Distribution of Heavy Metals In Sediments of Mwanza Gulf of Lake Victoria, Tanzania

Kishe, M.A.[1] and Machiwa, J.F.[2]
[1]Tanzania Fisheries Research Institute, P.O.Box 475, Mwanza, Tanzania
[2]Department of Zoology and Marine Biology, University of Dar es Salaam,
P. O. Box 35064, Dar es Salaam, Tanzania

Abstract

A study was conducted in February - April 2000 with the aim of determination of heavy metal concentrations in lake sediment at areas, which were considered as point- and non-point sources. A trend of heavy metal variation in sediment with increasing distance towards the lake from the point- and non-point sources was also investigated. 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 point sources towards the lake except for Cd and Cr whose highest concentrations were found at approximately 2000 m from the shoreline.

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 ± 0.2 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. In this study, it was concluded that, urban areas contain high levels of heavy metals due to pollution generating activities, which are taking place in these areas. However, more researches on factors influencing the accumulation of heavy metals in the aquatic systems including the chemical make-up of the sampling stations are emphasized.

Keywords: Sediment, heavy metals, Mwanza Gulf, Lake Victoria, Tanzania

Introduction

Bottom sediments can acts as a reservoir for heavy metals, and should therefore be given 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 (Horowitz, 1997) 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 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 (NEMC, 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 $1 \mu g l^{-1}$ 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.

Recent studies (Hamza, 1996; Kondoro and Mikidadi, 1998; Mohammed, 2000) have shown wide variation of heavy metal contamination in water, sediment, fish and flora within Mwanza urban area (Mwanza South, Central and North) of Lake Victoria.

Mwanza north, an industrial area reported to contain relatively higher levels of heavy metals. Also, a significant difference was found between concentrations of heavy metals in urban and rural areas. Apart from mining activities, municipal and industrial discharges, 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).

Concentrations of heavy metals in sediments located adjacent to possible point sources in Mwanza Gulf of Lake Victoria, are herein reported. The variations of levels of heavy metals in sediment with increasing distance from the shoreline towards deep water are discussed.

MAterials and Methods

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 0^o21N and 3^o0S and longitude 31^o39 E and 34^o53E at an elevation level of 1,134 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). The recent sedimentary regime of the lake is complex, deposition rates ranges from zero to about 1 mm per annum in bays (Kendell, 1969) 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 characteristically sandy, containing low organic carbon (Kendell, 1969; Mothersill, 1976).

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 gulfs at the southern end of Lake Victoria (Figure 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).

