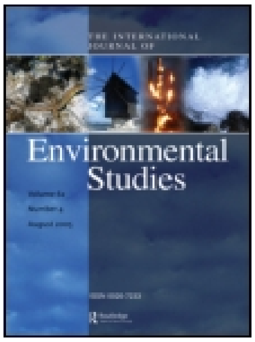

International Journal of Environmental Studies

ISSN: 0020-7233 (Print) 1029-0400 (Online) Journal homepage: https://www.tandfonline.com/loi/genv20

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To cite this article: Jolocam Mbabazi , J. Wasswa , J. Kwetegyeka & G.K. Bakyaita (2010) Heavy metal contamination in vegetables cultivated on a major urban wetland inlet drainage system of Lake Victoria, Uganda, International Journal of Environmental Studies, 67:3, 333-348, DOI: 10.1080/00207231003612613

To link to this article: https://doi.org/10.1080/00207231003612613

International Journal of Environmental Studies,
Vol. 67, No. 3, June 2010, 333–348

Heavy metal contamination in vegetables cultivated on a major urban wetland inlet drainage system of Lake Victoria, Uganda

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(Received 12 January 2010)

The population of the Ugandan capital, Kampala, located close to Lake Victoria, appears to be exposed to risk of ingesting the heavy metals Cadmium (Cd) and Lead (Pb) through vegetables in their diet. Lake Victoria is responsible for frequent torrential polluted runoffs in the city. The Nakivubo channel, the city's major wetland drainage system, empties directly into the lake. Vegetables are grown on the urban wetland soils. Heavy metal content in vegetables from the wetland cultivation sites was determined by wet acid digestion, with 87–92% recovery. The results showed that although the heavy metal levels of manganese (Mn), zinc (Zn), cadmium (Cd) and lead (Pb) were significantly higher than those in similar food crops from rural control sites, only Cd and Pb exceeded the World Health Organisation (WHO) maximum permissible levels. Cd and Pb pose serious human health risks. Early pollution control measures are advisable.

Keywords: Lake Victoria; Kampala; Urban wetland; Vegetables; Drainage system; Heavy metal pollution

1. Introduction

Investigative studies of heavy metal pollution in human food crops invariably include the soils on which they are grown. Relatively little is known about the effect of urbanisation on the soil quality in suburban wetland areas in Uganda, on which food crop cultivation is extensively practised. Pollution in the soils might eventually enter food chains through such crops, as the urban population is largely unaware of the threat. Urbanisation increases in Uganda with the shortage of land [1]. An increasing percentage of the country's population prefers to live and work in the city. The resident population of the capital Kampala was 774,000 in 1991 but increased to 1,209,000 in 2002 [2], and is now estimated to be well over two million. The city, Uganda's only urban district, takes the greatest share of the high rate of urbanisation and industrialisation, as well as the resulting pollution [3,4].

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International Journal of Environmental Studies
ISSN 0020-7233 print: ISSN 1029-0400 online
http://www.tandf.co.uk/journals
DOI: 10.1080/00207231003612613

Low-income earners in Kampala supplement their families' food requirements through cultivation of a wide range of crops and vegetables. The only readily accessible arable land is the suburban wetlands. Over 31 km^2, representing 16% of the city district's total land area, is under wetlands. Of these, the Nakivubo channel is by far the largest natural drainage system, covering an area of over 2.85 km^2 [5]. The channel drains directly into Lake Victoria, the second largest inland freshwater lake in the world, which serves as a reliable source of fresh water for both domestic and industrial use [6,7] for many towns, cities and inland ports in East Africa (figure 1). Lake Victoria, lying along the equator, is responsible for high annual rainfall and frequent torrential polluted runoffs in the city of Kampala, which is close to the giant water body.

The Nakivubo wetland can be cultivated all the year round, but it also acts as a dump-site for urban domestic waste. In the peri-urban areas, this wetland has been reclaimed and put under intensive cultivation, with vegetable growing accounting for over 50% of the agricultural activities in and around the drainage system. Other cultivated crops include cassava, cocoyam and sugarcane. These foods are not only consumed by the growers themselves but are also sold in markets and by the roadside daily.

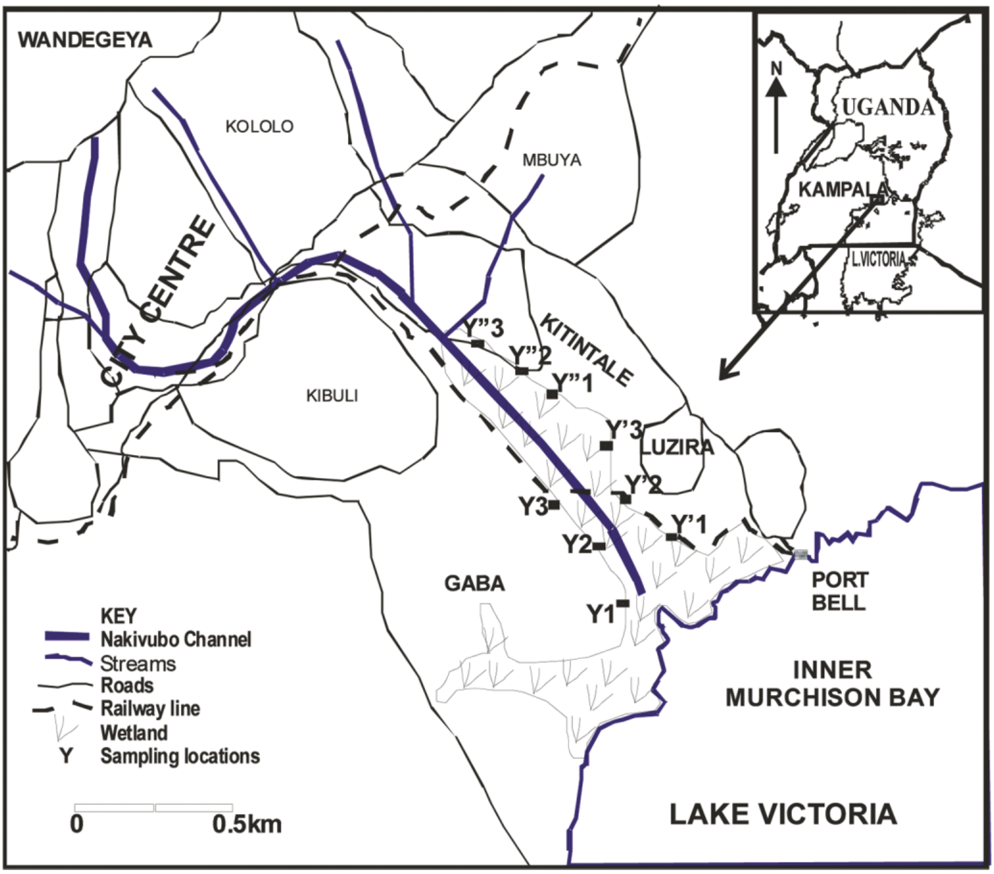

Figure 1. Schematic map of Kampala City showing major urban wetland drainage system to Lake Victoria (Nakivubo channel).

