School of Animal Plant and Environmental Science

Risks of Urban Agriculture: Lead and Cadmium Intake by Kigali Residents from Locally Grown Produce

Anita Etale

A research report submitted to the Faculty of Science in partial fulfillment of the requirements for the degree of Master of Science.

Johannesburg, May 2011

DECLARATION

I declare that this research report is my own, unaided work. It is being submitted for the Degree of Master of Science in the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in any other University.

16th day of May 2011

Abstract

This study determined the concentrations of lead and cadmium in edible parts of *Colocasia esculenta*, *Amaranthus spp.*and *Ipomoea batata* cultivated on farms in industrially polluted sections of Nyabugogo Marsh in Kigali, Rwanda. The concentrations in all three crops exceeded European Union (EU) standards for metal concentration in food crops. *C. esculenta* roots (Taro) contained the highest concentration of lead (1.02 mg kg^{-1}) and cadmium (0.56 mg kg^{-1}), approximately ten and six times over the EU limits, respectively. Even though *I. batata* (sweet potato) contained the lowest concentrations of lead (0.75 mg kg^{-1}), this is almost eight times the upper limit. The highest bioaccumulation factors (the ratio of plant metal concentration to that of the soil in which it is found growing) for both metals were observed in amaranth plants. The concentrations of lead and cadmium in the farm soils were all acceptable based on EU standards (300mg kg^{-1} for lead and 3mg kg^{-1} for cadmium) with the highest being 285 ± 28.05 mg kg^{-1} and 1.75 ± 0.38 mg kg^{-1}, respectively.

The average daily consumption by an adult in the community living around the Marsh and where some of the produce is sold is 50g of amaranth, 120g of taro and 180g of sweet potato. Based on the metal concentration and these rates of consumption, the daily dietary intake of lead by an adult in the community from amaranth, taro and sweet potato is 1×10^{-4}, 3×10^{-4} and 4×10^{-4} mg kg^{-1} respectively. The daily intake of cadmium is 4×10^{-4}, 1.7×10^{-4} and 1.2×10^{-4} mg

kg^{-1} for amaranth, taro and sweet potato respectively. These metal intakes are well within the recommendations set forth by the World Health Organisation.

The community also has access to multiple sources of dietary and non dietary zinc such as beans, milk and rain water collected from zinc coated roofing sheets, which serves to ameliorate the effects of cadmium. It is however worth noting that survey data may have yielded overestimates of these zinc sources, due to the conditions under which the surveys were conducted i.e. in the hearing of neighbors due to the cramped nature of housing, which may have prompted respondents to inflate consumption quantities of expensive food items.

The calculated maximum recommended quantities for daily intake of the crops are very large and are unlikely to be consumed by the population i.e. >2kg of amaranth, >2 kg of taro and 3 kg of sweet potato per day for an adult. Additionally, because this is a poor community, access to such quantities of food on a daily basis is not likely. The community is therefore not exposed to health risks from consuming metal contaminated crops, largely because of the small quantities consumed. The local population is therefore at no immediate risk to exceeding metal consumption limits by consuming vegetables grown in the Nyabugogo Marsh, but the threats will likely increase if the pollution of the Marsh is not addressed.

Key words: Health risk, urban farming, heavy metals, *Colocasia esculenta*, *Amaranthus spp.*, *Ipomoea batata*, wetlands, Rwanda.

Dedication

To Michael and Jordan

Acknowledgements

I would like to thank my supervisor, Dr Deanne Drake, members of my research committee and colleagues at the School of Animal, Plant and Environmental Science for valuable contributions, proof reading and encouragement during the production of this work.

CONTENTS

Appendix 1: Survey of consumption of taro, amaranth and sweet potato among the population around the Nyabugogo Marsh

List of Tables

List of Figures

1. Introduction

1.1 Urban agriculture in developing countries

Africa's industrial development has come with challenges, among them the protection of the environment and health of its people from pollution by industrial waste. This is due, in part, to the fact that infrastructural, organisational and regulatory frameworks for waste management have not developed at the same pace (Mwesigye *et al.*, 2009). This phenomenon, according to Jeffery (1985) is characteristic of the initial stages of industrial development. Rwanda's budding industrial sector faces similar challenges. Here, polluted water from industrial activities is disposed into rivers, mainly due to the absence of appropriate waste management infrastructure. In Kigali, the country's capital, untreated or partially treated wastewater is disposed of in the Kibumba and Ruganwa Rivers, which deliver the polluted water to the Nyabugogo Marsh further downstream. Unfortunately, much of the food consumed in the city is cultivated in this Marsh. Thus, agricultural activities in the Nyabugogo Marsh are carried out largely using polluted water (Gasana *et al.,* 1997; Sekomo *et al.,* 2010).

The use of polluted water for agricultural production is not unique to Rwanda. Approximately 20 million hectares of land polluted by untreated or partially treated industrial and domestic waste are cultivated by 200 million farmers in Africa, Asia and South America (Scott *et al.,* 2004; Marsalek *et al.*, 2005; Keraita *et al.*, 2008). The farmers are mostly low-income urban dwellers who cultivate fast-maturing crops with minimal space requirements such as vegetables, to supplement their dietary requirements and as a source of income (Lado, 1990; Foeken and Mwangi, 2000; Obuobie *et al.,* 2006). Urban farming is therefore an important activity, providing both food and employment to poor urban populations. However, risks exist when polluted water is used in the production of crops (Muchuweti et al., 2006). Specifically, the use of industrial wastewater presents the risk of accumulation of bio-available forms of heavy metals and other toxins in the receiving soils and the plants growing in them (Liu *et al.,* 2008; Zhuang *et al.,* 2008; Bindu *et al.,* 2009; Karanja *et al.,* 2010).

The cultivation of crops by urban communities using industrial wastewater occurs widely in the East African region (Table 1). Maili Saba, for example, is an informal settlement located downstream of the industrial area in Kenya's capital Nairobi. Here, farmers using wastewater for food crop production harvest produce with metal concentrations far exceeding those stipulated by European Union standards (Karanja *et al.*, 2010). In Uganda's capital, Kampala, metal concentrations were quantified in crops cultivated on plots in the outskirts of the city using storm and wastewater, and in those growing on a rural farm. Produce from urban farms contained higher concentrations of metals than those from rural farms, and even exceeded EU limits used in the study (Mbabazi *et al.,* 2010). In Tanzania's capital, Dar es Salaam, produce from vegetable plots along the Msimbazi and Sinza Rivers was found to be contaminated by lead and cadmium. This is because the city's industrial and domestic wastes were disposed of in these rivers that also supplied water for crop cultivation to downstream communities. In this case, however, the contamination was less than what was reported in Nairobi and Kampala, and the metal concentrations in produce did not exceed the maxima set out in EU standards (Bahemuka and Mubofu, 1999).

