TOTAL MERCURY CONCENTRATION IN COMMON FISH SPECIES OF LAKE VICTORIA, TANZANIA.

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ABSTRACT

Total mercury (THg) concentration was analysed in muscles of common fish species of Lake Victoria in the eastern and southern parts of the lake using cold vapour Atomic Absorption Spectrophotometric technique. Mercury concentration in all fish species was generally lower than the WHO maximum allowable concentration (500 ng/g ww) in edible fish parts. The maximum concentration of THg in Lates niloticus *samples was 396 ng/g ww. Samples of* Oreochromis niloticus *had THg concentration ranging between <0.01 and 419 ng/g ww.* Clarias gariepinus *had THg concentration ranging between 1.2 and 239.1 ng/g ww. All less common fish species, such as,* Labeo victirianus, Synodontis victoriae, Oreochromis leucostictus, Schilbe intermedius, Brycinus jacksonii, B. sadleri, Tilapia rendalii, Tilapia zilii *and Haplochromines had THg concentration below the WHO maximum allowable limit (500 ng/g ww). The study showed that Hg from small-scale gold mining activities in Lake Victoria basin is not transported to the lake by fluvial discharge. Other possible pathways of Hg input to Lake Victoria are discussed.*

INTRODUCTION

The Lake Victoria basin is well endowed with mineral wealth because of its prospective geology with a high potential for auriferous deposits. Lake Victoria gold fields (LVGF) comprise a number of gold mines that are located to the south and east of Lake Victoria in Northern Tanzania. The first discovery of gold in Tanzania was in 1898, gold was discovered in the southern part of Lake Victoria basin at Kahama/Geita area. During the late 1920s gold prospecting and mining activities were high, which led to the establishment of Geita mine in 1938. Between 1930 and 1950s, gold mining in LVGF was being conducted by registered small and medium scale companies as well as by individuals. Both medium and small-scale miners use mercury in the purification of gold. Because of this long history of mercury usage in gold mining in Lake Victoria basin, research is needed in order to accurately assess the impact.

Essentially all forms of mercury are toxic to humans (JPHA 2001). People who inhale mercury vapour or eat Hg-contaminated food may be harmed. Mercury is lost into the environment as a result of improper handling and inefficient recycling process by the miners. Metallic mercury (Hg^o)-containing wastes are disposed of in surrounding grounds and find their way through surface-runoff or groundwater and eventually may reach large water bodies. In the environment Hg^o can be oxidized to inorganic divalent mercury (Hg^{2+}), which in the soil or aquatic environment may undergo bioalkylation through the action of bacteria to form alkyl mercury, particularly methylmercury (CH_3Hg^+). Methyl mercury is a deadly poison, neurotoxic, lipophilic and accumulates in the food chain.

Studies that have been conducted between 1996 and 2003 (Ikingura and Akagi 1996, Migiro 1997, DHV consultants 1998, van Straaten 2000a' 2000b, Campbell 2001, Ikingura and Akagi 2002a, Campbell *et al.*

2003) do not indicate a pronounced Hg pollution of Lake Victoria by gold mining activities in the basin. It is also true that pathways, receptors, controls and fate of mercury released into the environment by LVGF mining activities are not well construed. Hence, more studies are required to assess the extent of loss of mercury to water, soil, tailings and atmosphere in the Lake basin Also studies to determine the amount of mercury that actually reaches into Lake Victoria and its fate in the lake are lacking. Indeed, there are a lot of unknowns in the mercury budget of the lake. For instance, erosion of contaminated soils in the lake basin, groundwater flows from contaminated aquifers, as well as atmospheric input from mining and biomass burning activities. The present study reports levels of mercury in common fish of Lake Victoria with the view to assess the influence of gold mining on Hg discharge into the lake by rivers.

MATERIALS AND METHODS

Sampling sites

Fish samples were collected in May and June 2002 in the southern and south-eastern parts of Lake Victoria in areas that were suspected to be affected by gold mining activities (Fig. 1). Mining areas that were targeted within Lake Victoria basin are mainly those of Mwanza and Mara Regions.

