

# Assessment of Heavy-Metal Pollution in Sediments and Tilapia Fish Species in Kafue River of Zambia

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**Abstract** We report results from an evaluation of the levels of heavy metals, i.e., copper (Cu), cadmium (Cd), lead (Pb), nickel (Ni), manganese (Mn), chromium (Cr), and iron (Fe) in sediment and tilapia fish samples from a wide stretch of the Kafue river of Zambia. In sediment samples, the highest Pb and Fe concentrations were recorded at Hippo Dam, i.e.,  $36.2 \pm 0.1$  mg/kg dw and  $733 \pm 37$  mg/kg dw at Kafue Town, respectively. Other notably high metal concentrations in sediment were Cr at Kafue Bridge ( $42.5 \pm 0.1$  mg/kg dw [dw]), Cu at Mpongwe ( $233 \pm 5$  mg/kg dw), and Mn at Kafue Town ( $133 \pm 1$  mg/kg dw); it was highest at Ithezi Tezhi Dam at  $166 \pm 1$  mg/kg d. Three fish species, i.e., three-spot bream *Tilapia andersonii*, red-breasted bream *T. rendalli*, and Nile tilapia *Oreochromis niloticus* were evaluated for levels of the seven metals. The concentrations of the metals in these fish species afforded estimation of the biota sediment-accumulation factor, which is the ratio of the concentration of the metal in liver to that in the sediment. The coefficients of condition (*K*) values, which give an indication of the health of the fish, were also estimated. The *K* values ranged from  $2.5 \pm 0.5$  to  $5.1 \pm 0.6$  in all of the three fish species. Partial least squares analysis showed that heavy metals are generally sequestered evenly in all of the parts of all of the

three fish species except for elevated levels of Mn, Cd, and Pb in the liver samples.

Mining has contributed to the expansion of economies in Africa and thus has led to increased industrial development. It is Zambia's leading industry because of the country's mineral resources such as copper (Cu). In 1997, Zambia contributed 20 % of the world's Cu production (Stockwell et al. 2001). This has caused a resurgence of interest, especially on the impact that the mines have on the environment.

Cu belongs to a class of metals called “heavy metals,” which are notorious pollutants of the environment if not well monitored and contained. In moderate amounts, metals such as Cu, manganese (Mn), and iron (Fe) are nutrients that have important biological contributions in humans; however, at high concentrations they cause adverse health effects. Cadmium (Cd) and lead (Pb), even at low concentrations, have adverse health effects and no physiological significance (Duruibe et al. 2007). “Minamata” has been coined to describe a disease that results from eating methylmercury-contaminated fish in Minamata, a city in Japan. It is thus imperative to monitor levels of heavy metals in the aquatic environment—in particular fish species that provide a significant amount of protein—especially in developing countries.

The Kafue River is one of the longest and widest rivers in Zambia spanning 960 km and is a tributary of the Zambezi River (Mwase et al. 1998). The river originates from Chimfushi, a small village in the Copperbelt province of Zambia. It flows through other mining towns of the Copperbelt province, which is an active mining area of the country, and then through Lake Itezhi Tezhi, which is located 450 km upstream of the mining area. The river is of

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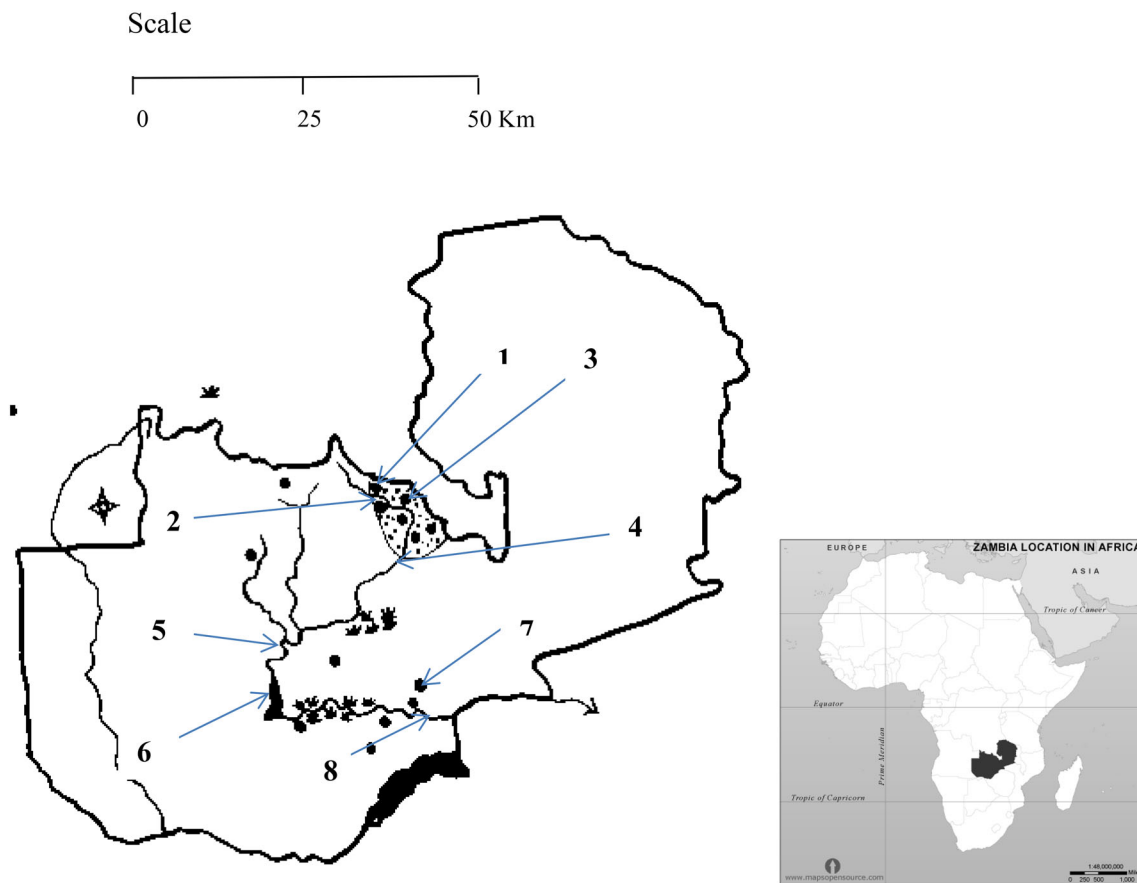
economic significance because it serves as a source of livelihood to a large population of Zambia. It is used extensively for fishing and agriculture. It also provides drinking water for both humans and wildlife. Although it serves all of these useful features, it has not been spared from anthropogenic pollution activities, especially mining and manufacturing. Figure 1 is a map of Zambia showing the Kafue River and sampling locations, the Global Positioning System (GPS) coordinates of which are listed in Table 1.

