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ORIGINAL ARTICLE

Copper, lead and cadmium concentrations in surface water, sediment and fish, *C. Carpio*, samples from Lake Naivasha: effect of recent anthropogenic activities

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Abstract Following recent concerns of chemical pollution around Lake Naivasha, especially originating from recent agricultural activities in the catchment, samples of water, sediments, and fish Common carp (*Cyprinus carpio*) were collected from the Hippo Point, Kasarani, Mouth of Malewa River, Mouth of Karati River, Crescent Island, Sher Karuturi Discharge outlet and Oserian Bay for analysis of Cu, Cd and Pb by FAAS. The mean heavy metal levels ranged from 5.12–58.11 (Pb), 1.06–1.73 (Cd), and <0.03–2.29 (Cu) mg/kg wet weight in *C. carpio* muscle, <100–179.83 (Pb), <10.00–10.06 (Cd) and <30.00–32.33 (Cu) µg/L in surface water, and 17.11–53.07 (Pb), 1.18–5.58 (Cd) and 3.00–8.48 (Cu) mg/kg dry weight in sediment and showed a wide variation within and between samples with relatively high concentrations in sediments and fish muscle tissues. The results indicate that Lake Naivasha, in some parts, is polluted with these heavy metals of which relatively higher concentrations are found at the discharge outlets near Sher Karuturi and Oserian Bay. This indicates possible contribution from surrounding horticultural/floricultural activities and the Mouths of the Rivers Malewa and Karati which flow from it's upper catchment.

Keywords Heavy metals · Lake Naivasha · Catchment · Sources

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Introduction

Studies on heavy metal pollution in aquatic ecosystems have been a major environmental focus especially in the last decade (Weis and Weis 1995; Ongeri et al. 2009a, b; Öztürk et al. 2009; Omwoma et al. 2010) particularly due to their potential toxic effects and ability to bioaccumulate in aquatic ecosystems (Censi et al. 2006; Batvari et al., 2007). Surface waters are most exposed to pollution due to their easy accessibility for disposal of wastewaters. Anthropogenic influences such as urban, industrial and agricultural activities, increasing exploitation of water resources as well as natural processes which include precipitation inputs, erosion and weathering of crustal materials degrade surface waters and damage their use for drinking as well as for industrial, agricultural and other purposes (Simeonov et al. 2003). Sediments serve as reservoirs for heavy metal residues and play a significant role in their remobilization and distribution in aquatic systems through interactions between water and sediment under favorable conditions (Klavinš et al. 2009). In aquatic ecosystems, water will have lower concentrations of heavy metals whose magnification increases in the recipient sediment and biota (through food chain transfer) (Öztürk et al. 2009). However, high concentrations of heavy metals in the aqueous phase indicate more recent input into the aquatic environment. Since heavy metals in the aquatic systems are usually predominantly associated with sediment, their concentrations in sediment are more sensitive and accurate indicators of contamination of the aquatic system when compared with their concentrations in the aqueous phase. Among the animal species, fish are the inhabitants that cannot escape from the detrimental effects of these pollutants (Olaifa et al. 2004) and are therefore widely used to evaluate the health of aquatic ecosystems as pollutants which build up in the aquatic food chain can accumulate and cause adverse effects including mortality (Farkas et al. 2002). Due to lack of adequate capacity, heavy metal contamination monitoring has been rare in Lake Naivasha in Kenya despite frequent calls by researchers for such monitoring. Cadmium (Cd), lead (Pb) and copper (Cu), selected in this study, are regarded as serious pollutants of aquatic ecosystems because of their environmental persistence, toxicity and ability to be incorporated into food chains (Forstner and Wittmann 1983) and hence the required obligatory monitoring of their concentrations by WHO and FAO (Staniškienė et al. 2009). In addition Pb and Cd are some of the heavy metals linked most with human poisoning. Cu is required in small amounts as an essential element, but is toxic in certain critical doses. Although some research has been done in Lake Naivasha, including speciation studies on some of the heavy metals in selected sites around the lake, including the Malewa river Mouth, in 2003 (Kamau et al. 2007) and analysis of As, Co, Cr, Cu, Ni, Pb and Zn to determine the background geochemical contributions (Tarras-Wahlberg et al. 2002), none has directly correlated heavy metal concentrations in sediments, water and fish. Further, no studies have addressed the potential impact of the recent commercial horticultural/floricultural activities along the lake with respect to these heavy metals. The objective of this study was to determine the concentrations of Cd, Cu and Pb in surface water, sediment and *C. carpio* muscle tissue samples from selected sites within Lake Naivasha, Kenya, and to assess the potential impact of the recent anthropogenic activities on their concentration levels.

