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Application of algae in biomonitoring and phytoextraction of heavy metals contamination in urban stream water

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ABSTRACT: Biological technologies for wastewater remediation techniques employed to remove contaminants in urban stream water are increasingly receiving attention worldwide. The purpose of this study was therefore to determine the concentrations of lead, cadmium, copper, zinc, manganese and iron in algal biomass and establish the feasibility of using algae in phytoextraction and bio-monitoring of environmental quality. Analysis of algal biomass samples in the Nakivubo urban stream ecosystem, Kampala, Uganda, showed that there was contamination by lead, cadmium, copper and zinc as indicated by enrichment factor and pollution load index values. It is suspected that industrial and vehicular emissions are the major sources of these pollutants. Calculated bio-concentration factor was $\geq$ 1000 but with low concentration thresholds in each element, suggesting that algal biomass was a very good heavy metal accumulator. The bio-concentration values in algal biomass were found to be in the order of copper > zinc > lead > cadmium in the Nakivubo Channelized stream. In conclusion, algae can be a promising aquatic bio-filter plant for phytoextraction and bio-monitoring of polluted urban stream ecosystems and wastewater.

Keywords: *Bio-filter; Biomass; Green algae; Phytosorption; Wastewater*

INTRODUCTION

Recent developments in environmental research have revealed that many living organisms can accumulate certain toxicants to body concentrations much higher than present in their environments (Nyangababo *et al*., 2005a; Igwe *et al*., 2008; Kord *et al*., 2010). This makes chemical analyses in biota important for use in routine assessment and monitoring procedures (Lam and Gray, 2003; Nwuche and Ugoji, 2008). Body contaminant concentrations can further be used in assessing and monitoring the uptake of contaminants by living organisms and the increase in concentrations of pollutants from the environment to the organisms (bioaccumulation/bio-concentration). Green algae have been recognised as one of the most important primary producers in some aquatic ecosystems that have a role to play in the regulation of dissolved oxygen in water through the phenomenon of photosynthesis. The adsorption, phytosorption and affinity of algae for heavy metal cations in wastewater treatment because of its high negatively charged surface (cell wall components) have been acknowledged for a long time. This property gives algae an added advantage as heavy metal accumulator in view of phytoextraction of such elements in urban stream ecosystems (Chmielewska and Medved, 2001; Kar *et al*., 2008). Algae have been qualified as a precise biomonitoring tool for determining and quantifying of heavy metals in aquatic ecosystems (Levkov and Krstic, 2002; Shah *et al*., 2009).

Biological water remediation techniques are preferred to chemical and physical treatment technologies because of their effectiveness, low cost and reduced impact on ecosystem (Thangavel and Subbhuraam, 2004). Recently, interests have focused on the study of aquatic plants in remediation and bio-monitoring of heavy metal contaminants in aquatic

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ecosystems (Girgin *et al*., 2010; Nouri *et al*., 2009).. In view of this, the environment is able to absorb pollutants and clean up itself through natural biological processes as bioremediation (Wuana *et al*., 2010). The uses of submerged aquatic plants in water quality assessment have been recognized and are reported to bio-concentrate and scavenge heavy metals in wastewater (Scott, 1992; Goyal *et al*., 2008). Plants have the ability to bio-concentrate metals at levels 100-fold greater than those typically measured in non-accumulator plants and can be categorised as Cd > 100 mg/kg, Pb and Cu > 1000 mg/kg and Zn and Mn >10000 mg/kg (Baker and Brooks, 1989). The extreme level of metal tolerance in vascular plants is called hyper-accumulation (Baker and Brooks, 1989). BCF values $\geq$ 1000 (Zayed *et al*., 1998) can be used together with the concentration thresholds in each element as mentioned by Baker and Brooks (1989) to characterise a plant as a good accumulator (hyperaccumulator). Bio-concentration Factor (BCF) is regarded as a better indicator to classify a particular plant as a hyperaccumulator because BCF takes into account the trace element concentrations in the solution (Zayed *et al*., 1998). BCF standard is applied as a threshold, above which a substance is considered bio-accumulative and therefore able to cause long term environmental impact. The objectives of this study were: 1) to determine the concentrations of Pb, Cd, Cu, Zn, Mn and Fe in algal biomass in urban stream water .2) to assess the feasibility of using algae in bio-monitoring of environmental quality. 3) establish the possibility of using algae for phytoextraction in urban stream water and wastewater. This study was conducted between August, 2008 and November 2009, along the Nakivubo Channelized stream of Kampala in Uganda.

MATERIALS AND METHODS

Study area and sites

The sampling area [$0^{0}15'$N and $32^{0}30'$E] is shown in Fig. 1. Algal materials were sampled from different localities along the Nakivubo Channelized stream (Table 1). The stream drains through Kampala city center, the most industrialised areas and Nakivubo wetland before discharging into Lake Victoria. The channel is the major recipient of runoff, organic and inorganic industrial and domestic waste effluents. Nakivubo Channel was constructed basically to carry storm water from Kampala city into Lake Victoria to minimise flooding and ponding effects.

Sampling and laboratory analytical procedures

Algal samples were collected for over one year along the Nakivubo drainage system (Table 1) as described by Chmieleseská and Medved' (2001). Samples were oven dried at 105 °C for 2 h and homogenized into a fine grained

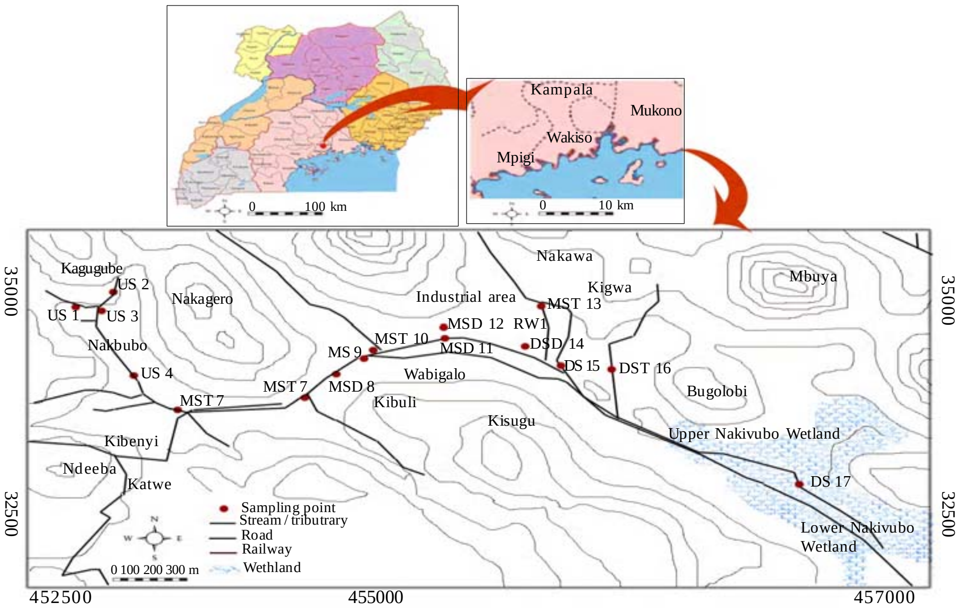

Fig. 1: Map of Uganda showing the locations of the sampling sites along the Nakivubo Channelized stream in Kampala

Table 1: Location and description of activities and establishments

Site*	Code	GPS Readings		Activity/Establishment
Upstream		Lat.	Long.	
Bativa Hotel Bridge	US02	0.324	32.5726	Car washing bay, gas/fuel station, slum residential and commercial and seepage
Nakivubo Stadium Bridge	US04	0.3169	32.5723	Recreational, commercial, market, vehicle traffic, bus park, gas/petro station and seepage
Tributaries				
Kayunga Stream	MT07	0.3081	32.5782	Solid waste dump sites, horticulture, recreational, slum and residential, vehicle traffic, gas/petro station
Kitante Stream	MT10	0.3099	32.5891	Horticulture, recreational, residential and commercial, vehicle traffic, gas/petro station
Lugogo Stream	MT13	0.3191	32.6011	Vehicle traffic, Commercial, residential and industrial, Electric power station, horticulture, carpentry works, pole treatment and seepage
Kibira Road Stream	DT16	0.3142	32.611	Battery , plastic and paper factory, industries, and gas/petro station

size. Decomposition of samples was performed using 20.0 mL fuming HNO_3 in open beaker digestion, left over night using a thermalmetrically controlled hot plate. Then 5.0 mL of hydrogen peroxide was added to complete the digestion and heated again to dryness. The beaker walls were washed with 2.5 mL of deionised water and heated to boiling point. The digest liquor was transferred into 25.0 mL flask and filled with deionised water to the mark. Sampling and chemical analysis of water and sediment samples were carried out as described by Sekabira *et al*, (2010 a, b). Heavy metals were analysed using Perkin-Elmer model 2380 Flame atomic absorption spectrophotometry. Accuracy of the analytical method was evaluated by comparing the expected metal concentrations in certified reference materials with the measured values. Simultaneous performance of analytical blanks, periodic aspiration of the standard, certified reference (JG-3) and calculation of the average recoveries of heavy metals show that the accuracy of the method was within acceptable limits (Table 2).

