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Concentrations and Health Risk Assessments of Heavy Metals in Fish from the Fosu Lagoon

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ABSTRACT: Concentrations of Cu, Pb, Cr, Cd, Mn, Ni, Fe and Zn were determined in the muscle samples of *Sarotherodon melanotheron* from the Fosu Lagoon in Cape Coast using atomic absorption spectrophotometer. The results showed that, metal concentration in the fish muscle was in the order Mn > Zn > Fe > Pb > Ni > Cd > Cu > Cr. Mean concentrations of Pb and Cd in the fish exceeded the maximum tolerable limit set by the European Union. Although the mean concentrations of some metals exceeded this limit, their estimated daily intakes were below their oral reference dose recommended by the international regulatory bodies. Health risk assessment of consumers from the intake of metal contaminated in the muscle of *S. melanotheron* from the lagoon was evaluated by using Health Risk Index (HRI) calculations. In this study, the total HRI through consumption of fish calculated by adding the individual HRIs was less than 1, indicating that there is no significant potential health risk associated with the consumption of fish from the Fosu Lagoon.

Key words: Estimated Daily Intakes, Fish, Health Risk, Heavy metals, Pollution

INTRODUCTION

Heavy metals such as Cr, Mn, Co, Cu, Fe and Zn play important biochemical roles in the life processes of many organisms, and their presence in trace amounts are essential. However, at high concentrations toxic effects are observed. For example Fe is required for the production of red blood cells but at high concentrations Fe and Mn can cause pathological events such as the iron oxides deposition in Parkinson's disease (Matusch *et al.,* 2010; Altamura and Muckenthaler, 2009). Excess Cu had been associated with liver damage and Zn may produce adverse nutrient interactions with Cu. Also, Zn reduces immune function and the levels of high density lipoproteins (Spears, 2000). Ni helps form enzymes that are needed in the formation of nucleic acids and DNA, but highly toxic at high concentration. It can cause gastrointestinal distress, increase red blood cells and reduce lung functions (Lu *et al.,* 2005). Other metals such as Pb and Cd are toxic even at low concentration and are not known to have any important biological properties in humans. Pb is known to induce renal tumours, reduce cognitive development, and increase blood pressure and in adults. Other symptoms of Pb toxicity include gastrointestinal disorders and some liver impairment. Cd may induce kidney dysfunctions, osteomalacia and reproductive deficiencies. It can also cause damage to the central nervous system and produce psychological disorder (Strömgren, 1998).

Heavy metals pollution in water bodies has become a major water quality issue in many fast growing cities over the last few decades. This is because heavy metals pose threats to public water supplies and can also cause health hazard to human consumption of fish resources (Akoto *et al.,* 2008; Terra *et al.,* 2007). Metals enter rivers and lakes from a variety of sources, such as rocks and soils that are directly exposed to surface waters, fallout of atmospheric particulate matter, and from man's activities, including the discharge of treated and untreated wastes into water bodies. Excess amounts of these metals entering into the aquatic ecosystem may pollute the environment and also affect the food chain and ultimately pose serious human health risks to those who depend directly or indirectly on the water

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body for the supply of fish and water (Weldegebriel *et al.,* 2012).

Fish is an important source of protein for humans. Fish provides essential fatty acids that reduce the risk of stroke and heart diseases. It contributes to lower cholesterol levels in blood and provides vitamins and minerals (Al-Busaidi *et al.,* 2011). Moreover, fish are at the top of the aquatic food chain, and can accumulate both essential and toxic metals which they absorb from contaminated sediments and water through their gills and skin as well as from organisms which are consumed by the fish (Saha and Zaman, 2012; Hadson, 1988). High concentrations of heavy metals in fish cause mutation of inner organs, disturb immune reactions and reduce their adaptation qualities and resistance to diseases (Staniskiene *et al.,* 2006).

