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Analysis of Heavy Metals in Water and Surface Sediment in Five Rift Valley Lakes in Kenya for Assessment of Recent Increase in Anthropogenic Activities

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Abstract The concentrations of heavy metals Ag, Cd, Co, Cr, Cu, Mn, Ni, Pb, Sn and Zn were analysed in water and surface sediments of five Rift Valley lakes Nakuru, Elementaita, Naivasha, Bogoria and Baringo in Kenya. The dissolved mean concentration levels (μg/L) in water ranged within 13.0–185.0 (Ag), 2.0–43.0 (Cd), 5.0–316.0 (Co), 25.0–188.0 (Cr), 4.7–100.0 (Cu), 50.0–282.0 (Mn), 19.0–288.0 (Ni), 25.0–563.0 (Pb), 300.0–1050.0 (Sn) and 29.0–235.0 (Zn). The mean sediment concentrations (in μg/g (dry weight)) ranged within 0.1–0.35 (Ag), 0.05–1.18 (Cd), 0.17–1.38 (Co), 1.94–4.91 (Cr), 1.46–20.95 (Cu), 667.7–3946.8 (Mn), 11.69–39.72 (Ni), 10.92–38.98 (Pb), 17.21–56.52 (Sn) and 96.2–229.6 (Zn). The data indicate that some of the sites analysed, especially in Lake Nakuru, had relatively higher concentration levels of heavy metals Cd, Co, Cu, Pb, Ni, and Zn in the water which points to anthropogenic addition. However, potential influence of geochemical processes on the concentration levels in sediment is also shown in Co, Ni, and Cu which were more concentrated in the remote Lake Baringo sediment as well as in Pb and Mn which were more concentrated in the remote Lake Bogoria sediment. Data on some important limnological parameters including pH, salinity, electrical conductivity and temperature are also presented.

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Trace elements are some of the main sources of metal toxicity problems in the aquatic environment since most of the aquatic organisms are not adapted to deal with them when they occur above threshold concentrations. The most toxic ones such as Pb, Cu and Cd have been subjects of ecotoxicological research for a long period of time (Hodson et al. 1981; Howarth and Sprague 1978; George and Pirie 1984; Chan 1995a, b; Gold-Bouchon et al. 1995; Wong et al. 1995; Ma et al. 2003). Some of the toxic effects of heavy metals in aquatic organisms which have been reported include bioaccumulation in various organs, tissue damage (e.g. in oysters), disruption in growth and reproduction (e.g. in marine bivalve *Cerastoderma edule*) and induction and synthesis of metallothionein (Bowner et al. 1994; Chan 1995a; Gold-Bouchon et al. 1995; Lim et al. 1995).

However, heavy metals are natural constituents of natural waters and some of the essential ones such as Fe, Mn, Zn, Co, Mo and Se are present at low concentrations and are biologically important in the aquatic environment. They enter natural waters from various sources. The natural geological weathering of rocks and soil, directly exposed to surface waters, is usually the largest natural source. The other main source of heavy metals is anthropogenic input from domestic, farming, mining, and other industrial manufacturing activities such as corrosion of copper tubing and discharge from waste water from electroplating smelting and metal engraving industries. Once they are in the aquatic environment, metals are adsorbed onto inorganic and organic particulate deposits and are incorporated into sediment resulting in elevated levels of heavy metals in bottom sediment (Chan 1995a, b; Cheevaporn et al.