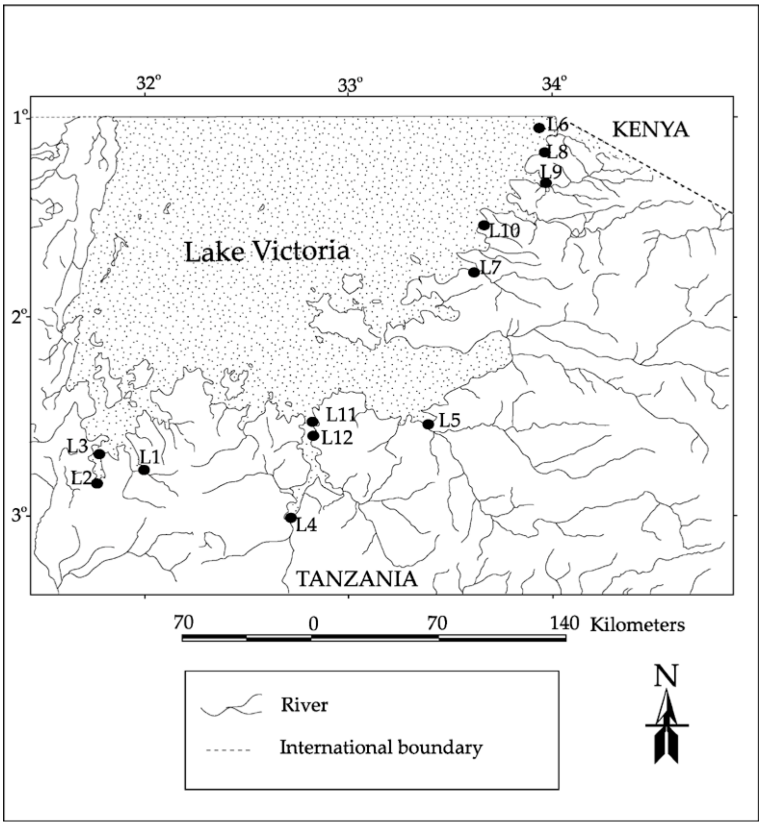

Figure 1. Map of Lake Victoria (Tanzania) and its basin showing locations (latitude in ° S and longitude in ° E) of In-lake (L1 – L12) sampling stations.

L1: Nungwe Bay (02º45_ 37.3 _S; 032º00_ 50.8_E)

The Bay receives runoff from gold mines such as Mugusu via Mugusu river. The shoreline of the Bay is choked with a dense overgrowth of *Cyperus papyrus* and other aquatic macrophytes including patches of the Water hyacinth (*Eichhornia crassipes*). Fish species that were collected are *Lates niloticus* (3 specimens), *Oreochromis niloticus* (7 specimens) and *Clarias gariepinus* (2).

L2: Nyikonga (02º48_ 45.0_S; 03º15_ 007.6_E)

This area receives discharge from Nyikonga River which drains mineralized areas such a Nyarugusu and other mining areas in Geita District. Only *O. niloticus* (5 specimens) was collected.

L3: Lukombo (02º41_22.9_S; 031º49_15.4_E)

This area is remote from influence of any river discharge. The hinterland is vegetated therefore silt input in the lake from the catchment at Lukumbo is minimum. Fish samples from Lukumbo served as a reference for fish samples from the southern part of the lake. Only *O. niloticus* (4 specimens) was collected.

L4: Mwanza Gulf at the mouth of Isanga River (03º01_56.0_S; 032º45_54.6_E)

Isanga River discharges into Lake Victoria at Smith Sound area. The shoreline including the river mouth has a dense vegetation of *C. papyrus* and other macrophytes. Isanga River drains gold mining areas in Kahama and Shinyanga Districts. Fish species that were collected are *L. niloticus* (4), *O. niloticus* (2), *O. leucostictus* (1), *Tilapia zilii* (1) and *C. gariepinus* (5).

L5: Magu Bay at the mouth of Simiyu River (02º31_37.0_S; 033º24_44.4_E)

Simiyu River discharges into Lake Victoria at Magu Bay. The shoreline of the Bay has fringing macrophytes especially *C. papyrus*. Species collected included *L. niloticus* (2), *O. niloticus* (2), *Schilbe intermedius* (3), *Synodontis victoriae* (2), *Labeo victorianus* (4), *Brycinus jacksonii* (2), *B. sadleri* (1) and *C. gariepinus* (1).

