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Full Length Research Paper

Heavy metal phytoremediation by *Commelina benghalensis* (L) and *Cynodon dactylon* (L) growing in Urban stream sediments

K. Sekabira[1]*, H. Oryem–Origa[2], G. Mutumba[2], E. Kakudidi[2] and T. A. Basamba[3]

[1]Department of Environment, School of Engineering and Applied Sciences, Kampala International University, Kampala, Uganda.
[2]Department of Biology, School of Biological Sciences, Makerere University, P. O. Box 7062, Kampala, Uganda.
[3]Soil Science Department of Agricultural Production, College of Agricultural and Environmental Sciences, Makerere University, Kampala, Uganda.

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Urbanisation and industrialization lead to heavy metal pollution in the Nakivubo drainage ecosystem. The objectives of this study were to determine heavy metal concentrations and distribution in *Commelina benghalensis* (L.) and *Cynodon dactylon* (L.) that grows in different polluted sites along the urban stream sediments of the Nakivubo drainage ecosystem in Kampala, Uganda. To investigate the possibility of using these plant species in phytoextraction and phytostabilisation of heavy metal pollutants, assessment of heavy metals was done using flame atomic absorption spectrophotometer. Bioaccumulation factor and translocation factor values (BAF and TF > 1) for both plant species were greater than one for Cu at some sites suggesting efficient accumulation in the shoot. BAF > 1 and TF < 1 values for Pb, Cd and Zn suggest accumulation in roots and qualify these plants also as good candidates for phytostabilisation. In conclusion, the heavy metal sequestration from urban stream sediments by plant parts that are harvestable are characterized and recommended as good candidates for phytoremediation (phytoextraction and phytostabilisation) and can be used as indicators of heavy metal pollution for the urban stream ecosystem.

Key words: Bioaccumulation, heavy metals, phytostabilisation, translocation, wastewater.

INTRODUCTION

Environmental heavy metal pollution is mainly of anthropogenic origin and results from activities such as fossil fuels, vehicular emissions, industrial emissions, landfill leachates, fertilizers, sewage and municipal wastes (Nyangababo et al., 2005a; Nyangababo et al., 2005b; Bu-Olayan and Thomas, 2009; Sekabira et al., 2010; Kord et al., 2010). Heavy metal deposition in plants has been used for biomonitoring of environmental quality (Nyangababo and Ichikuni, 1986; Chmielewska and Medved, 2001; Nabulo et al., 2008; Agunbiade and Fawale, 2009; Akguc et al., 2010; Kord et al., 2010). Transfer of heavy metal from soils to plants has been proved as an efficient way for removal of these heavy metals through harvestable plant parts such as roots, stems and leaves (Cataldo and Wildung, 1978; Malik et al., 2010). However, there are differences in concentration among species and plant parts, indicating their capacities for metal uptake (Abou-Shanab et al., 2007).

Since plant cultivation and harvesting are relatively inexpensive processes, phytoremediation may provide an attractive alternative for clean up of heavy metals in urban stream sediments. Phytoextraction may reduce the levels of heavy metals in sediments to acceptable levels with time, because metals are translocated to easily harvestable plant parts. A few plants are able to survive and reproduce heavily on polluted soils or sediments with Pb, Cd, Cu and Zn. Such species are regarded as metallophytes (Baker, 1981). Plant metal tolerance may take two forms: by metal exclusion which involves

*Corresponding author. E-mail: ssekaba@gmail.com. Tel: +256 772 855 348.

avoidance of metal uptake and restricted translocation to the shoot but with large amounts of heavy metals in the roots and by metal accumulation, which involves high metal uptake and storage in the vacuole to prevent toxicity (Sękara et al., 2005a; 2005b). Metal tolerant plants with low metal accumulation are preferred for phytostabilisation; such plants accumulate heavy metals in roots and are therefore poor translocators and hyperaccumulators (Abou-Shanab et al., 2007; Malik et al., 2010). The threshold concentrations of some metals in shoots are more than 100 mg/kg for Cd, more than 1000 mg/kg for Pb and Cu, more than 10000 mg/kg for Zn and Mn for hyperaccumulator plants.

