Evaluation of Bioavailability of Metals in Underground Water within the Vicinity of Dumpsites in Zaria Metropolis, Nigeria

Adamu Uzairu
Department of Chemistry, Ahmadu Bello University, Zaria, Nigeria
Email: adamuuzairu@yahoo.com

Sani Uba (Corresponding Author)
Department of Chemistry, Ahmadu Bello University, Zaria, Nigeria
Email: saniuba10@yahoo.com

Muhammad Sani Sallau
Department of Chemistry, Ahmadu Bello University, Zaria, Nigeria

Hamza Abba
Department of Chemistry, Ahmadu Bello University, Zaria, Nigeria
Email: habba@abu.edu.ng

Oluwole Joshua Okunola
National Research Institute for Chemical Technology, Zaria, Nigeria
Email: okunolaoj@gmail.com

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Abstract

A sequential extraction was used to fractionate Zn, Pb, Cu, Cd, and Hg in waters from the hand-dug wells 100m away from the ten dumpsites and a control site, 300m away from the Kusfa dumpsite in Zaria metropolis, Nigeria in both the wet and dry seasons. The bioavailable fractions across the seasons and sites were found to be the most abundant pools for all the metals with the exception zinc metal from the NTC dumpsites wells in the dry season which had only 31.50%. Furthermore, the total extractable fraction for cadmium (Cd), lead (Pb) and mercury were above the WHO (2006) tolerable limits in both the seasons while the nutritive metals, zinc (Zn) and copper (Cu) were within the acceptable limit. However, the total extractable concentrations recorded in the wet across the sites were found higher than those in the dry season, this is attributed leach ability of the metals to the underground water. Overall the potential bioavailabilities of the metals were found to follow similar trend across the seasons (wet and dry): Hg > Cd > Pb > Zn > Cu. In addition, the analysis of variance revealed a significant difference ($P<0.05$) among the metals concentrations across the sites and among the fractions. This strongly indicates the existence of pollution at the studied dumpsites communities. The bioaccumulation of the toxic metals noted in this study may lead to a serious health effects to the inhabitants as the bioaccumulation of lead affects the intelligence quotient in infants and it is carcinogenic whereas that of the cadmium leads to cancer of the kidney, hypertension and some vascular diseases, it also inhibits the activity of enzymes such as the adenosine triphosphate (ATP) and amylase. Mercury toxicity affects the cardiovascular, nervous, respiratory, gastro-intestinal, hematologic, immune and reproductive systems. The raw waters in these dumpsites were found unfit for drinking including those at the control site.

Keywords: Fractionation, Heavy metals, Hand-dug well waters, Dumpsites, Zaria Metropolis

1.0 Introduction

Water is essential for the survival of any form of life. On an average, a human being consumes about 2litres of water daily and it accounts for about 70% of the weight of a human body. Moreover considerable part of this limited quantity of water is polluted by leachates emanating from the dumpsites in the underdeveloped and developing countries. Nigeria cannot be an exception to the aforementioned. The rising population of Nigeria to about 140million (Monitor, 2007; Otokiti *et al.,* 2008) lack proper knowledge of waste disposal, waste are recklessly dumped without any environmental regards in major cities of many states in Nigeria which is a very common observation in Zaria metropolis, Kaduna State. In most of the dumpsites, waste collected are burnt in the open and ashes abandoned at the site. The practice of burning, destroys the organic component, oxidize metal, thereby enriching the ashes left behind in the metal. The leachates from these dumpsites percolate the soil and pollute the aquifer in the surrounding areas. Studies have shown that heavy metals can adversely affect mental and neurological functions as well as altering metabolic processes in human body system. Heavy metals could also induce the impairment and dysfunction in blood, cardiovascular, endocrine, immune, reproductive and urinary systems (Okuo *et al*., 2007).

