Available online at www.sciencedirect.com
SCIENCE DIRECT®
Environment International 28 (2003) 619–625
ENVIRONMENT INTERNATIONAL
www.elsevier.com/locate/envint

Distribution of heavy metals in sediments of Mwanza Gulf of Lake Victoria, Tanzania

M.A. Kishe[a,*], J.F. Machiwa[b]

[a] Tanzania Fisheries Research Institute, P.O. Box 475, Mwanza, Tanzania
[b] Department of Zoology and Marine Biology, University of Dar es Salaam, P.O. Box 35064, Dar es Salaam, Tanzania

Abstract

Sediment samples were analyzed for Cd, Cr, Cu, Pb, Hg and Zn by AAS. The highest concentrations (ppm) for Cu (26.1 ± 4.8), Hg (0.2 ± 0.05), Pb (30.7 ± 5.6) and Zn (45.4 ± 13.1) were found at approximately 25 m from the shoreline. Generally, heavy metals concentration in the sediment decreased with increasing distance from the shoreline except for Cd and Cr whose highest concentrations were found at approximately 2000 m from the shoreline.

The data also indicated that sediment samples which were collected at the shores within the urban area of Mwanza showed elevated levels of Pb (54.6 ± 11.1 ppm) and Zn (83.7 ± 21.5 ppm). However, the highest concentrations of Cd (7.0 ± 2.1 ppm), Cr (12. 9 ± 1.0 ppm) and Hg (2.8 ± 0.8 ppm) were recorded at sampling stations which were adjacent to river mouths.
© 2002 Elsevier Science Ltd. All rights reserved.

Keywords: Sediment; Heavy metals; Mwanza Gulf; Lake Victoria; Tanzania

1. Introduction

Bottom sediments serves as a reservoir for heavy metals and therefore deserve special consideration in the planning and design of aquatic pollution research studies. An undisturbed sediment column contains a historical record of geochemical characteristics in the watershed. If a sufficiently large and stable sediment sink can be located and studied, it will allow an investigator to evaluate geochemical changes over time, and possibly, to establish baseline levels against which current conditions can be compared and contrasted.

Heavy metals such as cadmium, mercury, lead, copper and zinc are regarded as serious pollutants of aquatic ecosystems because of their environmental persistence, toxicity and ability to be incorporated into food chains (Förstner and Wittman, 1983). In Lake Victoria, industrial, agricultural and domestic waste discharges have increased the levels of heavy metals in the lake (Mpendazoe et al., 1993; Muli, 1996). A study conducted by NEMC (1994) on heavy metal pollution in open pits in gold mining areas in the lake zone revealed that mercury levels were significantly higher than the permissible level of 1 μg l^{-1} in drinking water. Kahatano et al. (1995) also found high levels of Pb, Cu, Cr, Zn and Hg in water, sediments and soil of some streams and rivers in goldfield. These metals possibly end up in the lake.

Previous studies (Hamza, 1996; Kondoro and Mikidadi, 1998; Mohammed, 2000) showed wide variation of heavy metal contamination in water, sediment, fish and flora within Mwanza urban area (Mwanza South, Central and North) of Lake Victoria. A significant difference was found between concentrations of heavy metals in urban and rural areas (Mohammed, 2000). The industrial area located in Mwanza north was found to contain relatively higher levels of heavy metals. Apart from mining activities, municipal and industrial discharges are contributing on heavy metal pollution in Lake Victoria. Other possible sources of heavy metals include water and road traffic. Heavy metals that are mostly a result of technological development (e.g. Cu and Zn) occur at significant concentrations in the lake sediments (Onyari and Wandiga, 1989; Mwamburi and Oloc, 1997). Generally, the sediments of Lake Victoria, are rich in Pb, Cu and Mn compared to values reported in sediments collected from other areas within the East African sub-region (FAO/CIFA, 1994; Mwamburi and Oloc, 1997).

In this paper, the concentrations of heavy metals obtained from sites adjacent to possible point sources in Mwanza Gulf

* Corresponding author. Tel.: +255-744-467911; fax: +255-28-2550036.
E-mail address: maria_kishe@yahoo.co.uk (Mary Alphoce Kishe).

0160-4120/02/$ - see front matter © 2002 Elsevier Science Ltd. All rights reserved.
PII: S0160-4120(02)00099-5

of Lake Victoria are reported. The variations of levels of heavy metals in sediment with increasing distance from the shoreline towards deep water are discussed.

