Heavy Metal Contamination in Cocoyam Crops and Soils in Countries around the Lake Victoria Basin (Tanzania, Uganda and Kenya)

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Abstract
A study to determine heavy metals concentration and their correlation between soil and cocoyam crops grown at different wetland locations in Tanzania, Kenya and Uganda around Lake Victoria basin was done. A total of 48 cocoyams and 48 soil samples (taken at 0-15 cm deep) were collected in triplicate from various locations in three districts in each country. They were analysed for Mercury (Hg), Arsenic (As), Lead (Pb), Chromium (Cr) and Copper (Cu) concentrations using atomic absorption spectrophotometry (AAS). The mean heavy metals concentration in cocoyam samples were above maximum permissible limits of 0.1 mg/kg for Hg, As and Pb and 5 mg/kg for Cu established by FAO/WHO (1995) and EU (2004; 2006) rendering them unsafe for human consumption. Heavy metals concentrations in soils were higher than in cocoyam samples in all locations in all countries . As and Cr concentrations however, were below the maximum permissible limits of 20 and 75 mg/kg respectively, in all countries. Heavy metals variation occurred both within and among countries, with Kampala, Uganda having significantly ($p<0.05$) higher values than other locations and countries, respectively. With exception of Pb in Uganda, insignificant correlation ($p>0.05$) between soil and the corresponding cocoyam crops grown was observed for other metals. Soil and cocoyam crops grown in the selected locations along the wetlands of Lake Victoria basin are contaminated with heavy metals and thus pose health risk to the consumers

Keywords: cocoyams, soil, Mercury, Arsenic, Lead, Chromium, Copper

Introduction

Cocoyam (*Colocasia esculentum* and *Xanthosoma sagittifolium*) is one of the six most important root and tuber crops worldwide and a rich source of vitamins (B_1, B_2, B_3 and C), minerals (Calcium and Phosphorous), proteins and carbohydrates (Ndon *et al.*, 2003; Boakye *et al.*, 2018). Cocoyam flour can be used for soups, biscuits, bread, beverages, and puddings (Ojinnaka and Nnorom, 2015, Kabuo *et al.*, 2018) whereas leaves and stalks of cocoyam are used as vegetable. For many years, wetlands around Lake Victoria basin have been potential sources of livelihood and food security for the surrounding communities in the lake region providing a wealth of ecological, social and economic functions (Namakambo, 2000; Mott, 2001; Swallow *et al.*, 2001, Talwana *et al.*, 2009). However, most of these wetlands are prone to heavy metal pollution from surrounding soils because of pollutant inputs from increased population and anthropogenic activities as well as domestic and natural activities (Suciu *et al.*, 2008; Chopin and Alloway, 2007). Chemical and metallurgical industries are the most important sources of heavy metals in the environment (Cortes *et al.*, 2003). In Tanzania, the catchment regions around Lake Victoria are known for cotton and rice production, fishing and mining activities while in Uganda, the industries impacting on the wetlands of the Lake Victoria basin are in Kampala and Jinja. Heavy metal contamination of food crops is an issue of global concern that ultimately results in toxicity and diseases in humans and animals through consumption of contaminated food crops (Onakpa, 2018). Because of their toxicity and ability to partition into food chains, non-biodegradability and persistence, heavy metals can cause environmental hazards when polluted soils are used for agriculture (Yargholi and Azimi, 2008; Alloway 2013; Yan *et al.*, 2013). No studies have been reported to assess the level of metal contamination in the study catchment areas. Thus, studies to determine their levels and relationship between soil and corresponding plants grown on them is of great importance. This study was therefore conducted to investigate the concentration of heavy metals in soil and cocoyam grown on them in wetland areas around the Lake Victoria basin.

Materials and methods

Study locations

The study was carried out in wetland areas around Kampala urban, Mukono and Wakiso districts in Uganda; Bukoba urban, Bukoba rural and Misenyi districts in Tanzania and Kisumu, Vihiga and Kakamega districts in Kenya. Sites were carefully selected to include areas subjected to industrial and agricultural waste discharge including sewage, toxic waste and waste water irrigation from anthropogenic activities.

Sample collection and preparation

Cocoyam samples

A total of 48 samples of cocoyams (*X. saggitifolium*) were randomly collected in triplicate from farmers in selected sites at the peak of harvest period. Samples were wrapped in labeled plastic bags, transported to the laboratory where they were prepared according to a standard procedure described by Njintang *et al.* (2004). They were thoroughly washed with tap water and peeled using stainless steel knives and cut into small slices (0.5 cm thick), dried to a constant weight in an oven set at 105°C. The dried slices were then milled into flour using a grinder fitted with a 500-µm mesh sieve. The flour was packed in an airtight container and stored at 4°C until analysed.

