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LEVEL OF MERCURY IN FISH FROM THE ETHIOPIAN RIFT VALLEY LAKES: ITS IMPLICATIONS IN DIETARY EXPOSURE

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ABSTRACT: Environmental contaminants in fish pose a potential human health hazard. The level of mercury (Hg) was investigated in three fish species, i.e., *Labeobarbus intermedius*, *Oreochromis niloticus* and *Clarias gariepinus*, from Lake Koka and Lake Ziway, Ethiopia. The concentrations of Hg found in *C. gariepinus* and *O. niloticus* from Lake Koka and Lake Ziway were, in general, lower than the International Marketing Limit (IML) (0.5 μg g^{-1}) and World Health Organization (WHO) guidelines (0.2 μg g^{-1}) for consumption. This finding is, in general, in agreement with most studies conducted in other African lakes. However, of the total fish samples for each species, 67% of *L. intermedius* from Lake Koka and 27% of *L. intermedius* from Lake Ziway showed Hg concentrations that exceeded WHO guidelines (0.2 μg g^{-1}) for consumption. Species variation in total Hg (THg) accumulation is attributed to trophic position, and therefore, consumption of fish from a high trophic level may represent a potential health hazard. Consumption of *L. intermedius* from both lakes may pose a special health risk to children and pregnant women. However, *L. intermedius* has a low preference as a food fish, and is therefore not widely used by the local people.

Key words/phrases: Fish consumption, Fish species, Hg, Rift Valley Lakes.

INTRODUCTION

Mercury in fish is of global concern, and a widely studied topic, because of its established relevance to human health risks. Generally, organic mercury forms are more toxic to human than the inorganic forms (Boening, 2000). It is also documented that virtually all 50–98% of the total Hg (THg) in the edible tissue of fish is in the form of methyl mercury (MeHg) (e.g., Bloom, 1992: Carrasco *et al*., 2011; Nguetseng *et al*., 2015).

The first well-documented MeHg poisoning from fish diet occurred in Minamata, Japan in 1953 (Ninomiya *et al*., 2005). The negative health effects on the population in Minamata seemed to persist even thirty years

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after the termination of the exposure (Ninomiya *et al*., 2005). One of the most common ways of human exposure to Hg today arises from eating fish with elevated concentrations of Hg (Counter and Buchanan, 2004; Durrieu *et al*., 2005; Zaza *et al*., 2015). MeHg is a known potent human neurotoxin because of its ability to cross the blood-brain and placenta barriers. According to Grandjean *et al*. (1999), prenatal exposure to MeHg from maternal diet has been shown to result in an early detectable cognitive dysfunction in 7-year old children.

The key factor dictating total concentration of Hg in the biota (e.g. fish) is the MeHg concentration in water (Morel *et al*., 1998), and the important sources are precipitation, runoff from wetlands and in-lake methylation (Rudd, 1995; Downs *et al*., 1998). Hg can accumulate to elevated levels in the biota even in remote areas which are devoid of local industrial sources; due to long-range atmospheric transport followed by deposition (Fitzgerald *et al*., 1998). Local factors such as the presence of hot springs around lakes is also thought to account for high Hg concentrations in the waters of Ethiopian Rift Valley soda lakes (Zinabu Gebremariam and Pearce, 2003). It is also important to take into account biological factors such as the food web structure, to explain the behaviour of Hg, including bioaccumulation. The concentration of Hg increases through the food chain by biomagnifications i.e., the increase of Hg with trophic position in the food chain (Watras *et al*., 1998; Campbell *et al*., 2003a; Simoneau *et al*., 2005).

Literature survey showed that there have been several studies on Hg in fish from East African lakes. Lakes of which, for instance, published data exist are: Lake Victoria (Campbell *et al*., 2003b; Campbell *et al*., 2003c; Campbell *et al*., 2003d; Hollamby *et al*., 2004), Lake Mburo of Uganda (Hollamby *et al*., 2004), Lakes Turkana, Baringo, Naivasha of Kenya (Campbell *et al*., 2003a), and Lake Malawi (Kidd *et al*., 2003), also including some lakes in Ethiopia, Lake Hawassa (Zerihun Desta *et al*., 2006; Zerihun Desta *et al*., 2007; Zerihun Desta *et al*., 2008), Lake Ziway (Tariku Markos *et al*., 2011), and Lake Koka (Ermias Deribe *et al*., 2014). However, the mercury concentrations in fish may change due to spatial and temporal variations as well as to external supply. To address scientific and public health concerns, it is essential that biomonitoring of Hg in different fish species is carried out in the Ethiopian Rift Valley Lakes (ERVLs). The objective of the present study was therefore to quantify the THg concentration levels in key fish species; Big barb (*Labeobarbus intermedius*, Rüppell, 1835) (formerly *Barbus intermedius*), African sharp tooth catfish (*Clarias gariepinus*, Burchell, 1822) and the Nile tilapia (*Oreochromis* *niloticus*, Linnaeus, 1758) from Lakes Koka and Ziway, in order to assess potential human health risks related to consumption of fish by the local population.