2. Materials and methods

2.1. Study area

Lake Victoria is the second largest freshwater body in the world with an area of 68,800 km^2. It is situated at latitude 1°N and 4°S and longitude 31°E and 35°E at an elevation level of 1134 m above sea level (Van Densen and Witte, 1995). The rocks underlying the Lake basin are either Precambrian or Tertiary volcanoes depending on the location. Pleistocene and Holocene fine grained sediments overly these basement rocks (Scholz et al., 1990; Wakeham, 1990). The recent sedimentary regime of the lake is complex, however, deposition rates range from zero to about 1 mm per annum in bays (Scholz et al., 1990) or more than 1 cm per millennium in the open lake (Hecky et al., 1996). Surface sediments are dominated with biogenic remains and the organic carbon content is between 10% and 20% in bays and depositional basins. Non-depositional areas are charac-

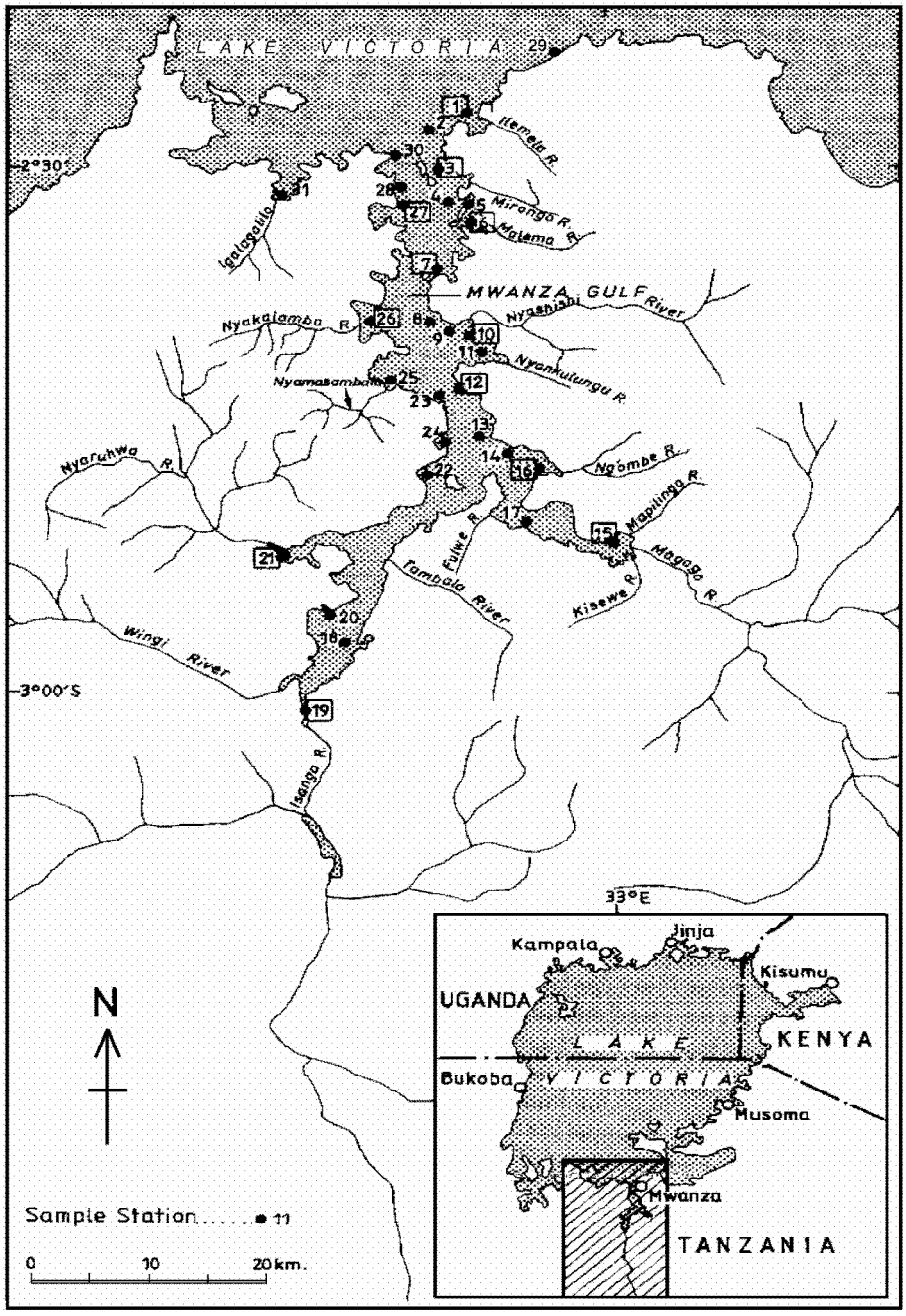


Fig. 1. Map Mwanza Gulf, showing the sampling stations.

teristically sandy, containing low organic carbon (Mothersill, 1976; Wakeham, 1990).

