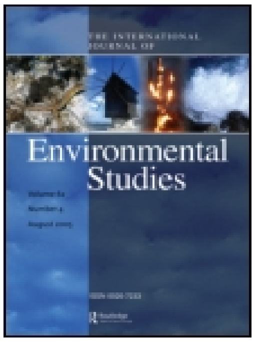

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Jolocam Mbabazi & John Wasswa

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Contamination by heavy metals in silver fish (*Rastreneobola argentea*) caught from Lakes Kyoga and Victoria, Uganda

JOLOCAM MBABAZI* AND JOHN WASSWA

Department of Chemistry, Makerere University, PO Box 7062, Kampala, Uganda

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Little information exists on heavy metal contamination in silver fish (*Rastreneobola argentea*) caught from Lake Victoria. A large number of Ugandans consume the species. Sun-dried silver fish were collected from 10 landing sites on Lake Victoria, and from five control sites along Lake Kyoga. The finely ground fish was digested with analytical reagent grade nitric acid. Analyses were performed by atomic absorption spectrophotometry. The specimens were found to contain significantly higher levels ($p \leq 0.05$) of zinc, Zn (86.1%), copper, Cu (99.1%), cadmium, Cd (99.3%) and lead, Pb (94.6%) compared with those from the control sites. The fish contamination was attributed to discharge into Lake Victoria of untreated industrial and anthropogenic effluent. Although mean Zn, Cu and Pb concentrations were still below, those of Cd were higher than the maximum permissible levels recommended by the World Health Organization (WHO). Overconsumption of the silver fish could pose Cd-related health risks.

Keywords: Lake Victoria; Lake Kyoga; Rastreneobola argentea; Contamination; Heavy metals; Uganda

1. Introduction

Poisoning by heavy metals as a result of fish contamination constitutes a major area of current scientific research [1–4], but little is known in this respect about silver fish (*Rastreneobola argentea*) caught from the Uganda side of Lake Victoria. Heavy metals may naturally enter aquatic environments through geological weathering; nevertheless large quantities of metals are usually introduced into localised areas of water bodies owing to human activities, with consequential upsetting of the natural state of balance. Recent studies carried out in Lake Victoria have revealed the presence of relatively elevated levels of heavy metals in the water [5] and sediment samples [6,7]. The discharge of untreated heavy metal pollutants from industrial [8–10], urban and agricultural sources has rendered Lake Victoria particularly vulnerable to the accumulation of substances that are potentially toxic to aquatic organisms, and their ultimate human consumers.

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*Corresponding author. Email: jolocammbabazi@chemistry.mak.ug

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The population density of Uganda's more than 30 million people is highest around the Lake Victoria region, which includes the capital city of Kampala and Jinja, the second largest city and leading industrial town in the country. Most of these people depend on the lake for their daily fish needs. Lake Victoria, the world's largest tropical freshwater lake and the largest in Africa, covers an area of 68,800 km^2 and is shared by Kenya (6%), Uganda (43%) and Tanzania (51%) [11]. There exist in the lake over 350 different fish species [12], some of which are edible, including Nile perch (*Lates niloticus*), Nile tilapia (*Oreochromis niloticus*), cat fish (*Chrysichthys nigrodigatatus*) and, among them, the silver fish (*Rastreneobola argentea*). Of these, the Nile perch is the largest in size; a full grown fish may weigh over 100 kg and measure up to a metre in length [11]. It is exported as fillet all over Africa and overseas. Fish production in Uganda is estimated at 220,000 metric tonnes, with frozen and chilled Nile perch fillet exports earning the country US$143 million annually [3]. On the lower end of the scale is the non-export silver fish (locally commonly known as *mukene*), a tiny but numerous species with full-grown adults (the size of a fat grasshopper) weighing ≤ 1 g [13] and measuring ≤ 50 mm in length from mouth to tail fin [14]. Of the various species in the lake, there is none that is caught and consumed in greater *numbers* than *mukene* [13,15].