Heavy Metal Assessment

Bio-concentration Factor (BCF) or coefficients: Bio-concentration Factor can be employed to qualify the toxic element accumulation efficiency in plants by comparing the concentrations in the biota (algal biomass) and an external medium (e.g. water).

$$BCF = C_b/C_w$$

Where, C_b and C_w are heavy metal concentrations in the biota (mg/kg) and in water (µg/L), respectively. BCF was categorised as: < 1 excluder, metal accumulator > 1 and $\geq$ 1000 a good metal accumulator (Zayed *et al*., 1998).

Analysis of variance (ANOVA): ANOVA was employed to determine whether groups of variables have the same means on data that are continuous or normally distributed and with homogeneous variance. Additionally, it was employed to assess the relationship between heavy metal concentrations and their elemental interaction at each site.

Correlation analysis: Pearson's correlation analysis was adopted to analyse and establish inter-metal relationship and physico-chemical characteristics of the stream water.

RESULTS AND DISCUSSION

Heavy metal concentrations in water, algal biomass and sediments

Mean physico-chemical characteristics are indicated in Table 3. Water pH ranged between 6.12 and 9.36 and was within the maximum permissible limit of discharge for wastewater except along Kibira Road and Kitante tributaries. Total dissolved solids ranged between 102.0 and 478.0 mg/L, Total Suspended Solids 3.0 and 733.0 mg/L, EC 5.3 and 961.0 µs/cm and BOD 5.6 and 952.0 mg/L. Nakivubo Stadium Bridge along Nakivubo Channelized stream showed very high BOD and TSS in the upstream

Table 2: Quality control (mean ± SD) (mg/kg trace and % for elements)

Heavy metals	Pb	Cd	Cu	Zn	Mn (%)	Fe (%)
Reference material	11.7	0.054	6.81	46.5	0.055	2.58
Measured values	10±0.981	0.05±0.002	6.75±0.131	48.25±1.041	0.048±0.003	2.35±0.139
Percentage Recovery	85.5	92.6	99.1	103.8	87.3	91.1

section suggesting high decomposition of organic matter and anoxic conditions.

Table 5 shows metal concentrations (µg/L) in water samples that were collected from Nakivubo stream, its tributaries and Watindo stream. The total mean heavy metal concentrations in the Nakivubo Channelized stream water were in the sequence of Fe (700 µg/L) > Mn (610 µg/L) > Zn (36 µg/L) > Pb (29 µg/L) > Cu (10 µg/L) > Cd (4 µg/L). The mean trace heavy metal concentrations in the water samples from tributaries were Fe (1.125 µg/L) > Mn (755 µg/L) > Pb (77 µg/L) > Zn (67 µg/L) > Cu (12 µg/L) > Cd (6 µg/L). The mean concentrations of heavy metals in Watindo stream which is considered to be unpolluted were in the sequence of Fe (4450 µg/L) > Mn (160 µg/L) > Pb (63 µg/L) > Zn (23 µg/L) > Cu (8 µg/L) > Cd (3 µg/L l). The mean heavy metal levels in tributaries and Watindo stream showed a similar sequence. Results show that elemental concentrations in water are comparable with that reported by Muwanga and Barifaijo (2006) but lower than those reported by Nabulo *et al*. (2008) in industrial effluents released into the Nakivubo Channelized stream and its tributaries. However, the concentrations of Pb, Cd, Cu, Zn and Mn in sediments are higher than those reported earlier by Muwanga and Barifaijo (2006). The mean heavy metal concentrations in the algal biomass (Table 5) in the Nakivubo stream followed the trend Fe (65290.45 mg/kg) > Mn (979.275 mg/kg) > Zn (349.08 mg/kg) > Pb (108.51 mg/kg) > Cu (97.94 mg/kg) > Cd (1.425 mg/kg) Table 3. In Nakivubo tributaries, heavy metals were observed in the sequence Fe (41885.430 mg/kg) > Mn (834.253 mg/kg) > Zn (462.528 mg/kg) > Pb (166.12 mg/kg) > Cu (50.228 mg/kg) > Cd (3.008 mg/kg). Watindo stream elemental concentrations followed the sequence Fe (47899.010 mg/kg) > Mn (1026.890 mg/kg) > Zn (119.535 mg/kg) > Pb (45.875 mg/kg) > Cu (24.575 mg/kg) > Cd (2.085 mg/kg). Heavy metal concentrations in algal biomass followed a similar sequence in Nakivubo tributaries and Watindo stream as well as Nakivubo stream water. Generally, metal ions with greater electronegativity and smaller ionic radii are preferentially sorbed by algal biomass. The concentrations of heavy metals in algal biomass were higher than those in the water and sediments in the Nakivubo Channelized stream sediments and water in the order of Algal biomass > sediments > stream water. This observation differs from the findings made by Levkov and Krstic (2002), since heavy metal concentrations were high in the sediments (sediments > algal biomass > river water) for most of the elements. Lead concentration was exceptionally high in sediments at site DT16 in this study (Muwanga and Barifaijo, 2006).

Table 5 showed high mean heavy metal concentration in algal biomass at site DT16 for Pb, Cd, Zn, and Mn. These high heavy metal concentrations in algae are attributed to Uganda Batteries factory, Plastic manufacture by Uganda House of plastics and a petrol station (Pb and Cd) and manufacture of galvanised iron sheets by Uganda Baati (Zn). The phenomenon show low heavy metal levels in water with algal biomass (Levkov and Krstic, 2002). The study shows that the value of algal bio-concentration factor at most of the sites including US02, US04, MT07, DT16 and CT03 were greater than 1000. The results of heavy metal bio-concentration in algal biomass qualify it as a good heavy metal accumulator (Conti and Cecchetti, 2003). The high rates of bio-concentration in algae may be attributed to its cell wall components. However, these algal samples showed total concentration in dry biomass < 100 mg/kg Cd, < 1000 mg/kg Cu Pb and < 10000 mg/kg Zn and Mn (Table 5) and thus algae could not be classified as a hyper-accumulator (Baker and Brooks, 1989). The trend of heavy metal concentrations in the algal biomass

Table 3: Mean physico-chemical characteristics of stream water samples from Nakivubo Channelized stream, tributaries and Watindo stream (n=16)

	pHw			TDS (mg/L)			TSS (mg/L)			EC (µs/cm)			BOD (mg/L)		
Site*	Mean	Min.	Max.	Mean	Min	Max.	Mean	Min	Max.	Mean	Min.	Max.	Mean	Min	Max.
US2	7.07	6.55	7.97	178.81	145	255	118.31	5	733	356.75	299	502	36.08	5.6	188.6
US4	7.18	6.3	7.89	251	114	298	195.13	48	357	471.52	5.3	618	166.97	58.52	952
MT7	7.33	6.91	7.86	305.5	236	361	69.19	9	367	612.63	479	722	49.09	6.24	200
MT10	7.09	6.59	9.35	129.69	102	166	24.19	6	49	260.63	208	335	30.31	5.18	156.2
MT13	7.15	6.35	7.62	199.81	163	478	24.13	3	128	405.38	328	961	46.66	5.6	224
DT16	6.86	6.12	9.36	263.56	156	405	115.31	18	289	526.06	319	807	155.87	12.46	672
CT2	7	6.55	7.72	51.83	40	60.8	97.97	12	877.5	103.11	80.1	122.2	16.69	2.24	38.08
CT3	6.88	6.51	7.51	53.19	12.8	69.6	105.87	12	370	106.23	25.7	140.2	31.97	5.6	197.1
*NEMA		6-8.			1200			100					50		

* NEMA (2006/2007) maximum permissible limits of discharge of wastewater into aquatic habitats; pH-w water pH.
For description of *sites refer to Table 1

correspond to the heavy metal content in water, sediments and BCF at each sampled site.

