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Water Quality and Trace Metal Distribution in a Pristine Lake in the Lake Basin in Kenya

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Abstract Water and surface sediment samples taken from various locations within Lake Kanyaboli in the Lake Victoria basin were analysed to determine the concentration and distribution of heavy metals. There were wide ranges in concentrations of the metals among the sampling points analysed. Sediment concentrations (µg/g dry weight) ranged from n.d.–2.54 (Ag), 0.25–1.08 (Cd), 0.89–1.64 (Co), 3.7–7.73 (Cr), 1.80–30.27 (Cu), 1073–2627 (Mn), 22.61–55.60 (Ni), 11.42–153.9 (Pb), 40.46–154.7 (Sn) and 65.0–146.5 (Zn). Dissolved metal concentrations (µg/L) ranged from n.d.–9.22 (Ag), n.d.–5.54 (Cd), n.d.–8.30 (Co), 5.26–60.82 (Cr), 10.96–43.11 (Cu), 184.7–375.9 (Mn), 1.84–38.3 (Ni), 5.98–47.77 (Pb), n.d.–540.6 (Sn) and 14.5–55.9 (Zn). Compared with WHO standards and other freshwaters worldwide, this lake was found to be unpolluted, with all metals, except Mn, being detected at concentrations lower than the highest desirable levels and maximum permissible levels. Some of the toxic metals, Cu, Zn, Pb and Cd (in sediment) and Ag, Co and Pb (in water) were detected at lower concentrations than those found in the polluted Kisumu Pier in Winam Gulf in the Lake basin, which confirms the anthropogenic influence on the latter.

Keywords Heavy metals · Water quality · Lake Kanyabobli · Kenya

Trace metal analysis in freshwaters in developing countries is important because these ecosystems provide drinking water as well as habitat for aquatic flora and fauna. In Kenya heavy metal pollution monitoring is a priority area of research since the concentrations of heavy metals in aquatic ecosystems in Kenya also affect the fish industry which is a major source of livelihood. Lake Kanyaboli (size 10.5 km^2) is situated in western part of Kenya at a geographical location of Latitude 0°05′N to 0°02′N and Longitude of 34°09′E to 34°11′E with an altitude of 1140 above sea level. It is considered a pristine lake within the Lake Victoria basin but recently there has been an increase in mechanized farming activities in Yala Swamp region which is a major feature within the catchment and is very close to the lake. The change in land use is bound to change the geochemical composition of the lake and its water quality. The lake is edged by papyrus reeds and clumps of floating papyrus which occasionally divide it in the middle into two sections i.e. the northern and southern zones. It has a maximum depth of 3 m and is located in a region with an average annual rainfall of 1,480 mm. It has neither outlets and nor inlets although it is believed that it may have an underground outlet. It has been suggested that with time it may one day become saline due to the high temperatures and high rates of evaporation due to its location in the tropics and this can cause extinction of some fish species not adapted to saline waters such as *Tilapia nilotica* which is the main fish type in this lake. Although baseline monitoring has been done in other freshwater systems in Kenya especially in the Lake Victoria (Wandiga et al. 1983; Onyari and Wandiga 1989; Ochieng et al. 2006), this lake which is of national importance because of the fishing and farming activities within close proximity, has not been studied.

Trace elements are some of the main sources of metal toxicity problems in the aquatic environment since most of

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the aquatic organisms are not adapted to deal with them when they occur above threshold concentrations (Hodson 1981; George and Pirie 1984; Bowmer et al. 1994; Chan 1995a, b; Gold-Bouchon et al. 1995; Lim et al. 1995; Wong et al. 1995). Therefore changes in geochemistry of heavy metals and the physico-chemical parameters such as pH, temperature, dissolved oxygen demand (DOD), turbidity, and alkalinity are very sensitive to aquatic ecosystems and should be known (Cole 1979; Alabaster and Lloyd 1984; Chan 1995a; Cheevaporn et al. 1995; Borg and Jonsson 1996; Jeon et al. 2003; Ma et al. 2003; Schmitt et al. 2003). These changes can be enhanced by rapid agro-industrial developments and high population growth rates in developing countries as has been reported (Berg et al. 1995; Chan 1995a; Cheevaporn et al. 1995; Lim et al. 1995). In our study, we determined the concentration levels of Ag, Cd, Co, Cr, Cu, Mn, Ni, Pb, Sn and Zn in water and sediment samples obtained from eight sampling sites in the lake. Our objective was to assess the current concentration levels of heavy metals within the lake and determine potential impacts of land use patterns on the water quality of the lake. We also determined important limnological parameters including water pH, temperature, turbidity, dissolved oxygen level, electrical conductivity and alkalinity.

