

## Heavy Metal Concentrations in Water, Sediments and Common Carp (*Cyprinus carpio*) Fish Species from Lake Naivasha, Kenya

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**Abstract:** Heavy metals are potentially toxic to organisms causing lethal and sub lethal effects. Above threshold levels, these metals have been shown to adversely affect both aquatic and terrestrial organisms. Human health may also be impacted negatively through consumption of metal-contaminated foods and water. Lake Naivasha, Kenya, like many freshwater bodies in developing countries is a source of fish and water for human consumption in Naivasha town and its environs. Ironically, the lake receives untreated floricultural, agricultural and industrial effluents from its catchment area. In the recent past, there have been unconfirmed reports that fish from this lake are contaminated with heavy metals mainly Cu, Hg, Cd and Pb to levels that are harmful to humans. It is against this background that this study was conducted to determine the sources of the aforementioned heavy metals in the lake, their concentrations in water and sediments and in common carp (*Cyprinus carpio*) that constitutes a major portion of the Lake Naivasha fishery. Water, sediment and fish samples were collected from purposefully selected sites in six sampling occasions during both the dry and wet seasons. Analyses for heavy metals in fish, sediment and water samples were done using an Atomic Absorption Spectrophotometer (AAS). The study findings indicate that the heavy metal concentrations in the water and sediments collected from impacted sites were significantly higher ( $p < 0.05$ ) compared to those from unexpected sites. In spite of this, the metal concentrations in water were significantly lower than those recommended by the WHO and USEPA as drinking water guideline values. Metal concentrations in *C. carpio* were also significantly lower ( $p < 0.05$ ) than the World Health Organization (WHO) recommended levels for fish intended for human consumption. Based on these findings, it is safe to conclude that drinking water and fish collected from Lake Naivasha do not pose immediate health risks to human health. Despite this observation, we recommend continuous monitoring of heavy metal concentrations in water and sediment in the lake given their potential for bioaccumulation and biomagnifications and likely adverse effects on aquatic organisms and humans.

**Keywords:** *Cyprinus carpio*, floriculture, heavy metals, Lake Naivasha, sediment quality, water quality

### INTRODUCTION

Metal-contaminated waters and sediments serve as sources of metals that can cause lethal and/or sublethal effects to stream macro invertebrates as well as fish and other higher organisms through food chain transfer (Jagoe *et al.*, 2002). Increased metal concentrations significantly reduce water and sediment quality (Taylor *et al.*, 1990) which may lead to fish kills (Pasava *et al.*, 1995), reduced survival and growth of macro invertebrates (Ogendi *et al.*, 2007c) and decreased taxa richness of other benthic macro invertebrates (Mize and Deacon, 2002; Ogendi *et al.*, 2008). In addition, adverse effects on the reproduction and recruitment of two endangered fish species (razorback sucker, *Xyrauchen texanus* and pike minnow, *Ptychocheilus lucius*) have also been attributed to elevated metal concentrations in surface water and sediments (Hamilton and Waddell, 1994; Deacon and Stephens, 1998). Some studies on this lake (Harper *et al.*, 2002)

have shown that birds such as the fish eagle may adversely be affected by consuming prey items that contain heavy metals. A recent study by Kamau *et al.* (2007) indicated that levels of lead in Lake Naivasha waters are high and the concentrations raise as one approaches the lake shore. Similar studies by Ochieng *et al.* (2007) also indicated unusually high concentration levels of selenium (1,050  $\mu\text{g/L}$ ) and lead (25.34  $\mu\text{g/L}$ ) in some areas of the lake.

