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Pollution assessment of the lower basin of Lakes Kainji/Jebba, Nigeria: heavy metal status of the waters, sediments and fishes

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Abstract

The objective of this investigation was to examine the heavy metal status of the lower basin of Kainji dam (used for hydroelectricity generation), which includes Lakes Kainji/Jebba, Nigeria, and the potential for human exposure to heavy metals from eating fish caught in the lakes. Water, sediments and fish were sampled from the lakes and evaluated for As, Cu, Co, Cr, Fe, Hg, Mn, Ni, Pb, Sb, Ti, V and Zn using the EDXRF technique. Fe and Mn were found to be present at high mean concentrations in the water (13 and 9 μg L^{-1}), sediment (7092 and 376 μg g^{-1}) and fish (11.4 and 4.6 μg g^{-1}) samples. Sb (3.2 μg L^{-1}), Ti (4.1 μg L^{-1}), Cr (2.2 μg L^{-1}), Co (1.2 μg L^{-1}), Cu (1.3 μg L^{-1}) and Pb (1.2 μg L^{-1}) in the water samples and Sb (29 μg g^{-1}), Ti (27 μg g^{-1}), V (27 μg g^{-1}), Cr (27 μg g^{-1}), Co (40 μg g^{-1}), Ni (33 μg g^{-1}), Cu (25 μg g^{-1}), Zn (59 μg g^{-1}) and Pb (19 μg g^{-1}) in the sediment samples were found to be of medium mean concentrations. The other metals were present at trace levels (<1 μg), including As and Hg in the fish and sediment samples. There was an appreciable increase in metal concentrations in going from the water to the sediment samples. The probable source of the pollutants is anthropogenic, arising from agricultural activities, corrosion/abrasion of the ferrous steel material and additives in the lubricants and insulation used for auxiliary services on the turbine floor of the dam constructed on the lakes. However, natural geological sourcing from the underlying lake rock cannot be totally ignored, particularly the high levels of Fe and Mn in the sediment samples. The potential risk for human exposure to these metals emanates from the fish caught in the lakes and subsequently consumed, as there are already significant levels of these metals in the two fish species analysed, Tilapia (*Oreochromis niloticus*) and Chrysicthys (*Chrysicthys auratus*).

Introduction

The Kainji/Jebba lakes represent two major water reservoirs in Nigeria. Both are formed from water flowing in the River Niger and are located at a distance of about 3200 km south of the source of the river. The River Niger rises in the mountains of Sierra-Leone on the Fouta-Djallon Highlands (240 km from the Atlantic ocean) and receives water from the numerous inflowing rivers that form its tributaries (NEDECO 1959) as it flows in a wide arc through Mali, Niger, and Nigeria to the Gulf of Guinea. In Nigeria, the rivers Sokoto, Malende, Kontagora, Oli, Mushi, Awum and others contribute to localized flooding of River Niger, which occurs between August and November; the driest period is between May and July (Olagunju 1972; Obot 1984). In December 1968, the Niger River was dammed, and the river upstream of the dam was backed up to form Lake Kainji, the surface level of which is hundreds of meters higher than that of the original river. The lake covers an area of about 800 km^2 (130 km long and 24 km wide). The dam's screens, gates and linings of intake passage are constructed from steel. Water of the lake is regulated to flow through the dam, producing power by turning turbines located in the dam itself. The hydroelectricity generated from the dam provides most of energy supply for domestic and industrial use in Nigeria (NEPA 1977). The panoramic view of the countryside from the top of the dam is a major tourist attraction (NEPA 1977). The lake also serves as a large source of fish for human consumption. Just below the Kainji dam, downstream of Lake Kainji, is Lake Jebba (100 km long).

Lakes and surface water reservoirs are the planet's most important freshwater resources and provide innumerable benefits. They are a source of water for domestic use, irrigation and renewable energy in the form of hydro power and are essential resources for industry. Lakes provide ecosystems for fish, thereby functioning as a source of essential protein, and for significant elements of the world's biological diversity. They have important social and economic benefits as a result of tourism and recreation, and are culturally and aesthetically important for people throughout the world. They also play an equally important role in flood control (U.N.E.P. 1994).

