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Research Paper

Quantitative Neutron Activation Analysis of Some Elements in Muscle Tissues of Four Fish Species and Water from the Weija Lake in Ghana

E. Ameko[1, *], J. Okai-Armah[2], S. Achio[1] and S. Afful[2]

[1] Department of Science Laboratory Technology, Accra Polytechnic, Box 561, Accra, Ghana

[2] Ghana Atomic Energy Commission, Kwabenya, Accra, Ghana

* Corresponding author, e-mail: (edmundameko@yahoo.com)

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Abstract: *Mg, Ca, Na, K, Cl, Br, and Ipollution of the Weija Lake in Ghana was assessed by quantitative Neutron Activation Analysis ofwater and muscles of Tilapia zillii, Clarias gariepinus, Sarotherodon galilea, and Oreochromis niloticus from the lake. Concentrations in fish muscles (Na > K > Ca > Cl > Mg > Br > I) correlated: very weakly with concentrations in water (Na > Br > Cl > Mg > Ca > K > I); strongly negatively with fish lengths and weights; weakly negatively with condition factor (K_f) of T. zilli and; strongly positively with K_f of C. gariepinus, O. niloticus and S. galilea. Concentrations in water did not differ significantly ($p\leq0.05$) among sampling sites, with Chlorine and Bromine exceeding the reference ranges of 0.005µg Cl/ml and 0.5µg Br/ml. Bioaccumulation Factors were: K > Na > Ca > Cl > Mg > Br > I. Muscle concentrations were insignificantly different ($p\leq0.05$) among individual fish samples. Estimated Average Daily Intake (EADI) for Na (6,621,261.4 µg – 10,085,485.2 µg Na) > Recommended Average Daily Intake (RADI) of 1,000,000 µg – 1,200,000 µg Na. EADI for Br (49,121.2 µg – 151,621.2 µg Br) > RADI (24,000 µg Br). EADI's for the remaining elements were within the respective RADI's except for Potassium EADI for C. gariepinus (13,847,916.7 µg K) > RADI (4,700,000 µg K). The results indicatedsafelevels ofMg, Ca, K, Cl, andI,andunsafelevels ofNa and BrinT. zillii, C. gariepinus,S. galilea, andO. niloticus from the lake.*

Keywords: Pollution, Weija Lake, Water, Fish, Neutron Activation Analysis.

Introduction

The Weija Lake on the Densu River in Ghana is one of the most polluted rivers in the country due to garbage littering its banks (Ocansey, 2006), agricultural activities and the indiscriminate discharge of untreated wastes into the lake (Paintsil and Abrahams, 2008; Karikari and Ansa-Asare, 2006). The water quality of the lake can be compromised by leachate from two major decommissioned landfill sites which flow down a slope into the lake (Dadzie, 2012; All Africa, 2011; James, 1977). Currently, only four fish species, *Tilapia zillii*, *Clarias gariepinus*, *Sarotherodon galilea*, and *Oreochromis niloticus* are caught in the Weija Lake by artisanal fishermen, and these have over time shrunk in size (The Ghanaian Chronicle, 2011). The fishes which are in very high demand in Ghana (Antwi - Asare and Abbey, 2011) are main protein sources especially for Ghanaians living along the coast (Rao et al, 2012).

Fish and other species living in polluted water tend to accumulate heavy metals more in their tissues compared to other organisms (Kupeli, 2013; Jezierska and Witeska, 2006). The monitoring of metal concentrations in fish is therefore useful for assessing the impact of metal pollution in freshwater systems (US EPA, 2012) as well as the health risks associated with consumption of fish from these water bodies (Lasheen et al, 2012). Studies (Yi and Zhang, 2012) have also showed positive relationships between fish sizes and metal concentrations in fish.

One of the most sensitive microanalytical methods for measuring trace amounts of elements in various types of samples is Neutron Activation Analysis (NAA). Neutrons are used to bombard a sample causing the sample to release a radioactive isotope of the element of interest. The radioactive isotope in turn emits Gamma rays. The number of gamma rays emitted depends on the number of atoms present in the sample and this in turn depends on the concentration of the element from which the gamma rays were emitted. Therefore the concentration of an element can be determined by the amount of gamma rays it emits (NREP, 2013). The limits of detection reported by NREP (2013) for NAA for some elements are > 0.1 µg (Ca, Mg), 0.01 - 0.1 µg (K, Cl), and < 0.1 µg (I, Br).

The presence of high chloride levels in freshwater water is an indication of pollution from fertilisers, sewage and water softeners. This is can interfere with osmoregulation in aquatic organisms and can cause reduced growth and reproducibility and even death in the aquatic organisms (Hunt et al., 2012). Chloride levels are used as an indicator of pollution in watersheds (Hunt et al., 2012) such as the Densu Delta and Weija River. Potassium is quickly taken up by roots of plants.Therefore elevated levels in water would be unusual and would indicate excess runoff of fertilizers (Vimpany and Lines-Kelly, 2004). Acute bromine intoxication can lead to coma, paralysis and even death (WHO, 2009). Magnesium salt contamination of food or water can cause hypotension and diarrhoea (FAO – WHO, 2001). Increased sodium intake increases blood pressure and is linked to cardiovascular ailments (WHO, 2012).

This study used NAA to determine Ca, Mg, Na, K, Cl, Br and I concentrations in water from the Weija Lake as well as in the edible parts i.e. (the muscle tissue) of four fish species (*T. zillii*, *O. niloticus*, *S. galilea* and *C. gariepinus*) from the lake.

Also, the relationships between metal concentrations in the water, fish sizes (lengths and weights), condition factor, and bioaccumulation factor on one hand, and metal concentrations in muscle tissue of the various species of fish on the other hand were investigated by linear regression analysis. The estimated average daily intake of the selected metals were calculated and compared to internationally recommended values of safety.

Materials and Methods

The procedure used by Ameko et al. (2014) in the Instrumental Neutron Activation Analysis of metal concentrations in muscle tissues of fish was used in this study.

Study Area

The Weija Lake (5°34′N and 0°20′W) (Figure 1) in the Ga South Municipality of the Greater Accra Region of Ghana covers an area of about 9,000 square hectares. It was formed in 1977 by damming the Densu River at Weija to provide hydroelectric power and potable water supply to residents in Accra East and West.

