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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

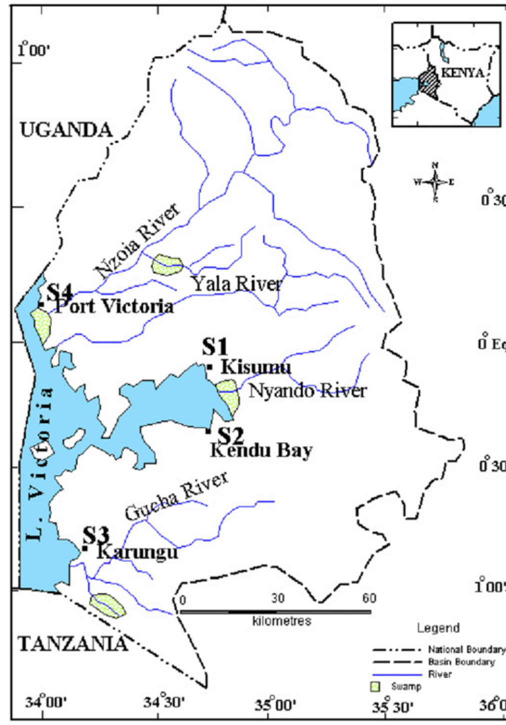

Fig. 1. Map of Lake Victoria basin (Kenya) showing the sampling sites.

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

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.

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

50 °C overnight in a drying oven. Before washing the hair and nail samples, any visible dirt on the surface of the nails were thoroughly washed using MilliQ water.

2.4. Metal analysis

All samples were analyzed in The Netherlands. The fish, hair and nail samples were crushed and homogenized, using a Fritsch, Pulverisette 5, planetary mill (Fritsch GmbH Laborgerate, Idar-Oberstein, Germany) for 5 min at 400 rpm. Water samples were not treated through this procedure. About 0.2000 g of fish, hair and nail samples and about 25 ml of water were accurately weighed in Telflon (© poly-tetra-fluor-etheen (*PTFE*), DuPont™) high pressure vessels. Then 4.0 ml concentrated nitric acid (65%), 1.0 ml concentrated hydrochloric acid (37%) and 1.0 ml ultra pure water was added to the samples. Six samples of each item were placed in the carrousel of a Paar Microwave oven (Anton Paar GmbH – Graz – Austria). The samples were digested, using a microwave oven (Anton Paarâ GmbH Kärntner Straße 322A-8054 Graz/Austria) at a maximum temperature set at 220 °C and pressure at 75 bar for 15 min. After cooling, the obtained clear solutions were quantitatively poured in 50 mL volumetric flasks and diluted to the mark with ultra pure demineralized water (Barnstead NanoPure, Thermo Fisher Scientific Inc, Barnstead International, Iowa USA). Finally the diluted solutions of respective samples were transferred into acid cleaned polyethylene bottles. All elements were determined by means of inductively coupled plasma-optical emission spectrometry (Perkin-Elmer Optima 3000 XL, ICP-OES), using the PE calibration standards. The concentrations of heavy metals in fish, hair and nails were calculated as μg/g dry weight, while heavy metals in water sample were calculated as $\mu g\ L^{-1}$. The method limit of detection for the selected metals were calculated as three times the standard deviation for the digestion blanks ($n=5$). Triplicate injections into the ICP-OES showed good reproducibility were generally $<5\%$. Due to the unavailability of appropriate and reliable certified human hair and nails standards for the validation of our methods, standard addition method was performed with several samples, which were spiked with standards and subjected to the same digestion and analysis procedures. Satisfactory recoveries were obtained for the elements (70–99%) and procedural replication showed RSD $<10\%$ for all the analyzed elements ($n=5$). During analysis of the fish samples, the quality of the analytical process was controlled by the analysis of IAEA MA-A-3/TM certified standard reference material of shrimp. Measured values deviated less than 10% from the certified values.