Thus the quality and the quantity of the clean water are of vital significance for the welfare of mankind (Dara, 2008). Studies have shown that impact assessment of various pollution sources on the quality groundwater have been receiving major attention both in the past and the present (Ozler *et al*., 2001; Ikem *et al*., 2002; Ebong *et al.,* 2007; SiaSu *et al*., 2008). Various major sources of pollution in groundwater include leachates from municipal refuse dumpsites, industrial discharge and domestic waste (Majolagbe *et al*., 2011). These sources generate pollutants ranging from heavy metals, N-species, chlorinated hydrocarbons, phenols, cyanides, pesticides, major inorganic species and bacteria (Adeniyi and Yusuf, 2007).

Access to portable water supplies in major cities across the country has been ever- increasingly difficult, more than 70% of the population lack access to improved water sources (World Bank Nigeria, 2000; Majolagbe *et al.,* 2011). Thus, populace would rely on the hand-dug wells and some few bore holes for their drinking water and most of this water are not suitable for drinking this is because the wells were haphazardly constructed near dumpsites discharging their leachates into them. Zaria metropolis is not an exception it has this problems due to the interrupted water supply in the entire metropolitan city. This would consequently lead to the adverse health effects on the populace. Thus the environmental impacts of municipal refuse are greatly influence by their heavy metal contents. However, while total heavy metal content is a critical measure in assessing the risk of a refuse dumpsite, it does not provide predictive insights on the bioavailability, mobility and fate of the heavy metal contaminants (Albores *et al.,* 2000). Thus, it is the chemical or species of the heavy metal that is an important factor in assessing their impacts on the environment as it controls the bioavailability or mobility (Norvell, 1984).

Past investigation on the heavy metals impacts of the underground water near dumpsites were concerned with the total heavy metal contents in soil and its sequential extraction only (Uba *et al.,* 2008). However published research on the fractionation of metals in water within the vicinity of the dumpsites in Zaria metropolis, Nigeria is not available. Thus, the research was aimed at sequentially extracting metals in the hand-well waters 100m away from the ten dump sites in Zaria metropolis. A control site was chosen at 300m away from one of the dumpsites with a view to determining the mobility and the bioavailability of Zn, Cu, Cd, Pb and Hg in the well waters in order to assess the human health and ecological risks associated with them.

2.0 Materials and Methods

2.1 Quality Assurance

All reagents used were of analytical grades, double distilled de-ionised water was used. Glass wares and polythene were washed with liquid soap, rinsed with water, soaked in 10% HNO_3 for 24hours, cleaned thoroughly with double distilled de-ionised water and dried. The analytical results obtained were validated with spiked samples. The analytical precision was confirmed by the triplicates throughout the study (Todorovi *et al*., 2001; Uba *et al.,* 2008).

2.2 Description of the Study Area

Zaria metropolis is located at latitude $11^{0}3'$ N and longitude $7^{o}40'$E and a total area of 300sq. kilometers. Presently it is one of the most important cities in Northern Nigeria. As at 2007 census, it had a population of 1,018,827people. Like many cities in Nigeria, Zaria faces problems of environmental sanitation such as improper disposal of refuse near residential areas, resulting in the contamination of the residential well waters due to the leachates migration and from the dumpsites to these water bodies since most of the wells are poorly covered. Zaria metropolis constitute four major settlements; Tudun wada, Zaria city, Sabon Gari and Samaru. Ten huge dumpsites covering the metropolitan city and a control site (CTR), 300m away from Kusfa dumpsite were selected for the study. These dumpsites are ; Samaru (SA), Alkali Jae (AJ), Babban gwani(BG), Kusfa(KU), Shafi road(SH), Prince road(PR), Jeka da kwarinka(JK), Dandaji (DD), National Tobacco Company(NTC) and Railway station(RA). Fig. 1 below showed one of the dumpsites.



Figure 1: Dumpsite Kusfa dumpsite from Zaria city

2.3 Sample Collection and Analysis

Water samples were collected from the thirty three shallow wells near the ten dumpsites, three samples from each sampling point in both dry and wet seasons (February to August, 2011) according TO standard method (APHA, 2005). The samples were collected in 1litre polyethylene bottles for metal analysis while those for mercury analysis were collected in glass bottles, labeled, kept in an ice-box and then transported to the laboratory. The samples for metal analysis were preserved with 2ml concentrated HNO_3 while those for mercury analysis were preserved in 1ml concentrated H_2SO_4 and 5% $K_2Cr_2O_7$

solution for every 100ml samples (APHA, 2005; Aiyesanmi and Imoisi, 2011).