Before the 1990s crop farming used to be confined to the upper and drier areas of the wetland, but currently encroachment is proceeding towards lower areas at an alarming rate. The only restriction to further extensive wetland reclamation is increased water-logging and poorer crop yields as one approaches wetter areas near the lake. There are also a number of industrial, commercial and domestic developments along the catchment areas of the sub-channels and streams leading to the wetland. These include small-scale Pb laden car-battery recycling industries, filling stations, motor car garages and service centres, car-washing bays, scrap metal depots, and, among them, densely populated low-cost settlements. These human activities discharge untreated effluent and wastewater into the water systems and also directly onto the land. Other non-point sources of contamination affecting agricultural soils include inputs such as fertilisers, pesticides, sewage sludge, organic manures and composts [8]. Motor vehicle emissions are a source of heavy metal pollutants due to combustion of leaded petrol, spills of motor oils as well as wearing of tyres, brake pads, bearings and radiators. Other routes of entry of heavy metal pollutants into soils and water bodies include the wet, dry or occult, depositions of atmospheric particulates from a busy modern urban establishment [9].

Heavy metals [10] find their way into human food chains when polluted soils are used for agriculture [11–16], their potential toxicity being largely controlled by their physico-chemical modifications [17,18]. The food crops grown on the urban wetland system receive heavy metal pollution from the soils owing to surface runoff, atmospheric deposition, untreated effluent and wastewater discharged into the wetland by the various urban activities. When the concentrations of the heavy metals are high in the wetland soils it is likely that crops grown there will also show a high total heavy metal content [14,16]. Consequently, there was a need for systematic studies to evaluate the levels of heavy metal pollutants Mn, Cd, Zn and Pb in the soils and in a number of selected vegetable crops commonly grown on them in an effort to establish the full extent of the problem.

The aim of our study was to establish the levels of Mn, Zn, Cd and Pb in the soils from a major urban wetland as they accumulated in the food crops grown on the same land, with the hope that the authorities might apply anti-pollution measures to safeguard human health and improve the quality of Lake Victoria.

2. Materials and methods

2.1. Sampling in the wetland cultivation study sites

Soil samples and vegetable crop specimens in the control wetland and in the urban wetland cultivation sites were taken at points that were at least 100 metres apart. In these places there was intensive cultivation of food crops by the wetland encroachers. The control sites were in the wetlands of Ntungamo (south-western Uganda), Kayunga (eastern Uganda) and Luweero (central Uganda), which were chosen because of their rural setting far removed from urban industrial and domestic sources of pollution. In each of the study sites three locations (X1–X3 and Y1–Y3) were selected, from which soil samples and specimens of various ready vegetable crops were freshly harvested after a modest payment to the small-holding farmers (figure 1). Samples of top soil down to 25 cm depth were taken using a hand auger from each of the three locations at each of the selected sites. Soil sampling was done at each site on three different rainy monthly occasions, October 2007, January and March 2008. This brought the number of soil samples, n, to 27 for the test urban wetland site and for all the three control wetland sites.

But the distribution of ready vegetable crops at each location was uneven. It was rare to find the vegetable species of interest all on one location. The soil samples and the vegetable specimens were separately packed in labelled plastic bags and transported in ice-coolers to the laboratory. The time lapse between the sampling process and the first laboratory analyses was usually two days, the delay being mainly due to travel. To avoid confusing samples, we collected vegetable specimens together with the soil samples on location rather than buy them from off-loading trucks in the city markets.

2.2 Analytical procedures

The soil pH and electrolytic conductivity (EC) measurements [19] were made as follows. The soil sample (20.0 ± 0.1 g) was measured into a 250 ml conical flask and 50 ml de-ionised water added. The mixture was thoroughly shaken for 10 min and allowed to stand for 30 min. Shaking was repeated for a further 2 min. The pH of the soil suspension was subsequently measured using a pH meter. The soil suspension was allowed to settle for 1 h before the EC of the supernatant liquid was taken using an EC bridge.

To determine the total concentrations of Mn, Zn, Cd and Pb in the wetland soils, soil samples were first spread out on aluminium foil and dried in an oven at 103°C for 24 h to a constant mass. 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 into a clean dry 250 ml Pyrex conical flask. 50 ml de-ionised distilled water, glass beads and *aqua regia*, that is, 50 ml nitric acid/hydrochloric acid (3:1, *v/v*) were added, and a funnel placed on top. The contents were heated in a fume cupboard on an electric hot plate set at medium heat until digestion was complete.

On cooling, 5 ml of the nitric acid (analytical grade) 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 de-ionised distilled water followed by 25 ml of the hydrochloric acid added. The boiling mixture was then cooled, quantitatively transferred to a 100 ml volumetric flask and made up to the mark. 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, less the samples. Analysis for heavy metals [20,21] was carried out with an atomic absorption spectrophotometer (AAS), Perkin-Elmer, Model 2380.

Determination of the total concentrations of the heavy metals in the vegetables required that the crops, *viz*. cabbages, carrots, cauliflower, cucumbers, egg plants, green peppers, parsley, pumpkins, spinach, sweet potatoes and tomatoes be thoroughly washed under the tap to remove all traces of soil and dirt. They were subsequently rinsed with de-ionised distilled water. The specimens were prepared according to a standard procedure [20]. The vegetables were cut into small pieces using a stainless steel knife and dried in an oven at 103°C for 24 h to constant mass, taking due care to avoid charring. After cooling, they were carefully ground in a ceramic mortar and passed through a 2 mm nylon sieve. The finely ground sample (1.250g) was weighed into a clean dry 250 ml Pyrex conical flask. 25 ml concentrated nitric acid was added, followed by glass beads and a funnel fitted on 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 and the mixture concentrated to ~10 ml.