Literature about the impact of environmental pollutants on aquatic life such as fish, such by heavy metals, in Zambia is scanty. Even where it is available, no comprehensive health and ecological risk assessments due to heavy metals have been reported. A study on the micro-toxicity of sediments along the Kafue river has been reported (Mwase et al. 1998). Results from this study showed that sediments near Kitwe town on the Copperbelt Province had 90-fold and tenfold hatching and mortality effects, respectively, on juvenile tilapia fish. The mortality rates were increased, and the hatching period of newly fertilized Zebra fish eggs was also prolonged by 11.8 days

**Table 1** GPS coordinates for the sampling sites

Sampling point (code)	GPS coordinates	
Chililabombwe (CHIL)	12°28'38.71"S	27°53'54.64"E
Hippo Dam (HIPO)	12°27'52.40"S	27°51'4.79"E
Mufulira bridge (MUF)	12°38'40.45"S	28°9'52.30"E
Mpongwe (MPO)	13°20'31.08"S	28°5'0.49"E
Kafue town (KFT)	15°46'59.91"S	28°9'19.18"E
Kafue Hook bridge (KHB)	15°47'10.43"S	28°10'40.34"E
Kafue bridge (KB)	15°50'20.68"S	28°14'7.90"E
Lake Itzhi Tezhi (ITT)	15°46'9.07"S	26°1'14.33"E
Luangwa river (LUA)	14°58'36"S	30°12'45"E

instead of 4.2 days due to the high Fe concentration in fish. The study was however confined to one particular segment of the river. In another study (Choongo et al. 2005), Cu levels in *Serranochromis* fish species and sediment was found to be high in both sediment and fish. The researchers in this study speculated that such high levels of Cu could pose a threat to human health as well as that of the fish. Similar conclusions were reached in another study



**Fig. 1** Map of Zambia showing the Kafue River and sampling locations. 1 = Chililabombwe; 2 = Hippo Dam; 3 = Mufulira; 4 = Mpongwe; 5 = Kafue Hook Bridge; 6 = Itzhi Tezhi Dam; 7 = Kafue

Town; 8 = Kafue Bridge Source: <http://www.mapsofsource.com> and (Choongo et al.2005)

involving one species of tilapia, *Oreochromis niloticus*, in Lakes Itzhi Tezhi and Kariba of Zambia (Nakayama et al. 2010). The same researchers conducted another study along roadsides in Kabwe and Lusaka towns of Zambia, in which they followed the distribution of heavy metals in wild rats. They concluded that wild rats found near the mining areas were more susceptible to metal contamination due to increased levels of metallothionein mRNA expressions, MT-1 and MT-2, compared with rates found in Lusaka, which were used as a control area because it has no active mining activities (Nakayama et al. 2011). In another study, the distribution of four selected heavy metals around the mining town of Kabwe was performed (Tembo et al. 2006). The defunct Kabwe zinc and Pb mine was used as the reference point, and results showed that it had a significant affect on the precipitation of heavy metals around the town. Notwithstanding this report, little work has been performed on the aquatic environment and corresponding aquatic species therein.

The aim of this study was to determine the levels of heavy metals, i.e., Cu, Cd, Pb, Mn, Cr, Ni, and Fe, in sediment and tilapia species along a longer stretch of the Kafue River spanning from the Copperbelt province to Kafue Town in the Lusaka province and to use the data collected to determine the biota sediment-accumulation factors (BSAFs) and the coefficients of condition (*K*s) for fish in an area that had not been studied previously.

## Materials and Methods

### Sampling

Fish species that were investigated were collected from the Kafue bridge (KB). These were three-spotted bream *Tilapia andersonii*, red-breasted bream *T. rendalli*, and Nile tilapia *O. niloticus*. These species are widely distributed in the Kafue River. Sampling was phased between August 2014 and November 2014. The Kafue River was divided into three zones. The first zone was the upstream, which included sampling sites around Chililabombwe (CHILI) and the Hippo dam (HIPO). The second zone was still upstream around Mufulira town (MUF) and the middle part of Mpongwe (MPO). The third zone was downstream of the river in Kafue town (KFT), Kafue Hook Bridge (KHB), KB, and Lake Itzhi Tezhi (ITT). Samples from the Luangwa River (LUA) of Zambia were used as controls. Table 1 lists the GPS coordinates for the sampling sites.

### Sediment and Fish

Between three and five portions from 1 kg of sediment were collected using a corer at a depth of 5 cm from one

sampling site. Each sediment sample was air dried in the laboratory at room temperature and sieved using a 2-mm sieve. Thereafter, it was dried in the oven at 105 °C for 12 h, and the dry weight was recorded.

Up to five of each fish species were caught with the help of local fishermen at the sampling sites. The fish samples were transported on ice to the laboratory. They were then separated into parts, i.e., muscle, liver, intestines, gills, and head. The parts were dried in the oven at 105 °C for 24 h, the dry weights were recorded, and the samples were stored in desiccators.

### Sample Preparation and Analysis

A 2-g sediment sample was weighed and placed in a digestion tube followed by addition of 30 mL of HCl (30 %; Merck) and 10 mL of HNO<sub>3</sub> (70 %; Merck). The mixture was digested on a hot plate at approximately 250 °C until all of the organic matter had dissolved. After the mixture had cooled, 2.5 mL of perchloric acid (HClO<sub>4</sub> 70 %; Merck) and 10 mL of distilled water were added. The mixture was then digested on a hot plate until the solution was clear. After cooling, 20 mL of water was added and then brought to the boil. The mixture was cooled and filtered into a 100-mL volumetric flask using Whatman1442-055 Ashless grade 42 quantitative filter paper (diameter 5.5 cm, pore size 2.5 μm [Sigma-Aldrich Co. LLC, Taufkirchen, Germany]), and the filtrate was made up to the mark using distilled water.

