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Human Health Risk Assessment of Heavy Metals in Kampala (Uganda) Drinking Water

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Abstract

Levels of aluminium, arsenic, cadmium, chromium, copper, iron, mercury, manganese, nickel, lead and zinc in tap water, groundwater-fed protected spring and bottled water were determined. The cancer and non-cancer risks associated with ingestion of heavy metals (HM) were also assessed for both children and adults. Forty seven water samples obtained from five divisions of Kampala city were analyzed using atomic absorption spectrophotometry. Cancer and non-cancer risks were determined using incremental lifetime cancer risk (ILCR) and non-carcinogenic hazard quotient (HQ), respectively. Lead content was higher than permissible limits (PL) according to East African Standard, World Health Organization, European Union and United States Environmental Protection Agency (USEPA). Arsenic showed minor exceedances above guideline values in tap water and groundwater-fed protected spring, whereas mercury, manganese and nickel were higher than PL. Levels of aluminium, cadmium, chromium, copper, iron, and zinc were below the PL. The lifetime risk of developing cancer through the oral route was greater than the USEPA acceptable level for both children and adults, revealing that exposure to HM in drinking water posed an unacceptable potential cancer risk. Arsenic contributed ca. 90% of the ILCR in tap water and groundwater-fed protected spring. The combined non-cancer risk of the HM expressed as hazard index (HI) was greater than one, with values for children being higher than those for adults. Lead contribution towards HI was in all cases above 90%. These results demonstrate the presence of alarming non-cancer risks for children.

Key words: heavy metal, risk, cancer, non-cancer, drinking water

1. Introduction

Environmental contamination and human exposure to heavy metals (HM) such as mercury (Hg), cadmium (Cd), lead (Pb), arsenic (As) and nickel (Ni), is a serious problem throughout the world (Orisakwe, 2014). Heavy metals accumulate in the environment through emissions from industries, industrial effluents, use of leaded gasoline and paints, agricultural activities, indiscriminate disposal of municipal wastes and incineration of toxic substances (Muwanga & Barifaijo, 2006). African countries, including Uganda, are nowadays faced with a crisis of industrial waste management due to absence or weak guidelines on HM pollution and environmental management (Okot-Okumu & Nyenje, 2011). Generated waste, in Uganda, is estimated between 1.2 and 3.8 kg/capita/day. Barriers to proper urban waste management also include lack of funds and poor governance (Oosterveer & Van Vliet, 2010). Therefore, reforms to build institutional capacity in order to mitigate the rapid buildup of HM in aquatic ecosystems in African countries are essential. So far, decentralization has been proposed to involve local actors in the environmental and natural resource management in Africa (Oosterveer & Van Vliet, 2010).

Human exposure to toxic metals is a global environmental health burden. Arsenic, Pb, Hg and Cd are systemic environmental toxicants that have been implicated in causing cancer, neurological and cardiac problems, and kidney damage (Fernández-Luqueño et al., 2013). In Uganda, Pb and Cd levels in excess of WHO limits have been reported in edible vegetables from the Lake Victoria basin wetlands (Mbabazi, Wasswa, Kwetegyeka, &

Bakyaita, 2010). Lead and Hg have been detected in African fish eagles, Marabou storks and Nile perch (Hollamby et al., 2004; Ogwok, Muyonga & Sserunjogi, 2009). Further, high levels of Pb and Cd have been reported in milk from farms in Wakiso district (Nyakairu, Muhwezi & Biryomumaisho, 2011). Based on the adverse effects of HM, information on their levels in drinking water is required to guide policy.

Access to safe drinking water contributes directly to good health, food security, poverty eradication and the long-term socio-economic development of a country (Opio, 2012). Many studies have been conducted in reference to the concentration and potential health risks associated with toxic metals, as well as necessary elements in surface, ground and bottled waters around the world (Hadiani, Dezfooli-manesh, Shoebi, Ziarati, & Khaneghah 2014; Kolawole & Obueh, 2015). However, there is limited data on both the chemical water quality monitoring and human health risk assessment (HHRA) of HM in drinking water in Uganda. Therefore, the objectives of this study were to determine the concentration of aluminium (Al), chromium (Cr), iron (Fe), manganese (Mn), As, Cd, Cu, Hg, Ni, Pb and Zn contained in tap water, groundwater-fed protected spring and selected brands of bottled water in Kampala city. The cancer and non-cancer risks associated with ingestion of HM from the daily water consumption were also assessed.

2. Materials and Methods

2.1 Study Area

The study area was Kampala, the Capital City of Uganda. The city lies at latitude 0.3476 °N and longitude 32.5825 °E, and 1223 m (4012 ft) above sea level. It covers a total area of 189 square kilometers (73 sq. miles) with a radius of 6 km. Kampala has a tropical climate with an average annual temperature of 21.3 °C, and average annual rainfall of *ca.* 1,400 mm, with peaks in April and November.The resident population of Kampala is estimated to be 1,936,080 (0.78 male: 1.0 female) inhabitants of whom 16% are children 5 to 9 years of age (UBOS, 2016). Sixty percent of Kampala's population resides and or works within the peri-urban areas of the city. Most peri urban areas are low lying (mostly reclaimed wetlands) with a high water table (< 1.5 m).

2.2 Materials

Analytical grade nitric acid (Sigma-Aldrich) was used in the study. Distilled water was used to prepare solutions and for dilution purposes. All glassware were washed and dried in the oven at 105 °C. Bottles for collecting water samples were cleaned by soaking in dilute nitric acid (10%) and rinsed several times with distilled water prior to sample taking. Water samples were obtained from public water-taps and groundwater-fed protected springs around Kampala. Bottled water was purchased from different places in the city.

