

Heavy Metals in Water and Surface Sediments in Winam Gulf of Lake Victoria, Kenya

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Heavy metals are natural constituents of natural waters; some are present at low concentrations and a number are biologically important in the aquatic environment. They enter natural waters from various sources. Natural geological weathering of rocks and soil, directly exposed to surface waters, is usually the largest natural source. Another source is anthropogenic input from mining, domestic and industrial activities such as corrosion of copper tubing and discharge from waste water from electroplating smelting and metal engraving industries. They are adsorbed onto deposits and incorporated into sediment resulting in elevated levels of heavy metals in bottom sediment (Chan 1995a; Cheevaporn et al. 1995; Borg and Jonsson 1996; Jeon et al. 2003; Schmitt et al. 2003). A large amount of heavy metal input therefore accumulates in estuarine and coastal waters since these are important sinks of suspended matter and associated land derived contaminants (Everaarts and Nieuwenhuize 1995). Several studies have shown that trace elements such as Cu, Fe, Mo, Se and Mn exist at low concentrations in natural waters, partly in solution form and partly adsorbed onto inorganic and organic particulate matter and that their toxicity can be attributed mainly to their soluble ionic forms (Howarth and Sprague 1978; Hodson 1981; Ma et al. 2003; Schmitt et al. 2003). The increasing contamination of the aquatic environments by heavy metals released from point sources and non-point sources as a consequence of industrialization and urbanization in this era is a major environmental impact assessment concern of all countries. 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 (Hodson 1981; George and Pirie 1984; Chan 1995a; Gold-Bouchon et al. 1995; Ma et al. 2003; Wong et al. 1995). Some of the toxic and biological effects of heavy metals such as bio-concentration in various organs and tissue damage in aquatic organisms (Gold-Bouchon et al. 1995; Lim et al. 1995), disruption in growth, development and reproduction in aquatic organisms (Bowmer et al. 1994) and induction and synthesis of metallothionein (Chan 1995b) have been reported. 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 heavy metal chemistry and toxicity influence on aquatic life and consequently act as indicators of existing water

pollution (Cole 1979; Alabaster and Lloyd 1984). Although developing countries have been considered least polluted in the past, 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; Cheevaporn et al. 1995; Lim et al. 1995).

In Kenya, pollution monitoring is a priority area of research in Kenya Marine Fisheries Research Institute (KMFRI) since the concentrations of heavy metals in aquatic ecosystems in Kenya affect the fish industry which is a major source of livelihood in this country. Some surveys on heavy metal concentrations have been done more recently in the Indian Ocean coast in the area around Mombasa [6] and in the 1980's in Lake Victoria (Wandiga et al. 1983; Ochieng 1987; Onyari and Wandiga 1989). Studies of chemical speciation and partitioning of elements among various sedimentary phases can show metal concentration patterns, comparing current metal fluxes to past natural fluxes which indicates pollution from anthropogenic deposition, airborne particulates, industrial effluents and sedimentation rates (through the scavenging by settling particles in the water column). Although part of the area we have covered in this study was surveyed in the late 1980's by other researchers who reported elevated levels of Pb from oils spills and waste water from car washing activities, there is need to determine the current concentration levels to assess the effects of elevated of Pb and other heavy metals since that period. The Lake Victoria Management Programme and Global Environment Facility of UNEP, stressed the need for continuous generation of environmental data and variables which play vital roles in reproductive biology and biodiversity of Lake Victoria and major pollution indicators which include heavy metals since elevated concentration levels of residues such as heavy metals can be directly related to their toxicity in fish and other aquatic biota and indirectly to other environmental variables critical to the ecology and aquatic biodiversity such as dissolved oxygen levels, pH, alkalinity and organic carbon load (Mwamburi et al. 1995). Comparing current metal fluxes to past fluxes can also indicate pollution from anthropogenic deposition, airborne particulates, industrial effluents and sedimentation rates in the water column. In the reported 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 these trace elements and provide baseline data. We also determined important limnological parameters including water pH, temperature, turbidity, dissolved oxygen level, electrical conductivity and alkalinity.