1995; Borg and Jonsson 1996; Jeon et al. 2003; Schmitt et al. 2003). A large amount of heavy metal input therefore accumulate in estuarine and coastal waters since these are important sinks of suspended matter and associated land derived contaminants (Everaarts et al. 1995; Lim et al. 1995; Schmitt et al. 2003). The role of inland waters as receptors of a variety of industrial and municipal waters containing varying loads of trace metals implies that concentrations of trace metals, their chemical forms and fluxes within these impacted ecosystems should be known. In addition, knowledge of the physico-chemical parameters of natural waters such as pH, temperature, dissolved oxygen demand (DOD), turbidity, and alkalinity is pertinent because these parameters can modify toxicities of various heavy metals and therefore indicate the water quality of the ecosystems. Although developing countries have, in the past, been considered least polluted, rapid industrial development and high population growth rates in the past decades have gradually degraded water quality of some of the natural waters of these countries (Berg et al. 1995; Chan 1995a, b; Cheevaporn et al. 1995; Lim et al. 1995). In Kenya, some of the Rift Valley lakes such as Lake Nakuru and Lake Naivasha which are important habitats for fish, birds and other wildlife have recently been at the centre of environmental conflict resulting from massive bird deaths and species extinction which is being blamed mainly on declining water quality due to pollutants emanating from discharge of waste from industrial activities and human settlements. Heavy metal pollution monitoring is needed in order to provide baseline data which can be used by local authorities for environmental management. In this paper we report baseline data of concentrations of Ag, Cd, Co, Cr, Cu, Mn, Ni, Pb, Sn and Zn in water and surface sediment in five Rift Valley lakes (Nakuru, Naivasha, Elementaita, Baringo and Bogoria). Some of the important limnological parameters including water pH, temperature, turbidity, electrical conductivity and salinity are also presented.

Materials and Methods

Samples of water and surface sediment were taken from four sites (BR1, BR2, BR3, BR4) in Lake Baringo, two sites (BG1, BG2) in Lake Bogoria, three sites (NK1, NK2, NK3) in Lake Nakuru, three sites (EL1, EL2, EL3) in Lake Elementaita, and one site (NV) in Lake Naivasha. The sampling sites were as follows BR1: 500 m inshore opposite the Fisheries office, BR2: 200 m inshore opposite the Fisheries office, BR3: at the shore at Lake Baringo Lodge point, BR4: at the shore at Fisheries office; BG1: Lake Bogoria Hot Springs, BG2: at the shore, 500 north west of Hot Springs; NK1: at the shore near President's Pavillion, NK2: at Hippo Point, NK3: at Hippo Point Stream; EL1: at Kariandusi point, EL2: at Lord Delamere's gate, EL3: Lake Elementaita Hot Springs; NV:Lake Naivasha. Sampling bottles were precleaned thoroughly with appropriate amounts of acid and distilled water, respectively, i.e. rinsing with concentrated HNO_3 and distilled water. A sample of 500 ml of water was taken by immersing the bottles and lifting up and was mixed with two pipette drops of concentrated HNO_3, filtered through 0.45 µm Millipore filters and stored in the laboratory at 4°C before analysis. This procedure was believed to be able to prevent microbial growth, flocculation and reduce any adsorption on container surfaces. At each site additional samples of water were taken for analysis of electrical conductivity, pH, salinity and transparency. The temperature of the water was also determined during sampling. Surface sediment (0–2 cm layer) samples were taken from the same sites in replicates of three using stainless steel Ekman grab and stored in polythene bottles and transported to the laboratory for storage at 4°C while awaiting analysis.

A Perkin-Elmer Atomic Absorption Spectrophotometer Model 2380 with an air/acetylene flame was used for analysis of the samples after preparation of appropriate calibration standards. Due to expected low concentrations of the metals in the natural water samples and limited instrument sensitivity, pre-concentration of the water samples was done by evaporating 100 ml of the water to 4 ml on a hot plate. The digestion of the water samples was then achieved by adding 5 ml of 11.1 M HNO_3 and heating on the hot plate for 30 min. Some 10 ml of 16.3 M HCl was added and digestion continued until the solution remained light brown or colourless. The volume was then adjusted to 25 ml with distilled water. Each sediment sample was mixed well and then 20 g was taken into a glass dish and dried at 105°C in a Gallenkamp oven. The sample was then ground in Mortar and Pestle and 0.667 g was weighed accurately to 0.1 mg accuracy and placed in a pre-cleaned digestion test tube and digested with 5 ml of 11.1 M HNO_3 at 95°C for 1 h. The solution was cooled and diluted with 13 ml distilled water, shaken well and then centrifuged at 5,000*g* for 10 min. The supernatant was then analysed for the metals. Calibration curve method for was used to quantify heavy metal concentrations. The accuracy of the method for sediment analysis was tested using an IAEA reference soils sample according to the IAEA established method which involved taking 2.5 g soil subdivided into 0.5 g sub-samples. The sub-samples, five replicates, were placed in test tubes with 5 ml concentrated 11.1 M HNO_3 for digestion. A mean recovery of 91% was obtained for the elements. The detection limit was 1 ppb for both water and sediment samples.