Materials and Methods

Samples of water and surface sediment of Lake Kanyaboli (Fig. 1) were taken from eight sites as follows: LKA: Kadenge point, LKB: Gendro point, LKC: Swila point, LKD: Open water between Kadenge and Swila points, LKE: Kanyaboli point, LKF: Kaugagi point, LKG: Open water in the middle of northern zone, LKH: Gang point. Sampling bottles were pre-cleaned thoroughly, 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 2 mL 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 (approximately 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 (AAS) 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 (Analar grade obtained from Kobian, Nairobi, Kenya) and heating on the hot plate for 30 min. Ten mL of 16.3 M HCl (Analar grade obtained from Kobian, Nairobi, Kenya) 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 0.70 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 was used to quantify heavy metal concentrations. The accuracy of the method for sediment analysis was tested using an IAEA reference soils (fortified 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 11.1M HNO_3 for digestion. A high mean recovery of 91% was obtained for this reference sample and was used to correct the AAS data obtained. The detection limit was 1 ppb for both water and sediment samples.

Results and Discussion

The determined concentrations of heavy metals in sediment and water are given in Tables 1, 2, 3 and 4. The data show that the concentrations of heavy metals are much higher in sediment than in the water column with concentration factors ranging from 75 (Cd) to 8982 (Mn). This distribution pattern of heavy metals between the water phase and sediment is expected as most heavy metal speciation studies have reported a similar pattern of distribution both in sea water as well as in lakes. It is known that a large percentage of heavy metals in non-polluted lakes and rivers are generally incorporated in the crystal lattice of minerals which make up the bottom mud. This percentage would form part of the natural background level in the bottom mud in polluted waters on which the anthropogenic input would be based on. However, the concentration factors would be expected to change from time to time depending on the mixing patterns of the water, the water chemistry as well as on the accumulation which in turn depends on