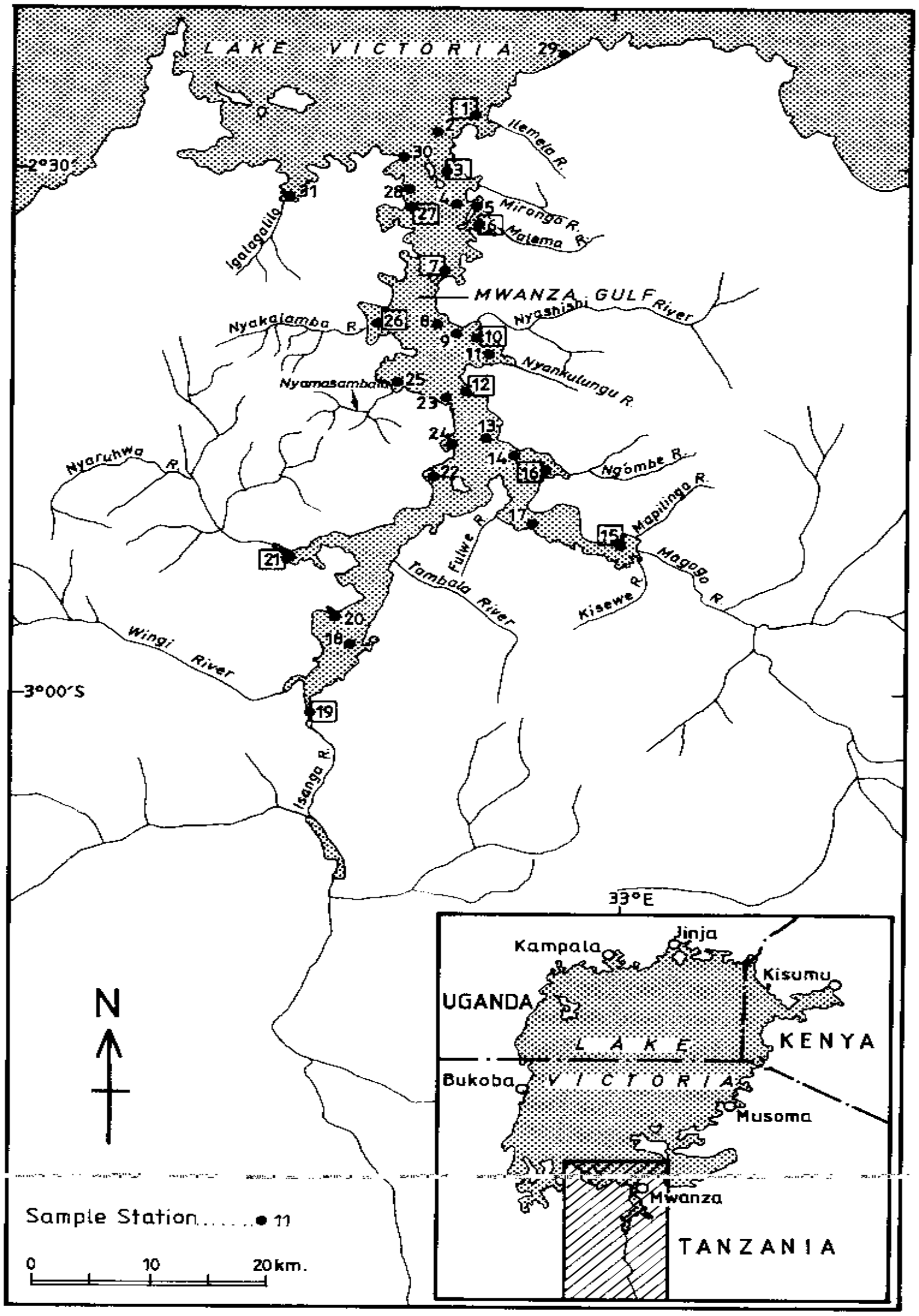

Figure 1. Map of Mwanza Gulf, showing the sampling stations

Sample collection and analysis

Selection of sampling stations for sediment samples put into consideration 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 in 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 m, 500 m and 2000 m from the shoreline, i.e. at an increasing distance toward the deep water. For convenience, the thirty one sampling sites were categorized into three groups as follows: [1]. Sampling stations adjacent to beaches within the city (CA) 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 port. Streams within the city, and storm water outfalls were also included; [2]. Sampling stations adjacent to river mouths (RM) included stations 6, 7, 10, 15, 16, 19, 21, 25, 26 and 31, in rural areas; [3]. Sampling stations adjacent to fish landing beaches (FB), included stations 8, 9, 11, 12, 13, 14, 17, 18, 20, 22, 23, 24, 27, 28, 29, and 30.

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^{o} C until analysis. Sediment samples were thawed, then were transferred into acid washed plastic containers and freeze dried for 72 hours (see, 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.

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 de-ionized 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.

Results

Heavy Metal Levels in Sediments of the Selected Location Categories

Heavy metal concentrations in bottom sediments from stations adjacent to urban beaches (CA) showed 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). 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), Cd (3.7 ± 1.1) and Hg (0.1 ± 0.03) were generally low (Figs. 2a and 2b).