Sampling area (●) and Fish Landing Site (★)

Figure 1: Map showing the Weija Lake, Sampling Area and Fish Landing Site

Water Samples

Water sampling and analysis were done according to APHA (2005). Water samples were collected from six points downstream on the Lake on 25th August, 2014. The researcher was transported to the sampling points in a canoe by fishermen. Water samples were collected directly into clean acid washed Teflon bottles which were then put on crushed ice blocks in an ice box and transported to the laboratory, where they were prepared for Neutron Activation Analysis.

The water samples were shaken in their containers to obtain homogenous samples. With the aid of a micropipette, 500 µl of each water sample was transferred into a small cylindrical polyethylene vial of diameter 1.2 cm and height 2.35 cm. Each vial was heat-sealed with a soldering rod. Each vial was put into a bigger polyethylene vial of diameter 1.6 cm and height 5.5 cm (rabbit capsule). The rabbit capsule was also heat-sealed with a soldering rod for irradiation.

Fish Samples

Twenty four freshly caught fish samples made up of six samples each of four species of fish *Tilapia zillii* (red belly tilapia), *Clarias gariepinus* (African Catfish), *Sarotherodon galilaea* (Tilapia galilaea), and *Oreochromis niloticus* (Nile tilapia) were purchased from fishermen at the landing site at Manhean near Galilee, a fishing community along the Weija Lake on 25th August, 2014. The samples were brought to the laboratory on crushed ice blocks in an ice box. The fish samples were washed several times with distilled and deionised water.

The total length (cm) of each sample was measured in a straight line from the tip of the snout to the tip of the longer lobe of the caudal fin, with the lobes compressed along the midline. The weight (g) of each sample was measured with an Explorer Pro weighing scale (Model EP2102C).

Since the aim of the study was to analyse the edible parts (Bat et al., 2012) which is mainly the muscle tissue of the fish (Murray and Burt, 2001), each fish sample was gutted with a stainless steel knife and the intestines, scales, head, tail, fins and backbone removed. The samples were cut into smaller pieces,rinsed several times with de-ionised water and then stored in a deep-freezer at -20^{o}C prior to analysis.

Preparation of Fish Samples for Neutron Activation Analysis

The pieces of fish were removed from the freezer and allowed to thaw. The pieces were thenfreeze dried in a freeze dryer (CHRiST LMC-1, Germany) for 72 h and then homogenized in a Waring Blender (8011ES, HGB2WTS3) to obtain dry fish powder. Two 200 mg portions of the dry fish powder were weighed as replicates for each sample and each wrapped in a transparent polyethylene film and further encapsulated in 7 ml polyethylene irradiation vials. The vials were heat-sealed for irradiation (IAEA, 2003).

Neutron Activation Analysis (NAA)

Samples were irradiated in the Ghana Research Reactor (GHARR-1) at the Ghana Atomic Energy Commission (GAEC), operating at a power of 15 KW at a neutron thermal flux of 1 x 1011 ncm^{2} S^{-1}. Samples were transferred into irradiation sites via a pneumatic transfer system at a pressure of 60 psi. Two separate irradiations were performed based on the elements of interest and on the half-life of the radionuclide (Table 1).

Table 1: Irradiation and counting scheme (IAEA, 2003) used for the Neutron Activation Analysis of Mg, Ca, Na, K, Cl, Br and I concentrations (µg/g) in four fish species and water (µg/ml) from the Weija Lake in Ghana

Element	Isotopes	Half – Life	Gamma Ray Energies (keV)	Irradiation times	Counting time
Ca	^{49}Ca	8.7 min	3084.4	120 s	600 s
Cl	^{38}Cl	37.3 min	1642.2, 2167.5	120 s	600 s
Mg	^{27}Mg	9.45 min	843.8, 1014.4	120 s	600 s
Na	^{24}Na	15.02 h	1368.6, 2754.1	3600 s	600 s
K	^{42}K	12.36 h	1524.7	3600 s	600 s
Br	^{82}Br	35.3 h	554.3, 776.5	3600 s	600 s
I	^{128} I	25 min	442	120 s	600 s

Two minutes and one hour irradiation times were used for short lived radionuclide(s) and medium lived radionuclide(s) respectively. Certified IAEA reference material (IAEA-407) for fish tissue (IAEA, 2003) was irradiated the same way as the samples and used to calibrate and validate the method.

Counting of Irradiated Samples

Radioactivity measurement of induced radionuclide was performed by a PC-based γ-ray spectrometry, which consisted of an N-type HpGe detector (coaxial type) coupled to a computer based multi-channel analyzer (MCA) via electronic modules. The energy resolution of the detector is 1.8keV at a γ-ray energy of 1332keV of 60Co. The data acquisition and identification of γ-rays of product radionuclide were identified by their γ-ray energies via ORTEC MAESTRO-32. Quantitative analysis was done via relative comparator method. The peak area determinations, processing and concentration calculation were done by multipurpose γ-ray spectrum analysis software; winSPAN-2010 version 2.10. Nuclear data used for Ca, Cl, Mg, Na, K, Br and I (IAEA, 2003) are shown in Table 1.

Condition Factor (Kf)

The condition factor was calculated as $K_f = 100W/L^3$
Where W is the weight of the fish in grams, and
L is the total length of the fish in centimeters (CDFO, 2004; Tacon *et al*, 1989).
The condition factor indicates the condition, fatness, and well-being of the fish, and is based on the assumption that heavier fish of a given length are in better condition (Froese, 2006). For the comparison of K_f among samples to be valid all the fish samples were collected from the same water on the same date (Williams, 2000).

Calculation of Estimated Average Daily Intake (EADI) (µg/day) of Element

Daily intake of element from fish = A × B, Where

A - Average quantity of fish consumed per individual per day

Maximum average per capita fish consumption in Ghana = 25kg (Global Fish Alliance, 2005)

Average fish consumption per individual per day = 25,000g / 365 days = 68.49g /day

B - Average concentration (µg/g) of element in studied fish

$$\text{EADI of element} = \frac{68.49\,\text{g fish}}{\text{day}}\; x \;\frac{\text{B}\mu\text{g}}{\text{g fish}}$$

Statistical Analysis

SPSS for windows (version 16.0) and Microsoft Excel were used to perform the statistical analysis and tests. Analysis of variance was used to make comparisons between any two groups. Regression analysis was used to determine the relationships between elemental concentrations in water, fish sizes (lengths and weights), condition factor, and bioaccumulation factor on one hand, and elemental concentrations in muscle tissue of the various species of fish on the other hand. A probability value of $P < 0.05$ was considered as statistically significant.

