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Determination of Heavy Metal Content in Water, Sediment and Microalgae from Lake Victoria, East Africa

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Abstract: Lake Victoria, which is the largest fresh water lake in Africa, represents a unique ecosystem that has the largest fresh water fishery in the continent. However, increased anthropogenic activities has increased the potential pollution of the lake especially the heavy metal pollutants which may be toxic to humans and aquatic fauna. There is need therefore for continuous monitoring of pollution levels in the lake. Samples of water, soil sediments and algae were collected in dry, long and short rainy periods of 2008 and analyzed for heavy metal by Atomic Absorption Spectrophotometry. The highest concentration of trace metals were found in sediment samples with Zn having the highest mean concentration values in both Winam (1.019 ppm) and Mwanza gulf (0.889 ppm). The mean concentration of Pb was higher in water samples from Winam gulf (0.823 ppm), while Hg in microalgae samples from Winam gulf had a mean concentration of 0.000148 ppm. The highest concentration of Zn (1.589 ppm) was determined in the sediment samples from Kirumba bay of the Mwanza gulf and the lowest was in sediments from Kishimba bay (0.327 ppm). Levels of trace metals in microalgae were not significant in different sites of the Mwanza Gulf. Like in the Mwanza gulf, levels of Zn was high in sediments from all the sites sampled in Winam Gulf, the highest recorded at Kisat. Pb levels were highest in the water samples from Hippo point, whereas concentration levels of Cd, Cr and Hg were lowest in all the four sites sampled. The maximum biomass of microalgae occurred at Kisat during the short rain season (November-December) followed by Kamito in the same season.

Keywords: Heavy metals, water, sediment, microalgae, pollution.

INTRODUCTION

Aquatic ecosystem is the ultimate recipient of almost everything including heavy metals. Pollution of heavy metals in aquatic environment is a growing problem worldwide and currently it has reached an alarming rate. There are various sources of heavy metals; some originates from anthropogenic activities like draining of sewerage, dumping of Hospital wastes and recreational activities. Conversely, metals also occur in small amounts naturally and may enter into aquatic system through leaching of rocks, airborne dust, forest fires and vegetation [1]. As heavy metals cannot be degraded, they are continuously being deposited and incorporated in water, sediment and aquatic organisms [2], thus causing heavy metal pollution in water bodies.

The pollution sources to the Lake Victoria include a number of industries such as shipping, mining, breweries, tanning, fish, and agro-processing factories. Industrial effluents pose direct threat to the lake and its wetlands because they are discharged directly into surface water with little or no treatment [3]. Furthermore, a study by Tole and Shitsama [4] suggested that, concentrations of metallic pollutants are greatest near towns, indicating their urban industrial origins. Within the lake basin, extensive mining occurs mainly in Tanzania where small-scale miners use water to remove mud and impurities and mercury to collect gold [3]. The wastewater from such processes is usually disposed off into nearby streams with ultimate destination into Lake Victoria basin. Other possible sources of pollution include; domestic effluents, urban storm water runoff, landfill leachate, atmospheric sources and boating activities [5].

Earlier studies on sediment, water and biota of Lake Victoria reflected no significant heavy metal pollution [6, 7]. However, subsequent studies have shown increased levels of especially lead [8, 9]. This was attributed to increased shipping traffic, car washing and discharge from local industries. In a review by Biney *et al.* [10], it was concluded that generally lower concentration of heavy metals occur in African aquatic ecosystems compared to other areas of the world. However, due to increases in urbanization and socio-economic activities, the threat of pollution was bound to increase within our aquatic systems. Similar conclusion was made following a study on 3000 lakes with the Nordic region

