management of water resources in Nigeria's urban and peri-urban centers is increasingly becoming necessary if the health and well-being of the residents is of utmost importance.

Keywords: Chemical water quality; potable water; water sources; AMAC.

1. INTRODUCTION

Water is an essential component of life on earth which contains minerals extremely important in human nutrition (World Bank, 1997) and is very essential for sustaining life. As pointed out by Kofi Annan (Ajibade, 2004), "fresh water is precious: we cannot live without it. It is irreplaceable: there are no substitutes for it. And human activity has profound impact on the quantity and quality of fresh water available." Of the many uses of water, the supply of safe drinking water is considered as having a significant impact on the prevention of transmissible water-borne diseases (Larson and Gnedenko, 1999). For instance, abundance of organic compounds, toxic chemicals, radio nuclides, nitrites and nitrates in potable water may cause adverse effects on human health, such as cancer, chronic illness and human body malfunction (Federal Government of Nigeria, 2000). The dramatic increase in population has resulted in an enormous consumption of the world's water reserves (Jain et al., 2006).

Unfortunately, about 2 billion people globally live in areas where there is chronic shortage of water (Ajibade, 2004). Similar studies carried out in different parts of Nigeria (Yerima et al., 2008; Waziri and Ogugbuaja, 2010; Akan et al., 2010; Muazu et al., 2012) and other parts of Africa (Demeke, 2009; Meseret, 2012) reveal that various sources of drinking water have been contaminated at varying scales. Lack of safe drinking water is considered a leading cause of many communicable diseases. Studies have estimated that the provision of clean water and basic sanitation alone would curtail the incidence of diarrhoea by 50%, sleeping sickness by 80% and guinea worm infestation by 100% (Anwar, 1993). Consequently, access to safe water is recognized to be the foundation for sound health (Kuma and Younger, 2000; Rakesh, 2006). Therefore, it is essential to constantly monitor water quality used for drinking purposes.

Water quality assessment is a very complex subject, in part because water is a complex medium intrinsically tied to the ecology of the planet (Kolo et al., 2009). To determine water quality therefore, several parameters must be examined. The complexity of water quality assessment as a subject is reflected in the many types of measurements of water quality. Among the key parameters listed by WHO (2011) for the determination of water quality are Conductivity, dissolved oxygen (DO), pH, color of water, taste and odour, turbidity, total suspended solids (TSS), chemical oxygen demand (COD), biochemical oxygen demand (BOD), micro-organisms such as faecal coliform bacteria (*Escherichia coli*), cryptosporidium and *Giardia lamblia*; nutrients (fertilizers), dissolved metals and metalloids (lead, mercury, arsenic, etc.) and dissolved organics.

The second most important criteria used in selecting Abuja as the capital of Nigeria is the availability of water sources, which had a high rating of 10%, the second highest after geographic centrality, health and climate (Balogun, 2001). Over the last twenty years, the FCC (and its neighboring satellite towns), have witnessed dramatic increase in human population which has exerted so much pressure on surface and ground sources of potable water. It is thus, unexpected that quality of potable water in the area will remain unchanged. Due to poor access to safe water, there is now increasing exploitation of groundwater, by both public and private institutions through sinking of boreholes and open wells. In addition, sachet and bottled water production is now a common enterprise in the territory. Given the potential effects of human activities on quality of these various potable water sources, there is a valid reason to investigate water quality in the area. However, to properly understand the quality of potable water in the area, studies are required that comprehensively look at the amounts of chemical constituents of different potable water sources. Also, integration of empirical studies from researchers, with policy and institutional support roles from government, would indeed provide a plausible and viable synergy necessary for tackling the complex potable water quality issues in Nigeria's urban and peri-urban areas. These collectively constitute the problem of research interest to this study.

2. MATERIALS AND METHODS

2.1 Study Area

AMAC is the largest and most developed of the six area councils of Abuja. The bulk of the built-up area of AMAC is made up of the Federal Capital City (FCC). AMAC is located between latitude 7º49´ and 8º49´ north of the equator and longitude 7º07´ and 7º33´ east of the Greenwich Meridian (Fig. 1). With a land mass of about 2,500sq km (Balogun, 2001), the area records a total annual rainfall of approximately 1,650mm. The temperature is highest, with greatest diurnal ranges, during the dry season months when the maximum temperature ranges between 30ºC and 35ºC. During the rainy seasons on the other hand, the maximum temperature ranges between 25ºC and 30ºC (Adakayi, 2000). There is a marked difference between the highest and lowest elevation within AMAC. The highest elevation is 213.3m to the North (which is largely urbanized) and 142.2m to the South (which is largely rural) of the FCT. Within AMAC is located the famous Aso Rock, Katempe Hill and Asokoro rock outcrops. The 2006 National Population and Housing Census puts the population of AMAC at 778,567, the highest within the FCT.

Generally, the geology of the FCT is underlain to the north by basement complex rocks and to the south by metamorphic rocks, all of pre-cambrian age. Specifically, Kogbe (1978) classified the rocks of the study area into (i) metamorphosed supra-crustal (exogenetic) rocks (e.g., mica schist, marble, amphibolite and amphibole schist, fine to medium grained gnesis; (ii) migmatitic complex (e.g., migmatite, migmatitic gneiss, granite gneiss, porphyroblastic granite gneiss, leucocratic granite gneiss, intrusive granite, coarse grained granite; (iii) minor intrusions (e.g., rhyolites, quartz feldspar porphyry, dacatitea and andesites, dolerites and Basalts; (iv) other formations (e.g., quartzite, pegmatite, quartz vein). The rock formations found within the study area do not present the possibility of any significant contamination by iron ore (or other chemical parameters) from underlying rocks.

2.2 Reconnaissance Survey and Site Selection

Reconnaissance surveys were initially conducted across the major settlements in AMAC on which basis settlements were grouped into four: urban; peri-urban; satellite towns and rural (see Fig. 2 and Table 1). The classification is based on availability of facilities and infrastructure at the sampled settlements. For the urban, peri-urban and satellite settlements, residents rely more on bottled, tap, borehole and sachet water sources while at the rural settlements, residents rely more on sachet, borehole and open-well water sources.

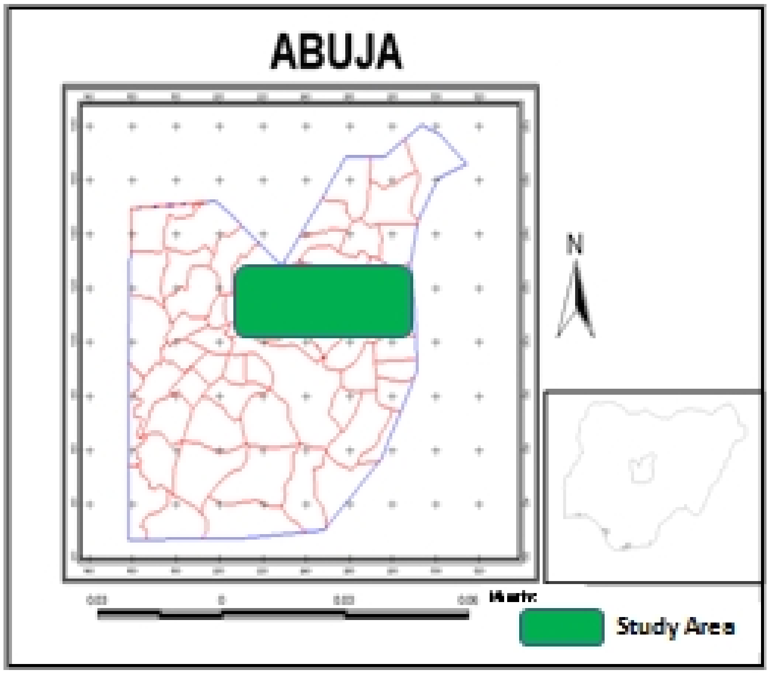

Fig. 1. Map of AMAC, the Study Area

The stratified random sampling technique was adopted for the selection of sample collection sites for this study. The choice of four settlements per category, though arbitrarily, was informed due largely to funding purpose. Four settlements per category were randomly selected from each of the four categories of settlements identified and samples of various potable water sources were collected. Thus, a total of 16 settlements were selected for this study (see Table. 1).

Table 1. Sample Sites of water sources in Study Area

S/No	Urban Locations	Peri-Urban Locations	Satellite Towns	Rural Areas
1	Asokoro	Gwarinpa	Galadimawa	Gosa
2	Garki	Jabi	Lugbe	Karshi
3	Maitama	Life Camp	Gwagwa	Shamati
4	Wuse	Karu	Karmo	Iddo
Total	4	4	4	4

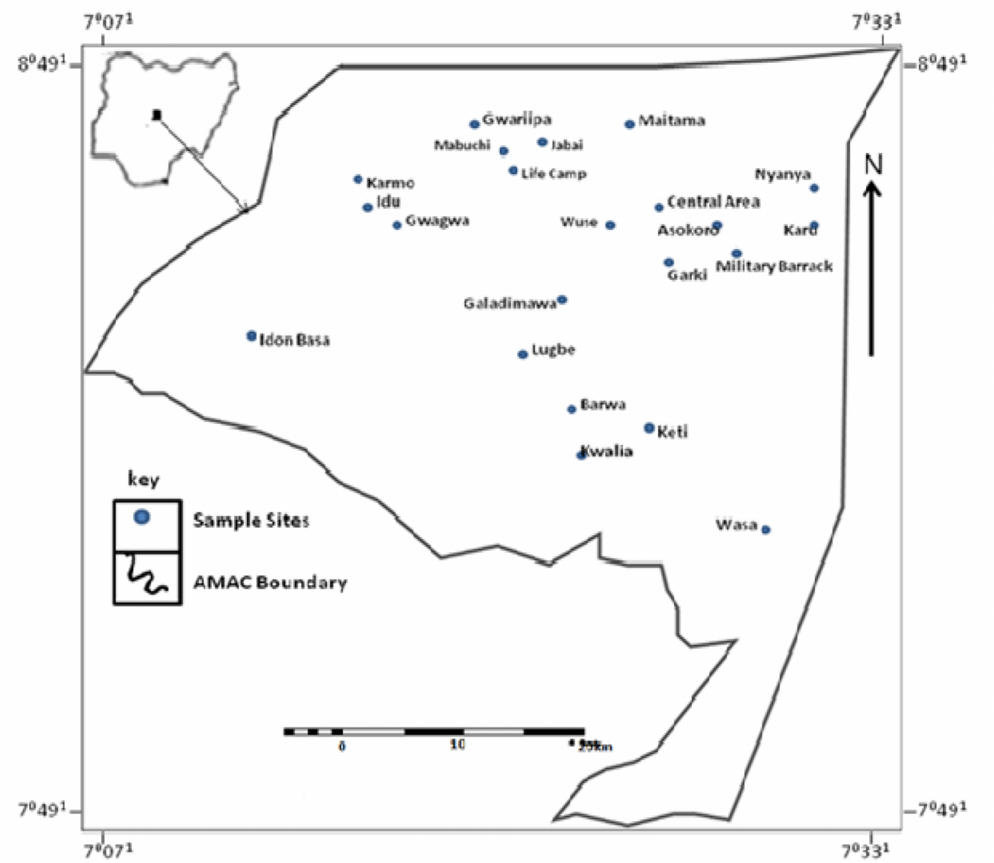

Fig. 2. Location map of the study sites

At each settlement, samples were collected from all 5 sources of potable water, amounting to a total of 20 samples from each settlement category. An overall composite water sample total of 80 were thus, collected from all four settlement categories for the study.

