Variations in the contents of heavy metals in arable soils of a major urban wetland inlet drainage system of Lake Victoria, Uganda

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Abstract

Little is known about the effects of urbanization on the chemical quality of soils in suburban wetland inlet drainage systems to the Uganda side of Lake Victoria, on which food crops are extensively grown. It is feared that pollution in the soils might eventually enter food chains through such crops being consumed by urban populations unaware of their occurrence. Soil samples were collected from cultivated areas of a major wetland drainage system (Nakivubo Channel), at Kampala, Ubanda, near Lake Victoria and from a rural control wetland site (Senge). The soil from this site had similar properties as those from the urban test site (i.e., soil texture; porosity; humus content). Analysis of heavy metals with atomic absorption spectrophotometry (AAS) yielded the following soil concentration ranges: manganese (190–780), cadmium (<0.001–1.0), zinc (6.0–10.0) and lead (10–20 mg kg^{-1}) dry weight for the control site, and 450–900, 1.0–2.0, 131–185, 40–60 mg kg^{-1} dry weight, respectively, for the urban wetland, indicative of relatively heavy metal pollution in the suburban drainage system. Heavy metal levels in cocoyam (*Colocasia Esculenta*) and sugarcane (*Saccharum Officinarum*) grown on both wetland soils also were evaluated via AAS with a modified wet-acid-digestion technique. The results highlighted high cadium and lead levels ($P \leq 0.0003$) in the crops from urban wetland cultivation. Cadmium and lead concentrations in cocoyam from urban wetland soils exceeded those from the control site by 0.17 and 3.54 mg kg^{-1}, respectively. The corresponding results for sugarcane indicated a similar increase of 0.56 and 2.14 mg kg^{-1} of juice extract. Cadmium and lead levels in both urban wetland crops were higher than the maximum permissible limits of the Codex Alimentarius Commission, indicating that these concentrations pose potential health risks to urban consumers, and call for early counter-measures to combat urban pollution entering the lake.

Key words

drainage system, heavy metal pollution, Lake Victoria, urban wetland cultivation.

INTRODUCTION

Most of the wetlands in the Kampala District of Uganda are all associated with Lake Victoria inlet drainage systems. The Nakivubo Channel wetland and swamp system are by far the largest of these wetlands. The inter-linkage among various ecosystems, such as wetlands and lakes (Islam & Gnauck 2008), necessitates studies to fill the knowledge gaps regarding pollution, especially heavy metals in soils, and their uptake by plant species. Such studies are essential if the effects and changes resulting from the control of metal pollution sources are to be realized (Cheng 2003). Thus, this study was undertaken to establish the extent of heavy metal pollution in urban wetland soils on the Ugandan side of the Lake Victoria basin, and to determine how this pollution affects the quality of the agricultural crops grown on them. The desire to control such contamination in food crops would ultimately lead to improved water quality in Lake Victoria, which is the second largest inland freshwater lake in the world, and serves as a reliable water source for both

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domestic and industrial uses (Mwamburi 2003, 2009) for many towns, cities and inland ports in East Africa (Fig. 1a).

The impacts of industrial activities (Muwanga & Barifaijo 2006) on heavy metal loads, and their physicochemical effects on the wetlands of the Lake Victoria Basin, are of considerable concern in regard to preserving this important East African international waterbody. In addition to their natural functions, these urban wetlands are used by local communities for agricultural production, as water sources for domestic consumption and as dump sites for urban domestic wastes. As they can be cultivated throughout the year, the wetlands also provide for food. Recent studies (Bbosa *et al.* 2009) indicated that the physicochemical parameters along Nakivubo Channel waters were relatively higher than those in Lake Victoria waters, being evidence of the slowly increasing pollution load along the channel. Contributing to this load is a number of industrial, commercial and domestic developments along the catchment areas of the channels and streams leading to the wetland, and ultimately to Lake Victoria. These include a fish-processing industry, a car-battery manufacturing and recycling industry, several fruit- and food-processing industries, an abattoir, petrol stations, automobile garages and service centres, Uganda Breweries, car-washing bays, scrap metal depots and, among them, densely populated and low-cost settlements. These establishments discharge untreated effluent and waste water into water systems and also directly onto the land surface. Motor vehicle emissions are another source of heavy metal pollutants, resulting from the combustion of leaded gasoline, motor oil spills and the wearing of tires, brake pads, bearings and radiators (Nabulo 2004). Other routes of entry of heavy metal pollutants into soils and waterbodies include the wet, dry or occult depositions of atmospheric particulate materials.

Heavy metals (UNECE 1979) are potentially toxic to humans when polluted soils are used for agriculture (Xian 1989; Cances *et al.* 2003; Kachenko & Singh 2004). Heavy metals, including cadmium, lead, manganese, mercury and zinc, are serious pollutants of aquatic ecosystems, mainly because of their environmental persistence, toxicity and their ability to partition into food chains (Mugabe *et al.* 1998; Kishe & Machiwa 2003; Ssebagala *et al.* 2004). Heavy metal toxicity may also adversely affect the genetic code of aquatic organisms because of nucleic acid-chelate formation (Sirover & Loeb 1976). Food crops grown on urban wetland systems are prone to heavy metal pollution from surrounding soils because of pollutant inputs from surface run-off, atmospheric deposition, effluents and wastewater discharged into the wetlands from various urban activities. When heavy metal concentrations in wetland soils are elevated, the total heavy metal content of food crops grown on such soils also may be elevated (Mugabe *et al.* 1998; Ssebagala *et al.* 2004). In the case of this study, leaching of heavy metals from the wetland drainage system into Lake Victoria results in degraded water quality (Chiswell & Mokhtar 1986; Bbosa *et al.* 2009) and possible poisoning of fish (Linnik 2000). Thus, systematic studies are necessary to evaluate the levels of the more likely heavy metal pollutants to be found in urban wetland systems, including