MATERIALS AND METHODS

Lake Victoria has a surface area of 68,000 km² covering parts of Kenya, Uganda and Tanzania. The sampling area was in Winam Gulf of the lake on the Kenyan side which lies within latitudes 0°11.2'N-1°12.6'S and longitudes 33°45.7'E-34°45.7'E. Samples of surface water and surface sediment of Winam Gulf of Lake Victoria were taken from 7 and 8 sampling sites, respectively, as follows. LV1 (on 0° latitude and 34°42.9'E) : at Caltex Depot in car Wash area of Kisumu pier; LV2: 50 metres inshore from the Caltex Depot; LV3: at Kusa at the point where River Nyando discharges into the lake, 7.5 km from LV1; LV4: 500 metres southwards

from Kusa sampling point, 8 km from LV1; LV5: at Asembo Bay gold recovery effluent discharge point, 12.25 km from LV1; LV6: 50 metres inshore from Asembo Bay (LV5) sampling; LV7: inside the lake at Kiwa Island, 6.25 km from LV1; LV8: 50 metres inshore at Homa Bay, 17.5 km from LV1; LV9: at Kendu Bay shore, 9.5 km from LV1. Sampling bottles were pre-cleaned and rinsed thoroughly with appropriate amounts of 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 to lower the pH of the water to $<\text{pH } 2$, filtered through $0.45 \mu\text{m}$ Millipore filters and stored in the fridge 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. The samples were taken during the rainy season in March, 2001.

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 (limit of detection was 1 ppb), 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 11.1M HNO_3 (Analar grade obtained from Kobian, Nairobi, Kenya) and heating on the hot plate for 30 minutes. Some 10 mL of 16.3 M HCl (Analar grade 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 Gallen Kamp 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 hour. The solution was cooled and diluted with 13 mL distilled water, shaken well and then centrifuged at 5000 g for 10 minutes. 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 a fortified IAEA reference soil sample according to the IAEA established method which involved taking 2.5 gram of soil, subdivided into 0.5 g sub-samples. The sub-samples, in five replicates, were placed in test tubes with 5 mL concentrated 11.1M HNO_3 for digestion. A high recovery of 91% was obtained for this reference sample and was used to correct the AAS data obtained.

RESULTS AND DISCUSSION

The determined concentrations of heavy metals in sediment and water are given in tables 1a, 1b, 2a and 2b, respectively. The data show that the concentrations of heavy metals are much higher in sediment than in the water column with concentration factors in sediment ranging from 345 (Co) to 75,696 (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 and in lakes.

Table 1a. Trace metal concentrations ($\mu\text{g/g}$ dry weight) in sediments of Winam Gulf, Lake Victoria.

Site	Ag	Cd	Co	Cr	Cu
LV1	0.81 \pm 0.01	0.94 \pm 0.14	1.20 \pm 0.11	5.45 \pm 0.18	39.66 \pm 3.11
LV2	Nd	0.73 \pm 0.12	0.54 \pm 0.03	3.90 \pm 0.13	24.36 \pm 1.04
LV3	0.39 \pm 0.03	1.26 \pm 0.10	1.00 \pm 0.12	3.90 \pm 0.11	48.73 \pm 2.56
LV4	0.39 \pm 0.01	1.35 \pm 0.02	1.00 \pm 0.04	3.91 \pm 0.11	49.70 \pm 3.44
LV5	0.10 \pm 0.01	0.62 \pm 0.04	0.76 \pm 0.06	4.22 \pm 0.22	31.35 \pm 2.12
LV6	0.09 \pm 0.02	0.73 \pm 0.10	0.70 \pm 0.21	3.90 \pm 0.14	29.72 \pm 2.54
LV7	3.34 \pm 0.22	0.59 \pm 0.02	1.89 \pm 0.13	6.50 \pm 0.11	47.67 \pm 4.44
LV8	0.27 \pm 0.01	0.73 \pm 0.11	0.83 \pm 0.05	4.36 \pm 1.44	20.42 \pm 0.54
LV9	Nd	0.19 \pm 0.00	1.13 \pm 0.01	6.28 \pm 0.21	57.31 \pm 4.11
Range	0.09-3.56	0.19-1.08	0.51-2.02	3.81-6.61	19.88-61.42
Mean	0.77	0.79	1.01	4.71	38.77
SD	1.07	0.33	0.37	1.01	12.13
n	21	27	27	27	27

Note: Each element was determined in triplicate and expressed as mean \pm standard deviation (SD) in the columns; Nd: Not detected. The overall means and standard deviations for all sampling sites are included at the bottom.

Table 1b. Trace metal concentrations ($\mu\text{g/g}$ dry weight) in sediments of Winam Gulf, Lake Victoria.

