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The Distribution and Concentration levels of Trace Metals in Water and Sediments of Lake Victoria, Kenya

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ABSTRACT

The water and bottom sediments of Lake Victoria (Kenya) were analysed for Al, Fe, Mn, Zn, Pb, Cu, Cr and Cd. The total metal concentrations were determined and their mean variations and distributions discussed. The bottom lake waters showed higher concentration levels than the surface waters. The range of values (in mg/l) in the bottom and surface lake waters were as follows:

Surface Waters: Al(0.08 - 3.98), Fe(0.09 - 4.01), Mn(0.02 - 0.10), Zn(0.01 -0.07),

Pb(0.001- 0.007), Cu(not detected - 0.006), Cr(not detected - 0.004).

Bottom Waters: Al(0.10 - 6.59), Fe(0.23 - 9.64), Mn(0.04 - 0.39),

Zn(0.01- 0.08), Pb(0.002 - 0.009), Cu(not detected - 0.03), Cr(not detected -0.002).

River mouths and shallow areas in the lake showed higher total metal concentrations than offshore deeper areas. Apart from natural metal levels, varied urban activities and wastes greatly contribute to the lake metal pollution as shown by high Pb and Zn levels in sediments, around Kisumu and Homa Bay areas. Other comparatively high values and variations could be attributed to the varied geological characteristics of the lake and its sediments.

Compared to the established W.H.O (1984) drinking water standards manganese, aluminium and iron levels were above these limits whereas zinc, lead, chromium, copper and cadmium were below.

Key words: Metal concentrations, sediments, water and Lake Victoria.

INTRODUCTION

Many trace metals are regarded as serious pollutants of aquatic ecosystems because of their environmental persistence, toxicity, and ability to be incorporated into food chains. The chemical behaviour of these elements in water (i.e speciation) and accompanying transformations in sediments, e.g. through methylation, Hg and Sn results in even more toxic forms. Sediments and water provide pathways for trace metals where they may become bioavailable to aquatic organisms, after deposition and translocation from various diffuse and point sources apart from geological sources.

Various metals from industrial, agricultural, domestic and urban wastes may enter the river and lake waters through leaching, runoff, effluents and dry deposition. In industrialized and heavily urbanized areas, studies on heavy metal sources, contamination and historical loadings exist world wide (BINEY *et al.*, 1991; OKOYE *et al.*, 1991; FORSTNER 1973; ISKANDAR *et al.*, 1974 and FITCHIKO, 1975). Trace metal studies in the Nyanza gulf (WANDIGA *et al.*, 1983; ONYARI (1985) and OCHIENG (1987) revealed low concentration levels. ONYARI *et al.*, (1989) noted elevated lead levels.

This study presents results of initial monitoring of concentrations of Al, Fe, Mn, Zn, Pb, Cr, Cu and Cd in water and sediment samples from Lake Victoria (Kenya).

MATERIALS AND METHODS

Lake water samples were collected from selected sampling sites (Fig. 1) at 1 m from the lake surface and 1 m from the lake bottom between the month of March 1994 and March 1995 except for the months of December 1994 and February 1995. Water samples were collected using a precleaned Van Dorn sampler and transferred into cleaned polythene bottles (soaked in dilute conc. Nitric acid, HNO_3) and rinsed with distilled water) as recommended in APHA (1985) and GEMS/WATER (1992).

1000 ml of unfiltered water sample was preserved with conc. Nitric acid (HNO3, Analytical Grade Quality. 70 % w/w) and stored under refrigeration before digestion with conc. Nitric acid (Analytical Grade Quality, 70 % w/w in the laboratory according to standard methods (APHA, 1985 and GEMS/WATER, 1992). Acid blanks were handled and prepared in a similar way as the samples.

Lake bottom sediments were collected using a precleaned Ekman grab sampler at each sampling site. The innermost part of the sediment (not in contact with the sampler) was scooped using a precleaned stainless steel spoon, transferred into polythene bags and frozen before drying at 105 °C for 24 hours in an oven. After crushing to powdered form, the less than 63 µm grain size fraction (seived using a stainless steel B.S 410 Standard sieve) was digested using 10 ml of Aqua- regia (i.e conc. HNO_3 : conc. HCl 1:3 vol. ratio, Analytical Grade Quality acids.) for 30 minutes at 60°C in an aluminium heating block. The resulting solutions were diluted to mark in 50 ml volumetric flask using distilled water. Reagent blanks were treated in a similar manner. The organic matter content in the lake sediments was determined as percentage loss on ignition (L.O.I) by drying about 1.0 g of the sediment at 550°C in a furnace for 1 hour. The L.O.I (HAKANSON *et al.,* 1983) was calculated as shown below:

$$\text{L.O.I.} = \frac{\text{Ws} - \text{Wr}}{\text{Ws}} \times 100$$

Where Ws = Weight of dry sediment; and
Wr = Weight of inorganic residue.

The digests were analysed using an automated Varian Techtron Spectra AA-10 atomic absorption spectrophotometer. The samples were run together with the blanks. Any element introduced into the sample digests was subtracted from the element concentration in the water and sediment samples analysed.

The pH, conductivity, temperature, dissolved oxygen and turbidity were determined in situ using standard meters. Total alkalinity and total hardness were also determined according to standard methods (APHA, 1985).

STUDY AREA

The study area (Fig.l) comprises of the Kenyan portion of Lake Victoria which constitutes about 6% (approx 4,000 km^2) of the entire lake. Nyanza gulf forms the main section of the Kenyan part of L. Victoria with a surface area of about 1,400 km^2 (MELACK, 1979) and a total catchment area of about 11,994 km^2. The lakeshore basin is relatively dry with a low lying southern shore and a hilly northern shore. The major river basins are Nyando (total area 3,450km^2) Sondu-Miriu (total area 3,489 km^2) and Nzoia basin (CALAMARI *et al.,* 1992).