The dried fish parts were digested using a slightly modified method (Ikenaka et al. 2010) adapted from the literature (Nakayama et al. 2011). For sediment, wet digestion using nitric acid (HNO<sub>3</sub> 70 %; Merck) and hydrochloric acid (HCl 30 %; Merck) was used. In the digestion of fish parts, a 0.5 g of either muscle, liver, intestine, gonad, or head sample was mixed with 10 mL of concentrated HNO<sub>3</sub> (70 %; Merck) and 1 mL of HClO<sub>4</sub> (70 %; Merck) and digested on a hot plate until a clear solution was formed. Then 20 mL of distilled water were added and the mixture boiled. After cooling, the extract was filtered, and the volume was made up to 100 mL with distilled water. Depending on the availability of the fish parts, analysis was repeated between three and five times to allow for statistical evaluation of data.

The elements were analyzed using a Perkin Elmer Atomic Absorption Spectrophotometer AAnalyst 200 (Waltham, Massachusetts, USA). The conditions used for analysis as follows: The flow of acetylene and oxidant were kept at 3.62 and 10.0, respectively, throughout. The slit widths were 1.8/0.6 for all except Cd, which was adjusted to 2.7/1.35. The wavelengths of detection in nanometers were as follows: Cd = 228.6, Cr = 357, Cu = 324.8, Fe = 252, Mn = 403.1, Ni = 305.1, and Pb = 283.

## Quality Control

To ensure that there was no contamination from the sampling tools, plastic materials were used, and the samples were kept in polythene bags. The glassware used was soaked in diluted HNO<sub>3</sub> overnight and further rinsed with deionized water just before use. To check for reagent and environmental contamination, reagent blanks were used. The precision of the analytical method and instrument was measured by performing replicate sample analysis. The accuracy of the method and the efficiencies of digestion were measured by performing in-house spike-recovery tests on random sediment and fish samples for the analytes of concern.

The analytical method was validated by using in-house-spiked matrices of sediment and fish using a multi-element standard solution (MESS) at three different concentration levels of each metal. Two grams of randomly selected ground fish muscle and river sediment were spiked at 0.025, 0.05, and 0.1 mg/kg with the MESS. The spiked samples were digested, and the concentration of the metals in the digests was determined using atomic absorption spectrometry. Blank samples were carried through the digestion procedure described later in the text for fish and sediments. The data adduced afforded the calculation of percent recoveries.

## Coefficient of Condition

*K* relates the length of a fish to its weight. The value is related to relative robustness/plumpness of the fish, which in turn is related to the environmental conditions of exposure (Choongo et al. 2005). It gives an indication of biological and ecological parameters, i.e., degree of fitness, gonad development in relation to environmental state as far as feeding conditions are concerned, etc. (MacGregor 1959). The coefficient depends on factors such as sex, season availability of feeds, and other water-quality parameters (Khallaf et al. 2003). The higher the *K* value, the healthier the fish. In this study, the *K* value was determined by weighing each fish and taking into account its standard length, which is the length from the tip of the upper lip to the bending point of the caudal fin, and used Eq. 1 to calculate *K*:

$$K = W \times \frac{10^5}{L^3} \quad (1)$$

where *W* is the weight of the fish in grams; and *L* its standard length in millimeters.

## BSAF

BSAF is the ratio between metal concentration in the liver of the organism to that in the sediment (Nakayama et al.

2011; Abdallah and Abdallah 2008). This is the simplest way to estimate contaminants in biota (United States Department of Energy 1998). For instance, evaluating sediment pollution can be performed using the BSAF value. The concentration of a pollutant in biota is the product of its concentration in the sediment by the BSAF. Ecological risk assessments are therefore simplified on the basis that ambient-media concentrations are always available. These data are a requisite for site characterization and human-health assessments usually performed in conjunction with ecological assessments. BSAFs are pollutant specific; in this study they were calculated as the ratio of the concentration of the metal in liver to that in sediment using Eq. 2 (Nakayama et al. 2011; Abdallah and Abdallah 2008).

$$\text{BSAF} = \frac{C_t}{C_s} \quad (2)$$

where *C<sub>t</sub>* is the concentration of the heavy metal in the organism; and *C<sub>s</sub>* is the concentration of the heavy metal in sediment.

## Data Analysis

Data analysis was performed using Microsoft Excel Version 10 and MINITAB Release 14.13. Partial least squares (PLS) analysis was used to compare the heavy-metal loads in different fish parts.