The flood control achieved as a result of the construction of the Kainji/Jebba dam has led to an intensification in agricultural practices, including irrigation agriculture and fishing, in the regions around the Kainji and Jebba lakes and in areas downstream of the dam. Coupled with this is the increased use of fertilizers, pesticides and herbicides. Run-off from agricultural lands and refuse from residences located along the shores of the lakes are directly or indirectly discharged into the lakes.

A previous investigation aimed at determining the levels of toxic contaminants in the important ecosystem compartment of Lake Kainji (Mbegwu & Ovie 1999) considered physico-chemical parameters such as pH, dissolved oxygen, conductivity, turbidity, nitrates and phosphates reported that the reservoir was safe for aquatic life, based on USA-Environmental Protection Agency (EPA) standards. However, an earlier, preliminary study on the pesticide residues in waters of the Kainji and Jebba lake areas (Adeniyi *et al.* 1985) showed varying concentrations of pesticide residues in all of the fish sampled, and the investigators concluded that the aquatic life was contaminated. The same study also reported the presence of some heavy metals.

Lakes can become polluted without obvious signs (Alloway *et al.* 1990; Biney *et al.* 1994) and, as such, environmental monitoring as a means of detecting insidious pollution becomes very pertinent. This investigation was designed to evaluate the content of heavy metals in the water reservoirs and sediments, and in the fishes, of Lakes Kainji and Jebba with a view of using the results as indicators of the pollution status around the Kainji dam in Nigeria.

Materials and methods

Sampling sites

Samples were collected from six sites located in the lower water basin formed by the Kainji dam: three in Lake Kainji (Sites 1–3) and three below the dam – in Lake Jebba (Sites 4–6). The sites were selected based on their nearness to agricultural and fishing settlements (Sites 1–3, 5 and 6) or the hydropower station (Site 4, which is just about 50 m below the dam). However, the same water body feeds the entire study area. Each sampling station was located approximately 10 m from the shoreline. The geology of the lakes consists of water cutting through sedimentary beds into underlying rocks of the basement complex, which consists of granites, gneiss, schist and quartzite (NEDECO 1959). Figure 1 is a map of the Kainji/Jebba lake basins, the dam and the sampling sites.

Water collection

Water samples were collected monthly over a period of 6 months (March–August 2002) using a commercial water sampler. One litre of water at a depth of 50 cm was collected at several points within each site and pooled together to obtain a litre monthly pooled sample (Keith 1991). A total of 36 pooled water samples were collected at the sites over the 6-month period.

Sediment collection

Sediment samples were collected using a core sediment grab sampler. Several cores of sediments were collected at different locations within each site every month to a make a composite bulk sample (Mudrock & Macknight 1994). A total of 36 composite sediment samples were collected at the sites over the 6-month period.