2.3 Sample Collection

Samples of water were randomly obtained from 8 public water taps and 12 groundwater-fed protected springs in the five divisions of Kampala, within a radius of 5 km from the city center. Three samples, each of 500 ml, were obtained per sampling point. Also, 3 samples of each of 9 bottled water brands were purchased from local shops, supermarkets and public transport stations. Sampling was done between September and November 2015.

2.4 Determination of Heavy Metals

Levels of metals in water were determined on a Shimadzu Electro-thermal Graphite Furnace Atomic Absorption Spectrophotometer (GF-AAS) equipped with High-speed Deuterium (BGC-D2) and Self-Reversal method background correction (BGC-SR) along with an ASC6100 auto-sampler (Shimadzu Corporation, Japan). Analysis was done at the Natural Chemotherapeutics Research Institute (NCRI) chemistry laboratory. Standard solutions of the respective metals were prepared at 5 different concentrations and the absorbance (A) determined. A calibration curve was in each case generated. The calibration curves were linear within the range of concentrations used, with regression coefficients (R^2) > 99.9%. Each of the water samples was aspirated into the AAS and the absorbance measured was used to determine the concentration of the metal from the calibration curve. This procedure was repeated three times and the average concentration obtained. Analysis was done at wavelength (λ) 309.3, 193.7, 228.8, 357.9, 324.8, 248.3, 253.7, 279.5, 232.0, 283.3, and 213.9 nm for Al, As, Cd, Cr, Cu, Fe, Hg, Mn, Ni, Pb and Zn, respectively. The metal concentrations expressed as mg/L, were compared with permissible limits for HM in drinking water set by East African Community (EAC), United States Environment Protection Agency (USEPA), World Health Organization (WHO) and the European Union (EU) shown in Table 1.

Table 1. Permissible limits of heavy metal concentrations (mg/L) in drinking water for different international agencies

Agency	Element										
	Al	As	Cd	Cr	Cu	Fe	Hg	Mn	Ni	Pb	Zn
EU (1998)	0.2	0.01	0.005	0.05	2	0.2	0.001	0.05	0.02	0.01	-
WHO (2008)	0.2	0.01	0.003	0.05	2	0.3	0.006	0.4	0.07	0.01	3
USEPA (2009)	0.2	0.01	0.005	0.1	1	0.3	0.002	0.05	0.1	0.015	5
UNBS (2014)	0.2	0.01	0.003	0.05	1	0.3	0.001	0.1	0.02	0.01	5

2.5 Human Health Risk Assessment

Human health risk assessment (HHRA) involves estimation of the nature and magnitude of adverse health effects in humans who may be exposed to hazards in contaminated environmental media. Risk assessment consisted of hazard identification, exposure assessment, dose-response (toxicity) and risk characterization (Adamu, Nganje, & Edet, 2015). The health risk assessment of each potentially toxic HM was done based on the quantification of the risk level and expressed in terms of cancer and non-cancer health risks (Sun, Zhang, Ma, & Chen, 2015). Two toxicity risk indices reported were the cancer slope factor (CSF) for cancer risk characterization and the oral reference dose (RfD) for non-cancer risk characterization (Adamu, Nganje, & Edet, 2015).

2.5.1 Exposure Assessment

In order to assess both non-cancer and cancer risks for children and adults from ingestion of drinking water, the chronic daily intakes (CDI) of toxic metals, which represents the lifetime average daily dose (LADD) of exposure to a chemical contaminant were used (Yu, Wang, & Zhou, 2014). The CDI ($mgkg^{-1}day^{-1}$) of toxic metals via water was calculated using equation 1:

$$CDI = (C \times IR \times EF \times ED)/ (BW \times AT) \quad (1)$$

where: CDI is the chronic daily intake (mg/kg/day); C is the concentration of the contaminant in tap, groundwater-fed protected spring and bottled water (mg/L); IR is the ingestion rate per unit time (1L/day for child and 2L/day for adult); ED is the exposure duration (6 years for child and 30 years for adult); EF is the exposure frequency (365 days/year); BW is body weight (15 kg for child and 70 kg for adult); AT is the averaging exposure time (for carcinogens, AT=70×365=25550 days for both children and adults; for non-carcinogens, AT=ED×365 which equals 2190 days and 10950 days for children and adults, respectively) (USEPA, 1989).

2.5.2 Non-cancer Risks

Non-cancer risks due to non-carcinogenic effects of HM in drinking water were determined by the non-cancer hazard quotient using equation 2:

$$HQ = CDI/RfD \quad (2)$$

where: HQ = non-cancer hazard quotient; CDI = chronic daily intake (mg metal/kg/day); RfD = chronic oral reference dose, which is an estimate of a daily oral exposure level for the human population, including sensitive subpopulations, that is likely to be without an appreciable risk of deleterious effects during a lifetime (Bamuwamye, Ogwok, & Tumuhairwe, 2015).

Potential risk to human health through more than one HM, was measured by the chronic hazard index (HI), which is the sum of all HQ calculated for individual HM (Li, et al., 2013). A value of HQ or HI < 1 implies no significant non-cancer risks; a value ≥ 1 implies significant non-cancer risks, which increase with increasing value of HQ or HI (Wei, et al., 2015).

2.5.3 Cancer Risks

Cancer risks were expressed in terms of incremental lifetime cancer risk (ILCR), which is the probability that one may develop cancer over a 70-year lifetime due to a 24 hour exposure to a potential carcinogen (Adamu, Nganje, & Edet, 2015). Cancer risk was calculated as the product of CDI (mg/kg-day) and cancer slope factor (CSF) measured in $(mg/kg/day)^{-1}$. The latter is the risk produced by a lifetime average dose of 1 mg/kg body weight/day of a contaminant. Cancer risk was calculated as follows (Adamu, Nganje & Edet, 2015):

$$ILCR = CDI \times CSF \quad (3)$$

where: ILCR = incremental lifetime cancer risk; CDI = chronic daily intake (mg/kg BW/day); CSF= cancer slope factor $(mg/kg/day)^{-1}$.

