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Excessive Copper(II) and Zinc(II) Levels in Drinkable Water Sources in Areas Along the Lake Victoria Shorelines in Siaya County, Kenya

Enos W. Wambu[1] · Wesley N. Omwoyo[2] · Teresa Akenga[1]

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Abstract Copper(II) and zinc(II) levels in drinkable water sources in the alluvium areas of the Lake Victoria Basin in Siaya County of Kenya were evaluated to assess the risk posed to resident communities by hydrogeological accumulation of toxic residues in the sedimentary regions of the lake basin. The levels of the metals in water were analyzed by atomic absorption spectroscopy. Metal concentrations ranged from 0.11 to 4.29 mg/L for Cu(II) and 0.03 to 1.62 mg/L for Zn(II), which were both higher than those normally recorded in natural waters. The Cu(II) levels also exceeded WHO guidelines for drinking water in 27 % of the samples. The highest prevalence of excessive Cu(II) was found among dams and open pans (38 %), piped water (33 %) and spring water (25 %). It was estimated that 18.2 % of the resident communities in the current study area are exposed to potentially toxic levels of Cu(II) through their drinking water.

Keywords Copper(II) · Pollution · Water sources · Hydrological translocation · Lake Victoria Basin · Zinc(II)

Hydrogeological discharge of materials into the shoreline areas of the Lake Victoria Basin (LVB) continues to raise serious environmental concerns in the African great lakes region (Ogoyi et al. 2011; Wambu et al. 2014). An increase in urbanization and other socio-economic activities within LVB has resulted in the potential for increased pollution within the basin. Current evidence indicates that heavy metal pollution in the riparian areas of the LVB has increased drastically in recent years (Mwamburi 2009). Inorganic Cu(II), for instance, is extensively used in farm applications among the areas of LVB (Gitonga 1992). Residues of the metal can therefore get translocated through natural drainage to accumulate into the alluvium regions of LVB (Bolan et al. 2003). Like Cu(II), Zinc(II) has a wide environmental interface in this region (Srivastava et al. 2006), and the materials such as distribution pipes, plumbing materials, connections and fittings used in water transport may contribute to increased copper and zinc content in the potable water sources in this area (Fuchs and Hoffmann 2005). Excessive intake of copper leads to 'Wilson's disease' (Brewer 2008) and it may result in gastrointestinal disorders, hemolysis, hepatotoxicity and nephrotoxic effects (Shrivastava 2009). Exposure to excessive Zn(II), on the other hand, has been associated with gastrointestinal disturbances, nausea, pancreas damage, interference with protein metabolism and arteriosclerosis (Oyaro et al. 2007). It is not surprising, therefore, that environmental assessment of Cu(II) and Zn(II) in the LVB has attracted a lot of research interest in the recent past (Yabe et al. 2010). However, previous studies focused only on the metal levels in lake sediments (Kishe and Machiwa 2000) and in the lake water (Mwamburi 2009). They did not consider the metal residues in riparian water sources used by the resident communities for their household water needs despite high concentrations (ppm) for Cu (26.1 ± 4.8) and Zn (45.4 ± 13.1), which have been reported in lake sediments close to the lake shores in this region (Kishe and Machiwa 2000). As a consequence, the state of ground water sources in the riparian areas of the lake remained unclear, and was the reason for conducting the present study.

✉ Enos W. Wambu
wambuenos@yahoo.com;
http://www.uoeld.ac.ke

[1] Department of Chemistry and Biochemistry, University of Eldoret, P.O. Box 1125-30100, Eldoret, Kenya

[2] Department of Chemistry, Maasai-Mara University, P.O. Box 861-20500, Narok, Kenya

The current work co-assessed Zn(II) and Cu(II) levels in water sources adjacent to the LV shoreline in Siaya County of Kenya and evaluated the public health risk associated with hydrogeological build-up of water-borne residues in the riparian areas of LVB. It is hoped that the accrued data will form a basis to inform strategies to safeguard the environment and the health of resident communities in the alluvium basins of the lake from the effect of exposure to undue levels of waterborne residues in these regions.