Lake Victoria is shared by three riparian states, Kenya, Uganda and Tanzania. On the Tanzanian side, Mwanza City and two other major towns (Musoma and Bukoba) are located at the lake shore with a population of about 5 million people (LVEMP, 1999). Mwanza Gulf is one of the largest gulf at the southern end of Lake Victoria (Fig. 1). The gulf extends 60 km southward with an average width of 5 km and a surface area of approximately 500 km^2 (Van Densen and Witte, 1995; LVEMP, 1999).

2.2. Sample collection and analysis

Selection of sampling stations for sediment samples considered the outlets for canals, streams and rivers which drain residential, commercial (garages, metal works and markets), industrial and mining areas into the lake. Thirty-one sampling stations were selected to provide information on the impact of natural and anthropogenic inputs of heavy metals into Mwanza Gulf of Lake Victoria. At each sampling station, sediment samples were collected at three sampling points that were located in the lake at approximately 25, 500 and 2000 m from the shoreline, i.e. at an increasing distance toward the deep water. For convenience purposes, the 31 sampling sites were categorized into three groups. The first category was sampling stations adjacent to beaches within the city (CA) which included stations 1, 2, 3, 4 and 5. The selected beaches within the city were in close proximity to commercial areas, such as market places, small-scale metal works, manufacturing industries, factories and ports. Streams within the city and storm water outfalls were also included. The second were stations adjacent to river mouths (RM) which included stations 6, 7, 10, 15, 16, 19, 21, 25, 26, 31 and third one were stations adjacent to fish landing beaches (FB) which included stations 8, 9, 11, 12, 13, 14, 17, 18, 20, 22, 23, 24, 27, 28, 29, and 30. All beaches were in the suburbs and rural areas.

Bottom sediment samples were collected during March and April 2000, using a box corer aboard an outboard engine fiberglass boat. Surface sediment (<5 cm) samples were transferred into labeled polyethylene bags and stored in the laboratory at −20 °C until analysis. Sediment samples were thawed, then transferred into acid washed plastic containers and freeze-dried for 72 h (Machiwa, 1992). The samples were sieved through a 2-mm sieve so as to remove any large debris and were then thoroughly homogenized using a pestle and mortar. An extensive quality assurance/quality control procedure was followed. Quality control samples that were analyzed included methods blanks, sample replicates, analyte spikes and surrogate spikes.

Duplicate sub samples of approximately 0.5 g of well homogenized sediment samples were accurately weighed on an analytical balance and then transferred into glass digestion tubes. Concentrated sulphuric (1 ml) and nitric (1 ml) acids (AnalaR®) were used to leach the samples. The extracts were diluted to a final volume of 10 ml using deionized water. The concentrations of Cd, Cr, Cu, Hg, Pb and Zn were determined in the supernatant using an Atomic Absorption Spectrophotometer (AAS), Varian model Spectra A55. All heavy metals except Hg were analyzed in the flame mode. Mercury was analyzed by cold vapour technique with an automatic hydride generator.

Sub-samples of freeze-dried sediment ($d>0.0125$ mm) were placed on mechanical shaker and grain size was determined using a series of sieves while the small particle sizes ($d<0.125$ mm) were determined by sedimentation. The two results were combined to one particle size distribution curve.

3. Results

3.1. Heavy metal levels in sediments from selected locations

Heavy metal concentrations in bottom sediments from stations adjacent to urban beaches (CA) revealed remarkable differences from other sampling stations. The highest mean levels of Zn (83.7 ± 21.5 ppm) and Pb (54.6 ± 11.1 ppm) were found at sampling stations that were located adjacent to beaches within the city area. "Hot spots" for Zn pollution were noted at station 3 (244.7 ppm) and station 4 (254.4 ppm). Station 3 was Mirongo area while station 4 was Mwanza South. The highest Pb concentration (189.0 ppm) was recorded at station 4. The mean concentrations of Cr (11.2 ± 1.2), Cu (17.9 ± 2.3) and Hg (0.1 ± 0.03) were generally low (Fig. 2a and b).