The regional geology consists of Precambrian rocks, Tertiary sediments and lavas, and Quaternary volcanics and sediments (NYAMBOK *et al.,* 1979). Surrounding areas include Nandi, Kericho and Kisii highlands. The main industries include sugar, tea and coffee in the highland and lake shore regions with others concentrated around the main Kisumu town (KIRUGARA *et al.,*1996). The area receives an annual rainfall ranging from 1,300 mm 1,800 mm with a long rainy season (March - May) and a short rainy season (October December).

RESULTS AND DISCUSSION

Lake Victoria (Kenya) waters

The mean pH, conductivity and turbidity values in surface waters ranged from 7.0 - 8.1, 97.8 - 163.3 μScm^{-1}, and 9.3 - 65.3 N.T.U. respectively. In the bottom waters the mean pH, conductivity and turbidity ranged from 7.1 - 8.2, 97.8 - 177.5 μScm^{-1}, and 7.2 - 245.8 N.T.U. respectively.

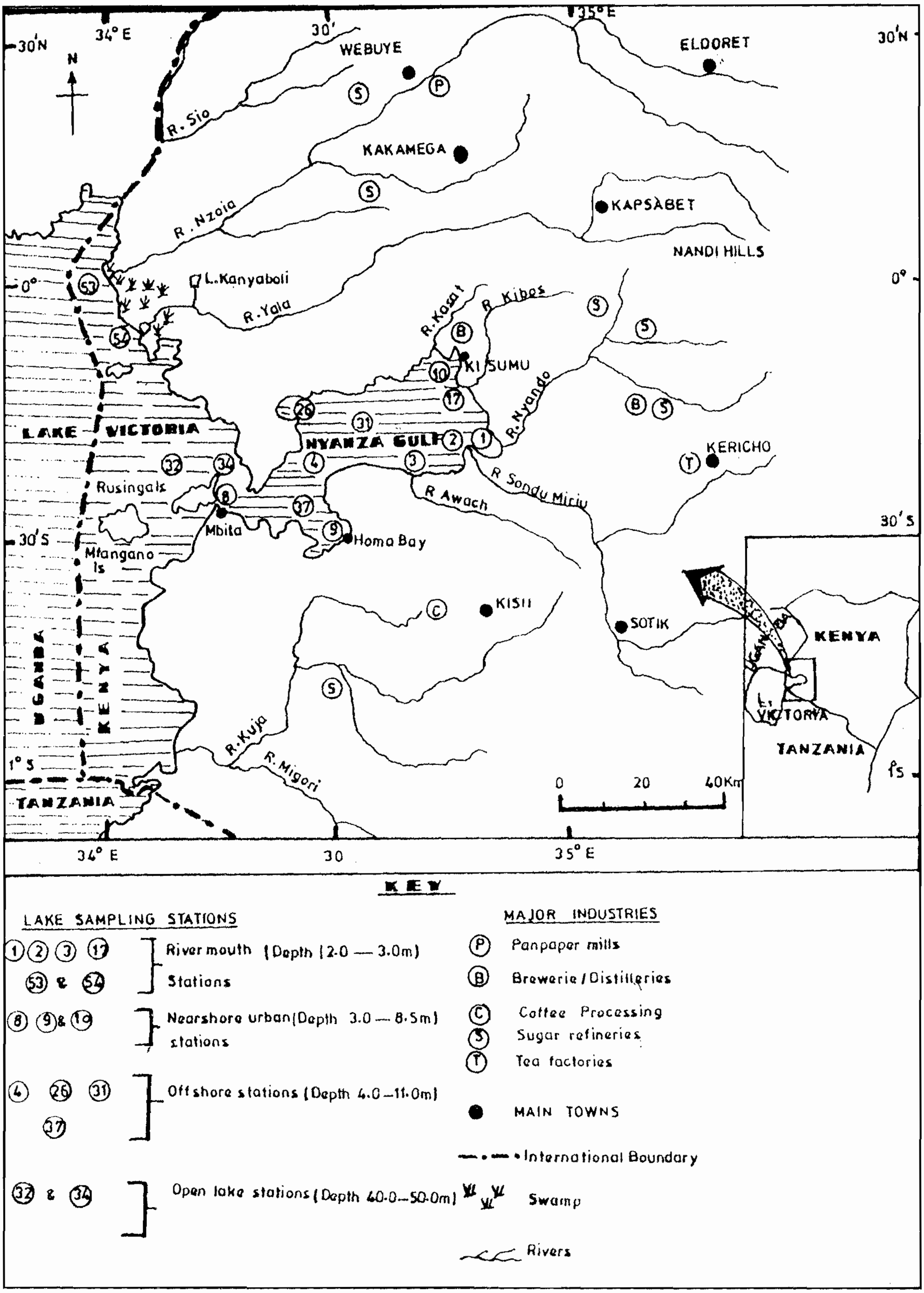

Fig. 1. The Kenyan portion of Lake Victoria showing the drainage area, lake sampling stations, major industrial sites and towns

The distribution of trace metals in the surface and bottom lake waters are presented in figures 2, 3 and 4 below. Cadmium was not detected in lake surface and bottom waters. Chromium was below detection limit in most of the stations. Relatively high levels of Al, Fe and Mn were noted at stations 1, 2, 3 and 53 (river mouth sites) which are characterised by shallow waters with excessive suspended particulate materials from erosion in the catchment. The same observation occurred at stations 9 and 10 (shallow nearshore urban sites) influenced by the urban activities (runoff, industrial effluents and municipal wastes) in the respective towns. The mean total range values for Zn Pb, Mn, Cu and Cr were (0.01 - 0.08 mg/l), (0.001- 0.009 mg/l), (0.01- 0.39 mg/l), (not detected to 0.03 mg/l) and (not detected to 0.004 mg/l) respectively. Relatively high Al and Fe concentrations in surface and bottom waters occurred from March 1994 to June 1994 with the lowest mean value during August 1994. Higher mean monthly total Mn values in bottom and surface lake waters were recorded between March 1994 and May 1994. During the rainy periods (March 1994 to June 1994) erosional action by the rivers in the catchment area releases large amounts of sediments into the lake. Absorbed metals on these particles remain in suspension, thus contributing to the high metal concentrations in the water column.