The chemical fractionation of the water samples were carried out in accordance with procedure describe by Bäckström *et al.* (2003). The extraction was carried out on each sample using 50ml of the sample in triplicate. Polypropylene centrifuge tube was used throughout the extraction. Basically three steps are involved in this extraction.

Fraction I (Dissolved fraction): 50ml of the water samples were decanted from the sampling vessel and filtered through 0.5µm Teflon filters. The solution was then acidified with 5ml of 2%HNO_3 then made up to 25ml with de-ionized water.

Fraction II (Mobile fraction): 50ml of the water samples were decanted and acidified with 5ml 2%HNO_3. The solution is the filtered through 0.5µm Teflon filters after 24hours.The solution was then made up to 25ml with the de-ionized water.

Fraction III (Total fraction): 5ml of 2%HNO_3 were added directly to the 50ml of the water samples, the solution were shaken vigorously to suspend all the particulate matter and through 0.5µm Teflon filters after 24hrs

Fraction IV is obtainable as the difference between the **Fractions III** and **I**.

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The extracts were analysed for metals using Varian AA240FS Spectrophotometer at the Multi-User Science Research Laboratory, Ahmadu Bello University, Zaria.

3.0 Results and Discussion

3.1 Quality Assurance

The recoveries of the added metal ions obtained with spiked samples were found to be >99.3%. The percent recoveries of the metals obtained by the sequential extraction in relation to total metals recovery ranged from 100.02, 100.05 and 100.10% for copper (Cu), mercury (Hg) and zinc (Zn) respectively. However, the recoveries for lead (Pb) and cadmium (Cd) were 99.40 and 99.85% respectively as presented in the Table 1 below. High recoveries obtained in the spiked experiments validated the experimental protocol and the efficiency of the atomic absorption spectrophotometer (Okunola *et al.*, 2011).

Table 1: Percentage recovery of sequential Extraction compared with the total digestion

Metals	Sequential Extraction	Total metal
Zn	100.1	100.05
Cu	100.02	95.5
Cd	99.85	99.4
Pb	99.40	92.38
Hg	100.05	99.75

3.2 Chemical fractionation of water

Summary of the metal concentrations in sequential extracted water samples in the wet and dry seasons are presented in Tables 2 and 3.

Zinc

The extractable fractions for zinc across the sites followed the pattern: Mobile > Dissolved > Particulate > Total. The range of the bioavailable fraction which is the sum of the dissolved and mobile fractions ranged from 31.567 %(NTC) – 99.513 % (AJ). Analysis of variance showed a significant difference among all the extractable fractions ($p<0.05$). This suggests that the distribution of zinc depends partly on sources of contamination which is the dumpsite leachates. When the result was compared with the WHO (2006) standard limit (5mg/L), all the concentrations recorded among the fractions were below the toxic limit but there is fear of bioaccumulation with the time. The potential bioavailability of the metal across the sites followed the trend:

AJ >DD >KU >SH > JK > PR > SA > BG > CTR > RA > NTC.

Zinc is nutritionally important metal to life at certain concentration, thus, it is known as the essential element as it helps in various metabolic activities in the body system.