On cooling, 4 ml of 30% hydrogen peroxide was added and the contents swirled and reheated for another 10 min. When the solution turned clear the contents were cooled, quantitatively transferred to a 25 ml volumetric flask and made up to the mark using de-ionised distilled water. After settling for 5 h the supernatant solution was carefully transferred to plastic bottles which were then sealed with plastic covers and labelled before being taken to the analytical laboratory for spectrophotometric analysis for the heavy metals using the AAS.

2.3 Recovery experiments

To test the efficiency, or to obtain fortified sample recoveries, of the technique used, pure standard 1×10^{-4} M aqueous solutions of each of Mn^{2+}, Cd^{2+}, Zn^{2+} and Pb^{2+} were prepared by dissolving requisite amounts of soluble salts of the metals in de-ionised distilled water, making up to 1 litre, and diluting 100 ml of the solution ten-fold. 500 ml of this solution was then subjected to a similar treatment as described earlier. Recoveries of 87–92% were obtained, which suggested that the method used was reliable. Consequently, no adjustment was made in the heavy metal data since the recoveries were >70%.

3. Results

3.1 Total heavy metal levels in rural and urban wetland cultivated soils

Measurements for the physico-chemical parameters showed that whereas the control site soils had a mean pH of 5.57 ± 0.09 and EC 145 ± 3 ($n = 27$), the urban wetland soils recorded a mean pH of 6.38 ± 0.08 and EC 171 ± 6 μS/cm. The soils had pH and EC values within the acceptable range for agricultural soils. But, the significantly higher EC value for the urban wetland soils over a wide area ($1^1/_2$ km length) suggested a presence of more soluble ionic substances, among them basic metallic hydroxides, carbonates and hydrogencarbonates that would in turn reduce the relative acidity of the soils over that of the control sites.

The soil concentrations were in the ranges Mn 183–804, Zn 5.8–11.7, Cd < 0.001–1.0 and Pb 9.7–21.1 mg/kg dry weight (*d.w.*) for the control sites, and 470–930, 141–205, 1.0–2.0, 41.7–63.9, respectively, for the urban wetland (figure 2). Heavy metal concentrations in the soil samples investigated were in the decreasing order: Mn > Zn > Pb >> Cd. The higher mean total levels of heavy metals (table 1) in the reclaimed soils of the urban wetland showed that pollution of the wetland had occurred.

Average Mn values of 497.14 ± 0.97 mg/kg *d.w.* were found in the soils from the wetland control sites. The normal range of Mn in agricultural soils has been reported as 20–1000 mg/kg [22]. The mean total level of Mn (770.68 ± 0.87 mg/kg *d.w.*) in the soil samples from the urban wetland site (table 1), though still within the range generally accepted for typically uncontaminated soils, showed a significant increase over that in the soils from the wetland

Table 1. Mean levels of pH, EC and heavy metals in studied cultivated wetland soils

			Concentration (mg/kg *d.w.*)			
Sites	pH	EC[a]	Mn	Zn	Cd	Pb
Rural control wetlands ($n = 27$)						
	5.57±0.09	145±3	497.14±0.97	6.90±0.71	0.681± 0.009	11.73±0.09
Urban wetland drainage ($n = 27$)						
	6.38±0.08	171±6	770.68±0.87	177.45 ±0.94	1.559±0.008	49.94±0.07

[a] Units: μS/cm.

control sites. The elevated soil levels of Mn in the two study areas may be attributable to geological factors, to which anthropogenic sources such as scrap metal processing might have made a notable further contribution for the urban wetland.

Mean Zn levels of up to 40 mg/kg were reported for non-contaminated soils [23]. The comparatively low average Zn concentration of 6.90 ± 0.71 mg/kg *d.w.* found in the soils from the wetland control sites were well within the levels of uncontaminated soils. The observed mean total levels of Zn 177.45 ± 0.94 mg/kg *d.w.* in the soils from the urban wetland drainage system (table 1) showed a significant increase over those in the control sites. This indicated comparatively high Zn contamination in the urban wetland soils. This is perhaps not too surprising, since galvanized iron has been the main roofing material in Kampala for over a century. Corrosion of such zinc-coated corrugated iron releases considerable amounts of zinc into the soil and its associated drainage channels, the leaching of which concentrates the metal in the wetland water catchment area. There is a growing shift, however, to the use of fired clay roofing tiles particularly for suburban residential housing. The critical total soil concentration for Zn above which toxicity is considered possible has been put at 70–400 mg/kg [24].

Whereas the mean cadmium concentrations of 0.681 ± 0.009 mg/kg *d.w.* found in the soils from the control sampling sites were incomparable to those in the earth's crust quoted as 0.1 mg/kg [22,25], they remain within the mean cadmium levels of 0.01–1.00 mg/kg in non-volcanic soils reported by Korte [26]. The soils in the central Uganda plateau are mainly non-volcanic in origin save for the north-east and south-west of the country where there are volcanic highlands. The mean total cadmium level of 1.559 ± 0.008 mg/kg *d.w.* (table 1) observed in the soil samples from the urban wetland cultivation site was above the permissible concentrations [26,27] of 0–1.0 mg/kg for soils used for agriculture. Thus, the soils from the Nakivubo urban wetland drainage system are contaminated with cadmium relative to those from the control sites. The traces of cadmium embedded in the scrap metal processed by small-scale industries distributed all over the outskirts of the city, and their untreated effluent, could be blamed for the relative rise of the toxic metal in the urban wetland soils.

In this study, the observed mean total Pb levels of 11.73 ± 0.09 mg/kg *d.w.* in the soil samples from the rural wetland control sites were comparable to those in the Earth's crust reported as 13 mg/kg [28], and to those of soils from areas remote from human activity estimated to be in the range of 5–25 mg/kg [29]. The soils from the urban wetland cultivation site recorded a mean total Pb level of 49.94 ± 0.07 mg/kg *d.w.* (table 1). The elevated level of this toxic metal in the urban wetland soils may be attributed to car-washers carrying out their washing work and emptying dead lead-acid accumulators along the streams and channels leading to the wetland over a long period. The effect of untreated effluent from a number of small-scale Pb laden car battery recycling industries, the runoff, and slow aerial deposition of particulates from the combustion of leaded fuel from the congested city transport sector were not underestimated.