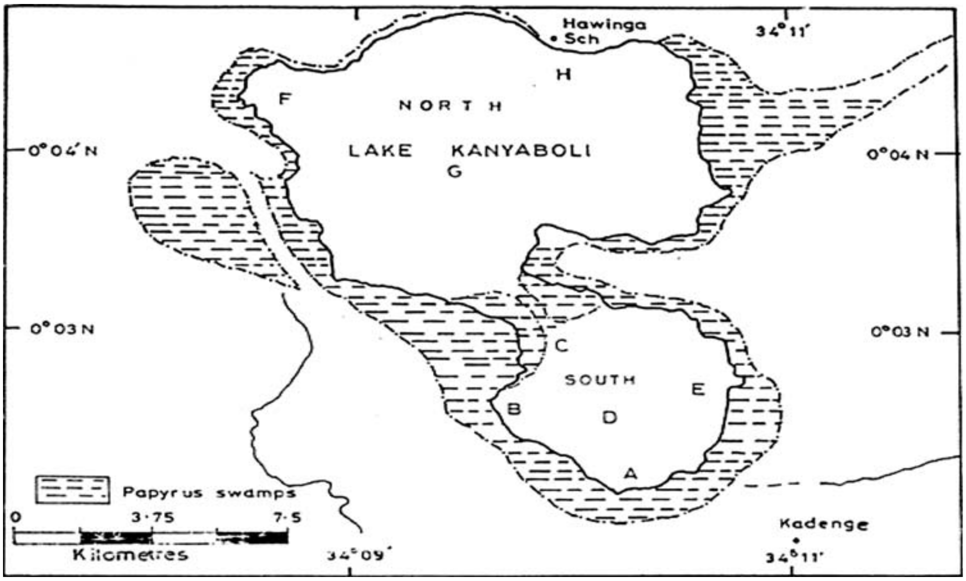

Fig. 1 The sampling points in Lake Kanyaboli

Table 1 Heavy metals (μg/g dry weight) in sediments of Lake Kanyaboli

Site	Ag	Cd	Co	Cr	Cu
LKA	1.01 ± 0.01	0.39 ± 0.14	1.24 ± 0.11	7.05 ± 0.18	18.71 ± 1.11
LKB	0.50 ± 0.00	0.52 ± 0.02	1.30 ± 0.03	6.99 ± 0.13	17.53 ± 1.04
LKC	nd	0.76 ± 0.10	1.52 ± 0.12	6.36 ± 0.11	23.07 ± 1.56
LKD	nd	0.96 ± 0.02	1.24 ± 0.04	4.13 ± 0.11	23.53 ± 1.44
LKE	0.44 ± 0.11	1.04 ± 0.04	1.58 ± 0.06	6.08 ± 1.22	27.15 ± 3.12
LKF	0.56 ± 0.02	0.48 ± 0.10	1.26 ± 0.21	5.16 ± 1.14	22.99 ± 2.54
LKG	1.32 ± 1.22	0.30 ± 0.02	1.26 ± 0.13	10.7 ± 2.11	21.16 ± 4.44
LKH	0.27 ± 0.01	0.68 ± 0.11	0.94 ± 0.05	4.19 ± 0.44	12.34 ± 0.54
Range	0.26–2.54	0.25–1.08	0.89–1.64	3.75–7.23	11.80–30.27
Mean	0.68	0.64	1.29	6.33	20.81
SD	4.39	0.25	0.18	1.97	4.25
n	18	24	24	24	24

Note: Each element was determined in triplicate ($n = 3$) and expressed as mean ± standard deviation (SD) in the columns; nd: not detected

Table 2 Heavy metals (μg/g dry weight) in sediments of Lake Kanyaboli

Site	Mn	Ni	Pb	Sn	Zn
LKA	2515.0 ± 112.2	45.15 ± 3.11	12.34 ± 0.92	79.90 ± 5.34	79.44 ± 10.4
LKB	1678.7 ± 92.5	47.42 ± 9.60	17.71 ± 1.08	73.15 ± 4.96	85.01 ± 16.2
LKC	1172.2 ± 98.6	45.39 ± 9.40	17.87 ± 1.44	54.83 ± 7.84	132.2 ± 14.3
LKD	2099.2 ± 101.2	47.65 ± 2.55	54.84 ± 6.22	69.14 ± 2.32	96.17 ± 12.4
LKE	2284.1 ± 102.2	51.49 ± 4.11	69.14 ± 5.22	43.07 ± 3.61	97.58 ± 11.4
LKF	1241.0 ± 56.7	41.78 ± 3.45	44.07 ± 6.01	86.68 ± 4.22	99.60 ± 21.2
LKG	1919.2 ± 101.6	39.13 ± 3.33	86.68 ± 7.89	149.5 ± 5.25	90.00 ± 14.7
LKH	2427.0 ± 110.2	26.80 ± 4.21	149.5 ± 4.4	58.72 ± 4.66	76.21 ± 11.2
Range	1073.6–2627.2	22.61–55.60	11.42–153.9	40.46–154.7	65.01–146.5
Mean	1917.05	43.1	56.52	76.87	84.4
SD	481.46	7.09	43.05	30.3	16.34
n	24	24	24	24	24

Note: Each element was determined in triplicate ($n = 3$) and expressed as mean ± standard deviation (SD) in the columns; nd: not detected

Table 3 Dissolved heavy metals (µg/L) in water samples of Lake Kanyaboli

Site	Ag	Cd	Co	Cr	Cu
LKA	1.0 ± 0.22	3.0 ± 0.31	6.1 ± 0.11	50.0 ± 7.2	20.0 ± 0.92
LKB	nd	nd	6.1 ± 0.24	20.1 ± 0.42	41.4 ± 4.20
LKC	nd	4.1 ± 0.40	6.0 ± 0.21	7.6 ± 0.55	11.6 ± 0.64
LKD	nd	nd	6.2 ± 0.10	20.5 ± 1.22	36.0 ± 7.11
LKE	nd	5.0 ± 0.32	6.0 ± 0.22	5.7 ± 0.44	23.4 ± 0.77
LKF	1.3 ± 0.12	5.1 ± 0.44	6.0 ± 0.32	14.3 ± 2.20	26.3 ± 2.45
LKG	1.1 ± 0.10	4.0 ± 0.16	6.0 ± 0.44	9.20 ± 1.11	16.1 ± 1.44
LKH	8.0 ± 1.22	5.2 ± 0.33	nd	50.6 ± 4.22	16.8 ± 3.20
Range	0.78–9.22	2.69–5.54	5.56–6.30	5.26–60.82	10.96–43.11
Mean	2.85	4.4	6.06	21.54	23.95
SD	2.98	0.79	0.01	16.97	9.59
n	12	18	21	24	24