The total cancer risk as a result of exposure to multiple contaminants due to consumption of a particular type of water was assumed to be the sum of the individual metal incremental risks (∑ILCR, n=1 to n). The USEPA considers the minimum or acceptable cancer risk for regulatory purposes within the range of 1×10^{-6} to 1×10^{-4} (Li et al., 2013).

3. Results and Discussion

3.1 Heavy Metal Concentration in Drinking Water

3.1.1 Tap Water

Levels of Pb in tap water ranged from 0.017 to 0.31mg/L (Table 2). Arsenic was detected in substantial amounts (0.005 to 0.014 mg/L) while Cu concentrations (0.006 to 0.036 mg/L) were low. Lead and As concentrations were above the 0.01 mg/L limit prescribed for either metal by WHO, EAC and EU. Manganese concentration ranged from not detected to 0.337mg/L. The levels of Mn in tap water were therefore below the maximum allowable limit set by WHO. However, two sampled water taps had Mn level above EU, EAC, and USEPA recommendations (Table 1). Nickel concentration (not detected to 0.17 mg/L) was higher than all maximum allowable limits considered in this study. Mercury concentration in tap water was below WHO recommendations but above USEPA, EU and EAC limits. The concentrations of Fe and Zn were rather low. Aluminium and Cd were not detected in all the samples.

Lead levels in tap water in Kampala were lower than previously reported in the East Africa region (Table 5). Lead in tap water is possibly a result of corrosion of older fixtures or from the solder that connects pipes (Gaur, Singh, & Saxena, 2011). Polyvinyl chloride (PVC) pipes, used on the national water supply grid in Uganda, and for domestic water supply around Kampala, also contain Pb compounds as cost effective form of stabilizer. Lead can leach into the water when it flows through leaded pipes for several hours. Similarly, Ni has its origin in pipes and installations (Sankar & Rao, 2014). This explains the observed levels of Pb and Ni in the tap water in Kampala city. Arsenic, Mn and Hg have been reported in high concentrations in drinking water in Africa (Ahoulé, Lalanne, Mendret, Brosillon, Maiga, 2015). In Kampala, As, Mn and Hg found in water may be related to sand mining operations, agricultural drains, improper waste disposal, and incineration of toxic wastes around Lake Victoria (Muwanga & Barifaijo, 2006; Okot-Okumu & Nyenje, 2011). Tap water contamination by Hg could be linked to gold mining reported along Lake Victoria shores (Van Straaten, 2000). On the other hand, drinking water naturally contains very low amounts (0.01 to 0.05 g/L) of Cr except for regions with substantial deposits (Mebrahtu & Zerabruk, 2011). Drinking water seldom contains Zn at concentrations > 0.1 mg/litre, but high levels in tap water can be due to leaching from older galvanized plumbing materials. Low amounts of Cd in tap water could be due to coagulation or precipitation used in municipal water treatment that reduces Cd concentration to levels ≤ 0.002 mg/litre. These factors support the observed levels of Cr, Zn and Cd in tap water in Kampala.

Table 2. Concentration (mg/L) of heavy metals in Tap water (mg/L) in Kampala

Metal	Water tap (n=08)								Minimum	Maximum
	1	2	3	4	5	6	7	8		
Al	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
As	0.014	0.005	0.009	0.011	0.011	0.013	0.010	0.011	0.005	0.014
Cd	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Cr	n.d.	n.d.	n.d.	n.d.	0.026	0.034	n.d.	n.d.	n.d.	0.034
Cu	0.008	0.036	0.014	0.024	0.017	0.019	0.032	0.006	0.006	0.036
Fe	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.029	0.029	n.d.	0.029
Hg	0.002	n.d.	n.d.	0.001	0.002	0.002	0.001	0.003	n.d.	0.003
Mn	n.d.	0.337	n.d.	n.d.	n.d.	n.d.	0.297	n.d.	n.d.	0.337
Ni	0.096	n.d.	n.d.	0.029	0.058	0.170	0.163	0.04	n.d.	0.170
Pb	0.178	0.192	0.266	0.192	0.178	0.017	0.310	0.090	0.017	0.310
Zn	0.756	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.756

n.d.: not detected

3.1.2 Groundwater-fed Protected Spring

Lead and As were in concentrations ranging from 0.105 to 0.412 mg/L and 0.008 to 0.014 mg/L, respectively (Table 3). Arsenic showed minor exceedances above guideline values in groundwater-fed protected spring while Pb was well above the prescribed limit of 0.01mg/L according to WHO, USEPA, EU and EAC (Table 1).

Mercury concentration of not detected to 0.004mg/L implies that all springs had Hg level below the WHO limit of 0.006 mg/L. However, the majority of the springs had mercury level above EU and EAC limits. The concentration (not detected to 1.501 mg/L) of Mn in most groundwater-fed protected springs exceeded recommended limits (Table 1). Nickel had a maximum concentration of 0.373 mg/L with half of the springs having values above WHO, USEPA, EU and EAC limits. Levels of Pb, As, Hg, Mn, and Ni in groundwater generally exceeded prescribed limits. Chromium, Cu, Fe Al, Cd and Zn were in low amounts in groundwater. Chromium was below detection limit with the exception of one spring, which had Cr concentration above WHO, EAC and EU recommendations. Similarly, the Cu concentrations (not detected to 0.062 mg/L) and that of Fe ranging from not detected to 0.084 mg/L were low. Aluminium, Cd and Zn were not detected in groundwater.