Soil samples

A total of 48 soil samples were taken simultaneously, and fresh cocoyam samples were harvested. Three sets of top soil samples down to 15 cm depth were collected at each sampling site by using a stainless steel Dutch equipment as described by ISO (1991) and Akerblom (1995). The soil samples were packed in labeled plastic bags and transported in ice box to the laboratory for analysis.

Chemical analysis

The analyses for both cocoyam crops and soil samples were carried out at the Geological Laboratory in Dodoma, Tanzania by using an Atomic Absorption Spectrophotometer (Model: UNICAM 919 England, UK) according to AOAC, (1995). Samples were analysed in triplicates for Mercury (Hg), Arsenic (As), Chromium (Cr), Lead (Pb) and Copper (Cu).

Data analysis

Data was subjected to analysis of variance using Generalized Linear Model (GLM) procedure of MSTAT-C computer statistical package (Michigan State University, 2001) and means were separated using Duncan's New Multiple Range Test.

Results

Heavy metal concentration in cocoyam samples at various locations in the selected sites

The mean concentrations of heavy metals in cocoyam samples at various study locations in Tanzania, Uganda and Kenya are presented in Table 1. Chromium was not detected in all samples collected from all the countries. For other metals, the concentration varied among sites in all countries. Copper appeared in highest concentration compared to other heavy metals. There was no significant difference ($p>0.05$) observed for Hg and Cu in all locations in all the three countries. It was highest in Kampala (Uganda) and was statistically different from all other locations in Kenya and Tanzania, which were much lower. Though no Pb was detected in Kenya, it was detected in two districts of Uganda and Tanzania. It was highest in Kampala which was statistically higher ($p<0.05$) than in all other locations in both Tanzania and Uganda (Table 1). No significant differences ($p<0.05$) in heavy metals were observed between the various locations in Kenya and Tanzania. In Uganda however, the mean concentrations of Hg, As and Pb were significantly higher ($p<0.05$) than all other locations.

Table 1. Heavy metals concentration (mg/Kg) in cocoyams collected from various locations

Country	Location	Hg	As	Pb	Cu
Tanzania	Bukoba Urban	0.09±0.09a	1.39±0.18b	0.95±0.70b	3.40±2.12a
	Misenyi	0.10±0.09a	0.72±0.32b	0.50±0.58b	5.28±3.19a
	Bukoba Rural	0.16±0.18a	1.9±0.78b	ND	6.50±0.71a
Uganda	Kampala	0.15±0.13a	3.50±1.51a	6.00±8.79a	6.10±4.38a
	Wakiso	0.03±0.30a	0.84±0.48b	ND	4.79±1.56a
	Mukono	0.09±0.10a	1.91±1.63b	1.86±2.73b	6.43±2.99a
Kenya	Kisumu	0.13±0.11a	0.04±0.04b	ND	4.00±2.83a
	Vihiga	0.17±0.16a	ND	ND	7.50±0.71a
	Kakamega	0.33±0.21a	0.13±0.15b	ND	3.00±1.00a

Means with different superscripts in the same column indicates significant difference at p<0.05;
ND: Not Detected

Heavy metal concentration in soil samples at various locations in selected locations

The mean concentrations of heavy metals in soil samples at various wetlands in Tanzania, Uganda and Kenya locations are presented in Table 2. The table shows lower Hg levels (< 1mg/kg) for all areas except Bukoba in Tanzania. As was lower than 3 mg/kg for Kenya and Tanzania but was higher in Uganda. Though Pb was not detected in several sites studied, it was highest in Kampala, Uganda. There were variations in Cu levels in all the countries, without a clear pattern.