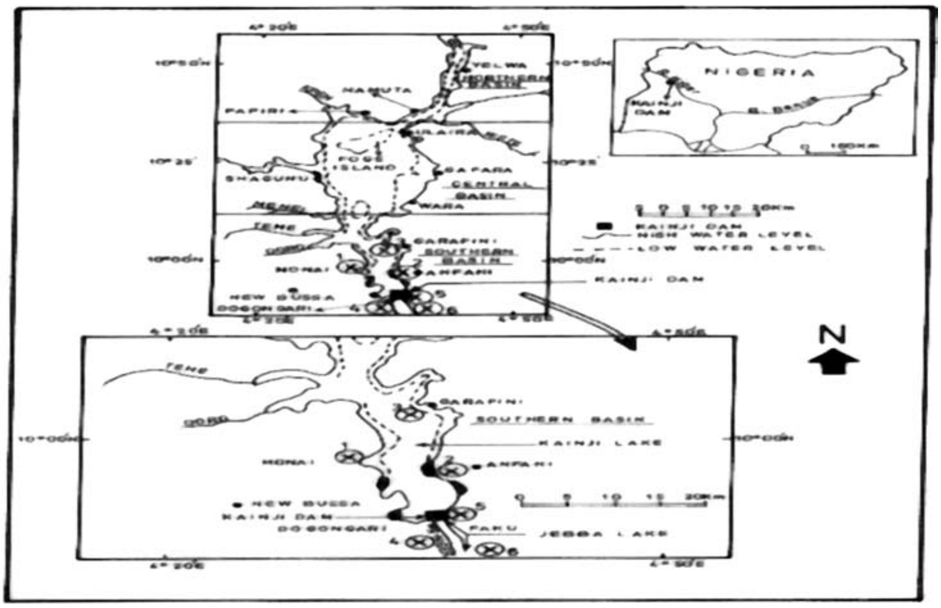

Fig. 1. Map of Lakes Kainji/Jebba showing the basins, dam and sampling sites (*X*) (modified from Obot 1984).

Fish samples

Two fish species, Tilapia (*Oreochromis niloticus*), a surface feeder, and Chrysicthys (*Chrysicthys auratus*), a bottom feeder, were sampled fresh from Lakes Kainji and Jebba. The species were of uniform size, with *O. niloticus* averaging 15.67 ± 0.84 cm in total length and 22.19 ± 2.31 g in body weight, while *C. auratus* averaged 18.21 ± 1.59 cm in total length and 24.85 ± 0.98 g in body weight (Sweet & Zelikoff 2001). A total of 24 fish samples were collected.

Sample preparation and extraction

Water samples were filtered using Whatman membrane filter paper (pore size: 0.45-μm), acidified with 3 ml HNO_3 (1:1, v/v) per litre and refrigerated in clean, sterile and labelled plastic containers (Ramos *et al.* 1999).

The sediment samples were stored in an ice-chest on site and deeply frozen later in the laboratory. The thawed sample was passed through a 10-mesh screen to remove large pieces of foreign materials, homogenized by blending, oven dried at 40 °C for 48 h and cooled, and the dry weight was then recorded (Ramos *et al.* 1999). The samples were then passed through a 125-μm sieve.

The fish samples were cleaned with distilled and deionized water and chilled at the point of sampling in an ice-box. Each fish was scaled and filleted, and the fillet dried at 40 °C in an oven for 96 h. The dried fillet was ground, homogenized in a blender and passed through a 125-μm sieve (Bio-Elite 2000; Bio-Elite, Johannesburg, South Africa). A 1.0-g of the homogenate was digested with two 5-ml portions of concentrated HNO_3 acid and made up to a 100-m volume with distilled/deionized water (Greenberg *et al.* 1992).

Sample analysis

For the water and fish digest samples, 100 ml of each sample was acidified to pH 2, following which 2 ml of 1% ammonium pyrrolidine dithiocarbamate (APDC) solution was added; the sample solution was then allowed to stand for 30 min (Elder *et al.* 1975; Valkovic 1989). The precipitated metal carbamates were filtered through Whatmanmembrane filter paper (pore size: 0.45 μm), dried and ground. The metal-complexed precipitates of the water and fish samples and the sediment samples were each homogenized with three drops of organic liquid binder (polystyrene dissolved in toluene) and pellets prepared from approximately 0.3 g of each sample using a 19-mm-diameter die with a hydraulic press. The spectra of each sample were then measured using an energy-dispersive X-ray fluorescence (EDXRF) system.

The EDXRF system is based on [^{109}Cd]-isotope excitation and consists of a 925-MBq [^{109}Cd] annular isotopic source with a Canberra Si(Li) detector having a resolution of 170 eV at 5.9 keV. The X-ray spectra were acquired using a computer-based MCA card (Trump 8k). The set-up provides for dead-time correction and pile-up rejection. Sensitivity calibration of the system was performed using thick, pure metal foils and stable chemical compounds. Measurement time for spectra collection was 50 min, and the AXIL software package (Van Espen *et al.* 1989; Bernasconi 1996) was used for spectra analysis. An absorption measurement method using a thick foil as target material for evaluating the concentration of the elements was used (Kump 1996; Oyewale *et al.* 2002).