## Results and Discussion

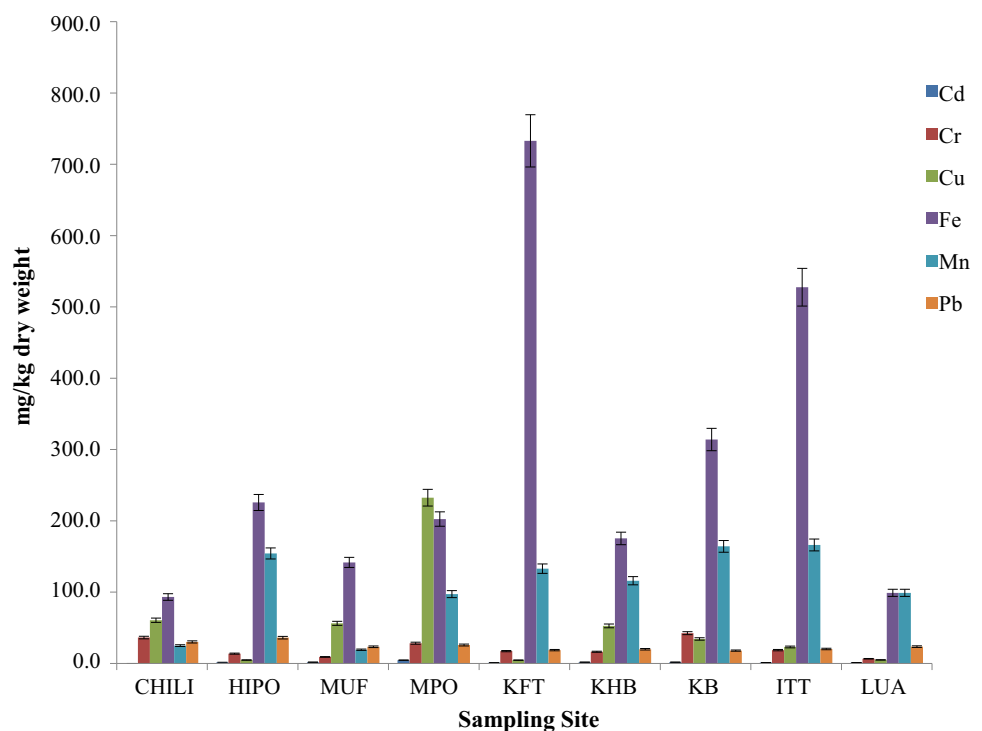
Method validation results are listed in Table 2. The mean percent recoveries in sediments ranged between 99 and 106 %, whereas in fish they ranged between 98 and 105 %. This is indicative of very good accuracy. The limits of detection (LODs) ranged between 0.1 and 1.1 µg/kg in sediments and between 0.2 and 4.3 µg/kg in fish. The analytical method was very precise with relative SDs <5 % except for Ni in fish, which was 7 %.

## Sediments

Figure 2 shows the mean concentrations in milligrams per kilogram (mg/kg) dw of heavy metals in sediment samples from the sampling sites along the Kafue River. The bars in Fig. 2 are arranged in the order of sampling sites along the river starting from upstream CHILI to downstream LUA. The highest Fe concentration was detected at KFT in the industrial area at 733 ± 37 mg/kg dw. Despite the fact that Fe is ubiquitous, Kafue town houses some of the largest manufacturing firms for fertilizer and textiles, including a leather tannery, the wastes of which are discharged into the

**Table 2** Mean percent recoveries, RSDs, and LODs for the method used to determine metal concentrations in sediment and fish

Sediment				Fish			
Analyte	Mean % recovery	% RSD ( <i>n</i> = 3)	LOD ( $\mu\text{g}/\text{kg}$ )	Analyte	Mean % recovery	% RSD ( <i>n</i> = 3)	LOD ( $\mu\text{g}/\text{kg}$ )
Cd	99	2.3	0.1	Cd	98	5	0.2
Cr	100	3.3	0.2	Cr	99	1.6	0.6
Cu	97	4.5	0.2	Cu	98	3.4	0.6
Fe	100	0.8	0.4	Fe	100	0.8	1.4
Mn	100	1.7	1.0	Mn	100	1.5	4.1
Ni	106	3.1	1.1	Ni	105	7	4.3
Pb	99	3.2	0.9	Pb	100	2.4	3.6

**Fig. 2** Mean concentrations of heavy metals in sediments at the given sampling locations

river, thus increasing the levels of metal elements. The high Fe level was observed all of the way downstream of the river to ITT. Lead was very high upstream ranging between  $36.2 \pm 1.8$  and  $23.4 \pm 1.2$  mg/kg dw between CHILI and MUF. This is in the central mining area of the Copperbelt, and the Kafue River would have absorbed all of the discharges from all of the mining activities at those point sources. Pb was slightly lower downstream ranging from  $18.0 \pm 0.9$  to  $19.9 \pm 0.9$  mg/kg dw from KFT to ITT. Speculation arose that perhaps the dispersion that could have occurred as the river flowed downstream from the Copperbelt province making it responsible for this dilution effect. However, it could also mean that industrial activities discharging metal-containing waste into the Kafue River in

the sampling locations are responsible, except that they vary in terms of quantities.

The mean concentrations of Pb, Mn, and Fe at the Kafue Bridge where the fish was sampled were  $18.0 \pm 0.9$ ,  $164 \pm 8$ , and  $314 \pm 16$  mg/kg dw, respectively. The concentration of Mn upstream at CHILI was low, but it increased slightly at HIPO. Thereafter, the concentration increased significantly downstream at KFT and stayed the same up to ITT, thus indicating industrial discharges from some point sources. The concentration of Cr was low and constant through all of the sampling points, although the highest mean concentration was recorded at KB at  $42.5 \pm 0.1$  mg/kg dw. The high mean concentration of Cr reflects its use at Kafue tannery, which is located upstream

of KB in Kafue town. The concentration ranges and detection frequencies for all of the metals are listed in Table 3.

The extremely high mean Cu concentrations upstream averaging at  $233 \pm 10$  mg/kg dw around the MPO area indicates much discharge into the Kafue River from the copper mines. The high % RSD values obtained showed the dispersion of the pollutants due to the high water currents in the river and the fact that the sediment samples were not compensated to form composite samples. Choongo et al. (2005) reported the levels of Cu in sediment between Chimfunshi and KB in the same river during the wet and dry season. They reported the highest Cu concentration at Kumasamba at 90 mg/kg in the dry season and 5 mg/kg during the wet season.