Lead

Similarly, the concentrations of the extractable fractions of lead in the underground water are shown in Tables 2 and 3. The most abundant pools for the extractable fractions are the bioavailable phase ranging from BDL (CTR) – 100% (SA, DD and BG). Bioavailability pattern across the sites was: BG > DD > SA > AJ > JK > SH > NTC > PR > RA > KU > CTR, the potential occurrence of the metal among the fractions was in the order: Dissolved > Total > Mobile > Particulate. One way ANOVA showed a significant difference ($p<0.05$) among the fractions across the sites and seasons. Compared to the WHO (2006) standard, the values recorded were all above the permissible limit of 0.001mg/L with few exceptions in the CTR and RA waters, respectively. Furthermore, values obtained in this study were higher than the values of BDL and 0.003mg/L reported by Majolagbe *et al.* (2011), in Ifo, Lagos, Nigeria. The relatively elevated levels of lead among the fractions indicate the deposition of lead containing products to the environment through the solid waste disposal thereby getting into the residential wells by the leachates percolation. Lead is generally toxic, it accumulates in the kidney and skeleton. Children up to the age of 6years and pregnant women are most susceptible to its adverse health effects, it also inhibits the activity of d-aminolaevulinic dehydrase, affecting the intelligence quotient in infant, renal tumour and carcinogenicity in adults are some other side effects (WHO, 2006), thus the inhabitants are likely to affected by the lead poisoning due bioaccumulation.

Cadmium

The concentrations of the extractable fractions of the cadmium are also presented in Tables 2 and 3. The bioavailable fraction is also the most abundant pools of the metal with few exceptions. The range of the bioavailable fraction ranged from 7.73(CTR) to 100% (NTC, SA, JK, DD, CTR and BG). The potential mobility and bioavailability of the metal across the sites followed the trend: BG > CTR > DD > JK > SA > NTC > RA > KU > SH > AJ > PR while among the fraction the pattern is: Dissolved > Total > Mobile > Particulate. Compared to the standard toxic limit of WHO (2006), the metal was above the tolerable limit of 0.003mg/L. The analysis of variance showed that the concentrations of all the extractable fractions were significantly different ($p<0.05$) both across the sites and among the fractions. The values reported in this study were higher than 0.005mg/L reported by Majolagbe *et al.* (2011) in a similar study in Benin City. Cadmium toxicity may lead to the cancer of kidney, development of hypertension, inhibition of enzymatic activity and some vascular diseases. The residents will show sign of the above mentioned diseases as they continue to consume the raw waters in the vicinity of the dumpsites. Leachates migration and air are the common sources of the metal due to the poor coverage of wells even at the control site.

Copper

Furthermore, Table 2 showed the results of copper among extractable fractions, the levels of copper found in this study were below the WHO (2006) and USEPA (2003) limits of 1.5 and 1.3mg/L, respectively. The range of the bioavailable fractions across the sites was: BDL (CTR) – 100 % (RA JK and DD), thus, DD, JK and the RA are most bioavailable and followed the distribution pattern: DD > JK > RA > AJ > PR > KU > NTC > BG > SA > SH > CTR. However, the trend observed among the fractions was: Total > Particulate > Dissolved > Mobile. The least concentrations were recorded at the control site. There was strong correlation between copper and zinc ($r = 0.984$), copper and lead ($r = 0.850$) suggesting that they have a common (dumpsites, Leachates and air). Copper was also mostly associated with the last three fractions in the PR and NTC water which is attributable to the formation constant of the organic copper complexes (Stumm and Morgan, 1981). Leachates from the dumpsites remain the major source of this metal based on its composition. Furthermore, the values recorded in this study were higher than the concentrations of 0.05 and 0.12mg/L reported in similar studies in the Ifo and Isolo from Ogun and Lagos, respectively (Majolagbe *et al.*, 2011).

Mercury

The results of the sequential extraction of mercury in the water samples are also presented in Tables 2 and 3. The bioavailability across the sites is > 85% and ranged from 85.73 (NTC) – 100% (PR, SA, KU, DD, CTR and BG wells) and followed the following pattern: BG > CTR > DD > KU > SA > PR > JK > RA > AJ > SH > NTC. Analysis of variance showed a significant difference among the fractions across the sites ($p<0.05$). In addition, mercury was positively correlated with Zn, Cu and Pb. The high concentration of mercury was also noted at the control site. Compared to the standard WHO (2006) limit of 0.001mg/L, the concentrations of mercury in this study were above the toxic limit across the sites. Furthermore, availability pattern among the fraction is: Dissolved > Mobile > Total > Particulate. The primary targets for the toxicity of to mercury and mercury compounds are nervous systems, the kidneys and the cardiovascular system. It is generally accepted that developing organ systems such as the fetal nervous system are the most sensitive to toxic effects of mercury. Other systems that may be affected include the respiratory, gastro intestinal, hematologic, immune and reproductive systems. Effects on the nervous system appear to be the most sensitive toxicological endpoint observed following exposure to elemental mercury and methylmercury while damage to the kidneys is the key end-point in exposure to inorganic mercury compounds (UNEP, 2008).