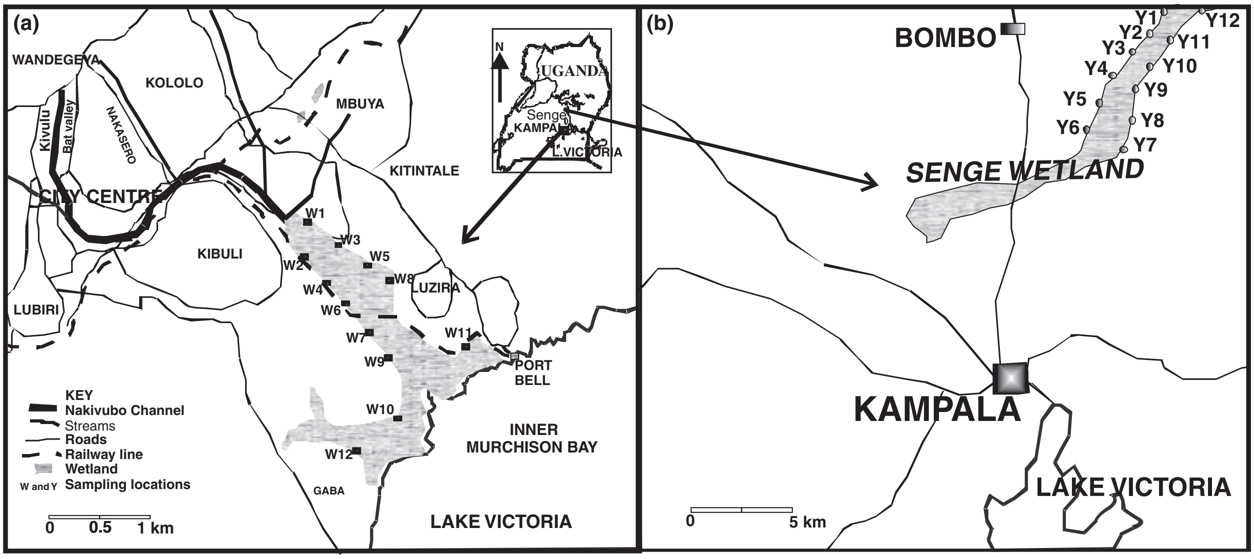

Fig. 1. (a) Schematic map of Kampala (Uganda), illustrating location of major urban wetland drainage system to Lake Victoria. (b) Senge rural wetland control site.

manganese (Mn), cadmium (Cd), zinc (Zn) and lead (Pb) in the soils and selected food crops commonly grown on them, to determine the magnitude of the pollution problem. Such studies will be valuable in regard to assessing potential public health impacts, as well as a trigger for counter-measures to address them.

The goal of this study was to evaluate the levels of Mn, Cd, Zn and Pb in the soils from a major urban wetland draining directly into Lake Victoria, with the objective of obtaining a better understanding of their subsequent concentrations in the food crops grown on the same land. The heavy metal concentrations may serve as an early indicator to the water quality and the fish frequently caught on the Uganda side of Lake Victoria.

MATERIALS AND METHODS

Study areas

Uganda is currently undergoing rapid urbanization and accelerated industrial growth (Rusongoza 2003), triggering an influx in the country's urban resident population. The resident population of Kampala, Uganda's capital, was 774,000 in 1991, but increased to 1,209,000 in 2002 (Uganda Bureau of Statistics 2005). At peak times (e.g., religious, school or other holidays), Kampala may accommodate well over 2 million people. Kampala, Uganda's only urban district, receives the greatest share of the high rate of urbanization, industrialization and rapid population growth, as well as the accompanying anthropogenic pollution. In this urban environment, the only accessible arable land available to the low-income earners, who must supplement their families' food requirements through cultivation of a wide range of crops and vegetables, is the suburban wetlands. Kampala covers a total surface area of 195 km^2, of which 31 km^2 (16% of the district's total land area) is wetland (Kakaata 2003). The Nakivubo wetland channel (Fig. 1a), the largest wetland drainage system in central Kampala district, covers an area of over 2 km^2 (Kakaata 2003). In the peri-urban areas, this wetland has been reclaimed and put under intensive cultivation of food crops. Growing of cocoyam accounts for 70–80% of the agricultural activities in and around the wetland. Other cultivated crops include cassava, sweet potatoes and sugarcane, which are not only consumed by the growers themselves, but also are regularly sold in markets and by roadsides to urban customers. Before the 1990s, crop farming used to be confined to the upper and drier areas of the wetland and is currently proceeding towards Inner Murchison Bay (Fig. 1a) at a highly undesirable rate. The only restriction to further extensive wetland reclamation is the increasing water depth as one approaches the bay shores of Lake Victoria. The control site was in Senge wetland, which was chosen because of its rural setting far removed from the urban industrial and domestic pollution sources, and because of close similarities between its soil parameters and those of the urban wetland site, in terms of soil texture, porosity and humus content. Senge wetland is located in Wakiso district, located 30–40 km north of Kampala (Fig. 1b). At each study site, twelve locations (W1–W12 and Y1¯Y12) were selected, from which soil samples and specimens of sugarcane and cocoyam were taken.