The silver fish species is not peculiar to Lake Victoria. It is predominantly found in Lake Kyoga, a shallow swampy depression lake with a maximum depth 5.7 m [16] linked by the Victoria Nile some 150 km downstream (figure 1). The Victoria Nile flows through the lake on its way from Lake Victoria to Lake Albert. The main inflow into Lake Kyoga from Lake Victoria is regulated by the Owen Falls Dam at Jinja. Between the two lakes the Victoria Nile passes through gently sloping swamps, marshland and papyrus wetland, undergoing considerable filtration and sedimentation. Another source of water into Lake Kyoga is the relatively pollution-free Mount Elgon region on the border between Uganda and Kenya. The only other lake in Uganda where *Rastreneobola argentea* are found – to a lesser extent – is Lake Victoria, another depression, but deeper (mean depth, 40 m) [11,13], water-body. The silver fish are caught by local fishermen mainly at night using brightly lit kerosene pressure lamps mounted on floating rafts. The fish, attracted to the light, are dragged out of the water [14] in their thousands with scoop-nets and are sun-dried directly on the beaches. Owing to their small size, between 100 and 200 (about two handfuls) of such silver fish may be boiled to supplement an average family's mid-day or evening meal. The fish in soups and stews are usually consumed whole by young and adult persons, bones and all, not scaled, but including the heavy metal laden endoparasites [13]. Some people prefer the fish roasted. The species is highly regarded by the local populace as a rich and easily affordable source of protein [14]. Consequently, the sun-dried fish are often ground by the millions in mills to make a fine powder. This is sold in supermarkets as baby food, and usually added to hot maize-flour porridge or gruel to fortify the early morning meal for infants and adults alike. It is also pounded with groundnuts to make a highly nutritious stew to accompany local dishes either in the home or in cheap eating places in the city and other towns. Many low-income earners, who form the majority, prefer these dishes. Silver fish are nowadays served in secondary schools as a welcome addition to kidney bean sauce. Because it is so nutritious and fortifies the body against a number of infections, the silver fish is commonly believed in Uganda to have miraculous curative properties, especially in infants, against ailments such as measles and whooping cough. Over 70% of the *mukene* catch, however, is ground and mixed with chicken feed [17]. The coarsely ground fish is mixed with mash for chicks, layers and broilers, so much so that fresh flesh from the chickens may bear a fishy smell as a result of over-consumption of silver fish grindings from the feeds. Chicken mash manufactured by local industries like *Ugachick* is exported to East African Community member states such as

Figure 1. Schematic map of Uganda showing study fish landing sites on Lake Victoria (1–10) and on Lake Kyoga (A–E).

Burundi. Silver fish leftovers from sales in local markets are often gathered, mixed with maize hullings and fed to poultry such as turkeys and domestic guinea-fowls. The poultry ends up on the dining table as meat and/or eggs. The ground silver fish may also be mixed with animal feed for cattle, sheep, goats, pigs and fish ponds [18]. Roast pork is considered a delicacy for the majority of urban dwellers; milk and beef is almost a must for everyone.

It thus becomes clear that this tiny fish species is consumed, directly or indirectly, by virtually the entire spectrum of the Ugandan population, from infants to adults and elites, through poultry, piggery, aquaculture, dairy and beef products. This fish species is caught from the waters of Lake Victoria, which are known to contain significant amounts of heavy metals such as mercury [3], zinc, copper, cadmium, lead [5] and toxic cyanobacteria [19,20]. Heavy metals may accumulate in fish tissue, especially if the source water contains them. *Rastreneobola argentea* feeds mainly on zooplankton which is superabundant in the organo-rich aquatic environment, and for which there is not much competition [15]. It is likely that the fish may absorb the metals from the plankton as well as through the gills, and the contamination ends up in human beings through direct or indirect consumption. The transfer of toxic metal contamination from the lake to the fish and on to poultry and eggs seems almost inevitable. The heavy metal content from this fish species may even find its way into cow-milk via cattle feed [18]. Fishes are known to concentrate heavy metals in their gills, gut and muscles. Each edible fish species needs to be carefully screened to ensure that undesirably high levels of toxic trace metals are not being transferred to human beings through fish consumption [21]. Chemical contaminants are likely to be in higher concentrations in fish and fish products from polluted waters [22]. The Nile perch, a predator at the top of the food chain [3,23], which feeds mainly on the silver fish species in Lake Victoria, has been found to contain significant amounts of heavy metals [3]. The levels of the metals in the Nile perch may be taken as an indirect indication of possible contamination in the much smaller fish upon which it predates, because small fish tend to become enriched with the accumulated substances. It is therefore likely that the silver fish themselves might have accumulated a certain level of the toxic metals. And yet there is almost no knowledge about the levels of toxic heavy metals in this highly consumed fish species [24]. Cadmium and lead are especially toxic to human beings; silver fish may well concentrate their effects in consumers. The problem is potentially enormous.

The object of this study, therefore, was to determine systematically and elucidate the levels of contamination by heavy metals in the silver fish caught from Lake Victoria. Comparison with levels laid down by food standards bodies may help alert the authorities about exposure of the national population to possible toxic-metal health risks arising from overconsumption of the contaminated fish.

2. Materials and methods

2.1. Study areas

The visited fish landing sites (figure 1) along the shores of Lake Victoria were Majanji (*1*, Tororo district), Wairaka, Masese (*2*, *3*, Jinja district), Katosi, Ssenyi (*4*, *5*, Mukono district), Ggaba (*6*, Kampala district), Kasenyi, Kigungu (*7*, *8*, Wakiso district) and Kyabasimba, Kasensero (*9*, *10*, Rakai district). Those on Lake Kyoga were Masindi port (*A*, Masindi district), Rwampanga (*B*, Nakasongola district), Bukungu (*C*, Pallisa district), Kayago (*D*, Lira district) and Akokoro (*E*, Apac district).