Groundwater-fed protected spring contained Pb, Cu, Ni and Mn concentrations within ranges previously reported for groundwater in Africa (Table 5). On the other hand, Cr, Fe, Al, Cd, Zn and As levels were far lower than reported elsewhere. Despite the high toxicity of Hg, it is not widely studied in Africa. However, surface water and borehole water from Nigeria has been reported to contain Hg concentrations (2.179 to 3.148 and 1.38 to 2.806 mg/L, respectively) far above recommended limits (Abdullahi et al., 2016). An increased level of HM in groundwater in Kampala can largely be attributed to indiscriminate disposal and incineration of toxic wastes, large-scale application of agrichemicals, use of lead-based gasoline and dissolution from rocks (Muwanga & Barifaijo, 2006; Okot-Okumu & Nyenje, 2011). Solid waste streams including domestic, industrial, healthcare, and commercial sources that contribute to urban waste load in Kampala are poorly managed (Okot-Okumu & Nyenje, 2011). Lack of appropriate waste disposal, and improper waste management in Kampala allows leakage of heavy metals into groundwater. A national strategy to control inappropriate waste disposal and use of agrichemicals to reduce influx of HM in water is therefore required.

Table 3. Concentration (mg/L) of heavy metals in groundwater-fed protected spring around Kampala

Metal	Groundwater-fed protected spring (n=12)												Minimum	Maximum
	1	2	3	4	5	6	7	8	9	10	11	12		
Al	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
As	0.011	0.009	0.008	0.01	0.01	0.009	0.01	0.013	0.008	0.014	0.012	0.008	0.008	0.014
Cd	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Cr	n.d.	n.d.	n.d.	n.d.	0.098	0.005	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.098
Cu	0.035	0.05	0.049	0.02	n.d.	0.032	0.38	0.062	0.049	0.051	0.038	0.047	n.d.	0.062
Fe	n.d.	n.d.	0.046	0.080	n.d.	n.d.	0.084	0.058	0.005	n.d.	n.d.	0.037	n.d.	0.084
Hg	0.003	0.004	0.004	n.d.	n.d.	0.002	n.d.	0.004	0.001	0.002	0.002	n.d.	n.d.	0.004
Mn	n.d.	n.d.	0.188	n.d.	0.712	n.d.	0.970	0.570	1.501	0.884	1.213	0.987	n.d.	1.501
Ni	n.d.	n.d.	n.d.	0.18	0.078	n.d.	0.185	n.d.	0.21	0.179	n.d.	0.373	n.d.	0.373
Pb	0.280	0.105	0.266	0.266	0.266	0.383	0.207	0.134	0.207	0.134	0.354	0.412	0.105	0.412
Zn	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.

n.d.: not detected

3.1.3 Bottled Water

Of the eleven elements considered in this study, Pb and Cr were detected in bottled water in Kampala city. Lead concentration was in the range of 0.091 to 0.241 mg/L (Table 4). Chromium was detected in most bottled water brands with concentration of up to 0.107 mg/L. Levels of Pb in bottled water exceeded prescribed limits by WHO, USEPA, EU and EAC. On the contrary, except for two bottled water brands, the amount of Cr was below permissible limits. In Uganda, bottled water is obtained from a variety of sources including protected underground springs, wells and municipal supplies. The water is filtered through multi-barrier filtration systems, reverse osmosis and micro-filtration. Further treatment may include exposure to ultraviolet light or ozonation. These methods remove up to 80% of HM, which explains why most elements were not detected in bottled water. However, the methods may probably not remove Pb and Cr to that magnitude. Lead levels in this study are within the range of 0.008 to 0.253 mg/L previously reported for bottled water in Kampala (Semuyaba, Segawa, & Wamala, 2014).

Table 4. Concentration (mg/L) of heavy metals in bottled water in Kampala

Metal	Bottled water Brand (n=27)									Minimum	Maximum
	1	2	3	4	5	6	7	8	9		
Al	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
As	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Cd	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Cr	0.0168	n.d.	n.d.	0.03	0.107	0.006	n.d.	0.031	0.065	n.d.	0.107
Cu	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Fe	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Hg	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Mn	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Ni	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Pb	0.195	0.180	0.169	0.172	0.2	0.241	0.146	0.091	0.182	0.091	0.241
Zn	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.

n.d.: not detected

Table 5. Levels (mg/L) of heavy metals in drinking water from selected African environments

Country	DW source	Element											Reference
		Al	As	Cd	Cr	Cu	Fe	Hg	Mn	Ni	Pb	Zn	
Uganda	TW	n.d.	0.005-0.014	n.d.	n.d.-0.034	0.006-0.036	n.d.-0.105	n.d.-0.003	n.d.-0.337	n.d.-0.017	0.017-0.31	n.d.-0.7558	This study
	GW	n.d.	0.008-0.014	n.d.	n.d.-0.098	n.d.-0.062	n.d.-0.084	n.d.-0.004	n.d.-1.501	n.d.-0.373	0.105-0.412	n.d.	
	BW	n.d.	n.d.	n.d.	n.d.-0.107	n.d.	n.d.	n.d.	n.d.	n.d.	0.091-0.241	n.d.	
Uganda	TW	-	-	-	-	-	-	-	-	-	0.9-1.9	-	Mghweno, et al. (2008)
	SW	-	-	-	-	-	-	-	-	-	3.2-6.1	-	
Uganda	BW	-	-	-	-	-	-	-	-	-	0.008- 0.253	-	Semuyaba, et al. (2014)
Uganda	SW	-	-	0.09-0.11	0.01-0.02	1.0-2.1	15.0-21.1	-	-	-	0.91-1.64	0.20-0.50	Fuhrimann, et al. (2015)
Kenya	SW	-	-	-	0.23 –0.79	0.69 – 0.94	-	-	0.05–3.276	-	0.26–0.99	0.22	Oyoo-Okoth, et al. (2010)
Tanzania	GW	-	-	-	-	n.d.-0.013	-	-	-	-	0.01-0.35	0.01-0.28	Mkude (2015)
Rwanda	Well	-	-	-	-	-	0.02-0.45	-	0.003-0.42	-	-	0.02-0.15	Nigatu et al. (2015)
Ethiopia	DW	-	0.39-1.06	n.d.	n.d.	n.d.	0.134-0.307	-	0.025-0.031	n.d.	0.052-1.347	0.439-5.055	Mebrahtu & Zerabruk (2011)
Egypt	SW	0.136-0.864	-	-	-	0.003-0.012	0.160-4.03	-	0.001-0.474	-	n.d.	-	El-Sayed & Salem (2015)
	GW	0.125-1.69	-	-	-	0.0001-0.018	0.40-1.88	-	0.017-1.095	-	0.028-0.179	-	
Nigeria	SW	-	-	0.004-0.011	0.16-1.65	-	0.351-12.0	-	0.10-5.15	-	0.02-2.5	-	Afiukwa (2013)
	GW	-	-	0.004-0.012	0.208-0.29β	-	0.40-1.88	-	0.10-3.34	-	0.028-0.179	-	
Nigeria	Well	-	-	n.d.-0.003	-	n.d.-0.003	n.d.-3.428	2.179-3.148	0.057-0.175	n.d.-0.006	n.d.-0.021	-	Abdullahi, et al. (2016)
	Borehole	-	-	n.d.-0.056	-	n.d.-0.193	0.228-23.256	1.38-2.806	0.035-1.787	n.d.-0.03	n.d.-0.194	-	