Bonzongo *et al.* (1996) revealed relatively higher total mercury concentrations (THg) in the rivers feeding the lake compared to the lake THg concentrations that ranged from 1 to 2  $\mu\text{g/L}$ . In fish, the largemouth bass *Micropterus salmoides* from Lake Naivasha had THg concentrations that ranged between 4 and 95  $\mu\text{g/g}$  (Bonzongo *et al.*, 1996). These results clearly indicate that the THg concentrations increase up the food chain and hence the possibility of having higher concentrations in humans that consume fish from this lake. A study by Dorea (2003) indicated that the health

of Amazonian forest dwellers was adversely impacted through the consumption of mercury-contaminated fish caught from rivers receiving mine-tailings from gold-mining. Long-term exposure to methylmercury (MeHg) can adversely affect a child's neurodevelopment. Other studies have shown that the most common form of prenatal exposure to mercury is maternal fish consumption that caused premature births and neuro development disorders among children (Myers *et al.*, 2003). Further, a study by Campbell *et al.* (2003) indicated that mercury concentrations in large predatory Nile perch, weighing between 5 and 10 kg were exceedingly higher than the limits set by World Health Organization to protect frequent fish eaters, children under age 15 and the pregnant women plus their developing fetuses.

Elevated cadmium levels have been shown to be detrimental to survival, growth and reproduction of cladocerans, fish and birds (Scheuhammer, 1987; Diamond *et al.*, 1992). Lead is a non-specific poison affecting all body systems of various organisms. Increased metal loads in lake water and sediments are also a human health concern due to biomagnifications of metals along the aquatic and terrestrial food chains and food webs. Overall, human health risks are primarily due to the elevated concentrations of Hg, Pb, Cd, Ar and Se in water and fisheries that are part of the local people's diet. Consumption of arsenic-laden water and food crops rice in Southeast Asia including Bangladesh, India and the Bengal region in general has also been linked to several health conditions such as cancer of the skin, kidneys, bladder and lungs (Dipankar *et al.*, 1999; Shoko *et al.*, 2001). Cadmium has been linked to kidney and liver damage as well as osteoporosis and pulmonary emphysema as was the case in Japan where people consumed rice cultivated using cadmium-contaminated irrigation water. Osteoporosis, brittle nails and hair loss have been attributed to consumption of selenium-contaminated foods as was the case in China. Water and foods containing elevated copper and nickel have been linked to liver and kidney failure. This study sought to assess the sources and concentrations of selected heavy metals in water and sediments of Lake Naivasha on a spatial and temporal scale. Additionally, the study sought to determine the heavy metal levels in *Cyprinus carpio* fish species that constitute a major portion of the Lake Naivasha fishery.

## MATERIALS AND METHODS

**Sampling sites and sample collection:** Sampling sites were purposefully selected based on the research objectives (Fig. 1). As such, five sites receiving effluents from the watershed (i.e., one at River Malewa mouth, three at flower farm discharge points and one urban wastewater discharge point) were chosen to study the impact of metal contamination on water and fish at

Lake Naivasha. One site located at Crescent Island at least 400 m away from inflows of major discharge points was selected to represent sites that are considered less impacted by heavy metals. Two replicate water and sediment samples were collected from each of the six sampling sites during each sampling occasion. Samples were collected between January 2010 and February 2011. A total of 72 samples of water and sediment (2 replicates X 6 sites X 6 sampling occasions) were collected during the study period. Additionally, 72 fish for each of the selected fish species were collected during this study period. The sampling occasions were intended to capture the hydrologic variations experienced in the study area and thus enabled us to capture the spatial and temporal variations in heavy metal concentrations in water, sediment and fish.