Cadmium is a mobile element and can be easily absorbed by the roots and translocated to shoots, while lead is largely immobile in sediments and its extraction is limited by solubility and diffusion through the root surface (Sękara et al., 2005a). Elemental complexation in plants may provide a basis for maintaining the solubility and mobility of chemically reactive species (metal ion) and allows conservation of substrates by allowing remobilization. Cataldo and Wildung, (1978) also observed that the uptake of non-essential species was not always proportional to soil/sediment solution concentrations (Cataldo and Wildung, 1978). The objectives of this t work were to determine heavy metal concentrations and distribution in plant parts (roots, stems and leaves) of *C. dactylon* and *C. benghalensis* relative to sediments and to evaluate the possible use of these plant species as phytoextractors and/or phytostabilisators of heavy metal pollution in an urban drainage ecosystem.

MATERIALS AND METHODS

Study area and sites

The Nakivubo channelized stream is 12.3 km long, of which 2.3 km is the channel length of the Upper and Lower Nakivubo wetlands. The study area (0°15'N and 32°30'E) is located 45 km north of the Equator and 8 km from Lake Victoria, with a total area of 190 km^2 (Figure 1).

Nakivubo channel drains through Kampala city centre and the most industrialised areas before discharging into the Inner Murchison Bay of Lake Victoria. The channel is the major recipient of runoff and organic substances from industrial and domestic waste as well as surrogate end point of effluents (Sentongo, 1998). Nakivubo channel was constructed basically to carry storm water from Kampala city into Lake Victoria so as to minimise flooding and ponding effects.

As with any other river ecosystem, the Nakivubo channel is not uniform and its flow varies greatly upstream as well as downstream. It has inflows from effluent discharge points and tributaries. Some of the tributaries seasonally originate from the streets and suburbs of Kampala city and eventually join the Nakivubo channel. The upstream portion of the channel floor is cemented, but silted and relatively vegetated, with the sides reinforced with hardcore stones held by a wire mesh. The channel is gradually vegetated as it descends towards the wetlands. It is increasingly polluted with direct discharge of raw industrial effluents, untreated sewage and wastewater from commercial, industrial and domestic establishments (Table 1).

Sampling and heavy metal analysis

This study was conducted between August, 2008 and November 2009, along the Nakivubo Channelized stream of Kampala in Uganda and samples of plant biota were collected from various sites a long the Nakivubo channelized streams (Table 1). Sampling of the plant biota was done manually. At list two plants of the same species were collected at each site. The samples were later packed in polyethylene bags and transported to the laboratory in an ice box at 4°C. Samples were separated into portions of roots, stems and leaves samples. Plant were then cut into smaller portions and washed with distilled water and then double rinsed with deionised water. The samples were wrapped in aluminium foil and dried for about 24 h at 105°C in the laboratory dryer and then homogenized into fine grained fractions in a grinding mill. Dried samples of 1.2 g were transferred into 250 ml Pyrex beakers, 20 ml of 65% HNO_3 added and left overnight before heating them on a hot plate. An open-beaker digestion was performed at 250°C hot plate attained gradually until the mixture was heated to near dryness. Then 5.0 ml of 30% hydrogen peroxide was added to complete the digestion and the resulting mixture heated again to near dryness. The residues were not completely dissolved. The beaker walls were washed with 2.5 ml of deionised water and the digest heated till boiling. The digest liquor was allowed to cool and later transferred into 25 ml standard flasks which were filled with deionised water to the mark. Sediment samples were analysed as described by Sekabira et al. (2010).

Heavy metals were then analyzed by direct aspiration of the sample solution into a Perkin-Elmer model 2380 Flame Atomic Absorption Spectrophotometer. Accuracy of the analytical method was evaluated by comparing the expected metal concentrations in certified reference materials (CRM) with the measured values. Simultaneous performance of analytical blanks, periodic aspiration of the standard at close interval, certified reference (JG-3) (Imai et al., 1995) and calculation of the average recoveries of heavy metals show that the accuracy of the method was within acceptable limits (Table 2).

Bio-accumulation Factor (BAF): Bio-accumulation Factor can be employed to quantify toxic element accumulation efficiency in plants by comparing the concentration in biota and an external medium (e.g. soil).

$$BAF = C_b/C_s$$

Where, C_b and C_s are heavy metal concentrations in aerial part of the plant (shoot) (mg/kg) and in soil (mg/kg), respectively. BAF was categorised as: < 1 excluder, 1-10 accumulator and > 10 hyper-accumulator (Baker, 1981; Ma et al., 2001).