MATERIALS AND METHODS

Study area

The Ethiopian Rift Valley Lakes are a chain of lakes that contain edible fish, and support a variety of aquatic and terrestrial wildlife. The lakes play a very important role in tourism, biodiversity conservation and in ameliorating the effects of drought and protein shortage of the population (Wood and Talling, 1988). Lake Koka, situated at 8°24'12.66"N and 39°05'31.50"E, is a hydroelectric reservoir dammed within the River Awash, and now receiving its inflows from River Awash and River Mojo. Lake Ziway, situated at 7° 58'18.37"N and 38°50'29.88"E, is a shallow lake in the Ethiopian Rift Valley, located approximately 40 km and 120 km south of Lake Koka and Addis Ababa, respectively. The main inflows to this lake are River Meki and River Katar (Fig. 1). Lakes Koka and Ziway have significant environmental, economic and cultural importance to the regions and have been used for commercial fisheries, irrigation, and recreation and for some domestic purposes. In spite of their importance to the livelihood of the population, there are indications that Lakes Koka and Ziway are going through changes that, unless immediate actions are taken, may lead to irreversible degradation in its water quality and fisheries. Lakes Koka and Ziway, being urban lakes, are exposed to increased population pressure. General water quality characteristics of these lakes and other details of the area description have been described in Ermias Deribe *et al*. (2011) and Alemayehu Esayas *et al*. (2011).

Mercury analysis

Fish sampling was carried out from July to October 2009 (Table 1). Fish dissection of muscle samples and handling were carried out following the EMERGE protocol (Rosseland *et al*., 2001). Fish muscle tissue for total mercury (THg) were wrapped in aluminum foil, kept in a plastic bag with zipper lock and stored in an ice box until transferred to a deep freezer, and transported to Norway.