2.2.1 Water samples analyses

At the laboratory, each water sample was filtered using membrane papers to remove all solids. The pH of the filtrate was then set to 2±0.2 with 1M nitric acid and stored at 4^{0}C until time of analysis. To prevent contamination, all glassware and plastic containers used for the analyses were treated with nitric acid and rinsed with distilled water. Quality assurance and control was performed according to the specified method of Soylak et al., (2002).

Heavy metals' analyses were carried out using atomic absorption spectroscopy (AAS) with electrothermic atomization in graphite furnace for the determination of the total content of Al, Cr, Mn, Fe, Co, Ni, Cu, Zn, As, Cd and Pb. The instrument used was Aanalyst100 (Perkin-Elmer) spectrophotometer (continuum background correction) located at the Analytical Laboratory of the National Metallurgical Development Agency, Jos Nigeria. The machine was equipped with a HGA-800 furnace and an AS-72 autosampler. All lamps used were hollow cathode multi-element lamps, except for As, Cd and Pb.

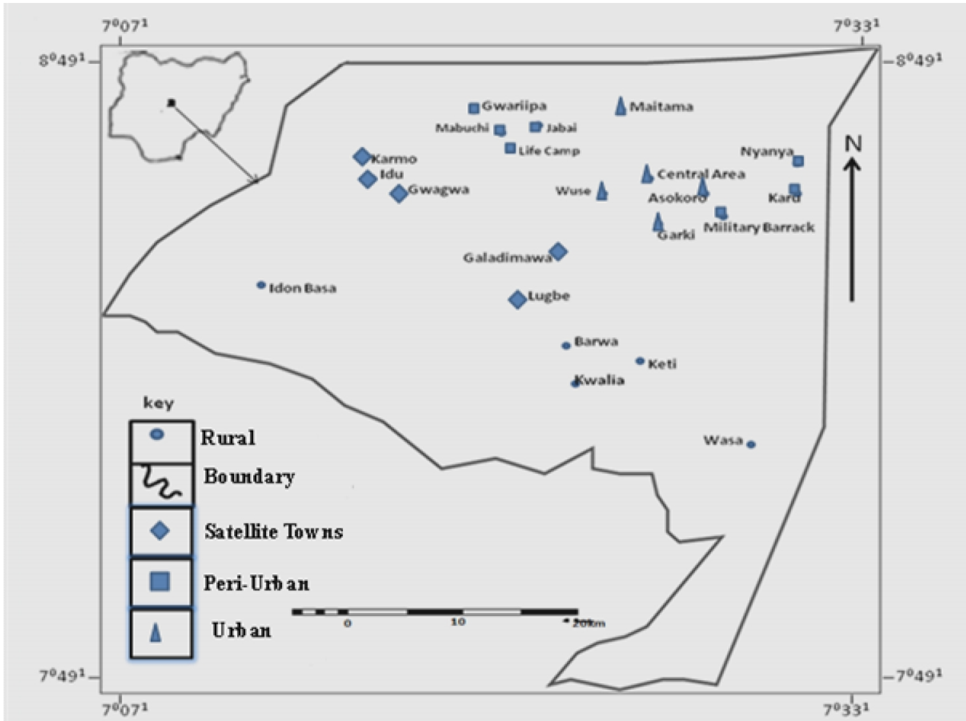

Fig. 3. Distribution of sample sites by settlement category

For other chemical parameters such as Chemical Oxygen Demand (COD), sulfate, carbonates, silicates and heavy metals, analyses were done according to standard analytical methods described by APHA (1995). To measure COD, the samples were oxidized using $K_2Cr_2O_7$ at 150ºC for two hours. After reaching room temperature the samples were analysed at 420nm using a spectrophotometer HACH DR2000. Ion Chromatography was used to test for Cl and SiO_2 (Soylak et al., 2002) and spectrophotocolorimetry for NH_4^+ (Sharma, 2003).

Concentrations of total nitrogen and total phosphorous were measured by digestion and filtration methods respectively, through membrane filter papers. The digestion was made with potassium peroxosulfate. After the digestion and filtration through a<0.45-Am membrane filter, the totals were determined by continuous flow analyzer as suggested by WHO (2011). Ammoniacal-N determination was performed by the phenate method described by Sharma (2003).

The analysis of sulfate anions was based on standard methods (APHA-AWWA-WEF, 1998). To do that, thirty drops of NaOH (1:1 mym) were added to 50 ml of sample. The solution was shaken for 2 min in order to precipitate Mg (OH). Hydroxy- 2 naphthol blue was added under stirring until a pink-violet color was obtained. The suspension was rapidly titrated by adding EDTA (0.0100 M) to the end point, characterized by a sky-blue color. The suspension was let aside for 1 min in order to check the stability of the color.

2.2.2 Statistical analysis

Descriptive statistics were computed for every chemical parameter for each sampling location. The parameters computed include mean, Standard deviation and minimum and maximum values. Mean values of the parameters obtained for the various locations were compared with the various permissible limits of the parameters set by WHO (2011) (Table 3) in order to identify areas of problems in quality of drinking water.

3. RESULTS AND DISCUSSION

3.1 Variation in Levels of the Parameters between the Drinking Water Sources[1]

Figs. 4 to 7 compare the levels of the various parameters in the five drinking water samples collected from the four sampling locations in the study area. A close look at Fig. 4 reveals that the pH values of the five water samples are relatively similar. For Cl, open well samples have slightly higher values than the other drinking water types, but borehole water samples have the least. Borehole and sachet water samples have the higher SO_4 values while those of bottled and tap water samples are almost the same, falling somewhat below the values recorded for open well water samples. There is no major difference in the NO_3 values of the five drinking water samples. For HCO_3^-, bottled and tap water samples have the highest values and borehole and sachet samples have the least while open well samples lie in between. SiO_2 values on the other hand are not seriously different in the five drinking water samples while TOT-P exhibits almost the same pattern of distribution in the five drinking water sources as the HCO_3. The NH_4-N values of borehole open well and sachet water types are nearly the same, and those of bottled and tap water types on the other hand are also the same. Values of parameters in this category generally indicate that no one drinking water source is consistently associated with high or low levels of the considered parameters, which implies that none can be considered as the best or worst in quality rating.

The distribution patterns of TOT-N and COD in the five drinking water samples (Fig. 5) indicate that the tap water maintains the highest level of the two parameters and borehole the least. The values of the two parameters are nearly similar in open well, sachet, borehole and bottled drinking water types. The similarity in pattern of the two parameters in the four drinking water sources are considered here as coincidental and the reason for that remains unclear.

The pattern of distribution of Mn, Fe and Al in the five drinking water samples (Fig. 6) reveals that Mn has the highest mean value in the sachet water sample, followed by tap, then bottled, then borehole and least in the open well water samples. For Fe, highest values were also recorded in the sachet water samples, then the tap water, then bottled, then borehole and least in the open well samples. In the case of Al, highest values were found also in the sachet water samples, then tap, then bottled, then open well and least in the borehole samples. These thus indicate in general that the sachet water samples contain the highest levels of the three metals while borehole water contains the least.

[1]Tables containing the mean, standard deviation and minimum and maximum values of all Laboratory data are attached in Appendix I.

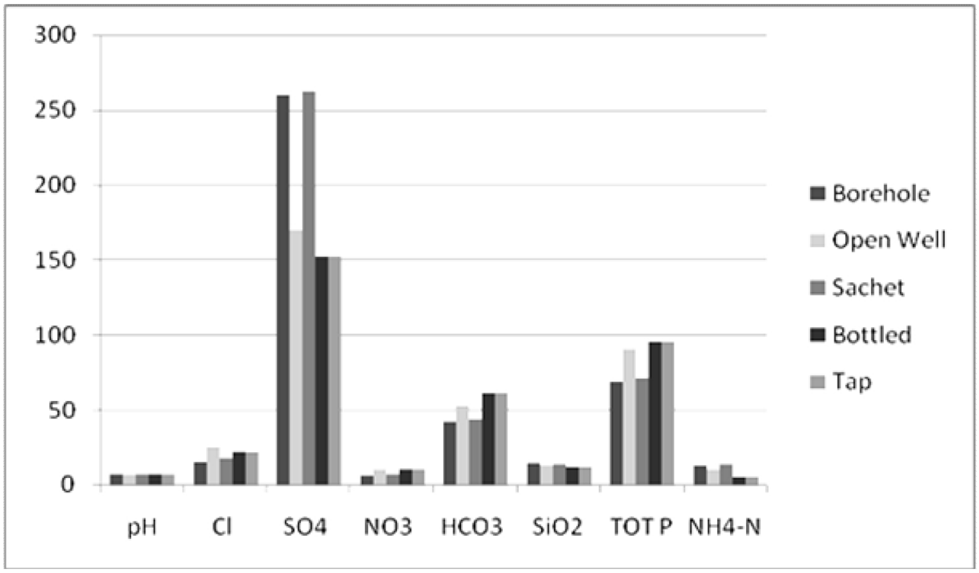

Fig. 4. Comparison of levels (mg/l, except for pH) of pH, Cl, SO_4, NO_3, HCO_3^-, SiO_2, TOT-P and NH_4-N in different drinking water sources in AMAC