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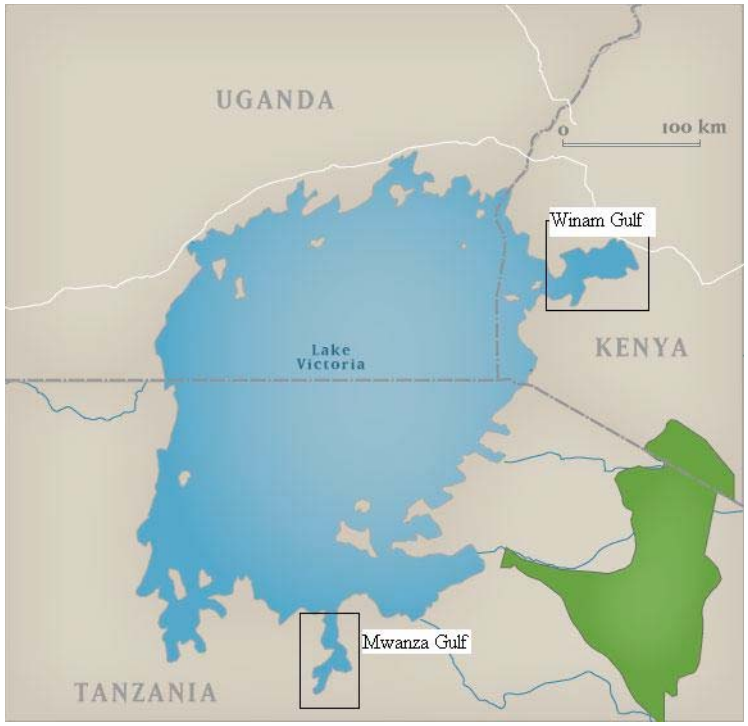


Fig. (1). Map of Lake Victoria showing the study sites

in which the sparsely populated Northern region was found to much less polluted compared to the south with heavy anthropogenic activities [11]

The presence of heavy metals in the water may have a profound effect on the microalgae which constitute the main food source for bivalve mollusks in all their growth stages, zooplankton (rotifers, copepods, and brine shrimps) and for larval stages of some crustacean and fish species. Moreover, bioconcentration and magnification could lead to high toxicity of these metals in organisms, even when the exposure level is low. Under such conditions, the toxicity of a moderately toxic metal could be enhanced by synergism and fish population may decline. Apart from destabilizing the ecosystem, the accumulation of these toxic metals in aquatic food web is a threat to public health and thus their potential long-term impact on ecosystem integrity cannot be ignored. The present study was therefore undertaken to assess the levels of heavy metals in water and sediment from Lake Victoria and how this relates to bioaccumulation of the pollutants in microalgae. The study also aimed at determining how the level of heavy metal pollution varies with dry, short rain and long rain seasons.

MATERIALS AND METHODS

Study Area

The study covered selected sites on Lake Victoria along the shores of Mwanza and Winam Gulfs (Fig. **1**). These sites were chosen due to their proximity to catchments with activities that potentially contribute to pollution of the lake according to available literature [12]. The study also focused on two less polluted areas to act as 'controls'one at the Winam Gulf (Dunga Beach) and another at the Mwanza Gulf (Kishimba). Sampling was carried out in three major seasons (dry, short rain and wet season) to account for seasonal variations. The samples were collected within 50-25 m from the landing beaches.

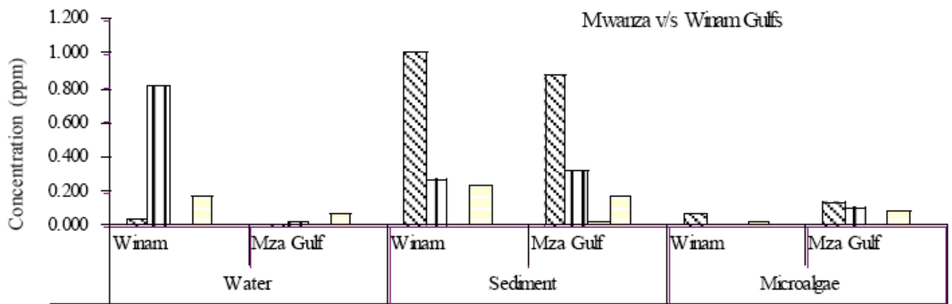
Sample Collection

Three seasonal samplings were carried out in Mwanza and Winam Gulfs between March, May and September 2008. Water and sediment samples were collected from all the six sites (three sites from each gulf) to analyze for heavy metals. Water samples were collected in polyethylene bottles (washed with detergent then with double-distilled water followed by 2 M nitric acid, then double-distilled water again and finally with sampled water). Water samples were acidified with 10% HNO3, brought to the laboratory and kept refrigerated until needed for analysis. Sediment samples were collected using Eckman grabber and put into wide-mouthed plastic containers, kept in ice boxes containing wet ice during the sampling trip and later stored at -80^{o}C until analysis.