### Sampling and analysis of heavy metals in water

**samples:** Water samples were collected using trace metal clean procedures (Shelton and Capel, 1994; Shafer *et al.*, 1997; APHA, 1998). All equipment used for sample collection, storage and analysis of heavy metals were pre-cleaned using high-purity nitric acid (GFS Chemicals Inc.) and rinsed with copious amounts of Milli-Q water to ensure that they are trace-metal free. After rinsing, the bottles were stored in double-bagged zip-lock polyethylene bags. Such cleaning and storage procedures ensured that there are no detectable metal contaminants in the sampling equipment (Shafer *et al.*, 1997). The samples were collected in polypropylene bottles and filtered immediately through 0.45  $\mu\text{m}$  and acidified with ultra-pure  $\text{HNO}_3$  to  $\text{pH} < 2$  and stored at  $4^\circ\text{C}$  prior to heavy metal analyses. Other water quality physico-chemical variables known to affect dissolved metals were measured (i.e., dissolved oxygen pH, electric conductivity) in the field according to APHA (1998). Heavy metals in the filtrate (0.45  $\mu\text{m}$ ) are here operationally defined as "dissolved". The study focused on the dissolved fraction as this fraction is more likely to have measurable biological effects on aquatic organisms (Di Toro *et al.*, 2000).

In addition, the dissolved metals have been shown to be similar to the exposure conditions used in toxicity tests (U.S. Environmental Protection Agency, 2002), allowing for comparisons between standard toxicity tests and field community surveys (Ogendi *et al.*, 2004a; Ogendi *et al.*, 2008). Metal concentrations were determined by the atomic absorption spectrophotometer (AAS). In brief, 15 mL of sample were transferred into a vial into which an internal standard containing 40  $\mu\text{g/L}$   $^6\text{Li}$ ,  $^{75}\text{Ge}$ ,  $^{115}\text{In}$  and  $^{209}\text{Bi}$  was added. 40  $\mu\text{g/L}$  of  $^{196}\text{Au}$  was added to the sample solutions to stabilize Hg. A standard calibration curve for all the analytes was established on standards prepared in a linear range from 1 ppb to 100 ppb. National Institute of Standards and Testing Reference material (NIST 1640) and procedural blanks were analysed for all selected heavy metals.