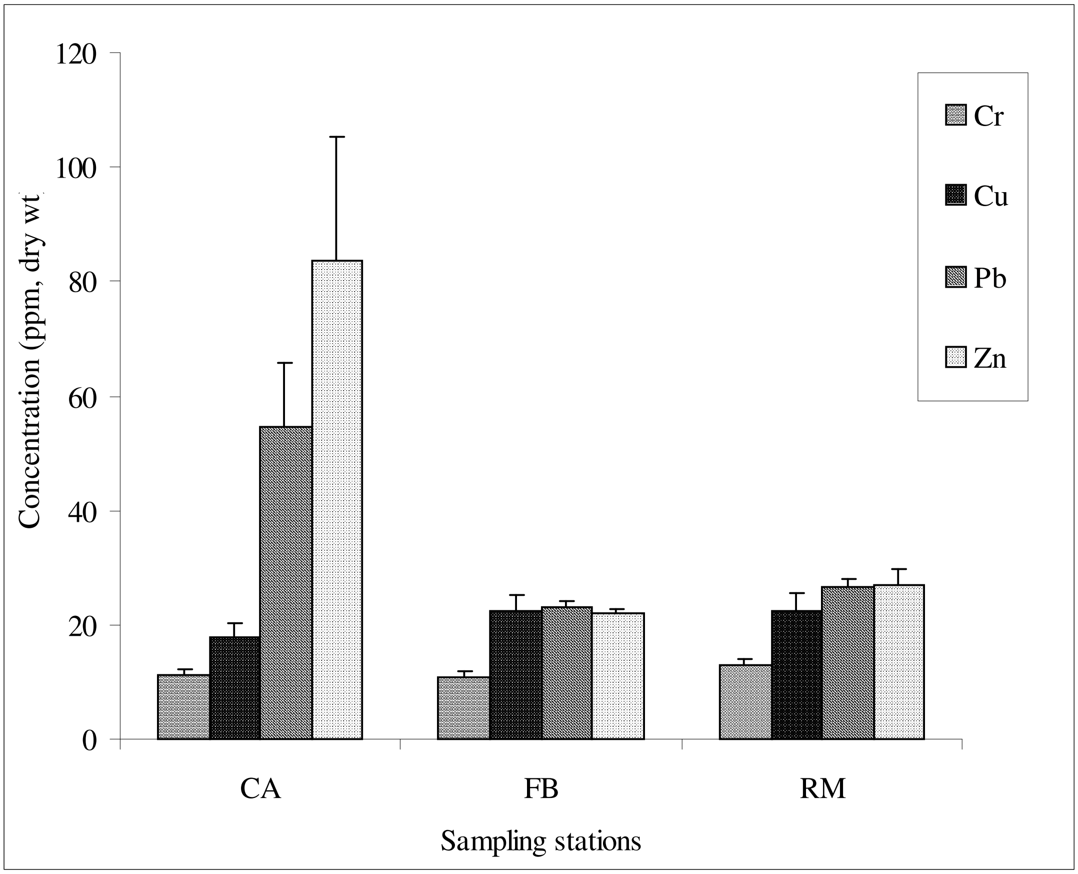

Figure 2a. Mean (± SEM) concentrations of Cr, Cu, Pb and Zn (ppm, dry weight) in sediment samples collected at different locations at Mwanza Gulf.
CA = Stations adjacent to Urban beaches (n = 5); FB = Stations adjacent to Fish landing beaches (n = 10) and RM = Stations adjacent to River mouths (n = 16)

Heavy metal concentrations in bottom sediments from stations adjacent fish landing beaches (FB) generally had relatively low mean concentrations of all the analyzed metals except Cd (Figs. 2a and 2b). The mean concentration of Cu was 22.3 ± 3.0 ppm, the highest concentration of Cu (136.8 ppm) was recorded at station 12. 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, the value was 32.2 ppm. Cadmium concentration (4.0 ± 0.02 ppm) was rather higher than its mean concentration that was obtained at the CA station category. Stations 20, 22, 23 and 24 had Cd concentration below detection limit. Mercury concentrations in the sediment samples from stations near fish landing beaches were mostly below the detection limit (0.1 ppm), the mean concentration was 0.1 ± 0.03 ppm.

