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Monitoring exposure to heavy metals among children in Lake Victoria, Kenya: Environmental and fish matrix

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ABSTRACT

This study used hair and nails to biomonitor heavy metals (Pb, Cd, Cr and Cu) from geological source and exposure through regular fish consumption among children in Lake Victoria, Kenya. Concentration of Pb and Cu in water reflected anthropogenic pathways, while Cd and Cr reflected accumulation from the catchment basin. Higher concentration of heavy metals in the nails samples than the hair samples suggested longer term exposure. The estimated intake of Cd and Cr from fish in one site associated with high concentration of the metals from geological source was appreciably above the respective recommended daily allowance, signifying possible health risks to humans. Significant correlations between Pb, Cd and Cu in hair, nails and heavy metals from fish consumed suggested fish consumption as possible pathway of heavy metals in humans. Possible health risks from heavy metals were likely due to consumption of higher quantities of fish and from geological basins.

1. Introduction

Heavy metals such as lead (Pb), cadmium (Cd), chromium (Cr) and copper (Cu) occur naturally in water, soil and biota. Their concentrations depend on local geology, local addition from mining and industry and/or globally distributed pollution (Cui et al., 2004; 2005; Zheng et al., 2007a; Khan et al., 2008; Hang et al., 2009). Elevated levels of these heavy metals in the environment may arise from natural or anthropogenic routes (Wilson and Pyatt, 2007; Zheng et al., 2007b), including consumption of food from contaminated environments (Airey, 1983; Wang et al., 2005; Zheng et al., 2007b; Sridhara et al., 2008; Whyte et al., 2009; Zhuang et al., 2009; Metian et al., 2009). The increasing demand of environmental and food safety has stimulated research regarding the risk associated with environmental exposure and consumption of foods contaminated by heavy metals (D'Mello, 2003).

In the background of the growing interest of public health concerns of human exposure to pollutants is the simple fact that the total extent of environmental pollution is often difficult to assess, based on the concentration of the pollutants in the environmental media (Evans and Jervis, 1987) and diet (Robson, 2003) only. Analyses of human biomarkers have been used to demonstrate criminal, nutritional status, occupational or environmental exposure to toxic elements (Jenkins, 1977; Suzuki et al., 1988; Nowak, 1994; Samanta et al., 2004; Were et al., 2008). The use of human hair as a tool of choice for monitoring the exposure to heavy metals in man is linked with the availability of suitable analytical procedures, sensitive enough to quantify the content of the respective element in the biological specimen tested. Since concentration of metals in human hair reflects their mean level in human body during a period of 2–5 months (Aharoni and Tesler, 1992), its use is far from being the universal tool for monitoring longer exposures to environmental pollutants. Nail analysis becomes a useful alternative for longer exposure period ranging between 12 and 18 months (Suzuki et al., 1988; Wilhelm and Hafner, 1991; Hayashi et al., 1993; Chen et al., 1999; Were et al., 2008). The element content of hair and nails tends to vary from one geographical region to another, depending on the natural background conditions, including composition of soil, element concentration in water and food and eating habits (Eads and Lambdin, 1973; Chattopadhyay and Jervis, 1974; Hefferre, 1976; Teraoka, 1981). However, the simultaneous use of hair and nails for biological monitoring from fish consumption has not been studied fully for the correlation with the exposure levels. A full understanding of to what extent any observed variability of

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metals from fish consumption can predict metal variation in hair and nails is thus called for.

To this purpose, the concentration of four heavy metals (Pb, Cd, Cr and Cu) in the hair and nails samples of children aged 5 years in the coastal zone of Lake Victoria were analyzed as biomarker of short- and long-term heavy metal exposures through fish consumption. Normally, the levels of metals in water provide background concentrations of metals in the environmental media, where fish are caught. Previous studies have reported high levels of these heavy metals in water (Wandiga, 1981), bottom sediments (Wandiga et al., 1983; Onyari and Wandiga, 1989; Kishe and Machiwa, 2003; Mwamburi, 2003), which is likely to accumulate in fish. Beside, previous studies have reported elevated levels of heavy metals in fish in this lake (Birungi et al., 2007; Oyoo-Okoth et al., 2010) likely to cause heavy metal risk to fish consumers. The fish chosen in this study is a cyprinid fish, *Rastreneobola argentea*. It is one of the three productive fish species; others are *Oreochromis niloticus* and *Lates niloticus*. Being the cheapest, it is the main source of protein for millions of lake side communities (Wanink, 1999) as the other two species are exported to Europe. During the past eight years *R. argentea* has composed between 37% and 45% of the commercial fish catch (Manyala and Ojouk, 2007) and has constituted upto 70% of the food in the diet of most children in the coastal zone of Lake Victoria (Abila and Jansen, 1997). These children were considered to have less mobility and as such, heavy metal body burdens were expected to be derived mainly from the food consumption.