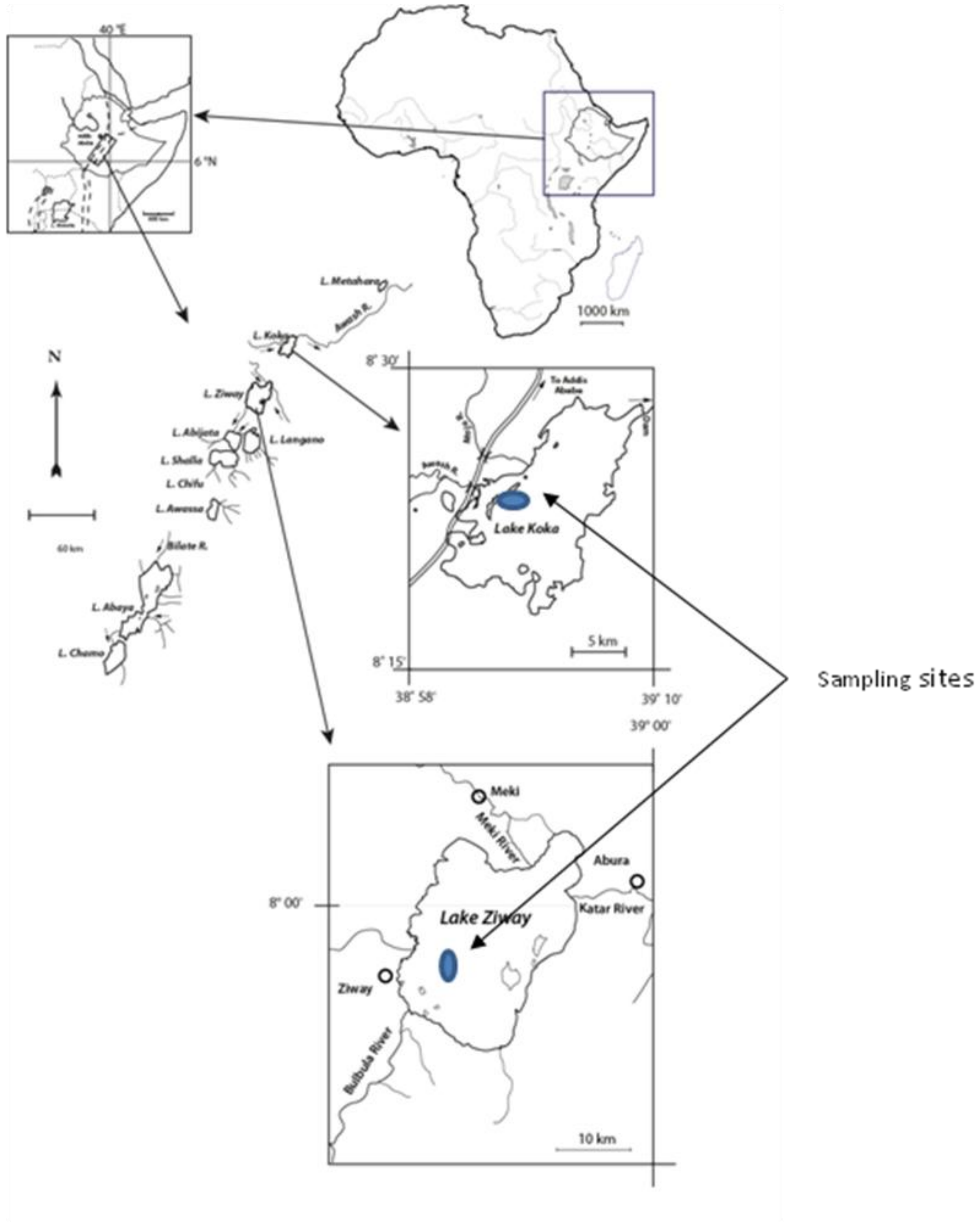

Fig. 1. Map of Lake Koka and Lake Ziway.

Tissue concentration of THg in all fish samples was analyzed at the Environmental Chemistry Section of the Department of Plant and Environmental Sciences (IPM), Norwegian University of Life Sciences (UMB). The wet muscle tissues (200 mg) were first weighed, and then digested, using an Anton Paar microwave oven. THg concentrations were analyzed using the Perkin-Elmer model FIMS 400 flow injection Hg system. The equipment was calibrated by plotting calibration curves using the measurement values of four different synthetic standards. The curves were linear, and calibration was rechecked after every five samples. The concentrations of synthetic standards varied depending on the concentrations of Hg in the samples. The accuracy of the method was controlled against DORM-2 (piked dogfish *Squalus acanthias* L.), certified reference material, National Research Council of Canada, Ottawa. The reference material was run once after every 15 samples and was measured five times during the routine of measuring THg including muscle samples of other fish species. The mean ± SD of the certified reference samples was 4.598 ± 0.093 mg kg^{-1}, and it is within the range of the certified reference value (4.64 ± 0.26 mg kg^{-1}, Recovery=110–125%). Blanks were used and values were <0.001 mg kg^{-1}. Sample values were corrected against blank values.

The concentrations of Hg found in the fish species from Lake Koka and Lake Ziway were compared against the International Marketing Limit (IML) (0.5 μg g^{-1}) and World Health Organization (WHO) guidelines (0.2 μg g^{-1}) for consumption.

Statistical analysis

Comparisons of the THg concentrations for each fish species between the two lakes were performed by analysis of variance (ANOVA), using MINITAB 16.

RESULTS AND DISCUSSION

The concentrations of Hg found in *C. gariepinus* and *O. niloticus* from Lake Koka and Lake Ziway were in general lower than the International Marketing Limit (IML) (0.5 μg g^{-1}) and World Health Organization (WHO) guidelines (0.2 μg g^{-1}) for consumption (Table 1). This finding is, in general, in agreement with most studies conducted in other African lakes (Table 2). In our study, only one large individual of *C. garipienus* in Lake Koka had an exceptionally high Hg concentration (0.64 mg kg^{-1} ww), a factor of 3 times higher than the THg concentration of the other individuals from the same lake. However, of the total fish samples for each species, 67% of *L.*

