MONITORING OF HEAVY METAL LOADING INTO THE WETLANDS SOUTH OF LAKE VICTORIA BASIN, NOTHERN TANZANIA

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ABSTRACT

The paper discusses sources, concentrations and physicochemical parameters of heavy metals of environmental concern in the wetlands of Lake Victoria basin in Tanzania. The metals investigated include copper (Cu), lead (Pb), zinc (Zn), cadmium (Cd), chromium (Cr), nickel (Ni), arsenic (As), manganese (Mn), cobalt (Co) and mercury (Hg). These metals are released into the wetlands via weathering and erosion of rock formations, mining operations and industrial activities, discharge of municipal and domestic waste, and use of agrochemicals. The levels of these heavy metals in soil, sediment, water, and biota differ. Wetlands impacted by gold mining activities in the South Lake Victoria basin show elevated heavy metal contents in soil and sediment, particularly Cu (13-415 mg/kg), Pb (24-94 mg/kg), Zn (9-80 mg/kg), Cr (19-77 mg/kg), Ni (12-37 mg/kg) and Hg (0.19-1.76 mg/kg), contrary to non-impacted wetlands, which contain relatively low concentration of these metals (Cu 1-18 mg/kg, Pb 0-27 mg/kg, Zn 5-22 mg/kg; Cr 5-25 mg/kg, Ni 2-8 mg/kg, Hg <0.075 mg/kg). Elevated metal concentrations in soil and sediment are correlated with high metal contents in some plants within the affected wetlands. Oxidation and leaching of sulfide-bearing gold mine tailings resulted in acid mine drainage (AMD) with pH 3.25 - 4.10) and enhancement of heavy metal load and dissolved solids in streams draining into Nungwe Bay wetland on the southwestern shore of the Lake Victoria. Water samples from Bulyankhulu wetland drainage system were found to contain abnormally high Cu concentrations in the order of 270 mg/l. Samples from Mwakitolyo-Isanga and Nungwe Bay had higher values of Cr concentrations than those from Bulyankhulu and Luchili wetlands. Manganese was recorded to be 2.04 mg/L in a sample from Nungwe Bay, the reason being its mobilization from deeply weathered terrain associated with iron oxides.

Keywords: Heavy metals; wetlands; Lake Victoria gold field; mining.

INTRODUCTION

Lake Victoria is the second largest freshwater lake in the world covering a surface area of 68,000 km^2. It is distributed among Tanzania (52%), Uganda (42%) and Kenya (6%). The catchment area of Lake Victoria basin is one of the densely populated parts of Africa, which also includes Rwanda and Burundi. The biodiversity in the catchment area of Lake Victoria is being devastated because of the increased population and associated increase in human activities such as mining, industries and use of agrochemicals. The lake catchment in Tanzania is heavily impacted by both large and small scale mining operations, which are potential sources of toxic heavy metals (e.g. As, Pb, Cu, Cd, Cr, Hg) through acid mine drainage and leaching of mine tailings. Additionally, Hg released from artisanal gold mining operations in the LVGF and in the Migori greenstone belt of Kenya is of environmental and human health concern, since its methylation in the wetlands could accelerate the entry of highly toxic methylmercury into aquatic food chain and bioaccumulation of mercury in fish resources (Ikingura 2003).

Levels and inputs of nutrients such as nitrate and phosphate and their ecological effects in the Lake Victoria basin have been discussed in detail by Machiwa *et al.* (2004). However, the studies paid little or no attention on how heavy metals from surface runoff and leachate from mining and industrial operations are impacting the wetlands and the lake ecosystem as a whole. Also, little is known about the impact of other pollutants which are sipping into the wetlands and taken up by flora and fauna, or accumulating in water and sediments. This knowledge gap makes the current research project of strategic importance. The study, therefore, contributes to the understanding of heavy metal loading in the south of Lake Victoria wetlands and sheds light on the impacts of mining operations and other human activities on the environment.

METHODOLOGY

Study site

Fieldwork was carried out in the southern parts of Lake Victoria basin in Tanzania (Figure 1). During the fieldwork, documentation of physiographical, geological, and biological characteristics of the wetlands were accomplished. Furthermore, documentation of socio-economic activities carried out in the wetlands, identification of sources of heavy metals and other pollutants were done. *In-situ* measurements of water quality parameters including temperature, pH, and conductivity, as well as collecting of soil, sediment, water and biota for laboratory investigations and analysis were also carried out.