TW: Tap water; BW: Bottled water; SW: Surface water; GW: Ground water; DW: Drinking water; n.d.: not detected

3.2 Human Health Risk Assessment

Cancer and non-cancer risks were determined based on the mean concentrations of carcinogenic and non-carcinogenic metals using the incremental lifetime cancer risk (ILCR) and the non-cancer hazard quotient (HQ), respectively (Liu, et al., 2013). Heavy metal mean concentrations, and oral reference doses and cancer slope factors used in the assessment are presented in Table 6.

Table 6. Mean metal concentrations, oral reference doses and cancer slope factors of the respective heavy metals

Metal	Al	As	Cd	Cr	Cu	Fe	Hg	Mn	Ni	Pb	Zn
Tap water (mg/L)	-	0.011	-	0.03	0.019	0.054	0.002	0.079	0.07	0.178	0.094
GWPS (mg/L)	-	0.010	-	0.051	0.043	0.059	0.002	0.585	0.087	0.251	-
Bottled water (mg/L)	-	-	-	0.025	-	-		-	-	0.175	-
RfD (mg/kg/day)**	0.14	0.0003	0.0005	1.5	0.04	0.7	0.0003	0.14	0.02	0.0004	0.3
CSF $(mg/kg/day)^{-1}$**	0.2	1.50	6.30	42	-	-	-	-	-	0.0085	-

GWPS: Groundwater-fed protected spring; RfD: Oral reference dose; CSF: Cancer slope factor (**Source: USEPA, 2016).

3.2.1 Non-cancer Risks

Tap water, groundwater-fed protected spring and bottled water had hazard quotient (HQ) values showing unacceptable risk (HQ > 1) for Pb in both children and adults (Table 7). Arsenic in tap water and groundwater-fed protected spring also showed unacceptable risk among children and potential risk in adults. The potential health risk of Cr was minimal (HQ < 0.001) in all the three water types for both adults and children in comparison to other HM investigated (Guerra, Trevizam, Muraoka, Marcante, & Canniatti-Brazaca, 2012). Hazard quotients for Al, Cd, Cr, Cu, Fe, Hg, Mn, Ni and Zn were < 1 for tap water, groundwater-fed protected spring and bottled water signifying that the population would not experience non-cancer risks due to exposure to these metals in drinking water. Hazard Index (HI) values of the heavy metals for groundwater-fed protected spring, tap water and bottled water for children were 50.226, 36.372, and 32.409, respectively. For adults, HI values of 21.525 for groundwater, 15.588 for tap water and 13.889 for bottled water were obtained. Hazard indices >1 were obtained in all water samples, indicating unacceptable risk for non-carcinogenic adverse health effect.

Lead contributed most towards exposure to non-cancer risks in the exposed population followed by As. A HQ value of 1 < HQ < 5 indicates a level of concern while a value of 10 < HQ < 100 suggests need for additional data gathering. This study therefore shows that As was in a level of concern in tap water and groundwater, while Pb needed further data collection. Hazard indices for children were higher than those for adults meaning that children would experience more non-cancer risks than adults. Young children absorb chemicals four times more than adults (Akkus & Ozdenerol, 2014). Similar observations have been reported (Guerra et al., 2012; Bamuwamye, Ogwok, & Tumuhairwe, 2015).

Table 7. Chronic daily intakes and Non-cancer hazard quotients for children and adults, by metal and water-type for drinking water in Kampala city

Metal	CDI-Children			CDI-Adults			HQ-Children			HQ-Adults		
	TW	GWPS	BW	TW	GWPS	BW	TW	GWPS	BW	TW	GWPS	BW
Al	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
As	0.001	0.001	0.000	0.000	0.000	0.000	2.444	2.222	0.000	1.048	0.952	0.000
Cd	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cr	0.002	0.003	0.002	0.001	0.001	0.001	0.001	0.002	0.001	0.001	0.001	0.001
Cu	0.001	0.003	0.000	0.001	0.001	0.000	0.032	0.072	0.000	0.014	0.031	0.000
Fe	0.004	0.004	0.000	0.002	0.002	0.000	0.005	0.006	0.000	0.002	0.002	0.000
Hg	0.000	0.000	0.000	0.000	0.000	0.000	0.444	0.444	0.000	0.190	0.190	0.000
Mn	0.021	0.059	0.000	0.009	0.025	0.000	0.151	0.418	0.000	0.065	0.179	0.000
Ni	0.006	0.012	0.000	0.003	0.005	0.000	0.310	0.580	0.000	0.133	0.249	0.000
Pb	0.012	0.017	0.012	0.005	0.007	0.005	32.963	46.481	32.407	14.127	19.921	13.889
Zn	0.006	0.000	0.000	0.003	0.000	0.000	0.021	0.000	0.000	0.009	0.000	0.000
∑HQ = HI							36.372	50.226	32.409	15.588	21.525	13.890