L6: Mara Bay at the mouth of Mara River (01º30_46.5_S; 033º55_59.3_E)

Mara River discharges into Lake Victoria at Mara Bay. Shoreline vegetation includes *C. papyrus* and patches of the Water hyacinth. Mara River and its tributaries drain mining areas such as Nyamongo, Sirorisimba and Majimoto. Fish samples included *L. niloticus* (17), *O. niloticus* (9), *S. victoriae* (1), Haplochromines (1) and *C. gariepinus* (3).

L7: Suguti area adjacent to Suguti River mouth (01º 46_34.8_S; 033º 38_43.3_E)

Some tributaries of Suguti River (e.g. Kyarano River) drain mining areas such as Buhemba and Murangi. The shoreline adjacent to Suguti River mouth is sparsely vegetated. Only *O. niloticus* (2) was collected.

L8: Shirati Bay (01º07_54.1_S; 033º59_16.6_E)

Shirati Bay is not influenced by any riverine discharge. The shoreline has few aquatic macrophytes. There is no active mining in the area the catchment of the Bay. The fish from Shirati Bay served as reference for fish samples collected in the eastern side of the lake. Fish samples included *L. niloticus* (6), *O. niloticus* (3), *O. leucostictus* (1), *T. rendalii* (3), *L. victorianus* (1).

L9: Mori Bay at the mouth of Mori River (01º20_18.3_S; 033º58_48.0_E)

Mori River drains mining areas of Tarime, such as Kibaga mine, where active gold mining is going on. The shoreline adjacent to the mouth has a dense growth of aquatic macrophytes. Fish samples were *L. niloticus* (4), S. *victoriae* (2) and Haplochromine (1).

L10: Ikungu area (01º33_40.0_S; 033º39_39.2_E)

Ikungu beach is adjacent to Ikungu mine in Musoma Rural area. Ikungu mine was actively mined before 1960s, reprocessing of heaps of tailings that were left behind still continues. Sluicing and panning sometimes take place at the beach. Fish samples were *O. niloticus* (5).

L11: Mwanza Gulf at the mouth of Mirongo River (02º30_41.8_S; 032º53_38.1_E)

This area receives untreated industrial and domestic wastes from a large portion of Mwanza city. The shoreline to a large extent is not covered by fringing macrophytes. Fish samples included *L. niloticus* (11), *O. niloticus* (3), *O. leucostictus* (1) and *C. gariepinus* (2).

L12: Luchelele (02º37_12.0_ S; 032º51_36.0_ E)

There is no major river discharge at Luchelele and the shoreline has a dense growth of aquatic macrophytes. Only *L. niloticus* (5) was sampled.

Sampling and Analysis

Fish samples were mainly purchased from fishers while still fishing in the lake, A total of 133 fish samples belonging to 12 species comprising piscivores/invertebrate feeders, omnivores and detririvores were collected. Weight of fish was measured to the nearest 0.01g and total length (TL) was recorded to the nearest 1.0 mm. Fish was dissected in the field to remove the liver by using stainless steel pair of scissors and forceps. A portion (ca. 10 cm^3) of the lateral muscle below the dorsal fin was removed from both sides of big fish, whereas small fish were filleted using stainless steel blades. Surgical gloves were worn all the time during processing of fish samples. Fish tissues were kept in clean 125 ml high-density polypropylene bottles and stored frozen until analysis. Frozen fish tissues were thawed, a sub-sample was used for dry weight determination by drying to constant weight at 105^{o}C, and the remaining portion was lyophilized. Freeze-dried samples were finely crushed and homogenized in agate mortar and pestle.

Approximately 0.5 – 1 g of homogenized fish tissue was weighed out accurately and digested using 1 ml conc. HNO_3 at 80^o C in a culture test tube on a water bath. After cooling the solution was diluted to 20 ml. THg was analysed using Atomic absorption spectrophotometer model GBC 906 equipped with a hydride generator model HG 3000.

CRMs DORM-2 (Dogfish muscle) and BCR–422 (Cod muscle) were used for quality assurance and quality control purposes. The laboratory results for Hg concentration in the CRMs were within ±5% of the certified values.

Linear regression analysis was used to describe relationship between fish length and total mercury concentration. Differences in mercury concentration within fish species from different fishing grounds and between fish species were tested using Friedman test followed by Dunn's multiple comparisons test (Zar 1999).