Results and Discussions

Table 2: Comparison of validation results from Certified IAEA Standard Reference Material (IAEA-407) for fish tissue used in this study to those established by IAEA (2003)

This Work				IAEA (2003)		
Elements	**This Work**	**This Work Standard Deviation**	**Percent deviation**	**IAEA-407**	**IAEA Standard Deviation**	**95% Confidence Interval(mg kg^{-1}) for IAEA-407**
Mg	2.82	0.07	3.55%	2.72	0.14	2.58 – 2.86
Ca	29	1.41	6.90%	27	1.80	25.7 – 28.3
Br	95.2	0.85	1.26%	94	9.00	86 – 102
Na	12.33	0.54	-6.24%	13.1	0.60	12.4 – 13.8
K	13.32	0.16	1.65%	13.1	1.20	12.2 – 14.0

The standard deviations values for Mg, Ca, Na, K, and Br obtained for the Certified IAEA standard reference material (IAEA-407) for fish tissue used in this study were 0.07 – 1.41 (Table 2).

The values agreed with the ranges of standard deviation values of 0.14 – 9.00 established by the IAEA for Mg, Ca, Br, Na, and K (IAEA, 2003). Concentrations of Mg, Ca, Na, K, and Br obtained for the Certified IAEA reference material in this study were all within the 95% confidence interval range of concentrations established by the IAEA for the metals and anions in the certified reference material. These results validated the NAA procedure used in this study to determine the concentrations of Mg, Ca, Na, K, Cl, Br, and I in the water as well as in the muscles of four species of fish from the Weija Lake.

Table 3: Correlation between Condition Factors (K_f) and Mg, Ca, Na, K, Cl, Br, and I concentrations (µg/g) in four fish species from the Weija Lake in Ghana

	Elements						
	Mg	**Ca**	**Na**	**K**	**Cl**	**Br**	**I**
T. zilli	-0.33	-0.22	-0.22	-0.26	-0.44	-0.29	-0.59
C. gariepinus	0.92	0.85	0.84	0.71	0.90	0.87	0.79
O. niloticus	0.85	0.84	0.81	0.88	0.74	0.80	0.88
S. galilea	0.71	0.77	0.77	0.74	0.72	0.72	0.66

The correlations between muscle concentrations of Mg, Ca, Na, K, Cl, Br, and I and the K_f of *T. zilli* were weak and negative (Table 3). Muscle concentrations of Mg, Ca, Na, K, Cl, Br, and I were thus higher in *T. zilli* samples with lower K_f. In the cases of *C. gariepinus*, *O. niloticus* and *S. galilea* increasing K_f led to corresponding increases in muscle concentrations of Mg, Ca, Na, K, Cl, Br, and I as evidenced by the very strong positive correlations between the concentrations of elements in the fish muscles and the K_f for the respective fish (Table 3).

The mean concentration of Magnesium in water samples in this study was4.4µg/ml which conformed to the maximum reference range of 4.0µg/ml magnesium in fresh water (Lenntech, 2014). Magnesium levels (7.23 ± 1.08 µg/ml, 7.55 ± 1.09 µg/ml) in two of the sampling sites (Table 4) were above the reference range. Mean Mg levels in fish muscles ranged between 1151 µg/g - 1718.3 µg/g (Figure 2). In a work by Mallick *et al* (2014) on fish (*Labeorohita Ham*) the content of Mg in the fish was low compared to that in the water medium. However, in this study the concentration of Mg in the fish was far above that in the water. The biomagnification factor for Magnesium was 264.1 – 394.2 (Table 5) which was far greater than the biomagnification factor of 10.79 reported by Stanek (2012) for Mg in perch muscle. The main route for magnesium uptake is the intestines through food, with the gills as a secondary route taking up magnesium from the surrounding water (Bijvelds et al, 1998).

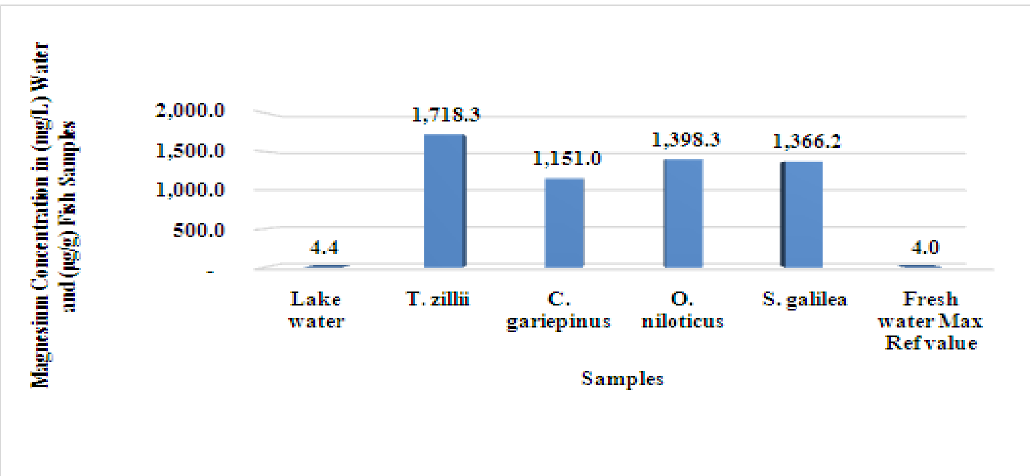

Figure 2: Mean Mg concentrations in water and in muscles of four fish species from the Weija Lake

Mean Calcium concentration in water samples was4.2μg/ml with mean levels in fish muscles of 1215.9 µg/g - 7666.8 µg/g (Figure 3). Biomagnification of calcium in fish muscles was 288.9 - 1821.8 which was far greater than biomagnification factor of 4.38 reported by Stanek (2012) for perch muscle. Calcium levels at four sampling sites as well as the mean level from all six sites (Table 4) exceeded the reference range of 1 – 2 µg/ml (Lenntech, 2014). Calcium uptake in fish occurs through the gills and intestine. Tilapia regulates the intake of calcium from calcium rich water by reducing calcium absorption through the intestine (Flik and Verbost, 1993).