2.2. Sampling of water from Lakes Victoria and Kyoga

At each of the fish landing sites on both lakes, surface water samples were collected by dugout canoe using 20-litre jerry cans, 200 m from the shore. The containers were cleaned and rinsed several times with the lake water before use. The water was filtered within a few hours of sampling, transferred to 5-litre polyethene containers and stored at room temperature (25°C) before being taken to the laboratory for analysis.

2.3. Collection of **Rastreneobola argentea** *fish specimens from Lakes Victoria and Kyoga*

Fifty (50) mature (40–50 mm in length from mouth to tail, and each weighing 0.5–1 g) silver fish were selected from catches at each landing site. The specimens of thoroughly sun-dried silver fish were bought from each of the ten fish landing sites on Lake Victoria, as well as from each of the five control sites along Lake Kyoga in northern Uganda. After careful labelling using permanent stickers, the specimens wrapped in aluminium foil were subsequently placed in polyethene bags before being transported in dry boxes, to avoid moisture, to the laboratory for analysis. The period of study was during the hot (average temperatures 28°C) and sunny months of May, June and July 2009 when drying of the silver fish catches on the beaches was easier and more complete.

2.4. Determination of total heavy metals in the waters of Lakes Victoria and Kyoga

To 500 ml of the filtered water sample was added 10 ml of concentrated hydrochloric acid (analytical reagent grade) and evaporated under gentle heat to 50 ml. The concentrate was quantitatively transferred to a 100 ml flask and made up to the mark with deionised distilled water. The resultant aqueous solution was analysed for each of the heavy metals Zn, Cu, Cd and Pb using a flame atomic absorption spectrophotometer, FAAS (Perkin-Elmer GmbH, Uberlingen, Germany. Model 2380).

2.5. Determination of total heavy metals in sun-dried silver fish specimens

Because the silver fish was normally consumed sun-dried by the local population, it was considered unnecessary to carry out analyses on fresh catches. Whole fish specimens of sun-dried silver fish from the two lakes were first pulverised and homogenised by grinding them thoroughly in a ceramic mortar. The resulting powder was further sun-dried under the bright tropical mid-day sun for 2 h before sifting it through a 2 mm nylon sieve. Accurately measured 4.000 g of the final product was calcined to constant mass in an electric furnace at 550°C for 2 h. After cooling, the ash was dissolved in 10 ml concentrated nitric acid (analytical reagent grade) and made up to 50 ml with deionised distilled water before being taken for heavy metal analysis by FAAS as indicated in section 2.4. For each site all analyses were carried out in triplicate ($n = 3$). The data were subjected to the Student's t-test for p values and standard deviations, using the SPSS version 12 statistical package. The average values were computed together with their associated standard deviations (± SD). All metal concentrations were obtained and expressed as micrograms per gram of dry weight fish sample ($\mu g\ g^{-1}$ *d.w.*).

2.6. Analytical quality assurance (for both water and fish sample analyses)

Analytical blanks were prepared by repeating the respective digestion procedures, minus the samples, and subsequently used to determine the instrument detection limits. The quality of the analytical process for the fish was also controlled by analysis of the NIST-CE278 certified standard reference material for fish tissues, with fortified sample recoveries in the range 80–84%, which lent support to the reliability of the technique used. As a result, there was little adjustment in the raw heavy metal data so obtained.

3. Results and discussion

3.1. Total heavy metals in the waters of Lakes Victoria and Kyoga

Table 1 shows the total metal concentrations in the water at each of the selected fish landing sites along the shores of each of the two lakes. The same table also gives the mean values for all the studied sites on each lake, together with the corresponding levels, obtained at Jinja on Lake Victoria one year earlier but using a different analytical technique [5], for ease of comparison (table 1a). Because knowledge of the current levels of heavy metals in water from Lake Kyoga was necessary, it was essential to carry out a similar investigation on Lake Victoria waters. Observing that quality assurance experiments gave values with ≥ 80% recovery using both methods, which confirmed the reliability of the techniques used, our data indicated that there had been a significant change in the heavy metal levels ($p \leq 0.05$) in Lake Victoria during this period. There has, however, been no major increase in the degree of industrialisation in the neighbouring city and other municipalities, and the time was perhaps too short an interval for sufficiently detectable observations to be made. But whereas the results [5] had been obtained for a localised (Jinja) area, the present data were for sites spread along more than 250 km of the Lake Victoria shoreline (figure 1). One matter was certain: the level of the heavy metals in the water was not decreasing. On the other hand, the mean total levels of the metals in the waters of Lake Kyoga (table 1b) were lower and exhibited a marked difference from those observed in Lake Victoria. This seemed to indicate that Lake Kyoga at present suffers lower heavy metal pollution than Lake Victoria. For this reason it was considered a satisfactory control water body for our fish studies.