Bioaccumulation Coefficient (BAC) was determined to qualify heavy metal accumulation efficiency in plants by comparing the concentration in the plant parts (roots, stems and leaves) and external medium such as soil using the formula below:

$$BAC = C_p/C_s$$

Where, C_p and C_s are heavy metal concentrations in plant parts (mg/kg) and in soil (mg/kg), respectively (Zayed and Gowthaman, 1998). Four categories of heavy metal accumulation are proposed: < 0.01 non accumulator plants, 0.01-0.1 low accumulator plants, 0.1-1 moderate accumulator plants, 1-10 high accumulator/hyper-accumulator plants. The content value of metal per plant or organ is a better estimate of heavy metal extraction efficiency in a given plant species (Huang et al., 1997). Further, Heavy metal translocation from root to shoot in plants was calculated using the formula as given below:

$$TF = C_s/C_r,$$

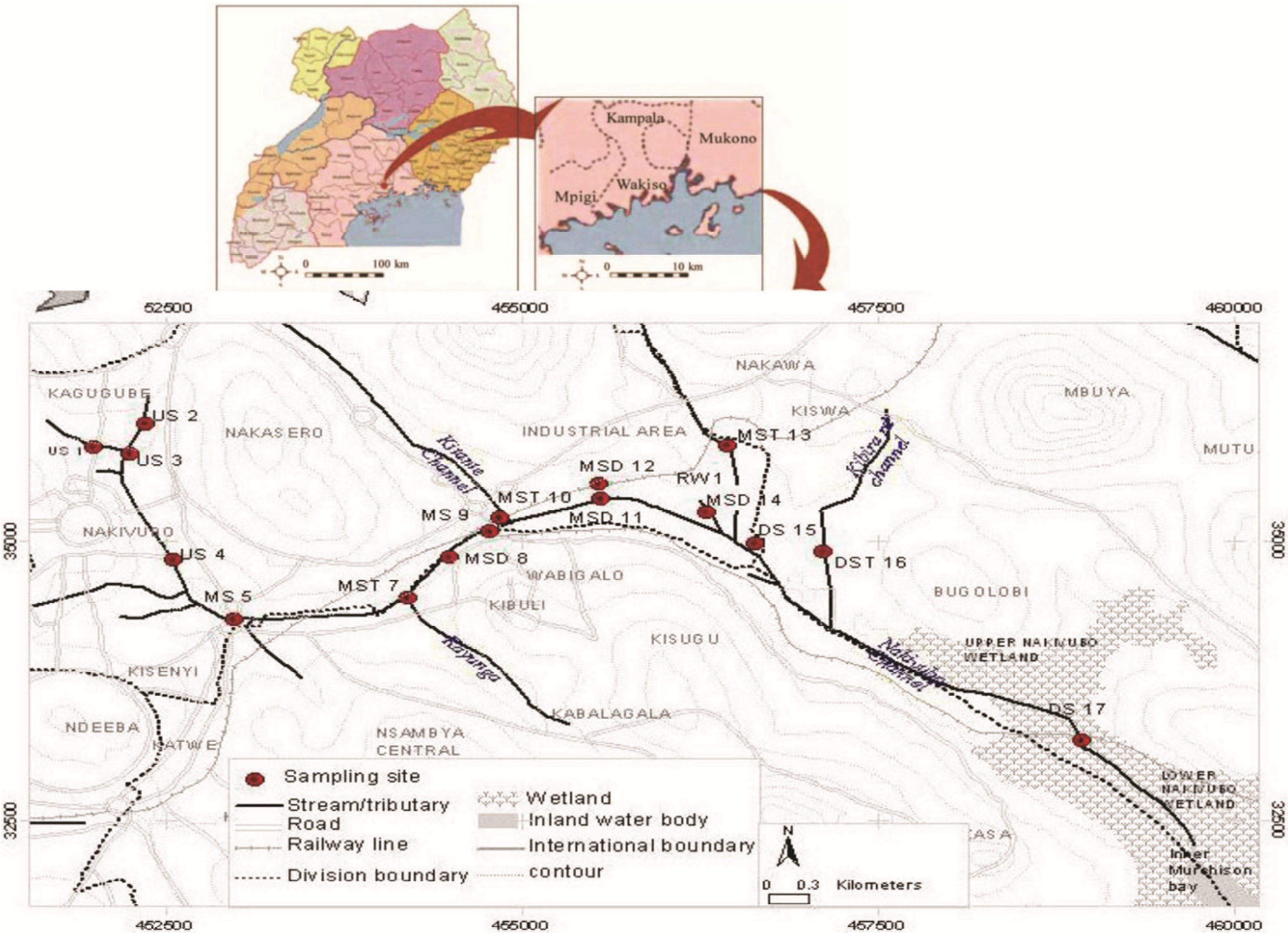

Figure 1. Map of Kampala city showing the locations of the sampling sites along the Nakivubo Channelized stream.