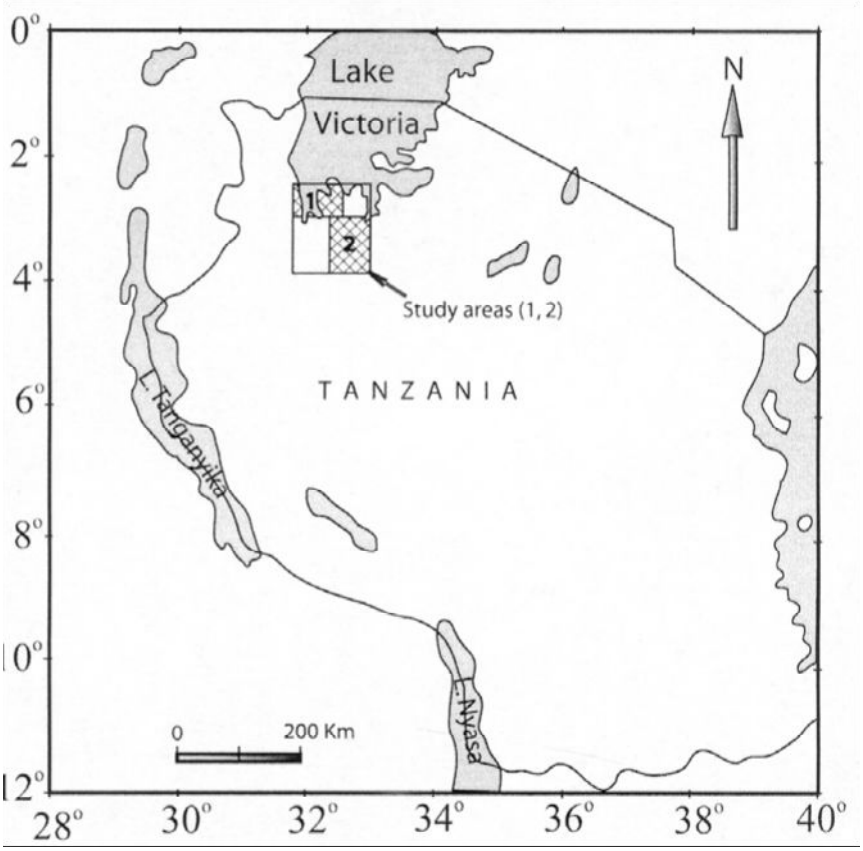


Figure 1: Location map of study areas south of Lake Victoria

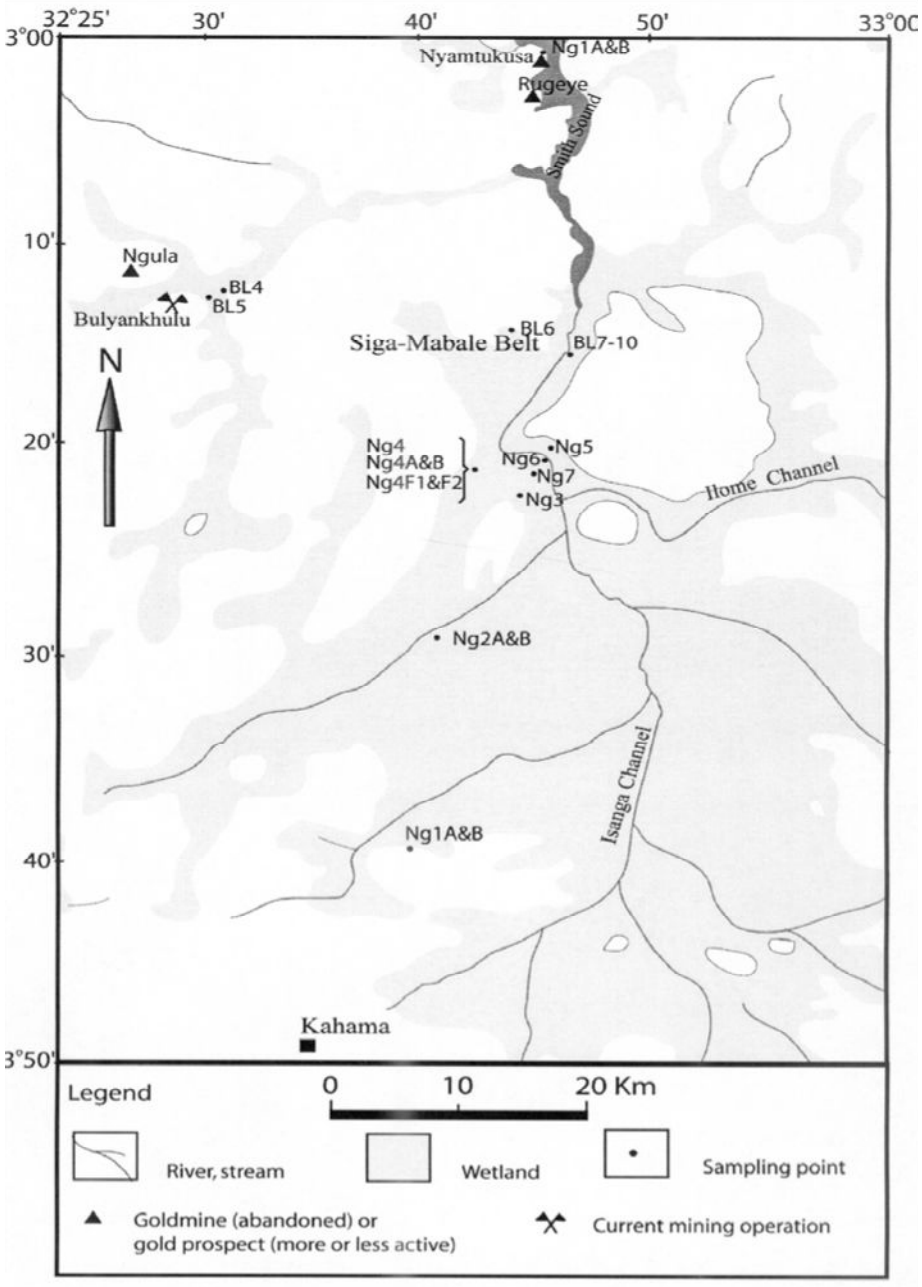


Figure 2: Locations of sampling sites in the study area block 1

The study area was divided into two sampling blocks as indicated in Figure 1. These blocks were further sub-divided into six sampling units. The first sampling unit was Mwakitolyo (MW) in Kahama District, which is influenced by gold mining

activities at Mwakitolyo artisanal gold mining center near the southern tip of Smith sound of Lake Victoria (Figure 2). The second sampling unit was Bulyankhulu-Nyamtukuza (NY), which is affected by mining activities at Bulyankhulu gold mine and artisanal mining activities within Bugarama – Kakola area. The third sampling unit was Geita (GT), which encompasses Nungwe Bay wetlands and surrounding areas around Geita town (Figure 3). This unit is influenced by Geita open-cast mine operations and artisanal gold mining activities around Geita town. The fourth unit comprised wetlands around Bukombe Bay (BU); the fifth unit was Nzera north of Geita, whereas the sixth unit included wetlands around Luchili Bay in Sengerema (SE) District. The last three sampling units are not impacted by mining operations and therefore served as control areas. Water, soil, sediments, flora and fauna were sampled at selected strategic points within each sampling unit. Sampling procedures for different media have been carefully sorted out following international procedures as described by Darnley *et al.* (1995).

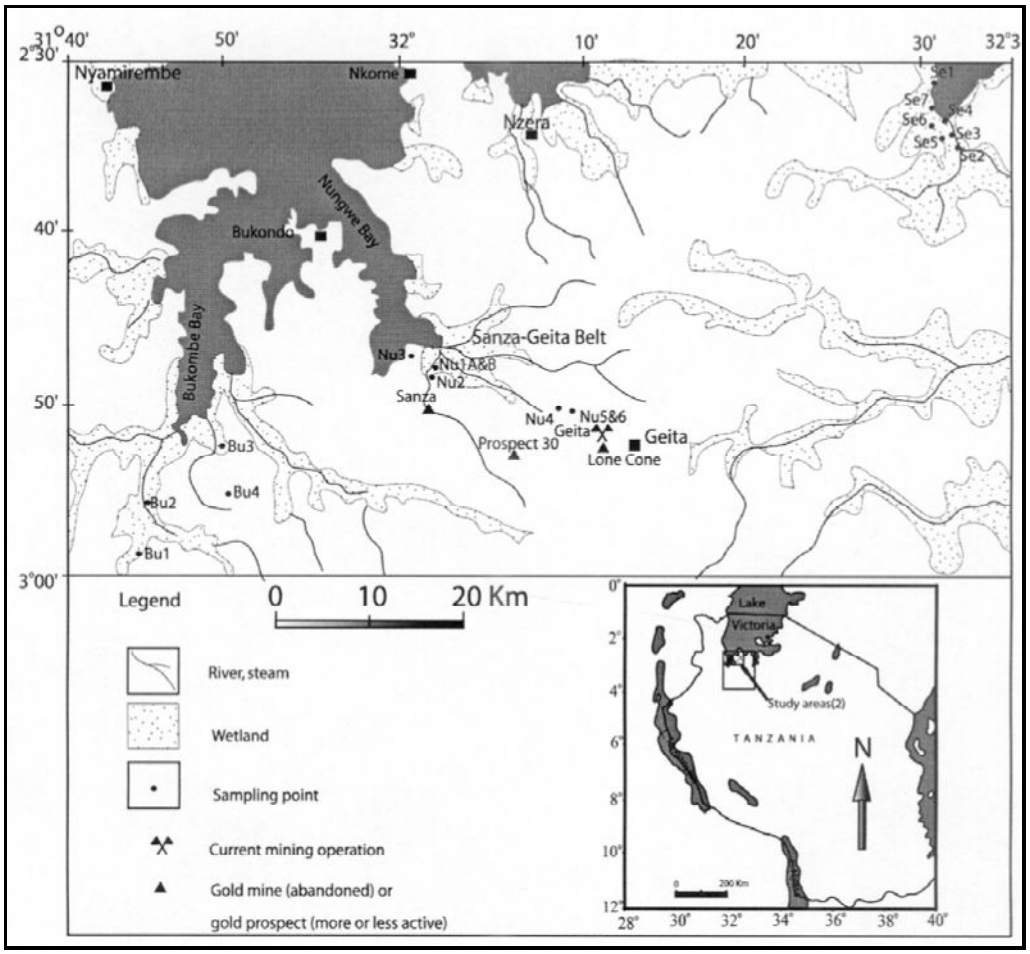


Figure. 3: Location of sampling sites in the study area block 2.