Consumption of fish is the main route through which aquatic pollutants such as heavy metals in this context, enter into the food chain and finally into the human system (APHA, 1981). In recent years, there has been an increasing interest in the utilization of fishes as bioindicators, of the integrity of aquatic environmental systems (Fausch *et al.,* 1990). The response of fish to environmental change makes it suitable for use as an indicator for environmental pollution. Fish is again a good bioindicator because it is easy to obtain in large quantities and has the potential to accumulate metal (Batvari *et al.,* 2007). The rate of heavy metals intake by fish in polluted environment depends on a variety of factors such as the exposure periods, concentration of the element and ecological factors such as pH, temperature changes and salinity. Fish raised in contaminated waters take up heavy metals in large quantities enough to cause potential health risks to the consumers (Copat *et al.,* 2012). The Fosu lagoon serves as a source of fish for the people of Cape Coast and has been intensively exploited for hundreds of years. Fish caught from the lagoon serves as a source of livelihood and food for the inhabitants. Report indicates that the lagoon is highly polluted and therefore all fishing and recreational activities must stop.The lagoon is contaminated because wastes generated from human activities in the area, including metal fabrication, auto garage services and farming, are deposited in the lagoon. These activities are sources of toxic metals and other chemicals which pollute the ecosystems.

Analysis of fish muscle helps to determine the direct transfer of heavy metals and other contaminants to humans via fish consumption. This study presents a data on concentrations of some heavy metals in muscle of *Sarotherodon melanotheron*, commonly known as the black chin tilapia, the most abundant and widely distributed fish species in the Fosu lagoon**.** The main objective was to evaluate the potential health risks associated with heavy metals via consumption of fish from the lagoon using the estimated daily intake (EDI) and health risk index (HRI) from single and combined heavy metals. *Sarotherodon* species appear to have great economic and ecological importance but its population has drastically declined because of environmental degradation due to human activities along the banks of the lagoon.

MATERIALS & METHODS

The Fosu lagoon is located in the of Cape Coast Municipality, a coastal city in the Central Region of the Republic of Ghana with geographical coordinates of 5° 6' 0'' North, 1° 15' 0'' West. The soils of the municipality are generally lateritic and are derived from the weathered granite and schist. The soil profile shows a topsoil of about 0.33 m (Armah and Amlalo, 1998). The Municipality has double maxima rainfall with mean values of 750 mm and 1000 mm. The major rainy season occurs between May to July and the minor around September to October. Cape Coast is a humid area with mean monthly relative humidity varying between 75% and 85%. The sea breeze has a moderating effect on the local climate **(**Gilbert *et al.,* 2006). The present vegetation of the municipality consists of shrubs of about 1.5 m high, grasses and a few scattered trees. The major economic activity in Cape Coast is fishing (Bannerman *et al*; 2001). Other economic activities that can be located in the settlements along the bank of the lagoon are automobile servicing garages, palm kernel oil production and metal fabrication. Apart from these, there are lots of residential settlements very close to the lagoon. Wastes from these human activities flow directly into the lagoon without any prior treatment. Due to the polluted nature of the lagoon, the Fosu lagoon is now one of the water bodies with “Dead zones” (UNEP, 2006).

Fish samples were purchased from commercial catches from the Fosu lagoon in Cape Coast in the months of May and July 2011. The samples were wrapped in polyethylene bags, kept in an ice box and transported to the laboratory for analysis. The fish samples were weighed, body lengths measured and dissected with clean stainless steel scissors and forceps after they had been identified at the Department of Freshwater and Fisheries Management, KNUST. The muscles were chopped into small pieces before air drying and then dried in an oven at 80 °C until a constant weight was obtained. The dried samples were pounded into fine powder and stored in desiccators in the dark until digestion. 1.0 g of these samples were digested with 6.0 mL of 60% HNO_3 and 3.0 mL of 35%