Table 1. Sample site location and description of activities and establishments.

Site/Location	Code	Activity/Establishment	Sediments
Upstream			
Agakhan High School Bridge	US1	Car washing bay, fish factory, gas/fuel station, residential houses, bus parking yard, seepage from walls	Sand
Bativa Hotel Bridge	US2	Car washing bay, gas/fuel station, slum residential and commercial houses and seepage	Sand
Kiseka market Bridge	US3	Car washing bay, garage, commercial buildings and seepage	Sand
Nakivubo Stadium Bridge	US4	Recreational, commercial, market, vehicle traffic, bus park, gas/petrol station, and seepage	Silty sand
Midstream			
6th Street Bridge Mukwano	MS9	Commercial, oil storage in vicinity, vehicle traffic, gas/petro station, seepage, Industries	Silty sand
Downstream			
5th Street Bridge	DS15	Industries, vehicle traffic, sewerage plant, seepage, garages, metal fabrication, petro station , residential	Sand
Tributaries			
Kayunga Stream	MST7	Solid waste dump sites, horticulture, recreational, slum and residential, vehicle traffic, gas/petro station	Sand
Kitante Stream	MST10	Horticulture, recreational areas, residential and commercial, vehicle traffic, gas/petro station	Sand
Lugogo Stream	MST13	Vehicle traffic, commercial, residential and industrial establishments, electric station, horticulture, carpentry works, pole treatment and seepage	Sand
Kibira Road Stream	DST16	Battery, plastic and paper factory, industries, and gas/petro station	Sand
Industrial outlets			
Mukwano industries	MSD8	Mukwano industries	Sand
Peacock factory	MSD11	Peacock paint factory	Sand

where, C_s and C_r are metal concentrations (mg/kg) in the shoot and root, respectively. TF > 1 signifies that the plant effectively translocate heavy metals from roots to the shoots (Baker and Brooks, 1989).

RESULTS

Heavy metal concentration in plants and sediments

The mean total heavy metal concentrations of *C. benghalensis* and *Cynodon dactylon* were in the order roots > leaves > stems (Tables 3). The mean heavy metal concentrations were observed in decreasing order of Fe > Mn > Zn > Cu > Pb > Cd, except along Kayunga tributary (MST7), Agakhan High School Bridge (US1), Mukwano bridge (MS9), Peacock Paint factory (MSD11) and 5th street Bridge (DS15) in *C. benghalensis. Cynodon dactylon* from Kibira Road tributary (DST16) showed Fe > Zn > Mn > Cu > Pb > Cd (Table 4). Generally, Pb, Zn, Mn and Fe concentrations in sediments were comparatively higher than in plants. Cadmium mean concentration in sediments was comparatively lower than mean concentrations in plants. Bioaccumulation factor values along the Nakivubo Channelized stream ranged between 0.29 and 1.33 for Pb, 0.72 and 4.83 for Cd, 0.77 and 8.11 for Cu, 0.73 and 2.10 for Zn, 0.36 and 2.25 for Mn and 0.11 and 0.80 for Fe (Table 5). Bioaccumulation factor values of plants growing in sediments along tributaries ranged between 0.2 and 1.29 for Pb, 1.21 and 1.97 for Cd, 0.63 and 16.29 for Cu, 0.42 and 2.47 for Zn, 0.39 and 5.58 for Mn and 0.06 and 0.23 for Fe. Bio-accumulation coefficient values along the Nakivubo tributaries ranged between 0.03 and 0.42 for Pb, 0.46 and 1.61 for Cd, 0.28 and 19.39 for Cu, 0.24 and 3.27 for Zn, 0.04 and 5.97 for Mn and 0.01 and 0.27 for Fe (Table 4). The mean heavy metal concentrations in C. benghalensis at industrial out fall were observed in decreasing order of Fe > Mn > Zn > Cu > Pb > Cd (Table 6)

Translocation and bioaccumulation of heavy metals in plant parts

Commelina benghalensis and *C. dactylon* (Table 8)

Table 2. Quality control (mean ± SD) (mg/kg trace and % for elements) (n=8).

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
Recovery (%)	85.5	92.6	99.1	103.8	87.3	91.1

Table 3. Mean concentrations (mg/kg) (n=16) and bio-accumulation coefficient (BAC) values for heavy metals in plant parts in the Nakivubo wetland.