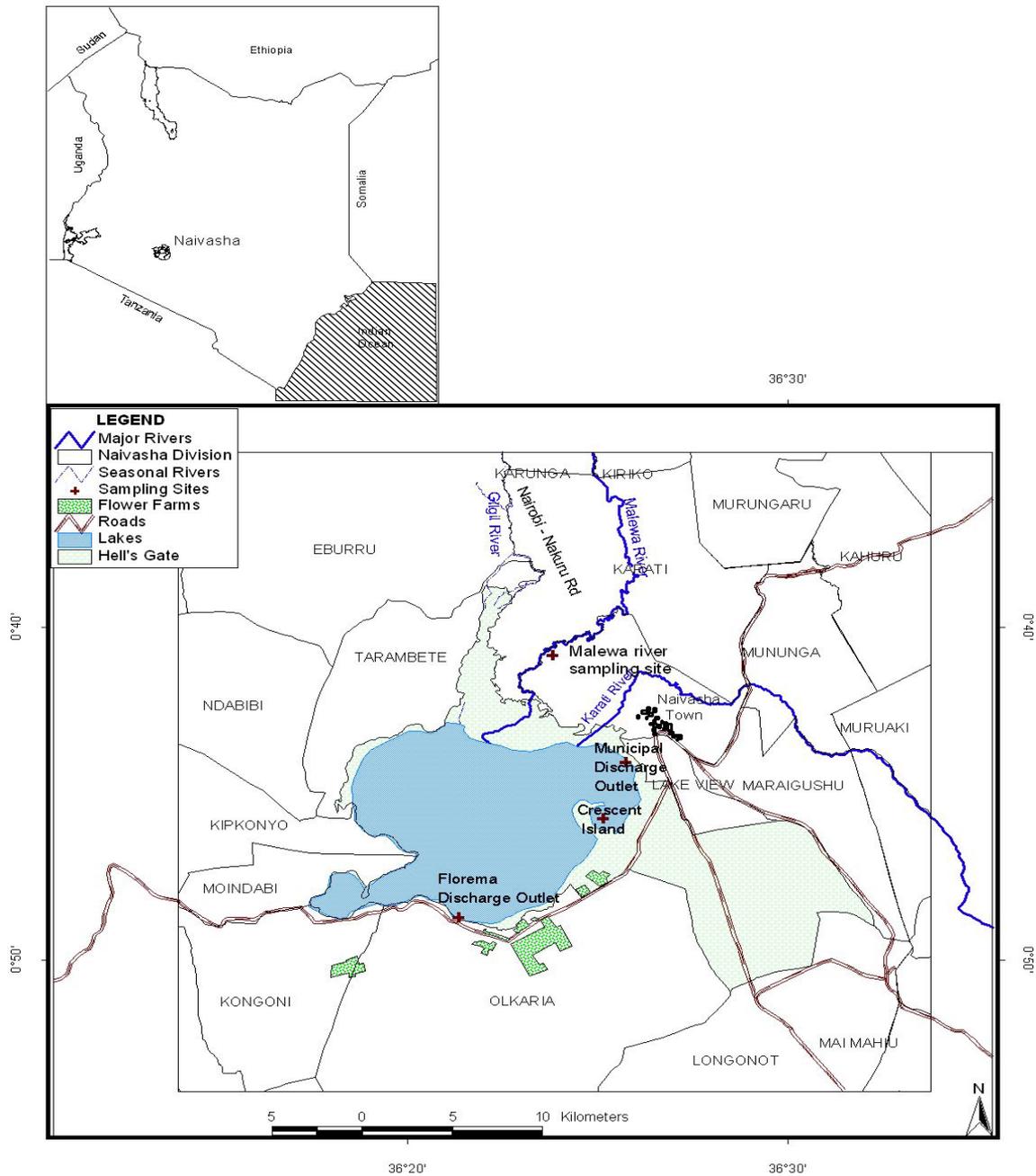


Fig. 1: Map of Lake Naivasha showing sampling sites

**Fish sampling and analysis for heavy metals:**

Gillnets and fish traps were used to capture fish for this study. Fish traps were is constructed at the selected sampling sites with the help of local fishermen. A total of 72 samples of fish (2 replicates X 6 sites X 6 sampling occasions) were collected for each species by the end of the study. Weight and total length measurements for two fishes for each of the selected species were recorded immediately after sampling. Thereafter, a 50-g sample of muscle tissue from each fish sample was taken according to methods described

in Campbell *et al.* (2003). Samples were wrapped in aluminium foil and stored on ice until transfer to a freezer. Heavy metal analyses on the fish samples were performed in a clean-room laboratory at the National Water and Sanitation Company (NAWASCO) Water Quality Lab, Nakuru.

Heavy metals in fish tissue samples were determined by digesting 50 mg of sample in ultra-pure nitric acid (HNO<sub>3</sub>) and Hydrofluoric acid (HF) and brought to a final volume of 100 mL in 2% ultrapure HNO<sub>3</sub>. Metal concentrations in the fish sample

were measured using the AAS. Standards were prepared in a linear range from 1 µg/L to 1000 mg/L. An internal standard consisting of Li-6, Ge, In, Tm and Bi were added to each fish sample and external standard. To ensure quality control and assurance, procedural blanks and analytical reference materials USGS-SDO-1 and USGS-SGR-1 were analysed. All equipment and glassware used in fish sample processing were HNO<sub>3</sub> washed and rinsed using Milli Q water.

#### Sediment sampling and analysis for heavy metals:

Sediment sampling and handling was performed following methods described in APHA (1998), USEPA (U.S. Environmental Protection Agency) (2000) and Shelton and Capel (1994). Two sediment samples were collected from each sampling site using a Petersen grab sampler (Cole-Parmer Company®, Vernon Hills, IL, USA) from the top 5 cm of the sediment. All samples were immediately stored at 4°C and transported to the laboratory for analyses. In the lab, the sediment samples were processed in similar way as were the fish samples described above.