Copper and chromium concentrations were determined from March 1994 to July 1994 with a maximum value of 0.004 mg/l (station 37). A mean Cr value 0.002 mg/l occurred at stations 8, 1, 53, 32 and 34, in the surface waters.

The total mean Cu values showed a maximum value of 0.006 mg/l in the surface water (stations 9 and 2) and in the bottom water (stations 4, 32 and 37). The maximum Cu value of 0.03 mg/l was recorded at station 53.

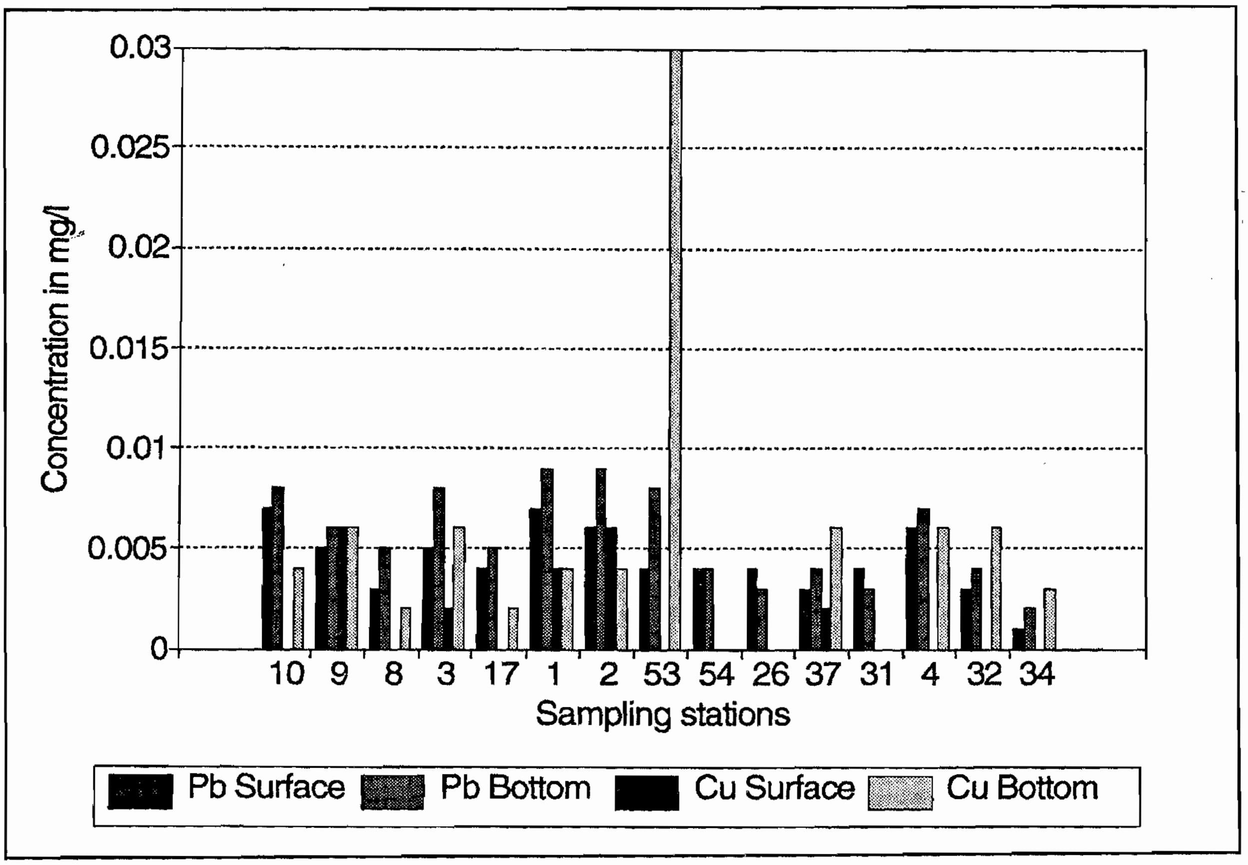

Fig. 2. Mean total Pb and Cu concentration variation in lake water

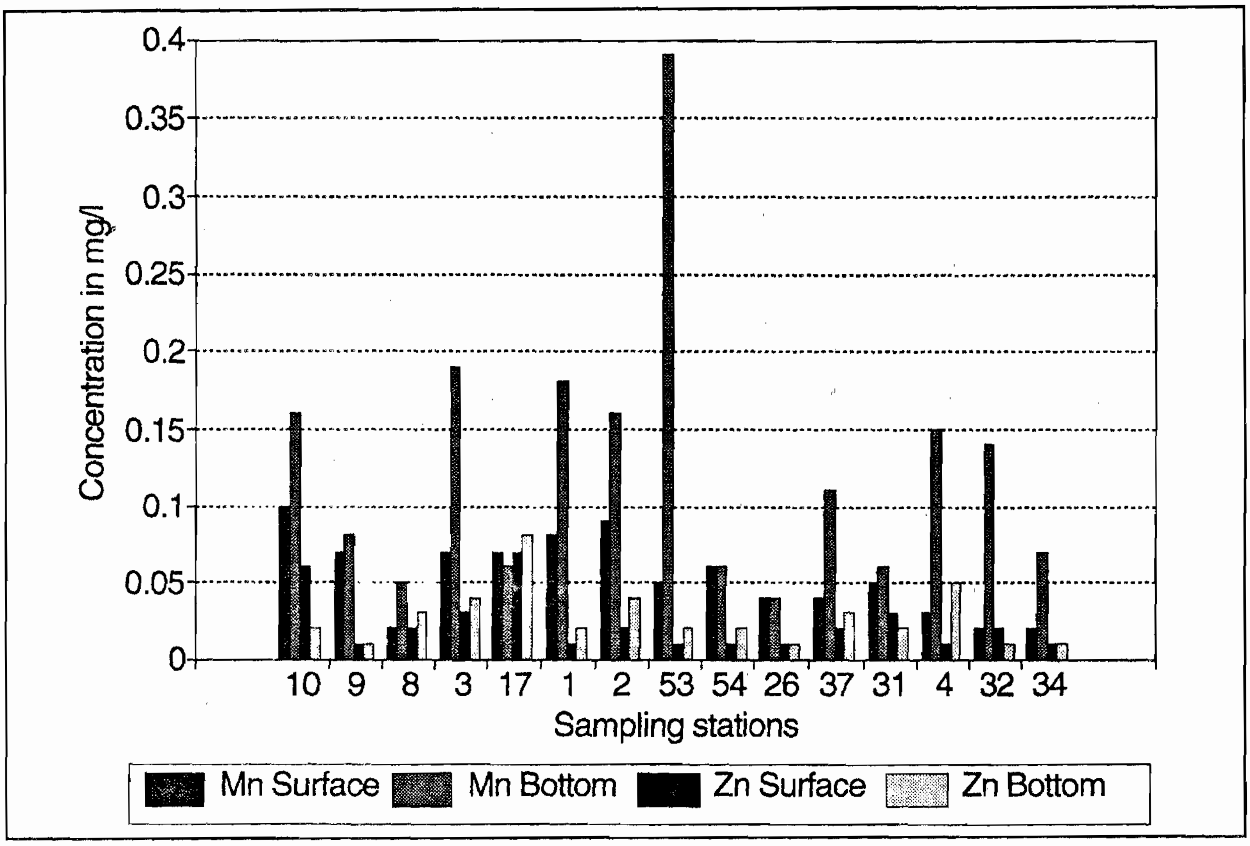

Fig. 3. Mean total Mn and Zn concentration variation in lake water

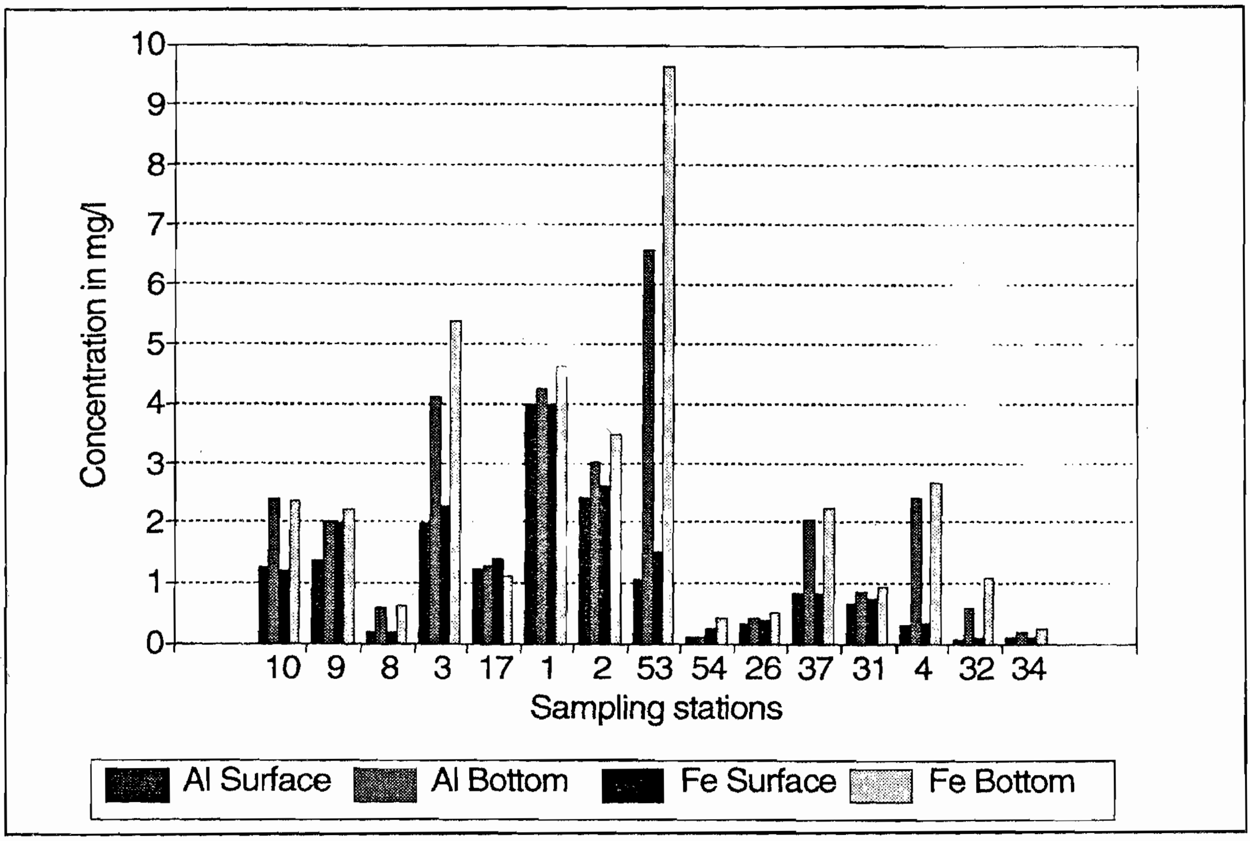

Fig. 4. Mean total Al and Fe concentration variation in lake water

Two way analysis of variance (ANOVA) revealed significant differences at 95% level in the levels of Pb, Cr, Mn, Fe in surface and Pb, Al, Fe in bottom waters for the months sampled. Al, Mn and Fe levels in surface waters were significantly different at 95% in the various stations. Most of the shallow (≤ 3.0 m deep) areas and river mouth stations receive much of the particulate materials from erosion and runoff. The mixture of organic and inorganic materials coupled with resuspended materials from the bottom tend to remain unsettled in the water column. Due to the adsorption of elements onto these particles, they tend to be more associated and remain in the particulate form. This may be reflected in the strong positive inter-element correlations between Fe, Mn, Pb and Cu with Al (Fe-Al r = 0.99; Al-Mn r = 0.71; Pb-Al r = 0.69; Al-Cu r = 0.68) in the surface waters. Other positive correlations in surface waters were observed between Mn, Pb, Cu with Fe (Fe-Mn r = 0.73; Fe-Cu r = 0.74; Fe-Pb r = 0.67) and between Mn and Pb (r = 0.61). In the bottom waters, Al showed strong positive correlations with Fe, Mn, Cu and Pb (Al-Cu r = 0.78; Al-Fe r= 0.99; Al-Mn r = 0.87 and Al-Pb r = 0.80). Al and Fe are dominant elements being always present in relatively high levels in natural waters and the elevated levels could be explained by the above factors.