Triplicate determinations were carried out for each sample and the mean concentrations reported. The accuracy and precision of the measurements were confirmed by analysis of International Atomic Energy Agency (IAEA) certified reference materials for the lake sediment (IAEA SL-1), soil (IAEA SOIL-7) and hay powder (IAEA V-10). There was generally good agreement between measured and certified values (Table 1). Uncertainties in the measurements included errors from counting statistics, calibration error and uncertainty of the absorption correction factor.

Statistical analysis

The sample results for both water and sediments were stratified in several ways to evaluate for similarities and differences. The results were compared by Pearson correlation analysis ($\alpha = 0.05$) within the sites and between sample types. The correlation of the metals in the water and sediment samples with the fish samples was also evaluated.

Results and discussion

Heavy metal content of the waters and sediments of Lakes Kainji/Jebba

The levels of heavy metals, given as mean values ± standard deviations, in the water and sediment samples collected at the six sites of the lower basin of Lakes Kainji/Jebba between March and August 2002 are shown in Tables 2 and 3, respectively. The concentrations of As, Cu, Co, Cr, Fe, Hg, Mn, Ni, Pb, Sb, Ti, V and Zn in the samples were estimated using the EDXRF technique. There were no significant variations in the concentrations of the metals between monthly water and sediment samples, hence only the mean concentration per site is presented. There were also no distinctive distribution patterns in metal contents in the samples collected within the sites of each lake and between the sites of Lakes Kainji and Jebba. Only the main components of the

Table 1. Measured and certified (IAEA standards) measurements for elements (ppm) in samples IAEA SL-1 (lake sediment), IAEA SOIL-7 (soil) and IAEA V-10 (hay powder) (*LOD* limit of detection).

Metal	IAEA-SL 1		IAEA-Soil 7		IAEA-V 10	
	Measured	Certified	Measured	Certified	Measured	Certified
As	24.3 ± 7	27.5 ± 2.9	12.9 ± 2	13.4 ± 2	–	–
Cu	29.3 ± 5	30	11 ± 4	11	10.4 ± 0.8	9.4 ± 0.9
Co	18.8 ± 2	19.8	8.9 ± 1.4	8.9	LOD	0.13
Cr	102 ± 9	104	59.4 ± 1.4	60	6.1 ± 2	6.5 ± 1.5
Fe (%)	6.46 ± 0.5	6.74 ± 0.2	2.69 ± 0.2	2.58 ± 0.03	0.15 ± 0.01	0.19 ± 0.01
Hg	–	–	–	–	LOD	0.013
Mn (%)	0.35 ± 0.03	0.35 ± 0.02	0.73 ± 0.09	0.63 ± 0.01	0.04 ± 0.01	0.05 ± 0.01
Ni	42.7 ± 3.5	44.9 ± 3	–	–	4.4 ± 2	4.2 ± 1.1
Pb	38.6 ± 10	37.7 ± 7.4	75.6 ± 12	62.2 ± 2.3	1.56 ± 0.4	1.6 ± 0.1
Sb	1.24 ± 0.09	1.31	1.4 ± 0.4	1.7	0.01 ± 0.004	0.009 ± 0.002
Ti (%)	0.47 ± 0.04	0.52 ± 0.04	0.32 ± 0.04	0.31 ± 0.02	–	–
V	167.8 ± 19	170	63.5 ± 10	66	–	–
Zn	218 ± 19	223 ± 10	106.7 ± 14	104 ± 5	22 ± 4	24 ± 2

Table 2. Mean concentration and standard deviation of heavy metals ($\mu g\ L^{-1}$) in the water samples collected from Lakes Kainji/Jebba (*LOD* limit of detection).