According to the World Health Organization (WHO), the maximum permissible levels of Zn, Cu, Cd and Pb in drinking water are Zn = 3; Cu = 2; Cd = 0.003; Pb = 0.01 µg ml^{-1} [25],

Table 1. Total heavy metal levels (µg ml^{-1}) in water at various fish landing sites

Landing site	Zn	Cu	Cd	Pb
a) Lake Victoria				
Ggaba	1.58 ± 0.05	1.43 ± 0.06	0.123 ± 0.005	1.29 ± 0.04
Kasensero	1.56 ± 0.07	1.13 ± 0.04	0.089 ± 0.004	0.89 ± 0.02
Kasenyi	1.51 ± 0.04	0.99 ± 0.03	0.065 ± 0.003	0.98 ± 0.03
Katosi	1.32 ± 0.02	0.89 ± 0.03	0.121 ± 0.004	0.99 ± 0.03
Kigungu	1.47 ± 0.04	0.86 ± 0.05	0.098 ± 0.005	1.19 ± 0.04
Kyabasimba	1.42 ± 0.06	1.43 ± 0.03	0.087 ± 0.004	1.09 ± 0.06
Majanji	1.44 ± 0.04	1.23 ± 0.02	0.079 ± 0.003	0.78 ± 0.02
Masese	1.54 ± 0.09	1.26 ± 0.01	0.098 ± 0.004	1.24 ± 0.06
Ssenyi	1.48 ± 0.04	1.03 ± 0.02	0.097 ± 0.006	1.15 ± 0.05
Wairaka	1.46 ± 0.06	0.98 ± 0.03	0.076 ± 0.004	0.94 ± 0.03
Average ± SD ($n = 10$)	1.478 ± 0.076	1.123 ± 0.208	0.093 ± 0.019	1.054 ± 0.165
Jinja [5] ± SEM ($n = 12$)	1.216 ± 0.051	0.978 ± 0.019	0.079 ± 0.002	0.942 ± 0.021
b) Lake Kyoga				
Akokoro	0.22 ± 0.02	0.14 ± 0.03	0.008 ± 0.002	0.37 ± 0.02
Bukungu	0.36 ± 0.06	0.10 ± 0.03	0.004 ± 0.002	0.19 ± 0.01
Kayago	0.18 ± 0.04	0.09 ± 0.02	0.003 ± 0.001	0.27 ± 0.03
Masindi port	0.34 ± 0.03	0.13 ± 0.01	0.006 ± 0.001	0.18 ± 0.01
Rwampanga	0.13 ± 0.02	0.09 ± 0.02	0.008 ± 0.002	0.22 ± 0.01
Average ± SD ($n = 5$)	0.246 ± 0.100	0.110 ± 0.024	0.006 ± 0.002	0.246 ± 0.078

whereas the Uganda environment management statutes [26] require them as Zn, 5; Cu, 1; Cd, 0.1; Pb, 0.1 µg ml^{-1}. Current mean total levels, in µg ml^{-1}, in the waters of Lake Victoria are estimated at Zn 1.478 ± 0.076, Cu 1.123 ± 0.208, Cd 0.093 ± 0.019, Pb 1.054 ± 0.165 (table 1a), while studies on the waters of Lake Kyoga put the corresponding levels at Zn 0.246 ± 0.100, Cu 0.110 ± 0.024, Cd 0.006 ± 0.002, Pb 0.246 ± 0.078 (table 1b). There is significant deviation ($p \leq 0.05$) between the values in the two lakes. The elevated levels of heavy metals in the waters of the Uganda side of Lake Victoria arose mainly because of uncontrolled industrial and anthropogenic pollution introduced by untreated effluent along the Nakivubo channel, the major drainage system from the neighbouring capital, Kampala [9] that empties into the lake after passing through a depleted terminal wetland. Leachates into the lake from the disused copper smelter and other factories in the industrial town of Jinja (figure 1) located at the source of the Nile are also a contributory factor. Increased use of artificial fertilisers in the agricultural Lake Victoria basin further enhances the presence of Zn and Cd in the waters as a result of drainage, arising from heavy equatorial rainfall, into the lake. Cadmium is widely used in plastics and paints, like zinc. The significant presence of toxic cadmium in the lake water (table 1a) may also be traced to the volume of both small- and large-scale metal processing industries [27] that has sharply increased owing to increased demand for iron and steel bars needed for the booming building construction in the city and elsewhere in Uganda. Not possessing nor importing iron ore, Uganda relies heavily on scrap metal from old cars, rusty steel doors, windows, corroded roofing iron and, occasionally, rail steel girders. Although the recycling of scrap metal should be encouraged, during the smelting process traces of cadmium embedded in the scrap iron and steel are released to the environment in the effluent of the processing plant.