Methodology

Study area

Lake Naivasha and its catchment characteristics

Lake Naivasha (0.45°S, 36.26°E), located at an elevation of 1,890 m above sea level, is a shallow freshwater lake in Kenya's Rift Valley, with an approximate area of 100 km^2 and a depth of 3–6 m (Hickley et al. 2004). It is a Ramsar site threatened by recent extensive human development activities in its catchment. Some of the activities that threaten the lake's ecosystem include the disposal of untreated effluents from industrial and human settlements, discharge of contaminated irrigation wastewater from small- and large-scale horticultural farms and inflow of rivers from its upper catchment where wheat, fodder, maize and cattle farming is practised (Kitaka et al. 2002; Becht et al. 2005; Mireri 2005; Owiti-Otianga and Osewe 2007). The effluents which get into the lake vary in composition and quantity and contain contaminants such as heavy metals. Some of the main sources of heavy metals into the lake include natural geochemical processes and heavy usage of agrochemicals such as fertilizers and pesticides in its catchment (Tyagi and Mehra 1990; Alloway and Aynes 1993). The lake is shallow and has no surface outlet and therefore there is potential accumulation of contaminants in sediment, water and biota. Fish, particularly the benthivorous *C. carpio*, which forms 93% by composition of all fishes in the lake, is likely to be impacted by these contaminants and therefore provides a good biological indicator (Hickley et al. 2004; Batvari et al. 2007). The lake gets its water from three rivers; Malewa (contributing about 90% of surface inflow), the Gilgil and Karati (Figs. 1, 2). Malewa is perennial, has tributaries originating from the slopes of Nyandarua (3,700 m above sea level), passes through agricultural areas and discharges directly into the lake. Some of its sediment-laden plumes reach up to about 500 m into the lake (Everaard et al. 2002). Gilgil, arising from 2,700 m above sea level, is also perennial and passes through Gilgil town carrying effluent from municipal wastes and pastoralist and agricultural activities. Karati enters the lake through various distributaries/channels which are not perennial. The river starts from Kinagop plateau (2,600 m above sea level) and passes through a catchment with various agricultural farming activities. The natural geochemical and erosion processes, wash off during rainfall as well as anthropogenic disturbances in the upper catchments of these rivers influence the heavy metal loads in the northern part of Lake Naivasha. Distribution within the lake water due to water currents is also evident and heavy metal-laden particulate matter can be transferred to other

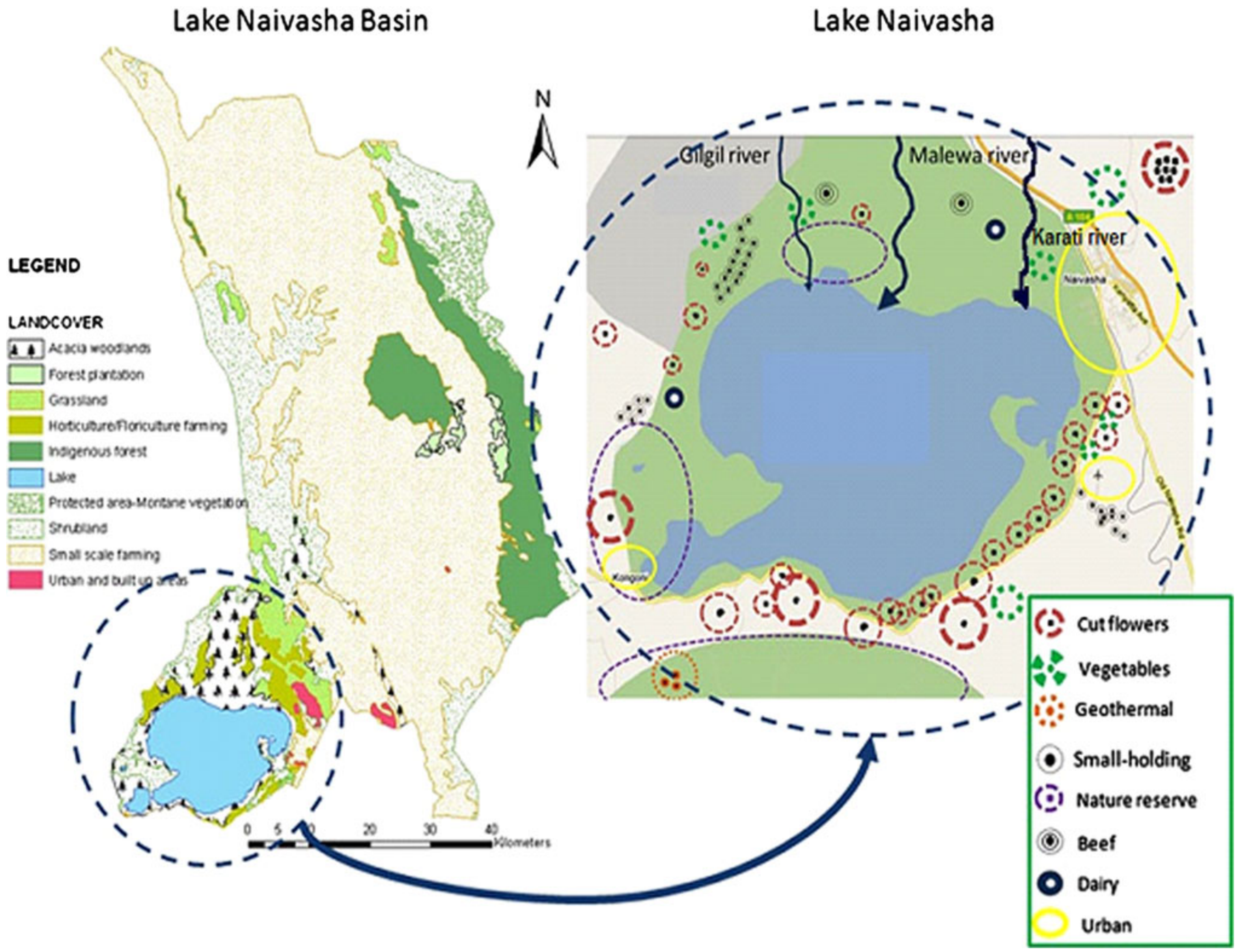


Fig. 1 Socio-economic activities surrounding Lake Naivasha (WWF 2010)