Metal	Lake Kainji lake			Lake Jebba		
	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
As	LOD	LOD	LOD	LOD	LOD	LOD
Cu	0.70 ± 0.08	1.42 ± 0.13	1.27 ± 0.10	1.54 ± 0.33	1.37 ± 0.15	1.58 ± 0.17
Co	1.09 ± 0.11	1.14 ± 0.10	1.21 ± 0.08	1.20 ± 0.22	1.33 ± 0.14	1.28 ± 0.06
Cr	2.10 ± 0.28	2.22 ± 0.19	2.18 ± 0.15	1.91 ± 0.08	2.43 ± 0.43	2.18 ± 0.12
Fe	13.00 ± 0.37	14.80 ± 1.75	14.10 ± 1.65	12.51 ± 1.31	12.81 ± 1.18	11.40 ± 0.50
Hg	LOD	LOD	LOD	LOD	LOD	LOD
Mn	6.42 ± 0.61	11.60 ± 1.29	6.74 ± 0.81	8.04 ± 0.60	14.80 ± 1.18	6.89 ± 0.67
Ni	0.91 ± 0.17	1.12 ± 0.14	0.90 ± 0.19	0.79 ± 0.33	0.86 ± 0.09	0.83 ± 0.09
Pb	1.67 ± 0.12	1.07 ± 0.25	1.27 ± 0.09	1.54 ± 0.05	0.88 ± 0.34	0.88 ± 0.19
Sb	2.80 ± 0.41	3.29 ± 0.55	3.12 ± 0.19	3.95 ± 0.13	2.72 ± 0.31	3.57 ± 0.32
Ti	3.96 ± 0.31	4.32 ± 0.22	3.87 ± 0.16	4.15 ± 0.23	3.91 ± 0.34	4.02 ± 0.18
V	LOD	LOD	LOD	LOD	LOD	LOD
Zn	0.80 ± 0.19	0.65 ± 0.16	0.71 ± 0.18	1.10 ± 0.21	1.07 ± 0.40	1.05 ± 0.20

Table 3. Mean concentration and standard deviation of heavy metals ($\mu g\ g^{-1}$) in the sediment samples collected from Lakes Kainji/Jebba.

Metal	Lake Kainji			Lake Jebba		
	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
As	0.10 ± 0.04	0.16 ± 0.08	0.16 ± 0.07	0.14 ± 0.05	0.15 ± 0.05	0.14 ± 0.07
Cu	22.84 ± 1.44	26.18 ± 2.05	23.14 ± 1.70	21.28 ± 2.49	31.60 ± 2.14	24.48 ± 1.87
Co	25.02 ± 1.62	52.63 ± 4.30	35.61 ± 3.26	26.39 ± 2.01	59.20 ± 2.47	43.00 ± 2.40
Cr	23.40 ± 3.35	30.31 ± 2.56	29.06 ± 3.32	28.00 ± 2.87	26.87 ± 2.22	26.01 ± 3.91
Fe	5240 ± 155	8600 ± 690	5640 ± 236	6971 ± 704	9299 ± 672	6802 ± 152
Hg	0.12 ± 0.04	0.22 ± 0.04	0.10 ± 0.02	0.13 ± 0.04	0.20 ± 0.03	0.14 ± 0.06
Mn	265 ± 26.7	416 ± 36	401 ± 22	374 ± 23	434 ± 40	368 ± 39
Ni	24.36 ± 1.65	49.02 ± 3.00	31.93 ± 2.96	25.00 ± 1.70	44.30 ± 3.24	22.80 ± 1.99
Pb	18.79 ± 2.63	20.82 ± 3.11	17.79 ± 2.73	18.51 ± 2.12	19.11 ± 2.73	17.94 ± 3.43
Sb	28.89 ± 1.75	24.68 ± 2.32	30.42 ± 2.92	29.47 ± 2.87	32.17 ± 3.86	28.34 ± 3.67
Ti	26.92 ± 1.72	27.46 ± 2.50	24.51 ± 1.21	28.11 ± 2.00	25.64 ± 1.43	30.29 ± 2.50
V	26.40 ± 3.13	22.87 ± 1.76	24.19 ± 3.06	31.51 ± 3.08	29.64 ± 2.62	27.26 ± 1.43
Zn	43.90 ± 2.42	71.52 ± 2.68	63.41 ± 3.24	38.46 ± 1.76	106 ± 15	29.20 ± 3.01

samples (i.e. Fe and Mn) showed standard deviations that were significantly high.