Lake sediments.

Bottom sediments in deeper areas consisted of black greyish clay material as compared to sandy sediments in inshore and river mouth regions which were shallow. Sediment mean organic matter content ranged from 4% - 32.52% as shown in figure 5. The mean metal sediment levels for Al, Fe, Mn, Zn, Pb, Cu, Cr and Cd are shown in figures 6, 7, and 8 below.

The sediment mean Al content appeared more uniform with the lowest values recorded at stations 17 and 54 probably as a result of less sediment input as compared to the other river mouth stations. The maximum and minimum mean Al concentration values were 0.810 wt.% and 0.121 wt.% in stations 9 and 54 respectively. Higher values occurred in stations 4 (0.647 wt.%), 37 (0.718 wt.%), 53 (0.678 wt.%), 3 (0.674 wt.%), 10 (0.663 wt.%), 2 (0.537 wt.%), 26 (0.574 wt.%), 31 (0.615 wt.%), 1 (0.581 wt.%) and 32 (0.542 wt.%).

Mean iron sediment concentration values ranged from 1.61 wt.% (station 26) to 5.55 wt.% (station 54). Other high Fe values noted were 3.19 wt.% (station 9), 4.42 wt.% (station 1), 3.89 wt.% (station 3), 3.11 wt.% (station 8), and 3.14 wt.% (station 53).

Manganese values were high in stations 1, 54, 2 and 3 with 0.181 wt%, 0.163 wt.%, 0.149 wt.% and 0.149 wt.% respectively. The minimum and maximum mean Mn concentration values were 0.029 wt.% (station 26) and 0.181 wt.% (station 1).

Zinc mean values ranged from 31.8 µg/g (station 54) to 136.4 µg/g (station 10). Other high Zn mean values of 113.6 µg/g (station 3), 95.5 ug/g (stations 9, 2 and 1), 77.3 µg/g (station 17), 72.7 µg/g (station 4) and 63.6 µg/g (station 32) were recorded.