## Fish

### Heavy metals in tilapia tissues

Figure 3 shows the mean concentrations of metals in fish muscle from KB in this study. The general trend of the concentrations of metals in muscles of different tilapia species were on the order of  $Fe > Cr > Ni > Pb > Mn > Cu > Cd$ . Although variations in metal levels in the fish could be attributed to the fish age, which was reflected in their weights, which I turn varied significantly between the three fish species. The weights of three *T. rendalli* species were 250, 200, and 170 g, and these weight were analyzed separately to obtain a mean concentration value. The same was performed for the other two species, i.e., *O.*

*niloticus* whose weights were 300, 400, 280, and 150 g, and *O. andersonii* whose weights were 390 for all three samples. The highest mean metal concentrations were found in *O. andersonii* where Fe was the highest at  $648 \pm 20$  mg/kg dw followed by Cr at  $189 \pm 5$  mg/kg dw and Ni at  $76.3 \pm 0.5$  mg/kg dw. The concentration of Pb was highest in *O. niloticus* at  $38.5 \pm 0.1$  mg/kg dw. *O. andersonii* and *T. rendalli* had  $26.9 \pm 0.1$  and  $27.5 \pm 0.1$  mg/kg dw Pb, respectively. Thus, in the three fish species, Pb ranged between  $26.9 \pm 0.1$  and  $38.5 \pm 0.1$  mg/kg dw (average 31). Syakalima et al. (2001) reported Pb levels of  $28.0 \pm 1.0$  mg/kg dw in *T. rendalli* from the Kafue Flats. The concentrations of Cd followed the same trend in the three species where it was  $0.40 \pm 0.01$ ,  $0.30 \pm 0.01$ , and  $0.2 \pm 0.01$  mg/kg dw in *T. rendalli*, *O. niloticus*, and *O. andersonii*, respectively. Cd and Pb have no biological importance in human biochemistry and physiology, but as a result of consumption of these two elements through contaminated food, their elevated levels can lead to biotoxic effects. Cd and Pb levels in all fish species in this study were all greater the European Union limits (2006), which puts the limit for Cd at 0.02 mg/kg and those of the United States Food and Agricultural Organization (1983), which put the limit for Pb at 0.5 mg/kg. Pb is toxic even at low concentrations. In children, Pb poisoning has been reported to lead to decreased intelligence quotient due to improper development of the brain gray matter (Fianko et al. 2007). It has been reported in literature that high concentrations of heavy metals do not only adversely affect human beings, they also affect fish. Mwase et al. (1998) observed that the

**Table 3** Sediment concentration ranges, number of data points, and % relative SDs and detection frequencies for the six analytes at each sampling point

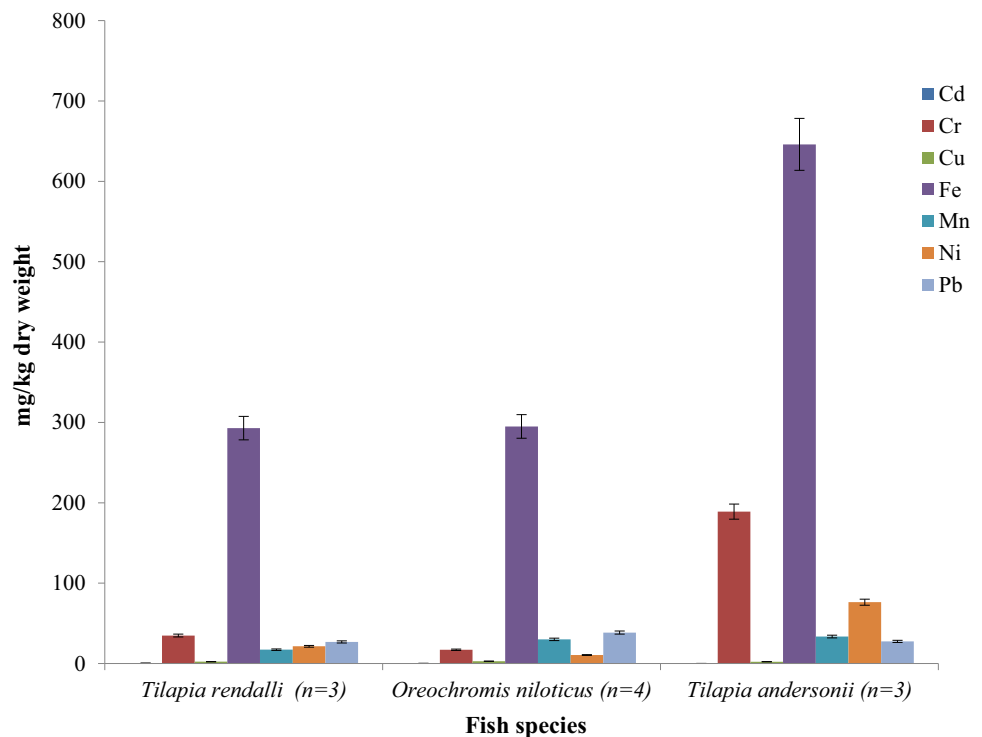
No.	Sampling site (n) <sup>b</sup>	Concentration ranges <sup>a</sup>						Detection frequency (%)
		Cd	Cr	Cu	Fe	Mn	Pb	
1	CHILI (3)	0.08–0.32 (78) <sup>c</sup>	5.80–30.2 (64)	63.2–517 (105)	773–782 (0.61)	88.4–317 (61)	5.52–69.8 (110)	100
2	HIPO (3)	0.44–0.92 (36)	12.8–37.4 (48)	35.9–1226 (157)	548–779 (18)	13.2–209 (133)	6.68–18.5 (53)	100
3	MUF (3)	0.44–1.28 (67)	8.40–50.9 (108)	343–852 (54)	499–2918 (94)	120–261 (36)	1.96–18.7 (94)	100
4	MPO (3)	0.08–0.24 (50)	3.60–30.2 (73)	14.3–517 (100)	760–794 (2.24)	41.8–205 (62)	13.6–22.2 (24)	100
5	KFT (4)	0.76–14.1 (138)	10.4–39.4 (48)	41.0–807 (165)	164–774 (92)	85.4–130 (23)	8.00–32.9 (46)	100
6	KHB (5)	1.68–1.72 (1.3)	9.20–21.8 (33)	33.8–60.2 (20)	142–236 (22)	103–119 (14)	1.04–25.5 (53)	100
7	KB (5)	1.68–1.92 (6.5)	5.04–124 (113)	4.84–109 (125)	130–737 (79)	113–199 (22)	3.24–36.16 (93)	100
8	ITT (3)	1.00–1.64 (29)	17.3–21.6 (13)	4.52–60.2 (139)	156–733 (61)	98.2–133 (16)	18.3–23.9 (15)	100
9	LUA (4)	1.16–1.32 (14)	0.48–9.20 (62)	4.20–6.00 (16)	697–737 (3.5)	80.6–130 (24)	19.9–26.1 (11)	100