Note: Each element was determined in triplicate for each site and expressed as mean ± standard deviation (SD) in the columns; nd: not detected

nutrients and organic matter in the water column. The heavy metals which are not present in the crystal lattice are therefore distributed in organic matter, in hydrous Mn and Fe oxides, and in any discrete minerals formed by the metals. In those places where argillaceous rocks predominate, sorption capacity of clays in relation to heavy metal ions depend on mineral composition and on pH of the medium, besides the redox potential between surface sediments and overlying water mass.

The total concentration of dissolved trace metals and other inorganic minerals in natural waters is a useful parameter in describing the chemical density as a water quality fitness factor and as a general measure of edaphic relationships which contribute to productivity within the water column. The inorganic composition of closed lakes i.e., those lacking any significant effluents such as Lake Kanyaboli, is greatly modified by precipitation and concentration of salts determined by evaporation. Although seasonal variation in rainfall, surface run-off and geochemical nature of drainage basin strongly influence composition of waters of small streams and therefore variability in small streams with origin and location, this is not the case in such large lakes. Therefore we sampled only once during the rainy season.

The ranges of determined mean concentrations of the heavy metals are also given in Tables 1–4. The standard deviations (SD) show significant variations in sediment concentrations of some of the elements among the sampling sites. For example, the variations were shown in the determined mean concentrations of Mn in sediment being much higher at sampling points A and H compared with the rest of the sites. In particular, the variations were seen in Pb concentrations being much higher in the northern zone of the lake, with mean concentrations ranging from 44.07 to 149.5 µg g^{-1} in sampling sites F, G and H compared with the southern zone which ranged from 12.34 to 69.14 µg g^{-1} in sites A, B, C, D and E, respectively. For the dissolved metal concentrations, higher concentrations of Cr at sampling sites A and H compared to the rest of the sites were obtained whereas Mn and Pb were more concentrated in the northern zone of the lake at sampling sites F, G and H.

The limnological data are shown in Table 5 and indicate that the lake is divided into two limnological zones. This division concurs with differences in metal concentrations in the two parts of the lake. The northern section of the lake is more alkaline (mean pH = 7.94) and well oxygenated with mean dissolved oxygen (DO) of 8.3 mg/L or 105% saturation. It had higher turbidity ranging within 20–26 ETU. The lake bottom contains saprosel which is a glossy black material with H_2S odour. It is apparent that the two zone waters, i.e. in southern and northern zones, do not mix well completely, as indicated by differences in temperature, pH, turbidity and electrical conductivity. The brown colour of the water and its high turbidity are attributable to high turbulence which stirs the shallow water, thereby mixing the muddy bottom water with surface water. The high Mn concentration of surface water of the northern zone also supports the fact that in this section the water is well oxygenated, i.e. 8.3 mg/L O_2 or 105% saturation.

We would expect that the effect of the concentration of dissolved salts (shown by the 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) 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

Table 4 Dissolved heavy metals (µg/L) in water samples of Lake Kanyaboli

Site	Mn	Ni	Pb	Sn	Zn
LKA	230.0 ± 31.3	13.0 ± 1.22	15.1 ± 2.44	450.0 ± 90.2	35.0 ± 7.94
LKB	230.0 ± 21.2	2.5 ± 0.66	15.0 ± 4.44	nd	25.0 ± 3.22
LKC	228.8 ± 44.1	32.0 ± 6.31	15.0 ± 2.42	nd	51.5 ± 4.44
LKD	305.0 ± 31.6	13.0 ± 0.54	7.1 ± 1.12	301.0 ± 46.4	37.5 ± 4.44
LKE	305.0 ± 42.0	25.1 ± 2.44	20.5 ± 0.44	296.2 ± 51.2	36.1 ± 7.33
LKF	343.2 ± 21.3	2.4 ± 0.42	38.0 ± 9.77	nd	37.0 ± 6.22
LKG	300.0 ± 64.2	30.0 ± 7.7	38.5 ± 7.64	nd	24.0 ± 2.41
LKH	332.2 ± 44.9	13.0 ± 1.55	16.0 ± 1.67	nd	16.2 ± 2.10
Range	184.7–375.9	1.84–38.31	5.98–47.77	254.6–540.2	14.10–55.94
Mean	284.27	16.38	20.65	349.07	32.79
SD	34.12	11.05	10.71	71.4	10.12
n	24	24	24	9	24