The highest Pb concentration value of 122.7 µg/g occurred at station 10 with a low value of 13.6 µg/g (station 32 and station 53). Other high values of Pb occurred at stations 1, 8, 54, 3, and 9 of 95.5 µg/g, 81.8 µg/g, 81.8 µg/g and 77.3 µg/g respectively. Station 10 is located around the Kisumu railway harbour which is adjacent to the town. Various "juakali" activities and wastes from these areas, leaded fuel used by vehicles, paints and the industrial and municipal waste discharges are the probable sources of lead and zinc input in these areas.

Copper was not detected in stations 17, 54 and 31. A relatively high mean value of 50 µg/g occurred at stations 53 while stations 10, 9, 1, 8, 3 and 32 recorded 30 µg/g, 30 µg/g, 30 µg/g, 40 µg/g, 30 µg/g and 33 µg/g respectively. Bottom waters at station 53 also showed a relatively high Cu value, and this could probably be an indication of some external source from the drainage area or the influence of Panpaper mill effluents upstream.

The maximum Cr content in lake bottom sediments was 85.7 µg/g in stations 9, 2 and 4. High values of 78.6 µg/g (stations 53 and 31), 71.4 µg/g (station 3) and 59.5 µg/g (station 32) were recorded.

In all the stations, Cd was below detection level in the bottom sediments. There is a strong correlation between Mn and Fe (r = 0.86) in lake sediments. A moderate positive correlation (r = 0.55) was observed for only Al and percentage organic matter content (determined as loss on ignition) whereas both Fe and Mn showed a negative correlation (Fe, r = -0.5, Mn, r = -0.54). Mn and Fe have similar chemical behaviour and this could account for this Association.

The results from lake sediments in less than 63 m grain size, were highly comparable to earlier results in the same area as shown in table (II), except high Fe and Mn values. Comparable levels were found in lake sediments as compared to data from N.W. of Lake Victoria, Uganda (MOTHERSILL, 1976) apart from high Zn levels.