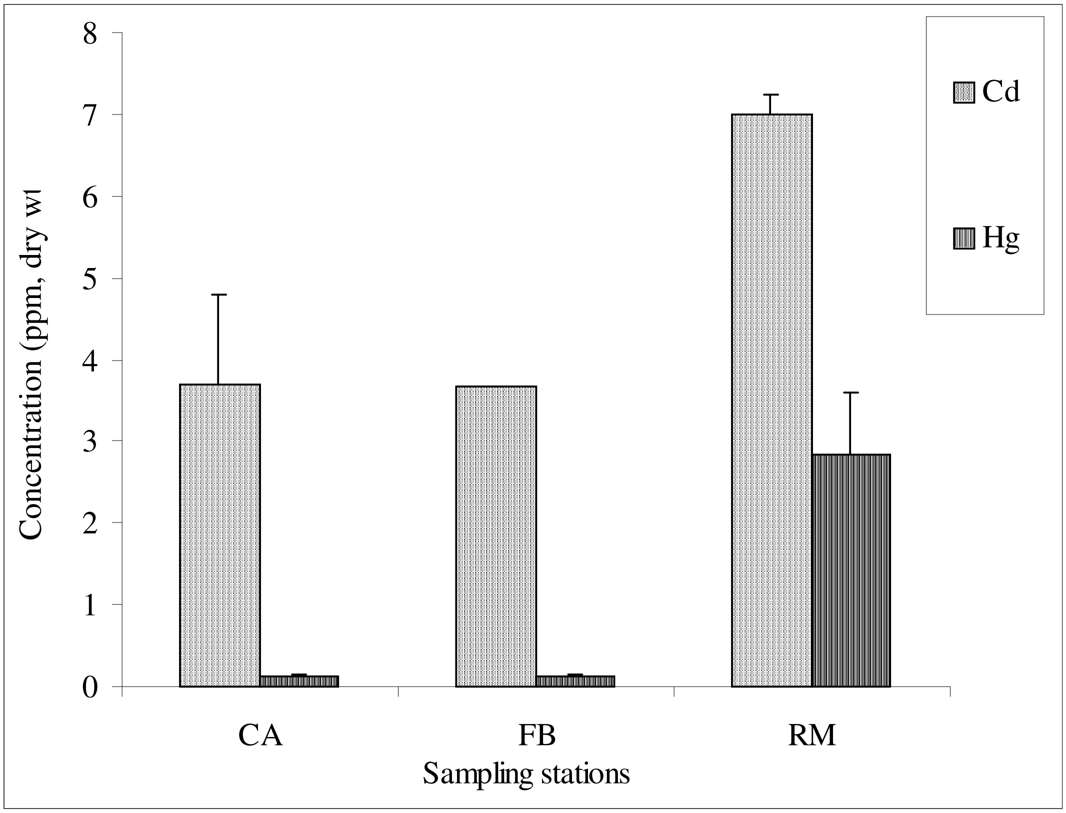

Figure 2b. Mean (± SEM) concentrations of Cd and Hg (ppm, dry weight) in sediment samples collected at different locations at Mwanza Gulf.

CA = 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)

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. 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) was almost equal to that of Zn (27.1 ± 2.5 ppm). The levels of Zn and Pb were intermediate between CA and FB station categories. Highest Zn concentration was recorded in sediment samples from station 6 (61.4 ppm). Figure 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 and 21 had Cd level below detection limit.

Variation of Heavy Metal Content in Lake Sediments with distance from shoreline

Chromium, Copper, Lead and Zinc

Chromium concentrations in the lake sediments were 10.6 ± 1.7 ppm, 11.4 ± 2.1 ppm and 12.8 ± 0.8 ppm at approximately 25 m, 500 m and 2000 m from the shoreline respectively (Fig. 3a). Friedman test and Dunn's multiple comparison test (Zar, 1986) were used to compare level of heavy metals at 25 m, 500 m and 2000 m from the shoreline. However, the difference in the concentrations of Cr with increasing distance from the shoreline was not statistically significant ($P > 0.05$).

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 indicated a significant difference ($Fr = 6.000$, $P = 0.0498$) in Pb concentration with increasing distance from the shoreline only at stations adjacent to fish landing beaches. Dunn's multiple comparison test confirmed that the difference was significant ($P < 0.05$) for the levels of Pb at 25 m and 2000 m from the shoreline at FB station category.

Zinc levels were 45.4 ± 13.1 ppm, 36.4 ± 9.5 ppm and 28.2 ± 1.9 ppm at approximately 25 m, 500 m 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 the shoreline.