Heavy metal concentrations in the Nakivubo stream sediments (Table 5) followed the trend Fe (49974.670 mg/kg) > Mn (474.030 mg/kg) > Zn (370.370 mg/kg) > Pb (159.820 mg/kg) > Cu (53.060 mg/kg) > Cd (1.670 mg/kg). The mean heavy metal concentrations in the tributary sediments followed the order Fe (47369.330 mg/kg) > Mn (563.080 mg/kg) > Zn (251.450mg/kg) > Pb (150.660 mg/kg) > Cu (34.450 mg/kg) > Cd (1.010 mg/kg). Watindo stream sediments heavy metal concentrations followed the order Fe (65874.670 mg/kg) > Mn (109-.530 mg/kg) > Zn (55.330 mg/kg) > Pb (37.220 mg/kg) > Cu (13.970 mg/kg) > Cd (0.970 mg/kg). Generally, heavy metals in the Nakivubo stream, its tributaries and Watindo stream sediments follow a similar elemental concentration trend. Sediments accumulated more heavy metals than the water in this study as revealed by Eja *et al*. (2003), suggesting high deposition of heavy metals into stream sediments. High heavy metal concentrations in sediments are attributed to vehicular and industrial emissions and residential establishments along the Nakivubo channel and support the findings of Nyangababo *et al*, (2005a) and Muwanga and Barifaijo (2006). Analysis of variance (ANOVA) was employed to determine whether heavy metal variables have the same mean on data that are normally distributed (Table 4). ANOVA results were based on BCF of heavy metals in algal biomass. Sites showed no significant effect on variations between means of heavy metal bioaccumulation factor ($p > 0.05$) (Table 4). This suggests that green algae follow a similar pattern of heavy metal sequestration since they are not differentiated into plant parts and heavy metals are mobile in solution form.

The mean BCF in all of the sites and elements in algal biomass were several orders higher (BCF > 1) (Table 6). The mean BAF values in algal biomass of the Nakivubo Channelized stream follow the trend Fe (93658.66) > Cu (10831.39) > Zn (9081.62) > Pb (6868.95) > Mn (1649.04) > Cd (383.23). The mean BAF values in tributaries can therefore be ranked in order of decreasing magnitude as Fe (63768.66) > Zn (6822.24) > Cu (4876.68) > Mn (2212.23) > Pb (1830.13) > Cd (567.77). Also Watindo stream algal biomass BCF values were ranked as Fe (10620.75) > Mn (6426.08) > Zn (5273.72) > Cu (3122.41) > Cd (852.00) > Pb (814.70). BCF values ranged from 30.84 to 482.01 for Pb, 1.08 to 4.53 for Cd, 15.29 to 126.69 for Cu, 105.7 to 1138.35 for Zn, 714.07 to 1072.25 for Mn and 27364.27 to 83075.05 for Fe. The sampled algae showed that BCF ranged between 411.20 and 12669.00 for Pb, 252.0 and 1392 for Cd, 1816.57 and 15836.25 for Cu, 4450.53 and 11422.17 for Zn, 436.15 and 6169.64 for Mn and 14865.31 and 95011 for Fe.

Cluster Analysis (CA) and Factor Analysis (FA): Cluster analysis was performed on the data using average linkage and correlation coefficient distance. Results of cluster analysis are shown in Fig. 2. Two groups of elemental associations with eigenvalues > 1 were extracted in the analyses. Heavy metal elements were fused into groups or clusters because of their relative elemental concentration in algal biomass at each site and their similarity coefficients. Group I contains Pb, Cu, Cd and Zn as well as sediment pH. Group II contains Mn and Fe (Fig. 3).

Biplot of sites and elemental concentrations (Fig. 2) suggest that inflows from Kibira Road and Lugogo are sources of Pb, Kitante streams are sources of Pb, Cu and Zn, whereas inflows from Kayunga stream are loaded with Fe, Mn and Cd. Bativa Hotel Bridge in flows are sources of Cd, Cu and Zn to Nakivubo Channelized stream. The first two factors account for 79.9 % of the total variance in the data set. The rotated factor matrix is explained by the two factors with high communalities of elements except Cd. The first factor accounts for 53.0 % of the total variance and contains Mn and Fe with high variable loadings on this factor and corresponds to group II of the cluster analysis. This association may be due to their common occurrence in the basic rock attributed to

Table 4: One-way ANOVA results for sites and heavy metal concentration variables (Dependant variables were log-normal transformed)

Source of variation	Dependent variables	SS	DF	MS	F	p
Sites	Pb	0.530	2	0.265	1.128	0.394
	Cd	0.063	2	0.031	0.349	0.721
	Cu	0.259	2	0.129	2.116	0.216
	Zn	0.051	2	0.026	1.568	0.296
	Mn	0.539	2	0.269	2.339	0.192
	Fe	1.029	2	0.515	4.584	0.074

DF-degree of freedom; F-factor mean square SS- Sum of Squares; MS- Mean Square; P = 0.05

Table 5: Mean heavy metal concentrations in water, sediment and algal biomass samples collected from Nakivubo Channel, Nakivubo tributaries and Wationdo stream (control)

Sites*	Water samples (µg/L)						Algal samples (mg/kg)						Sediment samples (mg/kg)					
	Pb	Cd	Cu	Zn	Mn	Fe	Pb	Cd	Cu	Zn	Mn	Fe	Pb	Cd	Cu	Zn	Mn	Fe
Nakivubo stream																		
US02	45	4	12	26	535	500	48.1	1.24	69.19	172.74	1072.25	47505.85	79.74	2.2	50.14	343	502.6	42664
US04	13	3	8	46	685	900	168.92	1.61	126.69	525.42	886.3	83075.05	239.91	1.14	55.98	397.75	443.47	57285.33
Mean	29	4	10	36	610	700	108.5	1.425	97.94	349.08	979.275	65290.5	159.8	1.7	53.1	370.4	473.03	49974.7
Tributaries																		
MT07	64	4	6	31	1915	2000	83.59	1.08	44.46	206.37	835.23	43368.95	84.26	1.01	33.26	310.96	1018.13	65685.33
MT10	63	3	16	49	155	250	61.98	2.07	69.06	220	723.79	38230.08	104.77	1.04	32.44	211.94	396.6	37164
MT13	75	13	18	32	475	1000	36.9	4.53	31.79	285.39	714.07	58578.41	103.91	1.07	35.05	540.93	502.6	47064
DT16	106	4	9	157	475	1250	482.01	4.35	55.6	1138.35	1063.92	27364.27	309.71	0.93	37.04	341.99	335	39564
Mean	77	6	12	67	755	1125	166.1	3.008	50.228	462.528	834.2525	41885.4	150.7	1	34.5	351.5	563.08	47369.3
Watindo stream																		
CT02	75	5	5	24	0.16	4300	30.84	1.56	15.29	105.7	1035.79	27417.61	32.73	1.1	12.91	50.87	1309.6	79264
CT03	50	2	11	22	0.17	4600	60.91	2.61	33.86	133.37	1017.99	68380.41	41.71	0.85	15.04	59.8	871.47	52485.33
Mean	63	3	8	23	160	4450	45.88	2.085	24.575	119.535	1026.89	47899	37.22	1	14	55.33	1090.5	65874.7
*Hyperaccumulation	-	-	-	-	-	-	1000	100	1000	10000	10000	-	-	-	-	-	-	-

*Normal threshold of elemental concentrations (Baker and Brook, 1989. For description of *sites refer to Table 1.

terriginous influence. The second factor accounts for 26.9 % of the variance and contains Pb, Cd, Cu and Zn as well as water pH with high variable loadings and corresponds to group I of cluster analysis. This may suggest the influence of vehicular and industrial emissions and water pH as the controlling factor, whereas the association of Cd and Zn may be due to their geochemistry.