RESULTS

The accumulation of mercury in fish muscle (meat) and liver is a result of biological concentration through the food chain. Unlike the concentration of Hg in gills and digestive tract contents which reflect more recent contamination conditions, the concentration of Hg in fish muscle, reflect contamination conditions of at least several months prior.

Total mercury analysis in fish specimens was performed on freeze-dried samples. Factors for conversion of THg concentration from dry to wet weight for each specimen were obtained using replicate samples. For example, conversion factors for the dominant species were 0.290 for *L. niloticus*, 0.256 for *O. niloticus*, 0.242 for *Clarias. gariepinus* and 0.242 for the Haplochromines.

The mean value (37.18±32.57 ng/g ww) of THg level in the carnivorous fish (*L. niloticus*) from Shirati Bay (which is remote from gold mining areas) was not significantly different ($P > 0.05$) from values for *L. niloticus* samples from other sampling sites including those that were close to mining areas. Fish samples that were collected from locations that were considered point sources of Hg (e.g.

Mirongo and Simiyu R mouths), had a wider range of THg (Table 1). The analysis of the results obtained for *L. niloticus* from different sites showed that while the highest value obtained was 366 ng/g, for a specimen from adjacent to the mouth of Mirongo River, the majority of *L. niloticus* specimens had values ranging between <0.01 and 100 ng/g.

All *L. niloticus* and *O. niloticus* samples showed THg levels below the limit established by FAO/WHO (1999). The FAO/WHO methylmercury guideline level for non-predatory fish is 0.5 μg/g ww and for piscivorous fish is 1.0 μg/g ww. However, in the case of *L. niloticus*, there were only few representative samples from many of the sampled sites. Only 9.6% of the samples of *L. niloticus* had THg concentration above the WHO recommended limit (200 ng/g ww) for vulnerable groups such as pregnant women and children. Only two samples of *O. niloticus* from Nungwe Bay (450 ng/g ww) and Lukumbo area (420 ng/g ww) had THg concentration approaching the FAO/WHO guideline level of 0.5 μg/g ww. Minor fish species such as *Labeo victorianus* had low mercury concentration, all below 500 ng/g ww (Table 1).

Table 1: Concentration of THg in fish muscle (Mean ±sd and range), total length and weight of fish samples (n = sample size) from Lake Victoria in Mara and Mwanza Regions

Fish Species	Mean THg (ng/g ww)	Range THg (ng/g ww)	Range Total length (cm)	Range Weight (g)
Lates niloticus (n = 52)	61.4	<0.01-395.9	9.8-83	8-9300
Oreochromis niloticus (n = 40)	117.0± 86.9	<0.01-.297.7	11.6-39.2	20-1200
Clarias gariepinus (n = 13)	60.1	1.2-239.1	19.3-57	150-1540
Labeo victorianus (n = 5)	32.2±32.2	<0.01-83.2	15.6-20.2	20-80
Synodontis victoriae (n = 5)	62.4±17.0	36.5-80.1	12.8-21.8	20-100
Oreochromis leucostictus (n = 3)	49.8±43.4	<0.01-81.2	18-23.5	80-220
Schilbe intermedius (n = 3)	73.9±22.1	48.5-88.2	19.8-22.8	60-600
Brycinus jacksonii (n = 2)	89.9±12.2	81.3-98.5	13.2-13.4	20-40
Brycinus sadleri (n = 1)	93.6	-	17.2	40
Tilapia rendalii (n = 3)	158.5	<0.01-317.0	18.5-19	140-160
Tilapia zilii (n = 1)	71.1	-	20.8	400
Haplochromines (n = 5)	154.1	<0.01-419.4	8.6-17.1	5-80

There was no significant difference (P > 0.05) between THg concentration in *L. niloticus* from L. Victoria in Mwanza and Mara sampling locations. However, highest THg concentration (395.9 ng/g ww) was obtained in *L. niloticus* collected from Nungwe Bay, followed by samples from Isanga (367.0 ng/g ww) and Mirongo (303.5 ng/g ww) River mouths. In Mara Region, *L. niloticus* from Mara Bay adjacent to the mouth of Mara River had the highest THg concentration (309.8 ng/g ww) followed by *L. niloticus* from Mori Bay (136.8 ng/g ww). *Lates. niloticus* from Shirati Bay had the lowest concentration of THg (Table 2).