Heavy metal concentrations in bottom sediments from stations adjacent to fish landing beaches (FB) had relatively low mean concentrations of all the analyzed metals except Cd (Fig. 2a and b). The mean concentration of Cu was 22.3 ± 3.0 ppm, the highest concentration of Cu (136.8 ppm) was recorded at station 12 (Kigongo area). The mean concentration of Pb was 23.0 ± 1.2 ppm, Zn was 22.0 ± 0.7 ppm and Cr was 10.9 ± 1.0 ppm. Highest concentration of Zn was found at station 18 (Mbalika), the value was 32.2 ppm. Cadmium concentration (4.0 ± 0.02 ppm) in FB sampling station was rather higher than its mean concentration (3.7 ± 1.1 ppm) that was obtained at CA station category. Stations 20 (Kaningu), 22 (Mulaga), 23 (Busisi) and 24 (Nyamasale) had Cd concentration below detection limit (0.01 ppm). Mercury concentration in the sediment samples from stations near fish landing beaches was mostly below the detection limit (0.1 ppm), the mean concentration was 0.1 ± 0.03 ppm.

Heavy metal concentrations in bottom sediments from stations adjacent to river mouths (RM) were almost similar to values obtained at FB. The concentration of Cr was 12.9 ± 1.0 ppm and Cu was 22.5 ± 2.9 ppm. The highest concentration of Cu (89.1 ppm) was found at station 10 (Nyashishi river mouth). Chromium and copper levels were more or less uniform at the three categories of sampling stations (Fig. 2a). The concentration of Pb (26.5 ± 1.5 ppm)

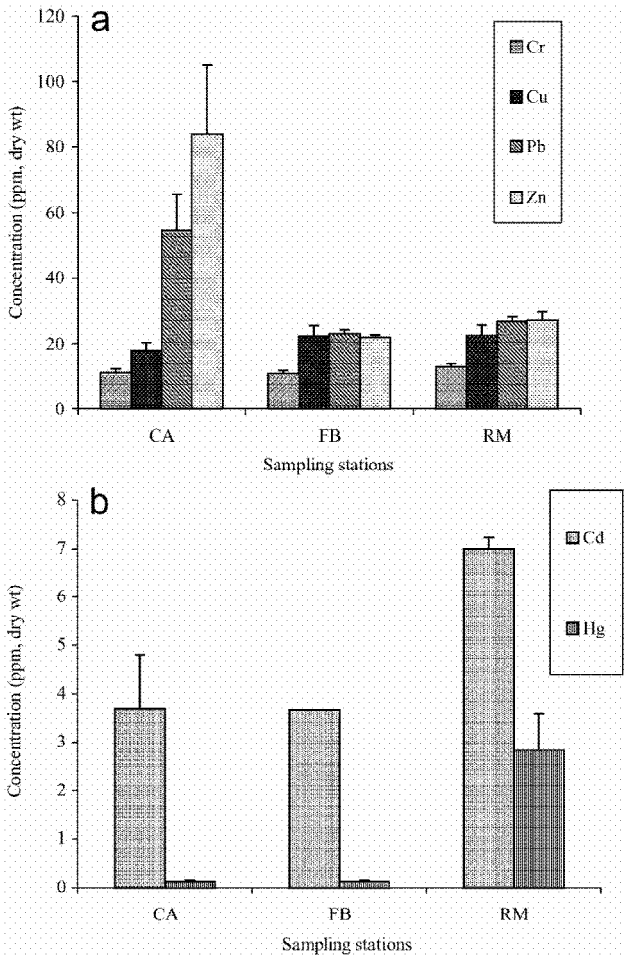


Fig. 2. (a) Mean (± SEM) concentrations of Cr, Cu, Pb and Zn (ppm, dry weight) in sediment samples collected at different locations at Mwanza Gulf. UA = Stations adjacent to Urban beaches ($n = 5$); FB = stations adjacent to Fish landing beaches ($n = 10$) and RM = stations adjacent to river mouths ($n = 16$). (b) Mean (± SEM) concentrations of Cd and Hg (ppm, dry weight) in sediment samples collected at different locations at Mwanza Gulf. UA = Stations adjacent to Urban beaches ($n = 5$); FB = stations adjacent to fish landing beaches ($n = 10$) and RM = stations adjacent to river mouths ($n = 16$).

was almost equal to that of Zn (27.1 ± 2.5 ppm) obtained from RM sampling stations. The levels of Zn and Pb were very high at CA compared to other station categories of sampling. Highest Zn concentration (61.4 ppm) was recorded in sediment samples from station 6 (Mkuyuni river mouth). Fig. 2b shows that RM category of stations had the highest mean concentrations of Cd (7.0 ± 0.2 ppm) and Hg (2.8 ± 0.8 ppm). Only stations 19 (Isanga river mouth) and 21 (Nyaruhwa) had Cd level below detection limit.