Table 1 Metal concentrations (μg/g dry weight) in sediments in the five Rift Valley Lakes

Site	Ag	Cd	Co	Cr	Cu	Mn	Ni	Pb	Sn	Zn
BR1	0.31 ± 0.01	0.76 ± 0.14	1.12 ± 0.11	2.17 ± 0.18	18.45 ± 1.11	1464 ± 110	39.72 ± 13.11	20.62 ± 0.92	43.41 ± 1.34	193.6 ± 10.4
BR2	0.27 ± 0.00	0.73 ± 0.02	1.08 ± 0.03	2.92 ± 0.13	18.52 ± 1.04	1354 ± 91	36.45 ± 9.60	21.83 ± 1.08	38.98 ± 0.96	179.3 ± 26.2
BR3	ND	0.68 ± 0.10	1.38 ± 0.12	4.87 ± 0.11	20.95 ± 1.56	1179 ± 89	38.98 ± 9.40	16.57 ± 1.44	23.39 ± 0.84	171.5 ± 14.3
BR4	0.35 ± 0.12	0.57 ± 0.02	0.69 ± 0.04	2.52 ± 0.11	15.12 ± 1.44	942 ± 100	25.70 ± 2.55	18.90 ± 1.22	30.23 ± 2.32	207.1 ± 12.4
BG1	0.27 ± 0.02	0.20 ± 0.03	0.48 ± 0.02	2.92 ± 0.14	1.95 ± 0.02	2627 ± 114	14.62 ± 1.61	38.98 ± 6.33	17.21 ± 1.24	172.1 ± 10.2
BG2	ND	0.92 ± 0.16	0.48 ± 0.04	1.95 ± 0.06	4.68 ± 0.11	3947 ± 121	28.25 ± 2.42	21.44 ± 2.44	23.39 ± 2.43	194.9 ± 21.7
NK1	0.10 ± 0.00	0.49 ± 0.16	0.39 ± 0.06	1.94 ± 0.04	3.70 ± 0.12	702 ± 57.4	17.50 ± 0.56	18.52 ± 1.12	56.52 ± 2.22	157.1 ± 10.1
NK2	ND	0.57 ± 0.11	0.24 ± 0.02	1.96 ± 0.11	3.51 ± 0.05	741 ± 66.4	17.54 ± 0.21	13.64 ± 0.91	23.39 ± 2.67	199.2 ± 26.3
NK3	ND	0.39 ± 0.04	0.17 ± 0.01	ND	1.46 ± 0.01	729 ± 70.3	11.69 ± 0.16	10.92 ± 0.22	ND	106.0 ± 9.46
EL1	ND	1.07 ± 0.11	1.17 ± 0.11	2.92 ± 0.06	9.26 ± 0.42	819 ± 106	28.26 ± 1.11	15.60 ± 1.11	38.98 ± 1.12	121.4 ± 10.4
EL2	0.10 ± 0.01	0.05 ± 0.00	0.48 ± 0.03	ND	5.85 ± 0.22	877 ± 97	22.41 ± 0.96	22.80 ± 0.91	38.88 ± 2.64	171.5 ± 13.3
EL3	ND	1.18 ± 0.02	1.09 ± 0.13	4.91 ± 0.13	12.96 ± 0.64	667 ± 55	36.72 ± 1.23	14.73 ± 0.61	39.28 ± 4.06	96.22 ± 8.66
NV	ND	0.73 ± 0.12	0.17 ± 0.00	1.95 ±	10.33 ± 0.52	1118 ± 81	11.69 ± 0.14	25.34 ± 0.69	23.39 ± 0.43	229.6 ± 9.88

ND Not detected, *BR* Lake Baringo, *BG* Lake Bogoria, *NK* Lake Nakuru, *EL* Lake Elementaita, *NV* Lake Naivasha, $n = 3$