Table 2: Heavy metals concentration (mg/Kg) in soil samples collected from various locations

Country	Location	Hg	As	Pb	Cr	Cu
Tanzania	Bukoba Urban	1.08±0.28a	2.16±0.99b	15.68±11.14c	14.90±7.77a	24.63±11.26b
	Misenyi	0.61±0.39a	1.11±0.94b	22.90±9.74b	13.70±2.79a	33.75±14.82b
	Bukoba Rural	0.64±0.75a	0.85±0.50b	19.80±4.66c	16.90±0.57a	23.65±4.17b
Uganda	Kampala	0.56±0.26a	3.36±0.13a	76.93±4.48a	17.54±1.34a	51.17±3.74a
	Wakiso	0.93±0.41a	3.64±0.18a	22.84±1.18b	8.28±0.59b	36.81±9.47b
	Mukono	0.49±0.32a	4.56±2.06a	23.47±2.25b	8.50±0.98b	31.37±6.49b
Kenya	Kisumu	0.47±0.28a	2.74±1.52b	16.6±5.96c	10.3±7.45a	21.13±17.77b
	Vihiga	0.48±0.37a	1.55±0.30b	32.60±11.03b	6.85±0.35b	30.35±9.40b
	Kakamega	0.66±0.11a	2.16±1.28b	39.20±20.08b	6.60±1.13b	29.50±2.12b

Means with different superscripts in the same column indicates significant differences at p<0.05

Further analysis showed that there were no significant difference (p<0.05) in mean soil Hg concentrations between the various locations in the three countries (Table 2). Samples from all locations in Kenya and Tanzania were statistically similar (p>0.05) in As concentrations, but significantly different (p<0.05) from all the three locations in Uganda. With the exception of Kampala, no significant difference (p>0.05) in Cu concentration was observed in the remaining locations in Uganda, Tanzania and Kenya.

Samples from Kampala (Uganda) had significantly higher values (p<0.05) for Pb, Cr and Cu concentrations than other locations while Wakiso (Uganda) had significantly (p<0.05) higher values of Hg. Mukono (Uganda) had significantly higher values (p<0.05) of As. Though Cr concentration was highest in Kampala, it did not differ significantly (p>0.05) from the three locations in Tanzania and Kisumu in Kenya.

No significant difference (p>0.05) in mean concentrations for Hg, As, Cr and Cu were observed in Tanzania.

Comparison of heavy metal concentrations in cocoyam plants and soil between the countries

The mean heavy metal concentrations in cocoyams and soil samples in the three countries are presented in Figure 1. Samples from Uganda and Tanzania had higher As than samples from Kenya. Uganda samples had significantly higher Pb concentration than Tanzania and Kenya. No significant differences ($p>0.05$) in Hg and Cu contents were observed between the countries.

Soil samples exhibited significant differences ($p<0.05$) in all heavy metals in the three countries. Uganda samples had significantly higher means for As, Pb, and Cu than Tanzania and Kenya samples which were statistically similar for the same metals, respectively. Although most samples from Tanzania had notable higher mean Hg concentration than in Uganda and Kenya, they did not have significant difference ($p>0.05$). In addition, Tanzania samples had higher mean Cr than Kenya.

Relationship in heavy metal concentrations between soil and cocoyam crops

Relationship in heavy metal concentrations between soil and their corresponding cocoyam crops in Tanzania, Uganda and Kenya locations