Materials and Methods

The study area covered both Bondo and Rarieda sub-counties of Siaya County of Kenya (Fig. 1). It was comprised of: Asembo and Uyoma divisions in Rarieda Sub-County and Maranda, Nyang'oma and Usigu Divisions in Bondo Sub-County. The elevation ranges from about 1100 m altitude at the lake shores to about 1350 m altitude in the north. The area is inhabited with some 300,000 people and the primary sources of drinkable water for the residents are: boreholes and shallow wells, dams and open-pans, the lake, ponds, river, springs, and streams (Kenya National Bureau of Statistics 2010).

A total of 63 water samples were collected from different types of potable water sources to cover the entire riparian region of Siaya County of Kenya. Sampling was done between 20th and 30th April 2013 using a completely randomized design as depicted in Table 1.

Standard procedure (AOAC 2000) was followed with slight modifications for the collection of samples for analysis. The water samples were collected into clean 60 mL polystyrene bottles by submerging and opening the sample bottle beneath the water surface. Three sub-samples were taken from each sample site and mixed to form a composite sample. The composite sample was then acidified with 1 mL of concentrated nitric acid (HNO_3) to a pH of 3.5 and transported to the laboratory where it was stored at −10°C until the day of analysis (Chilton et al. 2006). The determination of Cu(II) and Zn(II) in the water samples was done using the methods documented by Mzimela et al. (2003). Exactly 100.0 mL of each composite sample was mixed with 10.0 mL of aqua regia and 1.0 mL of perchloric acid in a culture test tube. The mixture was then digested at 80°C over a water bath until the volume was reduced to about 30 mL. After complete digestion and cooling, the samples were diluted with de-ionized water to 50.0 mL and analyzed for Cu(II) and Zn(II) levels using a PG-900 atomic absorption spectrophotometer (PG Instruments, Leicestershire, UK). Anhydrous salts of the metals (Table 2) were used to prepare standards for generation of calibration curves used to determine the metal concentrations in the waters. All measurements were done in triplicate and the results averaged. The data obtained were subjected to statistics using the Microsoft Excel statistical package. Concentrations were presented as mean ± SD, minimum, and maximum values. The instrument detection limits (IDL) for the two metals and the AAS operation specifications are recorded in Table 2.

For calibration, standard solutions containing 0, 0.1, 0.2, 0.4, 0.8, 1.6 and 2.0 ppm metal concentrations were employed. The resultant calibration curves are depicted in Fig. 2.