Table 1: Lead and cadmium concentrations in vegetables cultivated in East African capital cities (Bahemuka and Mubofu, 1999; Karanja *et al.,* 2010; Mbabazi *et al.,* 2010).

Country	Vegetable	Pb (mg kg^{-1})	Cd (mg kg^{-1})
Kenya (Maili Saba)	Kales	37.45 ± 7.24	9.49 ± 1.85
(Karanja *et al.*, 2010)	Black nightshade	38.7 5 ± 7.35	5.70 ± 1.30
	Taro	54.75 ± 5.50	4.83 ± 0.21
Uganda (Luzira)	Spinach	2.40 ± 0.03	0.358 ± 0.003
(Mbabazi *et al.*, 2010)	Sweet potato	3.31 ± 0.05	0.116 ± 0.001
	Tomato	3.70 ± 0.08	0.76 ± 0.004
Tanzania (R. Msimbazi)	African spinach	0.30 ±0.02	0.06 ± 0.001
(Bahemuka & Mubofu, 1999)	Cowpea leaves	0.28 ± 0.02	0.06 ± 0.001
	Leafy cabbage	0.19 ± 0.02	0.01 ± 0.001
EC (2001) Standards	Leafy vegetables	0.3	0.2
	Root vegetables	0.1	0.1

In Kigali, urban farms are particularly important as they provide approximately 80% of the city's food requirements (Kigali City Council, 2001). Most crops are grown in and around the city's marshes (Rwanda, 2007). Nyabugogo is a marsh in Kigali where vegetable crops such as maize, sugarcane, cassava, lettuce, cabbages, amaranth, taro and sweet potato are produced for sale in the city's markets. Large parts of the upstream sections of the Marsh are cultivated in spite of the high metal concentrations in soils and plants from uncultivated sections further downstream. Studies in uncultivated sections of Nyabugogo revealed concentrations as high as 23.4 mg kg^{-1} of cadmium and 45.2 mg kg^{-1} of lead in the umbels of *Cyperus papyrus* plants (Sekomo *et al.*, 2010). *C. papyrus* is a known hyperaccumulator (Rai, 2009) and may not be an appropriate measure for metal accumulation in all plants. It is, however, indicative of the concentrations of metals available in the ecosystem for plant uptake, and is a cause for concern. It is therefore important to quantify the accumulation of metals in food crops grown in Nyabugogo Marsh.

1.2 Physiology of metal accumulation in plants and humans

Plants accumulate bioavailable forms of metals from growth media to varying concentrations. Bioaccumulation is quantified as the ratio of a plant's metal concentration with respect to bioavailable concentrations in its growth media (Zayed *et al.*, 1998). Plants that accumulate high metal concentrations are considered “hyperaccumulators”. Several criteria are used to define hyperaccumulator plants (Salt *et al.*, 2002), including:

i. a root to shoot metal concentration quotient greater than 1 (Baker and Whiting, 2002);
ii. an extraction coefficient (plant to soil metal concentration quotient) greater than 1 (Chen *et al.*, 2004);

Important though, is the fact that metal accumulation can be determined, to a large extent, by the physical and chemical characteristics of the soil in which a plant grows. In studies on the uptake of cadmium by Swiss chard (*Beta vulgaris L.*), for example, soil chloride and sulphate contents were found to have differing effects on plant cadmium concentrations. In chloride-enriched soils, the uptake of complexed and free cadmium ions was enhanced, while sulphate-enriched soils had no such effect. As a result, cadmium content was higher in Swiss chard plants grown in chloride-enriched soils than those grown in sulphate enriched soils (Smolders and McLaughlin, 1996; McLaughlin *et al.*, 1998).

Metal accumulation by plants is also determined by the characteristics of the specific metal e.g. the characteristics of salts it forms and its interactions with other metals. Lead hyperaccumulation, for example, is rare due to:

i. the low solubility of most lead compounds
ii. the precipitation of lead by sulphates and phosphates in the root environment.

Plants with the ability to concentrate more than 5 mg kg^{-1} dry weight of lead are therefore considered hyperaccumulators (Baker *et al.,* 2000). Conversely, cadmium hyperaccumulation in plants is more common. This is mainly due to the fact that:

i. cadmium compounds are soluble over a wider pH range (Kirkham, 2006);
ii. the structural similarity of cadmium and zinc that results in cadmium uptake in zinc-deficient soils (Grant *et al.,* 1998).

Zinc is an important mineral in limiting the absorption of cadmium in both plants and humans. In studies on hard red spring wheat by Green *et al.,* (2003), zinc soil amendments reduced the translocation of cadmium from roots to shoots of the plant. Similarly, the consumption of zinc mineral suppresses cadmium absorption in humans (Fox, 1974). This antagonism is explained by the similarity in chemical properties of cadmium and zinc, conferred mainly by their structural similarity. Both are members of the same group (group 12) of the periodic table with similar number of valence electrons. However, due to decreasing reactivity with increase in atomic mass, zinc (atomic mass 65.39 amu) is more reactive than cadmium (atomic mass 112.411 amu) and the reactions required for the sequestration and transport of cadmium are inhibited in the presence of zinc.

Zinc also has an inhibitory effect on the binding of lead on delta-aminolevulinic acid dehydratase (δ-ALAD), an enzyme involved in the synthesis of heme protein which is essential for such important functions as oxygen and electron transfer, membrane transport and catalysis (Border *et al*, 1976; Dutkiewicz *et al.*, 1979). Thus, the risks to health from lead and cadmium exposure can be reduced in populations with access to dietary or non-dietary sources of zinc.

Health risks from dietary metal intake are a function of the concentrations in the consumed crops, the quantities of crops consumed and the detoxifying abilities of the individual consumer. Thus, this study seeks to assess the risk to the health of members of a poor, urban farming community in Kigali by:

1. Quantifying lead and cadmium concentrations and their rates of accumulation in widely consumed crops *Colocasia esculenta*, *Amaranthus spp.* and *Ipomoea batata*, prepared in the same way the residents would prepare them;
2. Estimating the dietary intake of metals through these foods to the consuming population;

3. Computing dietary guidelines for food consumption such that metal intake does not exceed World Health Organisation (WHO) standards.

2. Materials and Methods

2.1 Study Area

Nyabugogo Marsh, a natural wetland in Kigali, stretches from the Gikondo industrial area to Nyabugogo. It overlays sandy and clay soils covered by growths of *Cyperus papyrus* in uncultivated sections that are approximately 60 ha in size. The Marsh is bordered by a larger area under year-round food crop cultivation by the urban population (Rwanda, 2009; Sekomo *et al*., 2010). Rwanda's mean annual precipitation is 1,250 mm (Rwanda, 2009) and is bimodal, with the rains falling from October to December and March to May. The mean annual temperature is 18.5^0C. Kigali, characterized by steep undulating hills, lies at an elevation of 1300m -1856m.