Table 5 Limnological data in Lake Kanyaboli during the sampling period

Site	pH	Temp (°C)	DO (mg L)	Trans (cm)	Turb (FTU)	Alkalinity (mg $CaCO_3$/L)	Cond (µS cm^{-1})
LKA	7.43	24.4	7.6	30	21	318.5	720
LKB	7.5	25	6.5	30	12	270	660
LKC	7.65	25.6	6.3	30	10	302	638
LKD	7.63	25.4	6.4	35	17	391	725
LKE	7.85	26	6.7	30	18	252.5	705
LKF	7.85	27.1	7.1	40	20	302.5	360
LKG	8.03	26.4	8.2	45	22.8	198.5	365
LKH	7.93	25.9	8.3	35	26	332	370
Mean	7.73	25.7	7.14	34.4	18.4	295.9	568
SD	0.18	0.78	0.75	5.3	5	53.6	159.5

Note: Trans = transparency, Turb = turbidity, Cond = electrical conductivity

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. However this fact needs to be investigated by carrying out nutrient analysis of this lake. The results (Table 5) show that Lake Kanyaboli water had relatively higher electrical conductivity (ranging within 370.0–725.0 µS cm^{-1}) than Lake Victoria (ranging within 91.8–220.0 µS cm^{-1}) which lies in the same basin and therefore has the same geological rock structure. This higher electrical conductivity can be attributed to evaporation since it has no outlets. The water conductivity would be largely determined by Ca^{2+} and bicarbonate fluxes and would relate to these ions as does its pH. It would therefore be expected that the higher the water pH (say above pH 10) the higher would be the electrical conductivity. This has also been shown in closed Rift Valley lakes, e.g. Lakes Bogoria, Nakuru and Elementaita, whose water pH's ranged from 10.1 to 11.25 and had electrical conductivities ranging from 12,500 to 65,000 µS cm^{-1} (Ochieng 1987).

Based on the WHO drinking water standards (Table 6), our results show that Lake Kanyaboli is still relatively unpolluted with respect to trace metal concentrations. The trace metal concentrations were below the highest desirable levels (HDL) and maximum permissible levels (MPL). Comparing the trace metal concentration data of the Lake Kanyaboli with recommended environmental standards (Table 6) the data show that its water satisfies the recommended standards both for drinking water purposes and aquatic (fish) life (Ochieng et al. 2006). However, the concentration levels of Mn in all sampling sites were higher than the HDL. The range of mean concentrations show that Lake Kanyaboli had higher concentrations of dissolved and sediment bound Mn compared to Lake Victoria which is located in the same low lying basin but which is exposed to more anthropogenic sources due to its location in large cities.

Table 6 Acceptable levels (μg/L) of some heavy metals in natural waters according to WHO standards, compared with those of Kanyaboli water

Limit	Ag	As	Cd	Cr	Cu	Mn	Ni	Pb	Zn
HDL[a]	nl	nl	nl	nl	50	50	nl	nl	5×10^3
MPL[a]	50	50	10	50	1000	500	nl	100	1×10^4
TC[b]	10	1×10^3	10	50	2×10^4	nl	50	100	100
LK[c]	2.9	nd	4.4	22	24	280	16	21	33

Note: All data corrected to two significant figures; nl denotes 'not in literature cited'; nd denotes 'not determined'; HDL: highest desirable level in drinking water; MPL: maximum permissible level in drinking water; TC: threshold concentration for aquatic life tolerance (safe for most fishes)

[a] WHO Drinking water standards, 1981

[b] Burrel (1974)