The heavy metals analysed could be grouped into three classes based on their levels in the samples: (1) those present at significantly high concentrations; for example, Fe and Mn, with means of 13 and 9 $\mu g\ L^{-1}$ in the water samples and 7092 and 376 $\mu g\ g^{-1}$ in the sediment samples, respectively; (2) those whose mean concentrations ranged from 4.1 $\mu g\ L^{-1}$ (Ti) to 1.2 $\mu g\ L^{-1}$ (Co, Pb and Cu) in the water samples, and from 59 $\mu g\ g^{-1}$ (Zn) to 19 $\mu g\ g^{-1}$ (Pb) in the sediment samples; (3) those which present at trace levels ($<1\ \mu g$), including As and Hg in the sediment samples.

In the water samples, the levels of As, Hg and V were below the detection limits of the instrument, whereas the levels of these elements in the sediment samples ranged from 0.10 to 0.16 $\mu g\ g^{-1}$, 0.10 to 0.22 $\mu g\ g^{-1}$ and 23 to 32 $\mu g\ g^{-1}$, respectively.

Figure 2 compares the water/sediment levels of the metals at each of the six sites. As expected, at any one site the concentration of the metals in the sediment samples was appreciable higher than that in the water samples. However, Pearson correlation analysis showed no significant correlation between the two sets of data for any of the metals in the water and sediment samples. The concentration differentials in the samples for any of the

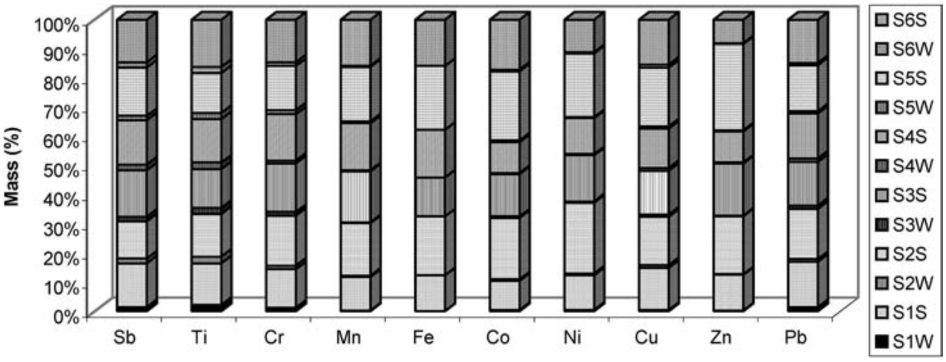

Fig. 2. Variation in the levels of metals analysed in the water (W) and sediment (S) samples from the experimental sites (S1–S6).

metals analysed between Lake Kainji (above the dam) and the water below the dam was not so striking as to suggest any significant discharge of pollutants from the hydropower station that separates the two lakes.

A comparison of the metal level in each of the sample types, however, indicated a good positive correlations between Ni/Fe ($r = 0.82$), Fe/Zn ($r = 0.86$) and Zn/Ni ($r = 0.82$) in the water samples, while similar correlations existed between Co/Fe ($r = 0.87$), Co/Cu ($r = 0.91$), Zn/Cu ($r = 0.86$), Ni/Zn ($r = 0.84$), Fe/Mn ($r = 0.80$) and Cu/Fe ($r = 0.81$) in the sediment samples. All of these are first-row transition metals that are extensively used as alloys in the construction industry.