3.2. Variation of heavy metal content in lake sediments with distance from shoreline

3.2.1. Chromium, copper, lead and zinc

Chromium concentrations in the lake sediments were 10.6 ± 1.7, 11.4 ± 2.1 and 12.8 ± 0.8 ppm at approximately 25, 500 and 2000 m from the shoreline, respectively (Fig. 3a). Friedman test indicated a significant difference ($Fr = 6.000$, $P = 0.0498$) in Cr concentration with increasing distance from the shoreline. Dunn's multiple comparison test confirmed that the difference was significant ($P < 0.05$) for the levels of Cr at 25 and 2000 m from the shoreline.

The highest concentration of copper (26.1 ± 4.8 ppm) was found at about 25 m from the shoreline. The concentration of Cu was 18.9 ± 2.1 ppm at 500 m and 19.7 ± 1.2 ppm at 2000 m (Fig. 3a). Statistically, the difference in concentration of Cu with increasing distance from the shoreline was not significantly different ($P > 0.05$).

The highest concentration of Pb (30.7 ± 5.6 ppm) was found close to the shore at approximately 25 m. Lead concentration was 30.5 ± 6.0 ppm at 500 m and 27.6 ± 1.3 ppm at 2000 m from the shoreline (Fig. 3a). Friedman test and Dunn's multiple comparison test (Zar, 1984) were used

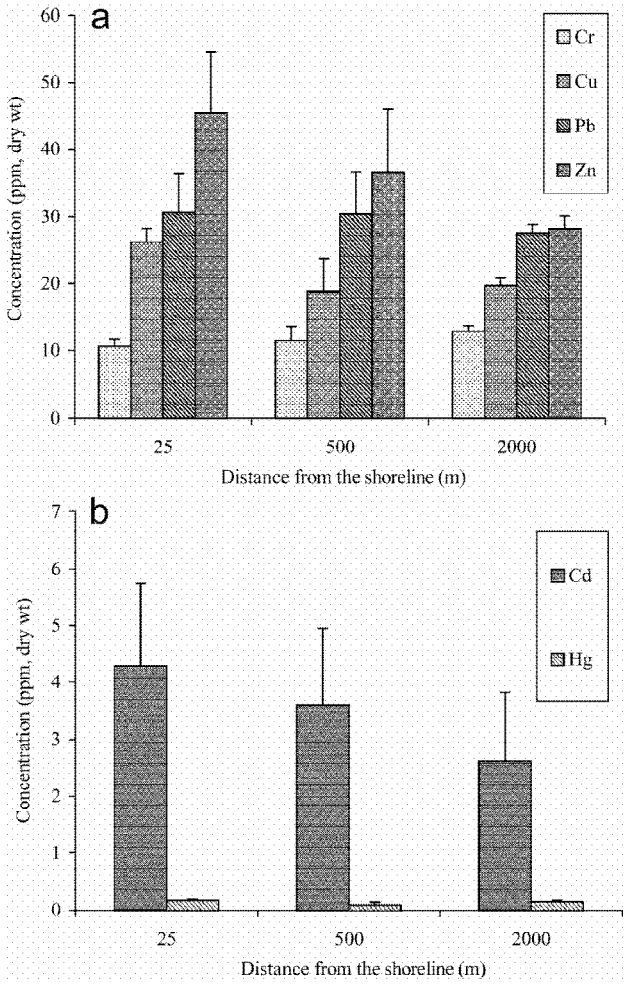


Fig. 3. (a) Variation of mean (± SEM) concentrations (ppm, dry weight) of Cr, Cu, Pb and Zn in lake sediments with increasing distance from the shoreline ($n = 31$ per sampling distance). (b) Variation of mean (± SEM) concentrations (ppm, dry weight) of Cd and Hg in lake sediments with increasing distance from the shoreline ($n = 31$ per sampling distance).