Sample processing and heavy metal analysis

Soil and sediment samples

The samples were oven-dried at 60°C overnight. Loose sediments were then sieved through a 200 μm mesh. Clayey organic rich sediments were hard on drying hence were subjected to gentle crushing in the motor and then sieved as above.

In the analysis of heavy metals, 0.5 g of each sample was digested with 2 ml aqua regia (HCl/HNO_3 3:1) in a marked test tube placed in a water bath. The water bath was thermostatically controlled at 95 °C. After the reaction has subdued and no any visible gases are evolving, the sample was cooled and then diluted to 20 ml. The sample was vigorously mixed by a vortex shaker, and then left to settle (Markert,1994). The clear solution was ready for analysis using a Flame Atomic Absorption Spectrometer (AAS) of heavy metals (Cu, Pb, Zn, Cd, Co, Ni, Cr, Mn).

Water samples

To each 100 ml bottle, exactly 0.1 ml of conc. HNO_3 was added to acidify the samples before analysis by AAS.

Vegetation samples

Randomly sampled vegetation parts (roots, branches and leaves, barks, tubers and fruits) or whole plants included wild herbs, shrubs and trees. Crop plants including rice (*Oryza sativa*) and maize (*Zea mays*) were also sampled. The samples were air-dried at 35-40°C in the field following the procedure recommended in Markert (1994). Unidentified specimens were pressed for further identification in the Herbarium. In the laboratory, aliquots of dry samples were cooled in liquid nitrogen and then finely ground by using agate mortar and pestle to pass a mesh size of 0.5 mm (Stewart 1989; Mtui *et al.* 2006).

For heavy metal analysis, 1 g of powered sample was accurately weighed and digested using conc. HNO_3 then evaporated to about just dry. The digestion was repeated several times until no any charred material was seen. After cooling, a digestion mixture of nitric acid/hydrochloric acid 1:1 was added and the sample was heated to a clear solution, evaporated to near dryness and diluted to 50 ml. After cooling the solution was centrifuged to remove any suspensions. The clear solution was analyzed for metal content using flame AAS.

Quality assurance

Precision and accuracy were checked using certified reference materials (CRMs) and analysis of duplicate samples. For soils and sediments, CRM used was TILL 2, whose results are shown Table 1. For plant matrices, BCR-60 Lagarosiphon major-plant material was used and the results are given in Table 2. Most of the heavy metal analyses were of good precision, except Cr whose results showed poor reproducibility in some duplicate samples. Poor precision for Cr analyses could be attributed to refractory nature of chromite, the principal ore mineral for Cr, and its heterogeneous distribution even in very fine-grained sediment and soil fractions. Aqua regia soluble metals indicated good accuracy based on the analysis of CRMs.

Table 1: Comparison of aqua regia extractable metal contents and certified values in TILL 2.

TILL 2	Cu ppm	Pb ppm	Zn ppm	Cd ppm	Co ppm	Cr ppm	Ni ppm	Mn ppm
Experimental	150.36	18.14	120	0.36	10	37	30	505.2
Certified value	149	21	116	0.30	13	40	31	530

Table 2: Comparison of experimental and certified values in BCR-60 Lagarosiphon plant.

BCR -60	Cu ppm	Pb ppm	Zn ppm	Cd ppm	Mn ppm
Experimental	49.8	59.12	300	1.85	1820
Certified value	51.20	63.8	313	2.20	1759

RESULTS

Physicochemical parameters

Water pH and temperature

Water pH values during dry season varied within a narrow range of 6.30 to 7.44 (*N= 20, mean 6.86±0.34)* in most areas of the wetlands, except for two sites that recorded pH values of 4.10 and 8.53. The low pH value was measured in a tributary of Mtakuja River which is affected by acid mine drainage from old Geita mine tailings and possibly from the on-going large scale mining operations. The high pH value was found in Bukombe Bay at Kibumba - Motafali boat landing site (Figure 2). This site is strongly affected by traffic of fishing boats and the cleansing of cloths and domestic utensils by local inhabitants. The high pH thus reflects detergents used locally at the site, which has limited water circulation, and mixing because of a narrow lake embayment and blooming of water plants. The water temperatures in the sampled areas ranged between 20.3° and 34.5°C, with an average level of 25.6° C.

Table 3: Physico-chemical Parameters for Water in the Wetlands in Dry Season.

Location	Sample No.	pH	Temp °C	Conductivity(µS/cm)
Isanga channel	MW7	7.40	34.5	340
Nyamtukuza Lake Victoria	NY1	6.83	25.0	175.9
Bulyankulu River	NY2-1	7.44	26.7	210
Mwakitolyo	NY3	7.16	27.3	200
Ikuyu Ponded water	NY5	7.26	25.5	150
Nyangomango-Bulyankulu/1	NY7	6.96	22.6	160
Nyangomango-Bulyankulu/2	-	6.96	22.1	158
Bulyankhulu	NY8	7.10	24.6	221
Mabubi River	GT3	6.46	25.0	139.8
Mabubi River	GT4	6.79	21.4	103
Mtakuja	GT5	6.73	20.3	315
Mtakuja	GT6	6.81	25.0	320
Mtakuja main channel	GT7a	6.30	20.3	395
Mtakuja stream	GT7b	4.10	20.8	507
Mtakuja Kamlale	GT8a	6.35	22.9	145
Mtakuja Kamlale	GT8b	6.41	22.4	123.7
Kibumba	GT10	8.53	28.7	126
Mwembeni Kasala	GT11a	7.15	34.9	120.2
Mwembeni Kasala	GT11b	6.96	33.4	105.1

Location	Sample No.	pH	Temp °C	Conductivity(µS/cm)
Makungurusi Village	GT12	6.38	31.0	35.3
Nzera Nyamboge River	GT13	6.93	22.5	131.4
Nzera River	GT14	6.75	24.5	90.8
	Mean (N = 20)*	**6.86±0.34**	**25.6±4.5**	

**Excluding samples GT7b, GT10*

The pH values measured in water samples at the end of the rain season varied between 6.62 and 8.17, excluding two samples that had pH values of 3.25 and 9.21. The average pH was 7.19±0.38 when the two anomalous samples are excluded. These results indicate that the water on average was slightly more alkaline at the end of the rain season compared to the dry season. The lowest pH value of 3.25 was recorded in the Mtakuja River sub-stream, which also gave the lowest pH value of 4.10 in the dry season. The water temperature varied between 16.8° and 27.5° C in the wetlands. The average temperature was 21.9°C, which was significantly lower than the average temperature recorded in the dry season.