Site	Plant species	Plant parts	pH	Heavy metal concentration (mg/kg)						Bioaccumulation coeficient (BAC)					
				Pb	Cd	Cu	Zn	Mn	Fe	Pb	Cd	Cu	Zn	Mn	Fe
US1	*C. benghalensis*	Leaves		16.57	1.02	20.34	378.31	252.55	2282.24	0.25	1.01	0.77	2.2	0.67	0.07
		Stems		14.8	1.17	13.21	82.42	198.48	591.02	0.22	1.16	0.5	0.48	0.52	0.02
		Roots		36.66	1.67	194.25	401.16	266.85	11104.66	0.54	1.65	7.33	2.33	0.7	0.36
		Mean		22.67	1.29	75.93	287.3	239.29	4659.31						
		Sediments	7.14	67.29	1.01	26.5	171.88	379.07	30442.67						
US2	*C. dactylon*	Leaves		9.9	0.66	25.78	99.5	160.87	2199.47	0.15	0.63	0.77	0.39	0.35	0.07
		Stems		6.7	0.54	5.35	85.73	148.35	821.67	0.1	0.51	0.16	0.33	0.32	0.03
		Roots		24.26	1.72	190.12	259.91	659.49	9035.16	0.37	1.64	5.67	1.01	1.42	0.3
		Mean		13.62	0.97	73.75	148.38	322.9	4018.77						
		Sediments	7.15	65.22	1.05	33.54	257.7	465.28	30131.2						
US2	*C. benghalensis*	Leaves		16.72	1.1	19.41	177.03	840.46	1511.71	0.26	1.05	0.58	0.69	1.81	0.05
		Stems		12.55	0.93	12.82	99.49	435.32	814.35	0.19	0.88	0.38	0.39	0.94	0.03
		Roots		34.02	1.28	65.15	328.11	1367.16	4604.54	0.52	1.22	1.94	1.27	2.94	0.15
		Mean		21.1	1.1	32.46	201.54	880.98	2310.2						
		Sediments	7.15	65.22	1.05	33.54	257.7	465.28	30131.2						
US3	*C. benghalensis*	Leaves		13.07	0.84	25.79	146.36	191.43	1329.63	0.17	0.86	0.75	0.78	0.22	0.04
		Stems		13.12	0.99	10.61	184.26	163.93	990.94	0.17	1.02	0.31	0.98	0.19	0.03
		Roots		30.36	4.1	24.34	300.03	444.59	6960.97	0.39	4.2	0.71	1.6	0.51	0.22
		Mean		18.85	1.98	20.25	210.21	266.65	3093.85						
		Sediments	7.3	78.14	0.98	34.24	187.77	879.67	31042.67						

plants showed both TF and BAF > 1 for Cu and hence, they could be labelled as heavy metal accumulators and potential plant species for phytoextraction of Cu at high sediment heavy metal concentrations. The results indicated that *C. benghalensis* growing at 6th street bridge site long

Table 3. (cont:) Mean concentrations (mg/kg) and bio-accumulation coefficient (BAC) values for heavy metals in plant parts in the Nakivubo wetland.

Site	Plant species	Plant parts	pH	Heavy metal concentration (mg/kg)						Bioaccumulation coeficient (BAC)					
				Pb	Cd	Cu	Zn	Mn	Fe	Pb	Cd	Cu	Zn	Mn	Fe
US4	*C. dactylon*	Leaves		16.9	0.45	12.54	121.09	138.58	4527.56	0.12	0.43	0.24	0.45	0.43	0.12
		Stems		7.42	0.37	6.89	39.2	26.69	3906.25	0.05	0.35	0.13	0.14	0.08	0.11
		Roots		115.6	1.05	79.67	281.28	562.85	19934.33	0.82	0.99	1.5	1.04	1.74	0.54
		Mean		46.64	0.62	33.03	147.19	242.71	9456.05						
		Sediments	6.75	140.5	1.06	53.07	270.48	322.88	36851.2						
MS9	*C. benghalensis*	Leaves		18.49	1.03	26.78	202.1	197	1645.4	0.19	1.01	0.7	0.62	0.4	0.04
		Stems		21.33	4.1	376.9	243	130.37	2924.4	0.22	4	9.82	0.74	0.26	0.06
		Roots		136.63	6.13	71.16	630.5	360.15	15639.19	1.4	5.99	1.85	1.93	0.72	0.34
		Mean		58.82	3.75	158.3	358.53	229.17	6736.33						
		Sediments	7.04	97.25	1.02	38.38	326.47	497.07	46176						
DS15	*C. benghalensis*	Leaves		35.06	0.9	25.59	171.76	159.73	1482.07	0.32	0.77	0.51	0.6	0.28	0.04
		Stems		16.57	3.16	39.91	269.82	86.35	922.78	0.15	2.69	0.8	0.94	0.15	0.03
		Roots		69.24	2.72	44.51	327.66	269.42	5218.32	0.63	2.32	0.89	1.14	0.47	0.15
		Mean		40.29	2.26	36.67	256.42	171.83	2541.06						
		Sediments	6.92	110.6	1.18	49.75	287.53	571.73	34576						
	*Zu et al. (2004)	Normal limits		5.0	10.0	100.0	100.0								