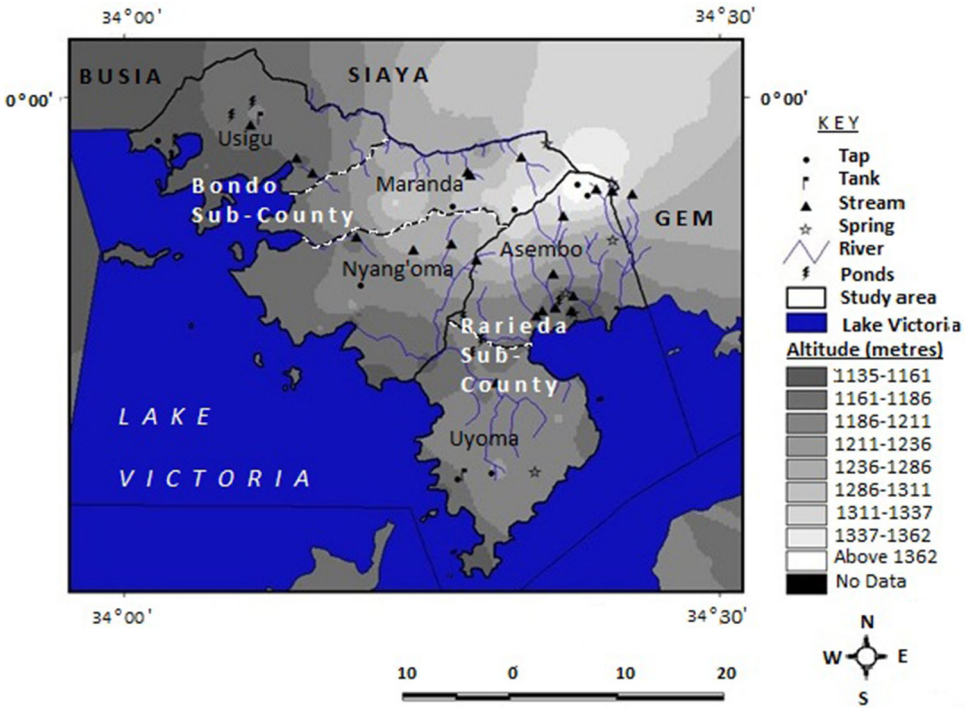

Fig. 1 A map of the riparian areas of Lake Victoria Basin in Siaya County, Kenya

Table 1 Distribution of sample sites by division and type of water source

Water source type	Divisions					
	Asembo	Maranda	Nyang'oma	Uyoma	Usigu	Total
Borehole	0	4	0	1	0	5
Dams and open-pans	5	9	2	1	8	25
Lake	0	2	0	1	2	5
Ponds	2	0	0	0	3	5
River Yala	0	1	0	0	1	2
Springs	3	1	0	0	0	4
Streams	6	3	0	0	1	10
Piped water	2	1	1	2	1	7
Overall	18	21	3	5	16	63

Table 2 Atomic absorption spectrophotometer experimental specifications

Elements	Cu	Zn
Lamp current (mA)	6	8
Wavelength (nm)	324.7	213.9
Slit width (nm)	0.7	0.7
Mode	BGC-D_2	BGC-D_2
Flame	Air-C_2H_2	Air-C_2H_2
Fuel flow (L/min)	1.8	2.0
Pre-spray time (s)	3	3
Integration time (s)	5	5
Calibrations (ppm)	0.1–0.6 ($CUSO_4{\cdot}5H_2O$)	0.1–0.6 ($Zn(NO_3)_2$
IDL (ppm)	0.04	0.11

MDL – instrument detection limit, BGC-D_2 – deuterium background correction (compensates for matrix interferences)

In view of the acute toxicities and high risks associated with exposure to undue Cu(II) levels, the public health implication of excessive Cu(II) in the water sources was analyzed. The percentage of the population that could be in constant contact with toxic Cu(II) levels through drinking water, $P_{excess\,Cu(II)}$, was then estimated based on the expression:

$$P_{excess\,Cu(II)} = \sum_{all\ water\ sources} \left\{ \frac{P_i \times p_{i_{Cu(II)}}}{100} \right\} \quad (1)$$

where P_i is total percentage of the population that use potable water from a particular type of water source, i, and $p_{i_{Cu(II)}}$ is the percent of water sources of the water type, i, that were found to contain excessive Cu(II) concentrations.

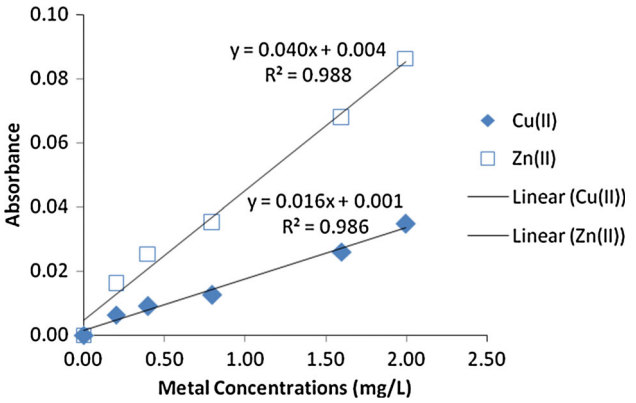

Fig. 2 Calibration *curves* used for the determination of Cu(II) and Zn(II) ions in the water samples by AAS

Results and Discussion

Table 1 shows that a total of 25 water samples representing 40 % of the water samples, were obtained from dams and open-pans, and a further 15 samples representing 24 %, from boreholes and shallow wells, ponds, and streams. Lake water, which represented 37.4 %, was still the most important primary source of household water for the residents in this area (Kenya National Bureau of Statistics 2010) but dams and open-pans, boreholes and shallow wells and streams were the main sources of household water for communities living outside walking distances from the lake shores. Most of the ground water sources were saline from accumulation of chemical residues through mineral-enriched underground drainage (Wambu et al. 2014).

The spatial distribution of Cu(II) and Zn(II) levels in the potable water sources with respect to elevation is presented in Fig. 3.