Table 1
Percentage grain size distribution (mean ± SD) in sediments samples collected from Mwanza Gulf ($n = 12$)

Sediment type	Sampling station			Distance from the shore (m)		
	CA	FB	RM	25	500	2000
Clay	16.1 ± 11.0	17.3 ± 8.6	28.2 ± 11.5	17.6 ± 10.7	18.5 ± 12.6	25.5 ± 10.5
Silt	61.9 ± 20.7	54.4 ± 18.9	41.0 ± 17.0	41.5 ± 19.5	61.8 ± 19.4	54.0 ± 18.4
Sand	23.7 ± 26.6	28.1 ± 20.7	31.3 ± 20.5	42.5 ± 26.2	21.4 ± 15.5	20.0 ± 17.7

to compare level of heavy metals at 25, 500 and 2000 m from the shoreline. However, the difference in the concentrations of Pb with increasing distance from the shoreline was not statistically significant ($P > 0.05$).

Zinc levels were 45.4 ± 13.1, 36.4 ± 9.5 and 28.2 ± 1.9 ppm at approximately 25, 500 and 2000 m from the shoreline, respectively. Statistical analysis indicated that levels of Zn in the sediment from all sampling stations did not change significantly ($P > 0.05$) with increasing distance from shoreline.

3.2.2. Cadmium and mercury

Cadmium levels showed slight variations with increasing distance from shoreline (Fig. 3b). The concentrations were 4.3 ± 1.5 ppm at 25 m, 3.6 ± 1.4 ppm at 500 m and 2.6 ± 1.2 ppm at 2000 m from shoreline. However, statistical analysis indicated that levels of Cd in sediment did not change significantly ($P > 0.05$) with increasing distance from the shoreline.

Mercury, the most toxic metal in the aquatic environment, was below detection limit (0.01 ppm) in sediments from the majority of the sampling stations. The mean concentrations were 0.2 ± 0.02, 0.1 ± 0.04 and 0.1 ± 0.02 ppm at approximately 25, 500 and 2000 m from the shoreline, respectively (Fig. 3b). The mean concentrations did not differ ($P > 0.05$) with increasing distance from the shoreline.

3.3. Grain size distribution

The percentage distribution of clay, silt and sand in the sediments of Mwanza Gulf is shown in Table 1. Depending on the sampling stations, the highest amounts of clay (28.2 ± 11.5%) and sand (31.3 ± 20.5%) were found at sampling stations that were adjacent to river mouths. The highest amount of silt (61.9 ± 20.7%) was in sediments that were collected at stations adjacent to beaches within the city. Statistically, the differences in grain size composition of the sediments from the different station categories were not significant ($P > 0.05$).

The highest clay content in the sediment (25.5 ± 10.5%) was found at 2000 m from the shoreline (Table 1). Silt content (61.8 ± 19.4%) was highest in sediments taken from 500 m and sand content (42.5 ± 26.2%) was highest at 25 m from the shoreline. The differences in grain size content of sediments collected at increasing distance from the shoreline was not statistically significant ($P > 0.05$).

4. Discussion

4.1. Spatial distribution of heavy metals in Mwanza Gulf

Sediment samples that were collected from stations adjacent to beaches within Mwanza City (CA) generally had higher concentrations of Pb and Zn than stations that were adjacent to rural beaches (FB) and river mouths (RM). The city area sampling stations comprised a number of places that were considered as point sources of pollution to the lake. For instance, Mirongo River, which is considered highly polluted, discharges industrial and domestic wastes from Mwanza City into the Mwanza Gulf. A number of activities, including fish processing industries, chemical industries (soap and oil), breweries, tanneries, beverages, metal works, oil depots, hospitals, hotels and restaurants are located in the city area. Such industrial and municipal wastes are discharged into the lake, either untreated or partially treated. The high levels of Pb and Zn in sediments from the city area sampling stations reflect the presence of lake polluting activities in the city. The most likely sources of Zn at the shores within the city are the Mirongo River and discharges from the Mwanza North harbour. The grain size distribution (Table 1) and mineralogy of the sediments of the three categories of stations (CA, FB and RM) were almost similar and cannot account for differences in the levels of Pb and Zn.