Tables 8 (a) to 10 represent correlation coefficients for the data obtained for Nakivubo Channelized stream (US02 and US04), its tributaries namely Kayunga stream (MT07), Kitante stream (MT10), Lugogo stream (MT13) and Kibira Road stream (DT16), respectively, for possible paired elements. Table 8 (a) shows that elemental pairs Cd-s/Cu-a, Cu-s/Cu-a, Mn-s/Mn-a, Fe-s/Fe-a, Cu-w/Mn-a, Mn-w/Fe-a, Fe-w/Fe-a, Mn-w/Pb-s, Fe-w/Pb-s, Cu-s/Cd-s, Zn-s/Cu-s, Fe-s/Mn-s, Cu-w/Mn-s, Fe-w/Mn-w, Zn-w/pH and Zn-w/BOD are positively correlated with the same elements and each other. The rest of the elemental pairs were not significantly correlated with each other. In Table 8 (b), elemental pairs Pb-s/Pb-a, Zn-a/Cu-a, Mn-a/Zn-a, Fe-a/Cu-a, Fe-a/Zn-a, Fe-a/Mn-a, Fe-s/Zn-a, Mn-s/Mn-a, Fe-s/Mn-a, Fe-s/Fe-a, Zn-s/Pb-s, Fe-s/Pb-s, Pb-w/Cd-s, Pb-w/Cu-s, Mn-s/Zn-s, Fe-s/Zn-s, Fe-s/Mn-s Mn-w/Zn-a, Mn-w/Mn-a, Fe-w/Cu-a, Fe-w/Zna, Fe-w/Mn-a, Fe-w, Fe-a, Fe-a/BOD, Zn-s/BOD and Fe-w/Mn-w are positively correlated with the same elements and each other except Cu-a/Cd-a which was negatively correlated. The rest of the elemental pairs were not significantly correlated. Table 9 (a) shows that elemental pairs Cd-a/Pb-a, Cu-a/Cd-a, Zn-a/Cd-a, Pb-w/Pb-a, Mn-a/Zn-a, Fe-a/Zn-a, Fe-a/Mn-a, Cu-w/Cd-a, Cu-w/Zn-a, Cu-w/Fe-a, Mn-s/Cd-a, Fe-s/Cd-a, Mn-s/Zna, Fe-s/Zm-a, Pb-s/Cd-w, Cu-s/Cd-w, Zn-s/Cd-w, Mn-s/Pb-w, Fe-s/Pb-w, Mn-s/Cu-w, Fe-s/Cu-w, Fe-w/Mn-w, Cd-s/Pb-s, Cu-s/Pb-s, Cu-s/Cd-s, Fe-s/Mn-s, Zn-a/pH-w, Mn-a/pH-w, Fe-a/pH-w, Mn-a/EC and Fe-a/pH are positively correlated with the same elements and each other, except Cu-a/EC, Zn-a/DO, Mn-a/DO, Fe-a/DO, Mn-w/EC and Fe-w/EC which were negatively correlated. The rest of the elemental pairs were not significantly correlated. Elemental pairs in Table 9 (b) shows that Pb-s/Cd-a, Fe-a/Zn-a, Zn-s/Zna, Mn-s/Zn-a, Fe-s/Zn-a, Zn-s/Mn-a, Mn-s/Fe-a, Fe-s/Fe-a, Cd-w/Mn-a, Zn-w/Fe-a, Mn-s/Zn-s, Fe-s/Zn-s, Cd-w/Mn-a, Cd-w/Zn-s, Fe-s/Mn-s and Mn-w/Cd-w and Fe-w/Cd-w, as well as Mn-a/pH, Zn-s/pH, Cd-a/BOD and Pb-s/BOD are positively correlated with each other except Fe-w/Zn-w and Mn-a/DO which are negatively correlated. The rest of the pairs were not significantly correlated. Table 9 (c) shows that Cu-a/Cd-a, Zn-a/Cd-a, Zn-a/Cu-a, Mn-a/Cd-a, Mn-a/Zn-a, Fe-a/Zn-a, Fe-a/Mn-a, Fe-a/Mb-a, Zn-w/Mn-a, Fe-s/Fe-a, Zn-w/Fe-a, Cu-w/Pb-s, Fe-s/Zn-s, Zn-w/Zn-s, /Mn-w/Zn-s, Fe-w/Zn-s, Fe-s/Mn-s, Zn-w/Mn-s, Zn-w/Fe-s, Mn-w/Fe-s, Fe-w/Fe-s, Cd-w/Pb-w, Fe-w/Zn-w, Mn-w/Zn-w, Fe-w/Zn-w, Fe-w/Zn-w and, Pb-s/EC, Zn-w/EC, Cu-w/DO, Cu-s/DO, as well as Mn-w/Ec were positively correlated with each other, except Zn-s/EC, Fe-a/Temp, Pb-s/pH and Zn-w/Temp which were negatively correlated. The rest of the pairs were not significantly correlated. Table 9 (d) shows that Mn-a/Zn-a, Fe-a/Zn-a, Fe-a/Mn-a, Zn-s/Cu-a, Mn-s/Cd-a, Pb-w/Pb-a, Mn-w/Zn-a, Mn-w/Mn-a, Mn-w/Fe-a, Fe-w/Zn-a, Fe-w/Mn-a, Fe-w/Fe-a, Cu-w/Fe-s, Zn-w/Fe-s, Zn-w/Cu-w, Fe-w/Mn-w and Pb-a/Temp, Cu-a/EC, Cd-a/BOD, Cu-s/EC, Mn-s/BOD except Cd-s/Cd-a, Cd-s/BOD, Cu-s/EC and Mn-s/Temp, were negatively correlated. The rest of the pairs were not significantly correlated. Elemental and physico-chemical characteristic pairs in Table 10 shows that Cu-a/Pb-a, Pb-s/Pb-a, Cu-s/Pb-a, Pb-s/Cu-a, Fe-a/Mn-a, Cu-s/Pb-s, Zn-

Table 6: Bio-concentration Factor (BCF) values of heavy metals in algal biomass of Nakivubo stream, Tributaries and Watindo stream

Sites	Pb	Cd	Cu	Zn	Mn	Fe
Nakivubo Stream						
US02	1068.89	283.43	5826.53	6741.07	2004.21	95011.70
US04	12669.00	483.00	15836.25	11422.17	1293.87	92305.61
Mean	6868.95	383.23	10831.39	9081.62	1649.04	93658.66
Tributaries						
MT07	1300.29	252.00	6916.00	6566.32	436.15	21684.48
MT10	991.68	662.40	4419.84	4512.82	4669.61	152920.32
MT13	492.00	362.40	1816.57	8953.41	1503.31	58578.41
DT16	4536.56	994.29	6354.29	7256.41	2239.83	21891.42
Mean	1830.13	567.77	4876.68	6822.24	2212.23	63768.66
Watindo stream						
CT02	411.20	312.00	3058.00	4450.53	6682.52	6376.19
CT03	1218.20	1392.00	3186.82	6096.91	6169.64	14865.31
Mean	814.70	852.00	3122.41	5273.72	6426.08	10620.75

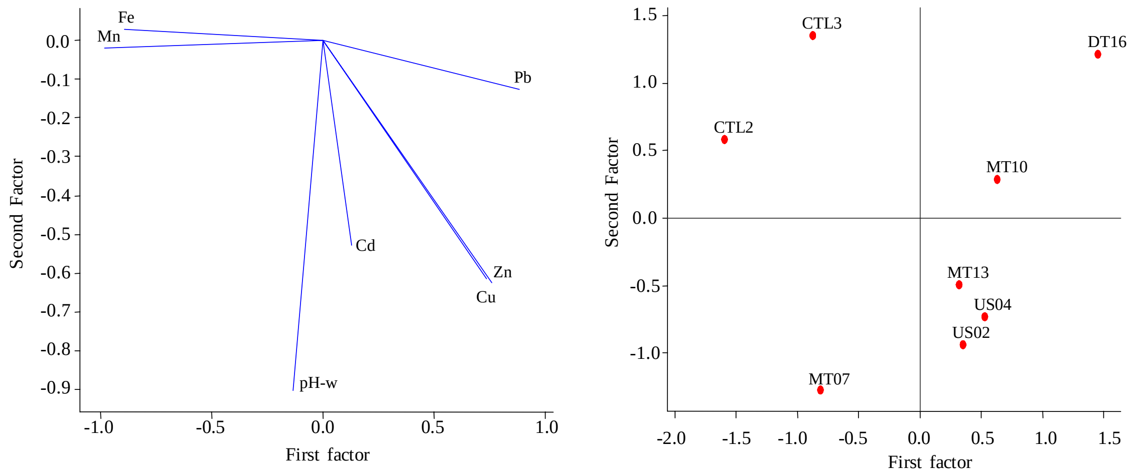

Fig. 2: Biplot of sites (a) along streams and elemental concentrations (b) of algal biomass