Conductivity measurements

Water conductivity was generally low in most areas of the wetlands and their drainage systems. The conductivity values varied from 35 to 507 µS/cm during dry season (Table .3), and from 80 to 820 µS/cm at the end of rain season (Table 4). Slightly elevated conductivity levels (> 300 µS/cm) in Mtakuja during the dry season were measured at an area upstream of Mtakuja River close to the Geita gold mine (Figure 3), and in the Isanga channel close to Mwakitolyo artisanal gold mining village (Figure 2). At the end of the rain season, elevated conductivity levels (300-820 µS/cm) were measured at a place where the river passes close to the old Geita mine tailings. A stream entering the Mtakuja River gave the highest conductivity value of 820 µS/cm (Table 4)

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Mwakitolyo	NY3	7.16	27.3	200
Ikuyu Ponded water	NY5	7.26	25.5	150
Nyangomango-Bulyankulu/1	NY7	6.96	22.6	160
Nyangomango-Bulyankulu/2	-	6.96	22.1	158
Bulyankhulu	NY8	7.10	24.6	221
Mabubi River	GT3	6.46	25.0	139.8
Mabubi River	GT4	6.79	21.4	103
Mtakuja	GT5	6.73	20.3	315

Location	Sample No.	pH	Temp °C	Conductivity(µS/cm)
Mtakuja	GT6	6.81	25.0	320
Mtakuja main channel	GT7a	6.30	20.3	395
Mtakuja stream	GT7b	4.10	20.8	507
Mtakuja Kamlale	GT8a	6.35	22.9	145
Mtakuja Kamlale	GT8b	6.41	22.4	123.7
Kibumba	GT10	8.53	28.7	126
Mwembeni Kasala	GT11a	7.15	34.9	120.2
Mwembeni Kasala	GT11b	6.96	33.4	105.1
Makungurusi Village	GT12	6.38	31.0	35.3
Nzera Nyamboge River	GT13	6.93	22.5	131.4
Nzera River	GT14	6.75	24.5	90.8
	Mean (N = 20)*	**6.86±0.34**	**25.6±4.5**	

**Excluding samples GT7b, GT10*

Table 4: Physicochemical Parameters for Water in the Wetlands - End of Rain Season

Location	Sample No.	pH	Temp °C	Conductivity (mS/cm)
Isanga Channel - Mwaloni	NG4	6.71	23.7	150
Isanga Channel	NG6	7.08	26.2	140
Bulyankhulu R. upstream	BL2	7.73	27.2	180
Bulyankhulu R. downstream	BL4	7.30	27.5	210
Nyugwa-Mwaloni 1	BL7	7.45	20.0	190
Nyugwa-Mwaloni 2	BL8	7.06	20.2	190
Nungwe Bay 2	NU2	7.63	20.0	140
Nungwe Bay 3	NU3	8.17	23.5	80
Mtakuja River downstream	NU4	7.15	19.7	350
Mtakuja River upstream	NU5	6.99	21.9	500
Mtakuja River - substream	NU6	3.25	26.9	820
Bukiliguru River	BU1	6.62	16.8	110
Bukiliguru	BU3	6.94	22.0	140
Bukiliguru	BU4	6.97	22.2	180
Sengerema - Kongwa R.	SE1	6.90	19.5	100
Kongwa River upstream	SE2	7.18	19.8	110
Kongwa River downstream	SE3	7.21	20.8	100
Kongwa R. further downstream	SE4	7.14	21.2	100
Luchili Bay - L. Victoria	SE7	9.21	23.1	80
	Mean (N = 17)*	**7.19±0.38**	**21.9±2.9**	

**Excluding samples NU6, SE7*

Heavy metals in water

Twenty one samples of whole water were analyzed for 8 heavy metals (Cu, Pb, Zn, Cd, Cr, Ni, cobalt Co and Mn) by Atomic Absorption Spectrophotometry (AAS). Lead and Ni were below detection limit (<0.01 mg/L) in all samples from different wetlands whereas Cu contents were high (i.e., 270mg/l) at Bulyankhulu area, downstream of the gold mine and artisanal workings. Zinc was detectable in 95% of the samples, but the concentration was generally low, commonly less than 0.07 mg/L except for one sample that had a concentration of 0.14 mg/L. Cadmium concentration was below detection limit of 0.001 mg/L in 57% of the samples, and between 0.001-0.002 mg/L in the rest of the samples. Sixty seven percent (67%) of the samples with detectable Cd were from Bulyankhulu and Nungwe Bay wetland drainage systems. The Mwakitolyo, Bukombe and Luchili Bay wetlands each consisted 11% of samples with detectable Cd in water. Chromium occurred in measurable concentration in 29% of the samples at a level of 0.02-0.11 mg/L. Samples from Mwakitlolyo-Isanga and Nungwe Bay wetland had relatively elevated Cr concentration in comparison with samples from Bulyankhulu and Luchili wetlands. Cobalt was below detection in all samples from Bulyankhulu wetland system but detectable in samples from Mwakitolyo, Nungwe, Luchili, and Bukombe wetlands. Cobalt concentration in the latter ranged between 0.02 - 0.06 mg/L. Mangenese concentration was nearly uniform (0.02 mg/L) in samples from Luchili Bay wetland, and below detection in Bukombe, Mwakitolyo-Isanga water samples. One sample from Nungwe Bay wetland recorded the highest Mn concentration (2.04 mg/L). Manganese concentration in the samples from Bulyankhulu varied from below detection to 0.07 mg/L.

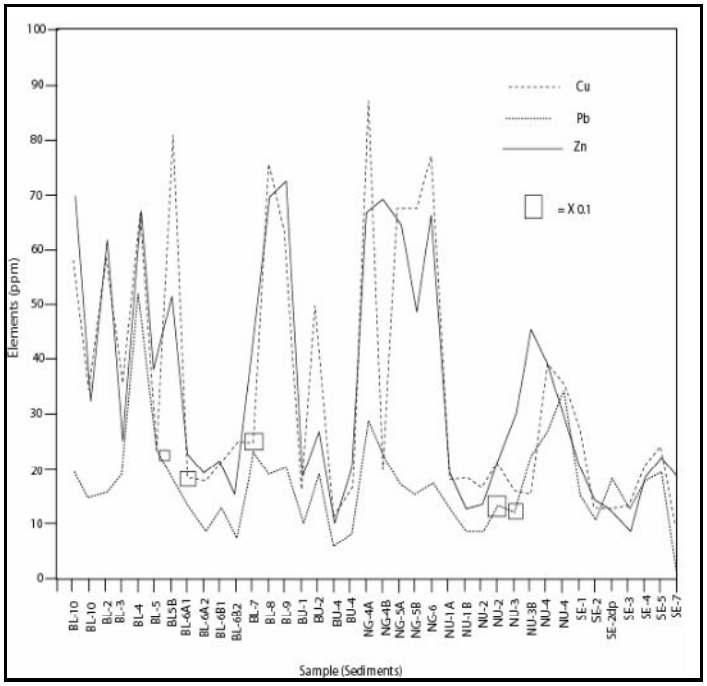


Figure 4(a): Heavy metal concentrations in sediments in the wetlands southeastern area of Lake Victoria basin during dry season