Figure 1: The location of Nyabugogo Marsh within Kigali

(Source: modified from http://maps.google.rw/maps)

The Kibumba and Ruganwa Rivers are tributaries of the Nyabugogo Marsh, flowing from the North-East and South-East of the city (Figure 1). Many of the city's industries and smaller operations such as automobile garages, car washing bays, fuel stations and metal recycling stations disposed of their wastes directly into these rivers (Sekomo *et al.,* 2010). These ranged from lubricants and detergents to automobile parts, clothes and plastic containers that could be seen floating on the water or deposited on the banks of the rivers. Further downstream, garden plots, carved out of the edges of the riparian zones, were cultivated by individuals and groups of farmers from the surrounding informal settlements. These settlements were typical of high-density, low-income areas, with houses consisting of one or two rooms constructed out of mud bricks and zinc-coated sheets. The houses had no connection to electricity supply and access to municipality-supplied water was by communal taps. Sanitation facilities were located away from the houses and were shared among members of several households and activities such as cooking were conducted in the small alley ways between the houses.

2.2 Field methods

The first batch of samples for this study was collected in June 2010. Samples were collected from three transects, two of which were perpendicular to the Kibumba River. The third transect was perpendicular to the Ruganwa River. Transects perpendicular to the Kibumba River were approximately 0.24 km apart, and 3.00 km from Gikondo industrial area. The transect perpendicular to the Ruganwa River was approximately 0.25 km from the discharge point of a textile factory (Figure 1).

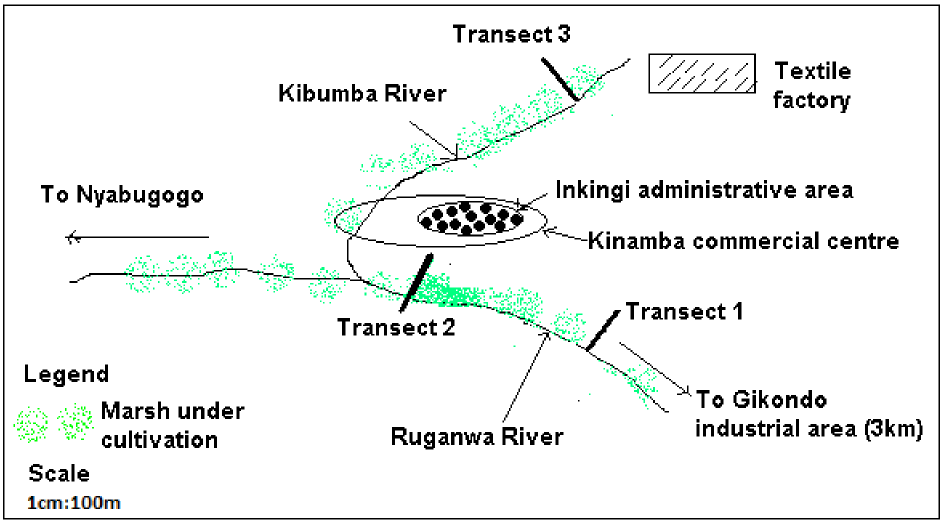

Figure 2: Schematic map of the area of the study area detailing the position of transects from which samples were collected and the administrative area in which surveys were conducted.

Plants and soils were collected from plots approximately 7 x 3m wide, surrounded by water channels dug by farmers for bucket irrigation (Figure 2). Taro was grown along the edges of each plot (taro is a wetland plant which requires access to water) and amaranth was cultivated in the center of the plots. Sweet potatoes were found in plots furthest away from the rivers, along the outer edges of the Marsh where soils were exposed to less water.

Figure 3: Crops on one of the samples plots. Amaranth is grown in the centre and taro along the edges of each plot. The arrow points to the location of the main river channel.

Within each transect, mature plants ready for harvest were collected from three locations identified by the haphazard placement of $0.75m^2$ quadrats. Five replicate plant samples were collected from within the quadrat and composited to one sample. This was repeated at two more points, yielding 3 composited samples of each crop per transect. Thus 15 individuals of each species were collected from each transect, and the total number of composited samples per plant species from all three transects was 12. All samples were then cleaned with river water on site to remove soil residues, as is done by the farmers prior to selling the produce. Samples were then transported to the agricultural laboratory of the National University of Rwanda (NUR) in Butare.

Soil samples were collected from within 30 cm of a sampled plant used for analysis. Soils, to a depth of 10 cm, were collected using a 55 mm-diameter soil core. This yielded a total of 12 composited soil samples, each containing material from five soil cores. These were transported to the NUR along with plant samples for analysis.

Because metal concentrations in living organisms can vary considerably over time and because different laboratories can yield very different results, a second sampling campaign was carried out two months after the first, in August 2010. Analysis of samples from this campaign was done at the chemistry laboratories of the University of the Witwatersrand, Johannesburg (Wits). As far as was possible, sampling and preparation techniques and procedures were accurately replicated. The only differences were in the cooking water used at the two laboratories and the sample size i.e.

1. samples from the first campaign were cooked in municipal treated tap water from laboratories at the NUR and those from the second campaign were cooked in tap water from laboratories at Wits;
2. although collected from the same plots as plants in the first campaign, samples in the second campaign were not composites of five plants, rather only one plant was collected from each quadrat.

Soil samples were not collected during the second sampling campaign.

2.3 Laboratory Methods

500g subsamples of food crops were prepared for heavy metal analysis. All samples were prepared and cooked to simulate local preparation methods i.e. taro and sweet potato subsamples were peeled, rinsed and cooked separately, and amaranth leaves were washed and boiled in tap water. The cooked samples were oven-dried at 100^{o}C for 24 hours and ground to powder.

For metal analyses, 0.1g of each powdered sample was digested with repeated additions of nitric acid and hydrogen peroxide until the solution was clear. This digest was then refluxed at 95^{o}C for 15 minutes after the addition of concentrated hydrochloric acid, and then diluted to 100ml with deionized water (US EPA Method 200.3; Jeniss *et al.,* 1997). The resulting solutions were analysed in triplicate, for lead and cadmium by atomic absorption spectrophotometry using a Varian AAS-240 spectrophotometer (Varian Inc., USA).

Soil samples were weighed, oven dried at 100^{o}C for 72 hours and re-weighed to determine bulk density. Soil pH was measured with deionised water (1:2.5, soil: solution ratio, dry w/v) and the bioavailable metals were extracted by the diethylenetriamine pentaacetic acid (DTPA) method

(Lindsay and Norvell, 1978). The total lead and cadmium concentrations in soil were determined as in plant samples. The soils' organic matter content was determined by loss-on-ignition at 500^{o}C (Goel, 2006). All analyses for soils were performed at the science laboratories of the NUR, except the determination of organic matter content and bulk density which were carried out at Wits.

2.4 Survey on consumption of food crops in the study

The daily intake of each of the three food crops by residents of the Inkingi administrative area was quantified using interview methods. This area, where many of the farmers cultivating in the Gikondo Marsh resided, was situated on a hill overlooking the Marsh. It consisted of 198 households each with at least 6 members, most of them children below the age of 13. It bordered the Kinamba commercial centre where most of the produce from the Marsh was sold to traders and the local population.