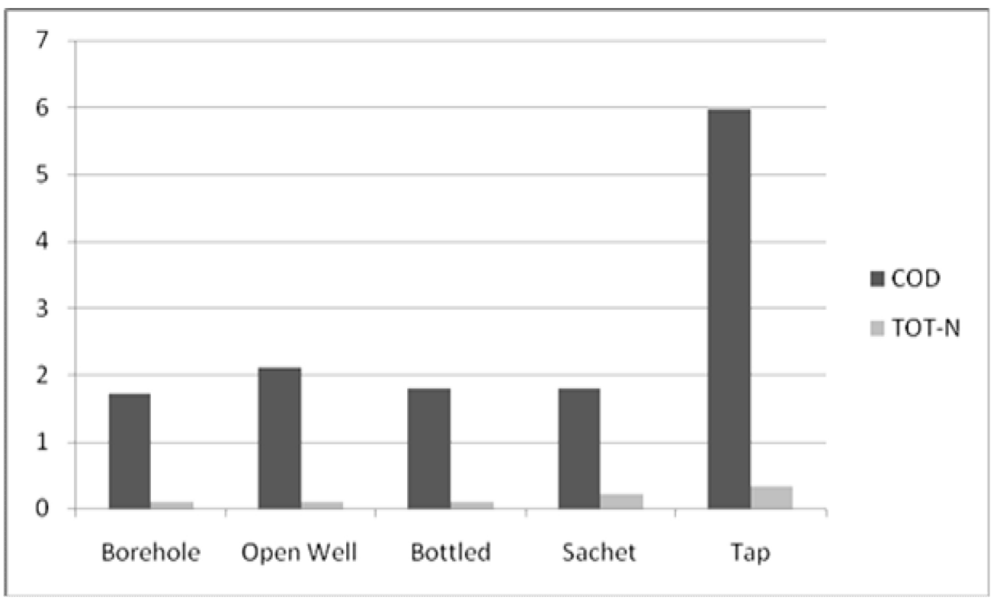

Fig. 5. Comparison of COD and TOT-N levels (mg/l) of the five drinking water sources in the study area

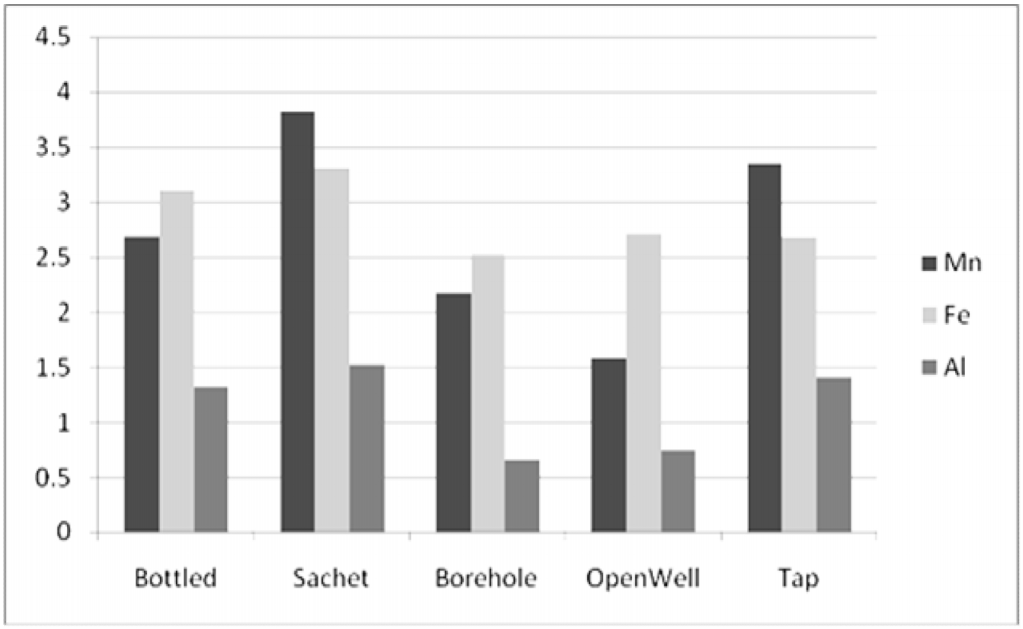

Fig. 6. Comparison of mean levels (mg/l) of Mn, Fe and Al in each of the five drinking water sources

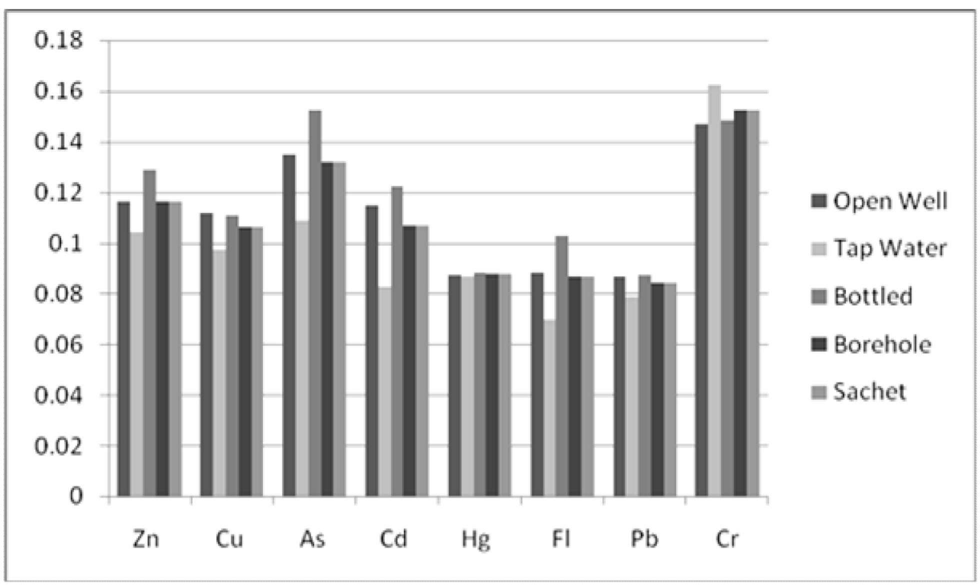

Fig. 7. Comparison of mean levels (mg/l) of Zn, Cu, As, Cd, Hg, F, Pb and Cr in each of the five drinking water sources

Table 3. WHO guidelines for drinking water quality

Parameters	WHO Recommended Values (mg/l)	Sample Values for Urban (mg/l)	Sample Values for Peri-Urban (mg/l)	Sample Values for Satellite (mg/l)	Sample Values for Rural (mg/l)	Remarks
Ammoniacal Nitrogen	<1.5	2.2 – 21.2	2.0 – 21.2	1.6 – 19.8	1.6 – 16.2	APL
pH	6.5-8.5	5.8 - 7.5	5.8 - 7.5	5.8 - 7.5	5.8 - 7.5	BPL
Electrical Conductivity	400	21.25 – 35	20.55 - 35	4.25 – 22.45	4.25 – 19.85	BPL
Sulfate	250 (>400 not permissible	Mostly above 500	Mostly above 500	All values below 500	23.9 – 159.8	APL for Urban and Peri-Urban; BPL for Satellite and Rural
Chloride	250	4.25 – 35	4.25 – 35	4.25 – 35	4.25 – 35	BPL
Nitrate (measured as Nitrogen)	50	1.79 – 25.3	1.79 – 25.3	1.79 – 25.3	1.79 – 25.3	BPL
** Calcium	100	6.23 – 102.4	6.23 – 102.4	6.23 – 102.4	6.23 – 102.4	Varied
** Magnesium	50	6.23 – 102.4	6.23 – 102.4	6.23 – 102.4	6.23 – 102.4	Varied
** Sodium	50	6.23 – 102.4	6.23 – 102.4	6.23 – 102.4	6.23 – 102.4	Varied
** Potassium	12	6.23 – 102.4	6.23 – 102.4	6.23 – 102.4	6.23 – 102.4	Varied
Iron	0.1*	3.0 – 5.6	2.6 – 5.6	1.2 – 5.0	1.2 – 4.8	Varied
Manganese	0.1	1.5 - 6.3	1.2 – 5.6	1.4 – 5.5	0.2 – 5.1	APL
Copper	2.0	0.05 – 0.14	0.05 – 0.14	0.05 – 0.14	0.05 – 0.14	BPL
Zinc	0.01	1.4 – 0.21	1.4 – 0.21	1.2 – 0.2	0.04 – 0.19	APL
Cadmium	0.003	0.1 – 0.17	0.09 – 0.17	0.05 – 0.17	0.05 – 0.10	APL
Lead	0.01	0.07 – 0.13	0.07 – 0.13	0.07 – 0.13	0.05 – 0.11	APL
Arsenic	0.01	0.09 – 0.19	0.09 – 0.19	0.09 – 0.19	0.09 – 0.19	APL
Chromium	0.05	0.07 – 0.17	0.07 – 0.17	0.07 – 0.17	0.07 – 0.17	APL
Aluminium	0.2	0.19 – 1.89	0.02 – 2.02	0.03 – 1.0	0.04 – 1.60	BPL for Urban, Satellite and Rural; APL for most of Peri-Urban
Mercury	0.006	0.082 – 0.093	0.082 – 0.093	0.082 – 0.093	0.082 – 0.093	APL

Source: WHO (2011)

** WHO (2011) does not provide guideline value but ties corrosivity to pH content of water. The 0.1 value adopted is suggested from the literature.*

*** Values for Bicarbonates are uniform for samples in all settlement groups*

APL = above permissible limit; BPL = below permissible limit

For the remaining heavy metals (Fig. 7), for Zn, Cu, Hg, Pb and Cr, there are no major differences in their mean values between the five drinking water samples. For As, bottled water samples have the highest content of the metal which is followed by open well water samples, and then borehole and sachet water samples (which are nearly the same) while the tap water samples have the least value. Cd has almost the same trend as As, only that the values are comparatively lower. These again indicate that within the study area, no drinking water source has exhibited the worst or best quality differentials in terms of the levels of the various heavy metals analyzed as shown from the mean scores of all water samples (Appendix I).

4. CONCLUSION AND RECOMMENDATION

Access to safe drinking-water is essential to health, a basic human right and a component of effective policy for health protection. The importance of water, sanitation and hygiene for health and development has been rightly emphasized in the outcomes of a series of international policy forums especially the Millennium Development Goal Number 7 which is concerned with providing access to safe drinking water to over 1 billion slum dwellers.

Over the last twenty years, Abuja has witnessed dramatic increase in human population and slum expansion which has exerted enormous pressure on quality of surface and ground sources of potable water. It is thus, unexpected that quality of potable water in the area will remain unchanged. Generally, the results vary between and within settlement groups as well as between the 5 water sources analyzed.