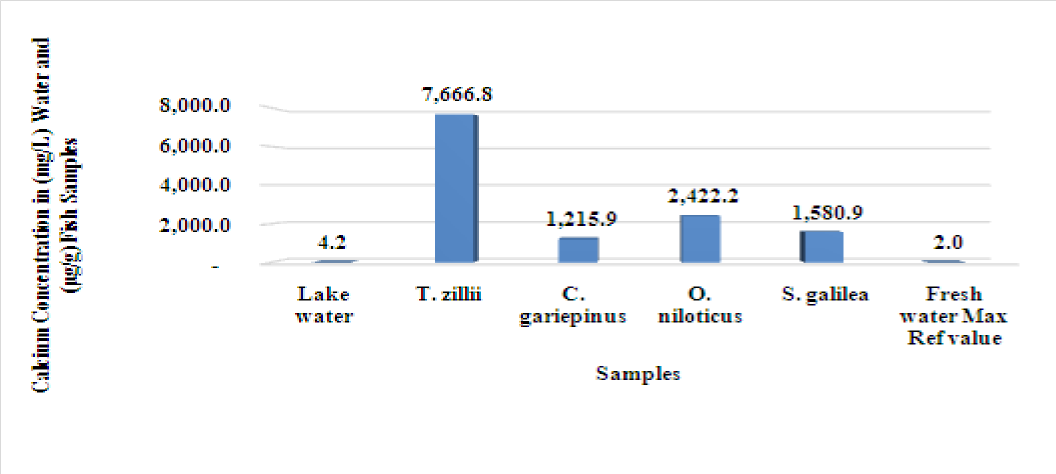

Figure 3: Mean Ca concentrations in water and in muscles of four fish species from the Weija Lake

The mean Sodium concentration in water samples was7.6µg/ml which was lower than the reference value of 9.0µg/ml for sodium in fresh water (Lenntech, 2014) and agreed with results of 7.6±0.712 - 7.2±2.002 reported by Mallick et al (2014). Sodium concentration at two sites in this study (Table 4) were above the reference value of 9.0µg/ml. Mean Sodium levels in fish muscles were 86,348.1 µg/g – 14,7248.1 µg/g (Figure 4) with biomagnification of 11,379.06 – 19,404.54 which was far greater than biomagnification factor of 29 reported by Stanek (2012) for perch muscle.

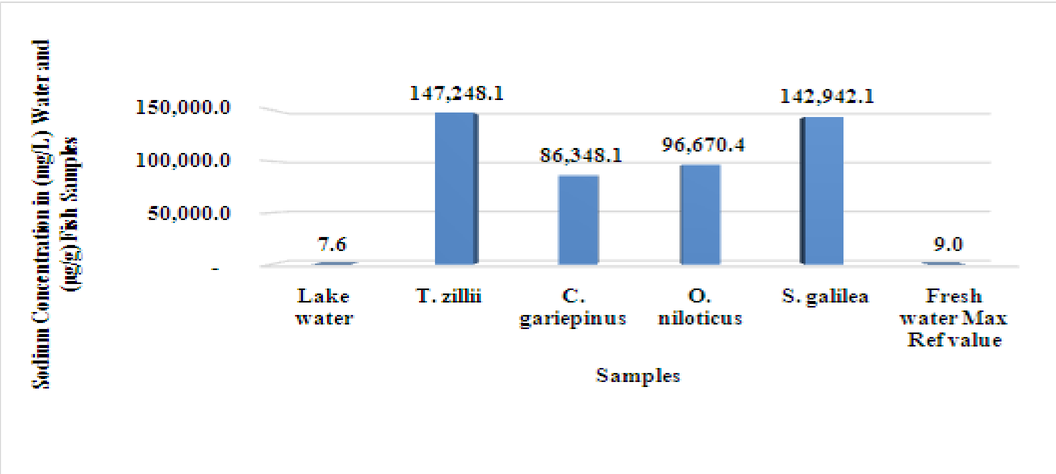

Figure 4: Mean Na concentrations in water and in muscles of four fish species from the Weija Lake

Potassium levels in fish muscles were 6932.1 µg/g - 202179.6 µg/g (Figure 5) with biomagnification of 2,355.2 - 68,690.7 (Table 5) which was far greater than biomagnification factor of 421.24 reported by Stanek (2012) for perch muscle. Potassium levels at all sampling sites (Table 4) as well as the mean concentration of 2.9µg/ml were below the reference value of ≤20 µg/ml for fresh water (Bartram and Ballance, 1996).

Chlorine levels in fish muscles were 1758.8 µg/g - 4010.3 µg/g (Figure 6). Chlorine concentrations in water from all sampling sites (Table 4) as well as the mean concentration of 6.0µg/ml from all sites were within the reference range of 1-250 µg/ml for fresh water (LEIEI, 2011). Biomagnification values for chlorine were 291.1 - 663.96 (Table 5). Increased intake of chlorine causes increased bromine excretion (WHO, 2009).

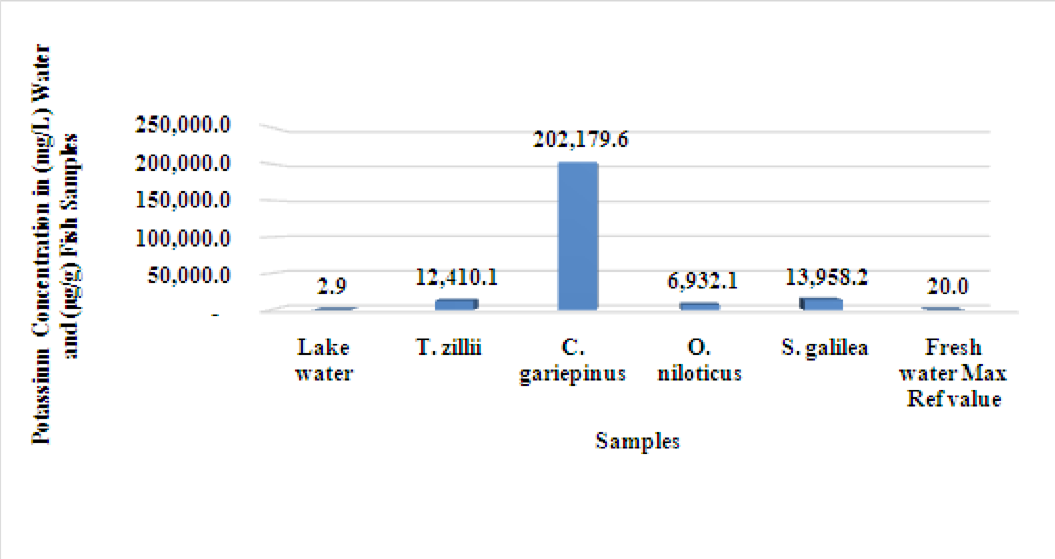

Figure 5: Mean K concentrations in water and in muscles of four fish species from the Weija Lake