An adult in each of 60 households was interviewed. The selection of households was based on size (number of people in the household) and acceptance of members to be interviewed and weighed. Households in which permission was not granted to weigh at least 75% of the members were left out of the study.

Permission to carry out surveys was sought from the local community leader, three weeks in advance. A week before the start of the survey exercise, he was informed and he availed a member of the community to accompany me during the surveys which were carried out over four Sundays in June 2010. Sundays were chosen in order to include members of the community who work or attend school in the survey.

During the surveys, respondents were asked to quantify their weekly consumption of taro, amaranth, and sweet potato, along with dietary sources of zinc such as peanuts, milk, beans and other green vegetables other than amaranth. Information was also collected on non-dietary zinc sources by observing the roofing materials used in the construction of houses (whether they were clay tiles or iron or zinc coated sheets) and the water storage containers (whether they were metallic or plastic, Appendix A: survey questionnaire).

During the surveys, samples of the plants in the study bought from garden plots in the Nyabugogo Marsh were provided. Amaranth was sold by the handful and so respondents did not have information on the weight of the quantities they consumed. To ascertain weight, therefore, respondents were asked to estimate the quantities from the vegetables provided, and the estimated quantity was then weighed. Sweet potatoes and taro are bought from grocers by the kilo and so respondents were able to provide information in kilograms. A weighing scale was used to weigh members of respondent households and the samples of amaranth.

3. Quantitative analyses

This section presents formulae employed in the calculation of metal bioaccumulation factors by taro, amaranth and sweet potato, as well as the existing metal intakes of community members and consumption guidelines.

3.1 Bioaccumulation factor

The bioaccumulation factors of plants were calculated using Equation 1:

$$BAF = \frac{Cplant}{Csoil} \qquad \textbf{(1)}$$

Where *Cplant* represents the metal concentrations in edible plant portions and *Csoil* represents the bioavailable metal concentration in soil (Rattan *et al.*, 2005)

3.2 Daily metal intake (DMI)

The daily intake of metals for an adult living in the Inkingi administrative area was calculated using Equation 2 where *Wfood* represents the average mass of each food crop consumed per day, *Cmetal* is the amount of lead and cadmium contained in that particular crop and *Bw* is the average body weight of an adult in the community under study (Khan *et al*., 2008). A conversion factor of 0.085 was used to convert the wet weight of the food crops to dry weight because metal concentrations are expressed on the basis of dry weight (Rattan *et al.*, 2005).

$$DMI = \frac{Cmetal * Wfood * 0.085}{Bw} \qquad \textbf{(2)}$$

The results were then compared with the reference doses (RfDo) set out by the WHO/FAO as safe limits for heavy metal consumption (0.0010 and 0.0035 mg kg^{-1} day^{-1} for cadmium and lead, respectively). The plant metal concentration (*Cmetal*) used was the average plant metal concentration of the two sampling campaigns.

3.3 Consumption guidelines

The average daily quantities of each of the food crops that can be consumed by the different age groups in the community, without the risk of adverse health effects (according to WHO standards) were computed using Equation 3 (after Khan *et al*., 2008). RfDo represents the WHO standards of recommended daily metal allowance i.e. 0.0035 mg kg^{-1} and 0.001 mg kg^{-1} for lead and cadmium respectively.

$$Wfood = \frac{RfDo * Bw}{Cmetal * 0.085} \qquad \textbf{(3)}$$

4. Results

4.1 Soil metal contamination and bioavailability

The Nyabugogo Marsh is classified as a riverine wetland based on the Corwardian wetland classification system (Cowardin, 1979). It is characterized by organic soils (Rugege et al., 2006) with pH values ranging from slightly basic (pH 7.69) to acidic (pH 5.38). The organic matter content in the soils ranged from 6.06% to 11.83% and bulk density ranged from 0.82 - 1.17 g cm^{-3} (Table 2).

Table 2: Nyabugogo Marsh soil physical characteristics (average of 5 samples).

	pH ± SE	**OM (%) ± SE**	**Bulk density (g cm^{-3}) ± SE**
T1	7.69 ± 0.29	6.31 ± 0.41	0.91 ± 0.12
T2	7.25 ± 1.79	6.04 ± 1.54	1.17 ± 0.27
T3	5.38 ± 1.87	11.83 ± 3.34	0.82 ± 0.25

The total lead concentration in soils ranged from 88.22 to 116.51 mg kg^{-1}, while cadmium concentrations ranged from 0.63 to 1.88 mg kg^{-1}. Bioavailable metal concentrations ranged from 2.43 to 5.46 mg kg^{-1} for lead and 0.07 to 0.09 mg kg^{-1} for cadmium (Table 3).

Table 3: Nyabugogo Marsh soil total and bioavailable metal content (average of 5 samples), and EU-stipulated upper limits (EC, 2001).

	Total soil Pb (mg kg^{-1} dw) ± SE	Bioavailable Pb (mg kg^{-1}) ± SE	Total soil Cd (mg kg-^{1} dw) ± SE	Bioavailable Cd (mg kg^{-1}) ± SE
T1	116.51 ± 97.53	5.46 ±2.58 (16.33%)	0.92 ± 0.40	0.07 ±0.05 (8.88%)
T2	182.75 ± 77.91	4.29 ± 2.06 (2.42%)	1.88 ± 0.60	0.09 ±0.05 (4.62%)
T3	88.22 ± 89.87	2.43 ± 2.01 (16.69%)	0.63 ± 0.55	0.09 ± 0.07 (11.81%)
EU stds	**300**		**3**	

4.2 Plant metal concentration and bioaccumulation factors

In plants sampled during the first campaign, lead and cadmium accumulation were highest in amaranth and lowest in sweet potato. Amaranth plants had the highest bioaccumulation factors (0.127 for lead and 0.66 for cadmium), and sweet potato the lowest (0.01 for lead and 0.11 for cadmium). The concentrations of metals in plants collected during the second sampling campaign were higher (6-75 times higher for lead and 19-111 times higher for cadmium) than those from the first campaign (Table 4). At these concentrations, lead hyperaccumulation was not exhibited by any of the three plants (Baker *et al.*, 2000).

Table 4: Metal concentrations in crop plants collected in the first and second sampling campaigns and bioaccumulation factors of plants from the first campaign (averaged for all transects).