The observed values of NH_4-N, Mn, Zn, As, Cd, Pb, and Cr exceed the WHO (2011) permissible limits for drinking water, whereas Cu, pH, Cl, NO_3, and HCO_3^- occur below the permissible limit, implying that drinking water is safe as far these latter group of parameters are concerned. However, only 16% of water samples exceed the permissible limit of SO_4, while 84% of samples are considered safe for human consumption. For TOT-N, it is considered safe from water samples analysis based on the suggestions of Sillanpaa et al. (2004), while Fe is considered unsafe as it records levels above those recommended in the water quality literature. Finally, an exceptional distributional pattern occurs in Al concentration where the urban locations have mean values in the five drinking water samples ranging between 0.19 and 1.89 mg/l. In the peri urban locations, the values range between 0.02 and 2.02 mg/l, with 60% of the values being below 0.5 mg/l. In the satellite towns, the mean values of Al range between 0.03 and 1.0 mg/l, while in the rural areas the values range between 0.04 and 1.6 mg/l, with about 80% of the values being below 0.1 mg/l. Al in drinking water samples analysed across the four sampling locations are in general within the prescribed limit of 0.5 mg/L permitted by WHO (2011). It appears thus, that the highest concentration of Al is in the urban areas as against the least recordings in rural areas.

This study does not lay claim to completely exhausting the water quality discourse within the study area as other key areas of water quality (such as anthropogenic and natural factors responsible for concentration of chemical parameters in water, measures for treating polluted water sources, etc.) were not investigated. However, in line with the findings and as we move towards the terminal years of the MDGs, the study suggests the urgent need for:

- NAFDAC to focus on issues related to potable water from sachet and bottle water sources generally assumed to be safest by consumers;

- Environmental protection agencies that prescribe regulations limiting the amount of certain contaminants in water provided by public and private water systems need to ensure enforcement to prevent violation of prescribed standard;
- The need for Nigeria's Ministries of Health and Environment to verify the permissible limit of guidelines set by international bodies such as the WHO in relation to local peculiarities with a view to creating harmony in order to provide uniform potable water guidelines;
- Since sales of sachet and bottled water remain a very common enterprise in AMAC, there is need to monitor for quality assurance;
- Continual research on issues relating to potable water sources in AMAC in order to identify and address grey areas in water quality delivery;
- Efficient management of water resources in AMAC if the health and well-being of the people is of utmost importance, particularly in the rural areas where safe potable water is not readily available;
- Sanitation and waste management strategies to be put in place for effective disposal of waste to avoid the possibility of ground water contamination; and
- Authorities in Nigeria to provide guideline values for drinking water for some parameters that presently do not have (for example Hg**,** SiO_2, TOT-P and Fe).

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

Adakayi, P.E. (2000). 'Climate'. In: Dawam P.D. (ed) Geography of Abuja: Federal Capital Territory*.* Famous/Asanlu Publishers, Abuja.

Ajibade, L.T. (2004). Assessment of Water Quality along River Asa, Ilorin, Nigeria.The Environmentalist*,* 24, 11–18, Kluwer Academic Publishers, The Netherlands.

Akan, J.C., Abdulrahman, F.I., Yusuf, E. (2010). Physical and chemical parameters in abbatoir wastewater sample, maiduguri metropolis, Nigeria. The Pacific Journal of Science and Technology*,* 11(1), 640 – 648.

Anwar, J. (1993). How safe is drinking water in Bangladesh? Bangladesh Observer, 22 January.

APHA-AWWA-WEF. (1998). Standard Methods for the Examination of Water and Wastewater*,* Washington, DC.

Balogun, O. (2001). The Federal Capital Territory of Nigeria: A Geography of Its Development. University of Ibadan Press Limited.

Demeke, A. (2009). Determinants of household participation in water resource management; Achefer Woreda, Amhara region, Ethiopia. Master's thesis in Integrated Agriculture and Rural Development. Cornell University, Ithaca NY, USA.

Federal Government of Nigeria. (2000). National Water Supply and Sanitation Policy,' 1st edn., Federal Ministry of Water Resources, Department of Water Supply and Quality Control.

Garzon, P., Eisenberg, M.J. (1998). Variations in the mineral content of commercially available bottled waters: Implications for health and disease. American Journal Medicine 105, 125–130.

Jain, P., Sharma, J.D., Sohu, D.P. (2006). Chemical analysis of drinking water of villages of Sanganer Tehsil, Jaipur district. Int. J. Environ. Sci. Tech., 2(4), 373-379.

Kolo, B., Dibal, J.M., Ndakawa, I.I. (2009). Elemental analysis of tap and borehole waters in Maiduguri, semi-arid region, Nigeria. European Journal of Applied Sciences, 1(2), 26-29.

Kumar, J.S., Younger, P.L. (2000). Conceptual ground water model and related environmental concerns in the Tarkwa area, Ghana. Ghana Min. J., 6, 42–52.

Larson, B.A., Gnedenko, E.D. (1999). Avoiding health risks from drinking water in Moscow: an empirical analysis. Environ. Dev. Econ., 4(4), 565–581.

Muazu, J., Muhammad-Biu, A., Mohammed, G.T. (2012). Microbial quality of packaged sachet water marketed in Maiduguri Metropolis, North Eastern Nigeria. British Journal of Pharmacology and Toxicology, 3(1), 33–38.

Meseret, B.A. (2012). Assessment of Drinking Water Quality and Determinants of Household Portable Water Consumption in Simada District, Ethiopia. Master's thesis in Professional Studies, Cornell University, Ithaca NY USA.

Rakesh, K.M. (2006). Analysis of physical and chemical parameters of bottled drinking water. International Journal of Environmental Health Research, 16(2), 89–98.

Sharma, M.K. (2003). Effect of fluoridated water on vital organs of albino rats (*Rattus norvegicus*). Ph.D. Thesis. University of Rajasthan, Jaipur.

Soylak, M., Armagan-Aydin, F., Saracoglu, S., Elci, L., Dogan, M. (2002). Chemical analysis of drinking water samples from Yozgat, Turkey. Polish J. Environ. Study, 11(2), 151-156.

Waziri, M., Ogugbuaja, V.O. (2010). Interrelationships between physico-chemical water pollution indicators: A case study of River Yobe, Nigeria. American Journal of Scientific and Industrial Research, 1(1), 76-80.

World Bank, (1997). Selecting an Option for Private Sector Participation in Water and Sanitation, Toolkits for Private Participation in Water and Sanitation, No. 1, The World Bank Publication, Washington, DC.

World Health Organization (WHO). (2011). Guidelines for drinking water quality, 4th Edition. Available online at http://whqlibdoc.who.int/publications/2011/9789241548151_eng.pdf Accessed on 25th March, 2012.

Yerima, F.A.K., Daura, M.M., Gambo, B.A. (2008). Assessment of groundwater quality of Bama Town, Nigeria. Journal of Sustainable Development in Agriculture and Environment, 3(2), 128 – 137.

APPENDIX I

Table A-1. Levels of chemical parameters in borehole water samples

	pH	Cl (mg/l)	SO_4 (mg/l)	NO_3 (mg/l)	HCO_3 (mg/l)	SiO_2 (mg/l)	TOT P (mg/l)	COD (mg/l)	TOT-N (mg/l)	NH_4-N (mg/l)
URBAN LOCATIONS										
Asokoro	5.9	4	3 .4	2.28	6.1	10.1	13.6	1.3	0.06	13.6
Garki	8.2	6 .5	492	5.6	1.3	27.3	52.3	2.1	0.05	32.4
Maitama	7.6	8 .3	577	4	0 .9	35 .2	13.9	2.6	0.09	21.6
Wuse	6.5	4	3 .5	1.9	11.29	23.6	16.7	0.6	0.21	17.3
Mean	**7.05**	**5.06**	**534.5**	**3.44**	**6.23**	**20.33**	**24.13**	**1.65**	**0.1025**	**21.23**
Max	**8.2**	**8.3**	**577**	**5.6**	**11.29**	**27.3**	**52.3**	**2.6**	**0.21**	**32.4**
Min	**5.9**	**4**	**492**	**1.9**	**1.3**	**10.1**	**13.6**	**0.6**	**0.05**	**13.6**
Stan Dev	**1.2**	**0.9**	**23.6**	**0.7**	**2.4**	**9.3**	**7.4**	**0.3**	**0.02**	**5.2**
PERI URBAN LOCATIONS										
Gwarinpa	7.3	32	124	1.1	8.54	10.2	20.6	1.7	0.05	21.3
Jabi	6.7	20	92	16	131.15	10.8	7.5	2.5	0.008	13.6
Life Camp	8.5	32	353.3	7.12	0.9	18.8	3.7	1.6	0.005	17.5
Karu	6.3	4	3 .2	1.6	9.46	10	113.5	2.4	0.06	8.7
Mean	**7.2**	**22**	**189.8**	**6.45**	**37.51**	**12.45**	**36.33**	**2.05**	**0.03**	**15.28**
Max	**8.5**	**32**	**353.3**	**16**	**131.15**	**18.8**	**113.5**	**2.5**	**0.06**	**21.3**
Min	**6.3**	**4**	**92**	**1.1**	**0.9**	**10**	**3.7**	**1.6**	**0.005**	**8.7**
Stan Dev	2.1	7.2	34.5	3.4	11.3	4.5	12.4	0.6	0.01	5.6
SATELLITE TOWNS										
Galadimawa	6.5	54	51	5.3	8.54	8 .4	10.2	1.7	0.0.9	6.3
Lugbe	6.2	17.33	0 .5	1.7	14.03	13.8	330.7	0.9	0.01	1.4
Gwagwa	8.2	3.6	5.3	2.12	31.11	8.8	34.7	2.3	0.11	7.8
Karmo	7.2	1.2	0 .7	2.3	105.97	9.2	22.6	1.7	0.003	6.5
Mean	**7.02**	**19.03**	**28.1**	**2.85**	**39.91**	**10.6**	**99.55**	**1.65**	**0.041**	**5.5**
Max	**8.2**	**54**	**51**	**5.3**	**105.97**	**13.8**	**330.7**	**2.3**	**0.11**	**7.8**
Min	**6.2**	**1.2**	**5.3**	**1.7**	**8.54**	**8.8**	**10.2**	**0.9**	**0.003**	**1.4**
Stan Dev	**2.1**	**4.3**	**10.2**	**0.3**	**11.3**	**6.5**	**23.4**	**0.5**	**0.008**	**1.2**

Table A-1 continues ……..