At each sampling time, algae biomass samples from the same sites were collected using plankton nets (30 μm in mesh size) and about 100 g immediately stored in dry ice and later frozen at -20^{o}C prior to heavy metal extraction. 250 ml of the water samples for phytoplankton analysis was collected and immediately fixed by a freshly prepared 0.7% Lugol's solution and stored prior to phytoplankton identification and analysis.

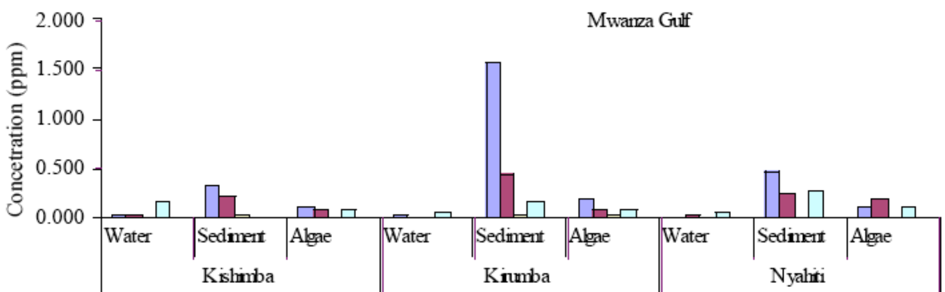
Sample Preparation and Analysis

Each frozen sample (sediment and algae) was thawed separately and sub-sampled for dry weight determination at 105^{o}C. The other portion of the samples was freeze-dried, finely crushed and homogenized using mortar and pestle, about 0.5g of the homogenized sample was digested in 10 ml



	Winam	Mza Gulf	Winam	Mza Gulf	Winam	Mza Gulf
	Water		Sediment		Microalgae	
Zn	0.050	0.018	1.019	0.889	0.081	0.147
Pb	0.823	0.022	0.283	0.330	0.000	0.118
Cd	0.000	0.007	0.000	0.021	0.004	0.014
Cr	0.178	0.070	0.238	0.177	0.031	0.102
Hg	0.000	0.000	0.004	0.007	0.000	0.004

Fig. (2). Mean trace metal concentrations in water, sediments and microalgae from the Mwanza and Winam gulfs of Lake Victoria.



	Water	Sediment	Algae	Water	Sediment	Algae	Water	Sediment	Algae
	Kishimba			Kirumba			Nyahiti		
Zn	0.043	0.327	0.127	0.023	1.589	0.195	0.000	0.472	0.121
Pb	0.031	0.240	0.078	0.013	0.451	0.091	0.035	0.255	0.187
Cd	0.020	0.031	0.015	0.009	0.025	0.021	0.000	0.012	0.007
Cr	0.159	0.000	0.097	0.063	0.167	0.095	0.049	0.275	0.114
Hg	0.001	0.003	0.008	0.000	0.009	0.002	0.000	0.007	0.002

Fig. (3). Trace metal concentrations in different samples and sites of the Mwanza Gulf, Lake Victoria.

aqua regia -HNO_3 (Loba Chemie PVT Ltd) : HCl- (Analar from Rankem) in the ratio of 3:1 and 1 ml perchloric acid (Loba Chemie PVT Ltd) in a culture test tube incubated at 80°C in a water bath, after total digestion and subsequent cooling, the solution was diluted to 50ml and analyzed for heavy metals in a closed system by atomic absorption spectrophotometry [13]. Heavy metals in water were analyzed using the same equipment. 100ml of water samples were measured, 10ml of aqua regia and 1 ml of perchloric acid added in a culture test tube, then incubated at 80°C in a water bath, after total digestion and subsequent cooling, the solution was diluted to 50ml and analyzed for heavy metals. The heavy metals analyzed were Zn, Pb, Cd, Hg and Cr.

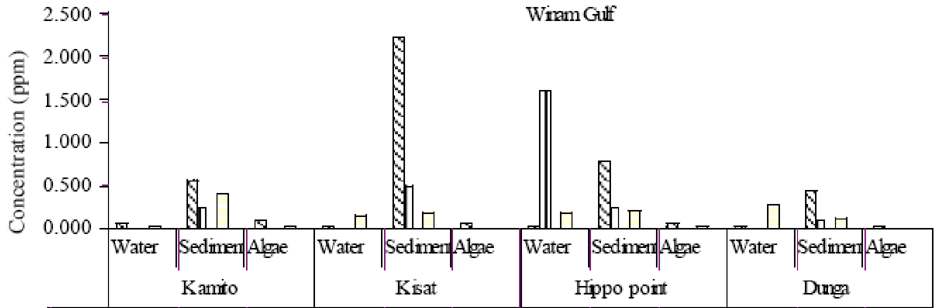
Identification of phytoplankton species followed the available keys [14, 15]. The phytoplankton numerical abundance was evaluated by counting and Shannon diversity index (H') was used to estimate phytoplankton species diversity. This part was done at the Water Quality Laboratory in Mwanza.