2.5. Statistical analyses

All analysis was performed, using SPSS for Windows Release 13.0 (SPSS Inc.). The W test (Gilbert, 1987) developed by Shapiro and Wilz was used to test the normal/log–normal distribution of the data for hair and nails of our studied population. Normality test of the data showed that few of data sets conformed to nonparametric distribution. To meet the criterion of normality before statistical procedure, all nonparametric data were log-transformed, using the equation: $x' = \log\ (x+1)$ (Zar, 1996). All data among sampling sites were calculated as geometric means (GMs). Comparison of heavy metal concentrations in water, hair, nails and fish samples in different sampling sites was done, using One-way ANOVA. Whenever the null hypothesis was rejected, a multiple comparison test (Tukey HSD test) was used following ANOVA, to determine, which groups of individuals differed from each other. The relationships between the heavy metal concentrations in the hair and nail samples for individual children were analyzed, using the linear regression model. The similarity/dissimilarity of the heavy metals in hair, nails and fish samples were graphically presented in a non-parametric multi-dimensional scaling ordination (NMDS), which represented matching similarities calculated in a triangular matrix of similarity coefficient computed between every pair of metal samples (Clark and Warwick, 1998). The reliability and validity of the MDS solution was determined by calculating the index of fit (R-square), which is the proportion of the variance of the optimally scaled data that can be accounted for by the MDS procedure (goodness of fit). Stress value was also determined to indicate quality of MDS, which indicated the badness of fit (proportion of the variance of the optimally scaled data not accounted for by the MDS model). All the levels of statistical significance were set at $P<0.05$, unless otherwise stated.

2.6. Ethical statement

All the experiments with the fish were conducted in accordance with national and institutional guidelines for the protection of animal welfare (Prevention of Cruelty to Animals Act, Cap 360 of the Laws of Kenya). During the whole study, the principles of the Ethical Committee for the Protection of Animals in Research of Moi University Institutional Research and Ethics Committee (IREC), (Formal approval no.: FAN: IREC 000301) were strictly followed.

3. Results

First the data were tested for distribution to better interpret the results. All the elements in hair and nail samples showed log–normal distribution, which indicates that the data are sufficient to provide the information about the shape of the target population. Thirty water samples were obtained in each of the four sites. Generally, heavy metal concentration in water was of the order Pb > Cd > Cu > Cr. In water, concentrations of Pb and Cu in the sampling sites were significantly higher ($P<0.05$) in site 1 than the other three sites (Table 2). The differences in concentration of these metals between sites, where they occur in highest concentration, and where they occur in the lowest concentration were more than three-fold. Concentrations of Cd and Cr were highest in site 3 than other sites, while similarity of Cr metal was discerned between sites 1 and 2 (Table 2).

Heavy metal content in children aged 5 years were analyzed in four sites along the coastal zone of Lake Victoria, using hair and nails as biomarkers of their level of exposure to heavy metal contamination. Means and standard errors of all heavy metals analyzed in the hair and nail samples are reported in Fig. 2. There were evidently metal specific differences in the elemental concentrations in children's nails and hair among the sampling sites. Unlike the heavy metal concentration in water, concentration of Pb, Cd and Cu in nails were highest in site 3, while in the nails, Pb was elevated in site 3. In general, concentrations of all the metals (Pb, Cu, Cr and Cu) were significantly ($P<0.05$) higher in the nails than hair samples regardless of the sampling sites.

To determine the relationships between elements in a sample, regression models were used (Fig. 3). There were positive relationships between all the heavy metals in nails and hair. However, increased concentrations of Pb, Cd and Cu in nails were better estimated ($>56\%$) by increased concentration of heavy metals in human hair, but not for Cr.

The concentration of heavy metals in fish tissues was also determined (Table 3). Concentrations of Pb, Cd and Cr in the samples of fish tissues were found to be elevated in site 3. The concentration of Pb in fish tissues in site 3 was four-fold in magnitude than concentration of this metal in fish tissues in site 4. Though significant differences ($P<0.05$) in the Cd and Cr were observed in fish tissues among sampling sites, the concentrations of these heavy metals in fish tissue between the site having the highest concentration and site with the lowest concentration never exceed three-fold. Copper concentration was not significantly different among sites ($P>0.05$).

Table 4 summarizes the estimated daily heavy metal ingestion among children from eating *R. argentea* among the sampling sites. For children sampled, the daily ingestion rates of fish were: 0.15, 0.27, 0.32, 0.24 $kg^{-1}\ child^{-1}\ day^{-1}$ in sites 1, 2, 3, 4, respectively. The mean weights of the children were: 19.4 ± 0.5, 20.0 ± 0.8, 19.3 ± 0.8 and 20.2 ± 0.9 kg in sites 1, 2, 3 and 4, respectively. Estimated daily intake of all heavy metals from consumption of fish was significantly higher ($P<0.05$) in site 3, albeit Cu intake

Table 2
Concentration of heavy metals (μg/L) in water at the different sampling sites.