Domestic and industrial effluents, municipal runoffs and atmospheric deposition may be the major sources of the observed high level of Pb. The contribution of Pb from the use of leaded petrol in outboard boat engines and automobiles and car batteries is possibly significant. Previous studies also have indicated elevated levels of heavy metals in aquatic systems receiving effluents from urban areas (Talbot and Chegwidden, 1983; Mohammed, 2000). The sources of the heavy metals were mainly industrial and domestic waste discharges. In some cases, the disposal of untreated sewage has been reported to contribute significantly to the level of heavy metals in the aquatic environment (Talbot and Chegwidden, 1983; Mohammed, 2000). The more or less uniform concentrations of Cr and Cu in lake sediment reflect their natural background levels in the local soils. Cd and Hg were highest in sediments that were collected at stations adjacent to river mouths. Some of these rivers and streams drain gold mining areas (Mpendazoe et al., 1993; NEMC, 1994; Kahatano et al., 1995). The occurrence of highest Hg content in sediments of the RM

Table 2
Comparison of mean concentrations ($\mu g/g^{-1}$, dry weight) of heavy metals in sediments from Mwanza Gulf, Lake Victoria and other literature values

Study area	Cd	Cr	Cu	Hg	Pb	Zn	Reference
Kali Nadi River (India)	0.3	7.3	0.2	nd	2.4	90.4	Ajmal et al., 1988
L. Kariba (Zimbabwe); ($n=33$; mean ± SD)	0.06 ± 0.01	29.3 ± 1.6	16.1 ± 0.8	nd	9.4 ± 0.6	42.4 ± 2.6	Berg and Kautsky, 1997
L. Victoria (Uganda)	nd	67	41	nd	nd	86.0	Mothersill, 1976
L. Victoria (Kenya)	0.5	nd	39.8	nd	37.7	133.8	Onyari, 1985
L. Victoria (Tanzania); ($n=93$; mean ± SD)	2.5 ± 0.5	11.0 ± 1.4	21.6 ± 2.4	0.1 ± 0.0	29.6 ± 1.6	36.4 ± 1.8	Present study

nd = Not determined.

category suggests an anthropogenic origin, for instance, use of mercury by small scale gold miners to extract gold from sand (Kahatano et al., 1995) from early 1990s. River Isanga and its tributaries drain the mining areas of Geita goldfield (NEMC, 1994). Apart from the RM sediments, Cd was also high in sediments that were collected at stations adjacent to rural beaches (FB). The results possibly suggest an anthropogenic input of Cd contained materials directly to the lake or through rivers that pour their water to the Lake Victoria. The most likely source is a result of land degradation and/or the use of inorganic fertilizers in agriculture.

The results of the present study show that heavy metals content of sediments in Mwanza Gulf on the Tanzanian side of Lake Victoria is generally lower than those reported in the Kenyan and Ugandan sides of Lake Victoria (Table 2). The concentrations of Cd, Cu and Pb obtained in this study are higher than those reported in Lake Kariba and River Kali Nadi in 1977 and 1988, respectively (Table 2).

4.2. Variation in heavy metal levels in lake sediments with increasing distance from the shoreline

It was assumed that point sources of heavy metals in the lake are located on beaches at the shoreline. All heavy metals, except Cr, did not show any significant variation in their concentrations in the sediment with increasing distance from the shoreline. The levels of Cr in the sediment at 25 and 2000 m from the shoreline varied significantly. The highest mean Cr concentration was recorded at 2000 m from the shoreline. The difference in the spatial distribution of heavy metals in an area can be due to several factors, for instance, the differences in chemical composition of sediment, grain size distribution in the sediment and organic matter content of the sediment. Grain size distribution in the lake sediments was almost uniform with increasing distance from the shoreline (Table 1). There was no clear reason for having relatively high Cr concentration at 2000 m than at 25 m from the shoreline.

In conclusion, this study has shown that sediments of Mwanza Gulf, especially in the urban area, are polluted with heavy metals. Interventions should be made to reduce anthropogenic discharges in Lake Victoria basin; otherwise, heavy metals may increase in the lake, resulting in the elevated concentration in fish and humans.

Acknowledgements

The authors are grateful to the Lake Victoria Environmental Management Project (LVEMP) for funding this study. We are also grateful for logistic support from the Director General of Tanzania Fisheries Research Institute, Prof. P.O.J. Bwathondi, Mr. S. Mahongo (LVEMP Component Coordinator) and Mr. Gowele of SEAMIC who helped with analysis of heavy metals.

References

Ajmal M, Uddin R, Khan AU. Heavy metals in water, sediments, plants and fish of Kali Nadi U.P (India). Environ Int 1988;14:515–23.