intermedius from Lake Koka and 27% of *L. intermedius* from Lake Ziway showed Hg concentrations that exceeded WHO guidelines (0.2 µg g^{-1}) for consumption (WHO, 2007). The concentrations of THg found in *L. intermedius* were higher than those found in the other fish species in our study, as well as in most other studies carried out in other African lakes (Table 2), although fish size, sample size etc. varied in these studies, and may make direct comparisons difficult. This result is consistent with the report by Zerihun Desta *et al*. (2007) for the same fish species from Lake Hawassa. However, a study in Lake Tanganyika (Tanzania, East Africa) by Campbell *et al*. (2008) showed that two individuals of the piscivorous fish species *Lates microlepis* (0.54, 0.78 µg g^{-1} ww) and *Polypterus congicus* (1.3 µg g^{-1} ww) contained a higher concentration of THg and exceeded the International Marketing Limit value of 0.5 µg g^{-1} ww.

Spatial differences were significant for the two species i.e., significantly higher concentration of THg was found in Lake Koka than in Lake Ziway for both *B. intermedius* and *C. gariepinus* (Table 1). The observed dissimilarity in Hg contamination between the two lakes probably reflects true differences in environmental Hg levels. This is probably because of high inputs of Hg from the nearby point sources (e.g. tannery factories) via River Mojo. However, the spatial variations need to be substantiated further using time series study.

Table 1. Mean values ± standard deviation (SD) of THg concentrations (in µg g^{-1} ww), with minimum and maximum values in the fish species *L. intermedius*, *C. gariepinus* and *O. niloticus* from Lake Koka and Ziway, sampled in 2009. ND means not detected.

Fish species	**Sample size (N)**	**THg Lake Koka Mean ± SD (Min -Max)**	**THg Lake Ziway Mean ± SD (Min -Max)**
L. intermedius	15	0.39 ± 0.3^{a}	0.13 ± 0.2^{b}
		(0.03–0.9)	(0.01–0.5)
C. gariepinus	24	0.14 ± 0.1^{a}	0.06 ± 0.04^{b}
		(0.05–0.64)	(ND–0.16)
O. niloticus	31	0.01 ± 0.0^{a}	0.01 ± 0.0^{a}
		(ND–0.02)	(ND–0.04)

Means of THg that do not share a letter are significantly different ($p<0.05$) between the two lakes.

Table 2. Mean values ± SD of THg concentrations (in μg g^{-1} ww), in fish species from other African lakes.

Authors	Lake	Fish speies	Mean ± SD, THg
Tariku Markos *et al.*, 2011	Lake Ziway	*O. niloticus*	0.01 ± 0.01
		C. auratus	0.03 ± 0.02
		C. gariepinus	0.03 ± 0.02
		T. zilli	0.03 ± 0.03
Zerihun Desta *et al*., 2007	Lake Awassa	*O. niloticus*	0.01 ± 0.02
		C. gariepinus	0.05 ± 0.03
Kidd *et al*., 2004	Lake Chad	*O. niloticus*	0.01 ± 0.00
		C. gariepinus	0.03 ± 0.00
Campbell *et al*., 2004	Lake Victoria	*O. niloticus*	0.01 ± 0.00
Campbell *et al*., 2006	Lake Nkuruba	*T. zillii*	0.02 ± 0.01
Campbell *et al*., 2003d	Lake Baringo	*C. gariepinus*	0.06 ± 0.03

Variation in THg accumulation in the different fish species is attributed to their trophic position. Consumption of fish from the higher trophic level may represent a greater health hazard as a result of bioaccumulation through diet (Watras *et al*., 1998; Rosseland *et al*., 1999). In Lake Hawassa, *L. intermedius* was found to have higher concentration of both mercury and POPs, especially DDT, than other species (Ermias Deribe *et al*., 2011). Consumption of *L. intermedius* from Lake Koka and Lake Ziway may pose health risk for children. However, consumption from the other fish species (*O. niloticus* and *C. garipienus*) does not pose a direct hazard to human health, based on the current recommendations. In the Ethiopian Rift Valley areas, the species, *O. niloticus* and *C. garipienus* are more preferred for consumption than *L. intermedius*, probably because of the high infection with tape worms encountered in *L. intermedius* which make this fish species unpleasant to eat by the local people. However, this information (personal communication) needs to be further investigated. Moreover, *L. intermedius* is also much more bony than the other species making it less attractive for consumption (e.g., the restaurants in Rift Valley Lakes towns like Hawassa) (Zerihun Desta *et al*., 2007). However, the fish fillet is still prepared and served as soup by the local fishermen families. For those who eat fish more or less on a daily basis, the mercury intake will thus be considerably higher.