Figure 3 shows the composition percentage ratio of the metals in the water and sediment samples at each site. The predominant metals at each site were found to be Fe (approx. 90%) and Mn (approx. 5%) in the sediment and Fe (approx. 45%) and Mn (approx. 20%) in the water samples. However, other metals – for example, Sb, Ti, Cr and Pb – were proportionately present at higher ratios (range: 10–20%) in the water than in the sediment samples at all sites. Although we found a considerable accumulation of all the metals analysed in all of the water and sediment samples, the variation was random. The enrichment in metal levels from water to sediment are in the orders of Fe (×540), V (×100), Zn (×65), Mn (×40), Ni (×36), Co (×33), Cu (×19), Pb (×15), Cr (×13), Sb (×10) and Ti (×7).

The nature and level of the heavy metals in the water and sediment samples were interesting as some were unusually high for an unpolluted lake. Anthropogenic sources such as corrosion/abrasion of ferrous steel used for the construction of the dam on the lake and agricultural fertilizer residue, washed into the lake waters, could account for the presence and/or high level of some of the heavy metals. Another likely source is the natural underlying geology of the rock around the lake. We were unable to ascertain the relative contribution of these pollution sources or of others to the concentration of heavy metals in the lakes.

Heavy metal content in the fish sampled from Lakes Kainji/Jebba

Fishing for consumption is one of the primary occupations of the inhabitants around the Lakes Kainji/Jebba. Wildly diverse species of fish are being caught in the lakes, however we directly sampled only two fish species, Tilapia (*Oreochromis niloticus*), a surface feeder, and Chrysicthys (*Chrysicthys auratus*), a bottom feeder, from the lakes. The choice of species was determined by availability, easy identification, non-migratory status and geographic spread (Dybern 1983; de Boer & Brinkman 1994). Fish type is known to be an important variable in the bioaccumulation of toxic metals, for example, methylmercury in fish and humans (Sweet & Zelikoff 2001; U.S. Food and Drug Administration 2001).

Figure 4 shows the plot of the variations in the levels of the analysed metals in the fillets of the two fish species caught in the two lakes.

The concentration of major metals Pb, Zn, Fe, Cu and Mn and of toxic elements As and Hg were found to be higher in the Chrysicthys samples than in the Tilapia samples for both Lakes Kainji and Jebba. The difference in the metal content may be

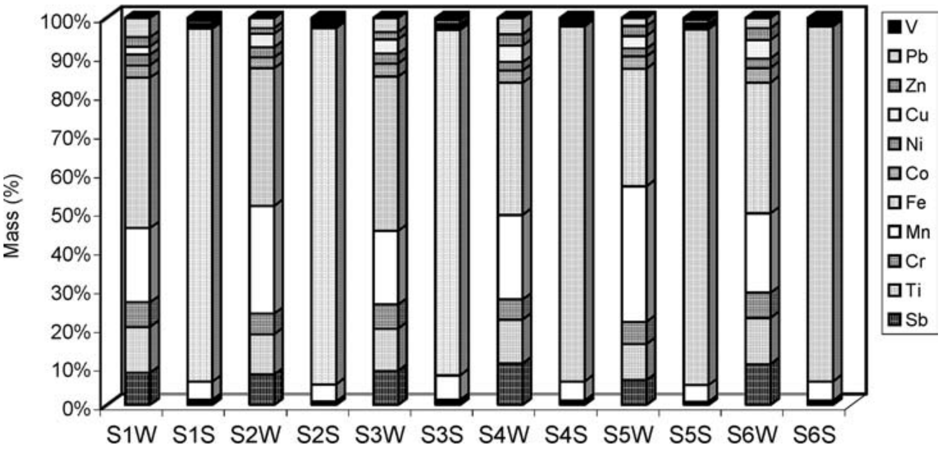

Fig. 3. Percentage ratio of metals composition at the six lake sites (S1–S6).