	Lead (mg kg $^{-1}$) ± SE			**Cadmium (mg kg $^{-1}$) ± SE**		
	Campaign 1	Campaign 2	Average	Campaign 1	Campaign 2	Average
Amaranth	0.31 ± 0.108	1.67 ± 1.365	0.99 ± 0.962	0.03 ± 0.015	0.58 ± 1.141	0.31 ± 0.389
BAF *	0.13			0.66	0	
Taro	0.08 ± 0.030	2.94 ± 0.403	1.02 ± 1.329	0.01 ± 0.003	1.11 ± 0.976	0.56 ± 0.778
BAF	0.02			0.11		
Sweet potato	0.02 ± 0.006	1.49 ± 1.183	0.75 ±1.040	0.01 ± 0.002	0.43 ± 0.304	0.22 ± 0.297
BAF	0.01			0.11		
EU Standards	**Leafy vegetables**		**0.3**			**0.2**
	Root vegetables		**0.1**			**0.1**

*BAF-Bioaccumulation Factor

4.3 Demographics and daily metal intake of consumers

The average surveyed household in Inkingi administrative area consisted of two adults and four children under the age of 13, most adult family members having resided there for at least seven years. The average weight of residents ranged from 10 kg for children under two, 16 kg for children aged 2-6 years, 25 kg for those aged 6 - 12 years to 57 kg for those above 13 years (Table 5).

Table 5: Mean weights of survey respondents

Age group	0-2 years	2-6 years	6-12 years	Adolescents above 13 years and adults
n	23	43	70	136
Weight (kg) ±SE	10 ± 1.91	16 ±3.76	25 ± 7.49	57 ± 12.89

All respondents reported that the taro, amaranth and sweet potato they consumed were sourced directly or indirectly from the Marsh (bought from grocers who sourced it from the Marsh). These crops were consumed with varying frequency during the week, as were the dietary sources of zinc available to members of the community. On average, beans were consumed seven times per week and peanuts consumed three times per week. Access to milk, meats and other green vegetables (apart from amaranth) was limited for financial reasons as this was a poor community. The primary non-dietary zinc source for this community was likely to be the zinc coated sheets used for roofing all houses, from which rain water was collected and used for drinking and cooking. The main source of water during the dry seasons was municipal treated water, supplied through communal taps and fetched in plastic containers by the residents.

The average quantities of amaranth, taro and sweet potato consumed per day by residents of Inkingi was 180 g, 480 g and 830 g per household. In most households food was shared amongst family members, sometimes from the same dish, making it difficult to estimate exactly how much each member consumed per meal. Consequently, in calculating the mean daily intake of metals, the assumption was made that the two adults in the household consumed 25% of the food prepared at every meal, and the rest was divided among the children. This means that the average intake of amaranth, taro and sweet potato by an adult in the study area was 50 g, 120 g and 210 g respectively. Thus, daily metal intake from each of the three crops based on these quantities (Table 6) was well within the limits set by the WHO (WHO, 1993).

Table 6: Daily mean metal intake by adults in the study area from each of the food crops

	Lead DMI ($mg\ kg^{-1} day^{-1}$)	**Cadmium DMI ($mg\ kg^{-1} day^{-1}$)**
Amaranth	0.0001	0.00004
Taro	0.0003	0.00017
Sweet potato	0.0004	0.00012
WHO Standards	**0.0035**	**0.001**

4.4 Consumption guidelines

Guidelines for daily intake of each crop were calculated for the age groups represented in the population surveyed. Average body weight and the metal concentrations of the food crops were used (Table 7). The consumption quantities for amaranth that did not exceed recommendations for daily lead and cadmium intake were almost the same i.e. for adults, 2.4 kg and 2.2 kg for quantities that met WHO guidelines for daily intake of lead and cadmium, respectively. The same was the case for sweet potato. In the case of taro, however, quantities that met guidelines for daily intake of lead were approximately double those that met guidelines for daily cadmium intake i.e. for adults, 2.3 kg versus 1.2 kg for quantities that met WHO guidelines for daily intake of lead and cadmium, respectively. This means that consumption of quantities of taro conforming to WHO guidelines for daily lead intake will provide twice the amount of cadmium.

Table 7: Recommended daily food intake for the different age groups in the community (kg day^{-1}).

Plant (kg day^{-1})	**Metal**	**0-2 years (10 kg)**	**3-6 years (16 kg)**	**7-13 years (25 kg)**	**Over 13 years (57kgs)**
Amaranth	Pb	0.4	0.7	1.0	2.4
	Cd	0.4	0.6	0.9	2.2
Taro	Pb	0.4	0.6	1.0	2.3
	Cd	0.2	0.3	0.5	1.2
Sweet potato	Pb	0.5	0.9	1.4	3.1
	Cd	0.5	0.9	1.3	3.0

5. Discussion

5.1 Plant metal concentration and accumulation rates

Plants growing in metal-contaminated environments can take up, accumulate and tolerate metals to varying degrees depending on species. Plants in this study concentrated lead and cadmium from soil to varying degrees and metal concentrations varied substantially between the two campaigns. In the first sampling campaign, amaranth plants contained the highest concentrations of lead and cadmium. In the second campaign, the highest concentrations of both metals were found in taro roots. Sweet potato from both sampling campaigns concentrated the least quantities of metals. Metal contamination in amaranth plants was likely as a result of bucket irrigation as they were grown in the centres of plots. With respect to the root vegetables, taro's higher concentration of metals may be a result of greater exposure from growing close to polluted water, coupled with bucket irrigation in the dry season. In contrast, sweet potatoes are grown in dry soil mounds, as far as possible from the water source and are infrequently irrigated due to their hardiness (Shu-Fen, 2006).

Bioaccumulation factors were calculated only for plants collected in the first sampling campaign as soil samples were not collected in the second campaign. The highest bioaccumulation factors for both lead and cadmium were exhibited by amaranth plants, but its' cadmium concentrations were relatively low compared to findings by Zhang *et al.,* (2010). In all three plants, the factors were greater for cadmium than for lead; a fact that can be attributed to the higher solubility of salts of cadmium compared with those of lead (Grant *et al.,* 1998; Baker *et al.*, 2000; Kirkham, 2006).

The formation, solubility and subsequent mobility of metal salt ions in soil are mainly factors of the soil's pH. A low pH favours the oxidation of metals by hydrated protons and the production of ions. Conversely, a high pH, (basic medium) favours the acquisition of electrons by ions (reduction) to form metals, thus reducing their availability for uptake by plants. The pH of soils in this study was almost neutral (7.25-7.69) except in transect three where it was slightly acidic (5.38). The pH in this transect therefore facilitated the increased availability of ions i.e. despite the soil metal concentration being lower than those in the first and second transects, the bioavailable concentration of lead was as high as that in the first transect, and that of cadmium was the highest of all three transects (Table 3).