Metals	Site 1	Site 2	Site 3	Site 4
Pb	114.1 ± 5.1^{c}	32.1 ± 4.3^{a}	82.3 ± 7.7^{b}	31.1 ± 0.2^{a}
Cd	80.1 ± 8.1^{c}	20.4 ± 3.3^{a}	151.1 ± 9.9^{d}	37.6 ± 7.3^{b}
Cr	29.1 ± 5.4^{a}	24.3 ± 6.4^{a}	87.9 ± 9.2^{c}	38.6 ± 2.3^{b}
Cu	94.2 ± 3.5^{c}	69.0 ± 4.7^{b}	32.1 ± 5.8^{a}	72.1 ± 5.2^{b}

Means with the same letters as superscripts in a row are not significantly different ($P>0.05$).

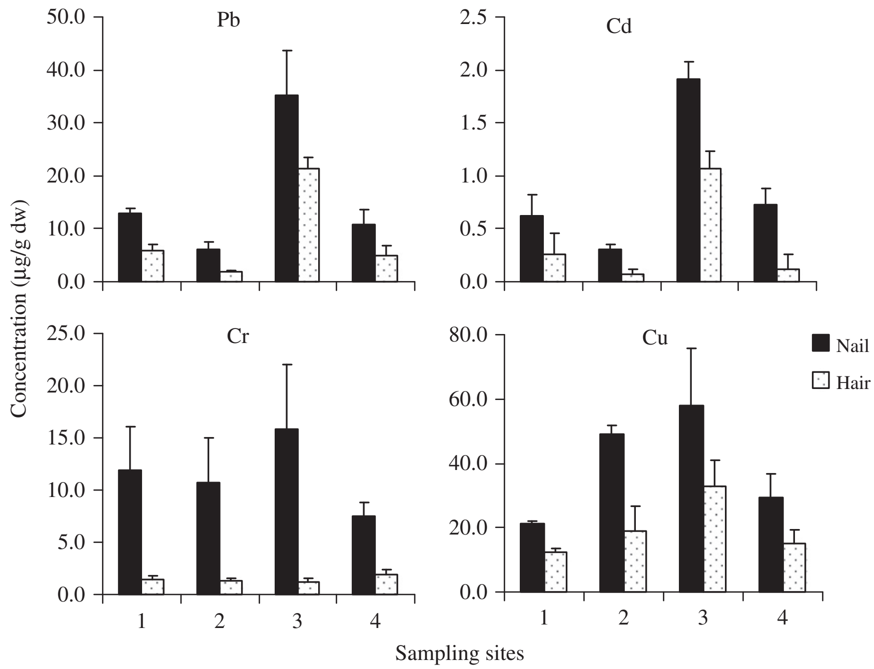

Fig. 2. Heavy metal concentrations hair and nail tissues of the children (µg/g dw) at the four sampling sites in Lake Victoria.