There is significant pollution of the Lake Victoria waters by zinc (1.478 ± 0.076 µg ml^{-1}). Whereas zinc is a naturally occurring metal and was expected to be present in low levels in a large water body such as Lake Victoria, its notable presence in the water is most probably due to several major factors. Currently, the building construction industry has increased tremendously in the city, with an extraordinary demand for wall and roof paints, most of which are zinc-based. New paint manufacturing industries have sprung up in the city's busy industrial area. The result is an increased release of zinc into the urban environment, which finds its way into the city's major drainage system and on to the lake. Zinc-coated corrugated iron sheets, the commonest roofing material in the country, on corrosion release considerable amounts of zinc as its oxide or sulphide into the soil [28], the leaching of which concentrates the metal in the water body via surface run-off and other processes. The oxides and sulphides of zinc presumably subsequently dissolve in the various corrodents in urban effluent and release the heavy metal mainly in its cationic form. Zinc is also extensively used in the manufacture of dry cells that are commonly used as chemical sources of electrical energy to operate radio sets, electric searchlights, remote controls, calculators, microphones, loudspeakers, etc. When they are spent, these dry cells are simply discarded into the environment. In a crowded city of over two million people [29], such throw-away cells could easily number in their thousands each day – and that is a considerable amount of zinc concentrated on a land area of only a few tens of km^2 [30]. All this eventually drains into the nearby lake. A policy on collection of used dry cell batteries would be a great improvement.

The average Pb level in the Lake Victoria waters was found to be 1.054 ± 0.165 µg ml^{-1}. The rather pronounced presence of this toxic metal in the lake waters [31], either as free cations or as associations with organic matters, could be attributed to several factors, which include the continued use of lead-based paints for face-lifting buildings in the city and their inappropriate disposal. In addition, there is poor management of industrial and municipal

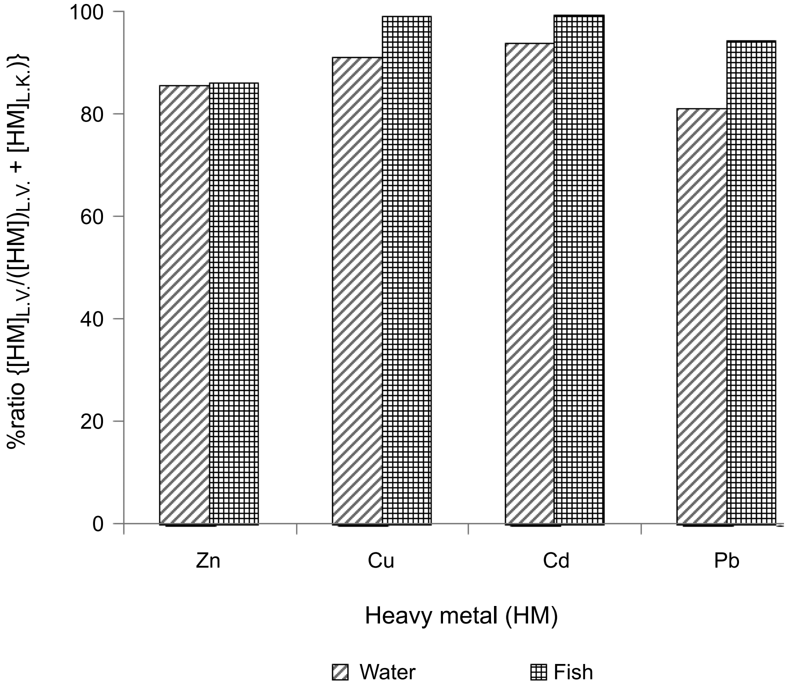

Figure 2. Percentage levels, relative to Lake Kyoga (L.K.), of heavy metals in water and silver fish from Lake Victoria (L.V.).

waste. Car washing and emptying of dead lead-acid accumulators regularly takes place directly along the streams and channels leading to the lake. A car-battery manufacturing plant is also located near the major urban Nakivubo drainage channel. The untreated Pb laden effluent discharges directly into tributaries that eventually join the Nakivubo channel and on to the Murchison Bay of Lake Victoria. From the turn of the century, the volume of motor vehicles on Kampala roads has greatly increased, with long traffic jams being a common sight on the busy city streets. Although unleaded petrol is available at fuel pump stations in the country, a number of operators and drivers do not insist on it. As a result, most car engines and numerous small electric generators still run on leaded fuel for hours on end, emitting exhaust fumes that form a dark blanket-like cloud that hangs over the city, especially late at night and early in the mornings. This ‘cloud cover’ over the city often results in the usual associated respiratory problems. The slow aerial deposition of, coupled with the run-off incorporating, particulates from the internal combustion of the leaded fuel [7,32,33], is another part of the problem [34]. The gradual shift to the use of unleaded petrol should lead to a reduction of the release of lead into the urban atmosphere.