RESULTS

The concentration of trace metals in water, sediments and microalgae from Mwanza and Winam Gulfs are presented in Fig. (**2**). The highest concentration of trace metals in general were found in sediment samples with Zn having the highest mean concentration values in both Winam (1.01 ppm) and Mwanza gulf (0.889 ppm). The mean concentration of Pb was higher in water samples from Winam gulf (0.823 ppm) and the mean concentration of Hg in microalgae samples from Winam gulf (0.000148 ppm) was the lowest trace metal value determined in this study (Fig. **2**).

Mwanza Gulf

The highest concentration of Zn (1.589 ppm) was determined in the sediment samples from Kirumba bay of the Mwanza gulf, followed by Nyahiti and the lowest was in sediments from Kishimba bay (0.327 ppm). Samples of water and microalgae from the gulf had trace amount of metals in all the three sites sampled, with Cd and Hg having the lowest concentration throughout the study area. Levels of trace metals in microalgae were not significant in different sites of the Mwanza Gulf. Zn, Pb and Cr were detected in samples from Kirumba and Nyahiti, whereas, levels of Hg were high in microalgae sampled from the Kishimba site (Fig. **3**).



	Kamito Water	Kamito Sediment	Kamito Algae	Kisat Water	Kisat Sediment	Kisat Algae	Hippo point Water	Hippo point Sediment	Hippo point Algae	Dunga Water	Dunga Sediment	Dunga Algae
Zn	0.076	0.578	0.110	0.036	2.248	0.081	0.047	0.803	0.078	0.040	0.445	0.055
Pb	0.000	0.249	0.000	0.000	0.505	0.000	1.622	0.270	0.000	0.023	0.109	0.000
Cd	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.013	0.000	0.000	0.000
Cr	0.052	0.402	0.040	0.157	0.183	0.021	0.203	0.228	0.040	0.298	0.139	0.021
Hg	0.000	0.001	0.000	0.000	0.001	0.000	0.000	0.013	0.000	0.000	0.001	0.000

Fig. (4). Trace metal concentrations in different samples and sites of the Winam Gulf, Lake Victoria.

Table 1. Microalgae Species Richness (in Bracket) and Abundance in Mwanza and Winam Gulfs

	Winam			**Mwanza**		
	Kisat	**Hippo**	**Kamito**	**Mirongo**	**Kishimba**	**Nyahiti**
Cyanoprokaryotes	66765 (9)	559 (7)	19828 (7)	7738 (18)	18444 (18)	9379 (21)
Chlorophyceae	511 (13)	835 (13)	186 (11)	1113 (30)	1247 (42)	1112 (27)
Bacillariophyceae	26 (3)	139 (7)	813 (6)	316 (12)	614 (8)	357 (18)
Dinophyceae	178 (2)	8 (1)	0	2 (2)	2 (2)	6 (1)
Euglenoidea	539 (14)	140 (11)	23 (5)	0	0	0
Others	27 (5)	1 (1)	1 (1)	1 (1)	0	0

Winam Gulf

Results for heavy metals from water, sediments and microalgae sampled in the four sites of Winam gulf are summarized in Fig. (**4**). Like in the Mwanza gulf, levels of Zn was high in sediments from all the sites sampled, the highest recorded at Kisat. Pb levels was highest in the water samples from Hippo point, whereas concentration levels of Cd, Cr and Hg were lowest in all the four sites sampled (Fig. **4**).

Microalgae Species Richness and Abundance in Mwanza and Winam Gulfs.