Highest mean levels of Cu(II) in water (>2.45 mg/L) were recorded in areas of altitudes of 1300 m and above. The mean Cu(II) levels dropped to 0.73 mg/L at 1251–1280 m altitudes before it increased to 2.0 mg/L at altitudes of 1100–1130 at the lake shores. The corresponding levels of Zn(II) were lower, but similar trends prevailed, as shown Fig. 3. Spatial distribution of Cu(II)

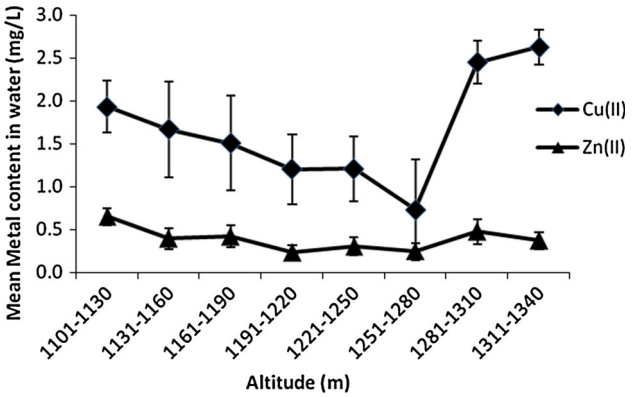

Fig. 3 Topographical influence on Zn(II) and Cu(II) distribution in the water

and Zn(II) levels in ground water sources reflected hydrogeological translocation and accumulation of the metal residues into the shoreline areas of the present study. It can be assumed that as water drains into the alluvium areas, it loses momentum due to sudden declines in the slope of the land toward the lake shore. Most of the dissolved and suspended matter in the water precipitates and deposits over soil colloids in these regions. The salt-laden soil colloids have therefore formed a natural reservoir from which solutes solubilize and enrich underground water systems in the area making them saline. The sources of high Cu(II) in drinking water sources from the higher altitude sample sites, however remains unclear.

The patterns of Cu(II) and Zn(II) concentrations in water by type of water source are presented in Table 3. Cu(II) and Zn(II) residues were detected in all types of water source over the entire study area. Highest mean levels of Cu(II) were found in samples from boreholes and shallow wells (1.59 ± 0.72 mg/L), dams and open pans (1.58 ± 1.02 mg/L), streams (1.35 ± 1.13 mg/L), and springs (1.32 ± 0.89 mg/L) and ponds (1.26 ± 1.22 mg/L). A total of 27 % of all the water samples had Cu(II) levels above WHO guidelines for drinking water (World Health Organization 1996) and the highest proportion of samples (sample count; percentage proportion) with excessive Cu(II) occurred in dams and open pans (10; 38 %), piped water (2; 33 %) and in spring water (1; 25 %).

The ground water sources in the current study were polluted with excessive Cu(II) and Zn(II), as the levels of both Cu (0.11–4.28) and Zn (0.01–1.62) in potable water sources were higher than those normally reported for copper (10–40 µg/L) and zinc (<1 mg/L) in natural water systems (World Health Organisation 1996, 2003). The quantity of Cu(II) in natural water sources increased with general depth of the type of water source in the order: boreholes and shallow wells > dams and open pans > springs > streams > ponds > lake and river. Zn(II) levels in water did not vary significantly with the type of water source. The levels of Cu(II) in water sources were also higher than those obtained in a previous study taken near a former copper smelter in Uganda (Muwanga and Barifaijo 2006). As it would be expected, the Cu(II) levels in the current study should have been lower than those in the former study, since there has been no Cu smelting in the current study area. This affirmed that groundwater sources in the current study were polluted with Cu(II). These results showed that a large proportion of resident communities that depend on ground water sources for their household water needs could be exposed to unhealthy Cu(II) levels through their drinking water.

Table 4 shows that the highest mean Cu(II) content of water (2.39 ± 0.59 mg/L) occurred in Nyang'oma Division, which is at a mean sample site altitude of 1186.7 ± 25.5 m, and the lowest (1.25 ± 0.88 mg/L) in Maranda Division at mean sample site altitude of 1218.5 ± 47.2 m. The overall mean levels of Cu(II) in water for the study area (1.49 ± 1.00 mg/L) and the mean