Overall, the potential bioavailability of the metals in the wet and dry season followed similar trend: Hg > Cd > Pb > Zn > Cu. The waters were heavily polluted by the toxic metals (Hg, Cd and Pb) investigated.

Moreover the trend of the metals bioavailabilities in the dry season across the sites followed the trends;

Zn: AJ > DD > KU > SH > JK > PR > SA > BG > CTR > RA > NTC

Pb : BG > DD > SA > AJ > JK > SH > NTC > PR > RA > KU > CTR

Cd : BG > DD > JK > KU > NTC > SA > RA > SH > AJ > CTR > PR

Cu : JK = DD = RA = KU > PR > AJ > NTC > BG > SA > SH > CTR

Hg : JK > KU > BG > CTR > DD > SA > PR > RA > AJ > SH > NTC.

Overall, order of the availability among the fractions followed the pattern;

Zn: Mobile > Dissolved > Particulate > Total; Pb: Total > Dissolved > Mobile > Particulate

Cd: Total > Particulate > Dissloved > Mobile; Cu: Dissolved > Mobile > Total > Particulate and Hg: Dissolved > Total > Mobile > Particulate respectively. Similarly, the bioavailability ranges for the metals were: Zn: 31.50(NTC) – 99.513%(AJ); Pb: BDL(CTR) – 100%(SA, DD and BG); Cd: 67.88(PR) 100% (NTC, RA, SA, KU, JK, DD and BG) ; Cu: BDL(CTR) – 100%(D, JK and RA) and the range for the mercury is 87.497(NTC) – 100% (BG, CTR, DD, JK, KU, SA and PR) respectively. The concentrations of cadmium, lead and mercury exceeded the WHO (2006) tolerable limits, more than 50% of the extractable fractions were in the bioavailable phase resulting in bioaccumulation in the tissues and organs of the inhabitants that usually use the water for drinking in addition to the other domestic use. Most of studied wells were open or poorly covered; this has made it easier for the heavy metals in the particulates to get into the water contaminating it. Other metals investigated in this study were within the WHO tolerable limits.

4.0 Conclusion

A sequential extraction was used to fractionate Zn, Cu, Pb, Cd and Hg in the hand-dug wells 100m away from the ten dumpsites in Zaria metropolis. The bioavailable fractions across the sites and among the fractions were the most abundant pools for all the metals. More than 60% of the total extractable fractions were not in the bioavailable fractions in most of the sites. The concentrations of the cadmium, lead and mercury were above the WHO (2006) tolerable limits in both the wet and dry seasons. However, higher concentrations of the entire metals were higher in the wet than those in the dry season; this is attributed to the leaching of the contaminants to the open wells contaminating the underground water. Overall, the trend of the metals availability in both seasons was found to be similar: Hg > Cd > Pb > Zn > Cu. The analysis of variance showed a significant difference among the fractions and across the sites ($p<0.05$). This strongly

indicates the existence of pollution at the wells in the vicinity of the dumpsites leading to serious health problems to the consumers. The toxicity of Pb, Cd and Hg leads to the kidney cancer, hypertension, inhibition of the enzymes, cardiovascular diseases, hematologic, gastrointestinal and immune systems. The concentrations of zinc and copper were found below the WHO (2006) tolerable limits; hence the raw waters in these sites were heavily contaminated by Cd, Pb and Hg and unfit for drinking including those in the control site until subjected to further treatment.

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References

Adeniyi, A. A. and Yusuf, K. A. (2007). Determination of heavy metals in fish tissues, water and bottom sediments from Epe and Badagry Lagoons, Lagos, Nigeria. *Environ. Monitor. Assess.*, **37:** 451-458.