RURAL AREAS										
Gosa	7.2	12	0 .5	3.22	78.93	10.4	45.6	0.9	0.004	2.6
Karshi	5.5	34	390	1.8	1.3 .	19.1	23.2	2.9	0.01	21.4
Shamati	7.4	7	9 .2	1.02	20.13	9.8	18.7	0.7	0.003	7.5
Iddo	6.4	2.7	185	31	150.54	9.8	374.6	1.5	0.004	1.6
Mean	**6.63**	**13.93**	**287.5**	**9.26**	**83.2**	**12.28**	**115.53**	**1.5**	**0.00525**	**8.275**
Max	**7.4**	**34**	**390**	**31**	**150.54**	**19.1**	**374.6**	**2.9**	**0.01**	**21.4**
Min	**5.5**	**2.7**	**185**	**1.02**	**20.13**	**9.8**	**18.7**	**0.7**	**0.003**	**1.6**
Stan Dev	2.1	5.6	54.3	4.2	26.5	2.3	34.5	0.5	0.001	4.2

Table A-2. Levels of chemical parameters in open well water samples

	pH	**Cl (mg/l)**	**SO_4 (mg/l)**	**NO_3 (mg/l)**	**HCO_3 (mg/l)**	**SiO_2 (mg/l)**	**TOT P (mg/l)**	**COD (mg/l)**	**TOT-N (mg/l)**	**NH_4-N (mg/l)**
URBAN LOCATIONS										
Asokoro	7.3	32	124	1.1	8.54	10.2	20.6	1.7	0.05	21.3
Garki	6.7	20	92	16	131.15	10.8	7.5	2.5	0.008	13.6
Maitama	8.5	32	353.3	0.07	0.9	18.8	3.7	1.6	0.005	17.5
Wuse	5.8	34	390	0.8	1.3	19.1	23.2	2.9	0.01	3.5
Mean	**7.08**	**29.5**	**239.82**	**4.49**	**46.86**	**14.73**	**13.75**	**2.18**	**0.018**	**13.98**
Max	**8.5**	**34**	**390**	**16**	**131.15**	**19.1**	**23.2**	**2.9**	**0.05**	**21.3**
Min	**5.8**	**20**	**92**	**0.07**	**0.9**	**10.2**	**3.7**	**1.6**	**0.005**	**3.5**
Stan Dev	2.1	7.6	56.4	1.2	11.4	5.2	2.5	0.5	0.006	3.5
PERI URBAN LOCATIONS										
Gwarinpa	5.8	2.8	197.7	38	126.88	9.8	10.25	3.5	0.02	2.7
Jabi	6.2	17.33	0 .5	1.7	14.03	13.8	330.7	0.9	0.01	4.2
Life Camp	6.2	96	490	60	193.61	19.2	13.9	2.1	0.03	21.4
Karu	8.3	4.0	0.7	0.4	34.16	6.5	328.8	2.3	0.04	1.6
Mean	**6.6**	**30.03**	**229.47**	**25.03**	**92.17**	**12.33**	**170.913**	**2.2**	**0.025**	**7.48**
Max	**8.3**	**96**	**490**	**60**	**193.61**	**19.2**	**330.7**	**3.5**	**0.04**	**21.4**
Min	**5.8**	**2.8**	**0.7**	**0.4**	**14.03**	**6.5**	**10.25**	**0.9**	**0.01**	**1.6**
Stan Dev	3.4	16.7	46.8	12.3	9.8	6.5	34.6	0.6	0.006	1.7

Table A-2 continues ……..

SATELLITE TOWNS										
Galadimawa	5.7	3.9	15.5	0.15	17.69	11.2	212.5	1.6	0.05	1.4
Lugbe	6.3	4.2	3 .2	1.6	9.46	10	113.5	2.4	0.06	1.7
Gwagwa	6.5	54	51	5.3	8.54	8 .4	10.2	1.7	0.0.9	22.5
Karmo	8.2	0.1	5.3	0.12	31.11	8.8	34.7	2.3	0.11	13.5.
Mean	**6.67**	**15.5**	**23.93**	**1.792**	**16.7**	**10**	**92.725**	**2.0**	**0.073**	**8.53**
Max	**8.2**	**54**	**51**	**5.3**	**31.11**	**11.2**	**212.5**	**2.4**	**0.11**	**22.5**
Min	**5.7**	**0.1**	**5.3**	**0.12**	**8.54**	**8.8**	**10.2**	**1.6**	**0.05**	**1.4**
Stan Dev	2.1	3.5	11.2	0.5	4.5	2.4	18.4	0.6	0.01	2.36
RURAL LOCATIONS										
Gosa	6.7	0.1	0 .7	2.3	105.97	9.2	22.6	1.7	0.003	7.8
Karshi	7.2	12	0 .5	0.22	78.93	10.4	45.6	0.9	0.004	2.1
Shamati	6.8	4.0	3 .4	0.28	6.1	10.1	13.6	1.3	0.06	3.1
Iddo	8.2	6 .5	492	5.6	1.3	27.3	52.3	2.1	0.05	2.3
Mean	**6.92**	**24.92**	**186.69**	**9.87**	**54.31**	**12.80**	**84.46**	**2.03**	**0.037**	**9.51**
Max	**8.5**	**96**	**492**	**60**	**193.61**	**27.3**	**330.7**	**3.5**	**0.11**	**22.5**
Min	**5.7**	**0.1**	**0.7**	**0.07**	**0.9**	**6.5**	**3.7**	**0.9**	**0.003**	**1.4**
Stan Dev	**2.4**	**9.4**	**34.6**	**3.7**	**13.6**	**3.7**	**23.5**	**4.5**	**0.01**	**3.2**

Table A-3. Levels of chemical parameters in bottled water samples

	pH	**Cl (mg/l)**	**SO_4 (mg/l)**	**NO_3 (mg/l)**	**HCO_3 (mg/l)**	**SiO_2 (mg/l)**	**TOT P (mg/l)**	**COD (mg/l)**	**TOT-N (mg/l)**	**NH_4-N (mg/l)**
URBAN LOCATIONS										
Asokoro	7.6	8 .3	577	4	0 .9	35 .2	13.9	2.6	0.09	21.6
Garki	6.5	4	3 .5	1.9	11.29	23.6	16.7	0.6	0.21	17.3
Maitama	7.4	7	9 .2	0.21	20.13	9.8	18.7	0.7	0.003	7.5
Wuse	6.4	2.7	185	31	150.54	9.8	374.6	1.5	0.004	1.6
Mean	6.97	4.56	381	9.27	60.65	14.4	105.98	1.35	0.077	12
Max	7.6	7	577	31	150.54	23.6	374.6	2.6	0.21	21.6
Min	6.4	2.7	185	0.21	11.29	9.8	13.9	0.6	0.003	1.6
Stan Dev	1.6	0.6	36.7	2.7	11.2	4.2	32.6	0.7	0.03	3.4

Table A-3 continues ……..

PERI URBAN LOCATIONS										
Gwarinpa	5.8	2.8	197.7	38	126.88	9.8	10.25	3.5	0.02	1.6
Jabi	6.2	17.33	0 .5	1.7	14.03	13.8	330.7	0.9	0.01	1.4
Life Camp	6.2	96	490	60	193.61	19.2	13.9	2.1	0.03	1.7
Karu	8.3	4	0.7	0.4	34.16	6.5	328.8	2.3	0.04	22.5
Mean	6.63	30.03	229.46	25.03	92.17	12.33	170.91	2.2	0.025	6.8
Max	8.3	96	490	60	193.61	19.2	330.7	3.5	0.04	22.5
Min	5.8	2.8	0.7	0.4	14.03	6.5	10.25	0.9	0.01	1.4
Stan Dev	1.4	13.2	45.6	11.3	45.2	4.6	52.7	0.5	0.001	1.6
SATELLITE TOWNS										
Galadimawa	5.4	3.9	15.5	0.15	17.69	11.2	212.5	1.6	0.05	13.5
Lugbe	6.3	4.1	3 .2	1.6	9.46	10	113.5	2.4	0.06	2.1
Gwagwa	6.5	55.2	51	5.3	8.54	8 .4	10.2	1.7	0.0.9	3.1
Karmo	8.2	0.2	5.3	0.12	31.11	8.8	34.7	2.3	0.11	2.3
Mean	6.6	15.55	23.93	1.79	16.7	10.0	92.73	2.1	0.073	5.25
Max	8.2	52.8	51	5.3	31.11	11.2	212.5	2.4	0.11	13.5
Min	5.4	0.2	5.3	0.12	8.54	8.8	10.2	1.6	0.05	2.1
Stan Dev	2.1	3.5	11.7	0.5	4.3	2.7	25.3	0.4	0.04	2.1
RURAL LOCATIONS										
Gosa	6.7	0.1	0 .7	2.3	105.97	9.2	22.6	1.7	0.003	6.5
Karshi	7.2	12	0 .5	0.22	78.93	10.4	45.6	0.9	0.004	2.6
Shamati	6.3	4	3 .4	0.28	6.1	10.1	13.6	1.3	0.06	13.6
Iddo	8.2	6 .5	492	5.6	1.3	27.3	52.3	2.1	0.05	32.4
Mean	**7.1**	**5.37**	**124.15**	**2.1**	**48.08**	**14.25**	**33.53**	**1.5**	**0.029**	**13.78**
Max	**8.2**	**12**	**492**	**5.6**	**105.97**	**27.3**	**52.3**	**2.1**	**0.06**	**32.4**
Min	**6.3**	**0.1**	**0.5**	**0.22**	**1.3**	**9.2**	**13.6**	**0.9**	**0.003**	**2.6**
Stan Dev	**3.2**	**1.6**	**45.3**	**0.7**	**9.4**	**3.4**	**6.2**	**0.4**	**0.01**	**4.3**