<sup>a</sup> Data presented as mg/kg dw

<sup>b</sup> No. of data points

<sup>c</sup> % RSD in parentheses

**Fig. 3** Mean concentrations of metals in tilapia muscles for the three species



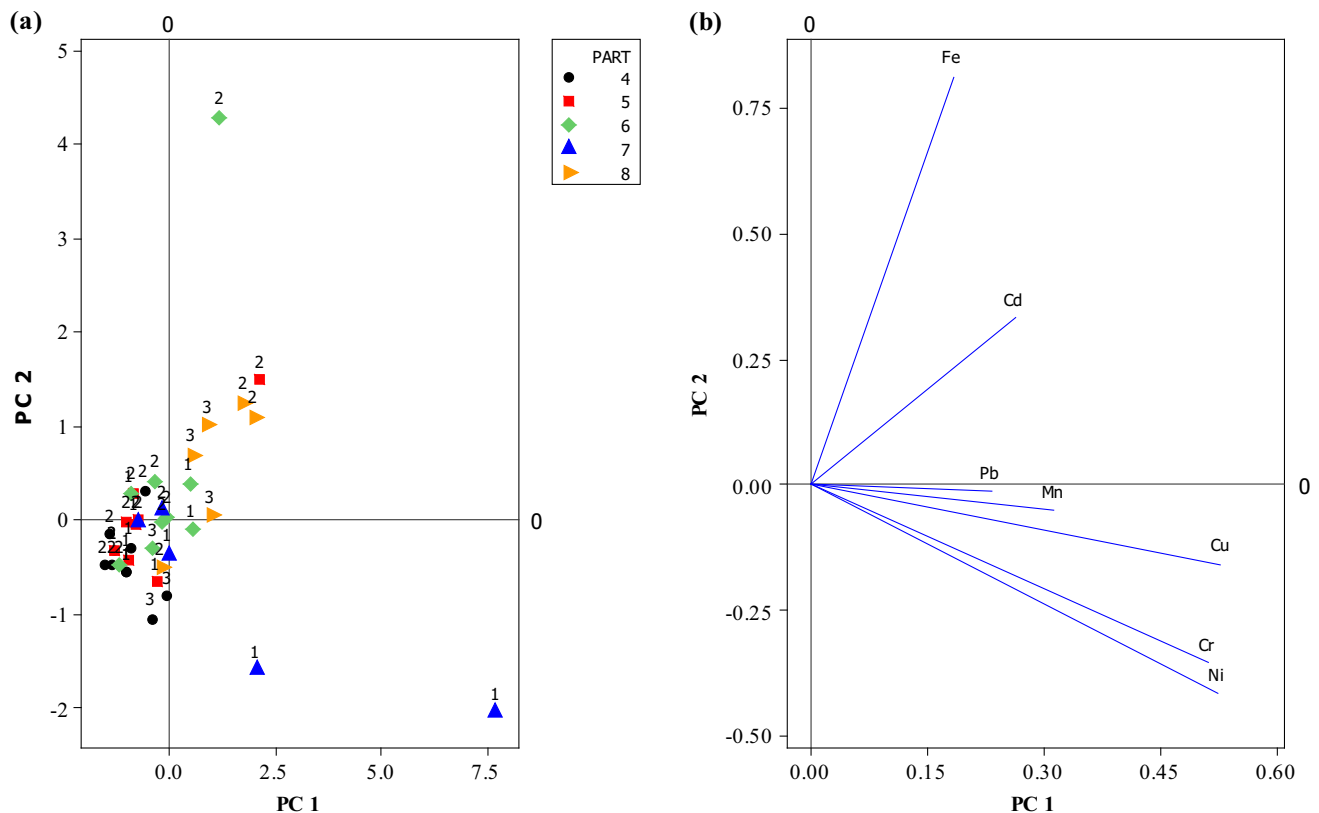
hatching and mortality of the juvenile tilapia fish were negatively affected by high Fe levels. They also observed increased mortality and delayed hatching in the polluted fish.

The mean concentration of Mn was  $17.2 \pm 0.001$ ,  $30.1 \pm 0.001$ , and  $33.6 \pm 0.001$  g/kg dw in *T. rendalli*, *O. niloticus*, and *O. andersonii*, respectively. Sykalima et al. (2001) reported high concentrations of Mn at 13 mg/kg in *T. rendalli* fish samples collected from the Kafue flats. This value is comparable with the one found in *T. rendalli* in this study. However, it was above the recommended dietary allowance (RDA) and adequate intakes (AI) for Mn of 0.003–0.6 mg/d (age 0–12 months), 1.2–1.5 mg/d (age 1–8 years), and 1.6–2.3 mg/d [age 9–70 years for adult females and males (The National Academies Press 1997–2005)]. Despite the fact that Mn has biological significance in preventing cardiac arrest, heart attack, and stroke in humans, if consumed in large quantities it can lead to increased levels and result in neurologic and psychological disorders with acute effects.

The mean concentration of Cu was  $2.3 \pm 0.001$ ,  $2.8 \pm 0.001$ , and  $2.2 \pm 0.001$  mg/kg dw in *T. rendalli*, *O. niloticus*, and *O. andersonii* respectively. The levels of Cu, Cr, and Fe were in some cases greater than the RDAs and AIs (The National Academies Press 1997–2005) of Cu = 0.20 mg/d (age 0–6 months), 0.22 mg/d (age 6–12 months), and 0.34–0.44 mg/d (age 1–8 years) and 0.7–0.9 mg/d (male and female adults); Cr = 0.2 to

5.5  $\mu\text{g}/\text{d}$  (age 0 to 12 months), 0.7 to 1.0  $\mu\text{g}/\text{d}$  (age 1–8 years), and 20–35  $\mu\text{g}/\text{d}$  (age 9–70 years); and Fe = 0.27–11 mg/d (age 0–12 months), 7–10 mg/d (age 1–8 years), and 8–15 mg/d (age 9–70 years). High Cu levels in fish have been reported by Choongo et al. (2005) who determined Cu values ranging between 5 and 5.5 mg/kg dw in the dry and rainy season, respectively, at KB. The dilution effect of the river was also showed by these researchers where Cu levels were 23 and 22 mg/kg in areas where the point sources discharged Cu directly into the Kafue River on the Copperbelt province. Nakayama et al. (2010) also reported levels of  $1.53 \pm 0.54$ ,  $3 \pm 1$ ,  $0.003 \pm 0.005$ ,  $0.12 \pm 0.25$ , and  $0.38 \pm 0.29$  mg/kg for Cr, Cu, Cd, Pb, and Ni in *O. niloticus* collected from ITT, respectively. These values compared well with the findings in this study. ITT is further downstream of KB, and the dilution effect of the river is notable in all metal concentrations in the fish species.