Site	Mn	Ni	Pb	Sn	Zn
LV1	3499.0 \pm 112.2	28.17 \pm 3.11	128.43 \pm 9.92	51.94 \pm 3.34	343.3 \pm 20.4
LV2	3196.1 \pm 92.5	24.41 \pm 2.60	140.54 \pm 10.0	38.98 \pm 2.96	199.2 \pm 16.2
LV3	1372.2 \pm 98.6	25.34 \pm 1.40	186.13 \pm 14.44	38.98 \pm 1.84	222.0 \pm 14.3
LV4	1403.0 \pm 101.2	28.26 \pm 2.55	132.20 \pm 6.22	36.90 \pm 2.32	253.4 \pm 12.4
LV5	1092.1 \pm 102.2	24.36 \pm 2.11	69.45 \pm 5.22	33.78 \pm 1.61	262.1 \pm 11.4
LV6	1238.0 \pm 56.7	28.26 \pm 3.45	71.33 \pm 6.01	38.90 \pm 2.14	190.1 \pm 21.2
LV7	2286.2 \pm 101.6	49.40 \pm 3.33	22.53 \pm 2.89	75.83 \pm 5.25	264.3 \pm 14.7
LV8	854.9 \pm 70.2	23.77 \pm 2.21	32.97 \pm 4.45	46.92 \pm 3.66	171.1 \pm 11.2
LV9	847.8 \pm 21.2	37.68 \pm 3.24	26.69 \pm 2.12	37.68 \pm 4.10	183.4 \pm 16.42
Ran	826.6-3611.2	21.56-52.73	19.64-200.57	32.17-81.08	159.9-363.4
M	1754.67	29.96	90.03	44.43	232.1
SD	943.41	7.94	53.29	12.26	51.39
n	27	27	27	27	27

Note: Ran=range, M=mean, SD=standard deviation, n=sample size

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 depending on the mixing patterns of the water, the water chemistry as well as on accumulation which in turn depends on 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. With increase in pH, the sorption capacity of clay minerals increases as a consequence of formation of stable hydroxo-complexes. 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. 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 is expected, this is not the case in such large lakes. Therefore we may not get any significant differences between seasons in Lake Victoria. The ranges of determined mean concentrations of the heavy metals are also given in Tables 1a, 1b, 2a and 2b. 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 1 and 2 compared with the rest of the sites. In particular, the variations were also seen in Pb concentrations in sediment being much higher in the Kisumu pier area i.e. sampling sites 1, 2, 3 and 4 with mean concentrations ranging from 128.4 – 186.1 ppm. These elevated concentrations of Pb can be attributed to anthropogenic inputs. For the water concentrations, there was less uniform distribution of metals in the water phase and a number of sites showed no presence of metals.

Based on the WHO drinking water standards (Table 3), our results show that Lake Victoria is still relatively unpolluted with respect to trace metal concentrations. Most of the trace metal concentrations were below the highest desirable levels (HDL) and maximum permissible levels (MPL). However the concentration levels of Mn in all sampling sites were higher than the HDL. The concentration levels of Ag in Lake Victoria water were 1-5 times the TC level recommended for fish life tolerance freshwaters (see Table 3). Ag concentration levels in Lake Victoria need to be determined further by increasing the number of sampling sites to be able to identify potential sources. However, all other determined heavy metal concentrations were below the aquatic life threshold concentrations listed in table 3. In general, although the overall concentration levels of trace metals in sediment and in surface waters of Lake Victoria were within normal ranges expected in dilute lakes, data obtained for sampling points 1, 2, 3 and 4 in the pier area of Kisumu city suggested abundant anthropogenic sources of trace metal contamination in these areas and their contribution in lake water. 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 is part of the natural background level in the bottom mud from polluted waters. The heavy metals which

are not present in the crystal lattice are distributed in organic matter, in hydrous Mn and Fe oxides, and in any discrete minerals formed by the metals. In particulate matter, heavy metals are present in non-lattice. 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. With increase in pH, sorption capacity increases as a consequence of formation of stable hydroxo-complexes and therefore total dissolution of sediment with strong acids (e.g. 11.1 M HNO₃), as was done in our analysis, is more likely to give high values based on total metal content rather than just available metals.

Table 2a. Trace metal concentrations (µg/L) in lake water samples of Winam Gulf, Lake Victoria.