**Statistical analyses:** The data was tested for normality and homogeneity of variance using Kolmogorov-Smirnov Normality Test ( $p \leq 0.05$ ) and Levene's Test for equal variances ( $p \leq 0.05$ ), respectively using (MINITAB® Statistical Software for Windows ver. 14). Using data that satisfied the assumptions of normality we compared the heavy metal concentrations in water and fish samples from the selected study sites using analysis of variance (ANOVA) to test for differences amongst sites and sampling occasions ( $\alpha = 0.05$ ). Non-parametric tests were applied to data that did not meet assumptions of normality and homogeneity of variance.

## RESULTS AND DISCUSSION

Significant differences were observed in dissolved oxygen concentrations with the highest values recorded in Crescent Island and Hippo Point water samples compared to samples from the impacted sites (e.g., Florema and Sher Karuturi) of Lake Naivasha ( $F = 8.7$ ;  $p < 0.05$ ; Table 1). Similar observations were made with regard to electrical conductivity, total dissolved solids and salinity (Table 1) with significantly lower values for both parameters being recorded in Crescent Island.

However, no significant differences were observed in pH and temperature among the sampling sites ( $p > 0.05$ ; Table 1).

**Heavy metals in water:** A one-way analysis of variance revealed that there were no significant temporal differences in heavy metal concentrations in water samples collected at Crescent Island ( $F = 0.67$ ;  $p = 0.6$ ). A similar pattern was observed for the remaining sampling sites ( $p > 0.05$ ). Pooled together, the concentrations of Cd, Cu and Pb (in ppb) in water ranged from 0.001, 0.002 and 0.011 to 0.06, 0.127 and 0.496, respectively. Comparatively higher metal concentrations were recorded in the anthropogenic ally impacted sites.

Copper is a vital element necessary for normal organism growth and metabolism and its uptake are regulated by physiological mechanisms according to nutritional demand. At high concentrations, Copper becomes toxic to the body. Copper was present in water samples from all sites but at levels below the WHO guidelines, with the lowest levels recorded at Crescent Island. This is contrary to a study by Olaifa *et al.* (2004a) where copper was not recorded in water samples both in wet and dry seasons. No significant differences in concentrations of Cd and Cu in water samples collected from the different sampling sites were observed ( $p > 0.05$ ; Table 2). However, the concentration of lead in Florema was significantly higher than those recorded at the other sampling sites ( $F = 12.5$ ;  $p < 0.05$ ). Nevertheless, the levels of the three heavy metals were significantly lower than WHO guideline values for drinking water (World Health Organization (WHO), 1993). Similar findings have been reported in related studies such as that of Ozturk *et al.* (2009) in Iran that indicated significantly lower metal concentrations in waters impacted by anthropogenic activities in the watershed. This implies that human health is not threatened by drinking water from Lake Naivasha. However, the use of this water for drinking and cooking may in the long-term cause adverse effects given the bioaccumulative nature of these metals. Additionally, the observed results imply that currently metal pollution at Lake Naivasha presents an ecological rather a human health concern. Similar findings were observed by Ogeni *et al.* (2007a and b) where heavy metal levels posed an ecosystem

Table 1: Means ( $\pm$ SE) of various physicochemical variables in water samples collected from Lake Naivasha