Aiyesanmi, A. F. and Imoisi, O. B. (2011). Understanding leaching behaviour of landfill leachate in benin-city, edo state, Nigeria through dumpsite monitoring. *British Journal of Environment & Climate Change,* **1(4):** 190-200.

Albores, A. F., Perez-cid, B., Gomes, E. F., Lopez, E. F. (2000). Comparison between sequential extraction procedures and metal partitioning in sewage sludge samples. *Analyst.* **125:** 1353-1357

APHA (2005). Standard method for examination of water and waste water. Water Environmental Federation, *American Public Health Association New York, U.S.A.*

Bäckström, M., Ulrika, N. Karsten, H., Bert, A. and Stefan, K. (2003). Speciation of heavy metals in road runoff and roadside total deposition. *Water, Air and Soil Pollution*, **147:** 343-366.

Dara, S. S. (2008). Envirnmental Chemistry and Polluiton Control. *S. Chand and Company Ltd.* 15th ed. Pp65-66

Ebong, G. A., Akpan, M. M. and Mkpenie, V. N. (2008). Heavy metal contents of municipal and rural dumpsite soils and rate of accumulation by *carica papaya* and *talinum triangulare* in Uyo, Nigeria. *E-Journal of Chemistry*, **5(2):** 281 – 290.

Fatta, D., Papadopoulos, A. and Loizidou, M (1999). A study on the landfill leachate and its impact on the groundwater quality of the greater area. *Environ. Geochem. Health*, **21(2):** 175-190.

Ikem, A., Osibanjo O., Shridhar, M. K., Sobande, A. (2002). Evaluation **of** groundwater quality characteristics near two waste sites in Ibadan and Lagos, Nigeria. *Water, Air and Soil Pollution*, 140: 307

Majolagbe, A. O., Kasali, A. A. and Ghaniyu, L. O. (2011). Quality Assessment of Groundwater in the Vicinity of Dumpsites in Ifo and Lagos, Southwestern Nigeria. *Advance in Applied Science Research*. **2(1):** 289-298

Norvell, W. A. (1984): Comparison of Chelating Agents for metals in Diverse Soil Materials. *Soil Sci. Soc. Am. J.* 48: 1285-1292

Norwell, W. A. *(*1984*).* Comparison of chelating agents as extractants for metals in diverse soil material. *Soil Sci. Soc. Am. J.*, **48:** *1285 – 1292.*

Odukoya, O. O., Bamgbose, O. and Arowolo, T.A. (2000). Heavy metals in Topsoil of Abeokuta Dumpsites. *Global J. Pure Applied Sci*. 7:467-472.

Okunola, O. J., Uzairu, A., Gimba, C. E. and Kagbu, J. A. (2011). Metals in roadside soils of different grain sizes from high traffic roads in Kano Metropolis, Nigeria. *Toxicological and Environmental Chemistry*, **93(8):** 1572 – 1590.

Ozler, H. M. (2001). 1st Morrocco international Conference on Saltwater Intrusion and Coastal Aquifer Monitoring, Modelling and management.

Siasu, L.G. (2008). Assessing the effect of a dumpsite to groundwater quality in Payatas Phillipines. *Am. J. Env. Sci*. 4(4): 276-280

Stumm, W. and Morgan, J. J. (1981). Aquatic Chemistry: An Introduction Emphasizing Chemical Equalibria in Natural Water.12 2nd Edn., John Wiley and Sons, New York, USA., pp: 86-213.

Todorovi, Z., Poli. P., Djordjevi, D. and Antoni jevi, S. (2001]) Lead Distribution in Water and it's Association with Sediment Constituents of the Barje Lake (Leskovae, Yugoslavia). *J. Serb. Chem. Soc*. 66(1): 697- 708.

Uba, S., Uzairu, A., Harrison, G. F. S., Balarabe, M. L. and Okunola, O. J. (2008). Assessment of Heavy Metals Bioavailabilty in Dumpsites of Zaria Metropolis. *African Journal Biotechnol*., **7(2):** 122-130.