The uptake of available metal ions and their accumulation by plants are, however, very complex factors that are not fully understood. This is partly due to the dependence on multiple factors such as chemical reactions in the root environment, as well as the soil mineralogical properties (e.g. clay content) and abiotic factors (e.g. organic matter). Organic matter and clay act as buffers to plant metal uptake because they bind and form complexes with metal ions thus making them unavailable for plant uptake (Jopony and Young, 1993; McBride *et al*., 1997). The low organic matter content of soils collected in this study therefore provides low buffering capacity, availing much of the metal ions for plant uptake. However, even in these conditions where plants have access to and can accumulate high concentrations of metals, there are multiple mechanisms to forestall toxicity by absorbed metals. These include:

i. Employing elaborate and metal-specific detoxification mechanisms. For example, *Spartina alternifora* convert selenium to dimethylselenoniopropionate (DMSeP), a volatile non-toxic form (Ansede *et al.,* 1999). Another example is the bacteria-aided detoxification of mercury by methylation, by sulphate-reducing bacteria in the roots of *Eichhornia crassipes* (Mauro *et al.,* 1999). *E. crassipes* plants also take up Cr (VI) but reduce it to the less toxic Cr (III) before it is translocated to leaves (Lytle *et al.,* 1998).

ii. Restricting metal translocation from roots to shoots (exclusion) or specifying organs of accumulation. For example, in studies on the effects of cadmium exposure on growth of tobacco plants, cadmium was found to have a higher affinity for sulphur ligands in

> phytochelatins produced in roots as a result of this exposure, than oxygen or nitrogen ligands in the xylem sap. As a result, more cadmium was stored in root tissues than was translocated to the shoots (Vogeli-Lange and Wagner, 1996). Root vegetables such as taro and sweet potato also employ the exclusion strategy over a wide range of soil metal concentration. They do this by accumulating metals in roots and preventing translocation and the risk of damage to photosynthetic apparatus (shoots). Conversely, accumulators, have high metal concentrations in shoots. In these plants, the leaf to root metal concentration ratios can be 1 or greater (Baker and Whiting, 2002).

Between the two sampling campaigns (June and September), metal concentrations increased by a factor of 8-90. It is possible that some of this difference was due to laboratory error, but it is more likely a function of plant age. Plants accumulate more contaminants with increased exposure duration (Salt *et al.,* 2002). The older plants collected during the second sampling campaign would therefore contain greater concentrations of metals. Also important to this study was the fact that plants from the second campaign, growing further into the dry season, were exposed to more contamination through bucket irrigation and less wash-out action as occurs in the rainy season. Thus, plants growing in the drier months will be exposed to greater concentrations of metal ions, and it is possible then that metal concentrations may continue to rise over the dry season. This finding warrants continued monitoring of metal concentrations in crop plants throughout the year.

5.2 Estimation of dietary metal intake

Metal intake through food is a function of the concentration of metal in the particular food item and the amount consumed. Thus, although sweet potato contained the lowest concentrations of metals, they provided were largest source of dietary lead (3×10^{-4} mg kg^{-1} day^{-1}), because they are consumed in the largest quantity. Taro provided the same concentrations of dietary lead as sweet potato but amaranth provided 1×10^{-4} mg kg^{-1} which is approximately one tenth of the daily maximum recommended dose. Taro provided the greatest exposure to dietary cadmium in the surveyed population, but even this was less than a fifth of the daily maximum recommended dose.

Zinc, which can help ameliorate the detrimental health effects of cadmium and lead, was available to members of the community from various sources. On average, the population consumed zinc-rich foods such as beans (seven days of the week), and peanuts (3 times per week). Additionally, rain water is used for drinking as it is considered, by the local population, cleaner than tap water and is preferentially used for cooking. It is collected by all households in the area from their zinc-coated roofing sheets. Thus, the health risks to the community are likely reduced, because of the low consumption quantities of contaminated food crops, and the consumption of zinc.

5.3 Consumption guidelines

Data on reported consumption volumes of the three food crops and the average metal content from the two sampling campaigns were used to calculate the maximum recommended quantities for daily intake, for all four age groups of residents in the study area (Table 7). The quantities recommended for consumption are those that do not exceed the recommendations for both metals i.e. for taro roots, it is recommended that only 0.2 kg are consumed by a child under 2 years, because even though consumption of 0.4 kg may be within the guidelines set for lead, it provides twice the recommended amount of cadmium. Similarly, only 1.2 kg of taro, and not 2.3 kg should be consumed by an adult, in order to ensure that the recommendations for both lead and cadmium not exceeded.

The calculated maximum daily intake quantities were quite large (e.g. 3 kg of sweet potato per day, per adult; Table 7). If these quantities were to be consumed, then the limits for daily metal intakes would be exceeded i.e. such quantities would provide 0.013 mg kg^{-1} of lead and 0.005 mg kg^{-1} of cadmium, well above the recommended quantities of 3.5 x 10^{-3} mg kg^{-1} and 1 x 10^{-3} mg kg^{-1} for lead and cadmium, respectively. However, consumption at this rate is unlikely, largely due to economic constraints.

According to the survey data, adults were consuming only 2%, 10% and 7% of the quantities recommended for amaranth, taro and sweet potato respectively. Furthermore, even if all the three food crops were consumed in a single day, the maximum recommended quantities for daily metal consumption would still not be exceeded. It is therefore concluded that under current conditions, the Inkingi population is at a low risk of heavy metal toxicity as a result of consuming food from the Nyabugogo Marsh.

6. Conclusions and Recommendations

Although the concentrations of lead and cadmium in soils in the Nyabugogo Marsh were within EU limits for crop production, the crops originating from the Marsh contain metals in concentrations exceeding EU standards. Fortunately, populations around the Marsh reportedly do not consume quantities large enough to accumulate substantial concentrations of these metals. As such, their daily metal intake through these foods is well within WHO standards.

Urban agriculture provides tremendous benefits to the economies and inhabitants of cities and other urban centers. Besides being a source of employment for a section of a city's population, urban agriculture also addresses the insufficiency and sometimes total lack of transportation and refrigeration infrastructure in developing countries, necessary for the delivery of food from far off farms to markets. Continued rural-to-urban migration and the growing disparities in incomes of urban populations also mean that there will always be a need, and a market, for produce from urban farms as it is cheaper and more accessible.

That said, in the case of Kigali, the metal contamination, and other types of contamination such as hydrocarbons etc, of soils in the Nyabugogo Marsh will continue to increase as long as industrial effluent continues to be released into tributaries of the Marsh. It is also worth noting that this study measured only two of the many potential toxins and that there may be others passing on to consumers through cultivated crops, or altering the Marsh ecosystem irreparably. Fortunately, a relocation of the industrial area away from Gikondo and a rehabilitation of the Marsh are planned and this issue will be addressed (Rugege *et al.*, 2006). The subsequent use of this Marsh land encompasses varying political and environmental interests beyond the scope of this study. It is hoped, however, that if crop cultivation is to continue, the current polluted state of the Marsh will be addressed, as it is has effects on the environment and the health of the city’s residents.

In the interim, it is important that research addresses the issue of differential contamination between seasons so as to develop consumption guidelines applicable in all seasons.

7. References

Ansede, J. H., Pellechia, P. J., and Yoch, D. C., 1999: Selenium biotransformation by the salt marsh cordgrass Spartina alterniflora: Evidence for Dimethylselenoniopropionate formation. *Environmental Science & Technology*, 33, 2064-2069.