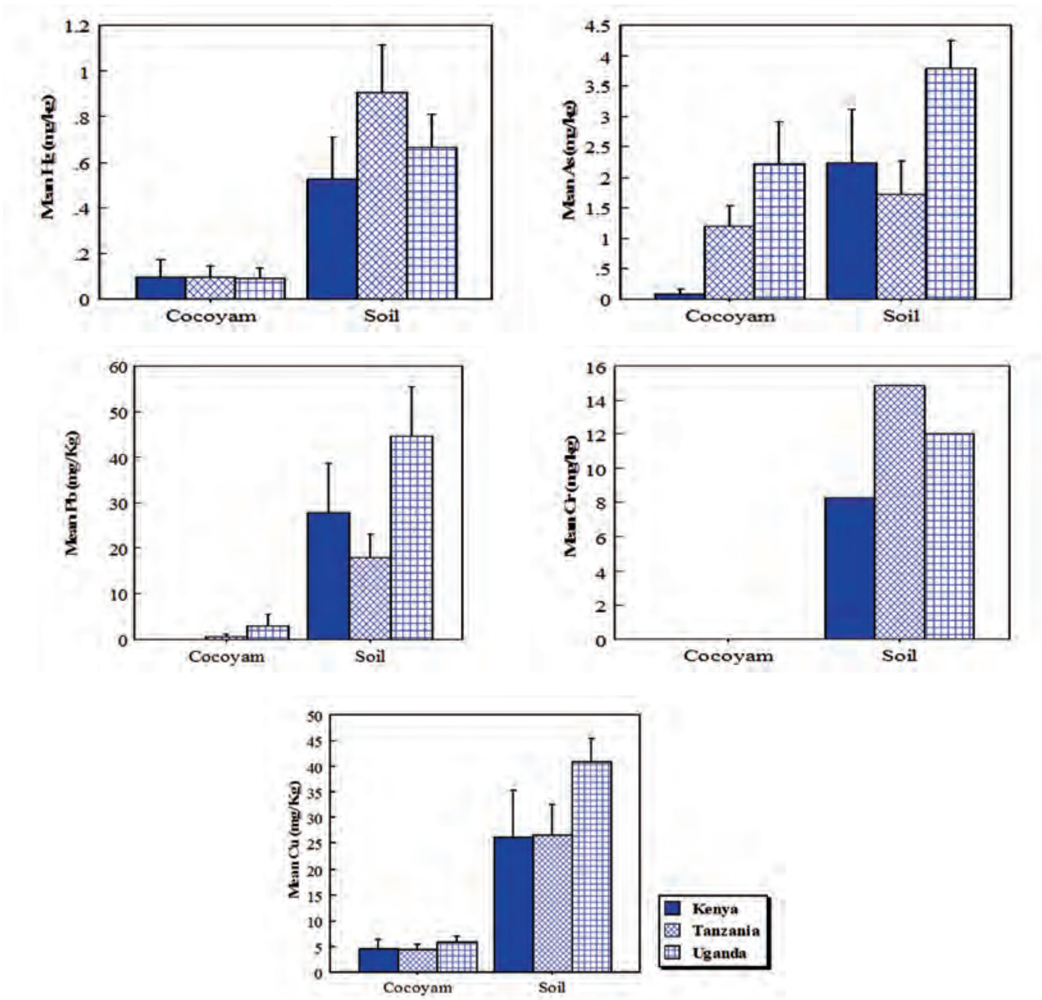

Figure 1: Heavy metal concentrations (mg/kg) in cocoyam and soil samples between the countries

are presented in Figures 2, 3 and 4 respectively. No significant correlation ($p>0.05$) in all heavy metals concentrations were found between soil and cocoyam samples from Tanzania. Hg and As concentrations showed insignificantly weak correlation between soil and cocoyam samples. The same was observed for Cu and Pb.

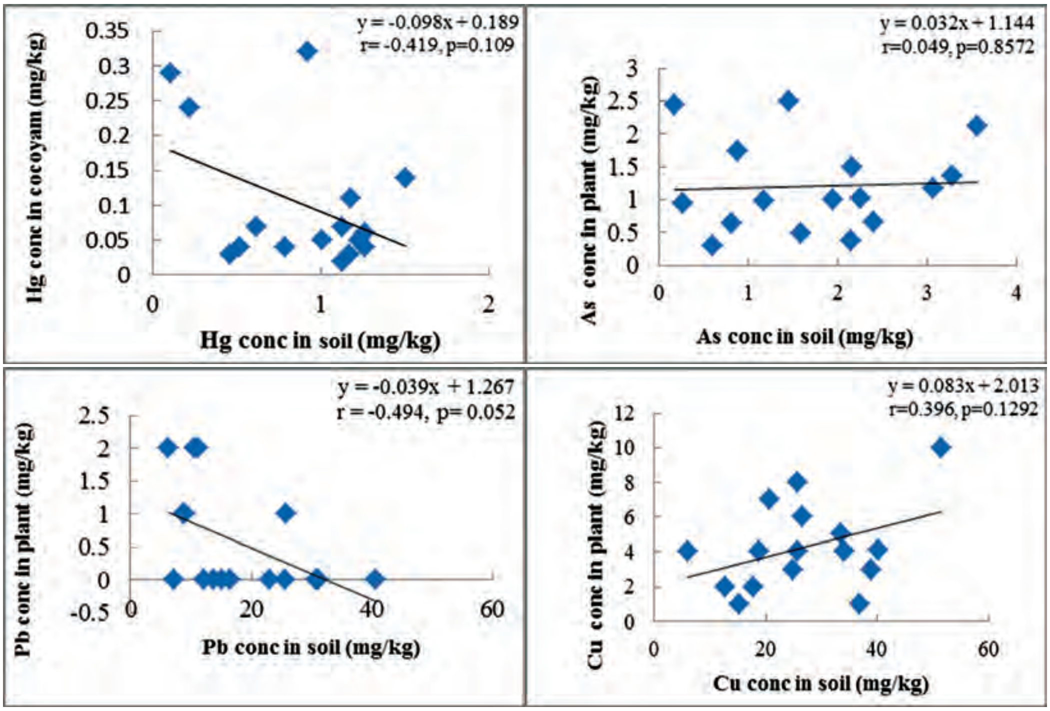

Figure 2: Scatter plots charts showing relationship between soil and cocoyam crops in Tanzania locations

Relationship in heavy metal concentrations between soil and their corresponding cocoyam crops in Uganda locations are presented in Figure 3. A significant correlation ($p<0.05$) in Pb concentrations between soil and corresponding cocoyam samples were observed. Hg, As and Cu showed insignificantly weak negative correlations between soil and cocoyam samples while Pb showed significantly positive correlation between the two samples.