UNEP (2008). United Nations' Environmental Programme. Issued by WHO Department of Food Safety, Zoonorses and Foodborne Diseases, *Geneva, Switzerland. UNEP chemicals.* 11-13 : CH-1219

WHO (2006). Guidelines for Drinking Water Quality Washington D.C. first addendum to third edition. Volume 1 recommendation.

Word Bank Nigeria(2000). Community Based Urban Development Project. NGPE 69901,1818H street, *N.W. Washington*.20433.

Table 2: Mean Concentration (mg/l) of fractionated heavy metals in the wells water near the dumpsites of Zaria Metropolis during the wet season

METAL	FRACTION	SITE											
		AJ	BG	CTR	DD	JK	KU	SA	SH	RA	PR	NTC	WHO
Zn	Dissolved	0.197	0.130	0.070	0.082	0.104	0.114	0.266	0.084	1.391	0.077	0.246	5.000
	Mobile	4.707	0.086	BDL	0.197	0.234	3.164	0.163	0.134	0.035	0.407	0.305	
	Total	0.221	0.185	0.141	0.085	0.090	0.171	0.324	0.091	2.364	0.099	1.462	
	Particulate	0.024	0.0547	0.027	0.003	0.013	0.067	0.059	0.007	0.973	0.029	1.217	
	Bioavailable (%)	99.513	79.891	72.450	98.938	96.303	97.998	87.967	97.581	59.737	95.026	31.567	
Pb	Dissolved	0.127	0.176	BDL	0.161	0.136	0.083	0.250	0.164	0.835	0.114	0.156	0.001
	Mobile	0.210	0.218	BDL	0.210	0.216	BDL	0.177	0.182	BDL	0.214	0.155	
	Total	0.129	BDL	BDL	0.128	0.159	0.187	BDL	0.194	1.877	0.248	0.20	
	Particulate	0.002	BDL	BDL	BDL	0.023	0.104	BDL	0.031	1.041	0.135	00.048	
	Bioavailable (%)	99.594	100.000	0.000	100.000	95.693	72.193	100.000	94.571	72.262	81.013	91.489	
Cd	Dissolved	0.046	0.037	0.003	0.039	0.037	0.051	0.056	0.037	0.150	0.033	0.040	0.003
	Mobile	0.059	0.0401	0.032	0.058	0.058	0.053	0.029	0.003	0.046	0.059	0.061	
	Tot	0.134	0.028	BDL	0.0338	0.028	0.0388	0.045	0.059	0.0597	0.060	0.040	
	Particulate	0.087	BDL	BDL	BDL	BDL	0.025	BDL	0.021	0.025	0.057	BDL	
	Bioavailable (%)	73.370	100.000	100.000	100.000	100.000	85.119	100.000	82.456	91.094	72.727	100.000	
Cu	Dissolved	0.120	BDL	BDL	BDL	BDL	0.006	0.013	BDL	17.862	BDL	BDL	1.300
	Mobile	0.037	0.035	BDL	0.092	0.042	0.016	0.004	BDL	0.077	0.070	0.062	
	Total	0.047	0.085	BDL	BDL	BDL	0.017	96.666	0.077	0.131	0.026	0.085	
	Particulate	0.047	0.085	BDL	BDL	BDL	0.011	96.653	0.077	BDL	0.026	0.085	
	Bioavailable (%)	81.275	58.537	0.000	100.000	100.000	78.000	50.008	50.000	100.000	78.689	63.362	
Hg	Dissolved	0.957	2.163	0.645	3.543	1.027	1.936	1.650	1.032	0.908	1.150	1.333	0.001
	Mobile	0.796	1.276	0.744	1.395	2.315	1.055	1.172	0.440	2.720	1.260	0.773	
	Total	1.358	1.769	0.581	1.238	0.721	0.593	1.077	1.411	1.259	0.880	2.021	
	Particulate	0.401	BDL	BDL	BDL	0.077	BDL	BDL	0.3781	0.351	BDL	0.687	
	Bioavailable (%)	88.582	100.000	100.000	100.000	98.140	100.000	100.000	88.406	93.299	100.000	85.729	