Berg H, Kautsky N. Persistent pollutants in the Lake Kariba ecosystem—a tropical man-made lake. In: Remane K, editor. African inland fisheries, aquaculture and environment. Oxford: Blackwell; 1997. p. 115–35.

FAO/CIFA (Food and Agriculture Organization/Canadian Food Inspection Agency). Technical Paper of Canadian Food Inspection Agency on review of pollution in the Africa aquatic environment. Calamari; 1994.

Förstner U, Wittman GTW. Metal pollution in the aquatic environment. Berlin: Springer-Verlag; 1983.

Hamza MM. Determination of heavy metal pollution in Lake Victoria using energy dispersive X-ray fluorescence analysis. MSc dissertation, University of Dar es Salaam, Tanzania; 1996.

Hecky RE, Bootsma HA, Mugidde RM, Bugenyi FWB. Phosphorus pumps, nitrogen sinks, and silicon drains: plumbing nutrients in the African Great Lakes. In: Johnson IC, Odada EO, editors. The limnology, climatology and paleontology of the east African lakes. Amsterdam: Gordon & Breach; 1996. p. 205–34.

Kahatano JM, Mutakyahwa MKD, Mnali S, Kinabo C, Kaaya CZ, Ikingura JR. Report on the environmental aspects of mining and industrialization in Tanzania. Lake Victoria goldfields geochemical. University of Dar Es Salaam, Department of Geology; 1995.

Kondoro JWA, Mikidadi MH. Heavy metal pollution in Lake Victoria. Tanzan J Sci 1998;24:9–21.

LVEMP (Lake Victoria Environmental Management Project). Importance of Lake Victoria. In: Mwambungu B, editor. Nyanza Review 1, vol. 2. Tanzania: Dar es Salaam; 1999.

Machiwa JF. Heavy metal content in coastal sediments of Dar es Salaam, Tanzania. Environ Int 1992;18:409–15.

Mohammed NK. The optimization of energy dispersive X-ray fluorescent (EDXRF) spectrometer for the study of heavy metal pollution. MSc thesis, University of Dar es Salaam, Tanzania; 2000.

Mothersill JS. The mineralogy and geochemistry of the sediments of Northwestern Lake Victoria. Sedimentology 1976;23:553–65.

Mpendazoe MTF, Kibogoya M, Rutagemwa KD, Kayombo S, Rugasira M, Marwa P. Report on the evaluation of point source discharge treatment options in the Lake Victoria area in Tanzania. World Bank, Dar es Salaam, Tanzania; 1993.

Muli JR. Environmental problems of Lake Victoria (East Africa): what the international community can do? Land Resour Manage 1996;2:47–53.

Mwamburi J, Oloc FN. The distribution and concentration levels of trace metals in water and sediments of Lake Victoria, Kenya. Afr J Trop Hydrobiol Fish 1997;7:37–48.

NEMC (National Environmental Management Council). Report of National Environmental Management Council and working group on monitoring of mercury and other heavy metals pollution in gold mining areas around Lake Victoria, Tanzania; 1994.

Onyari JM. The concentration of Mn, Fe, Cu, Zn, Cd and Pb in sediments and fish from the Winam Gulf of Lake Victoria bought in Mombasa town markets. MSc thesis, University of Nairobi, Kenya; 1985.

Onyari JM, Wandiga SO. Distribution of Cr, Pb, Cd, Zn, Fe and Mn in Lake Victoria sediments. Bull Environ Toxicol 1989;42:807–12.

Scholz CA, Rosendahl BR, Versfelt JW, Rach N. Results of high resolution eco-sounding of Lake Victoria. J Afr Earth Sci 1990;11:25–32.

Talbot V, Chegwidden A. Heavy metals in the sediment of Cockbun Sound, Western Australia and its surrounding area. Environ Pollut 1983;5: 187–92.

Van Densen WLT, Witte F. Introduction. In: Witte F, Van Densen F, editors. Fish stocks and fisheries of Lake Victoria. A handbook for field observations. Canada: Samara Publishing; 1995. p. 1–10.

Wakeham SG. Algal and bacterial hydrocarbons in particulate matter and interfacial sediments of Cariaco Trench. Geochim Cosmochim Acta 1990;54:1325–36.

Zar JH. Biostatistical analysis. 2nd ed. Englewood Cliffs (NJ): Prentice-Hall; 1984.