[c] LK: Lake Kanyaboli mean concentration values

Mainly geochemical weathering in the catchment and geochemical processes within the lake are expected to influence heavy metal distribution significantly in Lake Kanyaboli. Apart from the agricultural activities within the catchment and fishing in the lake, Lake Kanyaboli is not exposed to any industrial or mining activities that would increase the anthropogenic input of heavy metals into the lake. Notably concentrations of Ag, Zn and Pb were lower in both sediment and water in Lake Kanyaboli compared with Lake Victoria (Onyari and Wandiga 1989; Ochieng et al. 2006). The concentrations of heavy metals in Lake Kanyaboli represent the true natural sediment concentrations due to its rural location and not exposed to any significant agrochemical, industrial and municipal waste as opposed to Kisumu pier in the Winam gulf of Lake Victoria which has shown anthropogenic increase in concentrations of Pb, Zn Ag and Cd. These data thus indicate relatively more natural chemical composition of the sediment in the lake.

Comparing our trace metal concentration data with those of other researchers, Everaarts et al. (1995) obtained lower concentrations (in μg kg^{-1}) dry weight) of Cu (100.3), Zn (524), Cd (11.7), Pb (137) and Mn (1587) in estuarine sediment samples taken from Sabaki River mouth at the Indian Ocean Coast of Kenya. This is expected to be so due to mixing of the river water and the Indian Ocean water at the estuaries. The concentrations of these same heavy metals in sediments (μg kg^{-1}) in Lake Kanyaboli which ranged from 11,800–30,270 (Cu), 250–1,080 (Cd), 65,010–146,500 (Zn), 11,420–153,900 (Pb) and 1,073,600–2,627,200 (Mn) 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 concentrations of heavy metals (in μg kg^{-1}) ranged as Cu (15–304), Zn (24–403), Cd (8–109) and Pb (40–440) in seawater sediment 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. In Baltic sea surface sediments, high mean concentrations (in μg kg^{-1}), based on dry weights of sediments, of Cd (15,000), Co (18,000), Cr (39,000) Cu (63,000), Mn (700,000), Ni (49,000), Pb (71,000) and Zn (360,000) were reported and reasons given for these 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). These Baltic Sea sediment concentrations (in μg kg^{-1}) are all higher than concentrations obtained in our study for Lake Kanyaboli, except Pb and Mn. In previous monitoring in Kenya, Onyari and Wandiga (1989) obtained elevated levels of Cu, Cd, Zn and Pb in sediment samples taken at the car wash area of Kisumu city pier of the lake, which clearly indicated anthropogenic input as main source. In Lake Kariba in Zimbabwe mean surface sediment concentrations (in μg kg^{-1}) ranged as Cr (15,800–25,800), Cd (690–720), Cu (12,400–16,100) Pb (19,300–23,900), Mn (238,700–326,900), Ni (23,200–25,900) and Zn (68,200–71,100), in Kassesse bay and in Cages, respectively (Berg et al. 1995). In the drainage basin of Lake Kariba metal (Cu, Mn, Pb and Zn) mining takes place and elevated levels above natural concentrations in the ecosystem are attributed mainly to these mining activities. Other recent reports of toxic heavy metal contamination in freshwaters include those reported from India and Taiwan which indicated contaminations of River Yamuna sediments with Cu (22.2 μg/g), Pb (60.3 μg/g), Cd (9.5 μg/g) and Zn (59.2 μg/g) and the heavily polluted River Keelung sediments with Mn (430 μg/g), Zn (180 μg/g), Cu (50 μg/g), Pb (41 μg/g) and Cd (0.04 μg/g) in India and Taiwan, respectively (Huang and Lin 2003, Jain 2003).

The data indicate that the water concentrations of heavy metals in Lake Kanyaboli were within normal range. The water concentration levels of Ag, Co, and Pb were lower than those obtained in Kisumu pier of Winam Gulf of Lake Victoria which is located in the same drainage, confirming anthropogenic additions of these metals in the polluted Winam Gulf area of Kisumu. However, the concentration of Mn in Lake Kanyaboli water was higher than that reported in the Winam Gulf which is attributable to differences in geochemical processes in the water column and bottom sediment. The sediment concentrations of Cd, Cu, Pb and Zn in Lake Kanyaboli were also lower than those at Kisumu pier of Lake Victoria, indicating no anthropogenic influence on heavy metal input into Lake Kanyaboli.

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