Bahemuka, T. E. and Mubofu, E. B., 1999: Heavy metals in edible green vegetables grown along the sites of the Sinza and Msimbazi Rivers in Dar es Salaam, Tanzania. *Food Chemistry*, 66, 63-66.

Baker, A. J. M., McGrath, S. P., Reeves, R. R. and Smith, J. A. C., 2000: Metal hyperaccumulator plants: a review of the ecology and physiology of a biological resource for phytoremediation of metal-polluted soils. In: Terry, N. and Banuelos, G. (eds), *Phytoremediation of Contaminated Soil and Water*, Lewis Publishers, Florida. pp. 85–107.

Baker, A. J. M. and Whiting, S. N., 2002: In search of the Holy Grail-a further step in understanding metal hyperaccumulation. *The New Phytologist*, 155, 1–7.

Bindu, T., Sumi, M.M., Ramasamy, E.V., 2009: Decontamination of water polluted by heavy metals with Taro (*Colocasia esculenta*) cultured in a hydroponic NFT system. *The Environmentalist*, 30:35–44.

Border, E. A., Cantrell, A. C., and Kilroe-Smith, T. A., 1976: The in vitro effect of zinc on the inhibition of human delta-aminolevulinic acid dehydratase by lead. *British Journal of Industrial Medicine*, 33(2), 85–87

Chen, Y., Shen Z. and Li, X., 2004: The use of vetiver grass (*Vetiveria zizanioides*) in the phytoremediation of soils contaminated with heavy metals, *Applied Geochemistry,* 19, 1553–1565.

Cowardin, L. M., Carter, V., Golet, F. C., LaRoe, E. T., 1979: Classification of wetlands and deepwater habitats of the United States. U.S. Department of the Interior, Fish and Wildlife Service, Washington, D.C.

Drechsel, P., Graefe, S., Sonou, M. and Cofie, O. O., 2006: *Informal Irrigation in Urban West Africa: An Overview*. Colombo, Sri Lanka: International Water Management Institute. Research Report No 102, pp 40.

Dutkiewicz, B., Dutkiewicz, T., and Milkowska G., 1979: The Effect of Mixed Exposure to Lead and Zinc on ALAD Level in Urine. *International Archives of Occupational and Environmental Health*, 42, 341-348.

European Commission (EC), 2001: Setting maximum levels for certain contaminants in foodstuffs. *Official Journal of the European Communities, L 77/1*, No 466/2001.

Foeken, D. and Mwangi, A.M., 2000: 'Increasing food security through urban farming in Nairobi', in Bakker, N., Dubbeling, M., Gundell, S., Sabel-Koschella, U. and de Zeeuw, H. (eds) *Growing Cities, Growing Food Urban Agriculture on the Policy Agenda: A Reader on Urban Agriculture*, Deutsche Stiftung fur Internationale Entwicklung (DSE), Feldafing, Germany. pp 303-327.

Fox, M. R. S., 1974: Effect of essential minerals on cadmium toxicity: A review. *Journal of Food Science*, 39: 321-324.

Gasana, J., Twagilimana, L., Hallenbeck, W. and Brenniman, G., 1997: Industrial Discharges of Metals in Kigali, Rwanda, and the Impact on Drinking Water Quality. *Bulletin of Environmental Contamination and Toxicology*, 58 (4):523–526.

Goel, R. K., 2006: *Laboratory techniques in sericulture*. A. P. H. Publishing Corporation, India. pp 18-19.

Grant, C. A., Buckley, W. T., Bailey, L. D. and Selles F., 1998: Cadmium accumulation in crops. *Canadian Journal Plant Science,* 78, 1–17.

Green, C. E., Chaney, R. L., and Bouwkamp, J., 2003: Interactions between cadmium uptake and phytotoxic levels of zinc in hard red spring wheat. *Journal of Plant Nutrition*, 26, 417–430.

Jeffrey, L. H., 1985: Confronting Industrial Pollution in Rapidly Industrializing Countries: Myths, Pitfalls, and Opportunities. *Ecology Law Quarterly*, 12, 779.

Jenniss, S. W., Katz, S. A., and Lynch, R. W., 1997: *Applications of atomic spectrometry to regulatory compliance monitoring*, 2nd ed. Wiley-VCH, USA. Pp 75.

Jopony, M. and Young, S. D., 1993: The solid-solution equilibria of lead and cadmium in polluted soils. *European Journal of Soil Science,* 45 (1), 59-70.

Karanja, N., Njenga, M., Prain, G., Kang'ethe, E., Kironchi, G., Githuku, C., Kinyari, P., and Mutua, G. K., 2010: Assessment of environmental and public health hazards in wastewater used for urban agriculture in Nairobi, Kenya. *Tropical and Subtropical Agroecosystems*, 12, 85 – 97.

Keraita, B., Jimenez, B and Drechsel, P.: 2008. Extent and implications of agricultural re-use of untreated, partly treated and diluted wastewater in developing countries. CAB Reviews: *Perspectives in Agriculture, Veterinary Science. Nutrition and Natural Resources,* 3, 058, pp 15.

Kigali City Council, 2001: *Kigali Economic Development Strategy (KEDS).* Kigali Institute of Science and Technology, Rwanda.

Kirkham, M. B., 2006: Cadmium in plants on polluted soils: Effects of soil factors, hyperaccumulation, and amendments. *Geoderma,* 137, 19–32.

Lado, C., 1990: Informal urban agriculture in Nairobi, Kenya: Problem or resource in development and land use planning? *Land Use Policy*, 7 (3), 257-266.

Lindsay, W. L. and Norvell, W. A., 1978: Development of a DTPA soil test for zinc, iron, manganese and copper. *Soil Science Society of America Journal,* 42; 421–428.

Liu, X., Gao, Y., Sardar, K., Duan, G., Chen, A., Long, L., Zhao, L., Liu, Z., and Wu, X., 2008: Accumulation of Pb, Cu, and Zn in native plants growing on contaminated sites and their potential accumulation capacity in Heqing, Yunnan. *Journal of Environmental Sciences*, 20, 1469–1474.

Lytle, C. M., Lytle, F. W., Yang, N., Qian, J. H., Hansen, D., Zayed, A., and Terry, N. 1998: Reduction of Cr (VI) to Cr (III) by wetland plants: Potential for in situ heavy metal detoxification. Environmental Science & Technology, 32: 3087-3093.

Marsalek, B., Jimenez-Cisneros, B. E., Malmqvist, P. A., Karamouz, M., Goldenfum, J. and Chocat, B.: Urban water cycle processes and interactions. UNESCO-IHP-6 Program. Paris: UNESCO. December 2005

Mauro, J. B., Guimares, J. R. and Melamed, R., 1999: Mercury methylation in a tropical macrophyte: influence of abiotic parameters. *Applied Organometallic Chemistry*, 13, 1– 6.