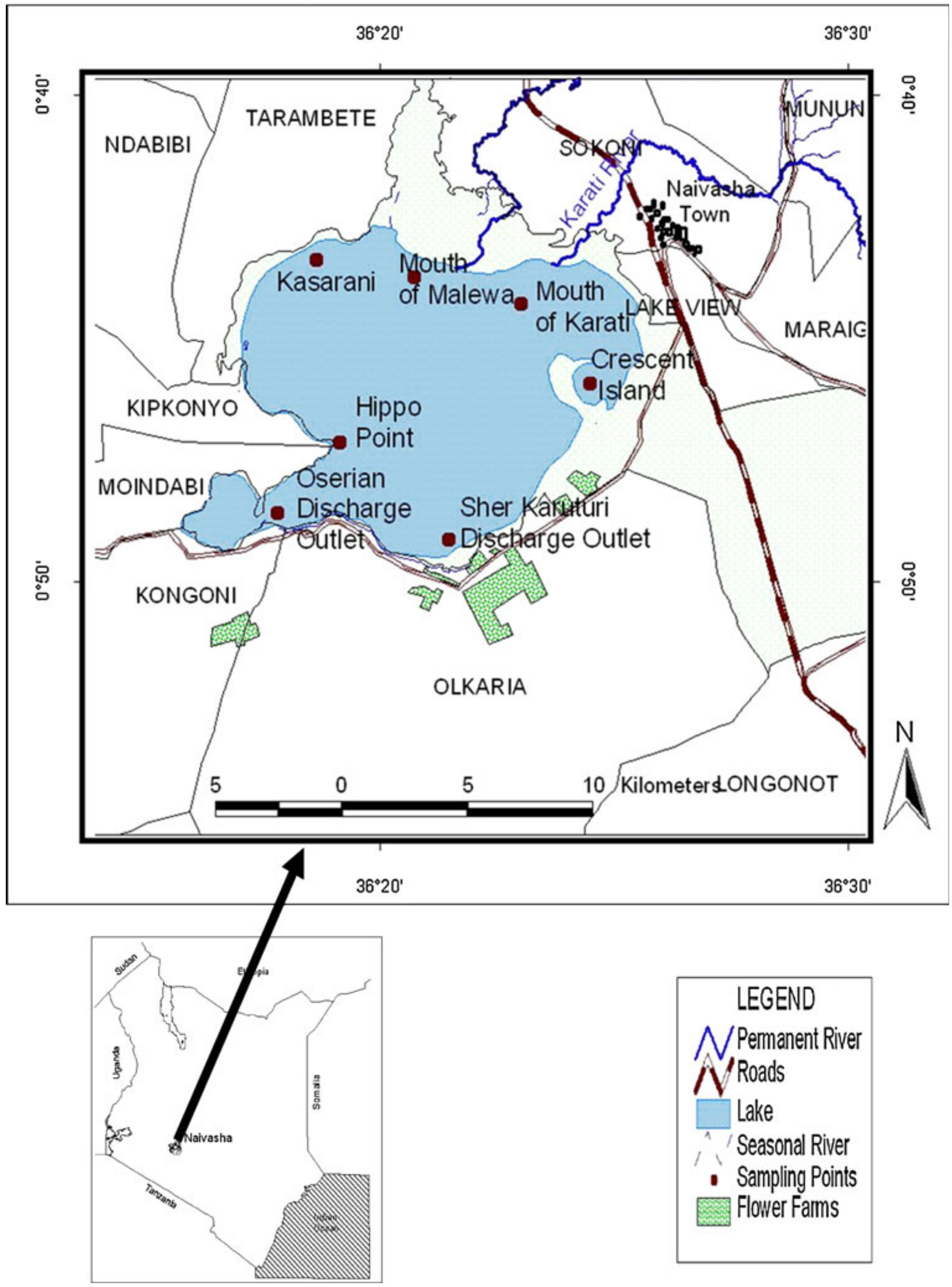
parts within the lake. The southern part of the lake (Fig. 1) is exposed to human activities including municipal and industrial waste disposal, abstraction of water for irrigation and intensive horticultural farming and use of fertilizers and pesticides which would influence heavy metal concentrations and distribution in the lake. The physical and biological changes as well as the various activities within the Lake Naivasha catchment which form a strong background of this study, have been described in detail in numerous earlier publications including those of Harper et al. (1995), Becht et al. (2005), Everaard et al. (2002), Everaard and Harper (2002), Kitaka et al. (2002), Tarras-Wahlberg et al. (2002) and Mireri (2005). In particular, some of the changing characteristics such as drop in water levels through imbalance in evaporation losses and depletion of the papyrus resulting in lack of water filtration can influence heavy concentrations as well as their distribution and bio-accumulation in various trophic levels in the food chain within the lake.

The catchment of Lake Naivasha is approximately 3,400 km^2 in area (WWF 2010) and has a mean annual temperature, varying with altitude, ranging from 25°C on the lake shore (1,890 m above sea level) to 16°C in the Aberdare mountains (3,700 m above sea level). The catchment has an annual bimodal rainfall pattern, with two rainy seasons in April–May (long rains) and October–November (short rains) and the annual average rainfall ranges from 1,350 mm in the higher altitude upper catchment to 600 mm near the shores of the lake. The sampling period in this study (late March–early June 2010) captured the long rainy season when agricultural activities were at their peaks and there was surface runoff carrying contaminants into the lake

The sampling sites

The sampling points (Fig. 2) were purposively chosen based on the possible routes of heavy metal residues into the lake

Fig. 2 Lake Naivasha: the study area



and included undisturbed areas which served as control. Areas with intensive agricultural activities and wetland discharge outlets around the lake represented disturbed areas due to the potent influx of contaminants into the aquatic ecosystem. Three chosen sites represented the discharge points for the floriculture farms which form a major agricultural activity around the lake and included Sher Karuturi, Kasarani and Oserian discharge outlets, respectively. The Mouths of Rivers Malewa and Karati served as principal sample sites together representing upstream natural processes, anthropogenic activities and possible contamination sources from their catchments as they channel used surface water into the lake. In their course downstream, many small-scale farmers divert water from portions of the two rivers into their farms for irrigation purposes and could potentially contaminate their waters with agrochemical residues which they eventually discharge into the lake. Hippo Point and Crescent Island characterized by minimal anthropogenic activities; mostly boating and fishing, served as undisturbed areas and hence control sites.