3.2 Total heavy metal concentrations in rural and urban wetland grown vegetables

Vegetable growing areas situated in, or near, sources of pollution have an elevated risk of potential contamination. In determining the heavy metal levels, therefore, the primary aim was to highlight the contamination status of the urban wetland soils and correlate it to the metal concentrations found in the vegetables grown on them. Such studies may lead to the application of early measures to combat the pollution in the urban wetland, for the sake of public health. Table 2 shows the total heavy metal concentrations in various selected vegetables

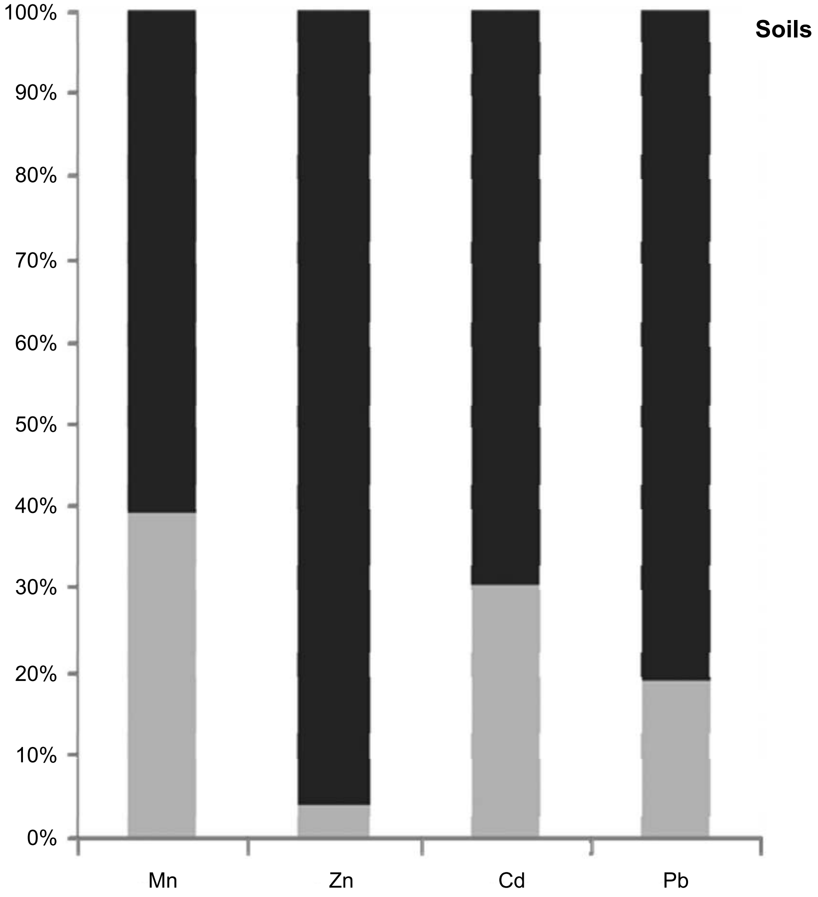

Figure 2. Relative magnitudes of mean levels of heavy metals in cultivated soils.
▨ Rural wetland; ■ Urban wetland

freshly harvested from rural and urban wetland cultivation sites. Table 3 shows the mean total metal levels in the vegetables from all the polluted and unpolluted soils for all the analyses performed on the oven-dried food crops. Distribution of Mn, Zn, Cd and Pb levels in most of the vegetables sampled (figure 3) followed a trend similar to soil heavy metal concentrations (figure 2). Levels were highest in vegetables from reclaimed urban wetland soils and least in those grown on upcountry wetland drainage systems.

The mean levels of Mn were on average higher in urban than in rural wetland grown vegetables by about 50% (table 3). The concentrations of the metal in the respective soils were higher by a similar percentage (table 1). In spite of this, green peppers cultivated on the urban wetland had Mn levels lower than upcountry ones, 44.28 ± 0.87 against 94.90 ± 0.65 mg/kg *d.w.*, respectively (table 3). This was so even when the Mn concentration in the urban wetland soils was higher than that from the control sites (table 1). A similar observation was made with the wetland spinach crop, an anomaly that has been attributed to soil pH and the amount of bioavailable metal in the soil. There was probably selective absorption of the

Table 2. Total heavy metal levels in vegetables from various rural and urban wetland cultivation sites (the tolerances are mean errors)