TW: Tap water; GWPS: Groundwater-fed protected spring; BW: Bottled water; CDI: Chronic daily intakes; HQ: Hazard quotient; HI: Hazard Index

3.2.2 Cancer Risks

Lifetime cancer risk through ingestion of Pb and As was 9.90×10^{-5} and 2.12×10^{-4} for tap water; 9.79×10^{-5} and 2.10×10^{-4} for groundwater; 8.50×10^{-6} and 1.82×10^{-5} for bottled water (Table 8), for children and adults, respectively. These results indicate higher cancer risks for adults than children. Arsenic contribution towards

ILCR for both children and adults was 91.3% and 87.6% in tap water and groundwater, respectively. Bottled water had a significantly ($p < 0.05$) lower ILCR, compared with tap water and groundwater, attributable to extremely low levels of As in bottled water. There was no pronounced difference between tap water and groundwater in terms of cancer risks. The USEPA proposed a one out of one million chance of additional cancers as a management goal for risks posed by environmental contaminants (Qu, Li, Wu, Wang, & Giesy, 2015). Risks ranging from 1 out of 10,000 to 1 out of 1,000,000 are considered as acceptable, depending on the circumstances (Qu et al., 2015). A risk of 1×10^{-3} will absolutely require protective measures (Pawełczyk, 2013). Compared with this risk range, the results of this study imply intolerable cancer risks for both children and adults due to heavy metals in drinking water over a lifetime. The ILCR method for calculating cancer risk estimates the incremental increase in risk for the exposed populations over a lifetime, but does not consider when the cancer will occur (Charnley & Putzrath, 2001). Exposure to cancer-causing chemicals in food, water, air, and consumer products early in life can lead to cancer later in life (Carpenter & Bushkin-Bedient, 2013). Therefore, prevention of early life exposure to cancer agents is essential.

Table 8. Incremental lifetime cancer risks for the children and adult populations of Kampala city through consumption of drinking water

Element	Tap water		Groundwater-fed protected spring		Bottled water	
	Children	adults	Children	Adults	Children	Adults
As	9.03×10^{-5}	1.94×10^{-4}	8.57×10^{-5}	1.84×10^{-4}	0	0
Pb	8.63×10^{-6}	1.85×10^{-5}	1.22×10^{-5}	2.61×10^{-5}	8.50×10^{-6}	1.82×10^{-5}
∑ILCR	9.90×10^{-5}	2.12×10^{-4}	9.79×10^{-5}	2.10×10^{-4}	8.50×10^{-6}	1.82×10^{-5}

ILCR: Incremental lifetime cancer risks

4. Conclusion

Tap water, groundwater-fed protected spring and bottled drinking water in Kampala was contaminated with heavy metals making it a health concern. Bottled water had low Pb levels compared to groundwater-fed protected spring and tap water. The concentration of other elements detected in drinking water was too low to present a health risk to consumers. All drinking water sources showed high hazard indices indicating unacceptable risk of non-carcinogenic adverse health effects. Compared with other elements, lead contribution towards the hazard index was highest in all cases. Excess lifetime cancer risks via the oral route revealed intolerable cancer risks for both children and adults due to heavy metals in drinking water over a 70-year lifetime. Arsenic, in particular, contributed most to the total incremental lifetime cancer risks in tap water and groundwater-fed protected springs. It is therefore conclusive that children, pregnant women and women of childbearing age in Kampala are at high risk of heavy metal poisoning from drinking water. There is need to update the current National policy on environmental management in order to control the influx of heavy metals in drinking water sources. Government water bodies and water bottling companies should adopt multi-purpose water and wastewater treatment procedures for effective purification of drinking water.

References

Abdullahi, S., Ndikilar, C. E., Suleiman, A. B., & Hafeez, H. Y. (2016). Assessment of Heavy Metals and Radioactivity Concentration in Drinking Water Collected From Local Wells and Boreholes of Dutse Town, North West, Nigeria. *Journal of Environment Pollution and Human Health, 4*(1), 1-8. https://doi.org/10.12691/jephh-4-1-1

Adamu, C., Nganje, T., & Edet, A. (2015). Heavy metal contamination and health risk assessment associated with abandoned barite mines in Cross River State, southeastern Nigeria. *Environmental Nanotechnology, Monitoring & Management, 3*, 10-21. http://dx.doi.org/10.1016/j.enmm.2014.11.001

Afiukwa, J. N. (2013). Evaluation and correlation study of heavy metals load in drinking water and update of water-related disease cases in Ebonyi State from 2001 –2011. *American Journal of Scientific and Industrial Research, 4*(2), 221-225. https://doi.org/10.5251/ajsir.2013.4.2.221.225

Ahoulé, D. G., Lalanne, F., Mendret, J., Brosillon, S., & Maïga, A. H. (2015). Arsenic in African Waters: A Review. *Water, Air, & Soil Pollution, 226*, 302. http://dx.doi.org/10.1007/s11270-015-2558-4

Akkus, C., & Ozdenerol, E. (2014). Exploring Childhood Lead Exposure through GIS: A Review of the Recent Literature. *International Journal of Environmental Research and Public Health, 11*, 6314-6334. http://dx.doi.org/10.3390/ijerph110606314

Bamuwamye, M., Ogwok, P., & Tumuhairwe, V. (2015). Cancer and Non-cancer Risks Associated With Heavy Metal Exposures from Street Foods: Evaluation of Roasted Meats in an Urban Setting. *Journal of Environment Pollution and Human Health, 3*(2), 24-30. https://doi.org/10.12691/jephh-3-2-1

Carpenter, D. O., & Bushkin-Bedient, S. (2013). Exposure to Chemicals and Radiation During Childhood and Risk for Cancer Later in Life. *Journal of Adolescent Health, 52*, S21-S29. http://dx.doi.org/10.1016/j.jadohealth.2013.01.027.

