METAL CONCENTRATIONS IN SEDIMENT AND FISH OF LAKE VICTORIA NEAR AND AWAY FROM CATCHMENTS WITH GOLD MINING ACTIVITIES.

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ABSTRACT

Concentrations of metals in sediment and fish as well as organic matter contents of sediment from Lake Victoria were investigated. The objective of the study was to compare levels of metals in sediment and fish from areas of the lake that are within and outside catchments with gold mining activities.

The results showed that the concentration of As was less than 6 $\mu g\ g^{-1}$ dw and Cd was below 1.9 $\mu g\ g^{-1}$ dw in sediment samples. Lead, zinc and copper concentrations were highest (58.1±17.6 $\mu g\ g^{-1}$ dw, 101.9±20.6 $\mu g\ g^{-1}$ dw and 32.6±2.8 $\mu g\ g^{-1}$ dw respectively) in sediment samples that were collected in the lake adjacent to the Mirongo River mouth in urban Mwanza. The results showed no correlation between levels of heavy metals and the organic matter content of the sediment.

Metal concentrations in fish muscles were generally low. For instance, in Lates niloticus *the highest concentrations of cadmium, lead and copper (4.67±1.87 ng g^{-1} ww, 0.13±0.04 $\mu g\ g^{-1}$ ww, 0.7±0.2 $\mu g\ g^{-1}$ ww respectively) were found in fish caught adjacent to the Mirongo River mouth. Apparently, zinc concentrations in* Lates niloticus *were highest (8.8±4.1 $\mu g\ g^{-1}$ ww) in specimens from Mara Bay. Concentrations of heavy metals in sediments and fish from areas within and away from catchments with gold mining activities were not statistically different ($P > 0.05$). It is concluded that at present mining in the lake basin has no significant impact on lacustrine environment.*

INTRODUCTION

The background levels of heavy metals in sediments of large freshwater bodies depend to a large extent on concentrations in soils derived from rocks in the watershed. The rocks of the Lake Victoria Gold Fields (LVGF) are chiefly granite-greenstones (Bell and Dodson 1981). These greenstones and the associated sediments have a high potential for gold and base metal deposits (Condie 1981; Anhaeusser 1984). In the southern and eastern parts of Lake Victoria basin, gold mineralisation in association with other metals commonly occurs in the greenstones. Auriferous deposits in LVGF are reported to be hosted in sulphides such as pyrite, chalcopyrite, pyrrhotite, arsenopyrite or even in traces of galena and sphalerite (Kahatano and Mnali 1997), Therefore gold mining activities may release considerable amounts of Cu, As, Pb and Zn in the environment. Gold ore processing activities include excavation of the soil, crushing the rocks and washing of the powdered rock to concentrate the ore. Metals in the excavated waste rock and tailings are easily leached by runoff.

Information on heavy metals pollution of Lake Victoria as a result of gold mining activities in the basin is still scanty. The heavy metal load from mining areas that eventually reaches Lake Victoria and the fate in the lake is still obscure. Few existing studies include that of Kishe and Machiwa (2003) on heavy metal concentration in sediment of Mwanza Gulf, a very small portion of Lake Victoria and Kishe (2001) on heavy metals in fish (*Oreochromis niloticus*) of Mwanza Gulf. This is the first report on concentration of heavy metals in sediment and fish from a wider geographical coverage of Lake Victoria in the Tanzanian portion.

METHODS

Sampling sites

Mining areas in Lake Victoria basin that were targeted for this study are those of Mwanza and Mara Regions. Sediment and fish samples were collected in May and June 2002 in Lake Victoria (Fig. 1). Samples were collected from areas potentially exposed to metal pollution from mining (M) and other anthropogenic activities (O) as well as from reference sites (R) for comparison purposes.