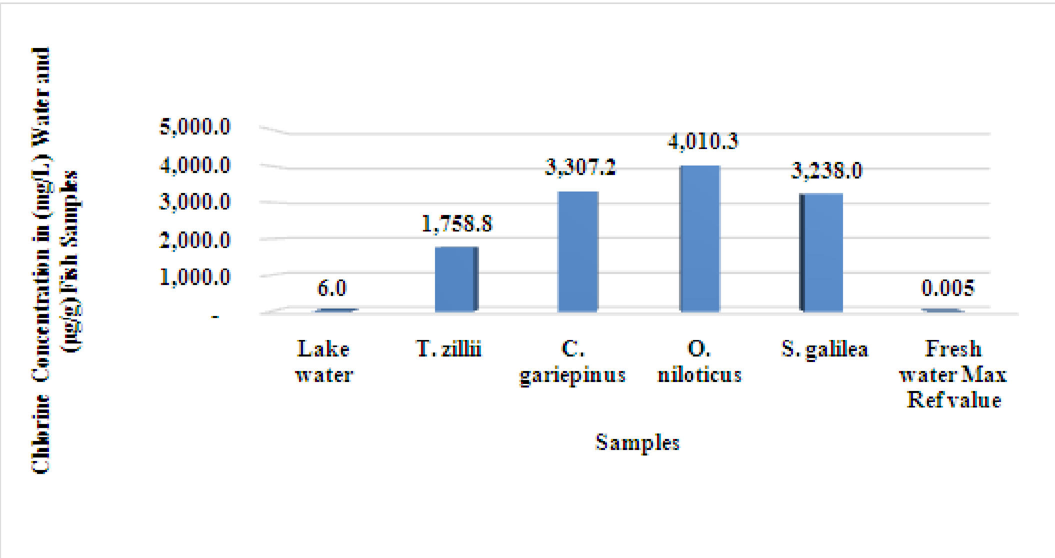

Figure 6: Mean Cl concentrations in water and in muscles of four fish species from the Weija Lake

Bromine levels in fish muscles were 717.2 µg/g - 2213.7 µg/g (Figure 7). Bromine levels from all the individual sampling sites on the lake (Table 4) as well as the mean concentration of 6.4µg/ml were far above the maximum reference range of 0.5 µg/ml for fresh water (WHO, 2009). Biomagnification values were 132.2 - 347.5 (Table 5).

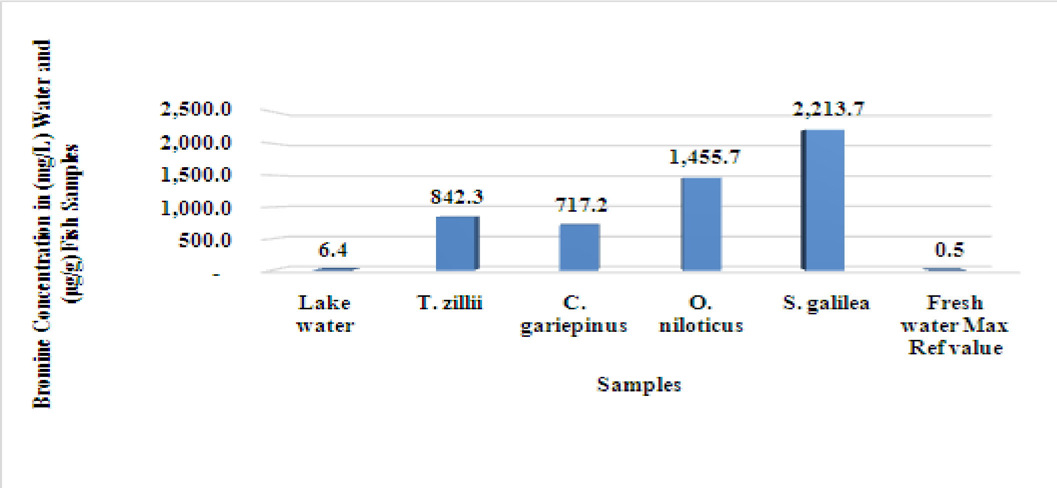

Figure 7: Mean Br concentrations in water and muscles of four fish species from the Weija Lake

The high levels of bromine in the lake could be from leaded fuel where it occurs as dibromoethane, and from pesticides and fertilisers (Flury and Papritz, 1993). Toxic levels of inorganic bromine from the food chain can damage the nervous system and the thyroid gland (Lenntech, 2014). Bromine competes with chlorine for uptake. Increased chlorine intake in the plasma results in reduced concentrations of bromine in the plasma (Flury and Papritz, 1993).

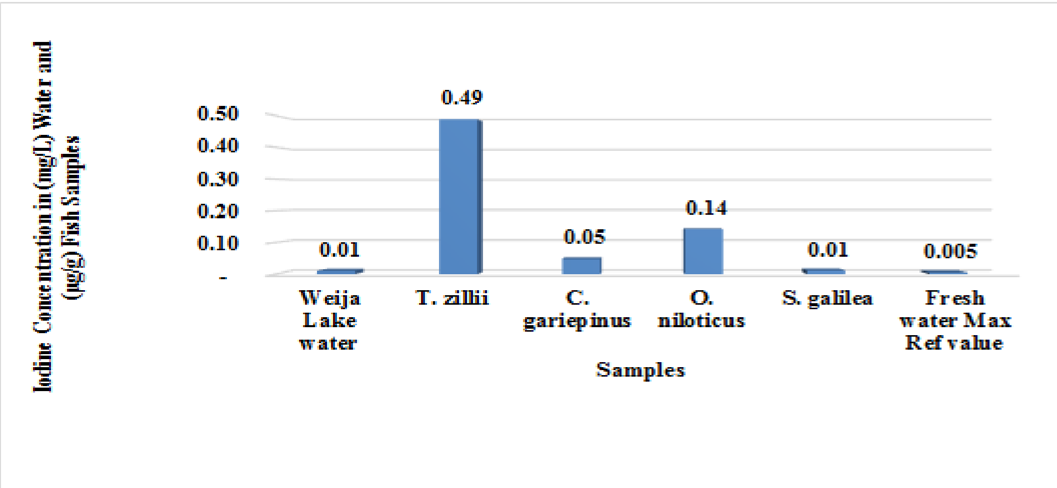

Figure 8: Mean Iodine concentrations in water and muscles of four fish species from the Weija Lake

Iodine concentrations of <0.01 µg/ml in water samples and concentrations of <0.01 µg/g – 0.49 µg/g in fish muscles (Figure 8) resulted in iodine biomagnification values of 1.0 - 49.0 in the fish muscles (Table 5). Iodine concentrations from all water samples conformed to the reference value of ≤0.005 µg/ml for fresh water (Lenntech, 2014). Iodine occurs naturally in water in the form of iodide I^- (WHO, 1996).