Sampling and sample preparation

Samples were randomly collected in triplicates from the seven sampling sites along Hippo Point, Kasarani, Mouth of Malewa, Mouth of Karati, Crescent Lake, Sher Karuturi and Oserian discharge outlet. In situ measurements were also undertaken for water quality parameters namely dissolved oxygen (DO), pH, water temperature (°C), electrical conductivity (μS/cm) and total dissolved solids (TDS) using the Hydro lab YSI meter model 85. A total of 84 *C. carpio* were assayed.

Sampling bottles were pre-cleaned thoroughly with detergent, soaked overnight in 6% nitric acid and thereafter rinsed well with distilled water. These were then stored in a dust-free place to avoid contamination. In the lake, a sample of 500 mL of surface water was taken by immersing the bottles and lifting them up. Immediately after, 4 mL of nitric acid was then added to the water samples to adjust the pH and maintain the heavy metals in solution. In the laboratory, the water samples were filtered into 100 mL pre-cleaned plastic bottles through Whatman No. 42 to remove any suspended organic materials and further prevent microbial growth, flocculation and adsorption on container surfaces. The water samples were then stored at 4°C in the refrigerator awaiting analysis.

Bottom surface sediment samples were taken from the sites (at an average depth of 3 m) in triplicates using a stainless steel Ekman grab sampler, stored in PTFE polythene bags to avoid contamination for transportation to the laboratory. In the laboratory, samples were dried in the oven overnight at 110°C; before crushing in a mortar and pestle and sieving using a 2 mm mesh to remove plant parts and debris. One-gram (dry weight) portions were then weighed into a 50-mL Pyrex digestion tube with 10 mL mixture of concentrated nitric acid and concentrated hydrochloric acid (4:1, aqua regia). The mixture was digested for 3 h in a digestion block at 100°C, the contents filtered through a 0.45 μm Whatman No. 42 filter paper into a 50-mL volumetric flask and then made up to volume with double-distilled water after addition of 1.5 mg/mL of strontium chloride (analytical grade, $SrCl_2 \cdot 6H_2O$). The extracts were analyzed for Cd, Cu and Pb by FAAS at wavelengths of 228.8, 324.7 and 283.3 nm, respectively, and calibration standards in the range of 0.1–0.6 mg/kg.

Freshly caught *C. carpio* were bought from local fishermen who were fishing at the different sampling sites and placed in a cool box before being taken to the laboratory for further processing and analysis. Research scientists from Kenya Marine and Fisheries Research Institute (KEMFRI) were consulted in the field for purposes of *C. carpio* identification. In the laboratory, *C. carpio* samples were washed with distilled water, scales removed and only muscle tissues without bone were taken for extraction and analysis. Two portions of 10 cm^2 area of wet fish muscle were cut and homogenized in a pestle and mortar. The digestion mixture for fish sample analysis was prepared consisting of 0.42 g selenium powder (catalyst), 14 g lithium sulphate (to improve the FAAS efficiency), 350 mL hydrogen peroxide and 420 mL sulphuric acid in an ice bath (Okalebo and Gathua 1993). Then, 10 mL of the digestion mixture was added to the 2 g wet weight (ww) of fish muscle in the digestion tubes for digestion in a digestion block for 2 h at 360°C until clear solutions were obtained. Digests were then left to cool to ambient temperatures (25°C) and the resulting solutions filtered using 0.45 μm Whatman No. 42 filter paper and volume topped to 100 mL using distilled water for analysis as explained above.

Chemical and data analysis

A flame atomic absorption spectrophotometer (FAAS), a Thermo Jarrell Ash AA/AE spectrophotometer S11 model was used in the analysis. All sample preparations and analysis were carried out using standard methods of analysis. The concentrations of the metals were assayed in triplicates by use of FAAS with acetylene flame. The accuracy of the instrument was checked by triplicate analysis of same samples. In addition, a standard and a blank sample were run after every seven samples to check instrumental drift. A series of standards were prepared for instrument calibration by serial dilution of a working solution (100 mg/L) prepared from analytical grade stock solutions (1,000 mg/L) obtained from BDH Poole and Sigma Aldrich. The percentage recoveries were determined for all metals. Calibration curve method was used to quantify the heavy metal concentrations. The concentrations of the heavy metals in various matrices were presented as arithmetic mean with standard deviation (mean ± standard deviation). All statistical analyses were done at $p = 0.05$ significance using ANOVA SIGMA STAT.

Results and discussion

Water quality

Table 1 shows the results of the water quality parameters that had been determined in situ at the study sites. Data show an average of four measurements taken at each of the seven sampling sites. The recorded limnological parameters were within the required WHO drinking water desirable limits in terms of pH range, electrical conductivity, total dissolved solids and dissolved oxygen concentration, respectively. The main observations that can be mentioned

Table 1 Limnological parameters obtained during sampling in Lake Naivasha compared with those of other lakes in Kenya