Charnley, G., & Putzrath, R. M. (2001). Children's Health, Susceptibility, and Regulatory Approaches to Reducing Risks from Chemical Carcinogens. *Environmental Health Perspectives, 109*, 187-192. http://ehpnet1.niehs.nih.gov/docs/2001/109p187-192charnley/abstract.html

El-Sayed, M., & Salem, W. M. (2015). Hydrochemical assessments of surface Nile water and ground water in an industry area–South West Cairo. *Egyptian Journal of Petroleum, 24*, 277-288. https://doi.org/10.1016/j.ejpe.2015.07.014

European Union (EU). (1998). Council Directive 98/83/EC of 3 November 1998 on the quality of water intended for human consumption. *Official Journal of the European Communities* (OJ L), 330, 42-45

Fernández-Luqueño, F., López-Valdez, F., Gamero-Melo, P., Luna-Suárez, S., Aguilera-González, E. N., Martínez, A. I., Álvarez-Garza, M. A. (2013). Heavy metal pollution in drinking water - a global risk for human health: A review. *African Journal of Environmental Science and Technology, 7*(7), 567-584. http://dx.doi.org/10.5897/AJEST12.197

Fuhrimann, S., Stalder, M., Winkler, M. S., Niwagaba, C. B., Babu, M., Masaba, G., & Cissé, G. (2015). Microbial and chemical contamination of water, sediment and soil in the Nakivubo wetland area in Kampala, Uganda. *Environmental Monitoring and Assessment,* 187(475), 15. http://dx.doi.org/10.1007/s10661-015-4689-x

Gaur, S., Singh, N., & Saxena, S. (2011). Status of lead present in ground drinking water samples of Uttarakhand (Garhwal Region) in India. *Asian Journal of Biomedical and Pharmaceutical Sciences, 1*(1), 32-38.

Guerra, F., Trevizam, A. R., Muraoka, T., Marcante, N. C., & Canniatti-Brazaca, S. G. (2012, January/February). Heavy metals in vegetables and potential risk for human health. *Scientia Agricola, 69*(1), 54-60. http://dx.doi.org/10.1590/S0103-90162012000100008

Hadiani, M. R., Dezfooli-manesh, S., Shoeibi, S., Ziarati, P., & Khaneghah, A. M. (2014). Trace elements and heavy metals in mineral and bottled drinking waters on the Iranian market. *Food Additives & Contaminants: Part B*, 07. http://dx.doi.org/10.1080/19393210.2014.947526

Hollamby, S., Afema-Azikuru, J., Sikarskie, J. G., Kaneene, J. B., Stuht, J. N., Fitzgerald, S. D., … Rumbeiha, W. K. (2004). Clinical Pathology And Morphometrics of African Fish Eagles In Uganda. *Journal of Wildlife Diseases, 40*(3), 523-532. http://dx.doi.org/10.7589/0090-3558-40.3.523

Kolawole, S. E., & Obueh, H. O. (2015). Evaluation of the minerals, heavy metals and microbial compositions of drinking water from different sourcesin Utagba-Uno, Nigeria. *ISABB-Journal of Health and Environmental Sciences*, *2*(2), 6-10. http://dx.doi.org/10.5897/ISAAB-JHE2015.0017

Li, P.-H., Kong, S.-F., Geng, C.-M., Han, B., Lu, B., Sun, R.F., Bai, Z.-P. (2013). Assessing the Hazardous Risks of Vehicle Inspection Workers' Exposure to Particulate Heavy Metals in Their Work Places. *Aerosol and Air Quality Research, 13*, 255-265. http://dx.doi.org/10.4209/aaqr.2012.04.0087

Liu, X., Song, Q., Tang, Y., Li, W., Xu, J., Wu, J., Brookes, P. C. (2013). Human health risk assessment of heavy metals in soil–vegetable system: A multi-medium analysis. *Science of the Total Environment*, 463-464, 530-540. http://dx.doi.org/10.1016/j.scitotenv.2013.06.064

Mbabazi, J., Wasswa, J., Kwetegyeka, J., & Bakyaita, G. K. (2010). Heavy metal contamination in vegetables cultivated on a major Urban wetland inlet drainage system of Lake Victoria, Uganda. *International Journal of Enviromental studies*, *67*(3), 333-348. http://dx.doi.org/10.1080/00207231003612613

Mebrahtu, G., & Zerabruk, S. (2011). Concentration of Heavy Metals in Drinking Water from Urban Areas of the Tigray Region, Northern Ethiopia. *Momona Ethiopian Journal of Science, 3*(1), 105-121. http://dx.doi.org/10.4314/mejs.v3i1.63689

Mghweno, L. R., Makokha, A. O., Magoha, H. S., Wekesa, J. M., & Nakajugo, A. (2008). Environmental lead pollution and food safety around Kampala City in Uganda. *Journal of Applied Biosciences*, *12*, 642-649.

Mkude, I. T. (2015). Comparative analysis of heavy metals from groundwater sources situated in Keko and

Kigogo residential areas, Dar es Salaam. *Journal of Water Resources and Ocean Science, 4*(1), 1-5. https://doi.org/10.11648/j.wros.20150401.11

Muwanga, A., & Barifaijo E (2006). Impact of industrial activities on the heavy metal loading and their physico-chemical effects on wetlands of Lake Victoria basin (Uganda). *African Journal of Science and Technolology, 7*(1), 51-63. http://dx.doi.org/10.4028/3-908158-03-6

Nigatu, W., Umuhire, C. A., Nsengimana, J., Nsabimana, A., & Dieudonne, S. (2015). Quantitative Assessment of the Chemical Safety of Groundwater Wells in Two Selected Districts of Rwanda. *International Journal of Environmental Protection and Policy, 3*(4), 104-110. https://doi.org/10.11648/j.ijepp.20150304.14

Nyakairu, G. W., Muhwezi, G., & Biryomumaisho, S. (2011). Assessment of Heavy Metals in Milk from Selected Dairy Farms and Shops in Wakiso District, Uganda. *SUZA Journal of Natural and Social Science, 1*(1), 36-52.