	Concentration (mg/kg *d.w.*)			
Samples	Mn	Zn	Cd	Pb
	a) Rural wetland control sites			
	i) Ntungamo			
Cabbages	38.54 ± 0.82	27.93 ± 0.02	0.039 ± 0.003	0.048 ± 0.002
Carrots	41.03 ± 0.98	16.71 ± 0.16	< 0.001	0.007 ± 0.002
Cauliflower	42.16 ± 0.88	17.10 ± 0.37	0.455 ± 0.005	0.008 ± 0.004
Cucumbers	26.09 ± 0.88	8.07 ± 0.01	0.004 ± 0.002	0.005 ± 0.002
Egg plants	21.01 ± 0.14	94.63 ± 0.42	0.004 ± 0.002	0.004 ± 0.003
Green peppers	91.48 ± 0.95	10.69 ± 0.71	0.008 ± 0.007	0.003 ± 0.001
Parsley	41.34 ± 0.28	6.08 ± 0.18	0.017 ± 0.001	0.003 ± 0.001
Pumpkins	30.06 ± 0.78	19.67 ± 0.74	0.008 ± 0.005	0.007 ± 0.004
Spinach	93.04 ± 0.54	8.13 ± 0.07	0.006 ± 0.005	0.009 ± 0.002
Sweet potatoes	45.86 ± 0.48	9.54 ± 0.70	0.008 ± 0.003	0.004 ± 0.001
Tomatoes	20.87 ± 0.12	9.56 ± 0.80	0.019 ± 0.006	0.009 ± 0.003
	ii) Kayunga			
Cabbages	56.30 ± 0.87	35.63 ± 0.02	< 0.001	0.037 ± 0.001
Carrots	51.10 ± 0.47	13.69± 0.14	0.004 ± 0.002	0.009 ± 0.003
Cauliflower	28.00 ± 0.34	33.59 ± 0.69	0.117 ± 0.003	0.009 ± 0.006
Cucumbers	21.00 ± 0.81	17.75 ± 0.03	< 0.001	0.008 ± 0.004
Egg plants	22.50 ± 0.14	151.17 ± 0.56	0.007 ± 0.006	0.007 ± 0.001
Green peppers	92.53 ± 0.67	20.81 ± 0.65	0.025 ± 0.003	0.005 ± 0.002
Parsley	33.65 ± 0.45	8.64 ± 0.66	0.016 ± 0.006	0.002± 0.001
Pumpkins	30.45 ± 0.82	28.37 ± 0.44	0.007 ± 0.002	0.025 ± 0.007
Spinach	90.79 ± 0.54	15.33 ± 0.14	0.006 ± 0.004	0.008± 0.003
Sweet potatoes	41.69 ± 0.21	6.97 ± 0.56	0.010 ± 0.002	0.005 ± 0.004
Tomatoes	25.67 ± 0.28	14.61 ± 0.85	< 0.001	0.006 ± 0.002
	iii) Luweero			
Cabbages	53.14 ± 0.98	20.32 ± 0.02	< 0.001	0.071 ± 0.003
Carrots	27.96 ± 0.55	17.00 ± 0.12	0.029 ± 0.004	0.017 ± 0.004
Cauliflower	21.22 ± 0.46	18.64 ± 0.44	0.823 ± 0.004	0.020 ± 0.002
Cucumbers	28.18 ± 0.65	4.24 ± 0.04	0.005 ± 0.001	0.008 ± 0.006
Egg plants	16.52 ± 0.35	156.61 ± 0.43	0.016 ± 0.004	0.016 ± 0.005
Green peppers	100.59 ± 0.43	15.87 ± 0.53	0.021 ± 0.005	0.007 ± 0.003
Parsley	46.03 ± 0.38	6.49 ± 0.36	0.009 ± 0.002	0.004 ± 0.001
Pumpkins	27.27 ± 0.92	9.03 ± 0.74	0.009 ± 0.002	0.010 ± 0.004
Spinach	65.29 ± 0.51	6.60 ± 0.03	0.009 ± 0.006	0.010 ± 0.004
Sweet potatoes	50.03± 0,78	5.99 ± 0.41	0.036 ± 0.002	0.003 ± 0.001
Tomatoes	36.94 ± 0.53	25.78 ± 0.45	0.044 ± 0.003	0.005 ± 0.001

Table 2. (*Continued*)

	Concentration (mg/kg *d.w.*)			
Samples	Mn	Zn	Cd	Pb
b) Urban (Nakivubo channel) wetland drainage site				
i) Gaba				
Cabbages	59.05 ± 0.25	147 78 ± 1.13	0.314 ± 0.003	5.03 ± 0.03
Carrots	81.05 ± 0.26	69.02 ± 0.32	0.451 ± 0.005	4.10 ± 0.04
Cauliflower	58.76 ± 0.11	139.67 ± 0.17	0.486 ± 0.004	3.71 ± 0.05
Cucumbers	51.43 ± 0.91	39.52 ± 0.48	0.099 ± 0.011	6.17 ± 0.07
Egg plants	40.86 ± 0.66	91.38 ± 0.29	0.475 ± 0.004	4.70 ± 0.02
Green peppers	49.00 ± 0.91	59.69 ± 0.59	0.693 ± 0.009	1.50 ± 0.04
Parsley	79.04 ± 0.90	39.96 ± 0.49	0.728 ± 0.005	0.63 ± 0.07
Pumpkins	87.65 ± 0.67	46.99 ± 0.58	0.279 ± 0.004	0.91 ± 0.04
Spinach	65.07 ± 0.24	59.12 ± 0.44	0.459 ± 0.003	2.70 ± 0.03
Sweet potatoes	59.64 ± 0.72	15.10 ± 0.59	0.086 ± 0.001	3.65 ± 0.07
Tomatoes	49.07 ± 0.67	54.67 ± 0.45	0.536 ± 0.004	4.30 ± 0.08
ii) Luzira				
Cabbages	67.01 ± 0.53	190.40 ± 0.95	0.430 ± 0.001	5.06 ± 0.04
Carrots	56.05 ± 0.59	60.60 ± 0.45	0.266 ± 0.006	3.60 ± 0.01
Cauliflower	26.03 ± 0.21	144.60 ± 0.06	0.747 ± 0.006	2.06 ± 0.04
Cucumbers	28.60 ± 0.96	39.60 ± 0.24	0.168 ± 0.008	3.14 ± 0.05
Egg plants	41.01 ± 0.76	126.65 ± 0.52	0.279 ± 0.006	2.05 ± 0.04
Green peppers	30.75 ± 0.88	75.65 ± 0.31	0.459 ± 0.008	2.51 ± 0.09
Parsley	59.34 ± 0.53	40.61 ± 0.32	0.594 ± 0.004	0.70 ± 0.09
Pumpkins	97.85 ± 0.34	69.37 ± 0.43	0.218 ± 0.007	1.15 ± 0.04
Spinach	75.34 ± 0.18	43.50 ± 0.63	0.303 ± 0.004	2.55 ± 0.03
Sweet potatoes	85.45 ± 0.62	35.67 ± 0.82	0.197 ± 0.002	4.61 ± 0.05
Tomatoes	37.91 ± 0.44	60.54 ± 0.83	0.883 ± 0.005	2.94 ± 0.04
iii) Kitintale				
Cabbages	81.15 ± 0.84	135.94 ± 0.83	0.531 ± 0.005	5.09 ± 0.05
Carrots	46.05 ± 0.44	56.44 ± 0.28	0.336 ± 0.007	1.60 ± 0.04
Cauliflower	61.49 ± 0.31	150.22 ± 0.19	0.510 ± 0.002	3.26 ± 0.12
Cucumbers	44.26 ± 0.86	35.84 ± 0.42	0.090 ± 0.005	2.99 ± 0.03
Egg plants	22.71 ± 0.53	87.13 ± 0.34	0.611 ± 0.002	3.15 ± 0.03
Green peppers	53.09 ± 0.82	37.73 ± 0.78	0.859 ± 0.003	3.49 ± 0.05
Parsley	68.74 ± 0.64	30.37 ± 0.39	0.262 ± 0.003	0.38 ± 0.05
Pumpkins	117.98 ± 0.43	52.81 ± 0.43	0.322 ± 0.007	0.97 ± 0.04
Spinach	39.80 ± 0.27	50.74 ± 0.85	0.312 ± 0.003	1.95 ± 0.06
Sweet potatoes	94.82 ± 0.82	24.53 ± 0.74	0.065 ± 0.001	1.67 ± 0.03
Tomatoes	15.23 ± 0.99	57.80 ± 0.67	0.864 ± 0.003	3.86 ± 0.04