BDL: BELOW DETECTION LIMIT
WHO: World Health Organization (2006). Standards for metals in water

Table 3: Mean Concentration (mg/l) of fractionated heavy metals in the wells water near the dumpsites of Zaria Metropolis during the dry season

METAL	FRACTION	SITE										
		AJ	BG	CTR	DD	JK	KU	SA	SH	RA	PR	NTC	WHO
Zn	Dissolved	0.131	0.086	0.051	0.0543	0.069	0.076	0.177	0.055	0.927	0.046	0.163	5.00
	Mobile	3.138	0.057	BDL	0.131	0.158	2.109	0.110	0.089	0.010	0.271	0.203	
	Total	0.147	0.123	0.056	0.094	0.060	0.114	0.216	0.060	1.576	0.065	0.975	
	Particulate	0.016	0.036	0.018	0.0019	0.008	0.044	0.040	0.005	0.650	0.019	0.811	
	Bioavailable (%)	99.513	79.986	74.164	98.987	96.602	98.027	88.056	96.913	59.401	94.304	31.499	
Pb	Dissolved	0.191	0.265	BDL	0.243	0.204	0.125	0.375	0.245	1.253	0.171	0.235	0.10
	Mobile	0.315	0.326	BDL	0.315	0.324	BDL	0.265	0.273	BDL	0.321	0.017	
	Total	0.194	BDL	BDL	0.192	0.239	0.281	BDL	0.292	2.816	0.373	0.307	
	Particulate	0.003	BDL	BDL	BDL	0.040	0.156	BDL	0.045	1.562	0.201	0.072	
	Bioavailable (%)	99.573	100.000	0.000	100.000	95.636	72.242	100.000	94.737	72.261	81.144	88.306	
Cd	Dissolved	0.031	0.025	0.020	0.026	0.030	0.034	0.040	0.025	0.100	0.002	0.027	0.003
	Mobile	0.040	0.027	0.02	0.039	0.038	0.035	0.019	0.003	0.010	0.040	0.040	
	Total	0.089	0.019	BDL	0.022	0.019	0.026	0.030	0.039	0.040	0.040	0.027	
	Particulate	0.060	BDL	BDL	BDL	BDL	BDL	BDL	0.014	BDL	0.039	0.020	
	Bioavailable (%)	73.272	100.000	72.581	100.000	100.000	100.000	100.000	82.788	100.000	67.884	100.000	
Cu	Dissolved	BDL	BDL	BDL	BDL	BDL	0.005	0.009	BDL	13.530	BDL	BDL	1.500
	Mobile	0.027	0.026	BDL	0.069	0.031	0.012	0.029	BDL	0.058	0.079	0.05	
	Total	0.040	0.060	BDL	BDL	BDL	0.0129	73.200	0.060	0.090	0.029	0.060	
	Particulate	0.040	0.06	BDL	BDL	BDL	0.079	73.22	0.060	BDL	0.029	0.064	
	Bioavailable (%)	63.918	58.442	0.000	100.000	100.000	79.045	50.008	49.915	100.000	78.468	63.429	
Hg	Dissolved	0.53	0.842	0.209	0.920	1.528	0.491	0.773	0.290	1.795	0.832	0.510	0.001
	Mobile	0.891	1.160	0.380	0.813	0.473	0.389	0.707	0.926	0.827	0.578	1.327	
	Total	0.896	1.170	0.380	0.817	0.476	0.391	0.711	0.931	0.831	0.581	1.33	
	Particulate	0.264	BDL	BDL	BDL	BDL	BDL	BDL	0.249	0.231	BDL	0.453	
	Bioavailable (%)	89.752	100.000	100.000	100.000	100.000	100.000	100.000	89.608	93.730	100.000	87.497	

BDL: BELOW DETECTION LIMIT
WHO: World Health Organization (2006). Standards for metals in water