The data adduced for the concentrations of the metals in the three fish species from different parts were subjected to PLS analysis. PLS scores and loadings using MINITAB Release 14.13 were used to analyze the data as shown in Fig. 4. Analysis of variance for the PLS model used yielded  $p$  (0.024), which is less than  $p$  (0.05), thus indicating that the model was valid. It had six components. All of the metals had positive regression coefficients except for Ni, the coefficient of which was negative, *i.e.*, Cd = 0.14, Cr = 0.65, Cu = 0.16, Fe = 0.27, Mn = 0.27, Ni = -0.56, and



**Fig. 4** PLS analysis of the results of metal contents in different fish species and parts. **a** Score plot. **b** Loadings plot 1 through 3 and fish types 1 *T. rendalli*; 2 *O. niloticus*; 3 *T. andersonii*; 4 muscle; 5 head; 6 gonads; 7 intestines; 8 stomach; 9 liver

Pb = 0.08. The score plot generated by plotting the x-scores using a scatterplot on MINITAB in Fig. 3a shows a generally even distribution of metals in the fish species and parts; however, exceptions can be drawn from the loading plot in Fig. 3b. From the loading plot in Fig. 3b, Pb, Mn, and Cu were highly correlated and were higher in the liver, stomach, and intestine of all three fish species, *i.e.*, *T. rendalli*, *T. andersonii*, and *O. niloticus*. Cd was highest in liver of *T. rendalli* and *O. niloticus* as well as gonad of *O. niloticus*. In contrast, Cr and Ni were also highly correlated and were of low concentration in stomach of *T. rendalli*, thus implying that the fish was less exposed to these two metals. Cr and Ni are not mined on the Copperbelt even though Cr is used on a small- to large-scale basis at the leather tannery in KFT. Fe was not highly correlated to any of the metals but was the highest in all fish parts; however, overall it was highest in intestine of *O. niloticus*, which is an indication of the ubiquitous nature of Fe in the environment to which the fish species are exposed.

A summary of metal variations is listed in Table 4, which shows mean concentrations of the six metals in the three fish species. The high % RSDs indicate the variations that were due to the noncompensation of fish parts to make composite samples.

It is interesting to note the high Pb in liver of the fish samples, which was quite significant. Norrgren et al. (2000) reported extremely high concentrations of the metals in liver from *T. andersonii* exposed for 2 weeks in situ at two localities in Kafue River. Cu was determined to be  $9700 \pm 810$  mg/kg downstream of the mining area compared with samples that were collected upstream of the mining area at  $4700 \pm 840$  mg/kg. Levels of the rest of the metals were as follows: Cd  $1.9 \pm 0.3$  mg/kg dw upstream and  $4.4 \pm 0.8$  mg/kg dw downstream; Cr =  $0.03 \pm 0.03$  mg/kg dw upstream and  $0.16 \pm 0.01$  mg/kg dw downstream; Fe =  $1800 \pm 740$  mg/kg dw upstream and  $6000 \pm 2700$  mg/kg dw downstream; Mn =  $21 \pm 3$  mg/kg dw upstream and  $108 \pm 8$  mg/kg dw downstream; Ni =  $0.17 \pm 0.05$  mg/kg dw upstream and  $1.40 \pm 0.3$  mg/kg dw downstream; and Pb =  $3.8 \pm 1.0$  mg/kg dw upstream and  $2.2 \pm 0.3$  mg/kg dw downstream.

#### BSAF

BSAF values estimated using Eq. 2 are listed in Table 5. From Table 5, the BSAF values for metals under study ranged from  $0.05 \pm 0.01$  for Cd in *O. niloticus* to  $10.5 \pm 0.6$  for Fe in *T. andersonii*. The values for Pb were



**Table 4** Mean concentrations of metals in three fish species in different fish parts from fish collected from KB

Fish species	Fish part	Cd	Cr	Cu	Fe	Mn	Ni	Pb
RBB ( <i>n</i> = 3)	H	0.4 (94) <sup>a</sup>	35.5 (3)	6.1 (114)	385.9 (13)	65.9 (37)	30.0 (7)	49.1 (57)
NT ( <i>n</i> = 5)	H	0.5 (116)	14.4 (71)	9.0 (134)	271.6 (70)	59.2 (57)	11.4 (57)	37.6 (95)
TSB ( <i>n</i> = 3)	H	0.3 (47)	169 (15)	3.9 (26)	556 (32)	37.0 (33)	61.2 (7)	46.8 (15)
RBB ( <i>n</i> = 3)	G	0.4 (63)	50.8 (37)	16.5 (27)	640 (23)	89.2 (22)	36.3 (67)	34.6 (76)
NT ( <i>n</i> = 5)	G	1.0 (103)	19.7 (46)	15.3 (75)	1234 (74)	104 (97)	20.2 (47)	90.5 (123)
RBB ( <i>n</i> = 3)	I	0.2 (3)	37.4 (22)	34.5 (76)	1229 (82)	338 (85)	34.8 (55)	23.7 (28)
NT ( <i>n</i> = 5)	I	0.2 (57)	26.5 (87)	46.8 (58)	3117 (155)	151 (59)	21.9 (15)	31.5 (46)
TSB ( <i>n</i> = 3)	I	0.2 (0.1)	67.9 (0.3)	14.1 (0.1)	1952 (0.4)	29.3 (0.3)	58.5 (0.3)	54.7 (0.1)
RBB ( <i>n</i> = 3)	S	0.7 (54)	284 (86)	130 (130)	826 (70)	274 (40)	148 (77)	110 (28)
NT ( <i>n</i> = 3)	S	0.4 (70)	27.1 (67)	50.9 (21)	741 (38)	181 (8)	20.3 (58)	11.6 (3)
NT ( <i>n</i> = 3)	L	2.0 (100)	64.6 (154)	49.5 (68)	433 (472)	199 (37)	43.4 (48)	92.7 (60)
TSB ( <i>n</i> = 3)	L	1.0 (84)	154 (27)	28.7 (42)	3300 (5)	38.4 (27)	55.0 (30)	70.3 (4)