Sampling wetland food plants

Selected sampling sites in the urban and control wetland cultivation sites were located at least 500 m apart. These locations were characterized as experiencing intensive cultivation of food crops by wetland encroachers. During October 2008, and January and March 2009, soil samples were taken simultaneously, as the food crop samples were being harvested. Entire crop plants were uprooted, and their leaves removed. To ensure a uniform quality of juice extract, only stems of similar flowering stages (i.e. at the same stage of growth) were analysed. The sugarcane stems were cut nearer to the roots, where the juice was most concentrated. To reduce the chances of the plant tissues being contaminated with soil and other external particulate matter, the samples were packed in carefully labelled and sealed plastic bags before being transported in ice-cooled containers to the laboratory. Both the soil and the crop sampling was carried out in triplicate ($n = 3$), with the specimens treated independently for each sampling trip.

Sampling wetland cultivation soils

Top soil samples down to a 15 cm depth were collected at each sampling site with a hand auger. The soil samples were packed in labelled plastic bags and transported in coolers to the laboratory. The soil sampling was carried out in triplicate at each sampling site in three different rainy months (October 2008, January and March 2009). To ensure uniformity in soil samples, they were taken within 1 m of the same spot, as noted by a tagged stick stuck in the ground in the previous 2 months.

Analytical procedure

Total concentrations of manganese, cadmium, zinc and lead in the wetland soils

The soil pH and electrolytic conductivity (EC) measurements were determined on the basis of soil analysis methods of Rhoades (1982). Other processes, such as top soil erosion, especially for heavy metal analysis, were considered minimal, based on the crop plant cover of the gardens. The soil sample (20.0 ± 0.1 g) was placed into a 250 mL conical flask, with 50 mL of deionized water being added to it. The mixture was thoroughly shaken for 10 min and subsequently allowed to settle for 30 min. Sample shaking was repeated for a further 2 min. The pH of the soil suspension was subsequently measured with a standard pH meter. The soil suspension was allowed to settle for 1 h, before the EC of the supernatant liquid was measured with an EC bridge.

Soil samples were spread on aluminium foil and dried to a constant mass in an oven at 103°C for 24 h. After cooling, the samples were carefully ground in a ceramic mortar and subsequently sieved through a 2 mm nylon sieve. The finely ground sample (1.250 g) was weighed in a clean dry 250 mL Pyrex conical flask. Distilled deionized water (50 mL), glass beads and nitric acid/hydrochloric acid (50 mL; 3:1, *v/v*) were then added and a funnel was placed on top. The contents were heated in a fume cupboard on an electric hot plate at medium heat, until digestion was complete. Upon cooling, 5 mL of nitric acid was added to the conical flask, followed by 4 mL of 30% hydrogen peroxide. The flask was swirled and reheated for 10 min, cooled, and a further 50 mL deionized distilled water added, followed by 25 mL of hydrochloric acid. The boiling mixture was then cooled, quantitatively transferred to a 100 mL volumetric flask and filled to volume. The sample was thoroughly mixed and allowed to settle for 5 h. The clear supernatant was filtered through Whatman No.40 filter paper into labelled plastic bottles and sealed with plastic covers. Blanks were prepared by repeating the digestion procedure, minus the soil samples. Heavy metal analyses (Okalebo & Gathua 1993) were carried out with an atomic absorption spectrophotometer (AAS, Model 2380; Perkin-Elmer GmbH, Uberlingen, Germany).

Total concentrations of heavy metals in the wetland cocoyam

Cocoyam corms were thoroughly washed to remove all traces of soil and subsequently rinsed with distilled deionized water. The specimens were prepared according to a standard procedure outlined by Okalebo and Gathua (1993). The corms were cut into small pieces with a stainless-steel knife and dried to constant mass in an oven at 103°C for 24 h. After cooling, they were carefully ground in a ceramic mortar and passed through a 2 mm nylon sieve. The finely ground sample (1.250 g) was weighed in a clean dry 250 mL Pyrex conical flask. Concentrated nitric acid (25 mL; analytical grade) was added, followed by glass beads, and a funnel was fitted on the top of the flask. The contents were heated in a fume cupboard on an electric hot plate at medium heat until digestion was complete. A further 5 mL of the acid was added to the sample and the mixture concentrated to ~10 mL. Upon cooling, 4 mL of 30% hydrogen peroxide was added, and the contents swirled and re-heated for another 10 min. When the solution turned clear, the contents were cooled, quantitatively transferred to a 25 mL volumetric flask and made to volume with distilled deionized water. After settling for 5 h, the supernatant solution was carefully transferred to plastic bottles, sealed with plastic covers and labelled before being taken to the analytical laboratory.

Total concentrations of heavy metals in wetland sugarcane

The nitric acid digestion procedure for water and waste water (American Public Health Association 1992) was utilized for the wet-acid digestion of the sugarcane juice. The sugarcane stems, which were cut at two nodal intervals to the roots, were washed, rinsed with distilled deionized water, peeled and cut into small pieces with a stainless steel knife. The specimens were subsequently crushed with a stainless steel blender. The juice was filtered by pressing through a plastic sieve. Preliminary analyses indicated that a volume of 40–60 mL of juice extract after digestion provided satisfactory AAS readings. Accordingly, a volume of 50 mL of juice extract was used for each run in this study. Glass beads and 50 mL of the sugarcane juice extract were introduced into a 250 mL Pyrex conical flask, and 20 mL of concentrated nitric acid was added. The mixture was allowed to slowly evaporate on a hot plate just until precipitation occurred. A further 5 mL of the acid was then slowly added until the solution turned clear and digestion was complete. After 1 mL of 30% hydrogen peroxide was added, the flask was swirled and reheated for 10 min. When the solution remained clear upon cooling, 25 mL of deionized distilled water was added, and the solution again boiled. After further cooling, the contents were quantitatively transferred to a 25 mL volumetric flask and made to volume. After settling for another 5 h, the contents were transferred to labelled plastic bottles, before being analysed for heavy metal analysis with the AAS. The data were subjected to the students *t*-test for *p* values and standard deviations, using the SPSS version 12 statistical package (SPSS/IBM, Chicago, Illinois, USA).