The concentrations of the elements in water did not differ significantly ($p \leq 0.05$) among the sampling sites. The order of concentrations of element in the water was Na > Br > Cl > Mg > Ca > K > I (Table 4). Generally, concentrations of Ca and Br were above the respective reference ranges of 1 – 2 µg Ca/ml and <0.5 µg Br/ml respectively (Table 4).

Table 4: Mean concentrations(µg/ml) of Mg, Ca, Na, K, Cl, Br, and I in water from the Weija Lake compared to reference ranges

Sampling sites	Elements						
	Mg	**Ca**	**Na**	**K**	**Cl**	**Br**	**I**
1	4.26 ± 0.62	2.38 ± 0.26	15.89 ± 0.11	3.05 ± 0.46	4.76 ± 0.71	6.17 ± 0.93	<0.01
2	7.55 ± 1.09	1.53 ± 0.13	1.70 ± 0.09	1.07 ± 0.12	8.33 ± 1.25	6.67 ± 1.01	<0.01
3	1.82 ± 0.25	0.68 ± 0.10	0.97 ± 0.03	0.88 ± 0.13	11.45 ± 1.72	7.21 ± 1.08	<0.01
4	3.63 ± 0.50	2.27 ± 0.14	4.24 ± 0.06	1.75 ± 0.26	0.19 ± 0.02	8.92 ± 1.34	<0.01
5	1.66 ± 0.24	15.14 ± 2.27	8.42 ± 1.26	6.27 ± 0.94	8.65 ± 1.29	5.32 ± 0.79	<0.01
6	7.23 ± 1.08	3.25 ± 0.49	14.31 ± 2.15	4.64 ± 0.69	2.87 ± 0.43	3.94 ± 0.59	<0.01
Mean ± SD	4.36 ± 0.29	4.21 ± 0.39	7.59 ± 0.42	2.94 ± 0.22	6.04 ± 0.44	6.37 ± 0.4	<0.01 ± 0
Reference ranges	4 µg/ml (Lenntech, 2014)	1 – 2 µg/ml (Lenntech, 2014)	9 µg/ml (Lenntech, 2014)	≤20 µg/ml (UNEP – WHO, 1996)	1 - 250 µg/ml (LEIEI, 2011)	≤0.5 µg/ml (WHO, 2009)	0.005 µg/ml (Lenntech, 2014)

Table 5: Bioaccumulation Factors (BAF) for elements in muscles of four fish species from the Weija Lake

	Elements						
	Na	**K**	**Cl**	**Mg**	**Ca**	**Br**	**I**
T. zillii	394.24	1821.82	19404.54	4216.34	291.18	132.23	49.00
C. gariepinus	264.09	288.93	11379.06	68690.69	547.54	112.59	5.00
O. niloticus	320.84	575.56	12739.35	2355.18	663.96	228.52	14.00
S. galilea	313.46	375.66	18837.09	4742.30	536.10	347.51	1.00
Mean ± SD	**323.16 ± 53.67**	**765.5 ± 714.37**	**15590.01± 4121.19**	**20001.13± 6735.02**	**509.7± 156.71**	**205.21± 107.55**	**17.25± 21.85**

There was a large variation in accumulation of the selected elements in the fish muscles. The order of bioaccumulation factors was K > Na > Ca > Cl > Mg > Br > I (Table 5). Bioaccumulation occurs when the level of uptake of an element exceeds that of elimination, and when the element can easily bind to tissues that have a high affinity for it (McGeer et al, 2004).

For each fish specie the concentrations of the elements in the muscles did not differ significantly ($p \leq 0.05$) among the individual samples. The order of concentrations of the elements in the muscles of the fish was Na > K > Ca > Cl > Mg > Br > I. In all four fish species the element with the lowest concentration was Iodine (Tables 6 – 9), while Sodium followed by Potassium were the elements with the highest concentrations.

Table 6: Mean concentrations (µg/g) of Mg, Ca, Na, K, Cl, Br, and I in muscles of *Tilapia zilli* from the Weija Lake

	Elements						
	Mg	**Ca**	**Na**	**K**	**Cl**	**Br**	**I**
T. zilli 1	1632 ± 244	7098 ± 1064	144569 ± 21685	11876 ± 1781	1036 ± 155	859 ± 128.11	0.07 ± 0.01
	1654 ± 248	7367 ± 1105	148920 ± 22338	12566 ± 1884	1087 ± 163	799 ± 119.12	0.08 ± 0.01
T. zilli 2	1478 ± 221	6098 ± 914	118765 ± 17814	9900 ± 1485	1036 ± 155	763 ± 114.03	0.01 ± 0.001
	1568 ± 235	6209 ± 931	123470 ± 18520	9908 ± 1486	1036 ± 155	672 ± 100.23	0.02 ± 0.003
T. zilli 3	1965 ± 294	8890 ± 1333	160087 ± 24013	14787 ± 2218	3271 ± 490	1006 ± 150	1.17 ± 0.18
	1992 ± 298	9047 ± 1357	170843 ± 25626	15097 ± 2264	5942 ± 891	909 ± 136.02	1.51 ± 0.17
T. zilli 4	1794 ± 269	8511 ± 1276	158865 ± 23829	13124 ± 1968	1517 ± 227	908 ± 136.12	1.17 ± 0.18
	1845 ± 276	8759 ± 1313	159908 ± 23986	13100 ± 1965	1538 ± 230	899 ± 134.11	1.51 ± 0.17
T. zilli 5	1589 ± 238	6800 ± 1020	137786 ± 20667	11094 ± 1664	1036 ± 155	777 ± 116.31	0.06 ± 0.01
	1595 ± 239	6905 ± 10365	138890 ± 20833	11703 ± 1755	1036 ± 155	775 ± 116.04	0.06 ± 0.01
T. zilli 6	1723 ± 258	8109 ± 1216	149985 ± 22497	12876 ± 1931	1202 ± 180	876 ± 131.14	0.09 ± 0.01
	1784 ± 267	8209 ± 1231	154889 ± 23233	12890 ± 1933	1368 ± 205	865 ± 129.04	0.11 ± 0.02
Mean ± SD	**1718.25 ± 74.56**	**7666.83 ± 922.31**	**147248.08 ± 6408.03**	**12410.08 ± 541.53**	**1758.75 ± 97.17**	**842.33 ± 36.52**	**0.49 ± 0.03**