Site	pH	Temp	DO	EC	TDS	Sal
OS	7.9 $\pm$ 1.3	21.5 $\pm$ 3.2	5.6 $\pm$ 0.8	0.3 $\pm$ 0.10	0.25 $\pm$ 0.1	0.16 $\pm$ 0.1
FL	6.9 $\pm$ 1.1	22.4 $\pm$ 2.4	2.8 $\pm$ 0.3	0.42 $\pm$ 0.1	0.31 $\pm$ 0.1	0.23 $\pm$ 0.1
SK	7.2 $\pm$ 1.0	23.2 $\pm$ 2.4	3.8 $\pm$ 0.2	0.58 $\pm$ 0.2	0.35 $\pm$ 0.1	0.25 $\pm$ 0.1
HP	7.9 $\pm$ 1.3	20.3 $\pm$ 2.3	6.9 $\pm$ 1.2	0.09 $\pm$ 0.0	0.02 $\pm$ 0.0	0.17 $\pm$ 0.1
FH	7.1 $\pm$ 1.2	23.4 $\pm$ 2.0	3.9 $\pm$ 0.1	0.29 $\pm$ 0.1	0.41 $\pm$ 0.1	0.86 $\pm$ 0.2
MA	7.5 $\pm$ 1.3	22.6 $\pm$ 1.9	4.5 $\pm$ 0.5	0.35 $\pm$ 0.1	0.33 $\pm$ 0.1	0.99 $\pm$ 0.2
CI	8.2 $\pm$ 1.1	21.9 $\pm$ 1.7	7.1 $\pm$ 0.9	0.05 $\pm$ 0.0	0.01 $\pm$ 0.0	0.15 $\pm$ 0.1

Temp = Temperature in °C; DO = Dissolved Oxygen in mg/L; EC = Electrical Conductivity in µSm/cm; TDS = Total Dissolved Solids in mg/L; Sal = Salinity in mg/L; OS-Oserian; FL-Florema; SK-Sher Karuturi; HP-Hippo Point; FH-Flamingo; MA-Malewa River and CI-Crescent Island

Table 2: Heavy metal concentrations in ppb (Mean±SE) in water samples collected from Lake Naivasha

Sampling site	Cadmium	Copper	Lead
Crescent island	0.001±0.001	0.002±0.000	0.033±0.004
Hippo point	0.003±0.002	0.003±0.000	0.011±0.003
Oserian	0.008±0.002	0.018±0.001	0.497±0.062
Florema	0.043±0.012	0.066±0.002	0.073±0.003
Sher Karuturi	0.023±0.008	0.041±0.001	0.037±0.014
Flamingo	0.057±0.003	0.127±0.001	0.102±0.006
Malewa river	0.004±0.001	0.005±0.002	0.062±0.002

WHO Drinking water Standards (HDL): Cd = 10; Cu = 50; Pb = 50. (WHO, 1993)

Table 3: Heavy metal concentrations in ppm (Mean±SE) in sediment samples collected from Lake Naivasha

Sampling site	Cadmium	Copper	Lead
Crescent island	0.250±0.009	1.329±0.524	4.642±0.624
Hippo point	0.310±0.019	3.159±0.112	21.74±1.103
Oserian	0.530±0.042	15.92±0.563	28.06±1.290
Florema	1.650±0.021	13.14±0.735	27.93±1.573
Sher Karuturi	1.023±0.004	16.66±0.921	27.09±1.143
Flamingo	1.053±0.003	24.27±1.132	25.75±1.162
Malewa river mouth	0.641±0.001	34.36±2.071	29.69±3.263

WHO limits for sediment: Cd = 0.6; Cu = 16; Pb = 31(Ozturk *et al.*, 2009)

but not human health risk given their significantly lower concentrations compared to the (USEPA, 2000) guideline values.

**Heavy metals in sediments:** The concentrations of Cd, Cu and Pb (in ppm) in sediment ranged from 0.25, 1.33 and 4.64 to 1.65, 34.36 and 29.69, respectively. Sediment samples collected from Crescent Island contained significantly low amounts of cadmium, copper and lead ( $p < 0.05$ ; Table 3) compared to the other sampling sites. The highest levels for cadmium and copper were recorded in samples collected from Florema and Malewa River mouth, respectively. Copper concentrations from Malewa River, Flamingo and Sher Karuturi sampling sites exceeded the WHO limits for sediment and significantly lower than those measured by Ozturk *et al.* (2009). The highest levels of lead were recorded in the Malewa River mouth samples. It is evident that sediments from the less impacted sites (Crescent Island and Hippo Point) contained lower levels of heavy metals compared to those from heavily impacted sites. River Malewa is a major source of heavy metals into this lake. The river drains through an agricultural area where pesticides and animal feeds are used intensively. The sources of heavy metals at Crescent Island and Hippo Point could be attributed to commercial and sport fishing. The concentrations of cadmium in sediments collected from Florema, Sher Karuturi and Flamingo sampling sites exceeded the WHO recommended guidelines for such sediments. Such elevated metal concentrations in water and sediment were recorded by Berger *et al.* (1995) and were attributed to increased agricultural activities associated with flower farms and industrial development. The metal levels in sediments in the