Analytical quality assurance

Fortified sample recoveries were performed on standard solutions and certified reference material (CRM). Blanks also were included in the analyses. Individual reference standards were used to identify and quantify the levels of heavy metals. The arithmetic mean values and standard deviations were calculated only from positive quantifiable samples and, in all cases, the differences were considered statistically significant if the exact P value was $\alpha \leq 0.05$. Throughout the analytical procedure, especially during the digestion process, sample contamination was kept to a minimum by using only clean dry apparatus and distilled deionized water.

RESULTS AND DISCUSSION

Total heavy metal concentrations in urban wetland cultivation soils

Measurements of the physicochemical parameters indicated that, whereas the control site soils had a mean pH of 5.39 ± 0.09 and an electrical conductivity (EC) of 125 ± 2 μS cm^{-1}, the urban wetland soils exhibited a mean pH of 5.98 ± 0.06 and an EC of 154 ± 7 μS cm^{-1}. The sample size n in each case was 12, and the tolerances are standard deviations. Although the pH and EC values for the soils were within the acceptable range for agricultural soils, the significantly higher ($P = 0.0023$) EC value for the urban wetland soils over a wide area (6 km length) suggested a presence of more soluble ionic substances. Among these substances were basic metallic hydroxides, carbonates and hydrogen carbonates that would, in turn, reduce the relative acidity of the soils over that of the control site. The soils from both sites were dark and rich in wetland vegetation humus (Pruned 1967).

Manganese (Mn) levels in arable wetland soils

The total heavy metals contents in the soil samples from the control site and the urban wetland are summarized in Table 1 for each sampling site. The average Mn values of 518.18 ± 178.64 mg kg^{-1} dry weight (*d.w.*) were measured for the soils from the wetland control site. The Mn levels have been reported to be about 400 mg kg^{-1} in low calcium granite rock (WHO 1973) and 20–500 mg kg^{-1} in sandstones (Graham *et al.* 1988). The normal range of Mn in agricultural soils has been reported as 20–1000 mg kg^{-1} (Bowen 1979). Although still within the range generally accepted for typically uncontaminated soils (Bowen 1979), the mean total level of Mn (715.59 ± 128.06 mg kg^{-1} *d.w.*) in the soil samples from the urban wetland site exhibited a significant increase ($P = 0.0051$) over that in the soils from the control site. As Skordas and Kelepertsis (2005) also suggested, it is thought that the elevated Mn levels in the soils in the two study areas may be attributable to geological factors, to which anthropogenic sources have made a notable contribution for the urban wetland.

Cadmium (Cd) concentrations in urban wetland soils

While the mean Cd concentrations of 0.741 ± 0.447 mg kg^{-1} *d.w.* measured in the soils from the control sampling site were incomparable to those in the earth's crust, quoted as 0.1 mg kg^{-1} (Bowen 1979; WHO 1992), they remain within the mean Cd levels of 0.01–1.00 mg kg^{-1} in non-volcanic soils, as reported by Korte (1983). The soils in central Uganda are mainly non-volcanic in origin. The mean total Cd level of 1.452 ± 0.415 mg kg^{-1} *d.w.* (Table 1) measured in the soil samples from the urban wetland cultivation site was above the recommended concentrations (ICRCL 1987) of 0–1.0 mg kg^{-1} for soils used for agriculture. Thus, it may be concluded that the soils from a major urban wetland drainage system of Lake Victoria were contaminated with cadmium, relative to those from the control site. Cadmium is widely used in paints and plastics. The traces of cadmium embedded in scrap metal (Moors & Dijkema 2006) processed by small-scale industries littered all over the outskirts of the city and their untreated effluents, therefore could be blamed for its relative increase in the urban wetland soils. Furthermore, increasing chemical usage, as well as organic fertilizers, especially in vegetable growing activities on the urban wetland, could also be another source.

Zinc (Zn) levels in arable wetland soils

An average Zn concentration of 40 mg kg^{-1} was reported for non-contaminated soils (Adriano 1986). The comparatively low mean Zn levels in the soils from the wetland control site (7.50 ± 1.62 mg kg^{-1} *d.w.*) were considered to be well within the levels of uncontaminated soils. The observed mean total Zn levels (151.54 ± 9.22 mg kg^{-1} *d.w.*) in the soils from the urban wetland drainage system (Table 1) were far above those for uncontaminated soils, even though they were still within the optimal concentration of 0–250 mg kg^{-1} recommended by the ICRCL, Interdepartmental Committee for the Redevelopment of Contaminated Land (1987) for soils used for agriculture. This finding suggested significant Zn pollution of the urban wetland soils, which is perhaps not too surprising, considering that the main roofing material in Kampala (Uganda's capital) for over a century has been, and continues to be, galvanized iron. Corrosion of such zinc-coated corrugated iron releases considerable quantities of

Table 1. Mean levels of heavy metals in soils and selected food crops at study sites (mg kg^{-1} *d.w.*, ±SD)