element depending on the nature of the vegetable species and on the total ionic strength arising from other metals present in the soil. Plants take up manganese in its cationic form, Mn^{2+}.

Bioavailability is also affected by biological oxidation, in which microorganisms oxidise Mn^{2+} and reduce the amount of metal available for absorption. Biological oxidation of manganese is greatest at pH 6.0–7.5 [30]. It appeared, therefore, taking the relative pH values (table 1) of the soils into account, that biological oxidation seemed to have the upper hand in controlling Mn absorption in the urban wetland, so rich in organic matter. As a result, green peppers and spinach from the urban wetland had Mn levels which were nevertheless still within the normal range (20–100 mg/kg) generally accepted for edible plants [22].

Trace amounts of manganese in human diet are a necessary requirement, reaching 2–3 mg/day [31] for adults. If a 60 kg person consumed 600 g pumpkin in a week, the manganese intake would on average be 0.145 mg/kg body weight per day from the urban wetland vegetable crop and 0.042 from that grown on the control site land. Where plants are grown on soils with high concentrations of the heavy metal, manganese levels may reach > 300 mg/kg *d.w.* Such plants when ingested tend to show manganese-related toxic effects, including brain lesions [32].

Zinc pollution in the urban wetland soils was also reflected in the levels in the vegetables. Concentrations of Zn in plants are often a function of various soil and climatic factors [33]. These include pH, organic matter content, microbial activity and the moisture regime of the soil, which is why rainy months were chosen for the study. The normal range in plants is 1–400 mg/kg [22]. Zinc levels were greatest in broadleaf vegetables, mainly cabbages and cauliflower, which exhibited a mean of 158.04 ± 0.97 and 144.83 ± 0.14 mg kg^{-1} *d.w.*, respectively. A study by Davies and White [34] reported Zn concentrations of 39.0 to 710 mg kg^{-1} *d.w.* in vegetables grown on Zn contaminated soils. Egg plants from the urban wetland sampling site had a concentration of 101.72 ± 0.97 while those from the control sites had 134.07 ± 0.47 mg Zn /kg *d.w.* (table 2). This was in contrast to expectation from the low level (6.90 ± 0.71) of the heavy metal in the rural wetland setting compared to that (177.45 ± 0.94 mg/kg *d.w.*) found in the urban wetland cultivated soils (table 1).

It seemed reasonable to assume that despite the zinc pollution in the urban wetland, the egg plant was able to shield its fruits from most of it, while at the same time optimising absorption in zinc-deficient soils. The daily dietary zinc intake proposed as adequate for adults are in the range 12–15 and 15–35 mg/day for pregnant or lactating females [35]. Although zinc is required in such trace amounts in the body, its toxic effects due to accidental excessive ingestion in the diet include stomach pains, diarrhoea and vomiting [12]. The observed concentrations of Zn in all the vegetable crops had not reached such alarming levels and were still within the normal range of 1–400 mg/kg for plants as described by Bowen [22].

The concentration of Cd in all the vegetable samples investigated from the urban wetland areas under cultivation was above the maximum permissible limit of 0.1 mg/kg *d.w.* [36] (table 3). The comparatively higher levels of cadmium in the soils of the urban wetland drainage system over those from the control sites (table 1) were also reflected in the vegetable crops grown on the wetland. Cadmium has been blamed for large-scale poisoning incidents [37]. Consequently, FAO and WHO offer guidelines on the human intake of heavy metals. The provisional tolerable weekly intake (PTWI) recommended for cadmium is 7 μg/kg body weight [38].

The tomato seemed to accumulate the toxic heavy metal to a larger extent than the other vegetables (table 2). Tomatoes were the most frequently consumed vegetables both in urban and rural homesteads, both as salads and as seasoning. In this respect, if a 60 kg person consumes an average of 0.6 kg of fresh unprocessed tomatoes in a week the intake of

Table 3. Mean total heavy metal levels in vegetable crops from various rural and urban wetland cultivation sites (the tolerances are mean errors)

	Concentration (mg/kg *d.w.*)							
	Mn	Zn	Cd	Pb	Mn	Zn	Cd	Pb
Samples	a) Rural control wetlands				b) Urban test wetland			
Cabbages	49.34 ± 0.89	27.96 ± 0.02	0.013 ± 0.001	0.052 ± 0.002	69.07 ± 0.54	158.04 ± 0.97	0.425 ± 0.003	5.06 ± 0.04
Carrots	40.03 ± 0.67	15.80 ± 0.14	0.011 ± 0.002	0.011 ± 0.003	61.05 ± 0.43	62.02 ± 0.35	0.351 ± 0.006	3.10 ± 0.03
Cauliflower	30.11 ± 0.56	23.11 ± 0.50	0.465 ± 0.003	0.037 ± 0.004	48.76 ± 0.21	144.83 ± 0.14	0.581 ± 0.004	4.81 ± 0.07
Cucumbers	25.09 ± 0.78	10.02 ± 0.03	0. 009 ± 0.001	0.007 ± 0.004	41.43 ± 0.91	38.32 ± 0.38	0.119 ± 0.008	4.10 ± 0.05
Egg plants	20.01 ± 0.21	134.07 ± 0.47	0.009 ± 0.004	0.009 ± 0.003	34.86 ± 0.65	101.72 ± 0.97	0.455 ± 0.004	3.30 ± 0.03
Green peppers	94.90 ± 0.65	15.79 ± 0.63	0.018 ± 0.005	0.005 ± 0.002	44.28 ± 0.87	57.69 ± 0.56	0.673 ± 0.007	2.50 ± 0.06
Parsley	40.34 ± 0.37	7.07 ± 0.40	0.014 ± 0.003	0.003 ± 0.001	69 04 ± 0.69	36.98 ± 0.40	0.528 ± 0.004	0.57 ± 0.07
Pumpkins	29.26 ± 0.84	19.69 ± 0.64	0.008 ± 0.003	0.014 ± 0.005	101.16 ± 0.48	56.39 ± 0.48	0.273 ± 0.006	1.01 ± 0.04
Spinach	83.04 ± 0.53	10.02 ± 0.08	0.007 ± 0.005	0.009 ± 0.003	60.07 ± 0.23	51.12 ± 0.64	0.358 ± 0.003	2.40 ± 0.03
Sweet potatoes	45.86 ± 0.49	7.50 ± 0.90	0.018 ± 0.003	0.004 ± 0.002	79.97 ± 0.72	25 10 ± 0.43	0.116 ± 0.001	3.31 ± 0.05
Tomatoes	20.87 ± 0.31	16.65 ± 0.70	0.021 ± 0.001	0.007 ± 0.003	34.07 ± 0.67	57.67 ± 0.65	0.761 ± 0.004	3.70 ± 0.08