Kishimba had the highest phytoplankton species richness compared to the other two stations in the Mwanza Gulf. The plankton community was dominated by chlorophytes in terms of species richness with *Scenedesmus*, *Surirella*, *Pediastrum* and *Staurastrum* having most of the species. Though the number of species identified differed between the sites, these variations were not statistically significant ($p < 0.5224$; KW = 4.190). The cyanoprokaryotes (Microcystis-flos-aquae, Anabaena-flos-aquae and *Merismopedia glauca*) were the most abundant microalgae in the gulf, with Kishimba having the maximum biomass composed of anabaena-flos-aquae and Microcystis-flos-aquae. Microcystis-flos-aquae dominated the microalgae biomass at Nyahiti and Mirongo stations (Table **1**).

At Winam Gulf, the phytoplankton species richness was dominated by chlorophytes (*Tetrastrum*, *Trachelomonas*, *Scenedesmus* and *Pediastrum* genera) as was in the Mwanza Gulf. Most of the Aulacoseira species was found in this gulf and *Trachelomonas* was only found in Winam Gulf. Total phytoplankton biomass in Winam Gulf was dominated by *Microcystis aeruginosa*. The maximum biomass occurred at Kisat during the short rain season (November-December) followed by Kamito in the same season. Microcystis-flos-aquae occurred throughout Winam Gulf though in low abundance compared to *Microcystis aeruginosa*. Other species of phytoplankton were scattered an evenly in different sites of the gulf (Table **1**).

DISCUSSION

Heavy metal pollution of rivers and lakes is a matter of great concern in any ecosystem especially in wetlands and water masses due to their human toxicity and bioaccumulative effect. In this regard, heavy metal pollution of Lake Victoria is of great interest due to its economic and domestic implication in East African region. An earlier review on the heavy metal situation in African aquatic environment by Biney *et al.* [10] generally pointed to lower concentrations of heavy metal pollution compared to other areas of the world. One of the most comprehensive studies on lake pollution was conducted in Europe under the "Nordic lake survey" in 1995 that measured the heavy metal concentrations in the water of 3000 lakes [11]. The study found that among other heavy metal pollutants, the concentrations of lead (Pb) were low (< 0.3 μg/l) particularly in the north and areas of high altitude where the population density is low compared to the southern areas of the countries where there were elevated concentrations of up to 1-10 μg/l. Our results support the hypothesis that Lake Victoria basin has significant basal contamination levels that however, do not reach those of clearly polluted areas. The present study further stipulates the importance of applying different possible biomonitors when studying the quality of ecosystem. Each biomonitor, such as benthic fauna, fish, bivalves and algae, respond differently to a particular metal fraction of an aquatic system. The low levels of trace metals found in this study could be brought about by dilution due to the influence of water waves in the lake, rainfall and rivers draining into the lake. Sedimentation could as well account for the low levels of metals observed in different samples from the lake. Although levels of Pb and Zn were below the recommended limits there was elevating levels of heavy metals in environment hence continuous environmental pollution monitoring is required to check heavy metals hazard.

Heavy metals concentration was determined from water, sediment and microalgae samples. The results clearly indicate that concentration were highest in the sediment samples from both gulfs compared to water and microalgae. In general, metal content in sediments is indicative of the degree of pollution and serves as a source of solubilization into water depending on the physico-chemical circumstances (pH, tempearture *etc*) and the uptake by benthic organisms. At Winam Gulf for instance, Zn, Hg and Cr were more concentrated in sediment samples, the same trend was also noted in Mwanza samples. Hg is the only metal known to be liquid at room temperature and with low solubility in water. Dissolved Hg is distributed among several chemical forms including elemental Hg, that is volatile but relatively unreactive, a number of mercuric species (Hg(II) and organic-Hg such as methyl, dimethyl and ethyl mercury. In general, the levels of total Hg and MeHg are higher near the sediments [16]. This could possibly account for the results of our study that indicated higher levels of Hg in sediments compared to either water or microalgae samples. The same explanation could apply for the other metallic elements, being non-biodegradable in nature [17], metals are commonly found adsorbed in sediments. The presence of higher concentration of heavy metal in sediments from this study is in agreement with other related studies. A study on heavy metal pollution in Lake Victoria sediments from samples collected from seventeen different locations around the lake town of Mwanza, representing three zones of activities. The results showed that sediments samples collected from southern part, which is the industrial area, had the highest concentrations of V, Cu, Zn, As and Pb but the same were generally low in the northern part which is least in anthropogenic activities. Another study on the shores of Lake Victoria, within the urban area of Mwanza showed elevated levels of heavy metal, notably Pb (54.6±11.1 ppm) and Zn (83.7±21.5 ppm) in sediment samples [3]. The link between anthropogenic activity and heavy metal pollution in lake Victoria was further supported by a study on the level of contamination in wetland soils and plants in lake basin around Kampala city and Jinja districts, which are the most industrialized areas in the Lake Victoria region in Uganda [18], the highest concentrations of 387.5±86.5 mg/kg Zn, 171.5±36.2 mg/kg Pb, 51.20±6.69 mg/kg Cu and 21.33±2.23 mg/kg Ni were found around Katanga area which receives waste from multiple industrial sources while the lowest level was observed from Munyonyo where there was no visible waste disposal. Similarly, Lake George in Uganda which supports a wetland with very high biological biodiversity, suffers serious metal contamination from the nearby copper mining activity [19]. Within Europe, sediments in Norwegian lakes were also found to have significantly elevated concentrations of Hg, Sb, Bi, Cd, As, Ni, Cu, Pb and Zn, most likely caused by anthropogenic depositions. High levels of heavy metals in the sediments, up to 10,000 times higher than in water, were found in Lake Baraton. Further study on heavy metals analysis and sediment quality in urban lakes in Bangalore, India showed sustained heavy metals in the bed sediments despite elaborate mitigation measures [20]. Lake sediments are therefore important abiotic environmental monitor for heavy metal contaminants, providing a unique medium to assess the impact of anthropogenic pollutants on freshwater systems.