Table A-4. Levels of chemical parameters in sachet water samples

	pH	Cl (mg/l)	SO_4 (mg/l)	NO_3 (mg/l)	HCO_3 (mg/l)	SiO_2 (mg/l)	TOT P (mg/l)	COD (mg/l)	TOT-N (mg/l)	NH_4-N (mg/l)
URBAN LOCATIONS										
Asokoro	8.3	4.2	0.7	0.4	34.16	6.5	328.8	2.3	0.04	22.5
Garki	5.6	5.1	15.5	0.15	17.69	11.2	212.5	1.6	0.05	13.5
Maitama	6.3	4.7	3 .2	1.6	9.46	10	113.5	2.4	0.06	8.7
Wuse	6.5	54	51	5.3	8.54	8 .4	10.2	1.7	0.0.9	3.1
Mean	**6.675**	**17**	**22.4**	**1.86**	**17.46**	**9.23**	**166.25**	**2.0**	**0.05**	**11.95**
Max	**8.3**	**54**	**51**	**5.3**	**34.16**	**11.2**	**328.8**	**2.4**	**0.06**	**22.5**
Min	**5.6**	**4.2**	**0.7**	**0.15**	**8.54**	**6.5**	**10.2**	**1.6**	**0.04**	**3.1**
Stan Dev	**1.3**	**2.7**	**5.2**	**0.5**	**2.4**	**3.6**	**23.5**	**0.6**	**0.01**	**3.5**
PERI URBAN LOCATIONS										
Gwarinpa	8.2	0.6	5.3	0.12	31.11	8.8	34.7	2.3	0.11	7.8
Jabi	6.7	1.2	0 .7	2.3	105.97	9.2	22.6	1.7	0.003	6.5
Life Camp	7.2	12	0 .5	0.22	78.93	10.4	45.6	0.9	0.004	2.6
Karu	6.2	96	490	60	193.61	19.2	13.9	2.1	0.03	12.4
Mean	**7.075**	**27.45**	**247.65**	**15.66**	**102.40**	**11.9**	**29.2**	**1.75**	**0.036**	**7.325**
Max	**8.2**	**96**	**490**	**60**	**193.61**	**19.2**	**45.6**	**2.3**	**0.11**	**12.4**
Min	**6.2**	**0.6**	**5.3**	**0.12**	**31.11**	**8.8**	**13.9**	**0.9**	**0.003**	**2.6**
Stan Dev	**2.4**	**6.3**	**56.3**	**3.5**	**23.5**	**4.6**	**5.2**	**0.5**	**0.01**	**4.2**
SATELLITE TOWNS										
Galadimawa	7.3	3.7	3 .4	0.28	6.1	10.1	13.6	1.3	0.06	13.6
Lugbe	8.2	6 .5	492	5.6	1.3	27.3	52.3	2.1	0.05	32.4
Gwagwa	7.6	8 .3	577	4	0 .9	35 .2	13.9	2.6	0.09	21.6
Karmo	6.5	4.8	3 .5	1.9	11.29	23.6	16.7	0.6	0.21	17.3
Mean	**7.4**	**4.25**	**534.5**	**2.945**	**6.23**	**20.33**	**24.13**	**1.65**	**0.10**	**21.22**
Max	**8.2**	**4.8**	**577**	**5.6**	**11.29**	**27.3**	**52.3**	**2.6**	**0.21**	**32.4**
Min	**6.5**	**3.7**	**492**	**0.28**	**1.3**	**10.1**	**13.6**	**0.6**	**0.05**	**13.6**
Stan Dev	**3.1**	**1.2**	**56.7**	**0.6**	**2.4**	**5.2**	**5.2**	**0.4**	**0.2**	**3.6**

Table A-4 continues ……..

RURAL LOCATIONS										
Gosa	6.3	34	390	0.8	1.3	19.1	23.2	2.9	0.01	21.4
Karshi	7.4	7	9 .2	0.21	20.13	9.8	18.7	0.7	0.003	7.5
Shamati	7.3	32	124	1.1	8.54	10.2	20.6	1.7	0.05	21.3
Iddo	6.7	20	92	16	131.15	10.8	7.5	2.5	0.008	13.6
Mean	**7.06**	**21.36**	**245.16**	**7.676**	**46.26**	**13.51**	**65.29**	**1.81**	**0.06**	**14.12**
Max	**8.3**	**96**	**577**	**60**	**193.61**	**27.3**	**328.8**	**2.9**	**0.21**	**32.4**
Min	**5.6**	**0.6**	**0.7**	**0.12**	**1.3**	**6.5**	**7.5**	**0.6**	**0.003**	**2.6**
Stan Dev	**3.2**	**6.5**	**76.2**	**2.3**	**4.6**	**6.2**	**13.5**	**0.5**	**0.02**	**4.2**

Table A-5. Levels of chemical parameters in tap water samples

	pH	**Cl (mg/l)**	**SO_4 (mg/l)**	**NO_3 (mg/l)**	**HCO_3 (mg/l)**	**SiO_2 (mg/l)**	**TOT P (mg/l)**	**COD (mg/l)**	**TOT-N (mg/l)**	**NH_4-N (mg/l)**
URBAN LOCATIONS										
Asokoro	7.3	54	51	5.3	8.54	8 .4	10.2	1.7	0.0.9	6.3
Garki	6.7	20	92	16	131.15	10.8	7.5	2.5	0.008	13.6
Maitama	8.5	32	353.3	0.07	0.9	18.8	3.7	1.6	0.005	17.5
Wuse	5.8	34	390	0.8	1.36	1.43.	19.1	23.2	2.9	3.1
Mean	**7.05**	**35**	**221.58**	**5.54**	**46.86**	**14.8**	**10.13**	**7.25**	**0.97**	**10.13**
Max	**8.5**	**54**	**390**	**16**	**131.15**	**18.8**	**19.1**	**23.2**	**2.9**	**17.5**
Min	**5.8**	**20**	**51**	**0.07**	**0.9**	**10.8**	**3.7**	**1.6**	**0.005**	**3.1**
Stan Dev	**3.2**	**12**	**72.3**	**2.4**	**11.2**	**7.2**	**4.5**	**3.2**	**0.3**	**4.2**
PERI URBAN LOCATIONS										
Gwarinpa	7.4	7	9 .2	0.21	20.13	9.8	18.7	0.7	0.003	2.7
Jabi	6.4	2.7	185	31	150.54	9.8	374.6	1.5	0.004	4.2
Life Camp	5.6	2.8	197.7	38	126.88	9.8	10.25	3.5	0.02	1.6
Karu	6.2	17.33	0 .5	1.7	14.03	13.8	330.7	0.9	0.01	2.3
Mean	**6.4**	**7.4575**	**191.35**	**17.7275**	**77.895**	**10.8**	**183.563**	**1.65**	**0.00925**	**2.7**
Max	**7.4**	**17.33**	**197.7**	**38**	**150.54**	**13.8**	**374.6**	**3.5**	**0.02**	**4.2**
Min	**5.6**	**2.7**	**185**	**0.21**	**14.03**	**9.8**	**10.25**	**0.7**	**0.003**	**1.6**
Stan Dev	**2.3**	**4.2**	**67.8**	**6.3**	**21.3**	**4.2**	**78.2**	**0.5**	**0.002**	**1.1**

Table A-5 continues ……..

SATELLITE TOWNS										
Galadimawa	6.2	96	490	60	193.61	19.2	13.9	2.1	0.03	1.7
Lugbe	8.3	4	0.7	0.4	34.16	6.5	328.8	2.3	0.04	0.9
Gwagwa	5.8	4	15.5	0.15	17.69	11.2	212.5	1.6	0.05	3.1
Karmo	6.3	4	3 .2	1.6	9.46	10	113.5	2.4	0.06	1.5
Mean	**6.65**	**27**	**168.73**	**15.54**	**63.73**	**11.725**	**167.175**	**2.1**	**0.045**	**1.8**
Max	**8.3**	**96**	**490**	**60**	**193.61**	**19.2**	**328.8**	**2.4**	**0.06**	**3.1**
Min	**5.8**	**4**	**0.7**	**0.15**	**9.46**	**6.5**	**13.9**	**1.6**	**0.03**	**0.9**
Stan Dev	**2.1**	**12**	**45.6**	**4.6**	**21.2**	**3.5**	**34.5**	**0.6**	**0.01**	**0.5**
RURAL LOCATIONS										
Gosa	6.5	54	51	5.3	8.54	8 .4	10.2	1.7	0.0.9	6.3
Karshi	8.2	0	5.3	0.12	31.11	8.8	34.7	2.3	0.11	7.8
Shamati	6.7	0	0 .7	2.3	105.97	9.2	22.6	1.7	0.003	1.6
Iddo	7.2	12	0 .5	0.22	78.93	13.4	10.4	45.6	0.9	2.6
Mean	**7.15**	**16.5**	**28.15**	**1.985**	**56.14**	**9.3**	**19.48**	**12.83**	**0.34**	**4.58**
Max	**8.2**	**54**	**51**	**5.3**	**105.97**	**9.2**	**34.7**	**45.6**	**0.9**	**7.8**
Min	**6.5**	**0**	**5.3**	**0.12**	**8.54**	**8.8**	**10.2**	**1.7**	**0.003**	**1.6**
Stan Dev	**3.2**	**5.6**	**6.7**	**0.5**	**12.3**	**1.2**	**4.3**	**5.4**	**0.1**	**2.1**

Table A-6. Levels of heavy metals in open well water samples

	Mn (mg/l)	**Fe (mg/l)**	**Zn (mg/l)**	**Cu (mg/l)**	**Al (mg/l)**	**As (mg/l)**	**Cd (mg/l)**	**Hg (mg/l)**	**F (mg/l)**	**Pb (mg/l)**	**Cr (mg/l)**
URBAN LOCATIONS											
Asokoro	0.35	3.46	0.03	0.23	0.36	0.102	0.03	0.083	0.06	0.05	0.05
Garki	0.03	0.37	0.02	0.07	0.22	0.091	0.08	0.081	0.04	0.09	0.17
Maitama	0.13	0.54	0.04	0.05	0.12	0.076	0.05	0.083	0.13	0.07	0.05
Wuse	0.28	0.75	0.22	0.15	0.07	0.137	0.14	0.093	0.05	0.14	0.05
Mean	**0.20**	**1.28**	**0.078**	**0.13**	**0.19**	**0.10**	**0.075**	**0.085**	**0.07**	**0.088**	**0.08**
Max	**0.35**	**3.46**	**0.22**	**0.23**	**0.36**	**0.137**	**0.14**	**0.093**	**0.13**	**0.14**	**0.17**
Min	**0.03**	**0.37**	**0.02**	**0.05**	**0.07**	**0.076**	**0.03**	**0.081**	**0.04**	**0.05**	**0.05**
Stan Dev	**0.03**	**0.6**	**0.02**	**0.04**	**0.04**	**0.02**	**0.02**	**0.04**	**0.03**	**0.04**	**0.06**

Table A-6 continues……..