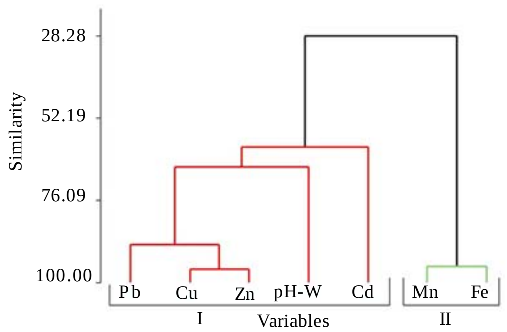

Fig. 3: Dendrogram of elemental concentrations in algal biomass and water pH of Nakivubo Channelized and Watindo streams

Table 7: Varimax rotated Factor Loadings and Communalities of elements in algal biomass and water pH in Nakivubo Channelized and Watindo streams

Variables	Factor 1	Factor 2	Communality
Pb	0.885	-0.126	0.800
Cd	0.131	-0.530	0.298
Cu	0.759	-0.624	0.965
Zn	0.736	-0.615	0.920
Mn	-0.985	-0.020	0.971
Fe	-0.897	0.027	0.806
pH-w	-0.134	-0.902	0.832
Variance	3.7112	1.8807	5.5919
% Var.	0.530	0.269	0.799

s/Pb-s Zn-s/Cu-s, Pb-w/Cu-s, Fe-s/Mn-s, Cu-w/Fe-s, Zn-w/Cd-w, Mn-w/Cd-w, Fe-w/Mn-a, Fe-w/Fe-a and Zn-a/pH, Cd-w/pH, Mn-a/BOD, as well as Fe-a/BOD are positively correlated with the same elements and each other. The rest of the pairs were not significantly correlated.

High correlation between Cd-s/Cu-a and Cu-s/Cu-a (Table 9 a) at site US02 suggests that the Car washing Bay and Kivuro slum establishment contribute to high Cd and Cu levels in stream sediments (Nyangababo and Ichikuni, 1986). Correlation coefficients between Pb-s/Pb-a, Fe-a/Cu-a, Zn-a/Cu-a, Fe-w/Cu-a, Mn-w/Zn-a, Fe-w/Zn-a and Fe-a/Zn-a at site US04 indicate that vehicular emission contributes to high Pb, Cu and Zn levels in the environment. Petrol combustion products contain lead and copper, whereas zinc may be a constituent of parts of vehicle engines. The high correlation of Fe-a/Mn-a in algal biomass (Table 8 a and b, 9 a,b and d) possibly suggests their essentiality for algal growth. The negative correlation coefficients between Cu-a/Cd-a possibly suggests inhibition of uptake or adsorption of Cd by algae in preference for Cu as an essential element. The correlation of Cd-a/Pb-a, Cu-a/Cd-a, Zn-a/Cd-a, Pbw/Pb-a, Cu-w/Cd-a, Mn-a/Zn-a, Fe-a/Zn-a, Fe-a/Mn-a, Cu-w/Zn-a and Cu-w/Fe-a along the Kayunga tributary may signify that each paired elements originate from identical source (Table 9 a). However, high correlation between these metal pairs possibly suggest that solid waste dumping along the sides of the tributary and vehicle traffic contribute to addition of Cu, Cd, Pb and Zn in the environment (stream water, sediments and algal biota). Elemental pairs along Kitante tributary (Table 9 b) indicate high correlation of Pb-s/Cd-a, Fe-a/Zn-a, Zn-s/Zn-a, Mn-s/Zn-a and Fe-s/Zn-a in sediments. This suggests that hotels, residential establishment and vehicle traffic

Table 8 (a): Correlation coefficients for the relationship between possible metal pair combinations in algae samples from site US02

	Pb-a	Cd-a	Cu-a	Zn-a	Mn-a	Fe-a	Pb-s	Cd-s	Cu-s	Zn-s	Mn-s	Fe-s	Pb-w	Cd-w	Cu-w	Zn-w	Mn-w	Fe-w	Temp	pH	EC	DO	BOD
Pb-a	1.000																						
Cd-a	0.447	1.000																					
Cu-a	0.037	-0.086	1.000																				
Zn-a	-0.019	0.506	0.639	1.000																			
Mn-a	-0.123	0.681	-0.274	0.548	1.000																		
Fe-a	0.157	0.631	-0.254	0.327	0.520	1.000																	
Pb-s	0.126	0.345	0.216	0.306	-0.034	0.760	1.000																
Cd-s	-0.003	-0.038	0.995**	0.664	-0.239	-0.218	0.257	1.000															
Cu-s	0.082	0.086	0.934**	0.692	-0.203	0.079	0.547	0.946**	1.000														
Zn-s	0.139	0.406	0.694	0.789	0.123	0.516	0.779	0.722	0.891*	1.000													
Mn-s	-0.077	0.726	-0.292	0.549	0.985**	0.658	0.121	-0.254	-0.163	0.211	1.000												
Fe-s	0.079	0.725	-0.292	0.444	0.751	0.955**	0.576	-0.252	-0.009	0.442	0.852*	1.000											
Pb-w	-0.608	0.057	-0.525	0.053	0.582	0.570	0.191	-0.491	-0.365	-0.053	0.626	0.643	1.000										
Cd-w	-0.460	-0.248	-0.413	-0.585	-0.323	0.059	0.258	-0.357	-0.288	-0.261	-0.273	-0.066	0.313	1.000									
Cu-w	-0.212	0.505	-0.203	0.488	0.924**	0.154	-0.380	-0.179	-0.271	-0.089	0.846*	0.441	0.418	-0.400	1.000								
Zn-w	0.745	0.357	-0.582	-0.358	0.166	0.163	-0.249	-0.626	-0.579	-0.417	0.179	0.184	-0.156	-0.299	0.120	1.000							
Mn-w	0.231	0.447	-0.180	0.152	0.190	0.937**	0.887*	-0.153	0.174	0.543	0.354	0.791	0.418	0.200	-0.200	0.120	1.000						
Fe-w	0.231	0.447	-0.180	0.152	0.190	0.937**	0.887*	-0.153	0.174	0.543	0.354	0.791	0.418	0.200	-0.200	0.120	1.000**	1.000					
Temp	-0.181	0.006	-0.354	0.067	0.327	0.729	0.455	-0.362	-0.128	0.193	0.434	0.678	0.786	0.052	0.052	0.055	0.705	0.705	1.000				
pH	0.689	0.039	-0.444	-0.637	-0.282	-0.289	-0.426	-0.489	-0.545	-0.607	-0.306	-0.322	-0.509	-0.079	-0.197	0.843*	-0.217	-0.217	-0.364	1.000			
EC	0.804	0.239	0.528	0.159	-0.450	0.039	0.402	0.505	0.591	0.505	-0.389	-0.126	-0.778	-0.319	-0.538	0.213	0.229	0.229	-0.317	0.323	1.000		
DO	-0.208	-0.578	-0.711	-0.787	-0.242	-0.043	-0.236	-0.751	-0.715	-0.681	-0.222	-0.118	0.421	0.392	-0.261	0.294	0.049	0.049	0.486	0.301	-0.464	1.000	
BOD	0.581	0.416	-0.410	-0.095	0.400	-0.081	-0.567	-0.447	-0.535	-0.452	0.337	0.077	-0.210	-0.532	0.499	0.861*	-0.256	-0.256	-0.207	0.719	0.045	0.025	1.000

*Correlation is significant at the 0.05 level (2-tailed); **Correlation is significant at the 0.01 level (2-tailed); w-water; a-algae; s-sediment; EC-electric conductivity; DO-dissolved oxygen; Temp-temperature; BOD-biological oxygen demand

Table 8 (b): Correlation coefficients for the relationship between possible metal pair combinations in algae samples from site US04