H_2O_2 (all analytical grade from Kanto Chemical Corp. Japan) in digestion tubes. Microwave digestion system (Speed wave MWS-2, Berghof) equipped with a temperature and pressure feedback control was used to digest the samples. After digestion, the samples were cooled and filtered through ashless filter paper 5B into 10 mL screw-capped polypropylene tubes and topped to the mark using 2% HNO_3. 0.1 mL of Lanthanum chloride (analytical grade, 100 gLa/L) from WAKO Chemical Industries was added to the filtrate to prevent chemical, physical and ionization interference during metal analysis in the AAS. A reagent blank was prepared by following the same procedure. Concentrations of Cr, Fe, Cu, Ni, Zn, Pb, Cd and Mn were measured with Atomic Absorption Spectrometer (AAS, Z-2010). Cu, Fe and Zn were determined using acetylene flame whiles Cr, Mn, Cd, Pb and Ni were determined with a graphite furnace. For quality assurance, the samples were digested in triplicate along with blanks to minimize error. The instrument was calibrated with a series of standard solutions supplied by the manufacturer. All determinations were replicated three times. Recovery tests were performed for all the investigated metals in samples by spiking with aliquots of the metal standards and then carrying out digestion. The overall recovery rates (mean ± SD) of Fe, Ni, Cr, Cu, Zn, Pb, Cd and Mn were 94 ± 9.6, 95 ± 3.9, 97 ± 2.3, 90 ± 3.3, 91 ± 2.3, 88 ± 8.1, 90 ± 2.6 and 94 ± 6.2% respectively.

For the purpose of calculating the coefficient of condition, all fish samples were individually weighed (W) and the standard length (L) which is the length from the tip of the upper lip to the bending point of the caudal fin was measured. The coefficient of condition of fish is the length-weight relationship used to express relative plumpness or robustness of fish. This is in turn related to environmental conditions. Healthy fish are more plump or robust and have a higher coefficient of condition than unhealthy fish (Choongo *et al.*, 2005). The coefficient of condition (K) in fish was determined by the formula:

$$K = W \times \frac{10^5}{L^3}$$

Where: K = coefficient of condition, W = weight in grams, L = body length in millimeters

The exposure pathway of heavy metals to human through ingestion of contaminated food has been studied by many researchers (Copat *et al.*, 2012; Xue *et al.*, 2012; Chary *et al.*, 2008). The estimated daily intake (EDI) of each heavy metal in this exposure pathway was determined by the equation:

$$EDI = \frac{E_F \times E_D \times F_{IR} \times C_f \times C_m}{W_{AB} \times T_A}$$

Where E_F is the exposure frequency (365 days/ year); E_D is the exposure duration, equivalent to average lifetime (64 years for Ghanaian population); F_{IR} is the fresh food ingestion rate (g/ person/day), which was considered to be 48 g/person/day for fish (Ali and Hau, 2001); C_f is the conversion factor (0.208) for fresh weight (F_W) to dry weight (Dw.) C_m is the heavy metal concentration in foodstuffs (mg/kg Dw.); W_{AB} is the average body weight (bw) (average adult body weight was considered to be 75 kg); and T_A is the average exposure time for non-carcinogens (equal to $E_F \times E_D$) (Saha and Zeman, 2012).

Health risk of consumers due to intake of metal contaminated fish was assessed by using HRI. A HRI less than 1 means the exposed population is unlikely to experience obvious adverse effects; whereas a HRI above 1 means that there is a chance of non-carcinogenic effects, with an increasing probability as the value increases. The HRI was calculated by using the equation below (Wang *et al.*, 2005).

$$HRI = \frac{EDI}{R_fD}$$

Where reference oral doses (R_fD) for Cr, Cu, Zn, Fe, Ni, Pb, and Cd are 1.5x 10^{-3}, 4.0 x 10^{-2}, 3.0 x 10^{-1}, 7.0 x 10^{-1}, 2.0 x 10^{-2}, 3.5 x 10^{-3}, 1.4 x 10^{-1} and 1.0 x 10^{-3} mg/kg/ day respectively (USEPA, 2009).