PERI URBAN LOCATIONS											
Gwarinpa	2.43	1.53	0.13	0.16	0.01	0.103	0.31	0.09	0.08	0.15	0.23
Jabi	5.7	6.75	0.26	0.05	2.7	0.22	0.05	0.094	0.09	0.05	0.05
Life Camp	4.6	10.1	0.23	0.21	4.8	0.281	0.31	0.097	0.09	0.21	0.22
Karu	0.07	4.04	0.07	0.05	0.02	0.117	0.01	0.089	0.16	0.05	0.05
Mean	**3.2**	**5.61**	**0.17**	**0.11**	**1.88**	**0.18**	**0.17**	**0.092**	**0.11**	**0.12**	**0.14**
Max	**5.7**	**10.1**	**0.26**	**0.21**	**4.8**	**0.281**	**0.31**	**0.097**	**0.16**	**0.21**	**0.23**
Min	**0.07**	**1.53**	**0.07**	**0.05**	**0.01**	**0.103**	**0.01**	**0.089**	**0.08**	**0.05**	**0.05**
Stan Dev	**1.5**	**2.1**	**0.03**	**0.04**	**0.4**	**0.06**	**0.05**	**0.05**	**0.05**	**0.03**	**0.01**
SATELLITE TOWNS											
	Mn (mg/l)	**Fe (mg/l)**	**Zn (mg/l)**	**Cu (mg/l)**	**Al (mg/l)**	**As (mg/l)**	**Cd (mg/l)**	**Hg (mg/l)**	**F (mg/l)**	**Pb (mg/l)**	**Cr (mg/l)**
Galadimawa	1.78	1.74	0.14	0.21	0.04	0.104	0.05	0.088	0.06	0.12	0.47
Lugbe	1.72	2.29	0.13	0.05	0.03	0.117	0.12	0.089	0.06	0.05	0.49
Gwagwa	0.05	0.49	0.04	0.17	0.05	0.109	0.08	0.087	0.03	0.07	0.05
Karmo	1.16	0.89	0.15	0.05	0.03	0.087	0.04	0.084	0.06	0.05	0.19
Mean	**1.18**	**1.35**	**0.12**	**0.12**	**0.038**	**0.104**	**0.073**	**0.087**	**0.053**	**0.073**	**0.31**
Max	**1.78**	**2.29**	**0.15**	**0.21**	**0.05**	**0.117**	**0.12**	**0.089**	**0.06**	**0.12**	**0.49**
Min	**0.05**	**0.49**	**0.04**	**0.05**	**0.03**	**0.087**	**0.04**	**0.084**	**0.03**	**0.05**	**0.05**
Stan Dev	**0.44**	**0.52**	**0.04**	**0.07**	**0.01**	**0.02**	**0.02**	**0.02**	**0.02**	**0.03**	**0.06**
RURAL LOCATIONS											
	Mn (mg/l)	**Fe (mg/l)**	**Zn (mg/l)**	**Cu (mg/l)**	**Al (mg/l)**	**As (mg/l)**	**Cd (mg/l)**	**Hg (mg/l)**	**F (mg/l)**	**Pb (mg/l)**	**Cr (mg/l)**
Gosa	0.13	0.43	0.04	0.05	0.16	0.076	0.05	0.083	0.16	0.07	0.06
Karshi	0.14	1.08	0.07	0.05	0.01	0.108	0.05	0.083	0.04	0.06	0.11
Shamati	0.03	0.63	0.06	0.05	0.13	0.111	0.16	0.082	0.07	0.11	0.06
Iddo	12.3	4.06	0.23	0.19	4.12	0.315	0.31	0.092	0.23	0.05	0.05
Mean	**3.15**	**1.55**	**0.1**	**0.085**	**1.105**	**0.1525**	**0.14**	**0.085**	**0.125**	**0.0725**	**0.07**
Max	**12.3**	**4.06**	**0.23**	**0.19**	**4.12**	**0.315**	**0.31**	**0.092**	**0.23**	**0.11**	**0.11**
Min	**0.03**	**0.43**	**0.04**	**0.05**	**0.01**	**0.076**	**0.05**	**0.082**	**0.04**	**0.05**	**0.05**
Stan Dev	**1.23**	**0.62**	**0.03**	**0.02**	**0.52**	**0.07**	**0.05**	**0.021**	**0.06**	**0.001**	**0.02**

Table A-7. Levels of heavy metals in tap water samples

	Mn (mg/l)	Fe (mg/l)	Zn (mg/l)	Cu (mg/l)	Al (mg/l)	As (mg/l)	Cd (mg/l)	Hg (mg/l)	F (mg/l)	Pb (mg/l)	Cr (mg/l)
URBAN LOCATIONS											
Asokoro	0.28	0.75	0.22	0.15	0.07	0.137	0.14	0.093	0.05	0.14	0.05
Garki	2.43	1.53	0.13	0.16	0.01	0.103	0.31	0.09	0.08	0.15	0.23
Maitama	5.7	6.75	0.26	0.05	2.7	0.22	0.05	0.094	0.09	0.05	0.05
Wuse	4.6	10.1	0.23	0.21	4.8	0.281	0.31	0.097	0.09	0.21	0.22
Mean	3.25	4.78	0.21	0.14	1.89	0.19	0.20	0.093	0.08	0.13	0.14
Max	5.7	10.1	0.26	0.21	4.8	0.281	0.31	0.097	0.09	0.21	0.23
Min	0.28	0.75	0.13	0.05	0.01	0.103	0.05	0.09	0.05	0.05	0.05
Stan Dev	1.21	2.02	0.11	0.07	0.67	0.04	0.10	0.023	0.04	0.06	0.05
PERI URBAN LOCATIONS											
Gwarinpa	0.07	4.04	0.07	0.05	0.02	0.117	0.01	0.089	0.16	0.05	0.05
Jabi	1.78	1.74	0.14	0.21	0.04	0.104	0.05	0.088	0.06	0.12	0.47
Life Camp	1.72	2.29	0.13	0.05	0.03	0.117	0.12	0.089	0.06	0.05	0.49
Karu	0.05	0.49	0.04	0.17	0.05	0.109	0.08	0.087	0.03	0.07	0.05
Mean	0.91	2.14	0.09	0.12	0.04	0.111	0.065	0.088	0.08	0.07	0.265
Max	1.78	4.04	0.14	0.21	0.05	0.117	0.12	0.089	0.16	0.12	0.49
Min	0.05	0.49	0.04	0.05	0.02	0.104	0.01	0.087	0.03	0.05	0.05
Stan Dev	0.21	1.16	0.01	0.02	0.007	0.052	0.016	0.012	0.02	0.01	0.009
SATELLITE TOWNS											
Galadimawa	1.16	0.89	0.15	0.05	0.03	0.087	0.04	0.084	0.06	0.05	0.19
Lugbe	0.14	1.08	0.07	0.05	0.01	0.108	0.05	0.083	0.04	0.06	0.11
Gwagwa	0.22	3.46	0.03	0.23	0.36	0.102	0.03	0.083	0.06	0.05	0.05
Karmo	0.03	0.37	0.02	0.07	0.22	0.091	0.08	0.081	0.04	0.09	0.17
Mean	0.39	1.45	0.068	0.10	0.155	0.097	0.05	0.083	0.05	0.063	0.13
Max	1.16	3.46	0.15	0.23	0.36	0.108	0.08	0.084	0.06	0.09	0.19
Min	0.03	0.37	0.02	0.05	0.01	0.087	0.03	0.081	0.04	0.05	0.05
Stan Dev	0.07	0.23	0.01	0.002	0.05	0.02	0.008	0.007	0.02	0.03	0.07

Table A-7 continues ……..

RURAL LOCATIONS											
Gosa	0.13	0.46	0.04	0.05	0.12	0.076	0.05	0.083	0.16	0.07	0.06
Karshi	0.07	2.47	0.03	0.05	0.02	0.118	0.06	0.08	0.09	0.05	0.23
Shamati	0.02	0.95	0.06	0.08	0.01	0.102	0.05	0.082	0.04	0.11	0.09
Iddo	0.11	4.1	0.06	0.05	0.01	0.098	0.05	0.083	0.11	0.25	0.05
Mean	**0.083**	**1.99**	**0.048**	**0.058**	**0.04**	**0.099**	**0.053**	**0.082**	**0.1**	**0.12**	**0.11**
Max	**0.13**	**4.1**	**0.06**	**0.08**	**0.12**	**0.118**	**0.06**	**0.083**	**0.16**	**0.25**	**0.23**
Min	**0.02**	**0.46**	**0.03**	**0.05**	**0.01**	**0.076**	**0.05**	**0.08**	**0.04**	**0.05**	**0.05**
Stan Dev	**0.02**	**0.74**	**0.008**	**0.02**	**0.01**	**0.002**	**0.01**	**0.007**	**0.003**	**0.02**	**0.03**

Table A-8. Levels of heavy metals in borehole water samples

	Mn (mg/l)	Fe (mg/l)	Zn (mg/l)	Cu (mg/l)	Al (mg/l)	As (mg/l)	Cd (mg/l)	Hg (mg/l)	F (mg/l)	Pb (mg/l)	Cr (mg/l)
URBAN LOCATIONS											
Asokoro	0.22	3.46	0.03	0.23	0.36	0.102	0.03	0.083	0.06	0.05	0.05
Garki	0.03	0.37	0.02	0.07	0.22	0.091	0.08	0.081	0.04	0.09	0.17
Maitama	0.13	0.54	0.04	0.05	0.12	0.076	0.05	0.083	0.13	0.07	0.05
Wuse	0.28	0.75	0.22	0.15	0.07	0.137	0.14	0.093	0.05	0.14	0.05
Mean	0.17	1.28	0.078	0.125	0.19	0.102	0.075	0.085	0.07	0.088	0.08
Max	0.28	3.46	0.22	0.23	0.36	0.137	0.14	0.093	0.13	0.14	0.17
Min	0.03	0.37	0.02	0.05	0.07	0.076	0.03	0.081	0.04	0.05	0.05
Stan Dev	0.06	0.53	0.021	0.015	0.03	0.053	0.013	0.012	0.01	0.012	0.01
PERI URBAN LOCATIONS											
Gwarinpa	2.43	1.53	0.13	0.16	0.01	0.103	0.31	0.09	0.08	0.15	0.23
Jabi	5.7	6.75	0.26	0.05	2.7	0.22	0.05	0.094	0.09	0.05	0.05
Life Camp	4.6	10.1	0.23	0.21	4.8	0.281	0.31	0.097	0.09	0.21	0.22
Karu	0.07	4.04	0.07	0.05	0.02	0.117	0.01	0.089	0.16	0.05	0.05
Mean	3.2	5.61	0.173	0.118	1.88	0.180	0.17	0.093	0.105	0.115	0.138
Max	5.7	10.1	0.26	0.21	4.8	0.281	0.31	0.097	0.16	0.21	0.23
Min	0.07	1.53	0.07	0.05	0.01	0.103	0.01	0.089	0.08	0.05	0.05
Stan Dev	1.12	0.76	0.032	0.06	0.52	0.005	0.02	0.011	0.024	0.06	0.062

Table A-8 continues ……..