Site	pH	Temp (°C)	Transp (cm)	Conductivity (μS/cm)	TDS (mg/L)	DO (mg/L)
Hippo Point	8.53 ± 0.93	23.53 ± 1.67	34	354.5 ± 21.92	175.5 ± 21.92	6.42 ± 0.31
Kasarani	7.80 ± 0.60	22.30 ± 0.43	28	344.5 ± 7.77	171.5 ± 12.02	5.24 ± 1.64
Mouth of Malewa	8.66 ± 1.05	23.16 ± 2.91	24	343.0 ± 15.55	170.0 ± 8.48	6.50 ± 1.83
Mouth of Karati	8.49 ± 0.71	23.36 ± 1.40	26	339.0 ± 12.72	169.5 ± 6.36	6.45 ± 1.20
Crescent Island	8.59 ± 0.33	23.66 ± 1.17	55	373.0 ± 16.97	187.5 ± 6.36	6.50 ± 0.70
Sher Karuturi	7.76 ± 0.86	22.46 ± 1.22	25	346.0 ± 14.14	162.0 ± 2.82	6.50 ± 0.70
Oserian outlet	8.89 ± 0.68	23.70 ± 2.33	26	369.5 ± 34.64	181.0 ± 15.55	6.80 ± 0.84
WHO (1984)	6.50–8.50			1,500	1,000	4.50–7.50
L. Naivasha[a]	9.2	20	80	320	nl	nl
L. Nakuru[a]	10.3–11.3	19–20	6–10	22,000–27,500	nl	nl
L. Bogoria[a]	10.8–10.9	28–50	5	12.500–14,500	nl	nl
L. Elementaita[a]	10.1–11.1	22–48	5	34,000–65,000	nl	nl
L. Baringo[a]	8.2–8.7	29–31	5	920–1,000	nl	nl
L. Kanyaboli[a]	7.4–8.0	24–27	0.30–0.45	360–725	nl	nl
L. Victoria[b]	7.1–8.1	24–28	5–180	91.8–220	nl	3.8–7.2

Temp temperature, *Transp* transparency, *TDS* total dissolved solids, *DO* dissolved oxygen, *WHO* WHO desirable and maximum allowable limits for drinking water, *nl* not in literature cited

[a] Ochieng et al. (2007)

[b] Ochieng et al. (2006); $n = 4$

include lower dissolved oxygen concentration at Kasarani and lower transparency of the water at Mouth of Malewa which could be due to presence of algae, as this part of the lake is least disturbed. The limnological data are also compared with those of other freshwater systems in Kenya. These parameters indicate that Lake Naivasha is suitable for aquatic life and for human use. The lake is slightly alkaline but the pH level is comparable with that recorded earlier by Ochieng et al. (2007). The electrical conductivity represents the quantity of dissolved salt in the freshwater and has been used by researchers as a general indication of their potential productivity. The conductivities in Kenya are known to be influenced by the carbonate salts which account for up to 80% of the conductivity in most cases, the remaining electrolytes including phosphates, and nitrates existing in relatively lower concentrations (Ochieng et al. 2006). It is expected that the higher the electrical conductivity of the water, the higher the water pH (Ochieng et al. 2006) and this is also evident in the other closed Rift Valley lakes including Lakes Nakuru, Bogoria and Elementaita. These limnological parameters can also vary from one location to another on the same water body and therefore the slight differences seen in the values of these Lake Naivasha parameters are expected. The massive fish kills, observed in February 2010, caused by rapid changes in water quality including a decrease in oxygen levels to zero leading to hypoxic conditions as well as an increase in TDS from 242 and 453 mg/L, respectively, indicate the important need to avoid localized degradation of water quality (Gichuki et al. 2010). These rapid physico-chemical changes were reportedly caused by a drop in water level to 1.5 m and an inflow of floodwaters containing decaying vegetation, animal dung and other wastes during El Nino rains (Gichuki et al. 2010).

Heavy metal concentrations in water

Overall, high % recoveries of 88, 89, 87 (sediment), 89, 92, 90 (water) and 91, 93, 96 (fish muscle) were obtained. The results in Table 2 indicate that lead is the most predominantly detected metal in water samples but only in samples from the Mouths of Rivers Malewa and Karati and from Sher Karuturi and Oserian discharge outlets. The concentrations were, however, low and in the ppb range. Cu and Cd concentrations were only detected at the Sher Karuturi discharge canal indicating possible significant inflows from the flower farms. Most of the metal concentrations were below quantification limits (μg/L) of 100 (Pb), 30 (Cu) and 10 (Cd) as indicated in Table 2. The amounts of Pb, Cu and Cd at Hippo Point, Kasarani and Crescent Island were, as expected, below quantification limits. At Sher Karuturi, all the three metals, Pb, Cd and Cu were detected, whereas at Oserian outlet only Pb was detected, with Cd and Cu being below quantification limits. Elevated levels of Pb concentrations in water samples from Sher Karuturi and Oserian outlet are attributable to inflow from the flower farms. The high concentrations of Pb in water at these sites are of concern because Pb is among heavy metals, such as Hg, As,

Table 2 Heavy metal concentrations in water and sediment

Sampling site	Water (μg/L)			Sediment (mg/kg dry weight)		
	Pb	Cd	Cu	Pb	Cd	Cu
Hippo Point	<100.00	<10.00	<30.00	17.11 ± 0.10	2.09 ± 0.003	3.00 ± 0.005
Kasarani	<100.00	<10.00	<30.00	26.75 ± 0.09	2.19 ± 0.003	8.22 ± 0.010
Mouth of Malewa	179.83 ± 0.01	<10.00	<30.00	53.07 ± 0.07	2.74 ± 0.004	8.48 ± 0.101
Mouth of Karati	127.49 ± 0.01	<10.00	<30.00	47.37 ± 0.09	3.28 ± 0.003	3.66 ± 0.011
Crescent Island	<100.00	<10.00	<30.00	20.47 ± 0.00	1.18 ± 0.004	3.00 ± 0.010
Sher Karuturi	108.63 ± 0.10	10.06 ± 0.003	32.33 ± 0.01	34.21 ± 0.06	2.38 ± 0.003	5.85 ± 0.005
Oserian outlet	108.63 ± 0.11	<10.00	<30.00	36.84 ± 0.18	5.58 ± 0.002	6.36 ± 0.011
KEBS[a]	50	nl	100			
WHO HDL[b]	nl	nl	50			
WHO MPL[c]	100	10	1,000			
WHO TC[d]	100	10	2×10^{d}			
LEL				31.0	0.60	16.0
TEC				35.8	0.99	31.6
SEL				250	10.0	110.0
L. Naivasha[e]	42.1	8.0	4.70	25.4	0.73	10.33
L. Nakuru[e]	106–503	3.0–43.0	5.0–100	10.9–18.5	0.39–0.57	1.46–3.70
L. Bogoria[e]	38–313	5.0–41	10–90	21.4–39.0	0.20–0.92	1.95–4.68
L. Elementaita[e]	38–188	3.0–25.1	5.0–40	14.7–28.3	0.05–1.18	5.85–9.26
L. Baringo[e]	nd-65.1	2.0–5.0	5.0–20.2	16.6–21.8	0.57–0.76	15.1–21.0
L. Victoria[f]	7.0–44.4	nd-3.1	5.1–25.0	22.5–186.1	0.19–1.35	20.4–57.3
L. Victoria[g]	<3.83	<1.79	<1.53–3.86	31.1–138	0.73–1.91	22.8–100.0
Back[h]				23 ± 3.7	0.20 ± 0.1	21 ± 6.4
Shale[i]				20	0.30	45