Table 7: Mean concentrations (µg/g) of Mg, Ca, Na, K, Cl, Br, I and in muscles of *C. gariepinus* from the Weija Lake

	Elements						
	Mg	**Ca**	**Na**	**K**	**Cl**	**Br**	**I**
C. gariepinus 1	1334 ± 200	1401 ± 210	100567 ± 15085	100756 ± 15113	5839 ± 875	812 ± 121.21	0.17 ± 0.03
	1324 ± 198	1460 ± 219	102670 ± 15400	101768 ± 15265	6280 ± 942	885 ± 132.13	0.17 ± 0.03
C. gariepinus 2	1224 ± 183	1344 ± 201	90001 ± 13500	95043 ± 14256	4812 ± 721	743 ± 111.03	0.05 ± 0.01
	1269 ± 190	1352 ± 202	99870 ± 14980	90268 ± 13540	5076 ± 761	780 ± 117.21	0.06 ± 0.00
C. gariepinus 3	1213 ± 181	1212 ± 181	88056 ± 13208	79033 ± 11854	3686 ± 552	712 ± 106.33	0.03 ± 0.004
	1214 ± 182	1249 ± 187	89076 ± 13361	86742 ± 13011	4209 ± 631	743 ± 111.01	0.03 ± 0.004
C. gariepinus 4	1100 ± 165	1177 ± 176	82875 ± 12431	9081 ± 1362	2577 ± 386	690 ± 103.12	<0.01
	1145 ± 171	1178 ± 176	88032 ± 13204	9622 ± 1443	3271 ± 490	696 ± 104.30	<0.01
C. gariepinus 5	998 ± 149.11	1098 ± 164	77439 ± 11615	7904 ± 1185	1265 ± 189	657 ± 98.01	<0.01
	1005 ± 150	1145 ± 171	78904 ± 11835	8407 ± 1261	1903 ± 285	678 ± 101.12	<0.01
C. gariepinus 6	988 ± 148.01	980 ± 147.41	68032 ± 10204	7098 ± 1064	1067 ± 160	592 ± 88.32	<0.01
	998 ± 149.02	995 ± 149.22	70655 ± 10598	7709 ± 1156	741 ± 111.02	618 ± 92.34	<0.01
Mean ± SD	**1151 ± 50**	**1215.92 ± 52.91**	**86348.08 ± 3768.13**	**50285.92 ± 2847.02**	**3393.83 ± 166.64**	**717.17 ± 1.37**	**0.05 ± 0**

Table 8: Mean concentrations (µg/g) of Mg, Ca, Na, K, Cl, Br, and I in muscles of *O. niloticus* from the Weija Lake

	Elements						
	Mg	**Ca**	**Na**	**K**	**Cl**	**Br**	**I**
O. niloticus 1	1508 ± 226	2890 ± 433	111745 ± 16761	8437 ± 1265	6292 ± 943	1674 ± 251	0.36 ± 0.05
	1604 ± 240	3009 ± 451	113064 ± 16959	8167 ± 1225	6389 ± 958	1710 ± 256	0.78 ± 0.12
O. niloticus 2	1494 ± 224	2509 ± 376	103087 ± 15463	7645 ± 1146	5783 ± 867	1506 ± 225	0.15 ± 0.02
	1503 ± 225	2588 ± 388	103756 ± 15563	7327 ± 1099	5909 ± 886	1593 ± 238	0.32 ± 0.05
O. niloticus 3	1433 ± 214	2407 ± 361	100876 ± 15131	7321 ± 1098	5076 ± 761	1488 ± 223	<0.01
	1490 ± 223	2499 ± 374	99456 ± 14918	7248 ± 1087	5588 ± 838	1500 ± 225	0.02 ± 0.003
O. niloticus 4	1344 ± 201	2284 ± 342	94523 ± 14178	6541 ± 981	3855 ± 578	1390 ± 208	<0.01
	1366 ± 204	2386 ± 357	96354 ± 14453	6453 ± 967	4414 ± 662	1483 ± 222	<0.01
O. niloticus 5	1288 ± 193	2177 ± 326	86065 ± 12909	6326 ± 948	1036 ± 155	1303 ± 195	<0.01
	1295 ± 194	2232 ± 334	89055 ± 13358	6132 ± 919	2755 ± 413	1385 ± 207	<0.01
O. niloticus 6	1199 ± 179	1998 ± 299	77632 ± 11644	5945 ± 891	130.4 ± 19.12	1197 ± 179	<0.01
	1256 ± 188	2087 ± 313	84432 ± 12664	5643 ± 846	896.4 ± 134	1239 ± 185	<0.01
Mean ± SD	**1398.33 ± 60.63**	**2422.17 ± 105.5**	**96670.42 ± 4210.01**	**6932.08 ± 302.3**	**4010.32 ± 197.38**	**1455.67 ± 63.24**	**0.14 ± 0.01**

Table 9: Mean concentrations (µg/g) of Mg, Ca, Na, K, Cl, Br, and I in muscles of *S. galilea* from the Weija Lake

	Elements						
	Mg	**Ca**	**Na**	**K**	**Cl**	**Br**	**I**
S. galilea 1	1178 ± 176	1292 ± 193	115673 ± 17350	11954 ± 1793	863.2 ± 129.04	1842 ± 276	<0.01
	1198 ± 179	1321 ± 198	125643 ± 18846	12674 ± 1901	1351 ± 202	1977 ± 296	<0.01
S. galilea 2	1262 ± 189	1467 ± 220	128653 ± 19297	12845 ± 1926	1493 ± 223	2013 ± 301	<0.01
	1267 ± 190	1497 ± 224	132578 ± 19886	12934 ± 1940	1697 ± 254	2022 ± 303	<0.01
S. galilea 3	1278 ± 191	1516 ± 227	137684 ± 20652	13110 ± 1966	1821 ± 129	2030 ± 304	<0.01
	1327 ± 199	1534 ± 230	139734 ± 20960	13786 ± 2067	2300 ± 345	2060 ± 309	<0.01
S. galilea 4	1373 ± 205	1564 ± 234	145327 ± 21799	13876 ± 2081	2328 ± 349	2135 ± 320	<0.01
	1445 ± 216	1632 ± 244	148934 ± 22340	14793 ± 2218	2416 ± 362	2245 ± 336	<0.01
S. galilea 5	1452 ± 217	1703 ± 255	152331 ± 22849	14834 ± 2225	5812 ± 871	2372 ± 355	<0.01
	1473 ± 220	1720 ± 258	153473 ± 23020	15004 ± 2250	6092 ± 913	2512 ± 376	<0.01
S. galilea 6	1549 ± 232	1824 ± 273	163452 ± 24517	15234 ± 2285	6193 ± 928	2645 ± 396	<0.01
	1592 ± 238	1901 ± 285	171823 ± 25773	16454 ± 2468	6490 ± 973	2711 ± 406	0.02 ± 0.003
Mean ± SD	**1366.17 ± 59.25**	**1580.92 ± 68.77**	**142942.08 ± 6225.76**	**13958.17 ± 606.76**	**3238.02 ± 165.84**	**2213.67 ± 96.41**	**0.01 ± 0**