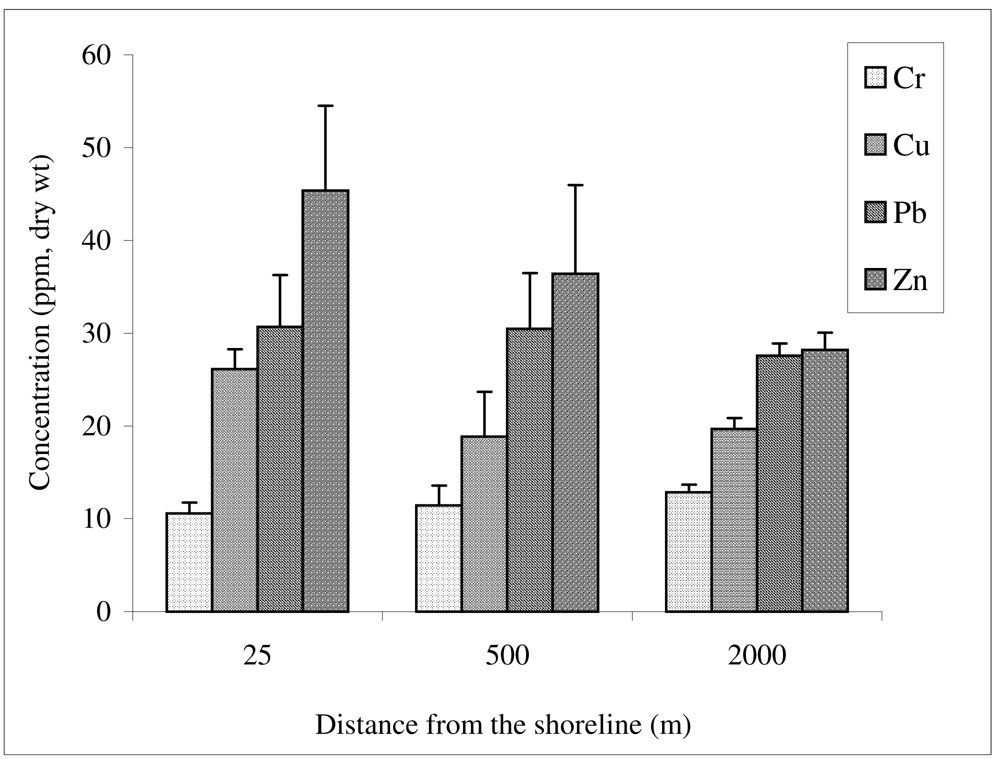

Figure 3a. Variation of mean (± SEM) concentrations (ppm, dry weight) of Cr, Cu, Pb and Zn in lake sediments with increasing distance from the shoreline (n = 31 per sampling distance)

Cadmium and Mercury

Cadmium levels showed slight variations with increasing distance from the 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 the 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 concentrations were 0.2 ± 0.02 ppm, 0.1 ± 0.04 ppm and 0.1 ± 0.02 ppm at approximately 25 m, 500 m and 2000 m from the shoreline respectively (Fig. 3b). The mean concentrations did not differ ($P > 0.05$) with increasing distance from the shoreline.