In the case of *O. niloticus*, the difference in THg concentrations in *O. niloticus* from within Mara Region and within Mwanza Region sampling locations were statistically significant (P = 0.0308 and P = 0.0202 respectively). In Mara region *O. niloticus* from Mara R. mouth had highest THg content (277.3 ng/g ww), followed by samples from Shirati Bay (213.3 ng/g ww). There was no representative sample of *O.*

niloticus from Mori Bay. According to Table 2, in Mwanza Region, *O. niloticus* from Nyikonga had the highest THg concentration (297.7 ng/g ww), followed by samples from Simiyu River mouth (259.3 ng/g ww), Nungwe Bay (246.0 ng/g ww) and Lukumbo area (212.8 ng/g ww).

Friedman test showed that the difference between mean THg concentrations of samples of *L. niloticus* (61.4 ng/g ww), and *O. niloticus* (117.9 ng/g ww) from Mara and Mwanza sampling sites was statistically significant (P = 0.0199).

Table 2: Ranges of Total mercury concentration (ng/g ww) in fish from different sampling sites in Mara and Mwanza Regions (n = sample size, ns = no sample). Mean ±sd values are shown in the parentheses.

Region and sampling location	*Lates niloticus*	*Oreochromis niloticus*	*Clarias gariepinus*
Mwanza Region			
L1: Nungwe Bay	95.1-395.9 (198.3±171.1); n = 3	80.5-246.0 (155.1±61.8); n = 7	<0.01-239.1 (119.6); n = 2
L2: Nyikonga	ns	14.8-297.7 (98.4); n = 5	ns
L3: Lukumbo	ns	<0.01- 212.8 (148.9±100.3); n = 4	ns
L4: Isanga R. mouth	2.1-367.0 (154.0); n = 4	9.3-94.1 (51.7); n = 2	8.1-81.9 (27.4); n = 5
L5: Simiyu R. mouth	15.8-209 (112.4); n = 2	82.5-259.3 (170.9±125.0); n = 2	121.0 (121.0); n = 1
L11: Mirongo R. mouth	<0.01-303.5 (65.6); n = 11	10.6-31.0 (20.6±10.2); n = 3	1.2-62.6 (31.9); n = 2
L12: Luchelele	<0.01-180.3 (80.9±76.0); n = 5	ns	ns
Mara Region			
L6: Mara Bay	<0.01-309.8 (62.5); n = 17	60.2-277.3 (155.3±85.0); n = 9	<0.01-135.3 (54.5); n = 3
L7: Suguti	ns	24.6-27.5 (26.0±2.1); n = 2	ns
L8: Shirati Bay	<0.01 –76.6 (37.7±32.1); n = 6	41.0-213.3 (102.0±96.6); n = 3	ns
L9: Mori Bay	3.9 -136.8 (76.6±57.0); n = 4	ns	ns
L10: Ikungu	ns	23.8-87.4 (56.8±27.4); n = 5	ns

Linear regressions were used to describe relationship between fish total length (TL) and THg concentration in its flesh. There was a significantly high correlation (Pearson r = 0.667; P <0.001) between length and THg in muscle of *O. niloticus*. (Fig. 2a) The coefficient of determination (r^2) suggests that more than 44% of cases of THg in *O. niloticus* population is a result of acquisition of Hg from their diet. The THg concentration in flesh increases with age (duration of exposure) of fish apart from location (intensity or level of exposure) of fish. Similarly, there was a significant correlation (r = 0.676; P =0.0310) between THg concentration and length of *C. gariepinus* (Fig. 2b). Correlation coefficient (r) was low (0.591) although significant (P = 0.0001) between length of *L. niloticus* and THg concentration in muscle (Fig. 2c). This was rather expected because *L. niloticus* samples were dominated with immature specimens. As shown in figure 2d, there were only six samples of *L. niloticus* that approached adulthood, they had TL > 50 cm.