It has been reported that exposure to two or more pollutants may result in additive and/or interactive effects. The total HRI of heavy metals for individual foodstuff was treated as the arithmetical sum of the individual metal HRI (Zheng *et al.*, 2007):

Total HRI (individual foodstuff) = HRI (toxicant 1) + HRI (toxicant 2) + . . . HRI (toxicant n)

All the data obtained in the study were analyzed using a statistical package SPSS 16.0 and subjected to statistical analysis of independent t test. Differences at the $P < 0.05$ level were considered significant.

RESULTS & DISCUSSION

Table 1 shows Concentrations, EDIs and HRIs of heavy metals in muscles of fish samples from the Fosu Lagoon (n = 20). The coefficient of condition (K) of the fish samples used in this work ranged from 1.43 to 1.93. There were no significant differences in K among the individual fish samples. This means that the length-weight ratio among the individual fish specimen used for the analysis were similar. In fisheries science, K is used to compare the health conditions of fish. It is

Table 1. Concentrations, EDIs and HRIs of heavy metals in muscles of fish samples from the Fosu Lagoon (n = 20)

Metals (mg/kg)	Range	Mean ± Std. Dev.	EDI	HRI
Fe	5.50 – 18.10	9.98±4.17	1.33x10^{-3}	1.90x10^{-3}
Cu	0.10 – 0.35	0.22±0.08	2.90x10^{-5}	7.25x10^{-4}
Mn	20.95 – 32.30	27.89±4.15	3.71x10^{-3}	2.65x10^{-2}
Cr	BDL	-	-	-
Ni	0.032 – 0.55	0.36±0.32	4.8 x10^{-5}	2.40 x10^{-3}
Pb	4.32 – 10.85	6.82 ± 2.28	3.04x10^{-4}	8.69x10^{-2}
Cd	0.17 – 0.32	0.275±0.47	3.70x10^{-5}	3.70x10^{-2}
Zn	18.25 – 23.15	20.66±1.51	2.75x10^{-4}	9.17x10^{-4}

∗BDL - below detection limit

based on the hypothesis that healthier fish of a particular length are in a better physiological condition (Barnham and Baxter, 2003). K is also a useful index for monitoring of feeding intensity, age, and growth rates in fish. It is strongly influenced by both biotic and abiotic conditions and can be used as an index to assess the status of the aquatic ecosystem in which fish live (Anene, 2005). Examining K values obtained in this study revealed that all the fish samples used in this exercise were in good health and under no form of stress in their habitat.

Summary of results of heavy metal concentration in the fish samples from the Fosu lagoon in Cape Coast is presented in Table 1. The results showed that all the fish samples contained some amount of Pb. The Pb concentration in the samples ranged from 4.32 mg/kg to 10.85 mg/kg with a mean value of 6.28±2.28 mg/kg. Excessive accumulation of heavy metals in food can result in serious systemic health problems in humans (Oliver, 1997). Therefore, the FAO, WHO, EU and other regulatory bodies of various countries have established the maximum permitted concentrations of heavy metals in foodstuffs (Xue *et al.,* 2012; Chary *et al.,* 2008). For example, the maximum tolerable limit (MTL) of Pb in fish meat by the EU is 0.3 mg/kg (EU, 2006). The concentrations of Pb in all the fish samples from the Fosu lagoon exceeded the maximum permitted limit. Other researchers have also reported similar levels of Pb in fish muscles. For example, Staniskiene *et al.,* (2006) reported Pb levels of 3.125 mg/kg in fish from the Obelija Lake in Lithuania. Copat et al (2012) also reported high levels of Pb in 3 different fish species in Sicily.