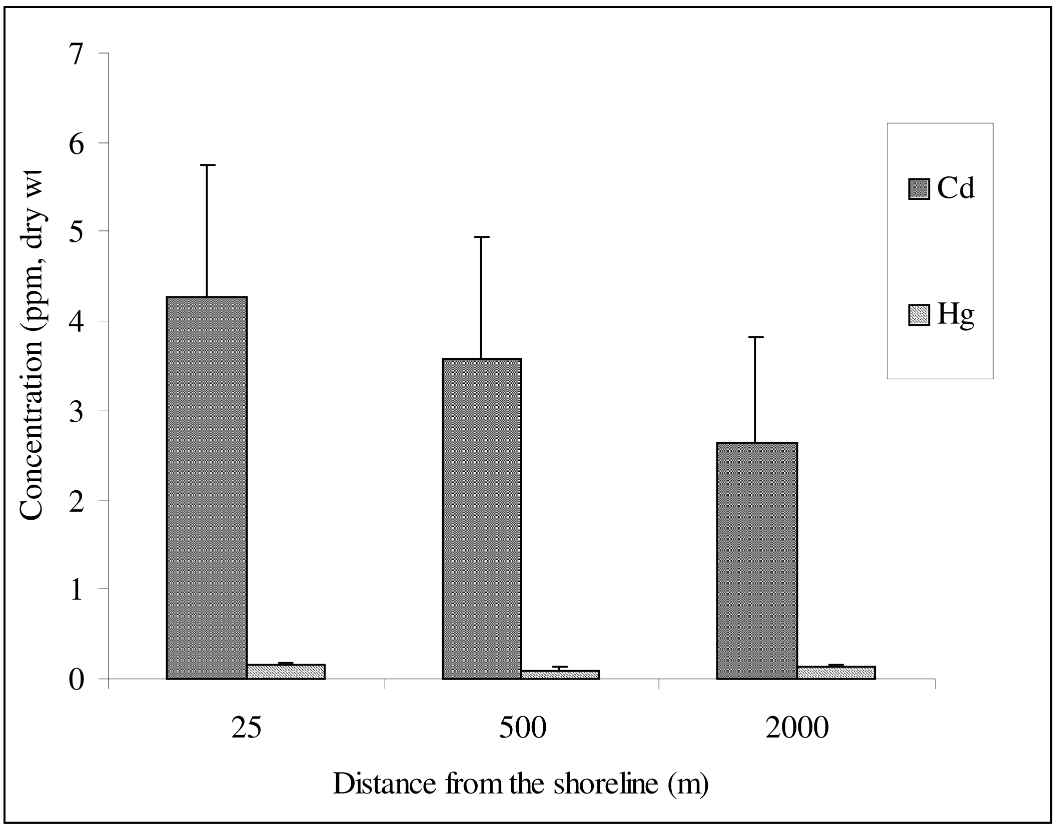

Figure 3b: Variation of mean (± SEM) concentrations (ppm, dry weight) of Cd and Hg in lake sediments with increasing distance from the shoreline (n = 31 per sampling distance)

Grain Size Distribution in the Sediments of Mwanza Gulf.

The percentage distribution of clay, silt and sand in the sediments of Mwanza Gulf is shown in table 1. 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 were not statistically significant ($P > 0.05$).

Table 1. Summary of percentage grain size distribution (mean ± SD) in sediments Samples collected from Mwanza Gulf (n = 12)

Sediment grain sizes	Location Categories			Distance from shoreline (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

Note: CA – City area sampling station
FB – Landing beaches sampling station
RM – River mouth sampling station

Discussion

Spatial Distribution of Heavy Metals in Mwanza Gulf

Sediment samples that were collected from stations adjacent to beaches within Mwanza City generally had higher concentrations of Pb and Zn than stations that were adjacent to rural beaches (FB) and river mouths. 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 that is considered as highly polluted river in Mwanza municipality drains industrial and domestic wastes from Mwanza City. 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 and discharges either untreated or partially treated wastes into the lake. 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 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. The most likely sources of Zn at the shores within city are the Mirongo River and discharges from the Mwanza North and South harbour. Mohammed (2000) reported similar concentrations of metals in Mwanza South.

The results indicate that urbanization has contributed to the rise of Pb content in the sediment. Domestic and industrial effluents, municipal runoffs and atmospheric deposition may be the major sources. 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, 1993; Mohammed, 2000). 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, 1993; Mohammed, 2000). The more or less uniform concentrations of Cr and Cu in lake sediment reflect their natural background levels in the local soils.

Cadmium and Mercury were highest in sediments that were collected at stations adjacent to river mouths. Some of these rivers and streams drain gold mining areas. The occurrence of highest Hg content in sediments of the RM category suggests an anthropogenic origin, for instance, use of mercury by small scale gold miners to extract gold from sand (Kahatano *et al.,* 1995). River Isanga and its tributaries drain the mining areas of Geita goldfield. 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 in sediments of RM and FB station categories. The most likely source is a result of land degradation and/or the use of inorganic fertilizers in agriculture and tanneries industry in the Mwanza City.

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 (except for Hg) than those reported in the Kenyan and Ugandan sides of Lake Victoria (Table 2). Possibly, Tanzanian side has few pollution generating activities as compared to other riparian countries or the variations of chemical make up of natural soils in studied areas.

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 = 3; 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, 1977
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 ±SEM)	4.9 ± 0.1	11.6 ± 0.8	20.9 ± 1.6	1.0 ± 0.3	34.7 ± 4.6	44.3 ± 7.4	Present study

nd = not determined

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 Pb, did not show any significant variation in their concentrations in the sediment with increasing distance from the shoreline. The levels of Pb in the sediment at 25 m and 2000 m from the shoreline varied significantly only at stations that were adjacent to fish landing beaches. The highest mean Pb concentration was recorded at 25 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 Pb concentration at 25 m than at 2000 m from the shoreline at FB stations.

In conclusion, this study has shown that sediments of Mwanza Gulf in the urban area are polluted with heavy metals. However, Pb and Zn were recorded in high concentrations. Lake Victoria being an important source of fish and sole source of water for all the residents around the lake basin, it is of paramount importance to protect it from pollution.

Acknowledgement

The authors are grateful to the LVEMP for funding this study. Thanks also to the Director General of TAFIRI, Prof. P. O. J. Bwathondi and Mr. S. Mahongo (LVEMP Component Coordinator) for providing logistic and administrative support. We are indebted to Mr. Gowele of SEAMIC for analysing the samples and special thanks are due to Drs Kishimba and Makundi for critically reading the manuscript and making useful comments.