Mbabazi, J., Wasswa, J., Kwetegyeka, J. and Bakyaita, G. K., 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.

McBride, M., Sauve, S. and Hendershot, W., 1997: Solubility control of Cu, Zn, Cd and Pb in contaminated soils. *European Journal of Soil Science*, 48, 337-346.

McLaughlin, M. J., Andrew, S. J., Smart, M.K. and Smolders, E., 1998: Effects of sulfate on cadmium uptake by Swiss chard: I. Effects of complexation and calcium competition in nutrient solutions. *Plant and Soil,* 202: 211–216.

Muchuweti, M., Birkett, J. W., Chinyanga, E., Zvauya, R., Scrimshaw, M. D. and Lester, J. N., 2006: Heavy metal content of vegetables irrigated with mixture of wastewater and sewage sludge in Zimbabwe: implications for human health. *Agriculture, Ecosystems and Environment,* 112, 41-48.

Mwesigye, P., Mbogoma, J., Nyakang'o, J., Idan, I. A., Kapindula, D., Hassan, S. and Van Berkel, R., 2009: *Africa review report on waste management*. United Nations Economic and Social Council, Sixth Session of the Committee on Food Security and Sustainable Development (CFSSD-6) / Regional Implementation Meeting (RIM), Addis Ababa, Ethiopia. pp 44.

Obuobie, E., Keraita, B., Danso, G., Amoah, P., Cofie, O. O., Raschid-Sally, L. and Drechsel, P., 2006: *Irrigated urban vegetable production in Ghana: Characteristics, benefits and risks.* IWMI-RUAF-IDRC-CPWF, Accra, Ghana: IWMI, 150 pp. http://www.cityfarmer.org/GhanaIrrigateVegis.html

Rattan, R. K., Datta, S. P., Chhonkar, P. K., Suribabu, K. and Singh, A.K., 2005: Long-term impact of irrigation with sewage effluents on heavy metal content in soils, crops and groundwater—a case study. *Agriculture, Ecosystems and Environment,* 109, 310-322.

Rugege, D., Dhetchuvi, J-B. and Gakwavu J., 2006: Mapping of Wetlands and other Fragile Aquatic Ecosystems in Kigali City. Rwanda Environmental Management Authority (REMA), Kigali, Rwanda. Pp.1-33.

Rwanda, 2007: *Economic Development and Poverty Reduction Strategy (EDPRS) 2008 –2012*. Ministry of Finance and Economic Planning.

Rwanda, 2009: *Rwanda state of environment and outlook Report*, Rwanda Environmental Management Authority (REMA), 67-82.

Salt, D. E., Prince, R. C. and Pickering, I. J., 2002: Chemical speciation of accumulated metals in plants: evidence from X-ray absorption spectroscopy. *Microchemical Journal*, 71, 255–259.

Scott, C. A., Faruqui, N. I. and Raschid-Sally, L., (eds.) 2004: *Wastewater Use in Irrigated Agriculture: Confronting the Livelihood and Environmental Realities*. Wallingford, UK: CABI Publishing.

Sekomo, C., Nkuranga, E., Rousseau, D. P. L., and Lens, P. N. L., 2010: Fate of Heavy Metals in an Urban Natural Wetland: The Nyabugogo Swamp (Rwanda). *Water Air and Soil Pollution.*

Shu-Fen, C. and Chin-Yuan, H., 2006: Influence of Cadmium on Growth of Root Vegetable and Accumulation of Cadmium in the Edible Root. *International Journal of Applied Science and Engineering*, 4, (3), 243-252.

Smolders, E. and McLaughlin M. J., 1996: Chloride increases cadmium uptake in Swiss chard in a resin-buffered nutrient solution. *Soil Science Society of America Journal*, 60, 1443–1447.

Vogeli-Lange, R. and Wagner, G. J., 1996: Relationship between cadmium, glutathione and cadmium-binding peptides (phytochelatins) in leaves of intact tobacco seedlings. *Plant Science*, 114, 11-18**.**

World Health Organization, 1993: Evaluation of Certain Food Additives and Contaminants (Forty-first Report of the Joint FAO/WHO Expert Committee on Food Additives). *WHO Technical Report Series No. 837*.

Zhang, X., Zhang, S., Xu, X., Li, T., Gong, G., Jia, Y., Li, Y. and Deng, L., 2010: Tolerance and accumulation characteristics of cadmium in *Amaranthus hybridus L. Journal of Hazardous Materials*, 180, 303–308.

Zhuang, P., McBride, M. B., Xia, H., Li, N. and Li, Z., 2008: Health risk from heavy metals via consumption of food crops in the vicinity of Dabaoshan mine, South China. *Science of the Total Environment*, 407 (5), 1551-1561.

Appendix 1: Survey of consumption of taro, amaranth and sweet potato among populations around the Nyabugogo Marsh

<table>
<tr><td>Household No.</td><td colspan="2">Date:</td><td colspan="3">Duration of living/farming in area ______years</td></tr>
<tr><td>Age group of household members</td><td colspan="5">Infants (0-2years)____ Young children (2-6 years)____ Children (6-12 years)_____ Adolescents and Adults (over 13 years)_____</td></tr>
<tr><td rowspan="5">What are the weights, in kgs, of infants, children and adults in the household?</td><td></td><td>Infants (0-2years)</td><td>Young children (2-6 years)</td><td>Children (6-12 years)</td><td>Adolescents and Adults (over 13 years)</td></tr>
<tr><td>1</td><td></td><td></td><td></td><td></td></tr>
<tr><td>2</td><td></td><td></td><td></td><td></td></tr>
<tr><td>3</td><td></td><td></td><td></td><td></td></tr>
<tr><td>4</td><td></td><td></td><td></td><td></td></tr>
<tr><td>What is the source of these food crops for the household? An allotment in the study area, far away/upcountry/ market.</td><td colspan="5">Taro __________
Amaranth ___________
Sweet potato _________</td></tr>
<tr><td>How many times in a week are these food crops eaten, and what is their approximate wet weight per meal</td><td colspan="5"><table><tr><th>Food crop</th><th>Number of times the food crop is consumed per week</th><th>Number of Kgs consumed per meal</th></tr><tr><td>Amaranth</td><td></td><td></td></tr><tr><td>Taro</td><td></td><td></td></tr><tr><td>Sweet potato</td><td></td><td></td></tr></table></td></tr>
<tr><td>How many times a week are foods rich in Zinc and iron included in the diet?</td><td colspan="5">Meat / Chicken_______ Beans________ Milk ________Peanuts_______ Other Green Vegetables______</td></tr>
<tr><td>What are your sources of water for domestic use (cooking, drinking)?</td><td>River_____
Municipal supply______</td><td>Is the water collected stored at home? If yes, what containers are used?</td><td>Plastic______
Metal_______</td><td>What is the roofing material of the house</td><td>Tiles______
Zinc coated sheets______-</td></tr>
</table>