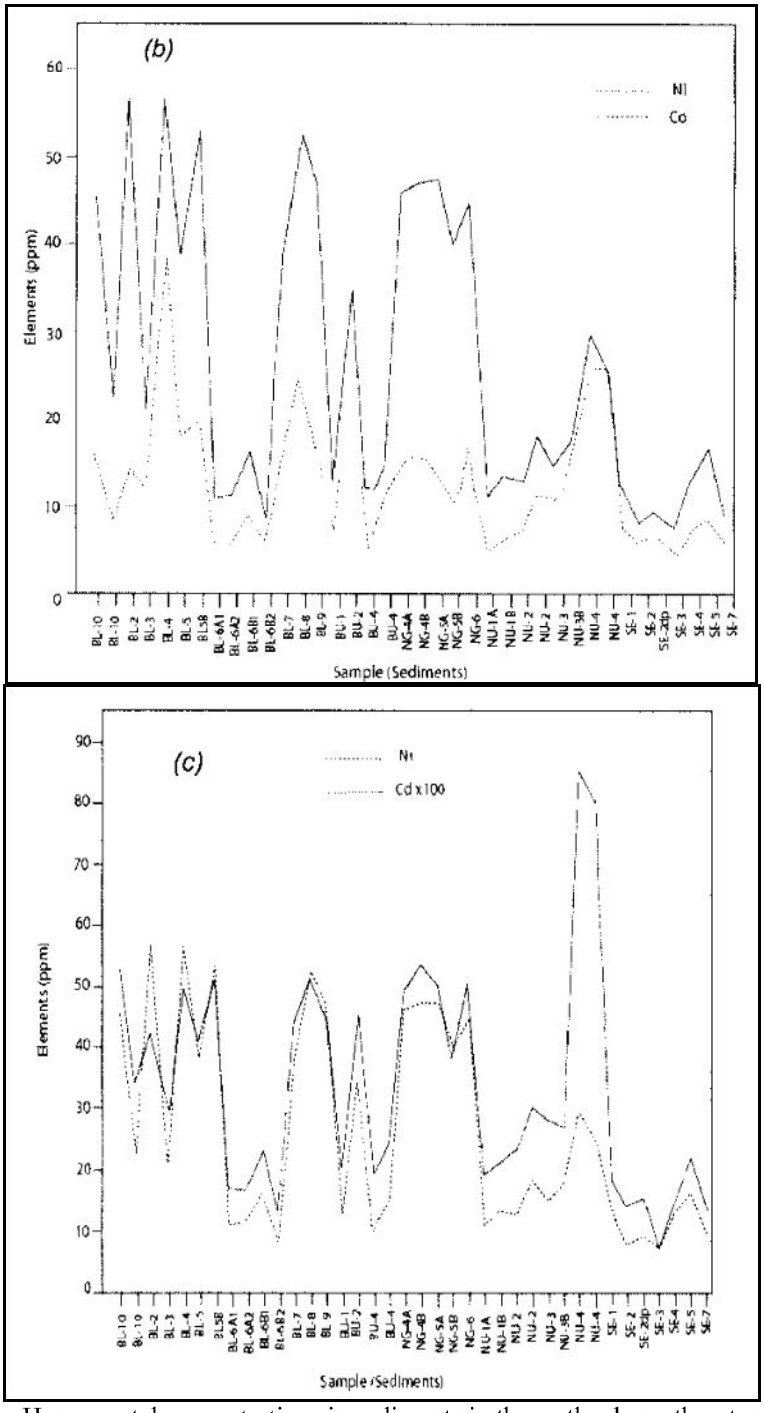


Figure 4(b,c): Heavy metal concentrations in sediments in the wetlands southeastern area of Lake Victoria basin during dry season

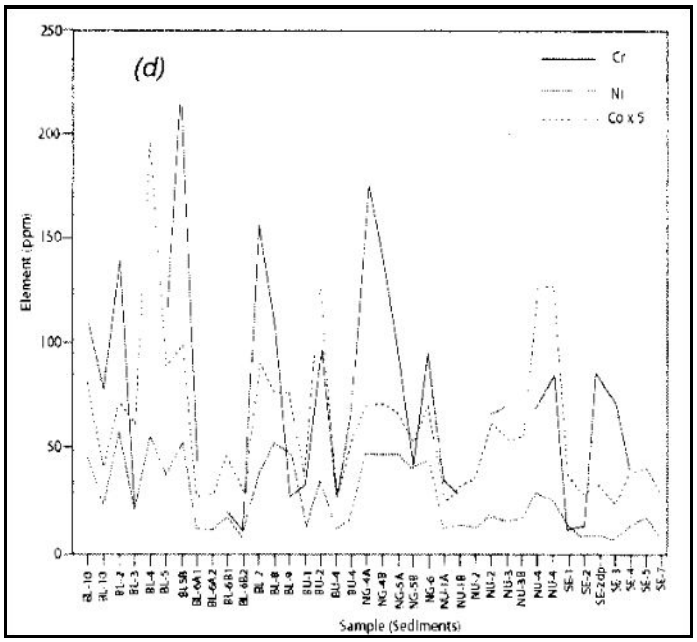


Figure 4(d): Heavy metal concentrations in sediments in the wetlands southeastern area of Lake Victoria basin during dry season

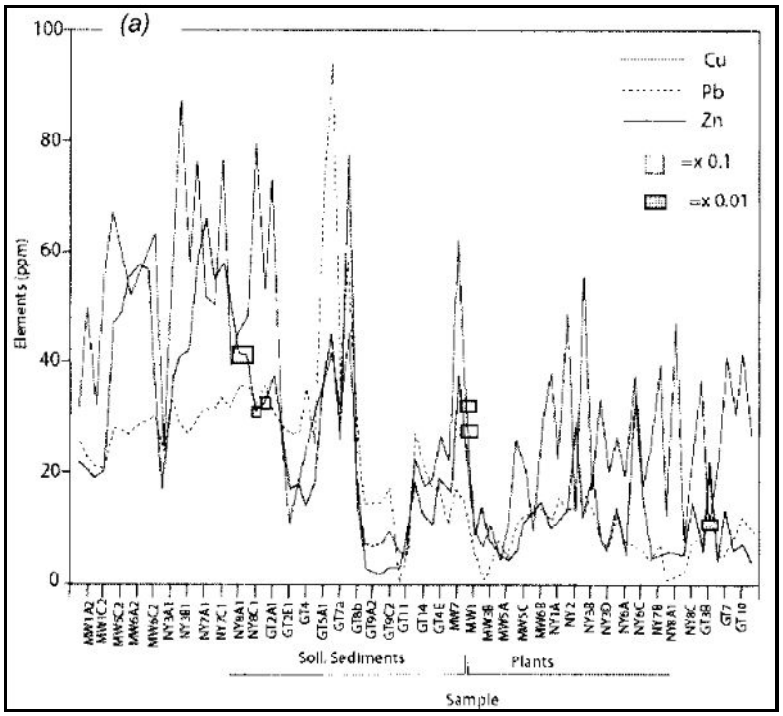
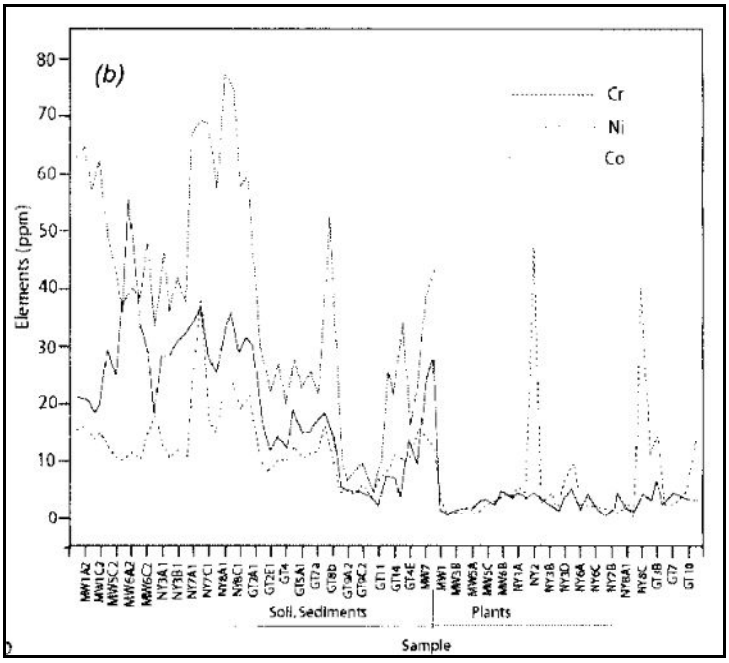


Figure 5(a): Heavy metal concentrations in soils, sediments and plants in the wetlands southeastern area of Lake Victoria basin at the end of rain season.