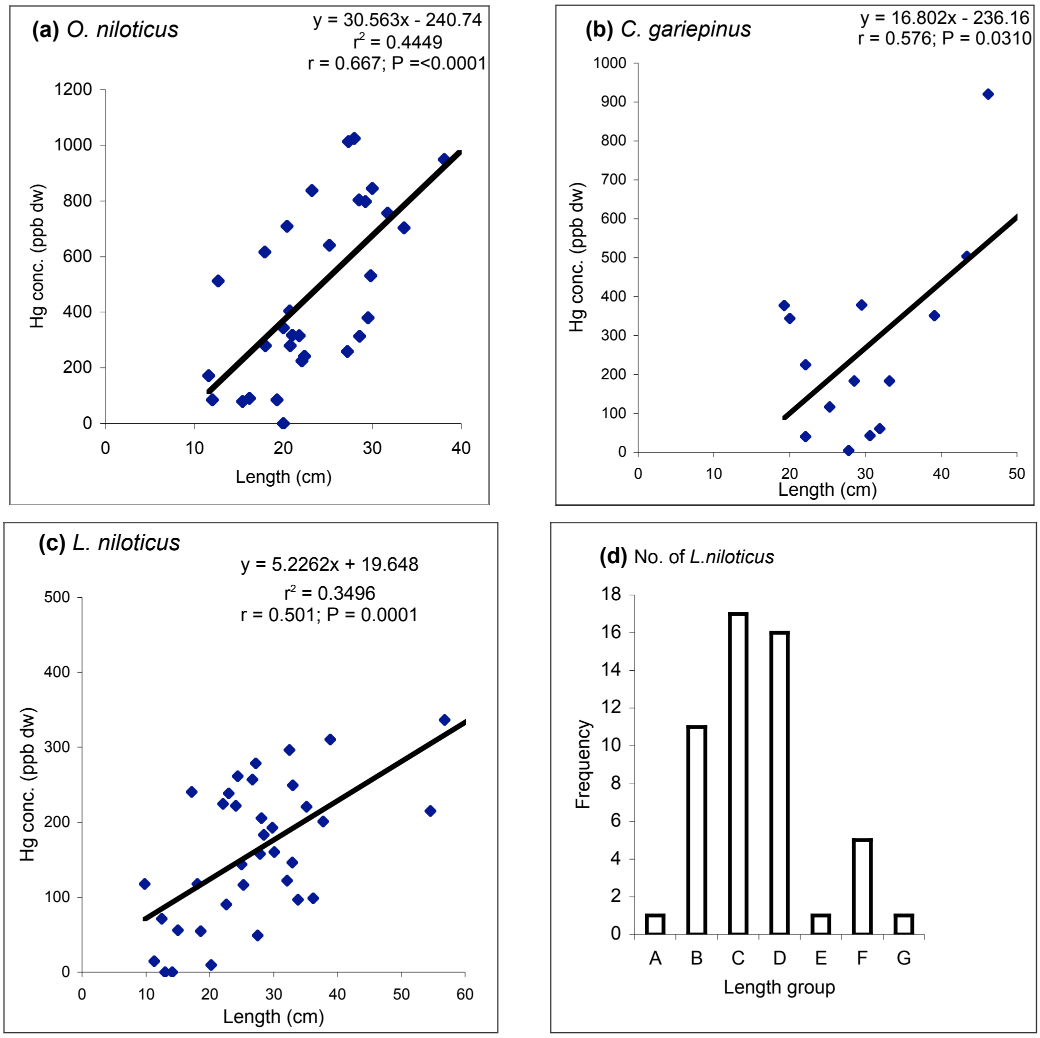

Figure 2: Relationships between THg concentration in fish muscle and Total length of fish

DISCUSSION

Although almost all large Nile Perch inhabit open lake waters where point sources of Hg are absent, there is still a health concern about consumption of these fish by humans mainly because of being the top piscivore in the lake. The alleged Global/regional atmospheric deposition of Hg is also threatening the well being of the large water bodies. Typical background levels of THg in freshwater fish from non-polluted areas range from 100 ng/g to 200 ng/g ww (WHO 1976), although Hg concentration in large carnivorous species can be as high as 0.8

μg/g ww. The present study has investigated mercury concentration in fish from areas suspected to be affected by mining activity and areas that are remote from mining activity. The results of the study did not show significant difference ($P > 0.05$) in THg content in fish from different locations in Lake Victoria. Generally, the concentrations of THg in fish were in the same order of magnitude as those reported by Ikingura and Akagi (2002b) in hydroelectric reservoirs in Tanzania.