Table 3 Distribution of Zn(II) and Cu(II) in water by type of water source

Water source type	Cu(II)				Zn(II)			
	[Cu(II)] ± SD (mg/L)	Max. (mg/L)	>2 (mg/L)	Min. (mg/L)	[Zn(II)] ± SD (mg/L)	Max. (mg/L)	Min. (mg/L)	*n*
Borehole	1.59 ± 0.72	2.63	1 (20 %)	0.72	0.32 ± 0.20	0.603	0.06	5
Dam and open-pans	1.58 ± 1.02	3.34	10 (38 %)	0.15	0.34 ± 0.23	0.78	0.02	26
Lake	0.74 ± 0.50	1.44	0 (0 %)	0.36	0.35 ± 0.18	0.54	0.01	4
Pond	1.26 ± 1.22	3.3	1 (20 %)	0.11	0.55 ± 0.25	0.77	0.3	5
River	0.26 ± 0.13	0.36	0 (0 %)	0.17	0.42 ± 0.04	0.45	0.4	2
Spring	1.32 ± 0.89	2.44	1 (25 %)	0.42	0.34 ± 0.25	0.59	0.12	4
Stream	1.35 ± 1.13	3.63	2 (20 %)	0.19	0.31 ± 0.18	0.56	0.02	10
Tap	1.57 ± 1.74	4.28	2 (33 %)	0.28	0.39 ± 0.60	1.62	0.02	6
Overall	1.49 ± 1.00	4.28	17 (27 %)	0.11	0.34 ± 0.27	1.62	0.01	63

Table 4 Distribution of the heavy-metals in water by administrative division

Division	Asembo	Maranda	Nyang'oma	Usigu	Uyoma	Overall
Mean altitude (m)	1231 ± 62	1219 ± 47	1187 ± 26	1152 ± 19	1196 ± 36	1203.0 ± 54.1
Cu(II)						
[Cu(II)] ± SE(mg/L)	1.5 ± 1.0	1.3 ± 0.9	2.4 ± 0.6	1.6 ± 1.2	1.8 ± 0.4	1.5 ± 1.0
Maximum (mg/L)	3.6	2.87	2.81	3.34	4.28	4.28
>2 (mg/L)	5 (28 %)	4 (19 %)	1 (33 %)	4 (25 %)	3 (60 %)	17 (27 %)
Minimum (mg/L)	0.3	0.2	0.3	0.1	1.1	0.1
Zn(II)						
[Zn(II)] ± SE (mg/L)	0.3 ± 0.2	0.5 ± 0.2	0.8 ± 0.5	0.5 ± 0.3	0.3 ± 0.2	0.3 ± 0.3
Maximum (mg/L)	0.6	0.7	1.6	0.8	0.5	1.6
>3 (mg/L)	0	0	0	0	0	0
Low (mg/L)	0.2	0.03	0.6	0.1	0.1	0.0
Total count (*n*)	18	21	3	16	5	63

Table 5 Forecasting community exposure to excessive Cu(II) levels in riparian areas of Siaya County, Kenya through drinking water

Water type, *i*	Dams and ponds	Lake water	Streams and springs	Boreholes and shallow wells	Piped water	Overall
P_i^{a}	30.2	37.4	8.7	9.3	8.6	94.2
$p_{i_{Cu(II)}}$	38.5	0.0	21.4	20.0	33.3	27.0
$\frac{P_i \times p_{i_{Cu(II)}}}{100}$	11.6	0.0	1.9	1.9	2.9	$\sum_{all\ water\ sources} \left\{\frac{P_i \times p_{i_{Cu(II)}}}{100}\right\} = 18.2$

[a] Source of these values: Kenya National Bureau of Statistics (2010)

levels of Cu(II) for individual divisions (1.25 ± 0.88–1.79 ± 0.43 mg/L) apart from Nyang'oma Division (2.56 ± 1.43) were within WHO guidelines (2.0 mg/L) for drinking water. Cu(II) content of the water samples varied significantly among the shoreline areas of Usigu (SD = 1.20 mg/L) and Asembo (SD = 1.03 mg/L) divisions. All the divisions had significant proportions of potable water sources polluted with Cu(II) above permissible limits. The highest proportion of water samples with excessive Cu(II) was observed in Uyoma (60 %) followed by those in Nyang'oma (33 %), Asembo (28 %), Usigu (25 %) and then Maranda Division (19 %). However, the mean levels of Zn(II) (0.36 ± 0.22 mg/L) were well within the recommended limits (3 mg/L).

The results of the analysis of the percentage of the population that could be in constant contact with toxic Cu(II) levels through drinking water are presented in Table 5.