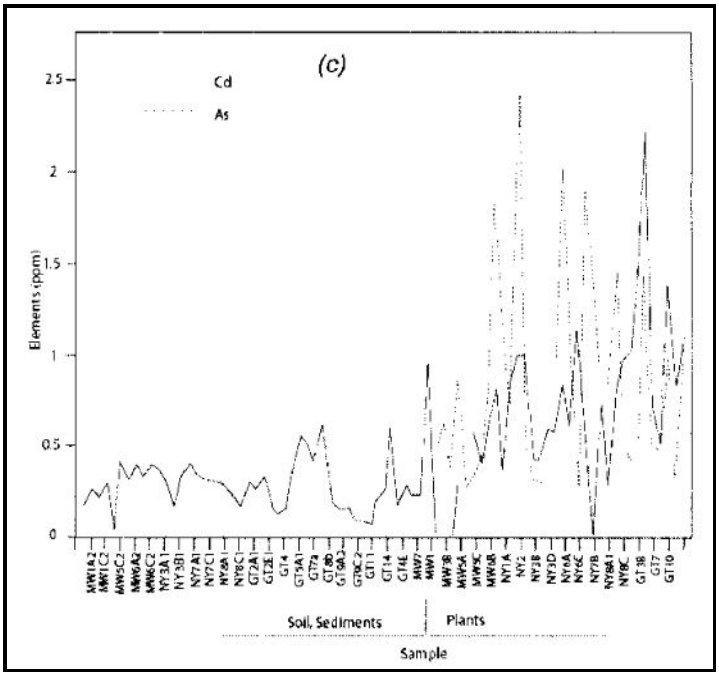


Figure 5(b,c): Heavy metal concentrations in soils, sediments and plants in the wetlands southeastern area of Lake Victoria basin at the end of rain season.

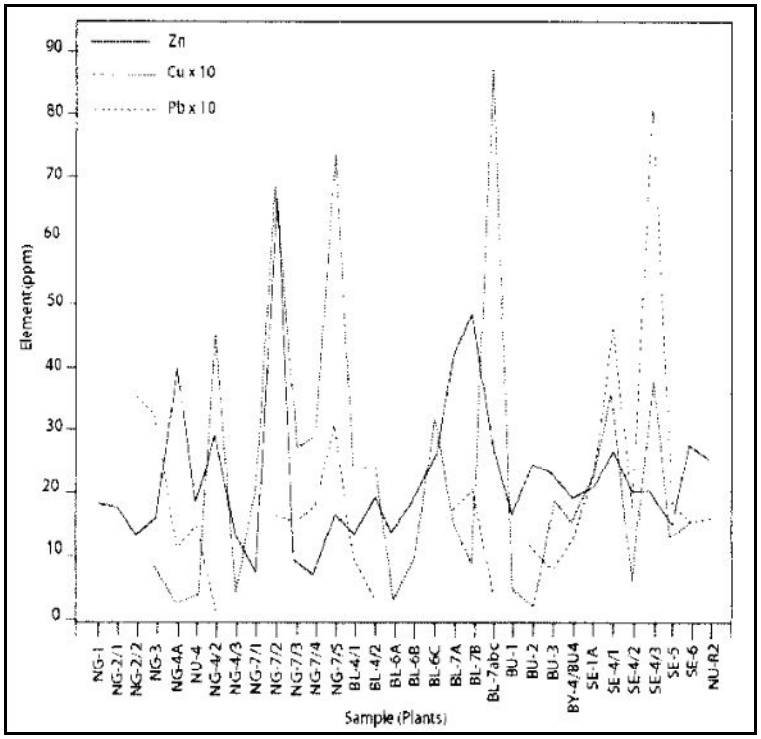


Figure 6: Concentration of Zn, Cu and Pb in plants during the end of rain season in the wetlands southeastern area of Lake Victoria basin.

Heavy metals in soil and sediment

Dry season

The results of heavy metal analysis in soil, sediment and plants are summarized in Figures 4 to 6. Copper concentration in soil ranged between 16-415 mg/kg in wetlands within the influence of gold mining activities and between 1-18 mg/kg in the control wetlands away from mining influence. The concentration of Cu was 19-57 mg/kg in Mwakitolyo-Isanga wetland, 37-415 mg/kg in Bulyankhulu, 16-45 mg/kg in Nungwe Bay wetland in Geita, 1-3 mg/kg in Bukombe Bay wetlands, and 18 mg/kg in one sample from Nzera wetland. Highest Cu concentrations (37-415 mg/kg) were associated with soils from Bulyankhulu wetlands, and the lowest concentrations (1-3 mg/kg) with the Bukombe Bay wetland.

Lead concentration varied from 21 to 94 mg/kg in soils from wetlands located within gold mining areas and from 14 to 27 mg/kg in the control wetlands. Soil lead content varied within a narrow range in Mwakitoloyo (21-30 mg/kg), Bulyankhulu (27-36 mg/kg), and Bukombe (14-17 mg/kg) wetlands, but showed wide variation in the samples from Nungwe-Geita wetland (27-94 mg/kg). Lead concentration in one sample from Nzera wetland, which served as a control, was 27 mg/kg.

The results for Zn analysis showed the concentration to vary between 31-67 mg/kg in Mwakitolyo, 39-80 mg/kg in Bulyankhulu, 9-73 mg/kg in Nungwe-Geita, and 7-9 mg/kg in Bukombe wetlands, and 22 mg/kg in one sample from Nzera wetland. The control wetlands had the lowest Zn concentration in the soil (7-22 mg/kg). Cadmium concentration ranged

between 0.04-0.57 mg/kg in thirty-three samples analyzed from 5 wetlands. There were overlaps in Cd concentration in soil from wetlands affected by gold mining and those wetlands which served as a control. Of the three wetlands affected by mining operations, i.e. Mwakitolyo-Isanga, Bulyankhulu and Nungwe, Bulyankhulu and Nungwe had relatively higher soil Cd concentration (0.13-0.57 mg/kg); the highest concentration was recorded in the samples from the Nungwe wetland affected by mining activities around Geita town.

Soil Cr concentration varied between 37-65 mg/kg in Mwakitolyo-Isanga wetland, 36-77 mg/kg in Bulyankhulu, 22-45 mg/kg in Nungwe-Geita, and 6-10 mg/kg in Bukombe wetlands. The Bukombe wetland had the lowest Cr concentration in soil. Chromium concentration in one sample from Nzera wetland was 25 mg/kg, which is within the range of Cr concentrations found in the Nungwe-Geita wetland soils.