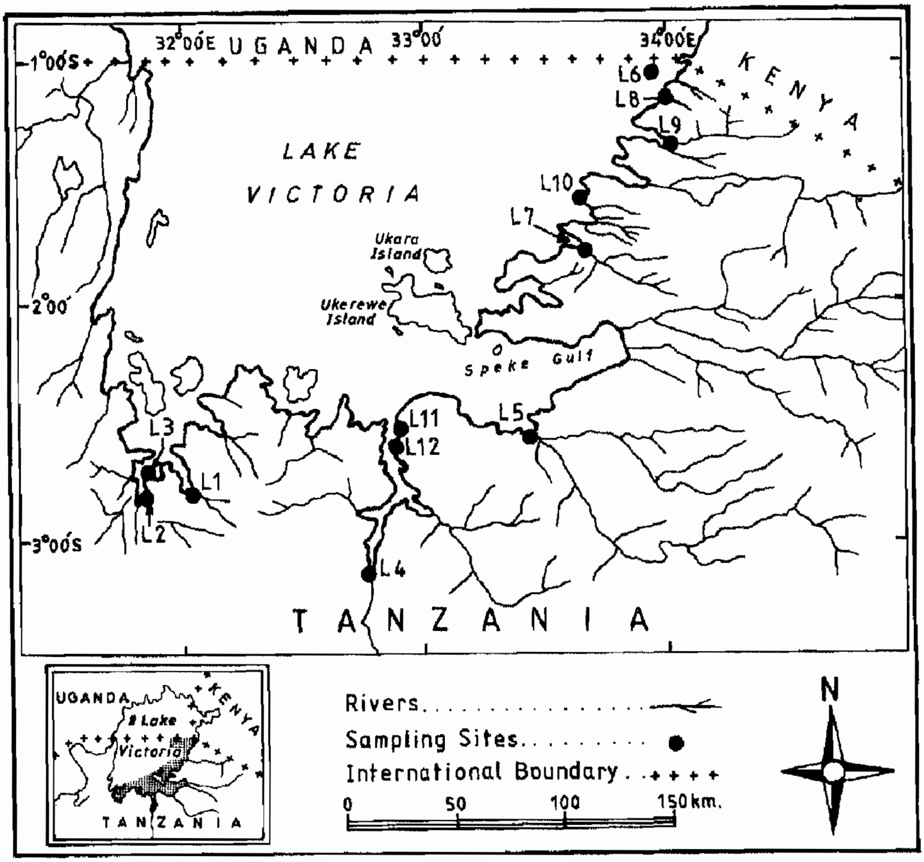

Figure 1: Map of Lake Victoria (Tanzania) and ists basin showing locations (latitutde °S, and longiude °E) of sampling sites.

Mwanza Region
L1: Nungwe Bay, 02°45′ 37.3 ″S; 032°00′ 50.8″E. (M)
Nungwe Bay receives runoff from gold mines such as Mugusu via Mugusu river. The shoreline of the Bay has a dense overgrowth of *Cyperus papyrus* and *Phragmites mauritianus*, Water hyacinth (*Eichhornia crassipes*) is patchy.
L2: Nyikonga, 02°48′ 45.0″S; 03°15′ 007.6″E. (M)
Nyikonga area receives discharge from Nyikonga River that drains Nyarugusu and other mining areas in Geita District. Shoreline vegetation includes *Typha capensis*, and patches of water hyacinth and water lilies.
L3: Lukombo, 02°41′22.9″S; 031°49′15.4″E. (R)
Lukumbo area is remote from the influence of any river discharge. The hinterland is vegetated, therefore soil erosion and the likelihood of influence by metals from mining areas is minimum. The site served as a reference for sediment fish samples of Mwanza
L4: Mwanza Gulf at the mouth of Isanga River, 03°01′56.0″S; 032°45′54.6″E. (M)
Isanga River drains gold mining areas of Shinyanga and discharges into Lake Victoria at Smith Sound. The river mouth has a dense growth of *C. papyrus* and other aquatic weeds including patches of water hyacinth.
L5: Magu Bay at the mouth of Simiyu River, 02°31′37.0″S; 033°24′44.4″E. (O)
Simiyu River discharges into Lake Victoria at Magu Bay. During the period of sampling the Bay harboured floating Islands of *C. papyrus* and patches of water hyacinth.
L11: Mwanza Gulf at the mouth of Mirongo River, 02°30′41.8″S; 032°53′38.1″E. (O)
This area receives untreated industrial and domestic wastes from part of the city of Mwanza. The shoreline to a large extent lacks fringing macrophytes.

L12: Luchelele, 02°37′12.0″ S; 032°51′36.0″ E. (R)
Luchelele is a fish-landing beach located about 15 km south of the city of Mwanza. The area has densely growing aquatic macrophytes.