The elevated copper content in the water on the Uganda side of Lake Victoria probably stemmed in the first place from the period of copper smelting at Jinja, which released much untreated effluent into the lake. The closure of the smelting plant in the mid-1970s owing to fluctuating prices of metallic copper on the world market, coupled with the unfavourable political climate prevailing in the country at the time, saw a reduction in the volume of the contaminant effluent. But the increased usage of imported electrical copper wire and cables in the city produces on a daily basis a considerable amount of waste metal in the form of bits, choppings and cut-offs. Metallic copper washed down in the city run-offs dissolves in the fluctuating acidities and alkalinities of the effluent. Besides, the use of copper pipes for running water in the city and surrounding townships should not be underestimated. Together, these factors were presumed to be partly, if not wholly, responsible for maintaining the levels of copper in the lake water at fairly steady, but not declining, values.

The main inlets of water into Lake Kyoga are the Victoria Nile and the Mt Elgon region. The Victoria Nile waterway passes through tens of kilometres of swamps, marshland and wetland, undergoing filtration by vegetation and silting in the process [16]. By the time it travels from Lake Victoria to Lake Kyoga some 150 km downstream it has lost much of its original turbidity and become clearer. The other source of water into Lake Kyoga is the considerably pollution-free Mount Elgon region on the border between Uganda and Kenya. There is relatively little municipal activity in the immediate vicinity of the lake. The nearest scantily populated towns of Lira and Apac are 50 km away from the shore and their effluents drain northwards away from Lake Kyoga. Direct sources of heavy metals arising from human activity are therefore comparatively few, and the lake water is by comparison relatively uncontaminated (table 1b). Figure 2 shows, on a linear percentage scale, the heavy metal contamination levels of Lake Victoria relative to those of Lake Kyoga. At the 50% mark there would hypothetically be equal distribution of each heavy metal in the waters of both lakes. In each case, however, the Lake Victoria bars are much longer than those of Lake Kyoga (Zn 14.3%, Cu 9.0%, Cd 6.0%, Pb 19.0%), covering 80–95% of the scale, indicating that the Lake Victoria waters are currently not as fresh (with respect to heavy metal contamination) as those of Lake Kyoga. Consequently, heavy metal absorption by the freshwater fish in Lake Kyoga was expected to be correspondingly lower.

3.2. Total heavy metals in sun-dried silver fish specimens

Though Lake Victoria mainly empties into Lake Kyoga via the Victoria Nile (figure 1), there is sedimentation and filtration of the water by dense papyrus vegetation as the impeded river runs through 150 km of gently sloping wetland in central Uganda. By virtue of this, there were far less elevated trace metal levels in the waters of Lake Kyoga than in those of Lake Victoria (table 1). For this reason, we found it justifiable to use the fish in Lake Kyoga for our heavy metal contamination control studies. Heavy metals were determined in the silver fish caught from both Lake Victoria and Lake Kyoga. Table 2 shows the levels, expressed in $\mu g\ g^{-1}$ *d.w.*, of Zn, Cu, Cd and Pb in samples of whole *Rastreneobola argentea* fish, for each of the 10 landing sites on Lake Victoria as well as the five control sites on Lake Kyoga. There were statistically significant differences ($p \leq 0.05$) between the average levels (± SD) of each metal in the fish in the two water bodies, with the silver fish from Lake Victoria exhibiting much higher levels than those from Lake Kyoga. For silver fish caught from Lake Victoria, the Zn concentration varied from 2.71 to 9.62 (mean, 5.64 ± 2.16), that of Cu from 0.79 to 7.94 (mean, 3.43 ± 2.18), Cd from 0.37 to 0.69 (mean, 0.57 ± 0.09) while Pb ranged from 0.09 to 0.24, with a mean of 0.17 ± 0.05 $\mu g\ g^{-1}$ *d.w.* The corresponding ranges for silver fish caught from our control sites on Lake Kyoga were Zn, 0.34–1.32 (mean, 0.91 ± 0.37); Cu, ND–0.9 (mean, 0.03 ± 0.04); Cd, ND–0.01 (mean, 0.004 ± 0.005); Pb, ND–0.02 (mean, 0.01 ± 0.01) $\mu g\ g^{-1}$ *d.w.* (ND = not detected). Figure 2 also shows a comparison of the relative degree of contamination in the fish caught from both lakes; the mean percentage ratio levels of each metal are expressed on the same scale. If the fish in both lakes shared the same extent of heavy metal contamination the dividing line would be at the 50% level. It is noticeable from figure 2 that there is a direct correlation between the level of contamination of fish and the degree of heavy metal pollution of the water from which it had been caught. Further, it is interesting to note that whereas the total concentration of the metals in the Lake Victoria water decreased in the order: Zn > Cu > Pb >> Cd (table 1), the heavy metal contamination of Lake Victoria silver fish appeared to be in the order: Zn > Cu > Cd > Pb (table 2). The ranges of international safety standards for heavy metals in fish are reported as Zn, 150 [35,36]; Cu, 3–20; Cd, 0.05–0.3; Pb, 0.1–0.3 μg g^{-1} [36,37]. These values contrasted sharply by three orders of magnitude with those quoted by Oze *et al*. [35] as Zn 150 mg g^{-1}, Cd 0.2 mg g^{-1} and Pb 1.5 mg g^{-1}, arising most probably from a mix-up of appropriate units, which are normally expressed either as μg g^{-1} or mg kg^{-1}, rather than, as quoted in [35], mg g^{-1} of fish.