Sampling site number	Soils				Cocoyam				Sugarcane juice			
	Mn	Cd	Zn	Pb	Mn	Cd	Zn	Pb	Mn	Cd	Zn	Pb
Rural wetland control site												
Y1	549.34 ± 0.74	<0.001	7.96 ± 0.07	9.95 ± 0.04	96.00 ± 0.59	0.270 ± 0.002	135.60 ± 0.43	2.01 ± 0.02	340.45 ± 0.67	<0.001	42.41 ± 0.35	2.66 ± 0.04
Y2	240.03 ± 0.82	0.941 ± 0.003	5.80 ± 0.09	10.11 ± 0.03	102.00 ± 0.35	<0.001	130.60 ± 0.64	2.10 ± 0.03	331.20 ± 0.56	0.230 ± 0.002	45.87 ± 0.18	3.30 ± 0.02
Y3	190.11 ± 0.49	0.965 ± 0.003	7.11 ± 0.36	10.03 ± 0.04	101.00 ± 0.34	0.108 ± 0.003	143.60 ± 0.48	1.90 ± 0.02	275.56 ± 0.57	<0.001	42.57 ± 0.44	2.33 ± 0.02
Y4	695.09 ± 0.85	<0.001	10.02 ± 0.17	17.51 ± 0.04	102.00 ± 0.41	0.120 ± 0.002	147.80 ± 0.67	1.05 ± 0.04	296.92 ± 0.65	0.270 ± 0.003	46.82 ± 0.43	2.99 ± 0.04
Y5	420.01 ± 0.32	0.993 ± 0.004	5.60 ± 0.36	16.14 ± 0.03	102.51 ± 0.44	0.105 ± 0.002	150.20 ± 0.56	1.27 ± 0.03	396.50 ± 0.55	0.270 ± 0.001	50.65 ± 0.43	1.92 ± 0.04
Y6	780.58 ± 0.34	0.983 ± 0.004	5.79 ± 0.42	20.03 ± 0.04	103.54 ± 0.59	0.125 ± 0.003	110.71 ± 0.75	1.46 ± 0.04	360.11 ± 0.43	0.175 ± 0.002	36.71 ± 0.47	2.75 ± 0.03
Y7	490.34 ± 0.48	1.024 ± 0.003	7.07 ± 0.33	15.03 ± 0.04	74.65 ± 0.51	0.125 ± 0.002	147.65 ± 0.56	1.00 ± 0.03	350.34 ± 0.54	0.265 ± 0.002	48.51 ± 0.36	2.30 ± 0.04
Y8	650.06 ± 0.57	0.981 ± 0.003	9.69 ± 0.71	10.01 ± 0.05	80.45 ± 0.26	0.107 ± 0.002	149.37 ± 0.51	1.25 ± 0.03	265.93 ± 0.36	0.108 ± 0.002	49.70 ± 0.54	2.93 ± 0.04
Y9	493.04 ± 0.62	0.977 ± 0.006	10.02 ± 0.25	9.98 ± 0.05	130.79 ± 0.34	0.105 ± 0.003	115.44 ± 0.49	0.98 ± 0.05	330.61 ± 0.31	0.175 ± 0.003	39.50 ± 0.33	3.50 ± 0.04
Y10	705.86 ± 0.40	0.988 ± 0.003	7.50 ± 0.73	10.02 ± 0.05	91.69 ± 0.32	0.110 ± 0.002	126.97 ± 0.59	2.05 ± 0.04	370.45 ± 0.70	0.250 ± 0.002	36.51 ± 0.41	2.57 ± 0.03
Y11	520.87 ± 0.42	<0.001	6.65 ± 0.94	10.79 ± 0.04	105.67 ± 0.79	0.109 ± 0.002	145.61 ± 0.51	1.96 ± 0.04	330.46 ± 0.65	0.180 ± 0.003	36.60 ± 0.26	2.05 ± 0.02
Y12	482.78 ± 0.47	1.034 ± 0.005	6.78 ± 0.30	9.98 ± 0.11	123.59 ± 0.78	0.107 ± 0.002	145.05 ± 0.47	1.20 ± 0.04	360.59 ± 0.72	0.210 ± 0.004	39.55 ± 0.32	1.94 ± 0.03
Av. (*n* = 12)	518.18 ± 178.64	0.741 ± 0.447	7.50 ± 1.62	12.47 ± 3.66	101.16 ± 15.55	0.116 ± 0.059	137.38 ± 13.61	1.52 ± 0.45	334.09 ± 38.60	0.178 ± 0.096	42.95 ± 5.26	2.60 ± 0.52
Urban wetland drainage site												
W1	570.07 ± 0.44	1.010 ± 0.006	156.23 ± 0.44	50.50 ± 0.06	33.80 ± 0.74	0.312 ± 0.005	69.01 ± 0.64	5.07 ± 0.03	39.30 ± 0.73	0.683 ± 0.005	83.80 ± 0.77	3.75 ± 0.04
W2	859.07 ± 0.58	1.025 ± 0.004	147.78 ± 0.67	40.03 ± 0.04	19.01 ± 0.54	0.230 ± 0.001	94.40 ± 0.42	4.06 ± 0.02	41.68 ± 0.83	0.856 ± 0.006	82.20 ± 0.33	3.65 ± 0.02
W3	681.05 ± 0.53	1.051 ± 0.006	162.02 ± 0.35	45.10 ± 0.03	56.05 ± 0.79	0.266 ± 0.005	69.60 ± 0.45	6.60 ± 0.01	79.89 ± 0.55	0.628 ± 0.003	48.43 ± 0.22	6.23 ± 0.05
W4	898.76 ± 0.26	1.981 ± 0.004	137.67 ± 0.47	42.01 ± 0.07	26.03 ± 0.31	0.347 ± 0.006	143.60 ± 0.75	6.06 ± 0.04	69.19 ± 0.52	0.674 ± 0.004	63.74 ± 0.24	2.33 ± 0.04
W5	451.43 ± 0.91	2.019 ± 0.008	138.32 ± 0.38	46.10 ± 0.05	28.60 ± 0.56	0.468 ± 0.007	179.60 ± 0.74	3.10 ± 0.05	65.69 ± 0.37	0.560 ± 0.005	49.22 ± 0.47	5.21 ± 0.06
W6	601.86 ± 0.70	1.455 ± 0.004	161.49 ± 0.39	45.30 ± 0.03	41.01 ± 0.76	0.209 ± 0.004	146.65 ± 0.52	6.05 ± 0.03	81.52 ± 0.53	0.366 ± 0.002	49.80 ± 0.34	7.81 ± 0.03
W7	769.00 ± 0.57	1.673 ± 0.004	157.69 ± 0.56	39.50 ± 0.06	20.75 ± 0.68	0.159 ± 0.001	125.65 ± 0.41	4.51 ± 0.02	39.20 ± 0.42	1.011 ± 0.004	80.55 ± 0.71	5.72 ± 0.04
W8	799.04 ± 0.69	1.928 ± 0.004	136.98 ± 0.40	54.57 ± 0.07	19.34 ± 0.53	0.194 ± 0.005	190.61 ± 0.41	4.70 ± 0.03	45.55 ± 0.62	0.853 ± 0.006	75.55 ± 0.34	4.50 ± 0.02
W9	787.65 ± 0.29	1.273 ± 0.006	156.39 ± 0.48	46.01 ± 0.04	27.85 ± 0.34	0.217 ± 0.004	66.37 ± 0.53	5.15 ± 0.04	69.02 ± 0.43	1.064 ± 0.004	55.71 ± 0.31	5.52 ± 0.04
W10	660.07 ± 0.23	1.858 ± 0.003	151.12 ± 0.64	48.40 ± 0.03	15.34 ± 0.68	0.303 ± 0.003	63.50 ± 0.63	4.55 ± 0.03	55.51 ± 0.58	0.946 ± 0.006	69.70 ± 0.41	6.32 ± 0.08
W11	749.97 ± 0.72	1.116 ± 0.001	155.10 ± 0.53	53.31 ± 0.05	25.45 ± 0.42	0.197 ± 0.002	95.67 ± 0.42	4.97 ± 0.03	49.11 ± 0.34	0.850 ± 0.003	83.65 ± 0.65	2.93 ± 0.03
W12	759.07 ± 0.67	1.036 ± 0.004	157.67 ± 0.65	59.70 ± 0.08	37.91 ± 0.24	0.383 ± 0.005	90.54 ± 0.53	5.94 ± 0.04	58.20 ± 0.45	0.594 ± 0.004	45.30 ± 0.54	2.95 ± 0.04
Av. (*n* = 12)	715.59 ± 128.06	1.452 ± 0.415	151.54 ± 9.22	47.54 ± 6.08	29.26 ± 11.47	0.274 ± 0.092	111.27 ± 44.97	5.06 ± 0.99	57.82 ± 15.22	0.757 ± 0.207	65.64 ± 15.37	4.74 ± 1.66