	Pb-a	Cd-a	Cu-a	Zn-a	Mn-a	Fe-a	Pb-s	Cd-s	Cu-s	Zn-s	Mn-s	Fe-s	Pb-w	Cd-w	Cu-w	Zn-w	Mn-w	Fe-w	Temp	pH	EC	DO	BOD
Pb-a	1.000																						
Cd-a	-0.060	1.000																					
Cu-a	-0.197	**-0.681***	1.000																				
Zn-a	-0.469	-0.399	0.680*	1.000																			
Mn-a	-0.424	-0.244	0.448	0.837**	1.000																		
Fe-a	-0.479	-0.349	0.612*	0.949**	0.960**	1.000																	
Pb-s	0.599*	-0.064	-0.146	-0.083	0.184	0.044	1.000																
Cd-s	0.045	-0.289	0.071	0.013	-0.039	-0.007	0.187	1.000															
Cu-s	0.098	-0.420	0.181	0.030	-0.126	-0.027	-0.174	0.237	1.000														
Zn-s	0.421	-0.123	-0.040	0.097	0.362	0.222	0.921**	0.303	-0.061	1.000													
Mn-s	0.083	-0.196	0.147	0.449	0.573*	0.491	0.478	0.306	0.068	0.756**	1.000												
Fe-s	0.080	-0.290	0.271	0.576*	0.725**	0.650*	0.616*	0.250	0.003	0.831**	0.943**	1.000											
Pb-w	0.013	-0.298	-0.103	-0.153	-0.251	-0.183	-0.111	0.558*	0.660**	-0.136	-0.228	-0.231	1.000										
Cd-w	-0.155	0.257	-0.445	-0.100	-0.105	-0.159	-0.172	0.039	-0.114	-0.097	0.131	-0.033	0.178	1.000									
Cu-w	-0.045	-0.049	-0.177	-0.320	-0.324	-0.315	-0.310	-0.397	0.004	-0.490	-0.527	-0.535	-0.079	-0.123	1.000								
Zn-w	-0.014	0.528	-0.129	-0.037	-0.283	-0.195	-0.415	-0.190	-0.454	-0.518	-0.348	-0.430	-0.276	0.287	0.000	1.000							
Mn-w	-0.514	-0.378	0.529	0.843**	0.872**	0.894**	-0.125	-0.209	-0.138	-0.001	0.281	0.433	-0.172	0.031	-0.176	-0.114	1.000						
Fe-w	-0.520	-0.397	0.585*	0.898**	0.896**	0.936**	-0.109	-0.161	-0.098	0.026	0.314	0.473	-0.164	-0.025	-0.207	-0.119	0.993**	1.000					
Temp	0.103	-0.546	0.347	0.213	0.162	0.181	0.194	-0.096	0.410	0.358	0.504	0.464	-0.156	-0.053	0.134	-0.565	0.096	0.119	1.000				
pH	0.323	0.047	-0.374	-0.259	-0.455	-0.387	-0.060	-0.007	-0.038	-0.285	-0.373	-0.385	0.132	-0.036	0.528	0.356	-0.330	-0.333	-0.219	1.000			
EC	-0.336	0.231	-0.217	0.246	0.378	0.311	0.186	-0.138	0.096	0.331	0.309	0.359	0.068	0.169	-0.485	-0.349	0.265	0.267	0.057	-0.401	1.000		
DO	-0.154	0.367	0.033	-0.172	-0.523	-0.361	-0.486	0.087	0.098	-0.504	-0.446	-0.543	0.179	0.098	-0.179	0.560*	-0.429	-0.391	-0.354	-0.021	-0.059	1.000	
BOD	0.510	0.028	-0.271	-0.289	-0.038	-0.175	0.848**	-0.064	-0.327	0.695**	0.154	0.301	-0.240	-0.310	-0.078	-0.390	-0.231	-0.241	0.118	0.091	0.233	-0.423	1.000

*Correlation is significant at the 0.05 level (2-tailed); **Correlation is significant at the 0.01 level (2-tailed); w-water; a-algae; s-sediment; EC-electric conductivity; DO-dissolved oxygen; Temp-temperature; BOD-biological oxygen demand

Table 9 (a): Correlation coefficients for the relationship between possible metal pair combinations in algae samples from site MT07

	Pba	Cda	Cua	Zna	Mna	Fea	Pbw	Cdw	Cuw	Znw	Mnw	Few	Pbs	Cds	Cus	Zns	Mns	Fes	Temp	pHw	EC	DO	BOD
Pba	1.000																						
Cda	0.589*	1.000																					
Cua	0.040	0.594*	1.000																				
Zna	0.471	0.545*	0.257	1.000																			
Mna	0.016	0.190	-0.135	0.652**	1.000																		
Fea	0.182	0.258	-0.092	0.812**	0.939**	1.000																	
Pbw	0.713**	0.380	-0.150	0.185	-0.222	-0.098	1.000																
Cdw	0.333	0.274	-0.087	0.032	-0.090	-0.056	0.502	1.000															
Cuw	0.385	0.565*	-0.009	0.668**	0.473	0.582*	0.469	0.146	1.000														
Znw	-0.077	0.159	0.086	0.171	0.133	0.249	-0.015	0.184	0.111	1.000													
Mnw	-0.037	0.168	-0.070	0.075	0.487	0.425	-0.364	0.015	-0.087	0.331	1.000												
Few	-0.048	0.111	-0.079	0.058	0.413	0.393	-0.342	-0.064	-0.136	0.435	0.967**	1.000											
Pbs	0.452	0.416	0.042	-0.079	0.008	-0.129	0.285	0.571*	-0.054	-0.217	0.262	0.095	1.000										
Cds	0.425	0.214	-0.258	-0.018	-0.060	-0.153	0.303	0.369	0.090	-0.435	-0.020	-0.160	0.738**	1.000									
Cus	0.332	0.281	0.031	-0.129	-0.217	-0.333	0.350	0.560*	-0.139	-0.461	-0.069	-0.170	0.760**	0.756**	1.000								
Zns	-0.085	0.162	0.015	0.056	-0.059	-0.077	0.349	0.615*	0.194	0.000	-0.223	-0.223	0.072	0.109	0.518	1.000							
Mns	0.518	0.633**	0.148	0.713	0.218	0.414	0.552*	0.167	0.859**	0.052	-0.151	-0.142	-0.104	0.144	0.040	0.334	1.000						
Fes	0.477	0.628**	0.133	0.704**	0.255	0.423	0.544*	0.136	0.871**	0.030	-0.158	-0.149	-0.109	0.150	0.057	0.368	0.993**	1.000					
Temp	-0.486	-0.605*	-0.493	-0.398	0.048	-0.152	-0.423	-0.180	-0.466	-0.410	0.047	0.012	0.011	0.272	0.300	0.141	-0.474	-0.428	1.000				
pHw	-0.347	-0.275	-0.183	-0.676**	-0.556*	-0.685**	-0.011	-0.131	-0.253	-0.023	-0.355	-0.314	0.000	0.237	0.133	0.013	-0.300	-0.259	0.304	1.000			
EC	-0.010	-0.233	-0.591*	0.265	0.679**	0.691**	-0.238	0.089	0.104	0.373	0.628*	0.626*	-0.043	-0.036	-0.290	-0.171	-0.082	-0.090	0.202	-0.376	1.000		
DO	-0.127	-0.165	0.119	-0.551*	-0.596*	-0.592*	0.160	0.266	-0.330	-0.200	-0.329	-0.270	-0.028	-0.256	0.238	0.366	-0.243	-0.253	0.010	0.224	-0.456	1.000	
BOD	-0.002	0.257	0.171	0.087	0.212	0.087	-0.054	0.046	0.054	-0.044	0.356	0.188	0.483	0.304	0.150	-0.160	-0.038	-0.040	-0.027	-0.188	-0.036	-0.517	1.000

*Correlation is significant at the 0.05 level (2-tailed); **Correlation is significant at the 0.01 level (2-tailed); w-water; a-algae; s-sediment; EC-electric conductivity; DO-dissolved oxygen; Temp-temperature; BOD-biological oxygen demand

Table 9 (b): Correlation coefficients for the relationship between possible metal pair combinations in algae samples from sited MT10