Mara Region
L6: Mara Bay at the mouth of Mara River, 01°30′46.5″S; 033°55′59.3″E. (M)
During sampling the Mara Bay haboured floating islands of *C. papyrus*. The shoreline vegetation included *C. papyrus* and patches of water hyacinth. Mara River and its tributaries drain mining areas of Nyamongo, Sirorisimba and Majimoto.
L7: Area adjacent to the mouth of Suguti River, 01° 46′34.8″S; 033° 38′43.3″E. (M)
Some tributaries of Suguti River (e.g. Kyarano River) drain mining areas of Buhemba and Murangi. The shoreline adjacent to Suguti River mouth is sparsely vegetated.
L8: Shirati Bay. 01°07′54.1″S; 033°59′16.6″E. (R)
Shirati Bay at Sota has no river discharge and the shoreline sparsely vegetated. The hinterland has no gold mining activity, hence the Bay served as a reference site for sediment and fish samples.
L9: Mori Bay at the mouth of Mori River, 01°20′18.3″S; 033°58′48.0″E (M)
Mori River drains mining areas of Tarime, e.g. Kibaga mine, where active gold mining is going on. The shoreline at the river mouth has dense growth of *Phragmites* sp, and other aquatic weeds.
L10: Ikungu area, 01°33′40.0″S; 033°39′39.2″E. (M)
Ikungu beach is adjacent to Ikungu mine in Musoma Rural area. Ikungu mine was actively mined before 1960s, reprocessing of the abandoned heaps of tailings still continues. The shoreline has patches *Phragmites* sp, and other aquatic vegetation.

Sampling and Analysis

Sediment samples
Sediment samples were retrieved from the lake bottom by grab sampling or box coring. Sediment samples were placed in glass jars and stored frozen at –20°C. Sediment sub-samples for the determination

of organic matter content were dried to constant weight at 105°C. Organic matter content of the sample was determined as weight loss on ignition at 550°C for three hours.

Sediment sub-samples for metal analysis were Freeze-dried and homogenized (Machiwa 2000). Copper, Zn, Pb and Cd concentrations in the homogenized sediment samples were determined by Atomic Absorption Spectrophotometer (AAS), GBC (Germany) model 906 operated in the Flame mode, after digestion of sediment samples (ca. 0.5 g) with aqua regia at 80° C. For Hg and As analysis, boric acid (7g) was added to 5g of homogenized sediment sub-sample and analysed by a scanning Sequential X-Ray Fluorescence (XRF) Spectrometer (Siemens, model SRS 3000).

Fish samples

Fish samples were fished at respective fishing grounds (Fig. 1) in the lake. Weight of fish was measured to the nearest 0.01g and total length (TL) was recorded to the nearest 1.0 mm. Fish were dissected to remove the liver and a portion (ca. 10 cm^3) of muscle was removed from both sides of fish using stainless steel blades. Fish tissue samples were kept in polypropylene bottles and stored at –20°C. Sub-samples of fish tissues for dry weight determination were dried to constant weight at 105°C. Deep-frozen fish samples were lyophilized and homogenized. Copper, Zn, Pb and Cd were measured by AAS in the Flame mode after digestion of homogenized fish tissue (ca. 0.5 g) by conc. HNO_3 at 80° C on a water bath.

Quality assurance/Quality control (QA/QC)

Certified Reference Materials (CRMs), PACS-2 and DORM-2 from National Research Council Canada as well as BCR-143R and BCR–422 from Institute for Reference Materials and Measurements (Belgium) were used for QA/QC purposes. The laboratory results for As, Cd, Pb, Cu and Zn concentrations in the CRMs were in agreement (±10% or better) with the certified values.

RESULTS

Organic matter and heavy metals in sediment

Nungwe Bay sediment samples had the highest organic matter content (49.3±9.4%). The lowest organic matter content in sediment (2.3±0.6%) was observed in samples from the southern tip of Mwanza Gulf, at the Isanga River mouth.

Table 1: Mean (± Standard deviation) concentration of heavy metals (µg g^{-1} dry weight) and organic matter (OM) content (%) in sediment samples (n = 3 at each site) from Lake Victoria