The results of Ni analysis showed that there were no large differences in Ni concentration in soils from the three wetlands that are within or close to gold mining areas. The concentrations varied within a narrow range of 19-36 mg/kg for Mwakitolyo, 25-37 mg/kg for Bulyankhulu, and 12-30 mg/kg for Nungwe-Geita wetlands. Lowest Ni concentrations (5-8 mg/kg) were associated with samples from Bukombe and Nzera wetlands that were sampled as controls or reference wetlands. Cobalt showed similar pattern as Ni, being elevated in wetlands that are within or close to mining areas than those that are away from any mining influence. Soil Co concentration varied from 10-16 in Mwakitolyo, 10-38 mg/kg in Bulyankhulu and 8-12 mg/kg in Nungwe-Geita wetlands. Lowest Co concentrations (4-9 mg/kg) were recorded in samples from Bukombe and Nzera wetlands as in the case of soil nickel distribution.

Manganese concentration showed wide variation among soil samples from within the same wetland as well as from different wetlands. The concentration was 105-223 mg/kg in samples from Mwakitolyo-Isanga wetland, 93-1,539 mg/kg in Bulyankhulu samples, 96-278 mg/kg in Nungwe-Geita samples, and 51-128 in Bukombe samples, and 188 mg/kg in a single sample from Nezara wetland. The highest concentration was found in a sample from Bulyankhulu.

Heavy metal concentrations measured in stream sediments from wetlands that were sampled during the dry season are expressed in graphical form in Figures 4-6. No samples were collected from Mwakitolyo-Isanga wetland as the sampling transect did not cross any well-defined streams or rivers. The number of samples from the remaining wetlands was also small, reflecting lack of well-defined stream channels in this semi-arid region. A few samples collected from Bulyankhulu, Nungwe-Geita, Bukombe and Nzera wetlands indicated copper concentration in the range 3-78 mg/kg, the highest concentrations being recorded in sediments from Nungwe-Geita wetland (13-78 mg/kg), and the lowest concentrations (3-8 mg/kg) from Bukombe wetland, which was sampled as a control. Concentrations of Pb, Zn, Cd, Cr, Ni and Co were also lowest in sediments from Bukombe and Nzera wetlands. Manganese distribution did not show any defined pattern in the sediments from wetlands impacted or not impacted by mining operations. Manganese concentrations ranged from as high as 109-412 mg/kg in sediments from Nungwe-Geita wetland, to as low as 8-204 mg/kg in sediments from Bukombe wetland.

End of rain season

Forty six soil and sediment samples collected at the end of rain season (June 2004) were analysed for eight heavy metals (Cu, Pb, Zn, Cd, Cr, Ni, Co, Mn).(Figures 4-6). Copper content ranged between 17 – 249 mg/kg in samples from Bulyankhulu. The copper content was also higher in samples from Mwakitolyo and Geita wetlands, 15 to 87 mg/kg, than Bukombe

and Luchili wetlands (8 to 50 mg/kg). Lead was found to be high in samples from Geita, Bulyankhulu and Mwakitolyo in that order of decreasing concentration. The maximum Pb contents were 222 mg/kg, 52 mg/kg and 29 mg/kg, respectively in those wetlands. Samples from Bukombe and Sengerema had the maximum values in the range 19 mg/kg to 22 mg/kg. Zinc content varied between 49 to 69 mg/kg in samples from Mwakitolyo, whereas in Bulyankhulu wetlands the maximum content was 72mg/kg. Geita wetlands had relatively low Zn content, ranging from 13 to 39 mg/kg. Bukombe and Luchili wetlands indicated more or less similar Zn content within 8 to 27 mg/kg in soil and sediment. The three heavy metals Cu, Pb, and Zn showed more or less positive correlation in the samples (Figure 4a).

Cadmium contents were rather uniform in the wetlands. However, there were relative high values in Geita, Bulyankhulu and Mwakitolyo wetlands, ranging from 0.19 to 0.85 mg/kg in comparison with Bukombe and Luchili wetlands with low Cd content, ranging from 0.07 to 0.45 mg/kg.

Nickel values are variable in the wetlands, ranging from 7 mg/kg to 57 mg/kg. The lowest Ni values were found in Sengerema wetlands 7-16 mg/kg while the highest values were encountered in Bulyankhulu and Mwakitolyo 8-57 mg/kg and 40-48 mg/kg, respectively. Bukombe and Geita wetlands indicated more or less the similar values, ranging between 10 and 35 mg/kg. Nickel and cadmium showed a positive correlation in most samples (Figure 4c).

Cobalt showed little variation in Mwakitolyo-Isanga channel wetland; the Co content varied between 11 to 13 mg/kg. Samples from Bulyankhulu, Geita and Bukombe had a wide range of variation in Co content; the maximum content was 39 mg/kg and the lowest 5 mg/kg. Cobalt content in Luchili-Sengerema wetland ranged between 4 and 10 mg/kg. Bukombe and Luchili wetlands generally had lower Co content in comparison with other wetlands. A graphic presentation shows a positive correlation between Ni-Cd, Ni-Co, and Cr-Ni-Co in the samples (Figure 4 – 6).

Manganese indicated a wide range of variation in all wetlands. The highest Mn concentration (1536 mg/kg) was recorded in a sample from Bulyankhulu and the lowest (58 mg/kg) from Nungwe-Geita (Table 3.5). The range of Mn concentrations recorded in different wetlands were 79-184 mg/kg for Mwakitolyo-Isanga channel, 123-1536 mg/kg for Bulyankhulu, 58-514 mg/kg for Nungwe in Geita, 142-720 mg/kg for Bukombe and 151-388 for Luchili in Sengerema. Chromium varied from <0.01 to 221mg/kg in the wetlands. Samples from Nungwe-Geita had relatively low Cr content (0.01-84 mg/kg) in comparison with samples from Mwakitolyo-Isanga channel (42-175 mg/kg), Bulyankhulu (0.01-221 mg/kg), Bukombe (27-140 mg/kg) and Luchili-Sengerema (<0.01-103 mg/kg).

A general pattern of the distribution of the eight metals in soil and sediment in the study areas indicate elevated contents of those metals in Mwakitolyo, Bulyankhulu, and Nungwe-Geita wetlands that are more impacted by gold mining than in Bukombe and Luchili-Sengerema wetlands which are not mining-impacted.

Heavy metals in plants

Dry Season

Heavy metal concentrations measured in plant tissues, including leaves, barks, tubers and fruits collected in dry season are presented in Figures 5-6. Chromium was below detection limit (<0.01 mg/kg) in all plant tissues analyzed. Background Cu concentrations ranged between 3-7 mg/kg, on dry weight basis. Upper range of copper concentration (22-34) was recorded in plants from Bulyankhulu and Nungwe-Geita wetlands. Pb concentration varied from 0.1 to 20 mg/kg in the tissues, highest concentrations being again associated with

plants from Bulyankhulu and Nungwe-Geita wetlands. The limited number of samples analyzed from control wetlands does not permit rigorous comparison of lead and other metals between the controls and those impacted by gold mining operations. Zinc concentration ranged from 4 to 1,060 mg/kg. The highest concentrations were recorded in samples from Bulyankhulu and Nungwe-Geita wetlands. For cadmium, lowest and highest concentrations were measured in plant tissues from wetlands that are within the goldfields, including Mwakitolyo-Isanga, Bulyankhulu, and Nungwe-Geita wetlands. Cadmium concentration in the tissues ranged from 0.01-1.22 mg/kg in 11 plants samples from Mwakitolyo, 0.01-1.16 mg/kg in 18 samples from Bulyankhulu, and 0.51-2.22 mg/kg in 5 samples from Nungwe-Geita wetlands. One plant sample analyzed from each of the control wetlands, indicated Cd concentration of 0.84 mg/kg for Bukombe plant tissues and 1.08 mg/kg for Nzera wetland plants.