	Pba	Cda	Cua	Zna	Mna	Fea	Pbw	Cdw	Cuw	Znw	Mnw	Few	Pbs	Cds	Cus	Zns	Mns	Fes	Temp	pHw	EC	DO	BOD
Pba	1.000																						
Cda	0.589*	1.000																					
Cua	0.040	0.594*	1.000																				
Zna	0.471	0.545*	0.257	1.000																			
Mna	0.016	0.190	-0.135	0.652**	1.000																		
Fea	0.182	0.258	-0.092	0.812**	0.939**	1.000																	
Pbw	0.713**	0.380	-0.150	0.185	-0.222	-0.098	1.000																
Cdw	0.333	0.274	-0.087	0.032	-0.090	-0.056	0.502	1.000															
Cuw	0.385	0.565*	-0.009	0.668**	0.473	0.582*	0.469	0.146	1.000														
Znw	-0.077	0.159	0.086	0.171	0.133	0.249	-0.015	0.184	0.111	1.000													
Mnw	-0.037	0.168	-0.070	0.075	0.487	0.425	-0.364	0.015	-0.087	0.331	1.000												
Few	-0.048	0.111	-0.079	0.058	0.413	0.393	-0.342	-0.064	-0.136	0.435	0.967**	1.000											
Pbs	0.452	0.416	0.042	-0.079	0.008	-0.129	0.285	0.571*	-0.054	-0.217	0.262	0.095	1.000										
Cds	0.425	0.214	-0.258	-0.018	-0.060	-0.153	0.303	0.369	0.090	-0.435	-0.020	-0.160	0.738**	1.000									
Cus	0.332	0.281	0.031	-0.129	-0.217	-0.333	0.350	0.560*	-0.139	-0.461	-0.069	-0.170	0.760**	0.756**	1.000								
Zns	-0.085	0.162	0.015	0.056	-0.059	-0.077	0.349	0.615*	0.194	0.000	-0.223	-0.223	0.072	0.109	0.518	1.000							
Mns	0.518	0.633**	0.148	0.713	0.218	0.414	0.552*	0.167	0.859**	0.052	-0.151	-0.142	-0.104	0.144	0.040	0.334	1.000						
Fes	0.477	0.628**	0.133	0.704**	0.255	0.423	0.544*	0.136	0.871**	0.030	-0.158	-0.149	-0.109	0.150	0.057	0.368	0.993**	1.000					
Temp	-0.486	-0.605*	-0.493	-0.398	0.048	-0.152	-0.423	-0.180	-0.466	-0.410	0.047	0.012	0.011	0.272	0.300	0.141	-0.474	-0.428	1.000				
pHw	-0.347	-0.275	-0.183	-0.676**	-0.556*	-0.685**	-0.011	-0.131	-0.253	-0.023	-0.355	-0.314	0.000	0.237	0.133	0.013	-0.300	-0.259	0.304	1.000			
EC	-0.010	-0.233	-0.591*	0.265	0.679**	0.691**	-0.238	0.089	0.104	0.373	0.628*	0.626*	-0.043	-0.036	-0.290	-0.171	-0.082	-0.090	0.202	-0.376	1.000		
DO	-0.127	-0.165	0.119	-0.551*	-0.596*	-0.592*	0.160	0.266	-0.330	-0.200	-0.329	-0.270	-0.028	-0.256	0.238	0.366	-0.243	-0.253	0.010	0.224	-0.456	1.000	
BOD	-0.002	0.257	0.171	0.087	0.212	0.087	-0.054	0.046	0.054	-0.044	0.356	0.188	0.483	0.304	0.150	-0.160	-0.038	-0.040	-0.027	-0.188	-0.036	-0.517	1.000

*Correlation is significant at the 0.05 level (2-tailed); **Correlation is significant at the 0.01 level (2-tailed); w-water; a-algae; s-sediment; EC-electric conductivity; DO-dissolved oxygen; Temp-temperature; BOD-biological oxygen demand

Table 9 (c): Correlation coefficients for the relationship between possible metal pair combinations in algae samples from sited MT13

	Pb-a	Cd-a	Cu-a	Zn-a	Mn-a	Fe-a	Pb-s	Cd-s	Cu-s	Zn-s	Mn-s	Fe-s	Pb-w	Cd-w	Cu-w	Zn-w	Mn-w	Fe-w	Temp	pH	EC	DO
Pb-a	1.000																					
Cd-a	-0.032	1.000																				
Cu-a	-0.103	0.942**	1.000																			
Zn-a	0.363	0.839**	0.719*	1.000																		
Mn-a	0.220	0.771*	0.603	0.958**	1.000																	
Fe-a	0.324	0.566	0.366	0.880**	0.960**	1.000																
Pb-s	-0.313	-0.469	-0.611	-0.424	-0.231	-0.103	1.000															
Cd-s	0.181	0.597	0.628	0.416	0.277	0.095	-0.421	1.000														
Cu-s	-0.075	0.113	0.128	0.034	0.083	0.064	-0.020	0.532	1.000													
Zn-s	0.574	-0.128	-0.337	0.323	0.419	0.627	0.262	-0.294	0.131	1.000												
Mn-s	0.356	0.390	0.201	0.627	0.667	0.719*	-0.368	-0.176	-0.187	0.531	1.000											
Fe-s	0.473	0.269	0.045	0.643	0.721*	0.841**	-0.144	-0.218	-0.074	0.788*	0.929**	1.000										
Pb-w	0.030	-0.087	-0.083	-0.212	-0.275	-0.288	-0.437	-0.288	-0.340	-0.157	0.453	0.167	1.000									
Cd-w	-0.185	-0.063	-0.075	-0.269	-0.296	-0.331	-0.258	-0.386	-0.446	-0.247	0.375	0.079	0.956**	1.000								
Cu-w	-0.582	-0.177	-0.294	-0.424	-0.294	-0.305	0.784*	-0.337	-0.252	-0.169	-0.319	-0.316	-0.051	0.213	1.000							
Zn-w	0.585	0.235	0.017	0.701	0.765*	0.897**	-0.012	-0.126	-0.161	0.783*	0.730*	0.895**	-0.181	-0.262	-0.319	1.000						
Mn-w	0.586	-0.175	-0.376	0.283	0.377	0.592	0.270	-0.306	0.132	0.999**	0.506	0.767*	-0.152	-0.247	-0.174	0.765*	1.000					
Fe-w	0.401	-0.190	-0.380	0.319	0.475	0.700	0.257	-0.429	-0.055	0.841**	0.555	0.787*	-0.213	-0.285	-0.214	0.867**	0.839**	1.000				
Temp	-0.285	-0.285	-0.225	-0.658	-0.693	-0.755*	0.177	0.222	0.410	-0.369	-0.530	-0.614	0.241	0.266	0.375	-0.788*	-0.348	-0.665	1.000			
Water	0.484	-0.048	0.141	0.067	-0.135	-0.140	-0.781*	-0.056	-0.275	-0.069	0.233	0.094	0.502	0.321	-0.714	0.002	-0.055	-0.102	-0.195	1.000		
EC	0.014	-0.446	-0.583	-0.214	-0.043	0.159	0.710*	-0.617	0.096	0.729*	0.066	0.323	-0.207	-0.139	0.374	0.277	0.736*	0.551	-0.002	-0.355	1.000	
DO	-0.356	0.152	0.030	-0.041	-0.027	-0.100	0.267	-0.343	-0.762*	-0.260	0.141	-0.034	0.340	0.571	0.721*	-0.055	-0.277	-0.220	-0.012	-0.248	-0.049	1.000

*Correlation is significant at the 0.05 level (2-tailed); **Correlation is significant at the 0.01 level (2-tailed); w-water; a-algae; s-sediment; EC-electric conductivity; DO-dissolved oxygen; Temp-temperature; BOD-biological oxygen demand

Table 9 (d): Correlation coefficients for the relationship between possible metal pair combinations in algae samples from sited DT16

	Pb-a	Cd-a	Cu-a	Zn-a	Mn-a	Fe-a	Pb-s	Cd-s	Cu-s	Zn-s	Mn-s	Fe-s	Pb-w	Cd-w	Cu-w	Zn-w	Mn-w	Fe-w	Temp	pH	EC	DO
Pb-a	1																					
Cd-a	-0.821	1.000																				
Cu-a	0.250	-0.748	1.000																			
Zn-a	-0.191	-0.403	0.897	1.000																		
Mn-a	-0.325	-0.247	0.828	0.965*	1.000																	
Fe-a	-0.325	-0.247	0.828	0.965*	1.000**	1.000																
Pb-s	0.584	-0.758	0.732	0.419	0.440	0.440	1.000															
Cd-s	0.768	-0.996**	0.805	0.482	0.333	0.333	0.779	1.000														
Cu-s	-0.578	0.896	-0.911	-0.641	-0.578	-0.578	-0.924	-0.926	1.000													
Zn-s	0.109	-0.656	0.957*	0.945	0.837	0.837	0.507	0.716	-0.773	1.000												
Mn-s	-0.918	0.968*	-0.610	-0.203	-0.077	-0.077	-0.803	-0.949	0.852	-0.464	1.000											
Fe-s	0.402	-0.292	-0.135	-0.216	-0.460	-0.460	-0.390	0.241	0.135	0.036	-0.226	1.000										
Pb-w	0.947*	-0.649	-0.020	-0.419	-0.577	-0.577	0.293	0.577	-0.301	-0.105	-0.755	0.607	1.000									
Cd-w	0.688	-0.375	-0.023	-0.405	-0.333	-0.333	0.657	0.333	-0.376	-0.297	-0.590	-0.290	0.577	1.000								
Cu-w	0.405	-0.375	0.000	-0.079	-0.333	-0.333	-0.318	0.333	0.028	0.176	-0.282	0.990**	0.577	-0.333	1.000							
Zn-w	0.350	-0.403	0.107	0.056	-0.202	-0.202	-0.290	0.373	-0.033	0.296	-0.279	0.963*	0.498	-0.415	0.990**	1.000						
Mn-w	-0.325	-0.247	0.828	0.965*	1.000**	1.000**	0.440	0.333	-0.578	0.837	-0.077	-0.460	-0.577	-0.333	-0.333	-0.202	1.000					
Fe-w	-0.325	-0.247	0.828	0.965*	1.000**	1.000**	0.440	0.333	-0.578	0.837	-0.077	-0.460	-0.577	-0.333	-0.333	-0.202	1.000**	1.000				
Temp	0.982*	-0.900	0.419	-0.019	-0.144	-0.144	0.715	0.862	-0.722	0.263	-0.975*	0.297	0.871	0.682	0.323	0.290	-0.144	-0.144	1.000			
pH	0.149	-0.364	0.272	0.314	0.070	0.070	-0.285	0.361	-0.088	0.494	-0.181	0.847	0.252	-0.614	0.906	0.955	0.070	0.070	0.131	1.000		
EC	0.518	-0.891	0.953*	0.721	0.641	0.641	0.867	0.927	-0.991**	0.849	-0.815	-0.081	0.248	0.250	0.036	0.111	0.641	0.641	0.667	0.194	1.000	
DO	0.903	-0.698	0.234	-0.211	-0.236	-0.236	0.765	0.657	-0.613	-0.004	-0.855	-0.019	0.774	0.919	-0.026	-0.086	-0.236	-0.236	0.914	-0.276	0.515	1.000