Data presentation: mean ± standard deviation, $n = 3$, quantification limits: Pb—100,000 μg/L, Cd—10.000 μg/L and Cu—30.000 μg/L. The concentrations in water refer to acid soluble metals

nl not in literature cited, *LEL* lowest effect level in sediment, *TEC* threshold effect concentration in sediment, *SEL* severe effect concentration in sediment (Öztürk et al. 2009)

[a] Kenya Bureau of Standards drinking water limits

[b] WHO highest desirable level in drinking water

[c] WHO maximum permissible level in drinking water

[d] WHO threshold concentration for aquatic life tolerance (safe for most fish)

[e] Ochieng et al. (2007)

[f] Ochieng et al. (2006)

[g] Ongeri et al. (2009a)

[h] Background levels (Adamo et al. 2005)

[i] Average shale concentration (Jain 2004)

and Cd, detected frequently in fertilizers and linked most to human poisoning. These results also show the impact of anthropogenic activities upstream in the catchment of the lake. Although Cd and Cu were below quantification limits at the Mouths of Rivers Malewa and Karati, high Pb levels were detected at these sampling points which could indicate Pb coming in through wash off from upstream; most likely from the roads because of the use of leaded gasoline. The use of leaded gasoline was banned in 2006 in Kenya but Pb may still be persisting in the environment even though no new residues are likely to be added into the environment from this source now. Pb residues could also be coming from upstream bound to sediment and other particulates from natural sources and from anthropogenic activities including farming. High levels (μg/L) of Cd (range 3–40), Cu (range 5–100) and Pb (range 106–563), attributable to anthropogenic sources, have also been reported in L. Nakuru (Ochieng et al. 2007). The water at Kasarani, Hippo Point and Crescent was, as expected, found to be relatively clean with respect to the three heavy metals.

The concentrations of the three metals in water were also compared with those of other lakes in Kenya as well as with Kenyan and WHO acceptable standards which indicated that Lake Naivasha water, especially at the Mouths of the Rivers Malewa and Karati and at Sher Karaturi and Oserian outlets, may be polluted with Pb since the concentrations in water samples from these sampling points are higher than the KEBS drinking water limits as well as the WHO highest desirable level in drinking water, the WHO maximum permissible level in drinking water and WHO threshold concentration for aquatic life tolerance, respectively (Table 2). The water concentrations of Pb at these contaminated sites were only comparable with Lake Nakuru but were above all the levels detected in most other Kenyan lakes (Table 2). Cu and Cd were, however, within acceptable limits because their concentrations were lower than the Kenyan and WHO endpoints and comparable with those of other Kenyan rift valley lakes.

Heavy metal concentrations in sediments

The heavy metal contents in sediments (mg/kg dry weight) are also presented in Table 2 with quantification limits of 0.1 (Pb), 0.01 (Cd) and 0.03 (Cu), respectively. The data indicate that Pb is the most concentrated followed by Cu and Cd. The highest Pb and Cu contents were found in sediment samples from the Mouth of Malewa River which could be due to the inflow of contaminated sediments from the catchment as explained in the previous section. The data also indicate that Cd and Cu concentrations in sediments are low which can be explained by assuming that most of the Cd and Cu inflows into the lake are still in dissolved form, still suspended in water and not settled at the bottom due to water turbulence and/or that most of the Cd and Cu is taken up by aquatic plants. The Crescent Lake and Hippo Point, as expected, had the lowest levels of these metals in the sediments, most likely due to lack of discharge canals and other inflows. However, the impact of anthropogenic activities is shown by the high concentrations of Pb. The mean heavy metal concentrations in all sediments showed wide variations ($p < 0.05$) among sites, with ranges (mg/kg) from 17.00–37.03 (Pb), 1.18–5.58 (Cd) and 2.99–8.578 (Cu).

The sediments from the Mouths of Rivers Malewa and Karati, Sher Karuturi and Oserian outlet indicated Pb concentrations above the TEC whilst Hippo Point, Crescent Island and Kasarani had concentrations below the LEL (Table 2). The TEC level marks the significance of this study as it is the concentration at which heavy metals are beyond permissible lowest effect level and can have significant effects on ecological components. The Mouths of Malewa and Karati are key sources of sediment deposition into the lake as they originate from the upper catchment areas, as described earlier, and are the major inlets into the lake. In addition, a major highway above the Malewa Bridge could also be a contributing factor with respect to motor vehicle Pb emissions and deposition on roadside soil. The Sher Karuturi and Oserian flower farm discharge outlets showed significant Cd and Cu metal loads as well, which could be attributed to the agrochemicals use, although Cu concentrations were below the LEL (Table 2). The Mouth of River Malewa still had the highest concentration of these metals in sediments showing that they emanate from natural processes through erosion and anthropogenic activities upstream.