zinc into the soil (Suciu *et al.* 2008), the leaching of which concentrates it in the wetland water catchment area. There is a growing shift to the use of fired clay roofing tiles, however, particularly for suburban residential housing. The building construction industry has increased tremendously in the city during the current time, precipitating an excessive demand for wall paints, most being zinc-based. The result is an increased release of zinc into the urban environment, subsequently finding its way into the city's major drainage system. The critical total soil Zn concentration, above which toxicity is considered possible, has been put at 70–400 mg kg^{-1} (Kabata-Pendias & Pendias 1984). There is a likelihood this relatively high level of zinc-related pollution may eventually seep into the waters of Lake Victoria. Thus, contamination of heavy metals, including zinc (Yoon *et al.* 2006), represents one of the most pressing threats to water and soil resources, as well as human health.

Lead (Pb) concentrations in urban wetland cultivation soils

The mean total Pb levels of 12.47 ± 3.66 mg kg^{-1} *d.w.* in the soil samples from the rural control site were comparable to those in the earth's crust, reported as 13 mg kg^{-1} (WHO 1989), and to those in soils from areas remote from human activity, estimated to be in the range of 5–25 mg kg^{-1} (Swaine 1955). The soils from the urban wetland cultivation site exhibited a mean total Pb level of 47.54 ± 6.08 mg kg^{-1} *d.w.* and were apparently relatively more contaminated with this heavy metal than those from the control site by a factor of four (Table 1). This relatively elevated Zn level in the urban wetland soils (Yoon *et al.* 2006) may be attributed to continued use of lead paints, and to prolonged car-washing and emptying of dead lead-acid accumulators being conducted by unknowing car washers directly along the streams and channels leading to the wetland. The effects of the untreated effluent from a car-battery manufacturing and recycling industry in the neighbourhood, and the run-off that incorporates particulates from the combustion of leaded fuel (Matagi 2002; Nabulo 2004) from the congested city transport sector, also should not be underestimated. It is hoped that a gradual shift to the use of unleaded petrol might lead to a reduced release of lead into the urban atmosphere.

Heavy metal concentrations in the soil samples analysed in this study were in the decreasing order: Mn > Zn > Pb > Cd. The mean total heavy metal levels in the reclaimed soils of the urban wetland indicated that wetland pollution has occurred. The soils from a major urban wetland drainage system to Lake Victoria have been found to contain comparatively higher levels of manganese, zinc, lead and cadmium (Table 1).

Manganese, cadmium, zinc and lead levels in urban wetland cocoyam

The results of the analyses performed on the oven-dried cocoyam corms are summarized in Table 1.