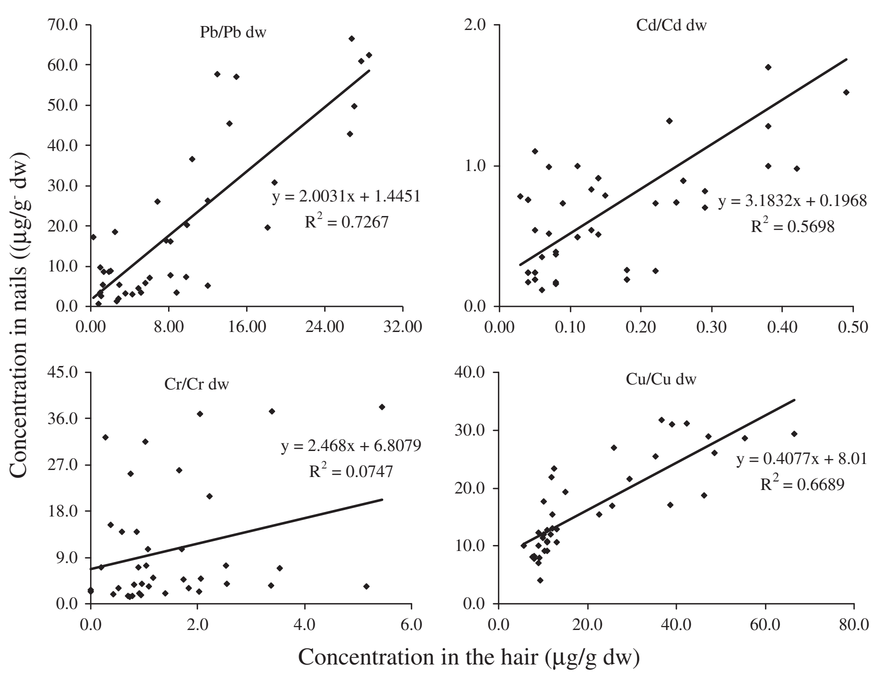

Fig. 3. Regression plots for heavy metals concentration (µg/g dw) in nails (*Y*-axis) against heavy metals in the hair (*X*-axis) for all children.

Table 3
Heavy metal concentrations in *R. argentea* (µg/g dry weight) at the four sampling sites in Lake Victoria.

Metals	Site 1	Site 2	Site 3	Site 4
Pb	0.33 ± 0.07^{b}	0.18 ± 0.03^{a}	0.57 ± 0.02^{d}	0.32 ± 0.05^{b}
Cd	0.13 ± 0.01^{a}	0.19 ± 0.01^{b}	0.38 ± 0.01^{d}	0.18 ± 0.01^{b}
Cr	0.49 ± 0.03^{b}	0.47 ± 0.07^{b}	0.80 ± 0.09^{c}	0.22 ± 0.02^{a}
Cu	6.20 ± 1.54	6.01 ± 1.27	5.38 ± 1.14	5.42 ± 1.21

Means with the same letters as superscripts a row are not significantly different ($P > 0.05$).

Table 4
Estimated dietary intake of heavy metals (µg/day) through fish consumption.

Metals	Site 1	Site 2	Site 3	Site 4
Pb	49.5 ± 3.6^{b}	40.3 ± 8.2^{a}	182.4 ± 6.4^{b}	46.8 ± 5.6^{b}
Cd	15.0 ± 2.7^{a}	43.2 ± 4.3^{b}	121.6 ± 8.9^{c}	43.6 ± 10.8^{b}
Cr	73.2 ± 10.1^{b}	126.9 ± 12.1^{c}	$160.1 \pm 10.9d^{c}$	52.8 ± 9.7^{a}
Cu	930.0 ± 107.2^{a}	1620.0 ± 242.1^{b}	1721.1 ± 110.11^{b}	1300.0 ± 194.1^{a}

Mean values in each row with a common superscript letter are not significantly different from each other ($P > 0.05$).

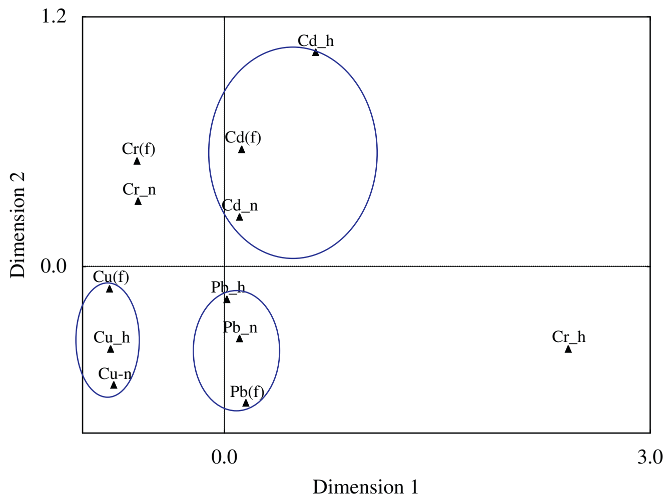

Fig. 4. Multi-elemental relationships in hair, nails and fish samples during the study.

from fish consumption was similar in sites 2 and 3. Daily ingestion of Pb in site 3 was four-fold the amount of Pb ingested by the children in other sites. The differences in daily intake of Cd from fish consumption in sites 3 and 1 were eight-fold, while the differences in concentration of between sites 3 and 4 were three-fold.