SATELLITE TOWNS											
Galadimawa	1.78	1.74	0.14	0.21	0.04	0.104	0.05	0.088	0.06	0.12	0.47
Lugbe	1.72	2.29	0.13	0.05	0.03	0.117	0.12	0.089	0.06	0.05	0.49
Gwagwa	0.05	0.49	0.04	0.17	0.05	0.109	0.08	0.087	0.03	0.07	0.05
Karmo	1.16	0.89	0.15	0.05	0.03	0.087	0.04	0.084	0.06	0.05	0.19
Mean	1.178	1.35	0.115	0.12	0.038	0.104	0.073	0.087	0.053	0.073	0.3
Max	1.78	2.29	0.15	0.21	0.05	0.117	0.12	0.089	0.06	0.12	0.49
Min	0.05	0.49	0.04	0.05	0.03	0.087	0.04	0.084	0.03	0.05	0.05
Stan Dev	0.65	0.62	0.012	0.04	0.006	0.052	0.011	0.010	0.007	0.012	0.02
RURAL LOCATIONS											
Gosa	0.16	0.43	0.04	0.05	0.12	0.074	0.05	0.077	0.13	0.07	0.06
Karshi	0.14	1.08	0.07	0.05	0.01	0.108	0.05	0.083	0.04	0.06	0.11
Shamati	0.03	0.63	0.06	0.05	0.13	0.111	0.16	0.082	0.07	0.11	0.06
Iddo	12.3	4.06	0.23	0.19	4.12	0.315	0.31	0.092	0.23	0.05	0.05
Mean	**1.73**	**2.63**	**0.12**	**0.118**	**0.81**	**0.134**	**0.112**	**0.089**	**0.084**	**0.091**	**0.156**
Max	**12.3**	**10.1**	**0.26**	**0.23**	**4.8**	**0.315**	**0.31**	**0.097**	**0.23**	**0.21**	**0.49**
Min	**0.03**	**0.37**	**0.02**	**0.05**	**0.01**	**0.074**	**0.01**	**0.077**	**0.03**	**0.05**	**0.05**
Stan Dev	**0.52**	**1.03**	**0.03**	**0.006**	**0.13**	**0.082**	**0.02**	**0.012**	**0.012**	**0.021**	**0.036**

Table A-9. Levels of heavy metals in bottled water samples

	Mn (mg/l)	**Fe (mg/l)**	**Zn (mg/l)**	**Cu (mg/l)**	**Al (mg/l)**	**As (mg/l)**	**Cd (mg/l)**	**Hg (mg/l)**	**F (mg/l)**	**Pb (mg/l)**	**Cr (mg/l)**
URBAN LOCATIONS											
Asokoro	1.16	0.89	0.15	0.05	0.03	0.087	0.04	0.084	0.06	0.05	0.19
Garki	0.14	1.08	0.07	0.05	0.01	0.108	0.05	0.083	0.04	0.06	0.11
Maitama	0.03	0.63	0.06	0.05	0.13	0.111	0.16	0.082	0.07	0.11	0.06
Wuse	12.3	4.06	0.23	0.19	4.12	0.315	0.31	0.092	0.23	0.05	0.05
Mean	3.41	1.67	0.13	0.085	1.073	0.155	0.14	0.085	0.1	0.068	0.1025
Max	12.3	4.06	0.23	0.19	4.12	0.315	0.31	0.092	0.23	0.11	0.19
Min	0.03	0.63	0.06	0.05	0.01	0.087	0.04	0.082	0.04	0.05	0.05
Stan Dev	1.01	0.32	0.02	0.006	0.26	0.023	0.05	0.024	0.03	0.031	0.02

Table A-9 continues ……..

PERI URBAN LOCATIONS											
Gwarinpa	5.7	6.75	0.26	0.05	2.7	0.22	0.05	0.094	0.09	0.05	0.05
Jabi	4.6	10.1	0.23	0.21	4.8	0.281	0.31	0.097	0.09	0.21	0.22
Life Camp	0.07	4.04	0.07	0.05	0.02	0.117	0.01	0.089	0.16	0.05	0.05
Karu	1.78	1.74	0.14	0.21	0.04	0.104	0.05	0.088	0.06	0.12	0.47
Mean	3.04	5.66	0.18	0.13	1.89	0.18	0.105	0.092	0.1	0.11	0.19
Max	5.7	10.1	0.26	0.21	4.8	0.281	0.31	0.097	0.16	0.21	0.47
Min	0.07	1.74	0.07	0.05	0.02	0.104	0.01	0.088	0.06	0.05	0.05
Stan Dev	1.03	2.12	0.03	0.04	0.43	0.05	0.04	0.02	0.05	0.03	0.04
SATELLITE TOWNS											
Galadimawa	1.72	2.29	0.13	0.05	0.03	0.117	0.12	0.089	0.06	0.05	0.49
Lugbe	12.9	3.75	0.29	0.28	3.82	0.346	0.05	0.089	0.14	0.06	0.04
Gwagwa	0.05	0.38	0.06	0.15	0.06	0.103	0.12	0.085	0.05	0.21	0.08
Karmo	0.28	0.75	0.22	0.15	0.07	0.137	0.14	0.093	0.05	0.14	0.05
Mean	3.73	1.79	0.175	0.16	1.0	0.18	0.11	0.089	0.075	0.12	0.17
Max	12.9	3.75	0.29	0.28	3.82	0.346	0.14	0.093	0.14	0.21	0.49
Min	0.05	0.38	0.06	0.05	0.03	0.103	0.05	0.085	0.05	0.05	0.04
Stan Dev	1.22	0.34	0.05	0.03	0.02	0.05	0.02	0.03	0.01	0.03	0.02
RURAL LOCATIONS											
Gosa	0.12	0.54	0.03	0.05	0.12	0.076	0.05	0.083	0.13	0.06	0.05
Karshi	2.43	1.53	0.13	0.16	0.01	0.103	0.31	0.09	0.08	0.15	0.23
Shamati	5.7	6.75	0.26	0.05	2.7	0.22	0.05	0.094	0.09	0.05	0.05
Iddo	4.6	10.1	0.23	0.21	4.8	0.281	0.31	0.097	0.09	0.21	0.22
Mean	**3.79**	**3.40**	**0.16**	**0.12**	**1.60**	**0.179**	**0.13**	**0.089**	**0.09**	**0.10**	**0.17**
Max	**12.9**	**10.1**	**0.29**	**0.28**	**4.8**	**0.346**	**0.31**	**0.097**	**0.23**	**0.21**	**0.49**
Min	**0.03**	**0.38**	**0.03**	**0.05**	**0.01**	**0.076**	**0.01**	**0.082**	**0.04**	**0.05**	**0.04**
Stan Dev	**1.21**	**0.46**	**0.02**	**0.04**	**0.32**	**0.06**	**0.0.3**	**0.02**	**0.03**	**0.02**	**0.05**

Table A-10. Levels of heavy metals in sachet water samples

	Mn (mg/l)	Fe (mg/l)	Zn (mg/l)	Cu (mg/l)	Al (mg/l)	As (mg/l)	Cd (mg/l)	Hg (mg/l)	F (mg/l)	Pb (mg/l)	Cr (mg/l)
URBAN LOCATIONS											
Asokoro	0.05	0.49	0.04	0.17	0.05	0.109	0.08	0.087	0.03	0.07	0.06
Garki	1.16	0.89	0.15	0.05	0.03	0.087	0.04	0.084	0.06	0.05	0.19
Maitama	0.14	1.08	0.07	0.05	0.01	0.108	0.05	0.083	0.04	0.06	0.06
Wuse	0.22	3.46	0.03	0.23	0.36	0.102	0.03	0.083	0.06	0.05	0.09
Mean	0.39	1.48	0.07	0.125	0.11	0.101	0.05	0.08	0.04	0.05	0.1
Max	1.16	3.46	0.15	0.23	0.36	0.109	0.08	0.087	0.06	0.07	0.19
Min	0.05	0.49	0.03	0.05	0.01	0.087	0.03	0.083	0.03	0.05	0.06
Stan Dev	0.12	0.56	0.65	0.62	0.012	0.04	0.006	0.052	0.02	0.03	0.02
PERI URBAN LOCATIONS											
Gwarinpa	0.11	4.1	0.06	0.05	0.01	0.098	0.05	0.083	0.11	0.25	0.05
Jabi	0.03	0.63	0.06	0.05	0.13	0.111	0.16	0.082	0.07	0.11	0.06
Life Camp	12.3	4.06	0.23	0.19	4.12	0.315	0.31	0.092	0.23	0.05	0.04
Karu	12.9	3.75	0.29	0.28	3.82	0.346	0.05	0.089	0.14	0.06	0.05
Mean	6.33	3.13	0.16	0.14	2.02	0.218	0.14	0.086	0.14	0.11	0.05
Max	12.9	4.1	0.29	0.28	4.12	0.346	0.31	0.092	0.23	0.25	0.06
Min	0.03	0.63	0.06	0.05	0.01	0.098	0.05	0.082	0.07	0.05	0.04
Stan Dev	1.65	1.12	0.04	0.03	1.00	0.061	0.06	0.03	0.03	0.02	0.01
SATELLITE TOWNS											
Galadimawa	0.05	0.38	0.06	0.15	0.06	0.103	0.12	0.085	0.05	0.21	0.18
Lugbe	0.03	0.37	0.02	0.07	0.22	0.091	0.08	0.081	0.04	0.09	0.05
Gwagwa	0.28	0.75	0.22	0.15	0.07	0.137	0.14	0.093	0.05	0.14	0.23
Karmo	2.43	1.53	0.13	0.16	0.01	0.103	0.31	0.09	0.08	0.15	0.05
Mean	0.69	0.75	0.11	0.13	0.09	0.108	0.16	0.08	0.05	0.14	0.12
Max	2.43	1.53	0.22	0.16	0.22	0.137	0.31	0.093	0.08	0.21	0.23
Min	0.03	0.37	0.02	0.07	0.01	0.091	0.08	0.081	0.04	0.09	0.05
Stan Dev	0.25	0.091	0.08	0.081	0.04	0.09	0.05	0.04	0.02	0.06	0.02

Table A-10 continues ……..

RURAL LOCATIONS											
Gosa	0.15	0.54	0.06	0.05	0.12	0.076	0.05	0.083	0.13	0.07	0.05
Karshi	5.7	6.75	0.26	0.05	2.7	0.22	0.05	0.094	0.09	0.05	0.22
Shamati	4.6	10.1	0.23	0.21	4.8	0.281	0.31	0.097	0.09	0.21	0.05
Iddo	0.07	4.04	0.07	0.05	0.02	0.117	0.01	0.089	0.16	0.05	0.16
Mean	**2.63**	**5.35**	**0.16**	**0.09**	**1.91**	**0.17**	**0.10**	**0.095**	**0.12**	**0.09**	**0.12**
Max	**5.7**	**10.1**	**0.26**	**0.21**	**4.8**	**0.281**	**0.31**	**0.097**	**0.16**	**0.21**	**0.22**
Min	**0.07**	**0.54**	**0.06**	**0.05**	**0.02**	**0.076**	**0.01**	**0.083**	**0.09**	**0.05**	**0.05**
Stan Dev	**1.13**	2.09	0.07	0.04	0.52	0.06	0.04	**0.03**	**0.04**	**0.03**	**0.04**

Source: Laboratory Tests, 2010