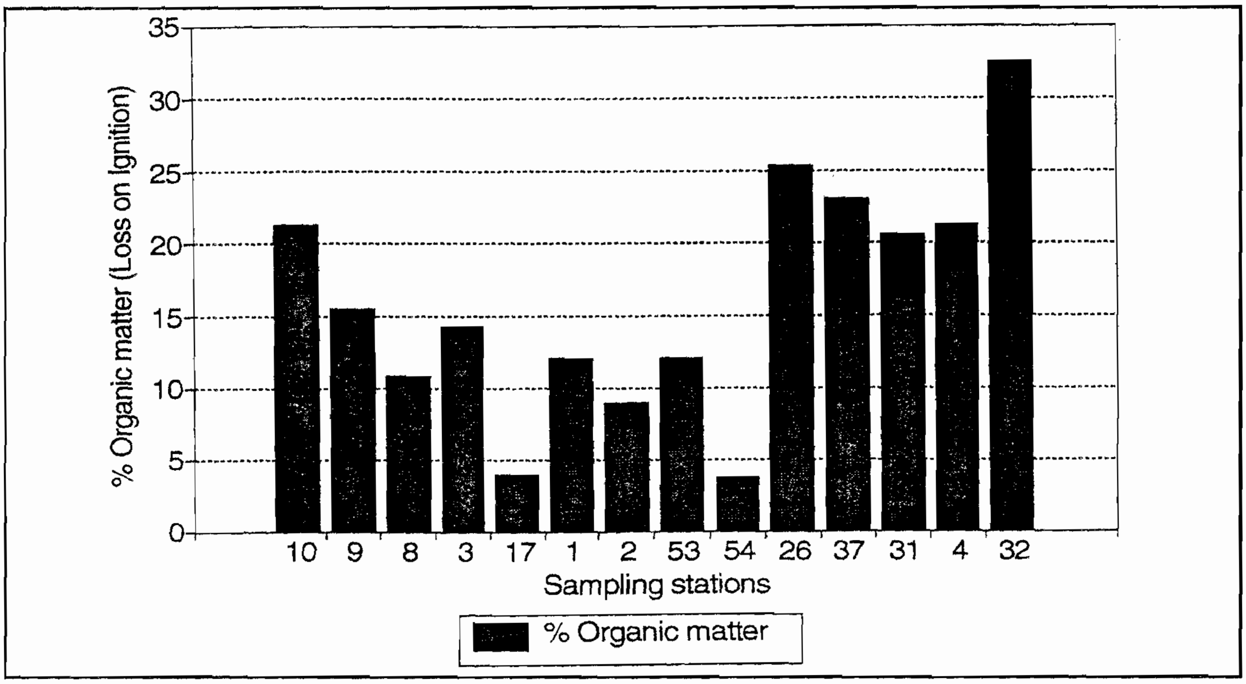

Fig. 5. Mean organic matter content (determined as loss on ignition) variation in bottom lake sediments