* Zu et al. (2004-Normal concentration limits of heavy metal in plant parts.

Table 4. Mean concentrations (mg/kg) (n=16) and bio-accumulation coefficient (BAC) values for heavy metals in plant parts along tributaries.

Site	Plant species	Plant parts	pH	Heavy metal concentration (mg/kg)						Bio-accumulation coefficient (BAC)					
				Pb	Cd	Cu	Zn	Mn	Fe	Pb	Cd	Cu	Zn	Mn	Fe
MST7	*C. benghalensis*	Leaves		11.57	0.79	18.95	115.38	117.35	1276.55	0.12	0.79	0.52	0.38	0.19	0.04
		Stems		14.32	1.04	29.58	134.79	34.83	473.07	0.14	1.03	0.81	0.44	0.06	0.01
		Roots		20.18	1.62	124.79	248.41	96.16	2844.04	0.2	1.61	3.43	0.81	0.16	0.08
		Mean		15.36	1.15	57.77	166.2	82.78	1531.22						
		Sediment	6.93	99.17	1.01	36.42	305	619.6	36264						
MST1O	*C. benghalensis*	Leaves		10.6	0.66	18.3	110.19	179.01	1388.83	0.15	0.57	0.5	0.58	0.21	0.03
		Stems		14.69	1.27	18.78	147.25	151.18	1141.25	0.21	1.1	0.51	0.77	0.18	0.03
		Roots		28.74	1.76	28.91	220.22	496.79	5727.03	0.42	1.53	0.79	1.16	0.59	0.13
		Mean		18.01	1.23	21.99	159.2	275.66	2752.37						
		Sediment	6.92	69.13	1.15	36.7	190.3	847.07	44776						

Table 4. (contd.) Mean concentrations (mg/kg) (n=16) and bio-accumulation coefficient (BAC) values for heavy metals in plant parts along tributaries.

MST1O	*C. dactylon*	Leaves		12.73	0.54	19.97	227.11	106.81	2033.12	0.18	0.46	0.54	1.19	0.13	0.05
		Stems		8.43	0.88	19.67	109.36	260.27	697.48	0.12	0.76	0.54	0.57	0.31	0.02
		Roots		104.61	2.99	86.62	622.92	5057.55	6529.25	1.51	2.59	2.36	3.27	5.97	0.15
		Mean		41.92	1.47	42.08	319.8	1808.2	3086.62						
		Sediment	6.92	69.13	1.15	36.7	190.3	847.07	44776						
MST13	*C. benghalensis*	Leaves		24.86	0.69	23.47	143.3	277.6	2960.54	0.19	0.61	0.67	0.28	0.6	0.08
		Stems		14.01	0.96	30.23	122.56	121.05	937.08	0.11	0.86	0.87	0.24	0.26	0.02
		Roots		32.24	1.82	26.74	293.68	523.61	8354.98	0.25	1.63	0.77	0.57	1.13	0.22
		Mean		23.7	1.16	26.81	186.5	307.42	4084.2						
		Sediment	6.51	127.9	1.12	34.81	513.9	463.07	38509.3						
DST16	*C. dactylon*	Leaves		98.33	0.84	570.29	557.92	180	1219.2	0.24	0.82	19.39	1.22	0.28	0.03
		Stems		13.05	0.51	8.14	210.36	26	479.2	0.03	0.5	0.28	0.46	0.04	0.01
		Roots		434.01	2.54	143.45	792.92	309.16	10192.51	1.06	2.48	4.88	1.73	0.48	0.27
		Mean		181.8	1.3	240.6	520.4	171.72	3963.64						
		Sediment	7.06	407.7	1.02	29.41	458.8	642.67	38442.7						

Nakivubo sediment and Mukwano industrial outfall had TF and BAF values greater than one for Cu (Tables 5 and 7) respectively accumulated it in stems (BAC=9.83) (Table 3) that are harvestable and with high biomass. This is a vital characteristic for phytoextraction. Also, *C. dactylon* had high TF and BAF values for Cu 3.34 and 16.29 respectively along Kibira Road tributary (Table 8) accumulated in leaves (BAC=19.39) (Table 4).