The maximum concentration of Cd reported in the fish muscle from the lagoon was 0.32 mg/kg and a minimum value recorded was 0.17 mg/kg with a mean value of 0.28±0.47 mg/kg. Variation in the concentrations of Cd in the fish samples was not significant. The amount of Cd found in the fish samples exceeded the limit (0.02 mg/kg) set by the EU in 87% of the fish samples analysed (EU, 2006). Pb and Cd are classified among the most toxic heavy metals which have no known biochemical benefits to animals and humans. Effects of Pb on fish include death and formation of veil-like film on the body and causes renal failure and liver damage in humans (Lee, 1977). The mean concentration of Pb, in the fish samples was above the FAO estimated limit of 0.5 mg/kg (FAO, 1983) for human health risk. Reported effects of Cd on fish include gill and kidney damage, poor bone mineralization and delayed growth (Muramoto, 1981). The main source of exposure of Cd in humans is through food consumption. Ingestion of high levels Cd, can lead to acute renal failure in humans (NAS-NRC, 1982). From the results, it can be predicted that consumption of fish from the lagoon by humans can lead to severe chronic Cd poisoning. Cadmium is known to be an endocrine disturbing substance and may lead to the development of prostate cancer and breast cancer in humans (Saha and Zaman, 2012). Mean Cd and Pb concentrations reported in this study were lower than those reported in some other studies elsewhere. Ahmed et al 2010, found Cd and Pb mean concentrations of 0.96±0.15 and 9.69±1.54 mg/kg respectively in fish muscles from Buriganga River, Bangladesh.

A number of studies have shown that Mn has considerable biological significant; it helps prevent cardiac arrest, heart attack, and stroke. But it is quite toxic at high concentrations. Acute toxicity to humans is manifested by a psychologic and neurologic disorder (Saha and Zaman, 2012). Concentration of Mn in the fish muscles ranged from 20.95–32.30 mg/kg with a mean value of 27.89±4.15 mg/kg. Manganese content in the examined fish samples was lower than that reported by Begum et al. (2005) in Dhamondi Lake, Dhaka, Bangladesh (8.8–23.5 µg/g) and 0.59–11.74 µg/g in Lake Tanganyika, Tanzania (Chale, 2002).

Cr is an essential trace element in humans and some animals but in excess, it could have undesirable lethal effect on fish and wildlife (Akan *et al*., 2009). The maximum guideline, 12–13 mg/kg, stipulated by the United States Food and Drug Administration (USFDA, 1993) was however, higher than the concentrations of Cr measured in all the fish samples used in this study. Deficiency of Cr results in impaired growth and disturbances in glucose, lipid and protein metabolism.

Cu is an essential part of several enzymes and it is necessary for the synthesis of haemoglobin but can cause harm at high concentrations (McCluggage, 1991). Concentrations of Cu in the fish muscle were in the range 0.10–0.35 mg/kg with an average value of 0.22±0.08 mg/kg. FAO/WHO (2001) established limits for Cu in fish as 30.0 mg/kg for human health risk concerns. The concentrations of Cu in these samples were far below this value therefore regular consumption of fish with such low amounts of Cu could not lead to any serious health risk so far as Cu is concerned.

Zinc concentrations in all the fish species were extremely high as compared to the concentrations of other micronutrients that were considered in this study. The maximum concentration of Zn recorded in the samples was 23.15 mg/kg and the minimum concentration was 18.25 mg/kg as presented in Table 1. Concentrations of Zn in all the fish samples were below the FAO maximum guideline of 30 mg/kg of Zn for safe human consumption (FAO, 1983). These amounts of Zn in the tissues cannot cause harm to the fish themselves as well as humans who consume them. Zn is an essential trace metal for both animals and humans. Zn toxicity is rare but, at concentrations up to 40 mg/kg, Zn may induce toxicity, characterized by symptoms of irritability, muscular stiffness and pain, loss of appetite, and nausea (NAS-NRC, 1974).

Ni recorded very low concentrations in all the fish samples relative to the other essential metals. The mean concentrations of Ni in the fish samples ranged from 0.032 to 0.550 mg/kg. The estimated maximum guideline (USFDA, 1993) for Ni is 70–80 mg/kg. Thus, the concentrations of Ni in all the samples were far below the stipulated limit. Concentrations above the set limit can cause cancer of the lung and nasal cavity (USFDA, 1993).