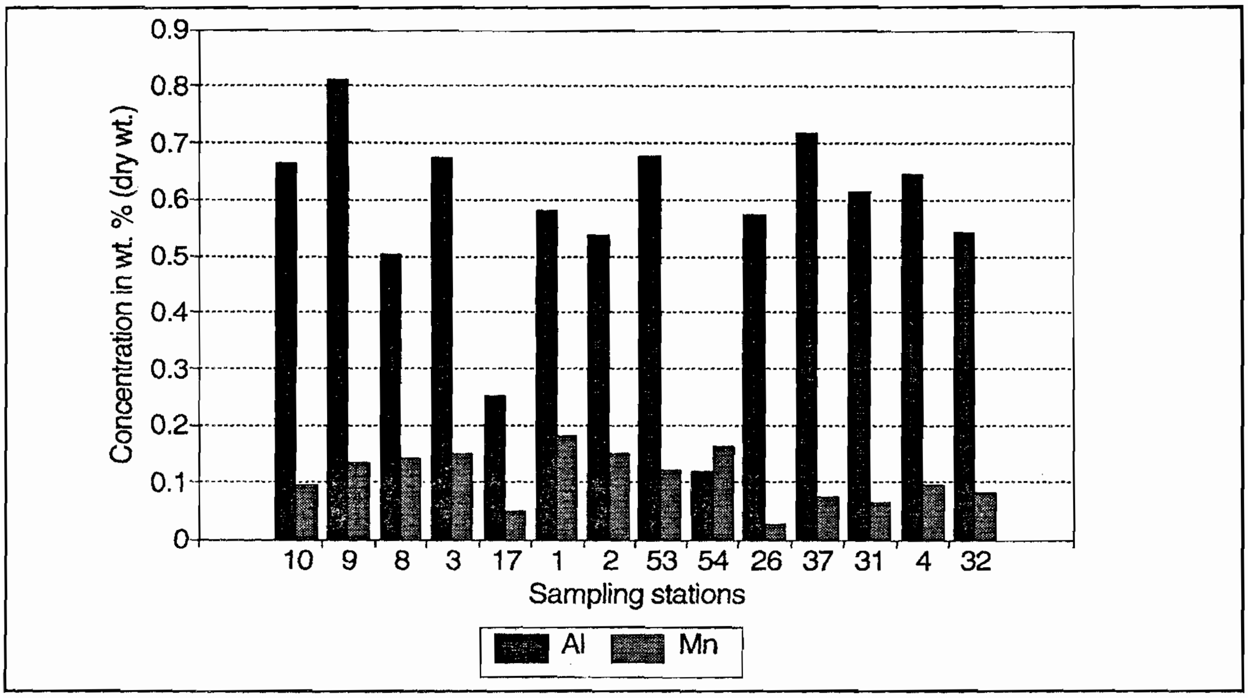

Fig. 6. Mean Al and Mn concentration in lake sediments

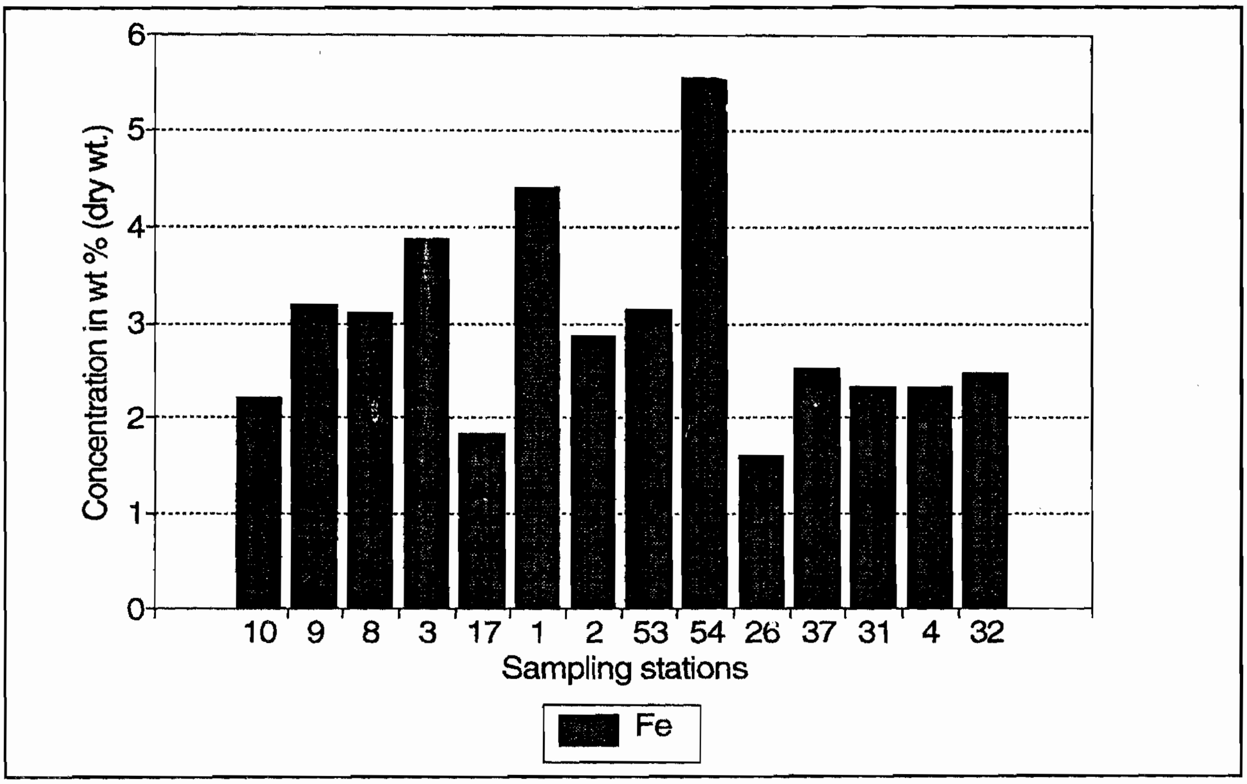

Fig. 7. Mean Fe concetration in lake sediments

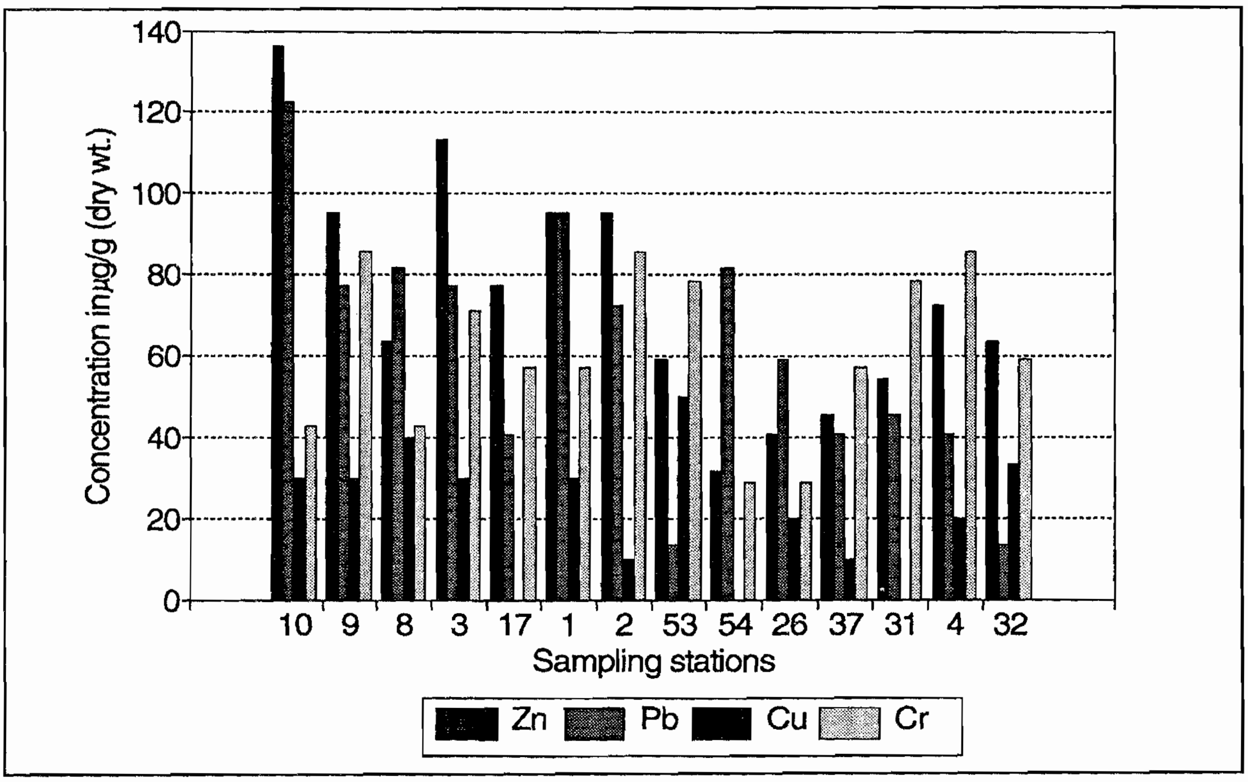

Fig. 8. Mean Pb, Zn, Cu and Cr concentration in lake sediments

Table II. A comparison between the metal concentration values (mean and ranges) in sediments of Lake Victoria with data from previous studies, unpolluted river sediments, continental crustal abundances, and average shale values (values in µg/g).