The study showed that THg concentration in *L niloticus* from Nungwe Bay was similar to other locations. However, Ikingura and Akagi (1996) found rather lower concentrations of THg in *L niloticus* from Nungwe Bay, the range was 6.9 – 11.7 ng/g ww, the authors did not report length or weight of the fish. In the present study the concentration range of THg in *L niloticus* from Nungwe Bay was 95.1-395.9 ng/g ww. This observation calls for periodic monitoring of the levels of mercury in fish so as to know whether levels are increasing or not, in order to allow sufficient time to take appropriate measures.

Kishe (2001) reported mercury concentration in *O. niloticus* from Mwanza Gulf. The reported values ranged from <10 to 62 ng/g, indicating that the concentration was below WHO maximum tolerable concentration (500 ng THg/g ww) for regular human consumption. The concentration of THg in *O. niloticus* was significantly different ($P = 0.0199$) between sampling locations of Mara and Mwanza Regions. In Mara Region, highest concentration (277.3 ng/g) was found in *O. niloticus* of Mara Bay, and in Mwanza Region, highest THg concentration (297.7 ng/g) was found in *O. niloticus* of Nyikonga. In Nungwe Bay the highest THg concentration in *O. niloticus* was 246.0 ng/g. Therefore, there is a likelihood of exposure of *O. niloticus* to Hg pollution in both Regions. In Mara Bay, during the onset of heavy rains, both *O. niloticus* and *L. niloticus* emigrate from the Bay to parts of the lake that have clear water. Therefore, the mere presence of *O. niloticus* and *L. niloticus* in Mara Bay does not indicate that they are bona fide dwellers of the area, indeed some of them could be mere passers by.

The present study indicated positive correlation between body burden of Hg and length of fish. As reported by Migiro (1997) and Campbell (2001), higher Hg concentrations were obtained in larger *L. niloticus* as compared to smaller specimens. Larger *L. niloticus* are favoured by several factors, for instance, their longevity results into a longer exposure time. The big *L. niloticus* are found in relatively deeper water of the lake where few fishers frequent, as a result the larger specimens have a long exposure time. Their slow metabolic rate, characteristic of long living organisms (Huckabee *et al.* 1979) can result into low excretion of Hg thereby enhancing their body burden of Hg. Further studies should target larger specimens of *L. niloticus* so as to confirm their body levels of Hg.

Calculation of total mercury daily ingestion assuming a daily consumption of 100g of *L. niloticus* edible tissue was done basing on WHO (1989). The highest consumption value for the specimen with highest THg content (0.396 μg/g) was slightly below the tolerable intake limit of 43 μg/day suggested by WHO (1989) for a 70 kg adult. Fish consumption by fishing communities riparian to Lake Victoria is well below 100 g/day for most of the families, therefore the likelihood of exceeding the 43 μg Hg/day limit is remote.

The regression analysis for the correlation between THg and TL of *O. niloticus*, *L. niloticus* and *C. gariepinus* showed a significant ($P < 0.05$) positive linear relationship. The value for the correlation between TL of *L. niloticus* and THg content is considered indeed a good correlation ($r = 0.5013$), however, it would have made more sense if there was adequate representation of adult specimens in the sample. The coefficient of determination (r^2) for *L. niloticus* was 0.3496. This means only 35% of the variation in THg values of *L. niloticus* could be considered related to the duration of exposure to Hg through feeding. Nevertheless, good correlations between TL and Hg concentration in fish muscle have also been acknowledged by Campbell (2001) in Lake Victoria, as well as de Pinho *et al*., (2002) in marine fish. The researchers confirm that feeding habit influences THg concentration in fish. Piscivorous species have highest THg and methyl mercury ($MeHg^+$) compared to species that feed mainly on small invertebrates. In the case of the proportion of $MeHg^+$ to THg, piscivorous fish generally contain a higher proportion (~ 90%) compared to their non-fish eating counterparts (~ 75%), even within the same family (de Pinho *et al*. 2002).

The present study also indicates municipal waste discharge (Mirongo river) and biomass burning or erosion (Simiyu river) are possible sources of mercury pollution of Lake Victoria. Therefore, rivers draining urban areas as well as those draining areas with pronounced biomass burning are possible point source of Hg. Therefore, other mercury input mechanisms such as atmospheric deposition (Ikingura and Akagi 2002a) should be given attention.

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