Iron is a mineral essential for life. It is present in every living cell and is necessary for the production of hemoglobin, myoglobin, and certain enzymes. Fe deficiency can cause weakness, inability to concentrate and susceptibility to infection. According to the World Health Organization, iron deficiency anemia is one of the most common nutrient deficiencies in the world (Anderson and Fitzgerald, 2010). Concentration of Fe in the fish samples ranged between 5.50 - 18.10 mg/kg with a mean concentration of 9.98 ± 4.17 mg/kg. The high concentration of Fe in the fish samples makes the fish a good source of Fe in the diet of consumers.
The average EDI of heavy metals in fish consumption from the Fosu Lagoon is given in Table 2.

The mean intakes of Fe, Cu, Mn, Zn, Pb, Cd, and Ni were 1.33 x10^{-3}, 2.90 x 10^{-5}, 3.71 x 10^{-3} and 2.75 x 10^{-4}, 3.04 x10^{-4}, 3.70 x 10^{-5} and 4.80 x 10^{-5} mg/kg bw/day, respectively. Mean EDIs of the individual heavy metals in the fish muscle from the Fosu Lagoon were far below R_fD values recommended by the international regulatory bodies (USEPA, 2009). The R_fD represents an estimation of the daily exposure of a contaminant to which the human population may be continually exposed over a lifetime without an appreciable risk of harmful effects. Even though the concentration of Pb and Cd found in fish muscles were above the limit set by European regulation, these metals do not pose a risk to human health since the EDIs calculated for these metals were far below the RfD values. But there is the need for a continuous monitoring of contamination level of these metals especially Pb and Cd since they can accumulate to toxic levels. This will help to detect any change in their accumulation pattern that could become a hazard to human safety.

Result of health risk assessments (HRI) of the various heavy metals considered in this study is presented in Table 1. The results indicate that there is no HRI value > 1, indicating that humans would not experience any significant health risk if they only consume metals from this species of fish from the Fosu Lagoon. Among the heavy metals examined in this study, Pb with a HRI value of 8.69 x 10^{-2}, would have a relatively higher potential health risk, whiles Cu (HRI = 7.25 x 10^{-4}) has the lowest potential health risk.

Reports have it that exposure to more than one contaminant may produce an additive effect on the organism. In this study, the total HRIs of the individual metals examined in the fish muscle samples was calculated by adding the individual HRIs of the metals. The total HRI through the consumption of fish was less than 1, indicating that there is no potential significant health risk associated with the consumption of fish from the Fosu Lagoon. Pb and Cd were the major health risk contributors, accounted for 55% and 23% respectively of the total HRIs in the study.

Distribution of pollutants among the various organs within an organism is not uniform but rather they accumulate in specific target organs (Terra et al, 2007). Gonads, liver, kidney and gills, are target organs for heavy metals accumulation in fish that can lead to pathological changes than the muscle tissues (Yilmaz, 2003). According to Allen-Gil and Martynov (1995) the low levels of binding proteins in the fish muscle may account for their low concentrations of heavy metals. Cinier et al. (1999) found that Cd accumulation in carps kidney and liver higher than in muscle, they also found that the loss of accumulated Cd was rapid and immediate in muscle and no loss of Cd was observed in kidney and liver. It can therefore be stated that levels of heavy metals is fish muscle cannot necessarily represent the real impact of metal contamination icthtyofauna. In order to assess possible pathological changes on the fish species due to heavy metal contamination, it is recommended that metals concentrations in other organs such as liver, gills and kidney mush be studied.

CONCLUSION

In this study, heavy metals content in the muscle of *S. melanotheron* from the Fosu Lagoon have been analysed. According the results, mean concentrations of Pb and Cd were above the maximum recommended values by the EU. The samples vary widely in their heavy metal contents, but the estimated daily intake if the various metals in the samples were below their respectively recommended limits. from the health point of view of consumers, the HRI values for the individual metals showed that there was no health risk for humans due to the intake of individual heavy metals in the fish from the lagoon. Again total HRI on humans due to the combined effect of all the metals considered in the study was also less than 1, which signifies that potential health risk for consumption of fish is insignificant.

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