Given that the consumption rate of fish in general, and *L. intermedius* that exceeded International Marketing Limit (IML) (0.5 μg g^{-1}) and World Health Organization (WHO) guidelines (0.2 μg g^{-1}) for consumption, in particular, the local people living in the island of Lake Ziway and the family of fishermen there, are the most vulnerable community of the local people. Although the level of mercury in *O. niloticus* and *C. gariepinus* were, in general, lower than the International Marketing Limit (IML) (0.5 μg g^{-1}) and

World Health Organization (WHO) guidelines (0.2 μg g^{-1}) for consumption, the presence of mercury residue in most samples indicates that any consumption of fish from the lake in the future will require continuous health risk assessment. Moreover, interactions and combined effects among contaminants should be taken into account in evaluation of the health risk posed by mercury exposure more precisely.

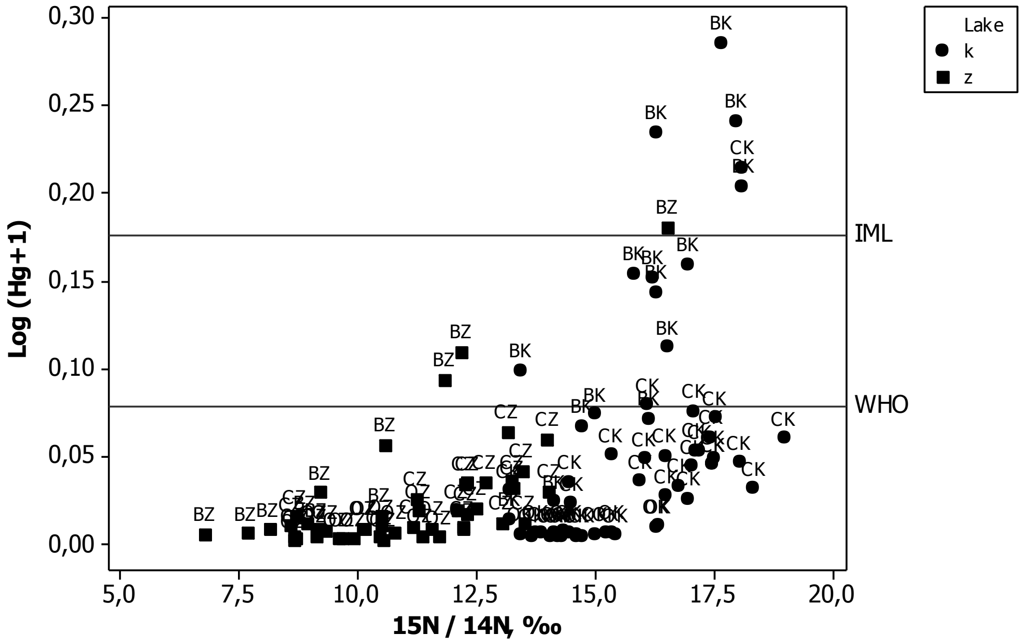

Fig. 2. Comparison of the level of THg in fish sampled from Lake Koka and Lake Ziway with WHO guideline values set for safe fish consumption (WHO; 0.2 μg g^{-1} ww) and International Marketing Limit (IML; 0.5 μg g^{-1} ww) (BK: *Labeobarbus intermedius* in Koka, OK: *Oreochromis niloticus* in Koka, CK: *Clarias gariepinus* in Koka, BZ: *Labeobarbus intermedius* in Ziway, OZ: *Oreochromis niloticus* in Ziway, and CZ: *Clarias gariepinus* in Ziway).

CONCLUSION

The concentrations of THg found in *L. intermedius* were, in general, higher than those found in other fish species in our study, as well as in most studies carried out in other African lakes, although variations in fish size, sample size etc, make direct comparisons difficult. Species variation in THg accumulation is attributed to trophic position; and therefore, a person with a daily intake from a high trophic level such as *L. intermedius* may be exposed to possible health hazards. Children and pregnant women of the local community, especially the local subsistence fishermen and their families, are the most vulnerable population sub-group. The other species, *O. niloticus* and *C. gariepinus*, have lower THg concentrations than *L. intermedius*, and the hazard evaluation indicates that there is no direct risk for humans using these species in their daily food intake.

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