current study are however significantly lower than those measured by Barakat *et al.* (2012) in Morocco in a study area characterized by similar anthropogenic activities. It is therefore likely that sediment dwelling organisms at these sites will be adversely impacted in terms of their growth, survival and reproduction. Similarly, sediments from Sher Karuturi, Flamingo and Malewa River mouth exceeded the WHO recommended guidelines for copper for such sediments. Like the other two heavy metals, lead concentrations in sediments were below WHO limits but samples from Malewa River, Oserian, Florema and Sher Karuturi recorded relatively high concentrations at 29.69, 28.06, 27.93 and 27.09 ppm, respectively.

Finally, benthic organisms in the Malewa River mouth are likely to be impaired by copper since its levels exceeded the WHO and (USEPA, 2000) recommended guideline values (Table 3). Such elevated concentration of copper is bound to impact negatively on the macro invertebrates and by extension their predators. Elevated metal concentrations have been shown to adversely affect macro invertebrates in terms of reproduction, growth, abundance and diversity (Ogendi *et al.*, 2008; Mize and Deacon, 2002). The high level of heavy metals in sediments in some sampling sites is probably due to anthropogenic activities such as agricultural activities and fishing. This result is contrary to the findings of a study in the U.S Arctic Lakes where the high levels of metals in sediments were attributed to the high background levels from natural sources (Allen-Gil *et al.*, 1997).

**Heavy metals in *Cyprinus carpio*:** The heavy metals that were analysed include Cadmium, Copper and Lead. All the selected metals were present in measurable quantities in water, sediments and fish samples from all the study sites. Whereas cadmium concentration in some sediment samples from Florema, Sher Karuturi, Flamingo and Malewa River exceeded the WHO limits for sediments (NOAA (National Oceanic and Atmospheric Administration), 2009; World Health Organization (WHO), 1993), its concentration in common carp was significantly lower than the WHO guideline values (Ozturk *et al.*, 2009). The highest levels of cadmium in fish samples collected from Oserian and Sher Karuturi were 0.074 and 0.079 mg/kg, respectively (Table 4). This finding is in agreement with the results of a study carried out in Awassa and Koka Lakes in Ethiopia where the Cadmium levels in sediments were higher than in fish samples within the same ecosystem (Dsikowitzky *et al.*, 2012).

Copper concentrations in fish were significantly lower than the WHO guideline values. Fish samples from Malewa River, Flamingo, Florema had relatively high copper levels compared to those from the other sampling sites. The highest levels of cadmium copper and lead in common carp fish were 0.04, 0.17 and 0.09

Table 4: Heavy metal concentrations in mg/kg (Mean±SE) in *Cyprinus carpio* fish samples collected from Naivasha

Sampling site	Cadmium	Copper	Lead
Crescent island	0.009±0.005	0.117±0.005	0.081±0.002
Hippo point	0.011±0.006	0.112±0.003	0.078±0.002
Oserian	0.074±0.004	0.151±0.012	0.084±0.003
Florema	0.009±0.004	0.166±0.006	0.086±0.003
Sher Karuturi	0.079±0.001	0.155±0.002	0.072±0.003
Flamingo	0.039±0.005	0.165±0.002	0.015±0.002
Malewa river mouth	0.029±0.002	0.167±0.004	0.073±0.002
WHO Guidelines <sup>a</sup>	0.100	2.000	0.200
USEPA guidelines <sup>b</sup>	0.180	3.280	0.300