Site	Ag	Cd	Co	Cr	Cu
LV1	Nd	2.5±0.31	19.1±2.11	9.9±0.32	10.0±0.92
LV2	44.0±1.44	Nd	18.8±0.24	6.9±0.32	10.1±0.20
LV3	50.0±4.12	Nd	19.0±0.61	19.3±0.55	25.0±2.64
LV4	11.2±0.44	Nd	6.0±0.14	10.3±0.52	10.0±1.11
LV5	Nd	3.0±0.32	Nd	7.4±0.44	10.1±0.77
LV6	10.0±0.12	3.1±0.44	Nd	Nd	5.1±0.45
LV7	25.1±0.10	2.0±0.16	Nd	13.1±1.11	7.5±1.44
Range	9.88-54.12	1.84-3.54	5.86-19.61	6.54-19.85	4.65-27.64
Mean	28.05	2.65	15.73	11.15	11.11
SD	16.41	0.44	5.61	4.19	5.95
n	15	12	12	18	21

Note: Each element was determined in triplicate for each site and expressed as mean ± standard deviation (SD) in the columns; Nd: Not detected. The overall means and standard deviations for all sampling sites are included at the bottom.

Table 2b. Trace metal concentrations (µg/L) in lake water samples of Winam Gulf, Lake Victoria.

Site	Mn	Ni	Pb	Zn
LV1	148.1±11.3	Nd	44.4±2.44	35.0±0.94
LV2	Nd	13.1±0.66	Nd	38.2±2.22
LV3	188.3±24.1	1.4±0.13	25.1±2.42	143.1±11.44
LV4	50.0±3.6	1.9±0.14	24.5±1.12	45.0±4.44
LV5	50.1±3.33	Nd	7.0±0.44	94.3±7.33
LV6	49.9±2.13	Nd	25.0±0.77	44.2±2.22
LV7	Nd	19.0±0.74	20.5±1.64	40.0±2.41
Range	47.77-212.4	1.27-19.74	6.56-46.88	34.06-154.5
Mean	97.28	8.85	24.42	62.83
SD	55.23	7.50	10.95	37.86
n	15	12	18	21

Table 3. Acceptable levels (mg/L) of some heavy metals in natural waters according to WHO standards.

Limit	Ag	As	Cd	Cr	Cu	Mn	Ni	Pb	Zn
HDL ¹	nl	nl	nl	nl	0.05	0.05	nl	nl	5.00
MPL ¹	0.05	0.05	0.01	0.05	1.00	0.5	nl	0.10	15.00
TC ²	0.01	1.00	0.01	0.05	0.02	nl	0.05	0.10	0.10

Note: nl denotes 'not in literature cited'; 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). References: ¹WHO Drinking water standards, 1981; ²Burrell, 1974.

Table 4. Limnological data determined in natural waters of lakes Victoria and Kanyaboli

Sampling Site	pH	Temp °C	DO mg/L	Trans cm	Turbidity ETU	Alkalinity mgCaCO ₃ /L	Conductivity μS cm ⁻¹
LV1	7.4	27.8	3.8	40	16.0	67.74	145.0
LV2	7.3	27.7	4.1	35	16.3	72.0	140.0
LV3	7.4	27.8	4.0	35	21.0	63.0	130.0
LV4	7.4	27.4	6.2	45	28.0	64.0	91.8
LV5	7.5	25.0	4.2	20	28.0	59.0	150.0
LV6	7.6	28.0	7.2	110	35.1	79.0	140.0
LV7	8.1	27.0	6.8	180	34.2	41.2	102.0
LV8	7.1	24.0	6.2	5	31.2	120.0	220.0
LV9	7.2	24.5	4.9	30	29.2	Nd	160.0

Note: Data given in the columns represent means of two data sets.

Trans= transparency.

The limnological data are shown in table 4. Lake Victoria can be classified as a drainage lake whose major outlet is River Nile. From the data, the lake water chemistry qualifies its suitability for aquatic life and for human use. The lake is slightly alkaline (pH ranging within 7.1 – 8.1) with dissolved oxygen content ranging within 3.8 – 7.2 mg/L (76-117% saturation range) and low alkalinities of 61.76 mg CaCO₃ /L (1.24 meq /LCaCO₃) in the sampling sites covered during the study. The temperatures (mean of 26.4±1.60 °C) were within maximum productivity range. Higher electrical conductivities and alkalinities were recorded in areas near the gold factory at Asembo Bay area (sampling sites 5 and 6). This was accompanied by low DO ranging from 3.8-4.9 mg/L. A similar trend was observed for trace metal contents implicating this area as another potential source of pollution in Lake Victoria. The lake water is soft with water hardness with mean 33.5±2.5 mg CaCO₃/L (equal to 0.67±0.04 meq Ca²⁺). In general soft water is expected to have a total hardness less than 200 mg/L (equal to 4 meq Ca²⁺). However, slight Diels changes in pH, alkalinity, conductivity, temperature, turbidity and DO are expected in Lake Victoria even though these were not determined during this analysis (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 this lake. 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 range from 10.1–11.25 and have electrical conductivities ranging from 12500 – 65000 $\mu\text{S cm}^{-1}$ (Ochieng, 1987).