Location	OM	As	Cd	Pb	Zn	Cu
L1: Nungwe Bay (M)	49.3±9.4	5.7±1.2	0.5±0.5	10.8±5.1	47.5±12.4	11.1±3.4
L2: Nyikonga (M)	13.0±11.3	3.7±2.3	1.2±0.1	14.5±3.1	60.7±13.8	31.4±5.0
L3: Lukumbo (R)	23.7±23.1	3.6±2.0	0.9±0.1	18.9±6.1	73.4±28.5	8.3±3.0
L4: Isanga R.mouth (M)	2.3±0.6	6.3±0.6	1.5±0.5	23.6±4.1	101.9±20.6	32.6±2.8
L5: Magu Bay (O)	6.8±2.3	6.0±1.0	1.8±0.2	37.0±6.6	143.0±20.6	17.4±3.7
L6: Mara Bay (M)	10.7±1.8	4.3±1.8	1.9±0.7	21.5±9.3	185.4±22.3	35.0±3.4
L7: Suguti (M)	2.5±0.5	6.0±3.6	1.3±0.4	6.5±5.8	62.6±4.9	27.2±16.1
L8: Shirati Bay (R)	6.3±4.3	2.3±1.2	1.2±0.2	19.9±3.3	100.2±12.0	25.8±1.3
L9: Mori Bay (M)	5.8±4.0	<0.01	1.6±0.2	23.2±7.4	120.6±41.5	14.9±3.5
L10: Ikungu Bay (M)	4.6±3.9	<0.01	1.2±0.7	18.8±8.3	79.4±15.8	14.6±1.6
L11: Mirongo R.mouth (O)	5.9±3.2	<0.01	1.6±0.2	58.1±17.6	189.7±16.7	47.1±1.2

Mercury concentration in all sediment samples from the surveyed areas was <0.01 μg g^{-1} dw, except in Magu Bay, Ikungu and Mori Bay where one of the three replicates of sediment samples had total mercury concentration of 1.0 μg g^{-1} dw. The concentration of arsenic in sediment samples was generally low (Table 1), below the average value (6 μg g^{-1} dw) for continental soils (Chester 1990). Sediment samples from Isanga River mouth, Magu Bay and Suguti had concentrations of As close to 6 μg g^{-1} dw. Sediment samples from Mirongo River mouth, Mori Bay and Ikungu had As content below the limit of detection (0.01 μg g^{-1}). Highest concentration of cadmium (1.9±0.7 μg g^{-1} dw) was recorded in sediment samples from the Mara River mouth and in Magu Bay (1.8±0.2 μg g^{-1} dw). Nungwe Bay sediments had the lowest concentration (0.5±0.5μg g^{-1} dw) of Cd (Table 1). The average concentration of Cd in continental soils is 0.35 μg g^{-1} dw (Chester 1990). Lead concentration was highest (56.1±17.6 μg g^{-1} dw) in sediment samples at the Mirongo River mouth followed by samples from Magu Bay. Suguti sediment samples had the lowest lead content (6.5±5.8 μg g^{-1}). Suguti area is quite remote from road traffic, petrol engine boats are also not common in the Lake at Suguti. The average value for Pb in continental soils is 35 μg g^{-1} dw (Chester 1990). Zinc concentration in the Lake sediments, like lead, was highest (189.7±16.7 μg g^{-1}) in samples from Mirongo River mouth followed by samples from Mara Bay (185.4±22.3 μg g^{-1}) and Magu Bay (143.0±20.6 μg g^{-1}). The lowest concentration of zinc (47.5±12.4 μg g^{-1}) was observed in sediments of Nungwe Bay. According to Chester (1990) the average concentration of Zn in continental soils is 90 μg g^{-1} dw. Student t-test (Zar 1999) showed no significant difference (P = 0.701) between zinc concentration in sediments from the lake areas that are within and away from catchments with gold mining activities. In the case of lake sediments from Mwanza Region, it was found that Zn content in lake sediments from non-mining areas was significantly higher (P = 0.042) than the concentration in lake sediments from mining areas. However, if the Zn content of lake sediment from Mirongo River mouth areas were excluded, the difference was not significant (P = 0.380). Copper levels in the lake sediments were higher at Mirongo River mouth (47.1±1.2 μg g^{-1}) and Mara Bay (35.0±3.4 μg g^{-1}) and lowest at Lukumbo (8.3±3.0 μg g^{-1}). There was no significant difference (P = 0.924) between Cu concentration in the lake sediments from areas within and away from catchments with gold mining activities. The average concentration of Cu in continental soils is 30 μg g^{-1} dw (Chester 1990). Heavy metals in sediments close to Mirongo River mouth that had higher concentration than their average values in continental soils were Cd, Pb, Zn and Cu (Table 1).

Organic matter contents of sediment samples were analysed in order to complement heavy metal data. Generally, there was no relationship between organic matter contents and concentrations of the heavy metals in sediment samples, for instance, for Cu and Zn the Pearson correlation coefficient (r) were –0.386 and – 0.206 respectively.