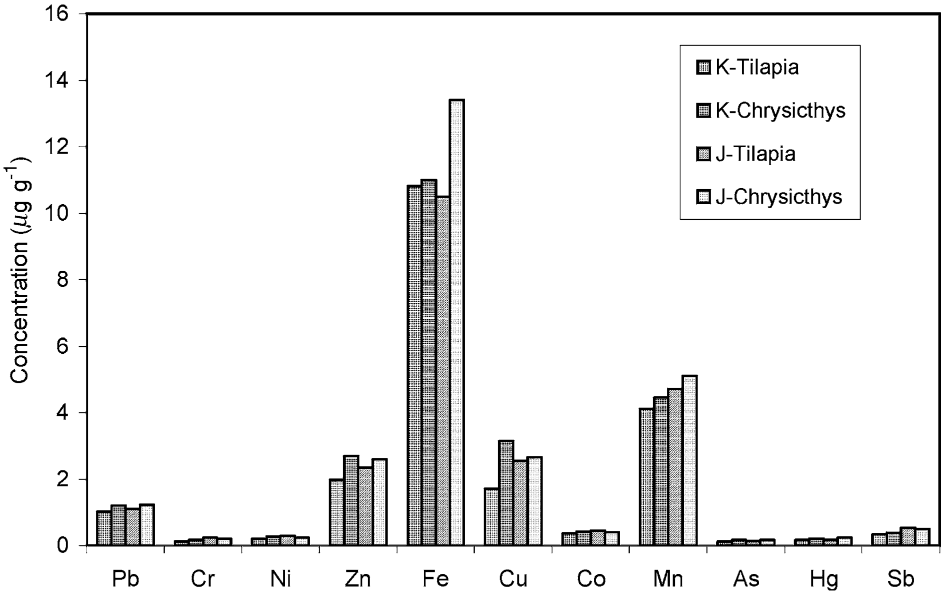

Fig. 4. Variations in the levels of heavy metals in two species of fish sampled from Lake Kainji (K) and Lake Jebba (J).

attributed to integumental differences between the two fishes: Tilapia (*O. niloticus*) are surface-feeders, and Chrysicthys (*C. auratus*) are bottom-feeders and scale less, hence the latter are in direct contact with metals in the water and sediment. However, the difference may also reflect differences in homeostatic control abilities of the species (Annune & Iyaniwura 1993). In an apparent reflection of the pollution status of the waters and sediments of the two lakes, the appreciable amounts of Fe, Mn, Zn, Cu and Pb in the fish samples indicate that these metals have become significantly bioaccumulated in the food cycle. Pearson correlation analysis indicated a strong positive correlationfor metal levels between sediment/fish ($r = 0.93$) and between water/fish ($r = 0.90$). On the other hand, Sb, V, Ti, Cr, Co and Ni, which were present at significant concentrations in the sediments, were found to be present at low concentrations,or even below detection levels, in the fish samples, which indicates that these elements are well tolerated by the fishes sampled. Although the fish sampled are a good nutritional source of the essential minerals, Fe, Mn, Zn and Cu, the accumulation of the toxic metals Pb, As and Hg in our samples – despite their low concentration in the water and sediments – is of concern. The transfer of health hazardous materials – metals, for example – to humans through fishing activities and fish consumption is a topic of great current interest (Daviglus *et al*. 1997; England & Middaugh 1997).

Conclusion

This study provides information on the quality of the water and sediments of Lakes Kainji/Jebba, Nigeria. The sediment samples were found to have significantly higher concentrations of metals than the waters although there was no significant correlation between the levels of the various metals in the water and sediment samples, either within one lake or between the two lakes. We found evidence of metal contamination due to the high levels of Fe, Mn, Zn, Sb, Ti, V, Cr, Ni and Pb in the lakes, which may be a result of corrosion/abrasion of the construction materials of the dam and/or discharges from agricultural activities around the dam. The concentrations of Fe and Mn in the samples were significantly higher than those of the other metals. High levels of Fe and Mn in sediment samples are usually attributed to geological sourcing; however, these metals are also significant constituents of steel, the construction material of the dam. The most important result of this study relates to the risk that some of these metals have to human health; this is particularly true with respect to the consumption of fishes caught in the lakes as these already show significant levels of these metals in addition to As and Hg. We found a significant positive correlation between the levels of metal contamination in the water and sediment samples and the fishes in the lakes. Future work will investigate the fish consumption habits of the fishermen and their families and the likely health impact.

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