Element	N.W. Lake Victoria (a)	1984 & 1987 Survey (b)	Unpolluted Sediments (c)	Continental Crustal Abundances (d)	Average Shale (e)	Lake Victoria Sediments
Al	-	-	-	82300	-	1210-8100
Fe	(33000-157000)	(1180-52800)	41000	56000	46700	16100-55500
Mn	-	53.1-616	770	950	850	290-1810
Zn	49-115	2.54-286	95	70	95	31.8-136.4
Pb	-	2.5-152	19	12.5-20	20	13.6-122.7
Cu	11-96	0.96-78.6	33	55	45	ND-50
Cr	40-103	33-131	-	100	90	ND-85.7
Cd	-	0.55-1.02	-	0.10	0.3	ND

ND = not detected
- = not determined

Sources:

(a) MOTHERSILL, J.S. 1976., (b) ONYARI, J.M. 1985 and ONYARI, J.M. et al 1989.,
(c) GESAMP 1982, SOLOMONS et al 1984., (d) TAYLOR, S.R. 1964., (e) TUREKIAN, K.K. et al 1961.,
(f) 1994/1995 sediments (< 63 µm grain size) current study.

CONCLUSION

The river mouths and shallow nearshore areas in the lake recorded relatively higher total concentration levels of Al, Fe and Mn. Cd was below detection levels in both water and bottom lake sediment.

The bottom lake waters contained relatively higher total metal concentration levels as compared to the surface lake waters. Significant variations between the surface and bottom lake waters were observed for total Al, Mn and Fe, with relatively higher levels during the rainy seasons. Cu, Al, Fe and Mn recorded maximum levels at the mouth of R. Nzoia. The high sediment loads input from the catchment area could probably result in more of the elements existing in particulate form due to metal adsorption. Pan-Paper mill factory effluent discharge upstream may modify the natural Cu levels observed, where significantly high Cu levels in sediments and bottom waters were noted at the mouth of R. Nzoia as compared to other areas.

Apart from station 54 (Off R. Yala mouth), which receives water after passing through the swamp and which recorded relatively lower metal levels, stations 3(Off R.Awach), 1(Off R. Nyando), 10(Railway pier), 2(Off R. Sondu-Miriu), 9(Homa bay), 17(Off R. Kibos) and 37(Off Soklo point) recorded higher metal levels. These are shallow nearshore and river mouth stations where bottom resuspended sediment and suspended particulate materials could possibly contribute to high metal levels as a result of metal adsorption onto these particles.

Compared to the W.H.O (1984) drinking water guideline values (Table I), the nearshore waters in this study contained elevated levels of Al, Mn and Fe. The levels of Cu, Cr, Cd, Zn and Pb were below these limits. Therefore, for safe consumption in regard to metals, efficient treatment of the lake water is required.

Lake bottom sediments around Kisumu and Homa bay towns showed relatively high Pb and Zn levels. These urban sites contribute varied types and levels of inorganic contaminants input through various industrial and municipal wastes from the effluents and runoffs. Leaded fuel, paints and associated harbour activities contribute to the external inputs of these metals, apart from the geological sources.

Fe and Mn levels in the sediments were higher than results from earlier surveys (ONYARI, 1985 & ONYARI *et al.*, 1989) whereas the rest of the elements were comparable. These elements most likely arise as eroded soils and their concentrations near river mouths and in shallow, nearshore waters will likely vary with river discharge and wind-generated turbulence causing re-suspension.

Table I. A comparison between the mean total metal concentration range values in lake (surface and bottom) waters and the established WHO (1984) drinking water guideline values (All values in mg/l).

Element	Total mean concentration range values		WHO drinking water guidelines
	Surface waters (n=11)	Bottom waters (n=11)	
Aluminium	0.08 - 3.98	0.10 - 6.59	0.2 (A)
Iron (Fe)	0.08 - 3.83	0.23 - 9.64	0.3 (A)
Manganese (Mn)	0.02 - 0.12	0.04 - 039	0.1 (A)
Zinc (Zn)	0.008 - 0.07	0.01 - 0.08	5.0 (A)
Lead (Pb)	nd - 0.01	0.002 - 0.009	0.05 (H)
Copper (Cu)	nd - 0.006	nd - 0.03	1.00 (A)
Chromium (Cr)	nd - 0.004	nd - 0.002	0.05 (H)
Cadmium (Cd)	nd	nd	0.005 (H)

nd = not detectable; A = Aesthetic limit; H = Health limit

SUMMARY

Results from the monthly study conducted between March 1994 and March 1995 in Lake Victoria (Kenya), on the concentration and distribution levels of total Al, Fe, Mn, Cu, Zn, Cr, Pb and Cd in sediments, surface and bottom waters, revealed high levels in bottom waters as compared to the surface waters. Relatively high levels of metals were observed in the shallow nearshore and river mouth areas.

The presence of particulate materials from river inputs coupled with resuspended sediments, remain in suspension in the water column where the adsorbed metals result is the high total concentrations observed. Various non-point and point sources tend to modify the metal levels in the waters. Relatively higher Pb and Zn levels were observed in sediments around the urban sites (Kisumu and Homa bay) compared to other areas in the lake. This indicates the influence of metal pollution from the surrounding towns activities ("juakali" and harbour activities, vehicle leaded fuel and paints), industrial effluents and municipal wastes.

The concentration levels of Al, Fe and Mn were higher than the recommended W.H.O (1984) drinking water guideline values, whereas Cu, Cr, Cd, Zn and Pb levels were below.

There is need to understand the source, pathway, loads and fate of inorganic contaminants from the catchment area into the lake. For rational exploitation of the aquatic resources, with minimal interference, proper watershed management policies and efficient control of pollutants into the natural surface waters is necessary.

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