Results and Discussion

The concentrations of heavy metals Ag, Cd, Co, Cr, Cu, Mn, Ni, Pb, Sn and Zn were analysed in surface sediments and waters of five Rift Valley lakes Nakuru, Elementaita, Naivasha, Bogoria and Baringo and are presented in Tables 1 and 2. Lake Elementaita sediments gave highest mean concentration values (based on dry weight) of Cd (1.18 μg/g) at sampling sites EL3, Lake Baringo sediment gave highest mean concentration values of Ag (0.35 μg/g at BR4), Co (1.38 μg/g at BR3), Cu (20.95 μg/g at BR3) and Ni (39.72 μg/g at BR1) (See Table 1). Highest mean concentrations of Cd (1.18 μg/g) and Cr (4.91 μg/g) were obtained in samples from site EL3 in Lake Elemementaita. Lakes Nakuru and Elementaita showed relatively lower concentration values of Mn (613.1–973.7 μg/g range) than the rest of the lakes, possibly due to the anoxic conditions or low surface area of bottom sediment in these two lakes. Highest mean concentration (3946.8 μg/g) of Mn was obtained in Lake Bogoria sediment from sampling site BG2. The mean concentrations of Pb in sediments from most of the sampling sites were below 25 μg/g, with highest mean value of 38.98 μg/g in samples from BG1 in Lake Bogoria though Zn concentrations were all higher, with means ranging from 96.22 μg/g to the highest mean value of 229.6 μg/g in Lake Naivasha sediment. The sampling sites BG2, NK1 and EL1, on respective lakes Bogoria, Nakuru and Elementaita represent the true natural sediment concentrations of these sites as the samples were taken in areas of non-external interference in terms of trace metal contaminant exposure. These data thus indicate the natural chemical composition of the sediments in the three lakes. Other locations, e.g. EL3 and NK2 are sites whose vicinities are fed by some small streams. EL4 and BG1 were samples from hot springs adjacent to the respective lakes.

In Lake Baringo besides Cd which was above MPL and Mn (HDL < Mn < MPL) the rest of the determined heavy metal concentrations showed values below the drinking water standards (Tables 2, 3). Lake Naivasha water sample showed no sign of contamination but the unusually high level of Sn (1,050 μg/L) was noted. The site was taken next to the hotel Safariland which may have been using food preserved in tin compounds/materials. Heavy metal concentration in water samples of Lakes Bogoria, Elementaita and Nakuru were above HDL and most of them above MPL. The high pH and low Dissolved Oxygen content in this sampling site can contribute towards this situation. Hot Spring waters of BG1, EL1 contained lower concentrations of heavy metals. High pH and temperature and very low oxygen can encourage solubilization processes and subsequent precipitation. The low concentration of heavy metals at NK2 and EL3 (a small stream inlet point) are

Table 2 Dissolved trace metal concentrations (μg/L) in waters of the five Rift Valley Lakes