DISCUSSION

This study showed that the sediments in Nakivubo ecosystem are polluted with Pb, Cd and Zn and their pH was slightly acidic to near neutral. Higher pH values in sediments result in greater retention and lower heavy metal solubility (Muwanga, 1997; Malik et al., 2010; Sekabira et al., 2010) and stabilised toxic heavy metal concentrations in sediments. This phenomenon may limit heavy metal uptake and translocation into shoots. The results showed that the plants studied accumulated high concentrations of Pb, Cd, Cu and Zn in plant tissues of *C. benghalensis* and *C. dactylon* (Table 3) above normal concentrations of 5 mg/kg Pb, 10 mg/kg Cd and 100 mg/kg Cu and Zn as observed by Zu et al. (2004). High metal accumulation in plant parts above the normal limits may indicate their tolerance to heavy metal pollution in sediments. Heavy metal concentrations in plant parts followed the sequence roots > leaves > stems. This may indicate low mobilization of heavy metals from sediments through roots, stems and leaves, and/or a tolerance mechanism developed by the plants to accumulate heavy metals in roots. This helps to reduce stress in shoots. Lead and cadmium concentrations in sediments were comparatively lower than in roots of *C. dactylon* growing in the Nakivubo tributaries but higher than those in stems and leaves (Table 4). This indicates accumulation of heavy metals in roots of *C. dactylon* from sediments in Nakivubo tributaries.

However, Cu in *C. dactylon* growing along Kibira Road tributary showed high concentration in leaves and was comparatively higher than in roots and sediments. At this site the sediment heavy metal concentrations was relatively higher than at other sites and it is the only site were Cu translocation to the leaves of *C. dactylon.* This suggests a threshold sediment heavy metal concentration above which translocation to the leaves is observed. There is high mobilization of Cu from sediments through roots and stems to leaves of *C. dactylon* (Bu-Olayan and Thomas, 2009; Ayari et al., 2010). This pattern of heavy metal concentration in sediments with plant parts seem to vary according to the heavy metals in the same or different plant species (Abou-Shanab et al., 2007), absorption and metal uptake capa-cities, elemental concentrations in the sediments and/or salinity in sediments at the different sites (Muwanga and Balifaijo, 2006; Sekabira et al., 2010) Kibira Road tributary and Mukwano industrial outfall had

Table 5. Bio-accumulation factor (BAF) and translocation factor (TF) values of heavy metal in shoot of plants in Nakivubo urban wetlands.

Site	Plant species		Pb	Cd	Cu	Zn	Mn	Fe
US1	*C. benghalensis*	TF	0.74	0.80	0.87	0.90	0.91	0.83
		BAF	0.40	1.33	6.35	2.10	0.64	0.30
US2	*C. dactylon*	TF	0.74	0.72	0.88	0.73	0.76	0.80
		BAF	0.74	0.72	0.88	0.73	0.76	0.80
US2	*C. benghalensis*	TF	0.74	0.88	0.75	0.75	0.77	0.76
		BAF	0.39	1.07	1.47	0.96	2.25	0.12
US3	*C. benghalensis*	TF	0.74	0.76	1.08	0.77	0.73	0.79
		BAF	0.29	3.18	0.77	1.23	0.37	0.18
US4	*C. dactylon*	TF	0.85	0.74	0.83	0.77	0.82	0.77
		BAF	0.70	0.73	1.25	0.80	1.43	0.41
MS9	*C. benghalensis*	TF	0.81	0.80	4.38	0.73	0.75	0.81
		BAF	1.13	4.83	8.11	1.42	0.54	0.27
DS15	C. benghalensis	TF	0.75	0.99	0.86	0.83	0.76	0.76
		BAF	0.47	2.27	0.77	0.95	0.36	0.11

Table 6. Mean values of heavy metal concentration (mg/kg) in *C. benghalensis* of the industrial outfall (n=16).