*Correlation is significant at the 0.05 level (2-tailed); **Correlation is significant at the 0.01 level (2-tailed); w-water; a-algae; s-sediment; EC-electric conductivity; DO-dissolved oxygen; Temp-temperature; BOD-biological oxygen demand

Table 10: Correlation coefficients for the relationship between possible metal pair combinations in algae samples from sited CT03

	Pb-a	Cd-a	Cu-a	Zn-a	Mn-a	Fe-a	Pb-s	Cd-s	Cu-s	Zn-s	Mn-s	Fe-s	Pb-w	Cd-w	Cu-w	Zn-w	Mn-w	Fe-w	Temp	pH	EC	DO
Pb-a	1.000																					
Cd-a	-0.157	1.000																				
Cu-a	0.947*	0.050	1.000																			
Zn-a	0.658	-0.194	0.730	1.000																		
Mn-a	-0.307	-0.199	-0.297	0.409	1.000																	
Fe-a	-0.335	-0.312	-0.380	0.317	0.984**	1.000																
Pb-s	0.977*	-0.324	0.917*	0.673	-0.300	-0.318	1.000															
Cd-s	-0.648	0.534	-0.549	-0.171	0.629	0.585	-0.761	1.000														
Cu-s	0.896*	-0.471	0.815	0.544	-0.401	-0.394	0.965**	-0.899**	1.000													
Zn-s	0.855	-0.639	0.718	0.673	-0.061	-0.032	0.923*	-0.737	0.925*	1.000												
Mn-s	0.301	-0.854	0.017	0.215	0.281	0.414	0.374	-0.350	0.419	0.676	1.000											
Fe-s	0.394	-0.813	0.164	0.474	0.448	0.540	0.462	-0.283	0.458	0.750	0.957**	1.000										
Pb-w	0.607	-0.752	0.455	0.250	-0.399	-0.328	0.743	-0.956**	0.886*	0.830	0.587	0.533	1.000									
Cd-w	-0.303	-0.667	-0.567	-0.231	0.458	0.611	-0.248	0.119	-0.181	0.110	0.805	0.695	0.134	1.000								
Cu-w	0.446	-0.598	0.344	0.793	0.655	0.667	0.492	-0.097	0.411	0.712	0.713	0.885*	0.327	0.408	1.000							
Zn-w	-0.428	-0.765	-0.571	-0.014	0.639	0.738	-0.294	0.108	-0.183	0.089	0.639	0.619	0.161	0.829*	0.492	1.000						
Mn-w	-0.320	-0.651	-0.568	-0.173	0.543	0.686	-0.267	0.182	-0.216	0.097	0.791	0.706	0.082	0.995**	0.458	0.854	1.000					
Fe-w	-0.338	-0.330	-0.393	0.301	0.978**	1.000**	-0.320	0.575	-0.391	-0.027	0.434	0.554	-0.315	0.634	0.666	0.752	0.708	1.000				
Temp	-0.121	-0.364	-0.216	0.413	0.937*	0.966**	-0.124	0.478	-0.227	0.157	0.562	0.689	-0.214	0.648	0.786	0.673	0.716	0.968**	1.000			
pH	0.399	-0.429	0.439	0.923*	0.641	0.581	0.466	-0.077	0.390	0.601	0.369	0.613	0.244	0.051	0.891*	0.360	0.119	0.569	0.624	1.000		
EC	0.194	-0.468	-0.055	-0.485	-0.629	-0.482	0.248	-0.660	0.408	0.320	0.496	0.252	0.655	0.386	-0.198	0.071	0.295	-0.456	-0.377	-0.491	1.000	
DO	-0.246	-0.134	-0.064	0.665	0.882	0.787	-0.162	0.403	-0.207	-0.022	-0.061	0.209	-0.254	-0.005	0.666	0.458	0.089	0.768	0.756	0.828	-0.813	1.000
BOD	-0.165	-0.172	-0.010	0.656	0.932*	0.932*	-0.106	0.399	-0.178	0.025	-0.037	0.305	-0.253	.0.000	0.635	0.779	0.932	0.932*	0.841	0.811	-0.883	1.000**

*Correlation is significant at the 0.05 level (2-tailed); **Correlation is significant at the 0.01 level (2-tailed); w-water; a-algae; s-sediment; EC-electric conductivity; DO-dissolved oxygen; Temp-temperature; BOD-biological oxygen demand

contribute Pb, Cd and Zn to the environment. Also, high correlation of elemental pairs along the Lugogo tributary of Cu-a/Cd-a, Zn-s/Cd-a, Zn-a/Cu-a, Mn-a/Cd-a, Mn-a/Zn-a, Fe-a/Zn-a, Fe-a/Mn-a, Fe-s/Mn-a, Zn-w/Fe-a, and Zn-w/Mn-a indicates that petro stations, washing bays and vehicle traffic introduce high amounts of Cu, Cd and Zn to the environment. Referring to Table 9 (c), high correlations of Cd-s/Cd-a, Mn-s/Cd-a, Pb-w/Pba, Zn-s/Cu-a, Mn-a/Zn-a, Fe-a/Zn-a, Fe-a/Mn-a, Mn-w/Zn-a, Fe-w/Zn-a, Mn-w/Mn-a, Fe-w/Fe-a and Mn-w/Fe-a along the Kibira Road tributary were noted. This may indicate that industries contribute high levels of Cd, Zn, Cu and Pb, since wastewater effluents from batteries (Uganda Batteries LTD), plastic (Uganda House of Plastics LTD) and Iron sheet (galvanised) (Uganda Baati LTD) factories contain these elements. Very high elemental pairs of Cu-a/Pb-a, Pb-s/Pb-a, Cu-s/Pb-a, Pb-s/Cu-a and Fe-a/Mn-a (Table 9 d) may be explained by the contribution from atmospheric deposition and/or geochemistry of the sediments (Chakravarty and Patgiri, 2009; Sekabira *et al*., 2010). Water pH was negatively correlated with heavy metal concentration in algal biomass, whereas it was positively correlated in Watindo stream, suggesting its influence on the adsorption and uptake of heavy metals.

CONCLUSION

This study indicates that the Nakivubo ecosystem is actively accumulating heavy metals in the environment and that algae have the potential to accumulate Pb, Cd, Cu, and Zn.

Algae can thus be used in bio-monitoring of heavy metal pollution in urban stream water since it can be used in quantification of pollutants. Concentrations of heavy metals in algal biomass reflect metal load in the stream water. Algae can therefore be used in the phytoextraction process of heavy metals in aquatic urban stream water and wastewater effluents.

Significant correlations of heavy metal concentrations in algal biomass with stream water and sediments and the ability to accumulate these heavy metals also strengthen algae as good bio-monitor of Pb, Cd, Cu and Zn.

Bio-concentration factor (BCF) of heavy metals in algal biota was found in decreasing order of Fe >Cu > Zn > Pb > Mn > Cd in the Nakivubo Channelized stream.

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