cadmium from the urban wetland crop would be 1.09 and 0.03 μg/kg body weight from those from the control sites. Thus, overconsumption of tomatoes grown on the urban wetland might in time pose a human health threat associated with exposure to cadmium.

The range of lead concentrations in the vegetables from both the control site soils and the arable urban wetland drainage system was 0.003 ± 0.001 to 5.06 ± 0.04 mg/kg *d.w.* (table 3). The elevated level of lead in the vegetable crops was commensurate to that observed in the urban wetland soils (table 1) on which they were cultivated. Higher Pb values, especially in broadleaf vegetables, of 54 mg kg $^{-1}$ *d.w.* have been reported [13] in more polluted soils. The mean levels of lead in vegetables in the urban wetland were higher than the maximum permissible limit of 2.5 mg/kg according to Indian legislation [39] while that set by the ANZFA [40] for Pb, like that of Cd, was 0.01 mg kg^{-1} fresh weight. The unpolluted rural wetland soils (table 1) gave mean levels of lead in similar food crops that were within the former maximum permissible limit. As a result, there seemed to be a lead exposure health risk arising out of consumption over a length of time of the food crops grown on the urban wetland. Lead and cadmium are two most commonly distributed metal poisons that have been cited in large-scale poisoning incidents [37].

4. Discussion

Figure 2 indicates the extent of heavy metal contamination in the urban wetland soils relative to the rural (background) levels, expressed on a linear percentage scale. Pollution was evident in the urban wetland drainage top soil and in the vegetable crops grown there (figure 3), and related very closely to the sources of heavy metal pollution in Kampala. If the urban wetland soils and the vegetables grown on them were uncontaminated with heavy metal, the borderline would be at approximately the 50% level. The observation that the urban wetland soil and vegetable bars are longer than the corresponding rural ones indicates relative contamination of the soils and the vegetables cultivated in them. Figure 2 showed that contamination of the urban wetland soils was in the order: Zn > Pb > Cd > Mn, whereas the degree of contamination in the vegetables grown on the same wetland (figure 3) decreased in the order: Pb > Cd > Zn > Mn. It was assumed that a similar order of the metals in the soils was not reflected in the crops because of selective absorption by plants.

Cadmium and lead are two of the most toxic heavy metals known, mercury and arsenic notwithstanding. The top soils sampled from the wetland contained mean concentrations of Mn (770.68 ± 0.87), Zn (177.45 ± 0.94), Cd (1.559 ± 0.008) and Pb (49.94 ± 0.07 mg kg^{-1} *d.w.*). The reported normal range of Zn of 11–86 mg kg^{-1} for unpolluted soils [40] compared favourably with those observed with the rural wetland control sites (table 1), but was much exceeded in soils from the urban wetland arable land. Cadmium concentrations in the cultivated soils of the urban wetland were greater than those in the rural control wetlands, and also exceeded the normal range (0.001–0.7 mg kg^{-1}) reported for the world's soils [41]. Levels of Pb in soils in the urban wetland drainage system were higher than those from the control sites by a factor of four (table 1). The urban wetland levels exceeded those from the rural control sites and also the background levels reported for world soils by some 130 and 325% for Cd and Pb, respectively.

Vegetables from all the wetland cultivation sites contained levels in the ranges Mn (20–100), Zn (7–160), Cd (0.08–0.76), and Pb (0.003–5.06) mg kg^{-1} *d.w.* In addition, it was notable that broadleaf vegetables such as cabbages and cauliflower grown on polluted soils tended to accumulate greater concentrations of the heavy metals over root