H head, G gonads, I intestines, S stomach, L liver, RBB red-breasted bream *T. rendalli*, NT Nile tilapia *O. niloticus*, TSB three-spotted bream *T. andersonii*

**Table 5** Biota BSAF values for three tilapia species from KB

Fish	Cd	Cr	Cu	Fe	Mn	Pb
TSB ( <i>n</i> = 3)	0.58 ± 0.01	3.63 ± 0.40	0.84 ± .05	10.51 ± 0.60	0.23 ± 0.01	3.9 ± 0.50
NT ( <i>n</i> = 3)	0.05 ± 0.01	0.28 ± 0.02	1.28 ± 0.10	0.24 ± 0.10	1.3 ± 0.20	8.03 ± 0.50
RBB ( <i>n</i> = 3)	0.37 ± 0.01	6.68 ± 0.40	3.78 ± 0.50	2.63 ± 0.60	1.67 ± 0.40	6.14 ± 0.20

RBB red-breasted bream *T. rendalli*, NT Nile tilapia *O. niloticus*, TSB three-spotted bream *T. andersonii*

quite high at  $8.0 \pm 0.5$  and  $6.1 \pm 0.2$  in *O. niloticus* and *T. rendalli*, respectively. BSAF values  $>1.0$  indicate the high level of sequestration of metals in liver of the fish at KB where they were collected. This can also be confirmed by the high level of these metals in sediments at this sampling point. All BSAF values for Cd were  $<1.0$  in all three fish species. This observation has been reported in the literature from other studies (Falusi and Olanipekun 2007; Nakayama et al. 2011). The tilapia species in this study are herbivorous in nature; their diets consist mainly of plant materials (Getachew and Fernando 1989). Because plants in the food chain are primary producers, they take up metals as they come into contact with the water and sediments. These metals are made bioavailable to the fish as they consume them. Fish also take up metals through their gills and skin. Due to the high BSAF values obtained in this study, it is conceivable that the ecology around this environment could be at the risk of heavy-metal contamination.

#### Coefficient of condition

Table 6 shows the weights, lengths, and *K* values of the tilapia species obtained in this study. The values are mean of three fish samples, i.e.,  $n = 3$  for each species. The *K* values ranged from  $2.5 \pm 0.5$  to  $5.1 \pm 0.6$  and

were comparable with values obtained in previous studies performed in different sites along the Kafue river. From Table 6, the highest *K* value was recorded in *O. niloticus* at  $5.1 \pm 0.6$  and the lowest in *T. rendalli* at  $2.5 \pm 0.5$ . Choongo et al. (2005) obtained *K* values of 2.2 and 2.5 in a different fish species, *Serranochromis*, in the rainy and dry season, respectively, at KB. Higher *K* values between 3.0 and 3.3 were obtained in the same study in fish obtained from the Kafue river source at Chimfunshi before the point sources from the mines on the Copperbelt mining area. In that same study, lower values of 2.0 to 2.5 were obtained from fish collected after the mining point sources. Nakayama et al. (2010) obtained *K* values of  $3.2 \pm 0.4$  in *O. niloticus* from ITT, i.e., the same tilapia species as in this study from KB, which yielded a *K* value of  $5.1 \pm 0.6$ . KB is upstream of ITT, and thus these results would be expected compared with those obtained in this study. A study of two tilapia species, i.e., *T. zillii* and *O. urolepis urolepis*, grown in freshwater in a pond, i.e., devoid of metal contamination and in full-strength seawater, reported *K* values (Nehemia et al. 2012) *T. zillii* yielded 3.3 and 0.74 in freshwater and full-strength seawater, respectively. *O. urolepis urolepis* yielded *K* values of 0.53 and 0.86 in fresh and full-strength seawater, respectively.

**Table 6** Weights, lengths and coefficients of condition (*K*) values for the three tilapia species

Fish	Mean weight (g)	Standard length (mm)	Total length (mm)	<i>K</i>
<i>Tilapia rendalli</i> ( <i>n</i> = 3)	206.7	186	231	2.5 ± 0.5
<i>Oreochromis niloticus</i> ( <i>n</i> = 3)	282.5	184	228	5.1 ± 0.6
<i>Tilapia andersonii</i> ( <i>n</i> = 3)	390.0	229	286	3.2 ± 0.4

In the present study in Kafue River, *K* values were significantly higher for locations that are downstream of the mining area, which is an indication of relatively healthy fish. Perhaps this could be attributed to the dispersion of the pollutants as well as the changes in salinity of the water as the river flows. The improvement in fish health from upstream to downstream was observable from this and other studies performed previously. Choongo et al. (2005) attributed the higher *K* values to changes in the contaminant toxicity as a result of dilution, diffusion, adsorption, and precipitation, all which are physicochemical processes.

## Conclusions

Levels of heavy metals, i.e., Cu, Cd, Pb, Mn, Cr, and Fe, in sediment and tilapia species of the Kafue river were estimated. BSAF values were also determined. The BSAF values of all metals, except Cd, were >1.00 implying that there is high sequestration of these metals in liver tissues of the fish species under study. In almost all of the tilapia species, Mn, Cd, and Pb were more sequestered in liver tissues than in other body parts. Pb and Cd are metals of concern due to their extreme toxicity, even at low concentrations. The two metals are also potential endocrine disruptors. The *K* values, compared with those from previous studies, suggested that fish were healthier as the river progressed from the upstream mining areas to the downstream areas far flung from the mines.

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