Zn ranged from 2.71–9.62 (mean 5.64 ± 2.16) and 0.34–1.32 (mean 0.91 ± 0.37) μg g^{-1} *d.w*. in silver fish from Lake Victoria and from Lake Kyoga, respectively. The fish were therefore not polluted with respect to Zn when compared with the WHO and other international standards of 150 μg g^{-1} [35,36]. In view of the observation that the level of Zn in the fish caught from Lake Victoria was higher than that in the water (1.478 ± 0.076 μg ml^{-1}, table 1a), it is reasonable to suggest that, weight for weight (1 ml of water weighs approximately 1 g), silver fish had a high ability to accumulate the metal inside their bodies, and that this effect is likely to increase as the level of the heavy metal in the water rises. Although traces of Zn in the human body are a necessary dietary requirement [38], symptoms of zinc-related poisoning as a result of, usually accidental, excessive ingestion normally appear as stomach pains, diarrhoea and vomiting [39]. The presence of copper in water damages marine life [40], whereas copper toxicity is the most common form of heavy metal poisoning in human beings [41]. The copper level range of 0.79–7.94 with a mean of 3.43 ± 2.18 μg g^{-1} *d.w*. found (this work) in the silver fish from Lake Victoria was, however, well within the maximum permissible limits of 3–20 μg g^{-1} laid down by international standards [36,37].

Table 2. Total heavy metal levels (μg g^{-1} *d.w.*) in silver fish at various landing sites

Landing site	Zn	Cu	Cd	Pb
a) Lake Victoria				
Ggaba	9.62 ± 0.06	7.94 ± 0.02	0.69 ± 0.02	0.24 ± 0.02
Kasensero	7.54 ± 0.04	4.35 ± 0.01	0.49 ± 0.01	0.19 ± 0.02
Kasenyi	5.74 ± 0.05	4.43 ± 0.03	0.57 ± 0.05	0.17 ± 0.01
Katosi	4.97 ± 0.01	0.79 ± 0.04	0.56 ± 0.03	0.12 ± 0.03
Kigungu	2.71 ± 0.02	2.34 ± 0.05	0.59 ± 0.04	0.19 ± 0.03
Kyabasimba	3.65 ± 0.03	3.05 ± 0.02	0.58 ± 0.02	0.09 ± 0.01
Majanji	2.95 ± 0.04	3.37 ± 0.03	0.37 ± 0.01	0.13 ± 0.02
Masese	6.65 ± 0.05	5.32 ± 0.04	0.68 ± 0.04	0.22 ± 0.03
Ssenyi	5.78 ± 0.07	1.26 ± 0.02	0.59 ± 0.02	0.17 ± 0.02
Wairaka	6.79 ± 0.06	1.47 ± 0.01	0.59 ± 0.03	0.19 ± 0.01
Average ± SD (*n* = 10)	5.64 ± 2.16	3.43 ± 2.18	0.57 ± 0.09	0.17 ± 0.05
b) Lake Kyoga				
Akokoro	0.98 ± 0.03	ND	ND	ND
Bukungu	1.13 ± 0.04	ND	0.010 ± 0.002	0.02 ± 0.01
Kayago	0.34 ± 0.02	0.06 ± 0.01	ND	ND
Masindi port	0.79 ± 0.02	0.09 ± 0.02	ND	0.01 ± 0.01
Rwampanga	1.32 ± 0.03	ND	0.010 ± 0.001	0.02 ± 0.01
Average ± SD (*n* = 5)	0.91 ± 0.37	0.03 ± 0.04	0.004 ± 0.005	0.01 ± 0.01

ND = Not Detected.

The results indicated that the fish were thus relatively unpolluted, and so consumption of this fish would seem to pose little or no threat of copper toxicity related problems among the population.

Previous studies on the Nile perch in Lake Victoria, which predates heavily on the silver fish, had indicated that Cd accumulation in its belly flap oil extracts [3] was still below detection limits, an observation attributed to the low amounts of the metal in the lake waters and lake sediments [7]. In this study, Cd in silver fish from Lake Victoria had exceeded detection limits, as opposed to the frequent ND levels of the trace metal in the same species caught from Lake Kyoga (table 2). Cadmium concentrations in the silver fish from Lake Victoria lay between 0.37 and 0.69, with a mean of 0.57 ± 0.09 $\mu g\ g^{-1}$ *d.w.*, which was considered rather high when related to international safety standards for fish consumption set at 0.05–0.3 $\mu g\ g^{-1}$ [36,37]. As a result, the fish may be viewed as containing an appreciable degree of Cd contamination. It looks probable, therefore, that overconsumption of silver fish caught from Lake Victoria would be associated with cadmium toxicity risks. This is attributable to the rising levels of the heavy metal in the lake, in whose waters cadmium was currently estimated at 0.093 ± 0.019 $\mu g\ ml^{-1}$ (table 1a), against a WHO maximum permissible limit of 0.003 $\mu g\ ml^{-1}$ [25] in drinking water. The undue presence of Cd in the water is presumably caused by increased metal works, paints and agricultural inputs currently being used on the Uganda side of the Lake Victoria basin. Cadmium is especially toxic to human beings and has been blamed for large-scale poisoning incidents [42].