Our results further indicate that there were differences in trace metal concentration in water and microalgae in the two gulfs. At Winam Gulf, for example, concentrations of metallic elements were higher in water samples than what was found in microalgae samples. The opposite was true for water and microalgae samples from the Mwanza Gulf. The explanation for the differences noted could be based on the ability of microalgae to filter trace metals from their environment. Microalgae have thin flat surfaces and draw their nutrients directly from the surrounding medium, when abundant at a particular site therefore, could clean-up the environment by bioaccumulation [21, 22]. Our previous report [23] identified one hundred and sixty four species of phytoplankton from the two gulfs, with only seventy one species isolated from Winam Gulf thus lower in abundance compared to the Mwanza Gulf. Phytoplanktons are important bioindicators of the of heavy metal pollution in aquatic ecosystems because their capacity to eliminate them from the water and accumulate and store them over a long period, even when the concentrations in the water is low. Several studies have shown that submerged plants such as microalgae tend to accumulate higher concentrations of metals consistently more than emergent or free floating plants [24, 25]. Further, the efficiency of accumulation is dependent on whether the bioindicator plant is passive or introduced as was shown in the study in Lake Manzala [26]. The differential accumulation rates of the metals in shoot and root system of the vascular plant may however be more accurate.

The cumulative algal distributions across the two gulfs examined in Lake Victoria were more or less homogeneous. The microalgae dominance, richness and diversity however, were reported elsewhere [23]. Areas like the Hippo point, though contributed less to the total cumulative percentage of algal classes, its contribution in terms of percentage trace metals detected from microalgae was highest compared to other sites of the Winam Gulf. Kishimba on the other hand, contributed a lot to Cd and Hg deposition in microalgae than the other sites in the Mwanza Gulf, as a consequence, the contribution of the Kishimba site to cumulative percentage of cyanobacteria and bacillariophytes was low. The differences could be due to the fact that most metallic elements such as Pb, Cd, Cr and Hg are toxic and do show their deleterious effect on aquatic biota and even to humans. The toxicity of heavy metal increase with high water temperature, oxygen concentration, basic pH and hardness of river water. Chances are that high levels of metallic elements at Winam Gulf [23] could have contributed to the differences in microalgae distribution across sites between the two gulfs of the lake examined.

CONCLUSIONS

The concentration of trace metals from three different samples i.e. water, sediments and microalgae from Winam and Mwanza gulfs of Lake Victoria were determined. Our results indicate that there were differences in trace metal concentration in water and microalgae between the Winam and Mwanza gulfs. At Winam Gulf, concentrations of metallic elements were higher in water samples than what we found in microalgae samples while the opposite was true for water and microalgae samples from the Mwanza Gulf. In both gulfs, heavy metal concentration were highest in the sediment samples. Our results indicate that Lake Victoria basin has significant basal contamination levels that do not reach those of clearly polluted areas. However, there is need therefore for continuous monitoring of pollution levels in the lake.

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