Ogwok, P., Muyonga, J. H., & Sserunjogi, M. L. (2009). Pesticide residues and heavy metals in Lake Victoria Nile perch, Lates niloticus, belly flap oil. *Bulletin of Environmental Contamination and Toxicology, 82*(5), 529-33. http://dx.doi.org/10.1007/s00128-009-9668-x

Okot-Okumu, J., & Nyenje R. (2011). Municipal solid waste management under decentralisation in Uganda. *Habitat International, 35*, 537-543. *http*://dx.*doi*. *org*/*10.1016*/*j.habitatint.2011.03.003*

Oosterveer, P., & Van-Vliet, B. (2010). Environmental Systems and Local Actors: Decentralizing Environmental Systems and Local Actors: Decentralizing. *Environmental Management*, 45, 284-295. http://dx.doi.org/10.1007/s00267-009-9423-4

Opio, C. (2012). Building effective drinking water management policies in rural Africa: Lessons from Northern Uganda. *Discussion paper series No. 6*. Ontario, Canada: Africa Initiative and The Centre for International Governance Innovation (CIGI). Retrieved from www.africaportal.org

Orisakwe, O. E. (2014). Lead and Cadmium in Public Health in Nigeria: Physicians Neglect and Pitfall in Patient Management. *North American Journal of Medical Sciences, 6*(2), 61-70. http://dx.doi.org/10.4103/1947-2714.127740

Oyoo-Okoth, E., Wim, A., Osano, O., Kraak, M. H., Ngure, V., Makwali, J., & Orina, P. (2010). Use of the fish endoparasite Ligula intestinalis (L., 1758) in an intermediate cyprinid host (Restreneobola argentea) for biomonitoring heavy metal contamination in Lake Victoria, Kenya. *Lakes & Reservoirs: Research and Management, 15*, 63-73. http://dx.doi.org/10.1111/j.1440-1770.2010.00423.x

Pawełczyk, A. (2013). Assessment of health risk associated with persistent organic pollutants in water. *Environmental Monitoring and Assessment, 185*, 497-508. http://dx.doi.org/10.1007/s10661-012-2570-8

Qu, C., Li, B., Wu, H., Wang, S., & Giesy, J. P. (2015). Multi-pathway assessment of human health risk posed by polycyclic aromatic hydrocarbons. *Environmental Geochemistry and Health*. http://dx.doi.org/10.1007/s10653-014-9675-7

Sankar, T. R., & Rao, P. T. (2014). Heavy metal assessment in industrial groundwater in and around vijayawada, andhra pradesh, india. *European Chemical Bulletin, 3*(10), 1008-1013. http://dx.doi.org/10.17628/ecb.2014.3.1008-1013

Semuyaba, A. S., Segawa, I., & Wamala, A. (2014). Potential Risk of Lead Toxicity from Bottled Water in Uganda. *Makerere Pharmaceutical Journal, 12*(1), e13-20.

Sun, C., Zhang, J., Ma, Q., & Chen, Y. (2015). Human Health and Ecological Risk Assessment of 16 Polycyclic Aromatic Hydrocarbons in Drinking Source Water from a Large Mixed-Use Reservoir. *International Journal of Environtal Research and Public Health, 12*, 13956-13969. http://dx.doi.org/10.3390/ijerph121113956

UBOS. (2016). The National Population and Housing Census 2014 – Main Report. Kampala: Uganda Bureau of Statistics.

UNBS. (2014, 10 15). *Uganda Standard* . US EAS 12: 2014 (Potable water Specification), First Edition. Kampala: Uganda National Bureau of Standards. Retrieved from www.unbs.go.ug

USEPA. (1989). Risk Assessment Guidance for Superfund Volume 1: Human Health Evaluation (Part A). Springfield: US Department of Commerce, National Technical Information Service.

USEPA. (2009). *United States Environmental Protetion Agency*. Retrieved from Ground Water and Drinking

Water: National Primary Drinking Water Regulations: https://www.epa.gov/ground-water-and-drinking-water/national-primary-drinking-water-regulations

USEPA. (2016). *United States Environmental Protection Agency (EPA)*. Retrieved from IRIS Chemical Assessment Quick list: https://cfpub.epa.gov/ncea/iris_drafts/simple_list.cfm?list_type=alpha

Van Straaten, P. 2000. Mercury contamination associated with small scale gold mining in Tanzania and Zimbabwe. *Science of the Total Environment, 259*, 105-113. *http*://dx.*doi.org*/*10.1016*/*S0048-9697*(*00*)*00553-2*

Wei, H., Le, Z., Shuxian, L., Dan, W., Xiaojun, L., Lan, J., & Xiping, M. (2015). Health risk assessment of heavy metals and polycyclic aromatic hydrocarbons in soil at coke oven gas plants. *Environmental Engineering and Management Journal, 14*(2), 487-496. http://omicron.ch.tuiasi.ro/EEMJ/

WHO. (2008). *Guidelines for drinking-water quality [electronic resource]: incorporating 1st and 2nd addenda, Vol.1, Recommendations. 3rd edition.* Geneva: World Health Organization (WHO).

Yu, B., Wang, Y., & Zhou, Q. (2014). Human Health Risk Assessment Based on Toxicity Characteristic Leaching Procedure and Simple Bioaccessibility Extraction Test of Toxic Metals in Urban Street Dust of Tianjin, China. *PLoS ONE, 9*(3), e92459. *http*://*doi.org*/*10.1371*/*journal.pone.0092459*

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