References

Ajmal, M., Uddin, R. and Khan A.U., 1988. Heavy metals in water, sediments, plants and fish of Kali Nadi U.P (India). *Environ. Int.* **14:** 515-523.

Berg, H.; Kautsky, N., 1997. Persistent pollutants in the Lake Kariba Ecosystem – a Tropical man-made lake. Remane, K. (ed.). African Inland Fisheries, Aquaculture and Environment. Blackwell, Oxford. 115-135.

FAO/CIFA, 1994. Technical Paper of Canadian Food Inspection Agency on review of pollution in the Africa aquatic environment. **25.** Calamari, D. 118pp.

Förstner, U and Wittman, G.T.W. (1983). Metal pollution in the aquatic environment. Springer-Verlag, Berlin. 486p.

Hecky, R.E., Bootsma, H.A., Mugidde, R.M., Bugenyi, F.W.B. (1996). Phosphorus pumps, nitrogen sinks, and silicon drains: Plumbing nutrients in the African Great Lakes. In: Johnson, I.C. and Odada, E.O. (eds). The Limnology, Climatology and Paleontology of the East African Lakes. Gordon and Breach Publishers, Amsterdam. 205-234.

Hamza, M.M., (1996). Determination of heavy metal pollution in Lake Victoria using energy dispersive X-ray fluorescence analysis. M.Sc. Dissertation, University of Dar Es Salaam, Tanzania

Horowitz, A.J., (1997). Some thoughts on problems associated with various sampling media used for environmental monitoring. *The Analyst*, **122:** 1193-1200.

Kahatano, J.M., Mutakyahwa, M.K.D., Mnali, S., Kinabo, C., Kaaya, C.Z and Ikingura, J.R. (1995). Report on the environmental aspects of mining and industrialization in Tanzania. Lake Victoria goldfields geochemical. University of Dar Es Salaam: Department of Geology.

Kondoro, J.W.A. and Mikidadi, M.H., 1998. Heavy metal pollution in Lake Victoria. *Tanz. J. of Sci.* **24:** 9-21.

Machiwa, J.F. (1992). Heavy metal content in coastal sediments of Dar Es salaam, Tanzania. *Environ. Int.,* **18:** 409-415.

Mohammed, N.K. (2000). The optimization of energy dispersive x-ray fluorescent EDXRF) spectrometer for the study of heavy metal pollution. M.Sc. Thesis, University of Dar Es Salaam, Tanzania.

Mothersill, J.S. (1976). The mineralogy and geochemistry of the sediments of Northwestern Lake Victoria. *Sedim.* 23: 553-565.

Muli, J.R. (1996). Environmental problems of Lake Victoria (East Africa): What the international community can do. *L. Res. Manag*. 2: 47-53.

Mwamburi, J. and Oloc, F.N. (1997). The distribution and concentration levels of trace metals in water and sediments of Lake Victoria, Kenya. *Afr. J. Trop. Hydrob. and Fish.* **7:** 37-48.

NEMC (1994). Report of National Environmental Management concil and working group on monitoring of mercury and other heavy metals pollution in gold mining areas around Lake Victoria, Tanzania. 69pp.

Onyari, J.M. (1985). 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. M.Sc. Thesis, University of Nairobi, Kenya.

Onyari, J.M. and Wandiga, S.O. (1989). Distribution of Cr, Pb, Cd, Zn, Fe and Mn in Lake Victoria sediments. *E. Afr. Bull. Environ. Toxicol.* **42:** 807-812.

Scholz, C.A., Rosendahl, B.R., Versfelt, J.W. and Rach, N. (1990). Results of high resolution eco-sounding of Lake Victoria. *J. Afr. Earth Sci.* **11:** 25-32.

Talbot, V. and Chegwidden, A. (1983). Heavy metals in the sediment of Cockbun Sound, Western Australia and its surrounding area. *Environ. Pollut.* **5:** 187-193

Van Densen W.L.T.; Witte, F. (1995). Introduction. Witte F. and Van Densen (eds). Fish stocks and fisheries of Lake Victoria. A handbook for Field Observations. Samara Publishing Limited, Canadian, Great Britain.

Zar, J.H. (1984). Biostatistical analysis (2nd ed.). Prentice-Hall, Inc., Englewood Cliffs, New Jersey.