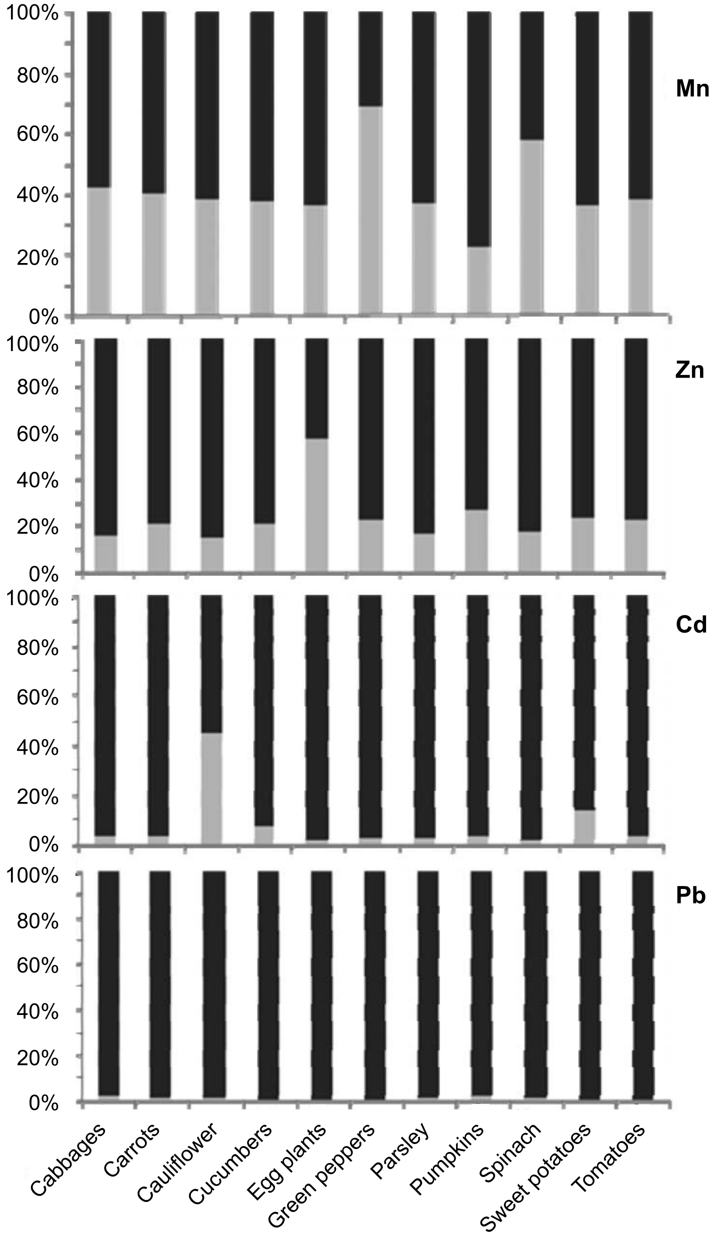

Figure 3. Relative magnitudes of mean total levels of heavy metals in vegetable crops from various rural and urban wetland cultivation sites.
■ Rural; ■ Urban

tuber vegetables such as carrots and sweet potatoes grown on the same location. This was contrary to expectation, since the latter were subject to direct absorption through and storage in the roots themselves. This finding was in agreement with Jinadasa *et al*. [42], who noticed that similar vegetable types stored heavy metals at a greater capacity than other vegetables. Small leaf vegetables like parsley gave values that did not deviate significantly from the rest. This strongly suggested possible aerial absorption of heavy metals by plants from perpetually polluted urban air.

All of the vegetables sampled from the urban wetland cultivation sites exceeded the 0.1 mg kg^{-1} maximum limit for Cd and Pb permissible in vegetable crops [40]. Soil properties may have further influenced the soil–plant transfer of the heavy metals. The mildly acidic nature, in part also attributable to pollution, of the top soils from the urban wetland (pH 6.38 ± 0.08) may have increased availability of metals for vegetable uptake, in particular cadmium. The relatively high accumulation of Cd in the vegetables from the urban wetland cultivation sites may be linked to this mildly acidic nature of the soil, resulting in greater Cd availability [8].

The uptake of aerial deposited Cd by vegetable leaves may also be a contributory factor. Lead levels were greatest in vegetables grown on the urban wetland, ranging from 0.57–5.06, compared to 0.003–0.052 mg kg^{-1}*d.w.* from similar crops in the rural wetlands, and exceeded the maximum limit for Pb (0.1 mg kg^{-1}) allowable in vegetable crops [40]. Since it is commonly believed that Pb was not readily translocated from roots to shoots [43], the high levels observed in the vegetables from the urban wetland may as well have resulted from aerial deposition of various modifications of the combined element [42].

This study highlighted the potential danger of heavy metal accumulation, especially Cd and Pb, in vegetables grown in the urban wetland drainage system areas. Almost all the vegetables from the wetland exceeded those in similar crops from rural wetland control sites, and also the WHO food standard guidelines for Cd and Pb. The routine consumption of the food crops grown on the wetland by unaware urban residents could pose serious health risks from exposure to cadmium and lead.

There should therefore be increased awareness of the risk in growing and consuming vegetables in urban wetland areas in general, and this should also be reflected in and regulated by the national environmental statutes and standards to minimise the potential health risks of ingesting vegetables suspected of containing high levels of heavy metals. It is imperative that the urban public health authorities make known to the general public the dangers associated with the overconsumption of foods grown on urban wetland drainage soils. Those consumers who have enough money can choose not to buy the vegetables sold in the city markets and by the roadside for fear of possible contamination. But the poor may have no option. The protection of law must be available to everyone. Informed urban consumers may be well advised to take greater care about the sources of the seemingly fresh foods in the local markets. They may wish to buy their vegetables directly from farmers upcountry.

The Uganda National Environment Management Authority (NEMA), under Ugandan law [44], has put in place statutory instruments (S.I.) for the proper management of national wetland drainage systems, contravention of which constitutes an offence. These generally discourage encroachment on wetlands for public, private, agricultural or other purpose, and will normally require a wetland resource use permit. S.I.153-11 states that 1) ‘Any person desiring to carry out any activity in a wetland shall make an application’, and that 2) ‘Any person who contravenes this order by the Executive Director commits an offence’. S.I.153-12 of the same law requires that ‘The Executive Director may issue a permit in Form B permitting the use of wetland resources’.

Nevertheless, few ordinary inhabitants in Uganda adhere to this directive and go about their daily subsistence agricultural activities on urban and other wetlands unhindered. The direct discharge of untreated effluent will continue to cause further increases in the heavy metal levels in the waters and soils of the suburban drainage systems, and ultimately, the wetlands. Many residents of Kampala purchase their fresh food there. The relevant authorities in the urban establishment should enforce measures for water-pollution control, particularly from industries.

Conclusion

There is conclusive evidence that heavy metal pollution in an urban wetland may eventually reach the dining table through the food crops grown directly on the soils. All the vegetable samples drawn from the urban wetland drainage system in this study were polluted with cadmium and lead, although individual crops were found to differ in their uptake and accumulation of the heavy metal pollutants. The relatively high levels of soil heavy metal contamination in the Nakivubo urban wetland appeared as a result of uncontrolled activities in Kampala. Further research should aim to quantify levels of heavy metals present in the urban atmosphere, the difference in mechanism between vegetable uptake from soil and through leaves, and the variations in uptake among different vegetable species.

Acknowledgements

We thank the Royal Belgian Government through the Belgian Technical Cooperation and Kyambogo University for financial support. We acknowledge the co-operation of Makerere University, Department of Chemistry, which allowed us to investigate these matters in the laboratories.

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