2. Materials and methods

2.1. Study areas and sampling sites

Lake Victoria, the second largest freshwater body in the world (area 68,800 km^2), is generally shallow (mean depth 40 m) and lies in a catchment of about 184,000 km^2. The lake lies astride the equator between latitude 2.5°S and 1.5°N and longitude 32° and 35°E (Lung'ayia et al., 2001) and is shared by three riparian states (Kenya, Tanzania and Uganda) (Fig. 1). Lake Victoria is fed by a number of large rivers in Kenya (Nzoia, Gucha-Migori, Sondu-Miriu, Mara, Yala, and Nyando), while the River Nile is the single outlet. The sites in the current study were chosen in Kenya based on the anthropogenic activity profiles along the coastal zones. Site 1 (Kisumu City) has a population of about 1.1 million and is the center of urban development with various industries and drainage of intense agriculture. Site 2 (Kendu-Bay) is a rural area with a population of about 40,000 and has light agriculture without fertilizer inputs. Site 3 (Karungu) has a population of 50,000 receiving drainage from light gold mines. Site 4 (Port Victoria) is a rural area with population of about 100,000 and the lake receives local inflow of water from River Nzoia that contains inputs of industrial effluents from two sugar factories and a paper mill factory situated about 100–150 km away from the Lake. Poverty levels are high in all the sampling sites, and therefore residents rely mostly on consumption of cheap sources of a cyprinid fish, *R. argentea* caught from the lake by local fishermen.

2.2. Sampling design and procedure

The sample consisted of 49 children aged below 5 years, who live at the shores of Lake Victoria, Kenya. The Helsinki 1996 protocols, which underline appropriate ethical considerations for studies involving human volunteer participants were followed and permission to carry out this study granted by the Moi University Institute of Ethical Research Committee (IREC). Hair was cut from the upper region at the back of the head, using stainless steel scissors. At least 0.5 g sample was collected. Fingernail samples were collected, using stainless steel nail clippers. The samples were stored in pre-washed polyethylene containers.

Only adult fish were sampled for this study first, because they are the ones normally consumed by the locals and immature fish cannot be captured by the local fishermen due to mesh size regulations. A total of 125 fish samples were obtained from local fisherman on two sampling occasions in June 2006 from the sites S1, S2, S3 and S4, using a beam trawl with 5 mm stretched mesh; fish was attracted in the night by luminescence and captured at the water surface. The information on the catch data is presented in Table 1. Fish were weighed (to the nearest 0.1 g) and measured (folk length in millimeters). The fish were bagged, kept in cool boxes at 0 °C and immediately transported to the laboratory for metal analysis, using metal-free techniques in the Netherlands at the Department of Earth Surface Processes and Materials at the University of Amsterdam. The duration of transport was about 8 h.

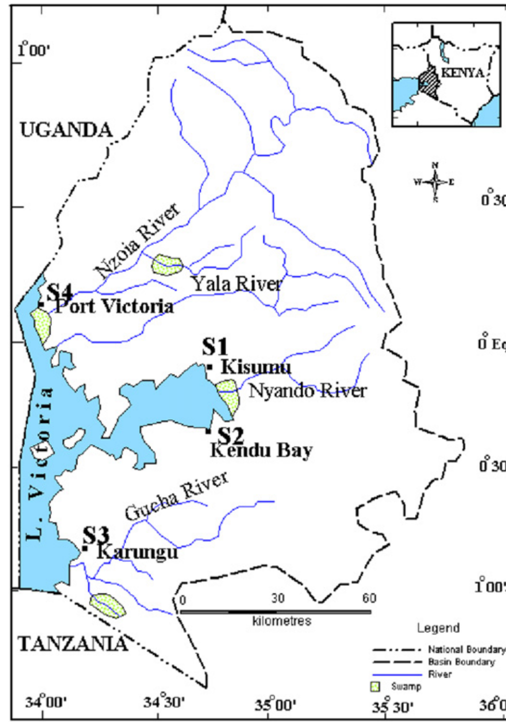

Fig. 1. Map of Lake Victoria basin (Kenya) showing the sampling sites.

Table 1
Data of the fish samples collected from the four sampling sites of Lake Victoria.

	Sampling sites			
	Site 1	Site 2	Site 4	Site 3
Number of fish	28	32	31	34
Sex ratio (M:F)	13:15	17:15	16:15	15:19
Mean length (mm)	36.5 ± 12.2	35.4 ± 17.2	37.1 ± 17.3	38.2 ± 22.1
Mean weight (mg)	0.49 ± 0.22	0.54 ± 0.64	0.61 ± 0.43	0.55 ± 0.32

Water samples were obtained from the same sites, where the fish were caught, about 2 m below the surface, using 3L Van Dorn bottle. The water samples were then transferred to half-litre polythene bottles pre-soaked in nitric and sulphuric acid solutions of 1:1 volume ratio, washed in 2 L of tap water and rinsed three times in ultra pure water and dried prior to the field work. The water samples were acidified to pH = 2 with concentrated nitric acid, placed into cool boxes and transported to the laboratory for chemical analyses in the Netherlands.

To determine the quantity of heavy metal intake per child per day of fish, the net fish consumption per day was estimated, using food frequency questionnaires. The weights of the children were determined, using standard beam balance to an accuracy of 0.1 kg. Based on the amount of fish consumed, the metal concentration in fish and body weight of the children, the estimated daily intake (EDI) of metal from fish was calculated, using the formula

$$EDI = \frac{C_{heavymetal} x W_{fish}}{B_w}$$

where $C_{heavymetal}$ (μg/g, on fresh weight basis) is the concentration of heavy metals measured in fish; W_{fish} represents the daily average consumption of fish among the children; B_w is the body weight. Comparison with recommended daily allowance (RDA) was undertaken for children, using a mean body weight of approximately 20 kg (NRC, 1989).

2.3. Preparation of nail and hair samples

Hair and nail samples were first washed with distilled water on a stirrer for 15 min in a beaker, and then washed with acetone-water-water-water-acetone as recommended by the International Atomic Energy Agency (IAEA, 1985). The washed samples were placed in glass beakers and individually allowed to dry at