Concentrations of heavy metals in fish

The conversion factor from dry to wet weight for for *L niloticus* was 0.290. Arsenic concentration in all the analysed fish species was below the limit of detection (0.01 ng g^{-1} ww). Cadmium concentrations in *L. niloticus* edible parts were highest (4.67±1.67 ng g^{-1} ww) in fish that were fished adjacent the Mirongo River mouth followed by those from Luchelele (3.67±1.49 ng g^{-1} ww) both areas are in Mwanza Gulf (Table 2). Lowest concentrations of Cd in *L. niloticus* muscles were found in fish from Mori and Shirati Bays, where the mean concentration was 1.23 ng g^{-1} ww. However, there was no significant difference in Cd content of *L. niloticus* from fishing areas of the lake that are within and away from catchments with gold mining activities in both Mwanza (P = 0.085) and Mara (P = 0.086) Regions The concentration of lead in *L. niloticus* was low, in most of the fishing areas it was below or just above the detection limit (0.01 µg g^{-1} ww). Nevertheless, the highest Pb concentration (0.13±0.04 µg g^{-1} ww) was found in *L. niloticus* specimens from the lake adjacent to Mirongo River mouth. Mean concentration of zinc in muscles of *L. niloticus* from different fishing grounds ranged from 4.6±1.6 µg/g ww (in Nungwe Bay) to 8.8±4.1 µg g^{-1} ww (in Mara Bay). Zinc content in *L. niloticus* from Mwanza Gulf adjacent to Mirongo river mouth was 7.1±2.5 µg g^{-1} ww (Table 2). There was no significant difference in Zn concentration in *L. niloticus* from lake areas that are within and outside catchments with gold mining activities both in Mwanza (P = 0.158) and Mara (P = 0.104) Regions. The concentration of copper in *L. niloticus* muscles was generally low (Table 2). The highest Cu concentration (0.7 µg g^{-1} ww) was obtained in specimens that were fished close to the Mirongo River mouth and Luchelele area (about 15 km from Mwanza city centre). The concentrations of Cu were not significantly different in *L. niloticus* from close and away from gold mining activities in Mwanza (P = 0.196) and Mara (P = 0.173) Regions.

Table 2: Mean (± Standard deviation) concentration (wet weight) of heavy metals in *Lates niloticus* muscles and liver (in parenthesis).

Fishing Area	Cu µg g^{-1}	Cd µg g^{-1}	Pb µg g^{-1}	Zn µg g^{-1}
L1: Nungwe Bay (M) (n = 3)	2.27±0.81	<0.01	4.6±1.6	0.2±0.1
	(5.19±3.18)	(<0.01)	(38.6±3.3)	(4.9±1.2)
L4: Isanga R. mouth (M) (n = 4)	3.18±0.70	0.07±0.02	5.1±1.3	0.4±0.1
	(2.25±0.13)	(0.06±0.00)	(23.5±1.4)	(3.9±1.1)
L5: Magu Bay (O) (n = 2	3.58±0.60	<0.01	7.8±2.6	0.2±0.1
L6: Mara Bay (M) (n = 17)	2.22±0.64	0.05±0.03	8.8±4.1	0.3±0.1
L8: Shirati Bay (R) (n = 6)	1.23±1.23	0.04±0.04	4.9±1.3	0.3±0.1
	(4.19±2.05)	(0.13±0.04)	(27.6±14.3)	(5.6±4.1)
L9: Mori Bay (M) (n = 4)	1.23±0.30	<0.01	6.5±1.9	0.5±0.3
	(1.29±0.12)	(<0.01)	(22.7±6.3)	(11.2±2.3)
L11: Mirongo R. mouth	4.67±1.67	0.13±0.04	7.1±2.5	0.7±0.2
L12: Luchelele (R) (n = 5)	3.67±1.49	0.06±0.05	6.3±0.3	0.7±0.1