It was found that 18.2 % of resident communities in these areas could be exposed to toxic Cu(II) levels through their drinking water, and may be at risk from chronic toxicity of exposure to excessive Cu(II). Dams, shallow wells and ponds were the biggest contributors to community exposure to toxic Cu (II) levels. Distribution of safer drinking water would be a solution to the problem. However, as alternative water sources are not available to the rural communities in these areas at the moment, simple innovative protocols for treatment of contaminated water and constant monitoring of available water are therefore desired.

This study has revealed that Cu(II) and Zn(II) levels in water sources in the riparian areas of the LVB in Siaya County, Kenya are polluted with excess Cu(II) and Zn(II) content.

References

AOAC (2000) Official methods of analysis, 17th edn. Association of Official Analytical Chemists (AOAC) International, Gaithersburg

Bolan NS, Khan MA, Donaldson J et al (2003) Distribution and bioavailability of copper in farm effluent. Sci Total Environ 309:225–236. doi:10.1016/S0048-9697(03)00052-4

Brewer GJ (2008) Iron and copper toxicity in diseases of aging, particularly atherosclerosis and Alzheimer's disease. Exp Biol Med 232:323–335

Chilton J, Dahi E, Lennon M et al (2006) Fluoride in drinking-water. IWA, London

Fuchs S, Hoffmann M (2005) Discharges of copper, zinc and lead to water and soil—analysis of the emission pathways and possible emission reduction measures. In: Research Report of the

Environmental Research of the Federal Ministry of the Environment, Nature Conservation and Nuclear Safety, Karlsruhe, Germany, pp 1–29

Gitonga JK (1992) Agricultural chemicals and wetlands: a review. In: Crater SA, Njuguna SG, Howard GW (eds) Wetlands of Kenya: proceedings of the KWWG seminar on wetlands of Kenya. International Union for Conservation of Nature and Natural Resources, Gland, pp 161–167

Kenya National Bureau of Statistics (2010) Kenya population and housing 2009 census results: population distribution by political units, vol 1B. Ministry of Planning, Nairobi

Kishe MA, Machiwa JF (2000) Distribution of heavy metals in sediments of Mwanza Gulf of Lake Victoria, Tanzania. Environ Int 28:619–625

Muwanga A, Barifaijo E (2006) Impact of industrial activities on heavy metal loading and physico-chemical effects on wetlands of Lake Victoria Basin (Uganda). Afr J Sci Technol 7:51–63

Mwamburi J (2009) Trace metal concentration in water and sediments of satellite lakes within Lake Victoria (Kenya) basin. Lakes Reserv Res Manag 14:203–220. doi:10.1111/j.1440-1770.2009.00408.x

Mzimela HM, Wepener V, Cyrus DP (2003) Seasonal variation of selected metals in sediments, water and tissues of the groovy mullet, Liza dumerelii (Mugilidae) from the Mhlathuze Estuary, South Africa. Mar Poll Bull 46:659–664

Ogoyi DO, Mwita CJ, Nguu EK, Shiundu PM (2011) Determination of heavy metal content in water, sediment and microalgae from Lake Victoria, East Africa. Open Environ Eng J 4:156–161

Oyaro N, Juddy O, Murago ENM, Gitonga E (2007) The contents of Pb, Cu, Zn and Cd in meat in Nairobi, Kenya. J Food Agric Environ 5:119–121

Shrivastava AK (2009) A review on copper pollution and ite removal from water by pollution control technologies. Indian J Environ Prot 29:552–560

Srivastava VC, Mall ID, Mishra IM (2006) Modelling individual and competitive adsorption of cadmium(II) and zinc(II) metal ions from aqueous solution onto bagasse fly ash. Sep Sci Technol 41:2685–2710. doi:10.1080/01496390600725687

Wambu EW, Agong SG, Anyango B et al (2014) High fluoride water in Bondo–Rarieda area of Siaya County, Kenya: a hydro-geological implication on public health in the Lake Victoria Basin. BMC Public Health 14:462–470. doi:10.1186/1471-2458-14-462

World Health Organization (1996) Copper in drinking-water background document for development of WHO guidelines for drinking-water quality, vol 2. World Health Organization, Geneva, pp 1–31

World Health Organization (2003) Zinc in drinking-water background document for development of guidelines for drinking-water quality, vol 2. World Health Organization, Geneva, pp 1–10

Yabe J, Ishizuka M, Umemura T (2010) Current levels of heavy metal pollution in Africa. J Vet Med Sci 72:1257–1263