The strong negative correlations between fish lengths and concentrations of Mg, Ca, Na, K, Cl, Br, and I respectively in fish muscles (Table 10) showed that longer fish had correspondingly lower concentrations of the elements in their muscles. This agreed with the findings of Stanek (2012) that Na, K, and Mg concentration in the meat of perch decreased as fish body length increased.

Table 10: Correlation between individual fish lengths and concentrations of elements in muscles of four fish species from the Weija Lake

	Elements						
	Mg	**Ca**	**Na**	**K**	**Cl**	**Br**	**I**
T. zillii	-0.52	-0.60	-0.57	-0.55	-0.25	-0.54	-0.25
C. gariepinus	-0.92	-0.83	-0.82	-0.59	-0.9	-0.82	-0.71
O. niloticus	-0.91	-0.88	-0.87	-0.93	-0.82	-0.86	-0.84
S. galilea	-0.84	-0.87	-0.89	-0.86	-0.79	-0.81	-0.58

Strong negative correlations results were also obtained in this study between fish weights and concentrations of the elements in fish muscles (Table 11).

The correlation results in this study support assertions by Canpolat (2013) that amounts of heavy metals in fish muscles depends on the weight and length of the fish, and also support the conclusions of Jezierska and Witeska (2006) and Damodharan and Vikram (2012) that concentrations of most metals in fish are inversely related to fish size.

Table 11: Correlation between individual fish weights and concentrations of elements in muscles of four fish species from the Weija Lake

	Elements						
	Mg	**Ca**	**Na**	**K**	**Cl**	**Br**	**I**
T. zillii	-0.97	-0.96	-0.94	-0.94	-0.76	-0.97	-0.93
C. gariepinus	-0.98	-0.94	-0.95	-0.65	-0.98	-0.93	-0.77
O. niloticus	-0.83	-0.78	-0.88	-0.81	-0.94	-0.88	-0.47
S. galilea	-0.90	-0.89	-0.92	-0.92	-0.80	-0.83	-0.49

Table 12: Correlations between concentrations of elements in water and in muscles of four species of fish from the Weija Lake

	Elements						
	Mg	**Ca**	**Na**	**K**	**Cl**	**Br**	**I**
T. zilli	-0.43	-0.37	0.03	-0.22	0.53	0.30	NC
C. gariepinus	0.06	-0.36	-0.15	-0.05	0.18	0.37	NC
O. niloticus	0.06	-0.38	-0.11	-0.54	0.27	0.47	NC
S. galilea	0.08	0.40	0.14	0.62	-0.11	-0.63	NC

NC – No Correlation

Mg, Ca, Na, K, Cl, Br, and I concentrations in water correlated very weakly with concentrations in fish muscles (Table 12). This showed that concentrations of the elements in the water at a particular time of the season was not a good indicator of the concentrations of the elements in the fish muscles which had bioaccumulated over several seasons.

Table 13: Comparison of Estimated Average Daily Intake (EADI) (µg/day) of Mg, Ca, Na, K, Cl, Br, and I from consumption of four fish species from the Weija Lake to recommended ADIs

	Elements						
	Mg	**Ca**	**Na**	**K**	**Cl**	**Br**	**I**
T. zilli	117,688.40	525,125.60	10,085,485.20	850,005.70	120,462.30	57,693.80	33.6
C. gariepinus	78,835.60	83,282.00	5,914,252.30	13,847,916.70	226,517.80	49,121.20	3.4
O. niloticus	95,776.30	165,901.80	6,621,261.40	474,800.20	274,679.50	99,703.40	9.6
S. galilea	93,573.10	108,282.00	9,790,553.70	956,038.80	221,782.20	151,621.20	0.7
Recommended ADI for 70Kg man	310,000 – 420,000 µg (Driskell, 2009)	1,000,000 – 1,200,000 µg (Driskell, 2009)	1,200,000 – 1,500,000 µg (Driskell, 2009)	4,700,000 µg (Driskell, 2009)	1,800,000 – 2,300,000 µg (Driskell, 2009)	24,000 µg (WHO, 2009)	150 µg (Driskell, 2009)

Calculations of the estimated average daily intake (µg/g) of metals are based on the estimated average per capita consumption of 25kg fish in Ghana (Global fish Alliance, 2005) and the average concentrations of metals detected in fish muscles in this study.

The Estimated Average Daily Intake (EADI) range for Na from the four fish species from the Weija Lake was 6,621,261.4 µg – 10,085,485.2 µg (Table 13) and this was above the recommended ADI of 1,000,000 µg – 1,200,000 µg Na (Driskell, 2009). Similarly the EADI range for Br from the four fish species was 49,121.2 µg – 151,621.2 µg Br which was also above the maximum recommended ADI of 24,000 µg Br (WHO, 2009). The EADI for the remaining elements were within the respective recommended ADI's with the exception of the EADI of 13,847,916.7 µg K from *C. gariepinus* which was above the recommended ADI of 4,700,000 µg for K (Driskell, 2009).

Conclusions

Magnesium, Calcium, Sodium, Potassium, Chlorine, Bromine, and Iodine pollution of the Weija Lake in Ghana was assessed by using Neutron Activation Analysis to determine the concentrations of these elements in the muscles of four fish species as well as water from the lake. The results indicated unsafe levels of Sodium and Bromine pollution of the lake, but safe levels of Magnesium, Calcium, Potassium, Chlorine, and Iodine.

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