The conversion factor from dry to wet weight for *O. niloticus* was 0.256. The concentration of cadmium in *O. niloticus* flesh was of equal maginitude as that was recorded in *L. niloticus* muscles. Highest Cd concentration (3.49±0.23 µg g^{-1} ww) in *O. niloticus* was recorded in fish from the southern tip of Mwanza Gulf, close to the Isanga River mouth. Specimens of *O. niloticus* from Shirati Bay had the lowest Cd content of 0.14 µg g^{-1} ww (Table 3). Nevertheless, Cd content of *O. niloticus* from fishing areas within and outside catchments that have gold mining activities was not significantly different both in Mwanza (P = 0.908) and Mara (P = 0.884) Regions. In the case of lead, the concentration in many *O. niloticus* muscle samples was below the limit of detection (0.01 µg g^{-1}), and only few specimens had concentration close to 0.1 µg g^{-1} ww (Table 3). The highest zinc concentration (14.1±8.1 µg g^{-1} ww) in *O. niloticus* muscles was recorded in samples fished in Mwanza Gulf, adjacent to Mirongo River mouth in the city of Mwanza. *Oreochromis niloticus* from Suguti fishing area had the lowest Zn content (2.6±0.5 μg g^{-1} ww) in their muscles. There was no significant difference (P = 0.629) in Zn content of *O. niloticus* from fishing areas within and away from catchments having gold mining activities in Mara Region. In Mwanza Region *O. niloticus* from fishing areas outside catchments with gold mining activities had significantly high Zn content (P = 0.030). However, if *O. niloticus* from the area adjacent to Mirongo River mouth were excluded, the difference in Zn content of *O. niloticus* from fishing areas within catchments with gold mining activities and those without was not significant (P = 0.268). Samples of *O. niloticus* from adjacent the Mirongo River mouth and Nyikonga had copper concentration of 0.5 μg g^{-1} ww, samples from other fishing areas had concentrations of about 0.2 μg g^{-1} ww in their muscles (Table 3). Generally livers of both *L. niloticus* and *O. niloticus* contained higher concentration of the analysed heavy metals (especially Zn and Cu) compared to their muscles (Tables 2 and 3).

Table 3: Mean (± Standard deviation) concentration (wet weight) of heavy metals in *Oreochromis niloticus* muscle and liver (in parentheses).

Fishing Area	Cd ng g^{-1}	Pb μg g^{-1}	Zn μg g^{-1}	Cu μg g^{-1}
L1: Nungwe Bay (M) (n = 8)	1.97±1.08	<0.01	6.2±2.1	0.2±0.1
	(3.81±2.10)	(<0.01)	(29.7±7.0)	(22.4±15.7)
L2: Nyikonga (M) (n = 5)	1.85±0.51	0.06±0.01	7.1±1.8	0.5±0.1
	(4.90±3.96)		(34.8±23.5)	
L3: Lukumbo (R) (n = 5)	2.49±1.42	<0.01	9.1±3.6	0.2±0.1
	(3.16±0.95)	(0.04±0.04)	(26.5±4.8)	(12.8±6.9)
L4: Isanga R. mouth (M) (n = 2)	3.49±0.23	0.06±0.00	5.4±3.2	0.4±0.1
L5: Magu Bay (O) (n = 2)	2.93±0.54	<0.01	3.8±0.6	0.2±0.0
	(6.32±2.80)	(<0.01)	(21.2)	(23.6)
L6: Mara Bay (M) (n = 9)	2.03±0.54	0.04±0.03	7.4±2.3	0.2±0.1
L7: Suguti (M) (n = 2)	3.11±0.42	0.08±0.01	2.6±0.5	0.2±0.0
	(2.56±0.15)	(0.05±0.01)	(14.1±6.7)	22.7±13.5)
L8: Shirati Bay (R) (n = 3)	0.14±0.05	0.05±0.04	4.8±2.3	0.3±0.2
L10: Ikungu Bay (M) (n = 5)	1.41±0.17	<0.01	3.6±0.8	0.2±0.1
	(2.47±0.67)	(<0.01)	(30.5±16.0)	(28.2±21.6)
L11: Mirongo R. mouth (O) (n = 3)	2.77±1.77	<0.01	14.1±8.1	0.5±0.3