Site	Ag	Cd	Co	Cr	Cu	Mn	Ni	Pb	Sn	Zn
BR1	44.0 ± 1.22	5.0 ± 0.60	25.1 ± 0.26	125.0 ± 11.2	15.0 ± 0.92	138.1 ± 12.3	38.0 ± 7	65.1 ± 5.44	300.0 ± 23	105.0 ± 8.94
BR2	185.0 ± 10.1	2.0 ± 0.11	24.9 ± 0.54	188.0 ± 10.2	20.2 ± 1.20	280.0 ± 21.2	25.0 ± 3	38.0 ± 2.44	ND	100.0 ± 12.2
BR3	ND	5.0 ± 0.40	5.0 ± 0.11	ND	5.4 ± 0.64	138.4 ± 10.4	ND	25.0 ± 2.42	301.0 ± 16	40.0 ± 3.44
BR4	ND	2.0 ± 0.01	6.2 ± 0.10	ND	5.0 ± 0.11	50.0 ± 9.64	ND	ND	ND	45.0 ± 4.44
BG1	ND	5.0 ± 0.44	34.0 ± 0.66	63.2 ± 9.77	10.0 ± 0.56	50.2 ± 7.84	31.0 ± 2.5	38.0 ± 3.32	ND	50.0 ± 5.22
BG2	88.1 ± 2.21	41.0 ± 2.56	313.0 ± 12.2	ND	90.0 ± 7.84	49.9 ± 6.88	263.0 ± 15	313.0 ± 14.6	725.0 ± 80	55.0 ± 3.64
NK1	41.0 ± 1.33	43.0 ± 1.40	316.0 ± 19.2	ND	100.0 ± 9.66	138.0 ± 10.6	281.0 ± 22	563.0 ± 57.4	500.0 ± 30	235.0 ± 24.4
NK2	44.0 ± 1.41	23.2 ± 1.01	256.2 ± 15.4	188.1 ± 15.5	30.0 ± 5.33	94.0 ± 8.92	288.0 ± 41	188.0 ± 21.0	ND	75.0 ± 10.6
NK3	ND	3.0 ± 0.12	6.0 ± 0.44	ND	5.0 ± 0.32	ND	19.0 ± 2.44	106.0 ± 15.8	300.1 ± 21	45.0 ± 5.68
EL1	25.0 ± 1.04	25.1 ± 0.90	288.0 ± 14.3	ND	40.0 ± 1.22	280.0 ± 21.2	175.0 ± 12	188.0 ± 21.2	ND	70.0 ± 4.76
EL2	44.0 ± 2.40	5.0 ± 0.31	72.0 ± 8.90	63.0 ± 2.21	15.0 ± 0.43	282.0 ± 18.6	81.0 ± 9.84	65.1 ± 4.33	303.4 ± 22	95.0 ± 7.54
EL3	13.0 ± .061	3.0 ± 0.03	18.8 ± 1.34	ND	5.0 ± 0.12	231.0 ± 12.4	25.0 ± 1.22	38.0 ± 2.43	ND	120.0 ± 9.00
NV	ND	8.0 ± 0.04	19.0 ± 1.11	25.0 ± 3.22	4.7 ± 0.22	ND	ND	42.1 ± 2.44	1050.0 ± 46	29.2 ± 2.44

ND not detected, *BR* Lake Baringo, *BG* Lake Bogoria, *NK* Lake Nakuru, *EL* Lake Elementaita, *NV* Lake Naivasha, $n = 3$

indicative of the dilution effects of incoming water. As for aquatic life tolerance (especially fish) these Rift Valley lakes waters have higher levels of heavy metals except Lake Naivasha.

Apart from Ag and Cr in Lake Baringo water other metals in the Rift Valley lakes had concentrations within the threshold limits. Note that Lake Baringo and Naivasha support subsistence, commercial and recreational fishing activities. Significantly raised levels of Ag and Cr in Lake Baringo are therefore a source of concern. However Lake Naivasha compared quite well with Lake Victoria in terms of trace metal concentrations (Onyari and Wandiga 1989; Wandiga et al. 1983). Rift Valley lakes Nakuru (NK), Elementaita (EL) and Bogoria (BG) waters had higher concentrations of heavy metals than Lake Victoria waters. Lake Baringo was fairly more concentrated with heavy metals but this could be due to high turbulence which stirs the shallow turbid water (Secchi disc transparency of 5 cm), thereby increasing the solubility of metals in the water column.

The pH of the Rift Valley lakes waters (see Table 4) showed that they were alkaline (pH > 10) except Lake Naivasha (pH of 9.15 ± 0.21) and Baringo (pH 8.25 ± 0.31–8.65 ± 0.44) as a result of the presence of carbonates and bicarbonates derived from the carbonatite volcanic rocks. The shallow soda lakes of Nakuru and Elementaita had high salinities (13.5–21.5%) and high electrical conductivities (22,500–65,000 μS/cm) with low transparencies and high turbidities. Lake Baringo and Lake Naivasha are closed seepage lakes and have no outlets but they are fresh (with salinities ranging from 0 to 0.5%) and low conductivities of 320 ± 16.40 and 963.75 ± 42.30 μS/cm. They also have contracted from a previously large area and volume over many years. Most of the lakes in the closed basins (Lakes Nakuru, Bogoria and Elementaita) have become saline due to evaporation resulting from high tropical temperatures.