Fig. 4 shows the results of the analysis of similarities between heavy metals in hair, nails and heavy metals from fish consumption (NMDS stress factor=0.09 and R^2=0.91). Generally when all the individuals' heavy metals measured in hair, nails and heavy metals estimated from fish consumption were compared, there was metal specific similarity in concentration of Cu, Cd and Pb in hair, nail and fish consumed. The variability of Cd in the three matrices was wide than the variabilities of Cu and Pb. Concentration of Cr obtained from fish consumption was positively related to Cr measured in the nails only.

4. Discussion

In Africa, studies of metal pollution are scarce (Banza et al., 2009), yet there are growing evidence that problems of heavy metals are posing increasing risks to the residents in the continent (Nriagu, 1992). Soils and water catchments areas in some areas have remarkable quantities of mineral elements, which are yet to be exploited. These metals cause enrichment of the soils and water, thus aquatic organisms accumulate high metal body burdens. This study which investigated the heavy metal risks from environment and fish consumption among children consuming large quantity of fish in the diets in the coastal zone of Lake Victoria seems to be an adequate tool with a sensitive approach to the corresponding pollution risk. As far as we know, no data are available regarding the human exposure to metals in this area, which receive increasing pollutants from the catchment and from geological sources rich in minerals, including gold deposits. We chose to use the most convenient approach to assess human exposure, i.e., measuring the concentrations of heavy metals in hair and nails as biomarker for short term and long-term exposure. We also measured the elements in fish consumed to determine the role of fish consumption in metallo-toxic risks to the human in the area.

In water, the selected sites differed mainly in their concentrations of heavy metals, although in site 1, increased concentrations of heavy metals in water and sediments have been documented in the past (Mwamburi, 2003). The elevated Pb and Cu at this site were linked to effluents discharged from the nearby Kisumu City. Earlier studies spanning over 20 years ago (Wandiga, 1981; Wandiga et al., 1983; Onyari and Wandiga, 1989) identified Kisumu City as the major source of heavy metals into Lake Victoria. In recent years, Mwamburi (2003) has established higher enrichment of metals in bottom sediments near Kisumu City. Lake Victoria continues to receive increasing metal contaminations (Wandiga, 1981; Wandiga et al., 1983; Onyari and Wandiga, 1989; Kishe and Machiwa, 2003; Mwamburi, 2003) due to various human activities as well as weak environmental legislation and enforcements, likely to contaminate the surrounding water with heavy metals. However, the elevated Cd and Cr in site 3 were associated with geological sources from the catchment basin. During our sampling, we witnessed alluvial 'search' for gold deposits in the river beds in site 3. Due to higher probability of co-occurrence Au with Cd, Cr Tn, Ni, As and other metals in the soils (Alloway, 1990), deposits of Cr and other minerals could be in higher quantity in the geological basin, which enrich the water in these areas. Comparison of heavy metals with surface water quality guidelines (CEQG, 2002; USEPA, 2002) showed that Pb in sampling site 1, Cd in sites 1 and 3, Cr in site 3 and Cu in all the sampling sites were above the maximum acceptable concentration (MAC). Thus toxic effects of these heavy metals likely in some of the sampling sites.

In the hair and nails samples (Fig. 2), concentration of the heavy metals in the present study were comparable with or even higher than those published in previous studies among the non-conventionally exposed (Rodushkin and Axelsson, 2000; Wang et al., 2005; Were et al., 2008; Wang et al., 2009). Although, there are no previous studies documenting the metal concentrations in children within the coastal zone of Lake Victoria, the concentration (and ranges) of Pb in the present study were lower than the occupationally exposed residents of Taizhou (electronic waste area), but the concentration of Cd, Cr and Cu in the present study were higher than the occupationally exposed residents of the area (Wang et al., 2009). Similarly, the present concentrations of Cd and Pb in hair and nails samples are higher than those reported in human nails in Nairobi, Kenya (Were et al., 2008). In comparison to non-occupationally exposed residents, the present study of all toxic metals were found to be higher in concentration with an element such as Pb being 20 time higher and Cd being 10 times higher (Rodushkin and Axelsson, 2000), and thus the content of toxic metals suggested high levels of exposure to heavy metals. The concentration of heavy metals in the nails could be a possible indicator of chronic exposure of the humans in the coastal zone of Lake Victoria.