For the minor fish species that are rarely caught by fishers (Table 4), the conversion factors from dry to wet weight was 0.242 for *Clarias gariepinus* and 0.242 for the haplochromines.. The highest concentration of cadmium (3.65±1.13 ng/g ww) was found in *Clarias gariepinus* from adjacent to Isanga River mouth and lowest (1.72±0.41 ng g^{-1} ww) in specimens from Mara Bay. The haplochromines were collected from only few locations, the specimens had relatively higher Cd concentration (> 3 ng g^{-1} ww) than most of the sampled minor fish species (Table 4). Samples of other fish species such as *Schilbe intermedius*, *Synodontis victoriae*, *Brycinus* spp and *Labeo victorianus* from Magu Bay had almost same concentrations of cadmium (ca. 2 ng g^{-1} ww). Lead concentration was generally low (from < 0.01 to 0.1 μg g^{-1} ww), in most of the minor fish species. The highest concentration (3.62 μg g^{-1} ww) of lead was found in the Haplochromines fished in Mara Bay (Table 4). The mean concentration of zinc in *C. gariepinus* ranged between 11.4 and 5.0 μg g^{-1} ww, the highest concentration (22.3 μg g^{-1} ww) was found in specimens from Magu Bay (Table 4). Zinc was also high in Haplochromines of Mori Bay (17.2 μg g^{-1} ww) and Mara Bay (14.3 μg g^{-1} ww). *Labeo victorianus* and *Brycinus* spp. that were fished in Magu Bay also had concentrations of same magnitude as the Haplochromines (Table 4). Copper concentration was highest in *S. victoriae* that was fished in Mori Bay (0.8±0.2 μg g^{-1} ww) and *C. gariepinus* (0.7±0.1 μg g^{-1} ww) of Mwanza Gulf, adjacent to the Mirongo River mouth. The concentration of Cu was consistently low (< 0.5 μg g^{-1} ww) in most of the fish species from the majority of fishing areas (Table 4).

Table 4: Mean (± Standard deviation) concentration (wet weight basis) of heavy metals in muscle tissue and liver (in parentheses) of minor fish species of Lake Victoria.

Fishing Area and Fish species	Cd ng g^{-1}	Pb μg g^{-1}	Zn μg g^{-1}	Cu μg g^{-1}
L1: Nungwe Bay (M)				
Clarias gariepinus (n = 1)	2.81	<0.01	6.2	0.2
	(2.12)	(<0.01)	(44.3)	(21.9)
L4: Isanga River mouth (M)				
C. gariepinus (n = 5)	3.21±1.76	0.07±0.05	5.0±1.5	0.5±0.3
	(3.28±0.67)	(0.09±0.02)	(59.3±8.4)	(39.7±5.7)
Tilapia zilii (n = 1)	3.26	<0.01	6.7	0.3
L5: Magu Bay (O)				
C. gariepinus (n = 2)	1.85	<0.01	11.4±10.9	0.5±0.4
Schilbe intermedius (n = 3)	1.73±1.02	<0.01	3.8±0.6	0.2±0.0
Synodontis victoriae (n = 2)	2.01±0.04	<0.01	5.5±0.4	0.3±0.0
Labeo victorianus (n = 4)	2.07±0.05	<0.01	14.4±6.0	0.5±0.3
Brycinus jacksonii (n = 2)	2.98±1.07	<0.01	18.8±4.7	0.5±0.1
Brycinus sadleri (n = 1)	2.36	<0.01	15.2	0.3
L6: Mara Bay (M)				
C. gariepinus (n = 2)	1.72±0.41	0.03±0.03	8.2±2.7	0.2±0.0
	(3.26±1.97)	(0.08±0.04)	(17.8±0.1)	(5.4±0.9)
Haplochromine (n = 1)	3.62	0.09	14.3	0.2
S. victoriae (n = 1)	1.70	0.06	10.0	0.5
L8: Shirati Bay (R)				
Haplochromines (n = 4)	3.16±0.27	0.10±0.02	12.0±4.3	0.3±0.2
Tilapia rendalii (n = 3)	<0.01	0.05±0.04	6.9±2.0	0.2±0.0
O. leucostictus	(n = 1)		3.7	0.2
L. victorianus (n = 1)	0.18	<0.01	13.7	0.5
L9: Mori Bay (M)				
Haplochromine (n = 1)	4.63	<0.01	17.2	0.6
S. victoriae (n = 2)	1.58±0.26	0.06±0.01	7.4±0.6	0.8±0.2
L11: Mirongo River (O)				
C. gariepinus (n = 2)	3.65±1.13	0.08±0.02	7.2±1.9	0.7±0.1
Oreochromis leucostictus	4.11	0.12	10.2	0.6

DISCUSSION

Heavy metals and Organic matter levels in Lake Victoria sediments

The results showed that organic matter content of sediment was not directly related with the concentration of heavy metals. For instance, at Ikungu Bay the concentration of heavy metals in the sediment was high despite the low organic matter content in the sediment. At Nungwe Bay the concentration of heavy metals in the sediment was low despite the high organic matter content of the sediment. This observation suggests that the organic matter in the sediment at the study area is chiefly of autochthonous origin, mainly resulting from *in situ* processes. At Nungwe Bay, the fringing macrophytes such as *C. papyrus* form a high proportion of sedimentary organic matter. If at all metals from mining activities are transported to the lake, they are likely to be trapped by the macrophytes at river mouths preventing their direct deposition in the lake.