Nickel concentration varied within a range of 1 to 5 mg/kg in most plant tissues analyzed, with the exception of a few samples from Bulyankhulu, which contained low Ni concentration (0.5 mg/kg). Cobalt concentration showed a wide range of variation in contrast to nickel in the plant tissues. The lowest concentration was 0.4 mg/kg and the highest concentration 47 mg/kg. Highest concentrations (15-47 mg/kg) were associated with plants from Bulyankhulu and Nungwe-Geita wetlands that are more affected by mining operations than the rest of the wetlands covered by the present study.

Abnormally high concentrations of manganese were associated with plants from all wetlands, regardless of the influence of mining operations. Manganese concentration ranged from 10 to 3,009 mg/kg, and in one case up to 11,127 mg/kg. It appears the bioavailability of Mn for uptake by plants was quite high in all wetlands covered in the study.

Arsenic concentration in plant matter ranged from <0.01 to 2.44 mg/kg. The highest concentration of 2.44 mg/kg was found in some plants collected from Mwakitolyo and Bulyankhulu wetlands. The concentration of As in two samples of plants from control wetlands, i.e. Bukombe and Nzera, was in the range from 0.33 to 1.12 mg. Since only two samples were analyzed from these two wetlands, it is difficult to establish the background variation level of Arsenic in plants growing in those areas. More sampling would be needed to assess the background level of Arsenic in wetlands not under the influence of mining activities.

End of Rain Season

Thirty-two samples of various parts of plants collected at the end of rain season (June 2004) were analysed for eight heavy metals (Cu, Pb, Zn, Cd, Cr, Ni, Co, Mn). Copper concentration varied from <0.01mg/kg to 31.57 mg/kg, the highest value was found in a plants from Bulyankhulu. Lead varied from <0.01 mg/kg to 4.6 mg/kg, the highest concentrations were recorded in plants from Luchili wetland in Sengerema District. Zinc content in plants was relatively high in comparison with all other elements except manganese. The lowest Zn content was 7.0 mg/kg and the highest was 66.4 mg/kg, both values were recorded in plant samples from Mwakitolyo-Isanga channel wetland. Within the Bulyankhulu wetland Zn content in plants varied from 13.65 mg/kg to 47.91 mg/kg. Plants in Bukombe, Geita and Sengerema had Zn levels ranging from 15.15 mg/kg to 27.55 mg/kg.

Cadmium in plants indicated low levels varying between <0.001 to 0.557 mg/kg. It is relatively high in plants samples from Sengerema and Mwakitolyo, 0.557 and 0.394 mg/kg, respectively. Plants in Geita and Bukombe contained extremely low

cadmium content that was generally below the detection limit (<0.001 mg/kg).

Chromium content in plant samples from all five wetlands covered by the study varied from <0.01 to 4.35 mg/kg. Highest Cr content was encountered in Bulyankhulu samples. Nickel in plants ranged between 0.01 and 4.76 mg/kg. The highest Ni content was recorded in Bulyankhulu plants as for the case of Cr. Nickel and Cr showed more or less a positive correlation in the investigated plants (Figure 5b). Cobalt levels ranged between 0.01 and 2.57 mg/kg; the highest levels were associated with plant samples from Sengerema and Bulyankhulu wetlands. The three heavy metals Co, Cr and Ni (Figure 5b) correlated more or less positively in the plants. Manganese contents in plants were highly variable, with a wide range in plants from Bulyankhulu (9 - 332 mg/kg) and Sengerema (8-737 mg/kg). In other localities the Mn content was as low as 4-54 mg/kg in Mwakitolyo-Isanga channel wetland, 14-58 mg/kg in Bukombe, and 31-40 mg/kg in Nungwe-Geita wetlands.

DISCUSSION

The availability of the eight heavy metal elements in levels above the background in the wetlands, south of Lake Victoria is attributed mainly to gold mining activities. Copper, Pb and Zn showed a tendency of positive correlation in the areas which are experiencing both large and small scale mining activities: Mwakitolyo, Bulyankhulu and Geita. These elements are intimately associated with relic minerals which may be present in soils in trace quantities from the immediate underlying bedrocks (Greger, 1999). The Bukombe and Sengerema wetlands have low levels of these elements as these areas are far from mining activity centres.

Nickel, Co and Cr showed the tendency of positive correlation in sediments and soils. These elements are very common in minerals of ultramafic and mafic rocks. The elements may be associated with chromite ore or spinel. The non-uniformity of the levels of these elements in the soils and sediments could be due to presence of spinel minerals that are very resistant to chemical weathering. It was also observed that the levels of these elements are comparatively low in Bukombe and Sengerema than in Mwakitolyo, Bulyankhulu and Geita where mining is active.

The upper limits of Mn levels in non-polluted soils vary from 500 to 3000 mg/kg (Mortvedt *et al.* 1972). In south Lake Victoria wetlands, several samples indicated the results within that limit. The wetlands are located in strongly weathered rock formations that have been altered to ferricretes, locally known as "Lukiri", comprising mainly Fe and Mn oxides. Changes in redox conditions due to fluctuation of water level in the wetlands would greatly influence the binding and release characteristics of Mn from the ferricretes, and hence its distribution in the soil and sediment.

Excess heavy metals have been noted to alter the functions of photosynthesis in plants (Prasad & Strzalka 1999). Copper, Cd and Pb affect the photosynthesis of plants in different ways. For instance, the critical toxic Cu level in leaves of all plant species is about 20 to 30 μg/g dry weight (Ouzounidou *et al.* 1994). It is obvious that the level of Cu in plant species from Bulyankhulu with up to 34 μg/g is already alarming. Elongation of roots, height (stunted plants) and malformed leaves have been observed in other parts of the world (Förstner and Wittman 1979)

The correlation aspects of certain heavy metals in plants can be explained by the fact that, sometimes the combination of elements in plants lead to increase or decrease in certain effects. That is, the interaction of more than one heavy metal may be of advantageous or deleterious to plant growth and crop yield (Hagemeyer, 1999). Most of heavy metals like, Cd, Cu,

Fe, Pb, Mg, Ni and Zn uptake by plants is promoted by low pH values and anaerobic conditions (Streit and Stumm, 1993; Ernst 2003). Certain plant species or races known as ecotypes may have elevated concentrations of heavy metals by virtual of being hyper-accumulators of particular element (Streit & Stumm 1993, Greger 1999).

The elevated concentrations of some heavy metals in higher plants are likely to be due to the fact that such elements are essential for their growth. Usually the impact of the metal surplus on plant growth depends on the availability of metal concentrations in the environment and its interaction with inorganic and organic matter as well as solubility, exchangeability and speciation. The presence of other elements, pH and Eh control the availability of the element in question (Bargagli 1997, Ernst 2003). From the numerous heavy metals occurring in the earth crust, Fe, Mn, Zn, and Cu are essential for all higher plants.

CONCLUSION

This study elucidated the physicochemical parameters and heavy metal concentrations in waters, soils, sediments and plants in the human-impacted (mining; industrial and domestic discharges) and non-impacted sites of south Lake Victoria wetlands. Overall, the impacted sites had more elevated physicochemical parameters and heavy metal concentrations compared to non-impacted sites. It is advised that monitoring of the sites should be extended beyond this study in order to assess the long term effects.

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