Manganese (Mn) in urban wetland cocoyam corms

The cocoyam corms from the urban wetland sampling site, from which the soil was mildly acidic (pH 5.98 ± 0.06), contained lower concentrations of manganese (29.26 ± 11.47 mg kg^{-1} *d.w.*) than those from the soils (pH 5.39 ± 0.09) from the rural control site, from which the corms contained 101.16 ± 15.55 mg kg^{-1} *d.w.* This situation occurred even when the manganese (Mn) concentration in the urban wetland soils was higher than that in the soils from the control site (Table 1). Plants take up manganese as Mn^{2+}. This indicates a probable selective absorption of the heavy metal, depending on the soil pH and the total ionic strength arising from other metals present in the soil. The factors affecting Mn bioavailability include biological oxidation, in which microorganisms oxidize Mn^{2+}, thereby reducing the quantity of available manganese for absorption by plants. The biological oxidation of manganese is the greatest at pH 6.0–7.5 (Alexander 1977). Thus, it would appear that, considering the relative pH values of the soils, the observed Mn levels in the cocoyams are consistent with these suppositions.

Trace quantities of Mn in the human diet are a necessary requirement, reaching 2–3 mg day^{-1} (WHO 1973) for adults. Thus, when a 60 kg adult consumes an average of 600 g cocoyam corm in a week, the manganese intake would be 0.042 mg kg^{-1} body weight per day from the urban wetland corms, and 0.145 mg kg^{-1} body weight per day from those grown on the control site land. Nevertheless, Mn levels may reach >300 mg kg^{-1} *d.w.* in plants grown on soils with high Mn concentrations. Such plants tend to exhibit toxic effects associated with manganese, including brain lesions (Graham *et al.* 1988).

Cadmium (Cd) levels in wetland cocoyam

The Cd level in cocoyam corms from the urban wetland was 0.274 ± 0.092 mg kg^{-1} *d.w.*, while that in those from the control site was 0.116 ± 0.059 mg kg^{-1} *d.w.* (Table 1). The maximum permissible Cd limit for such crops is 0.1 mg kg^{-1} (Codex Alimentarius Commission 2001). The cocoyam crop grown on the urban wetland soils evidently contains Cd levels that distinctly exceed this maximum tolerable limit. Cd has been blamed for large-scale poisoning incidents (Wendelaar-Bonga & Lock 2003). The comparatively higher Cd levels in the soils of the urban wetland drainage system over those from the control site (Table 1) also are reflected in the cocoyam crop grown on the wetland. The provisional recommended tolerable weekly intake (PTWI) for cadmium is 7 μg kg^{-1} body weight (FAO/WHO 1993). Thus, if a 60 kg person consumes an average of 0.6 kg of cocoyam in a week, the Cd intake from the urban wetland corms would be 2.7 μg kg^{-1} body weight, and 1.0 μg kg^{-1} body weight from those from the control site.

Zinc (Zn) concentrations in urban wetland cocoyam corms

The Zn levels in plants are a function of various soil and climatic factors (Kiekens 1995), including pH, organic matter content, microbial activity and the soil moisture regime. Plants absorb zinc as Zn^{2+}, and the normal range in plants is 1–400 mg kg^{-1} (Bowen 1979). The cocoyam corms from the urban wetland sampling site had a concentration of 111.27 mg kg^{-1} *d.w.*, while those from the control site had a concentration of 137.38 ± 13.61 mg kg^{-1} *d.w.* (Table 1). This finding contrasts with the expectations from the rather low Zn level in the rural wetland setting (7.50 ± 1.62 mg kg^{-1} *d.w.*), compared with that in the urban wetland cultivated soils (151.54 ± 9.22 mg kg^{-1} *d.w.*; Table 1). Thus, it would appear that, in spite of the relative Zn pollution in the urban wetland soils, the cocoyam plant is able to shield most of it from its corms. This may be attributable to soil Zn geochemical barriers, for example, while at the same time optimizing Zn absorption in zinc-deficient soils. The daily dietary Zn intake proposed as being adequate for adults is in the range of 12–15 and 15–35 mg day^{-1} for pregnant or lactating females (National Academy of Science 1989). Although Zn is required in such trace amounts in the body, its toxic effects from accidental excessive ingestion in the diet include stomach pains, diarrhoea and vomiting (Cances *et al.* 2003).

Lead (Pb) concentrations in cocoyam grown on urban wetland soils

The Pb concentration in the cocoyam corms from the arable urban wetland drainage system site was 5.06 ± 0.99 mg kg^{-1}, while that from those grown on the control site soils was 1.52 ± 0.45 mg kg^{-1} *d.w.* (Table 1). The mean Pb levels in the cocoyams grown in the urban wetland were higher than the maximum permissible limit of 2.5 mg kg^{-1} established by Indian Legislation (1954). Thus, it would appear that consumption of the food crop grown on the urban wetland over a period of time poses a human health risk. The elevated Pb level in the cocoyam crop is consistent with that observed in the urban wetland soils (Table 1). Thus, it also is reasonable to conclude that the Pb pollution observed in the urban wetland soils is evidently reflected in the cocoyam crop grown in them. The relatively unpolluted rural wetland soils (Table 1) results in mean Pb levels in cocoyam well within the maximum permissible limits. Lead and cadmium are two most commonly distributed metal poisons cited in large-scale poisoning incidents (Wendelaar-Bonga & Lock 2003).

Levels of heavy metals in sugarcane grown on urban wetland drainage system

The results of the analyses for the mean levels of Mn, Cd, Zn and Pb in the juice extract from the sugarcane stems grown on the control site and those from the urban wetland cultivation also are summarized in Table 1.