Site	Parts	pH	Pb	Cd	Cu	Zn	Mn	Fe
MSD8	Leaves		25.11	1.00	166.92	317.98	306.52	1896.88
	Stems		27.26	2.23	14.87	212.20	115.80	1757.28
	Roots		54.08	2.04	33.73	298.43	651.01	11774.31
	Mean		35.48	1.76	71.84	276.21	357.78	5142.82
	Sediments	7.01	93.14	1.35	48.43	335.76	611.73	33242.67
MSD11	Leaves		18.24	0.71	22.20	100.87	180.00	2600.00
	Stems		22.95	1.26	32.91	405.28	86.00	2200.00
	Roots		26.18	1.49	63.43	219.95	300.48	10817.31
	Mean		22.46	1.15	39.51	242.03	188.83	5205.77
	Sediments	6.95	89.56	3.21	27.57	662.33	2147.84	90611.20

Table 7. Bio-accumulation Factor (BAF) and Translocation Factor (TF) values of heavy metals in roots, stems and leaves of *C. benghalensis* in sediments of Industrial effluent outfall.

Site		Pb	Cd	Cu	Zn	Mn	Fe
MSD8	TF	0.75	0.94	4.02	0.95	0.76	0.80
	BAF	0.43	1.42	2.80	0.85	0.81	0.28
MSD11	TF	0.88	0.84	0.74	1.40	0.76	0.76
	BAF	0.26	0.39	1.71	0.46	0.11	0.09

higher Cu sediment concentration. Kibira Road tributary was influenced by Uganda Baati Ltd producing galvanised iron sheets, Uganda batteries limited (a batteries factory) and Plastic factory (Nice house of plastics, Uganda). These results are consistent with those of Barman et al. (2000) and Malik et al. (2010). BAC values for Pb in leaves of *C. dactylon* were lower than those obtained by Malik et al. (2010). High translocation value for Cu into plant parts is indicative of its essentiality (Sękara et al., 2005a). The results also show that, in most cases *C. dactylon* and C. *benghalensis* plant species had higher BAC values for all metals in roots

Table 8. Translocation Factor (TF) and Bio-concentration Factor (BAF) values of heavy metals in plant parts of the Nakivubo stream tributaries.

Site	Plant species		Pb	Cd	Cu	Zn	Mn	Fe
MST7	*C. benghalensis*	TF	0.80	0.77	0.78	0.75	1.01	0.76
		BAF	0.16	1.24	2.66	0.61	0.16	0.06
MST1O	*C. benghalensis*	TF	0.74	0.79	0.80	0.78	0.73	0.76
		BAF	0.31	1.21	0.63	0.91	0.43	0.10
MST1O	*C. dactylon*	TF	0.85	0.76	0.76	0.76	0.94	0.78
		BAF	1.29	1.97	1.79	2.47	5.58	0.11
MST13	*C. benghalensis*	TF	0.81	0.74	1.01	0.74	0.76	0.78
		BAF	0.20	1.21	0.78	0.42	0.86	0.17
DST16	*C. dactylon*	TF	0.84	0.75	3.34	0.80	0.81	0.87
		BAF	0.89	1.86	16.29	1.37	0.39	0.23

than in the aerial parts (stems and leaves) suggesting that the two plants are good candidates for phytostabilisation of Pb, Cd, Cu, Zn, Mn and Fe. High accumulation of heavy metals in roots and low translocation in shoots may indicate appropriateness of a plant species for phytostabilisation (Shu et al., 2000; Archer and Caiwell, 2004; Malik et al., 2010). Lead is largely immobile in sediments and its extraction is limited by solubility and diffusion through root surface (Cataldo and Wildung, 1978). However, the plant samples showed metal concentrations of less than 1000 mg/kg and thus none could be categorized as a hyper-accumulator (Ma et al., 2001). Both plants can form a dense mat on the soil surface and are cosmopolitan. They show very fast establishment through vegetative growth and seedlings.

Conclusions

Plants accumulate Zn, Cd and Cu and distribute them in plant parts that are harvestable. Lead, copper, zinc, manganese and iron in roots and stems and leaves indicate their transfer from the soil. TF and BAF values at different sites indicate that pollutants were mostly assimilated through the roots from sediments.

The present investigation revealed that *Cynodon dactylon* and *Commelina benghalensis* can be recommended to understand heavy metal pollution levels in urban stream ecosystems. A threshold sediment heavy metal concentration above which translocation to the shoot is observed is apparent for phytoremediation of Cu by *C. benghalensis* in stems and *C. dactylon* in leaves of urban stream ecosystem and wastewaters. *Cynodon dactylon* and *Commelina* benghalensis are good candidates for phytostabilisation of Pb, Cd, Cu, Zn and Mn in urban drainage ecosystems. Both plant species are ubiquitous, cosmopolitan and vegetative and have relatively high biomass.

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