Comparing our trace metal concentration data with those of other researchers, Everaarts and Nieuwenhuize (1996) obtained lower concentrations of Cu (100.3 ppb), Zn (524 ppb), Cd (11.7 ppb), Pb (137 ppb) and Mn (1587 ppb) in estuarine sediment samples taken from Sabaki River mouth at the Indian Ocean Coast of Kenya (Everaarts and Nieuwenhuize 1995). This is expected to be like this because of mixing of the river water and the Indian Ocean water at the estuaries. The concentrations of these same heavy metals in sediments in Lake Victoria ranged within 19,880 – 61,420 ppb (Cu), 150 – 1,080 ppb (Cd), 159,900 – 363,400 ppb (Zn), 19,640 – 200,570 ppb (Pb) and 826,600 – 3,611,200 ppb (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 (Chan 1995a). Chan (1995a) obtained concentrations of heavy metals in the range of 15 – 304 ppb (Cu), 24 – 403 ppb (Zn), 8 – 109 ppb (Cd) and 40 – 440 ppb (Pb) 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 (Chan 1995a). In Baltic sea surface sediments, high mean concentrations, based on dry weights of sediments, of Cd (15,000 ppb), Co (18,000 ppb), Cr (39,000 ppb) Cu (63,000 ppb), Mn (700,000 ppb), Ni (49,000 ppb), Pb (71,000 ppb) and Zn (360,000 ppb) 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 are all higher than concentrations obtained in our study for Winam Gulf of Lake Victoria, except Pb (mean of 90,030 ppb) and Mn (mean of 1,754,670 ppb). In Kenya, Onyari and Wandiga (1989) earlier obtained mean values Cu (ranging from 7,600 – 64,100 ppb), Zn (17,800 – 26,800 ppb), Cd (340 – 1,510 ppb), Pb (2,500 – 138,000 ppb) and Cr (37,100 – 131,000 ppb), Mn (100,000 – 6,200,000 ppb) in sediment samples taken from Winam Gulf of Lake Victoria (Onyari and Wandiga 1989). The elevated levels of Cu, Cd, Zn and Pb were detected in samples taken at the car wash area of Kisumu city pier of the lake, which clearly indicated anthropogenic input as main source. Our results indicate that the concentration levels of Zn and Pb have increased by approximately ten times and one-and-half times, respectively, in the Kisumu pier area known as car wash area, since the Onyari and Wandiga study showing the extent of anthropogenic input into the lake. In Lake Kariba in

Zimbabwe reported mean surface sediment concentrations ranged within 15,800 – 25,800 ppb (Cr), 690 – 720 ppb (Cd), 12,400 – 16,100 ppb (Cu), 19,300 – 23,900 ppb (Pb), 238,700 – 326,900 ppb (Mn), 23,200 – 25,900 ppb (Ni) and 68,200 ppm – 71,100 ppb (Zn), in Kasseke bay and in Cages, respectively (Berg et al. 1996). 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.

In conclusion, although our data suggest that the concentration levels of trace metals in surface waters of Lake Victoria were within normal range expected in dilute lakes, the sediment concentrations of certain elements, particularly Zn, Cu, Cd, Pb and Mn were elevated in the Kisumu pier near the car wash area indicating anthropogenic addition. The car wash area in Kisumu city is shallower and is a major recipient of anthropogenic input. Some of the port activities which can contribute towards elevated levels of heavy metals in the area include petroleum oil depot and handling, discharge of ship bilge waters and oil spillages during normal operations, use of leaded gasoline fuel to power vehicles and exhaust emissions from cars being washed into the water. This area also receives industrial and municipal waste water through the Kasat River which discharges into the lake at this point. The concentrations in surface water and sediment in samples from areas farther from the car wash area were within normal range when compared with other data reported earlier and in other regions of the world.

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