The mean Pb concentration was 0.17 ± 0.05 $\mu g\ g^{-1}$ *d.w.* in the silver fish caught from Lake Victoria. WHO and other international safety standards put maximum permissible Pb levels at 0.1–0.3 $\mu g\ g^{-1}$ [36,37]. Therefore, the observed Pb level of 0.2 $\mu g\ g^{-1}$ *d.w.* in the fish was well within the consumption safety levels, in spite of the water in the lake exhibiting higher levels of 1.054 ± 0.165 $\mu g\ ml^{-1}$ (table 1). The concentration of Pb in the silver fish species was well above the detection limit of 0.01 $\mu g\ g^{-1}$ (this work) but below the maximum permissible level recommended by WHO [37]. This seemed surprising at first because the observed Pb levels in the waters of Lake Victoria were much higher than the maximum permissible concentration of 0.01 $\mu g\ ml^{-1}$ laid down by WHO [36] in fresh water. It is generally accepted that there is often little accumulation of lead in marine and freshwater species, and that lead is consequently not a threat to fisheries resources except at extreme pollution [43]. The explanation usually given for the low level of Pb in fish muscle is the relatively low rate of its binding to –SH groups, beside the low solubility of lead salts that restrict movement across cell membranes. The need for continuous monitoring to guard against bioaccumulation is nevertheless essential, as large-scale poisoning incidents are also often associated with Pb [42], and might even lead to alterations in the genetic code [44]. Up to 0.2 $\mu g\ g^{-1}$ Pb has been detected in Nile perch belly flap oil [3], but higher Pb levels in fish have also been observed. Kisamo [17] reported Pb concentrations of up to 28.0 ppm (≡ $\mu g\ g^{-1}$) *d.w.* in fish samples from the Mwanza catchment region on the Tanzanian side of Lake Victoria. The fish samples, however, did not include silver fish because they were chosen from fish processing industries along the Mwanza Gulf, whereas silver fish are not subjected to any such pre-treatment.

The Nile perch (*Lates niloticus*), caught, processed as fillet and exported all over Africa and overseas, is Uganda’s major fish foreign exchange earner. The quality of the fish must therefore be jealously guarded. Although heavy metals had been found in the muscle, liver and oil [3] of the Lake Victoria Nile perch, the results of the present study reveal higher levels in silver fish than in Nile perch parts. The Nile perch is a large fish species introduced into both lakes Victoria and Kyoga in the mid-1950s [17] from Lake Albert, a Rift Valley lake in western Uganda. The species is absent in both Lakes Edward and George. It lives in deeper waters, does not feed on plankton but instead heavily predates over the smaller fish in the water such as Nile tilapia (*Oreochromis niloticus*) and silver fish. The remedy for heavy metals in the export fish is for the authorities to enforce point-source pre-treatment of effluent before discharge into the environment. Uganda has national statutes governing such discharge [5], but official documented information by Uganda fisheries and/or environmental authorities on standards for consumption of locally caught fish still remains scanty [45].

Conclusion

This study shows that whereas Cd and Cu were still predominantly below detectable limits ($< 0.01\ \mu g\ g^{-1}$) in silver fish from Lake Kyoga, Zn and Pb were present but far below the maximum permissible limits laid down by international safety standards. The silver fish caught from Lake Kyoga did not therefore pose any heavy metal-related threat to human consumption. The concentration of Cd in silver fish caught from Lake Victoria had, however, exceeded the levels stipulated by the WHO and other international standards. Overconsumption of the silver fish could therefore expose the Ugandan population to cadmium-related health risks. The Zn, Cu and Pb levels had not reached threshold levels but were much higher than those in silver fish from Lake Kyoga. A major cause was increasing pollution from untreated industrial and other effluent. An enforceable policy on collection of dry cell batteries or a more focused collection and separation and recycling of refuse might make significant improvements. If such changes are possible in India, Egypt, and the Philippines, they are possible also in Uganda. Inadequate environmental legislation and/or enforcement contribute to the problem of heavy metals in the environment. Appropriate measures such as legislative provision and other tools for constant and effective environmental monitoring should be mounted and used with a view to protecting and enhancing the quality and resources of Lake Victoria. Warnings to consume the fish with care and the installation of anti-pollution measures at point sources for improved sustainability of the lake should also be enforced. Because heavy metals are not easily biodegradable, there is also a need for deployment of technologies that can remove heavy metals to ensure the environmental rejuvenation of the lake basin as a whole. Health is a matter of national choice.

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