Table 5: Fish/Water (bolded) and Fish/Sediment heavy metal concentration ratios for samples in various sampling sites in Lake Naivasha

Sampling site	Cadmium		Copper		Lead	
	FWR	FSR	FWR	FSR	FWR	FSR
Crescent island	0.01	0.01	62.40	0.09	24.84	0.02
Hippo point	0.01	0.02	44.73	0.04	0.16	0.00
Oserian	0.01	0.12	7.98	0.01	2.49	0.00
Florema	0.00	0.05	2.52	0.01	1.20	0.00
Sher Karuturi	3.41	0.08	3.79	0.01	1.95	0.00
Flamingo	0.68	0.04	1.22	0.00	1.45	0.00
Malewa river	7.05	0.05	3.30	0.00	1.18	0.00

FWR: Fish/Water ratio; and FSR: Fish/Sediment ratio

mg/kg, respectively (Table 4). Elevated copper levels in water and sediments in Malewa, Sher Karuturi and Flamingo sites could be attributed to agricultural and horticultural activities in the catchment area.

Lead concentrations in fish were below the WHO and USEPA guidelines. The lead levels in fish collected from Oserian, Florema and Crescent Island were relatively high but lower than the WHO and USEPA guideline values. These findings were in contrast with the results of a study carried out in the India Coastal Fisheries where there were extremely high levels of Lead in fish tissues and water samples. These high concentrations were attributed to increase in fishing vessels and trawlers that have galvanized metal coating (Mitra *et al.*, 2000).

The heavy metal concentration profile in fish followed the sequence, Cu>Pb>Cd which was a similar sequence in heavy metal concentration in sediments. However, the heavy metal concentration in water and fish do not exceed WHO and (USEPA, 2000) guidelines. This finding is in agreement with the results of a study on heavy metals in fish of Avsar Dam Lake in Turkey (Ozturk *et al.*, 2009). The fish/water cadmium ratio ranged from 0.68 to 8.57; 1.22 to 62.4 for copper and 0.16 to 24.84 for lead. Similarly, the fish/sediment metal ratios varied between 0.01 and 0.12, 0.0 and 0.09 and 0.0 and 0.02 for cadmium, copper and lead, respectively. Comparing the ratio of heavy metals in fish to that found in water and sediments suggests varying bioavailability of sediment-bound and dissolved metals (Table 5). Similar observations have been observed by Dsikowitzky *et al.* (2012). Further, there was evidence of heavy metal biomagnifications as the levels of heavy metals in fish exceeded the concentration in water samples although the metal levels do not exceed WHO and USEPA

guidelines. This is in agreement with the findings by Olaifa *et al.* (2004b) whereby the heavy metal concentrations in common carp were within safe limits for human consumption. However, these findings are in contrast with other studies such as Javed and Usman (2011) and Muiruri *et al.* (2013) where heavy metal concentration in fish was beyond the permissible limits and therefore not fit for human consumption.

The areas with high temperature measurements also recorded high heavy metal concentration in sediments, fish and water. This finding is consistent with the findings of a study in Athi-Galana-Sabaki tributaries where the heavy metal concentration increased with increase in temperature. This phenomenon can be attributed to high rate of metabolism in fish, lower oxygen affinity of the blood and hence high rate of pollutant accumulation (Muiruri *et al.*, 2013). Based on these findings, it is safe to conclude that drinking water and fish collected from Lake Naivasha do not pose immediate health risks to human health. Despite this observation, we recommend continuous monitoring of heavy metal concentrations in water and sediment in the lake given their potential for bioaccumulation and biomagnifications and likely adverse effects on aquatic organisms and humans.

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