Comparing the limnological features of the lakes with recommended environmental standards the data show that, except for Bogoria, Nakuru and Elementaita, Lake Naivasha and Lake Baringo satisfy the recommended standards (Ochieng 1987). We would expect that the effect of the concentration of dissolved salts (shown by the high electrical conductivity) upon the solubility of oxygen would be that of decreasing oxygen concentration. Electrical conductivity would show diurnal variations, one of the principal causes apparently being the change in electrolyte concentration due to assimilation by green plants. Such diurnal variations have been demonstrated for Lake Victoria (Ochieng 1987). It has also been shown that turbidity relates directly to conductivity but varies inversely with DO, pH and temperature and that DO and pH would have diurnal pulses in the afternoon (between 12 noon and 2 pm)

Table 3 Acceptable levels (μg/L) of some heavy metals in natural waters according to WHO and USEPA compared with the five Rift Valley lakes

Limit	Ag	Cd	Cr	Cu	Mn	Pb	Zn
HDL[a]	NL	NL	NL	50	50	NL	5,000
MPL[a]	50	10	50	1,000	500	100	1.5×10^4
CMC[b]	NL	4.3	16	13	NL	65	120
CCC[b]	NL	2.2	11	9	NL	2.5	120
TC[c]	10	10	50	2×10^4	NL	100	100
Rift	13–88	2–43	25–188	5–90	49–282	25–563	40–235

All data corrected to two significant figures;

NL not in literature cited, ND not determined; *HDL* WHO highest desirable level in drinking water, *MPL* WHO maximum permissible level in drinking water, *TC* threshold concentration for aquatic life tolerance (safe for most fishes), *Rift* Ranges of mean concentrations in the five lakes studied

[a] WHO Drinking water standards (1981)

[b] USEPA (Demirak et al. 2006)

[c] Burrel (1974)

when the temperatures are at maximum and turbidities at minimum. Photosynthetic precipitation of $CaCO_3$ would occur during the daylight hours, which lowers the solubility of $CaCO_3$. When night falls the aggressive CO_2 from the excess respiration re-dissolves the calcite to raise the alkalinity to high dawn levels. An addition of CO_2 would lower the pH while a rise in pH would be accompanied by loss of free CO_2 matched by an increase in DO (Ochieng 1987). The quantity of dissolved salts (as represented by the electrical conductivity) in freshwaters has been used by some researchers as a general indication of their potential fertility. The conductivities in lakes in Kenya are influenced mainly by carbonate salts, which account for up to 80% of the conductivity in most cases. The remaining electrolytes are therefore present in low concentrations. Consequently the concentration of biologically valuable electrolytes such as phosphates and nitrates is therefore much lower than expected (Ochieng 1987). However this fact needs to be investigated by carrying out nutrient analysis of these rift valley lakes. The results (Table 4) show that Lakes Nakuru, Elementaita and Bogoria water had very high conductivities most likely due to evaporation since they have no outlets and their conductivities were >12,500 μS/cm. Their water conductivity would be largely determined by Ca^{2+} and bicarbonate fluxes and would relate to these ions as does their pH.

Comparing our data with those of other researchers, Everaarts et al. (1995) obtained lower concentrations (in μg/kg) of Cu (100.3), Zn (524), Cd (11.7), Pb (137), Mn (1587) in estuarine sediment samples taken from Sabaki River mouth at the Indian Ocean Coast of Kenya. This distribution is expected to be so due to mixing of the river water and the Indian ocean water at the estuaries. The concentrations of some of the heavy metals in sediments

Table 4 Limnological data obtained during the experiments for the sampling points in the five Rift Valley lakes