Heavy metal concentrations in Cyprinus carpio muscle tissues

The results of the *C. carpio* assay presented in Table 3 indicate that Pb is the most predominant metal in the fish followed by Cd and Cu, respectively. The highest Pb content was found in *C. carpio* caught at the Mouth of Malewa river with the lowest concentration in *C. carpio* caught at Crescent Island. The ranges of heavy metals in muscle (in mg/kg wet weight) were 1.16–2.30 (Cu), 1.06–1.73 (Cd) and 5.12–58.16 (Pb).

The results also show that fish from Lake Naivasha are more exposed to these heavy metals than fish from Lake Victoria. The difference in contamination levels can be explained by the differences in the two species, *L. niloticus* and *C. carpio*, and differences in their feeding habits. However, considering water, sediment and fish concentration data, together, the results indicate that Lake Naivasha is more polluted in terms of Pb and Cd. The concentration levels of Pb and Cd in edible muscle of *C. carpio* are much higher than those in edible muscle of *L niloticus* from Winam Gulf of Lake Victoria and are also above the maximum allowable FAO limits for edible portions of fish.

Conclusions and recommendation

The study shows that Lake Naivasha, in some parts, is polluted with Pb, Cu and Cd which can be originating mostly from the lake's upper catchment activities and the surrounding horticultural farming activities. The important potential pollution sources into the lake include the flower farms and Mouths of River's Malewa and Karati. Based on the chemical composition of samples collected from Sher and Oserian discharge outlets, the horticultural farming sector is a significant source of Cu, Pb and Cd. This is thought to be due to the intensive use of agrochemicals containing these heavy metals. There is need, therefore, to carry out more investigations within the farms and in the canals in order to confirm this conclusion and initiate mitigation measures, if necessary. However, samples collected from Crescent Island, Hippo Point and Kasarani

Table 3 Heavy metal concentrations (mg/kg wet weight) in *C. carpio* muscle compared with other freshwater fishes from other lakes and with FAO acceptable standards

Sampling sites	Pb	Cd	Cu
Hippo Point	33.63 ± 0.160	1.59 ± 0.002	1.66 ± 0.005
Kasarani	15.07 ± 0.176	1.73 ± 0.002	<0.03
Mouth of Malewa	58.11 ± 0.050	1.06 ± 0.004	2.12 ± 0.011
Mouth of Karati	48.03 ± 0.081	1.07 ± 0.003	<0.03
Crescent Island	5.21 ± 0.088	1.60 ± 0.003	<0.03
Sher Karuturi	41.23 ± 0.044	1.13 ± 0.002	2.29 ± 0.006
Oserian Outlet	29.46 ± 0.101	1.27 ± 0.002	1.83 ± 0.011
Lake Victoria[a]			
Lates niloticus	0.08–0.170	0.029–0.035	0.53–1.03
Rastrineobola argentea	0.09–0.31	0.032–0.033	1.15–1.56
Taiwan[b]			
Farmed tilapia	0.04–0.75	nl	0.32–1.48
Mexico[c]			
Oyster muscle	4.13–8.49	1.55–7.45	17.50–166.30
MAL[d]	2.0	0.3	20

Data presented as mean ± SD, $n = 3$, quantification limits: Pb—0.1 mg/kg, Cd—0.01 mg/kg, Cu—0.03 mg/kg

nl not found in literature

[a] Muscle of fish from Dunga Beach, Kisumu (Ongeri et al. 2009b)

[b] Muscle of fish from fish farms (Min-Pei et al. 2009)

[c] Soft tissue of *C. corteziensis* from lagoons (Frias-Espericueta et al. 2009)

[d] Maximum allowable concentration in edible portions of fish (Nauen 1983)

areas, which are not impacted by human activities, showed relatively low concentrations of Cu, Pb, and Cd.

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References

Adamo P, Arienza M, Imperato M, Nuimo D, Nurdi G, Stanzione D (2005) Distribution and partition of heavy metals in surface and subsurface sediments of Naples city port. Chemosphere 61:800–809

Alloway BJ, Aynes DC (1993) Chemical principles of environmental pollution. Chapman and Hall, New York

Batvari BPD, Kamala-Kannan S, Krishnamoorty KS, Lee KJ, Jayaprakash M (2007) Heavy metals in two fish species (*Carangoide malabaricus* and *Belone stronglurus*) from Pulicat Lake, North of Chennai, Southeast Coast of India. Environ Monit 79:1509–1800

Becht R, Odada EO, Higgins S (2005) Lake Naivasha: experience and lessons learned brief. In: Lake basin management initiative: experience and lessons learned briefs. Including the final report: managing lakes and basins for sustainable use, a report for lake basin managers and stakeholders. International Lake Environment Foundation Committee (ILEC), Kusatsu, pp 277–298

Censi P, Spoto SE, Saiano F, Sprovieri M, Mazzola S, Nardone G, Di Geronimo SI, Punturo R, Ottonello D (2006) Heavy metals in coastal water systems: a case study from the northwestern Gulf of Thailand. Chemosphere 64:1167–1176

Everaard M, Harper DM (2002) Towards the sustainability of the lake Naivasha Ramsar site and its catchment. Hydrobiologia 488:191–203

Everaard M, Vale JA, Harper DM, Tarras-Wahlberg H (2002) The physical attributes of the lake Naivasha catchment rivers. Hydrobiologia 488:13–25

Farkas A, Salanki J, Specziar A (2002) Relation between growth and the heavy metal concentration in organs of bream *Abramis brama* L. populating Lake Balaton. Arch Environ Contam Toxicol 43:236–243

Forstner U, Wittmann GTW (1983) Metal pollution in the aquatic environment, 2nd ed. Springer, New York