Manganese (Mn) in urban wetland sugarcane

Samples of juice extracts from the sugarcane stems grown on the rural wetland site exhibited an Mn level of 334.09 ± 38.60 mg kg^{-1} of juice, while those from the urban wetland drainage system was 57.82 ± 15.22 mg kg^{-1}. The sugarcane juice samples from the urban wetland cultivation exhibited lower Mn levels, although the soils indicated Mn pollution, relative to those of the control site (Table 1). A similar observation was made with the wetland cocoyam crop, an anomaly attributable to soil pH and biological oxidation of the more bioavailable Mn^{2+} species in the soil (Alexander 1977). Thus, the sugarcane juice extracts and the cocoyam corms from the urban wetland exhibited Mn levels within the normal range generally accepted for edible plants (20–100 mg kg^{-1}; Bowen 1979). The Mn levels in the sugarcane juice extracts from stems from the control site were within the threshold range in plants (300–500 mg kg^{-1}; Kabata-Pendias & Pendias 1984). In view of the Mn requirement of 2–3 mg day^{-1} for adults (WHO 1973), a 60 kg person ingesting an average of 0.6 kg of sugarcane juice per week from sugarcanes grown on the urban wetland would realize an Mn intake of 0.083 mg kg^{-1} body weight per day, and 0.477 mg kg^{-1} weight per day from those from the rural control wetland site.

Cadmium (Cd) in Urban Wetland-grown Sugarcane

The Cd concentration in the sugarcane juice extracts from the stems cut from the control site was

0.178 ± 0.096 mg kg^{-1} of juice, while that in the food crop from the urban cultivation site was 0.757 ± 0.207 mg kg^{-1} juice (Table 1). The Cd concentration in all the sugarcane juice extract samples in this study was above the maximum permissible limit of 0.1 mg kg^{-1} in the stalk and stem, as well as the root and tuber of vegetables (Codex Alimentarius Commission 2001). Considering that the Cd level in the urban wetland arable soil was 1.452 ± 0.415 mg kg^{-1} *d.w.*, as opposed to 0.741 ± 0.447 mg kg^{-1} *d.w.* for the rural control setting (Table 1), it would appear that the sugarcane stem absorbs this toxic heavy metal to a larger extent that the cocoyam corm. Thus, the Cd intake for a 60 kg individual consuming an average of 600 g of sugarcane juice per week from the stems grown on the urban wetland soils is 7.6 μg kg^{-1} body weight. This level only slightly exceeds the PTWI of 7 μg kg^{-1} recommended by FAO/WHO (1993). Thus, it is probable that over-consumption of the sugarcane grown on the urban wetland might pose a human health hazard related to cadmium intake over time.

Zinc (Zn) concentrations in urban wetland sugarcane

The extracts from the sugarcane stems grown on the control site yielded a Zn level of 42.95 ± 5.26 mg kg^{-1} of juice, while those from the urban wetland stems yielded 65.64 ± 15.37 mg kg^{-1} juice. Although these levels were significantly lower than those observed in cocoyam, the sugarcane stems yielded juice extracts with Zn levels roughly consistent with that in the soils on which they were grown (Table 1). The Zn pollution in the urban wetland soils also was reflected in the Zn level in the juice extracts from the sugarcane stems. Nevertheless, the observed Zn concentrations in the juice extracts were still within the normal range of 1–400 mg kg^{-1} for plants, as described by Bowen (1979).

Lead (Pb) Levels in Urban Wetland-grown Sugarcane

The mean Pb level in the sugarcane juice extracts from the stems grown on the urban wetland drainage system soils was about 4.74 ± 1.66 mg kg^{-1} of juice, while those from the stems from the rural control site was 2.60 ± 0.52 mg kg^{-1}. The Pb concentrations in the sugarcane from the urban wetland cultivation were significantly higher ($P = 0.0003$) than the maximum permissible limit of 2.5 mg kg^{-1} recommended by Indian Legislation (1954). The sugarcane stems grown on the rural wetland soils with normal Pb contents did not exhibit such relatively high levels. It appeared the Pb pollution observed in the urban wetland soils (Table 1) affected the nutritional quality of the sugarcane crop grown there. It appears, therefore, that excessive consumption of sugarcane in the mid-day heat of the African tropical sun is likely to pose health risks related to Pb poisoning. There is a possibility that plants may absorb Pb and other metals, not only by translocation from roots to leaves, but also directly through the leaves (Kabata-Pendias & Pendias 1992; Jinadasa *et al.* 1997). It also is likely, therefore, that the Pb from vehicles could influence Pb levels on vegetation growing along the roadside, especially in urban sites (Nyangababo 1987). Such realities also may be reflected with the elevated Pb levels in both cocoyam and sugarcane grown on the urban wetland, resulting from its aerial deposition onto the plant leaves.

CONCLUSIONS

These study results provide conclusive evidence that heavy metal pollution in an urban wetland may eventually reach the dining table, either through the food crops grown directly on the soils, or via the water and the fish in the lake into which the wetland system drains. All the cocoyam and sugarcane samples drawn from the urban wetland drainage system in this study were relatively polluted with cadmium and lead, although the two crops were found to differ in their abilities of uptake and accumulate these heavy metal pollutants. Routine consumption of the food crops grown on the wetland by unaware urban residents could pose serious cadmium- and lead-exposure health risks over the long term. Thus, it is imperative that urban public health authorities inform the general public about the possible health hazards associated with the over-consumption of foods grown on urban wetland drainage soils. Informed urban consumers also may do well to exhibit greater caution about the sources of the seemingly fresh foods they purchase in the local markets.

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