The regression trends (Fig. 3) in human hair and nails were interpreted as elemental competition for sorption in the active sites, since Pb and Cd have no known functions in the body, while Cu are required in low quantity. The positive relationships between metals in hair and nails could also indicate exogenous sources of metals, which reflect environmental exposures. A major problem in the use of hair and nails as biomonitors of environmental exposure is the inability to separate endogenous and exogenous deposition of metals, because proportions of substance from the environmental media are incorporated and strongly bound to the hair and nails structure (Kempson et al., 2006). It is also possible that washing of the hair and nail samples removed all the exogenously deposited contaminants in hair and nails, and thus the observed metals are from the physiological body systems and diet.

The health risks associated with fish consumption have been documented by Wang et al. (2005). Fish samples in the present study (Table 3) had elevated metal concentrations in site 3. Daily dietary metal intake through fish consumption was calculated based on the average metal content in fish and eating frequencies. The daily metal intake in fish was also found to be higher in site 3. It is evident from Table 4 when compared to the recommended daily dietary allowance (RDA) for Pb of 250 μg/day and Cu 3250–325,000 μg/day by FAO and USA (CAC, 1984; NRC, 1989; Chen and Chen, 2001; USEPA, 2002) that RDA was never exceeded at any site. However, RDA for Cd (57–72 μg/day) and Cr (150 μg/day) was exceeded by the children in site 3, suggesting that fish consumption was likely to expose the children to risks of metal toxicity. The overall risks of Cd and Cr in sites 3 was accounted for by the higher consumption of fish in these areas and the higher metal concentration in fish probably from the geological source. As yet, no studies have been conducted to quantify the geological metal sources in this area. Because the fish was cheap sometimes retailing at US $ 0.20/kg and also ease of capture by the local fishermen, it was consumed more by the poor rural folk who were mostly unable to afford other sources of food such as beef (currently retailing at US $ 2/kg). Furthermore, earlier study (Abila and Jansen, 1997) indicated that this fish source contribute upto 70% of food to the local inhabitants, due to its affordability and ease of capture by local fisher communities.

The interaction between metals in hair, nails and fish examined by NMDS (Fig. 4) indicated similarity between specific elements in fish, hair and nails matrix (at least for Pb, Cd and Cu). This could suggest metal uptake from fish consumption (at least to some degree) as suggested in other similar studies (Rodrigues et al., 2008; Whyte et al., 2009). The high variability in Cd determined in nails, hair and from ingested fish could suggest that other than fish consumption, there are other possible sources of Cd in the humans suspected to be from the geological sources. However, Cr was found to display similarity between nails and fish samples only, which could be a suggestion that if the uptake of Cr was from fish consumption, then it was due to long-term exposure to this metal. Because of the different types of food likely to be ingested, soils and water, it was not easy to quantify the exact amounts of element ingested from the fish, which was complicated by the interactions, yet the multivariate analysis showed closer relationships between metal burdens ingested from fish and the concentration of these metals in hair and nail tissues. It could also be possible that in multi-elemental samples, in the cells, differential sorption patterns occur across the hair follicle and nails tissues, (Wang et al., 2009) that would ultimately influence the concentration of the other present metals, cannot be overlooked.

5. Conclusions

In this study, we measured the heavy metal content in the environment, hair, nails and food to determine the role of hair and nails as biomarker of short- and short-term exposure to heavy metals among children aged 5 years in the coastal zone of Lake Victoria. There were evident heavy metal contaminations in sites. Furthermore, there were close associations established between the specific metals in hair/nails and metal estimated from fish consumed. Metal consumption patterns from fish suggested that the local residents though were not exposed to short-term metal risks, but consumption of higher quantity of fish could pose a potential long term health risk from heavy metals to the children aged 5 years in the study area. The present study demonstrated that determination of metals in human hair and nails, and relating this with heavy metals estimated from fish consumption has potential utility as a biomarker of exposure to heavy metals from the fish consumption.

The most frequently cited factors which may jeopardize the usefulness of hair and nail analysis include difficulties in differentiating between endogenous and exogenous depositions, inconsistency of hair and nail concentration anomalies with nutritional status and the absence of well defined reference concentration ranges (Bencze, 1990; Gulson, 1996). However, the simplicity with which hair and nails can be sampled, transported and handled, and generally higher element concentrations compared to other biological media, such as blood and urine (Rodushkin and Axelsson, 2000; Sukumar and Subramanian, 2007), together with finding from the present study, makes hair and nails to be suitable tool for monitoring localized exposure to metals from fish consumption.

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