Site	pH	Temp (°C)	Transp (m)	Conductivity ($\mu S\ cm^{-1)}$	Salinity (%)
BR1	8.25 ± 0.31	30.0 ± 0.03	5	963 ± 42	0.5
BR2	8.65 ± 0.44	29.0 ± 0.14	5	920 ± 46	0.5
BR3	8.30 ± 0.26	31.0 ± 0.16	5	1,000 ± 34	0.5
BR4	8.15 ± 0.22	30.0 ± 0.10	5	1,000 ± 17	0.5
BG1	10.85 ± 0.10	50.0 ± 0.11	5	12,500 ± 159	7
BG2	10.95 ± 0.22	28.2 ± 0.15	5	14,500 ± 159	9.7
NK1	10.25 ± 0.21	20.0 ± 0.09	6	27,500 ± 276	17
NK2	11.25 ± 0.08	19.0 ± 0.05	10	22,000 ± 222	13.5
EL1	10.3 ± 0.02	22.0 ± 0.08	5	34,000 ± 230	21.5
EL2	10.1 ± 0.04	43.8 ± 0.24	5	65,000 ± 401	3.5
EL3	11.1 ± 0.11	48.2 ± 0.54	5	56,000 ± 401	4.5
NV	9.15 ± 0.21	20.0 ± 0.10	80	320 ± 26	0

Transp transparency, *Temp* temperature (μg/kg) in the rift valley lakes, in our survey, are much higher than those of estuarine sediments at the Indian Ocean coast of Kenya and other coastal regions such as Victoria Harbour in Hong Kong (Chan 1995a). However, Chan (1995a) obtained concentrations of dissolved heavy metals ranging as Cu (15–304 μg/L), Zn (24–403 μg/L), Cd (8–109 μg/L) and Pb (40–440 μg/L) in seawater samples taken from Victoria Harbour in Hong Kong, a polluted city with 4 million people and an annual production of several hundred million tonnes of untreated domestic and industrial effluents. These concentration values (i.e. for Cd, Cu and Zn) from Victoria Harbour are higher than what we obtained in the Rift Valley lakes in this study but the concentration ranges of Pb in Victoria Harbour and Rift Valley lake waters are comparable. In Baltic sea surface sediments, higher mean concentrations (in μg/kg) based on dry weights of sediments, of Cd, Co, Cr, Cu, Ni, Pb and Zn were reported and reasons given for high metal inputs included anthropogenic load as well as changes in geochemical processes influenced by changes in redox potential and depleted oxygen as a result of organic and nutrient loads in the seawater (Borg and Jonsson 1996). In previous studies in Kenya, Onyari and Wandiga (1989) obtained elevated levels of Cu, Cd, Zn and Pb, detected in samples taken at the car wash area of Kisumu city pier in Winam Gulf of Lake Victoria, which clearly indicated anthropogenic input as main source. The concentration levels of Cu, Zn, and Cd obtained by Onyari and Wandiga (1989) are comparable with the concentrations we obtained in the rift valley lakes but the concentrations of Pb, Mn and Cr obtained in the Winam Gulf were higher than those in the Rift Valley lakes according to the present study. In Lake Kariba, Zimbabwe, elevated mean surface sediment concentrations of Cu, Mn, Pb and Zn were detected in Kassesse bay and in Cages, respectively, attributable to mining in the drainage basin (Berg et al. 1995).

The data indicate that some of the sites analysed, especially Lake Nakuru, had relatively higher concentration levels of metals Cd, Co, Cu, Pb, Ni, and Zn in the water which points to anthropogenic addition. However, potential influence of geochemical processes on the concentration levels in sediment is also shown in Co, Ni, and Cu being more concentrated in the remote Lake Baringo sediment and in Pb and Mn being more concentrated in the remote Lake Bogoria sediment. The two lakes Baringo and Bogoria are located in more pristine areas with low human settlement. It is also possible that these two lakes have lowest levels of nutrient and lowest possibility of acquiring anoxic conditions. Although these findings are very preliminary and the sampling sites considered were few, the data indicate that some parts of the five Rift Valley lakes in Kenya are relatively more polluted and therefore more extensive sampling and analysis would be necessary to provide more data in trace metal speciation in these inland waters to establish the potential environmental impact. Such information would also be necessary to determine the sources of elevated levels of trace elements analyzed as well as provide more accurate baseline data which can be used by authorities in their impact assessment and future planning of activities in these lakes. As all these lakes are ecologically significant because they are habitats for bird wild life and are important economically in provision of fish for the fish industry (e.g. Naivasha and Baringo) and others are major tourist attractions, close regular monitoring of heavy metal concentrations in their waters would be highly recommended.

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