Frias-Espericueta MG, Osuna-Lopez L, Banuelos-Vargas I, Lopez-Lopez G, Muy-Rangel MD, Izaguirre-Fierro G, Rubio-Carrasco W, Meza-Guerrero PC, Voltolina D (2009) Cadmium, copper, lead and zinc contents of the mangrove oyster, *Crassostrea corteziensis*, of seven coastal lagoons of NW Mexico. Bull Environ Contam Toxicol 83:595–599

Gichuki J, Morara G, Waithaka E, Njiru M, Mugo J, Werimo K, Wakwabi E (2010) Massive fish kills in Lake Naivasha Ramsar Site in February 2010 was caused by rapid changes in water quality occasioned by El Nino phenomenon. First Alexander von Humboldt Alumni Kenya Conference. Book of Abstracts. 24–26th November, 2010. Meridian Court Hotel, Nairobi, Kenya

Harper DM, Adams C, Mavuti K (1995) The aquatic plant communities of the Lake Naivasha wetland, Kenya. Wetlands Ecol Manage 3(2):111–123

Hickley P, Muchiri SM, Britton JR, Boar RR (2004) Management and ecological note. Discovery of carp, *Cyprinus carpio*, in the already stressed fishery of Lake Naivasha. Kenya. Fish Manag Ecol 11:139–142

Jain CK (2004) Metal fractionation study on bed sediments of River Yamuna, India. Water Res 38:569–578

Kamau NJ, Gachanja A, Ngila C, Kazungu MJ, Gatagwu J (2007) The seasonal and spatial variations of labile copper, iron, manganese, lead and zinc sediment fractions in Lake Naivasha, Kenya. Lakes Reserv Res Manag 12:303–313

Kitaka N, Harper DM, Mavuti KM (2002) Phosphorous inputs into Lake Naivasha, Kenya, from its catchment and the trophic state of the lake. Hydrobiologia 488:73–80

Klavinš M, Briede A, Rodinov V, Kokorite I, Parele E, Klavina I (2009) Heavy metals in rivers of Latvia. Sci Total Environ 262:175–184

Min-Pei L, Hui-Tsung H, Ruei-Hao S, Chin-Ching W, Yu-Syuan H (2009) Health risks of consuming heavy metals in farmed tilapia in central Taiwan. Bull Environ Contam Toxicol 83:558–564

Mireri C., 2005. Challenges facing the conservation of Lake Niavasha, Kenya. FWU Topics of Integrated Watershed Management-Proceedings 3:89–98

Nauen CE (1983) Compilation of legal limits for hazardous substances in fish and fishery products, Circular No. 764. FIRI/C 764. Food and Agriculture Organization of the United Nations

Ochieng EZ, Lalah JO, Wandiga SO (2006) Heavy metals in water and surface sediments in Winam Gulf of Lake Victoria, Kenya. Bull Environ Contam Toxicol 77:459–468

Ochieng EZ, Lalah JO, Wandiga SO (2007) Analysis of heavy metals in water and surface sediment in five rift valley lakes in Kenya for assessment of recent increase in anthropogenic activities. Bull Environ Contam Toxicol 79:570–576

Okalebo RJ, Gathua WK (1993) Laboratory methods of soil and plant analysis: a working manual. Marvel EPZ, Nairobi

Olaifa FG, Olaifa AK, Onwude TE (2004) Lethal and sublethal effects of copper to the African Cat fish (*Clarias gariepnus*). Afr J Biomed Res 7:65–70

Omwoma S, Lalah JO, Ongeri DMK, Wanyonyi MB (2010) Impact of fertilizers on heavy metal loads in surface soils in Nzoia Nucleus Estate sugarcane farms in Western Kenya. Bull Environ Contam Toxicol 85:602–608

Ongeri DMK, Lalah JO, Wandiga SO, Schramm K-W, Michalke B (2009a) Levels of toxic metals in multisectoral samples from Winam Gulf of Lake Victoria. Bull Environ Contam Toxicol 82:64–69

Ongeri DMK, Lalah JO, Wandiga SO, Schramm K-W, Michalke B (2009b) Trace metals in *Lates niloticus* and *Rastrineobola argentea* samples for human consumption at Winam Gulf of Lake Victoria. Toxicol Environ Chem 91(2):233–240

Owiti-Otianga G, Osewe I (2007) Human impact on lake ecosystems: the case of Lake Naivasha, Kenya. Afr J Aquat Sci 32(1):79–88

Öztürk M, Özözen G, Minareci O, Minareci E (2009) Determination of heavy metals in fish, water and sediments of Avsar dam lake in Turkey. Iran J Environ Health Sci Eng 6(2):73–80

Simeonov V, Stratis JA, Samara C, Zahariadis G, Voutsa D, Anthemidis A (2003) Assessment of the surface water quality in Northern Greece. Water Res 37:4119–4124

Staniškienė B, Matusevičius P, Urbonavičius A (2009) Distribution of heavy metals in muscles of fish: concentrations and change tendencies. Environ Res Eng Manag 48:35–41, Kaunas, Technologija. ISSN 1392-1679

Tarras-Wahlberg H, Everaard M, Harper DM (2002) Geochemical and physical characteristics of river and lake sediments at Naivasha, Kenya. Hydrobiologia 488:27–41

Tyagi OD, Mehra M (1990) Textbook of environmental chemistry. Animol, New Delhi, pp 45–55

Weis JS, Weis P (1995) Swimming after embryonic or larval exposure to methyl mercury. Can J Fish Aquat Sci 52:2168–2173

WHO (1984) Guidelines for drinking water quality, recommendations. World Health Organization, Geneva, p 130

WWF (2010) Shared risk and opportunity in water resources: seeking a sustainable future for Lake Naivasha, Pegasys Strategy and Development, South Africa. Worldwide Fund Report