Arsenic has rarely been determined in sediments of Lake Victoria despite its association with auriferous ores. It has been reported that some gold in Lake Victoria basin is included in the mineral arsenopyrite (Kahatano and Mnali 1997). The only available data (Makundi 2001) show elevated levels (up to 498±13 ppm) of As in Lake Victoria sediments adjacent to urban areas of Mwanza city. This high concentration of As was recorded at one of the fifteen sampling sites. Nevertheless, the study did not include quality assurance/control measures in the analytical protocol. The present results indicate low concentrations of cadmium in the lake sediments at locations that are within catchments with gold mining activities. In fact, the levels are of equal magnitude as those reported by Kishe and Machiwa (2003) in Mwanza Gulf sediments that are remote from mining areas. Although Cd concentrations in the study area are above continental soil average, it probably reflects the high background level of Cd in the lake basin soils. Lead concentration in lake sediment was highest in areas that are closer to the city of Mwanza. The Mirongo River drains a large area of Mwanza city, wastes from residential areas, schools and hospitals as well as storm water are discharged to the lake via this outlet. In lake sediment samples collected close to the city, Kishe and Machiwa (2003) obtained lead concentration of 54.6±11.1 $\mu g\ g^{-1}$ dw, which is equal to the present results (58.1±17.6 $\mu g\ g^{-1}$ dw). The higher Pb concentration in lake sediment closer to the city indicates influence of fossil fuel burning and municipal discharges rather than land denudation activities. Copper and zinc also had their highest concentration in sediments adjacent to Mirongo River mouth. Copper concentrations were slightly above the average for continental soils and Zn concentrations were double the continental soil average. Copper and Zn are metals that are strongly connected with technological development, hence the elevated levels adjacent to Mirongo River mouth suggests municipal sources, such as industrial discharges. Copper and Zn pollution of the lake via Mirongo River appears to be an emerging threat. The results further suggest that gold deposits that are associated with minerals sphalerite and chalcopyrite in the lake basin (Kahatano and Mnali 1997), are not sources of Zn and Cu in the lake. The current heavy metal levels in the Tanzanian part of Lake Victoria is of equal magnitude as that reported in other parts of the lake, for instance, Mothersill (1976) in the Ugandan portion, and Onyari (1985) in the Kenyan portion. The present study generally show that concentrations of metals in lake sediments close and away from mining activities are not statistically different.

Contamination of fish with heavy metals

Generally, the concentrations of any of the analysed metals were low in *L .niloticus*. For instance, the levels of Pb and Cu were below 1 $\mu g\ g^{-1}$ ww in *L niloticus* and *O. niloticus* specimens. Zinc concentrations in all fish samples were of equal magnitude (above 1 μg g^{-1} ww). The more or less equal concentrations of Pb, Cu and Zn in fish from fishing areas located close and away from mining activities suggest that levels of these metals in fish are not influenced by mining activities.

So far, there is little information on heavy metals (excluding mercury) content in fish from Tanzanian waters of Lake Victoria. Previous information on heavy metals in fish of Lake Victoria includes the unpublished reports by Onyari (1985) in Kenya, Mohammed (2000) and Kishe (2001) in Tanzania. The reports gave concentration values that are a bit high compared to results of the present study especially for copper, lead and zinc. However these studies did not include CRMs in the analytical protocols, an oversight which jeopardises the reliability of their results. Tuzen (2003) has reported very low heavy metal content in non-carnivorous marine fish from the middle Black Sea. Using a factor of 0.3 for conversion of dry weight (Tuzen, 2003) into wet weight, the concentration of Cd ranged between 0.03 and 0.14 μg g^{-1} ww, Pb ranged between 0.06 and 0.26 μg g^{-1} ww, Cu ranged between 0.4 and 0.9 μg g^{-1} ww and Zn ranged between 2.9 and 6.9 μg g^{-1} ww. With the exception of Cd that was high in the marine fish, the concentrations of lead, copper and zinc are of equal magnitude as that of Lake Victoria fish. The present results therefore, indicate that gold mining activity in the lake basin has no influence on current concentrations of heavy metals (As, Cd, Cu, Pb and Zn) in fish. The metal concentrations are equally low in Lake Victoria fish in areas close and away from gold mining activities. However, generally higher concentrations of the heavy metals in fish muscle were obtained in the minor fish species (Table 4) regardless of their small body size and fishing location. The reason for this apparent paradox is not well construed.

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