Relationship in heavy metal concentrations between soil and their corresponding cocoyam crops in Kenya locations are presented in Figure 4. A positive correlation ($p<0.05$) in Hg concentrations between soil and corresponding cocoyam samples were observed. However, As and Cu showed weak positive correlations between soil and cocoyam samples.

Discussion

Heavy metal concentration in cocoyam and soil samples in Tanzania, Uganda and Kenya

The mean heavy metals concentrations in cocoyam samples were above maximum permissible limits of 0.1 mg/kg for Hg, As and Pb and 5 mg/kg limit for Cu established by (FAO/WHO, 1995) and (EU, 2004; 2006). The permissible value are thresholds maximum limits by which no observable adverse effect will be seen in human beings who consume the foods containing these chemicals. The relatively high concentration of these metals in the cocoyam crops strongly suggests presence of heavy metals pollution in these locations due to increased human activities such as mining, agriculture and industries. Thus, it would appear that, consumption of the cocoyam and other food crops grown on some wetland areas of the Lake Victoria basin poses danger to the health of consumers. Several studies have demonstrated that the primary sources of heavy metals in the soil environment and agriculture are atmospheric deposition, livestock manure, irrigation with wastewater or polluted water,

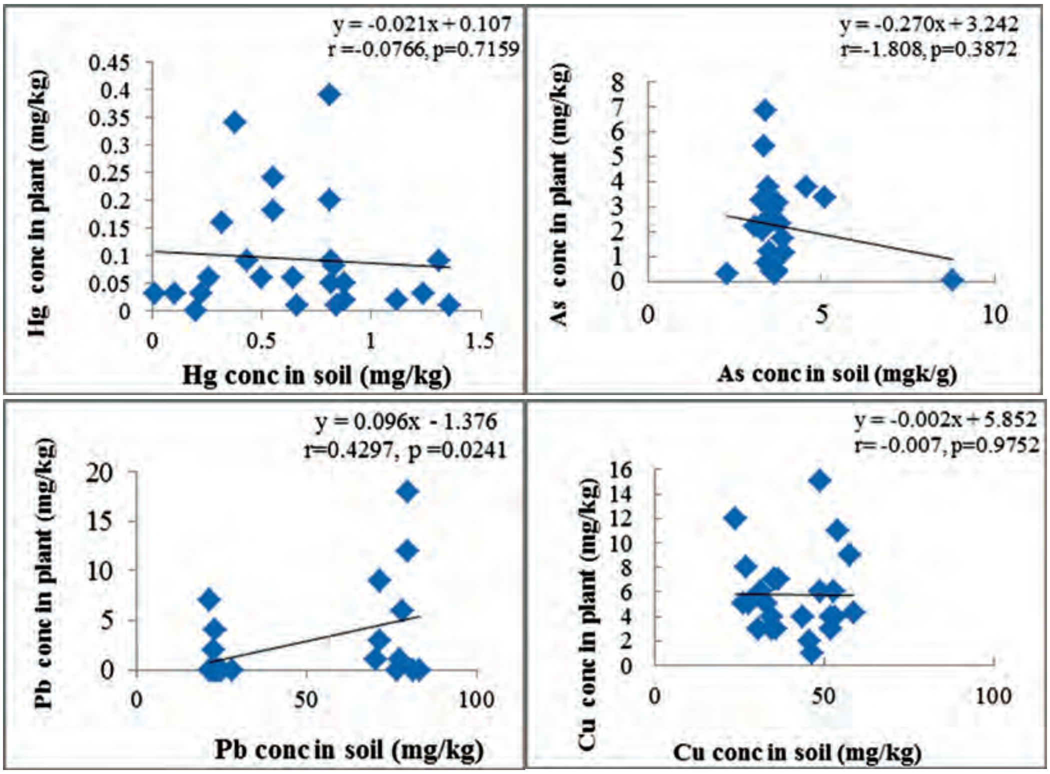

Figure 3: Scatter plots charts showing relationship between soil and uptake of heavy metals by cocoyam samples in Uganda locations

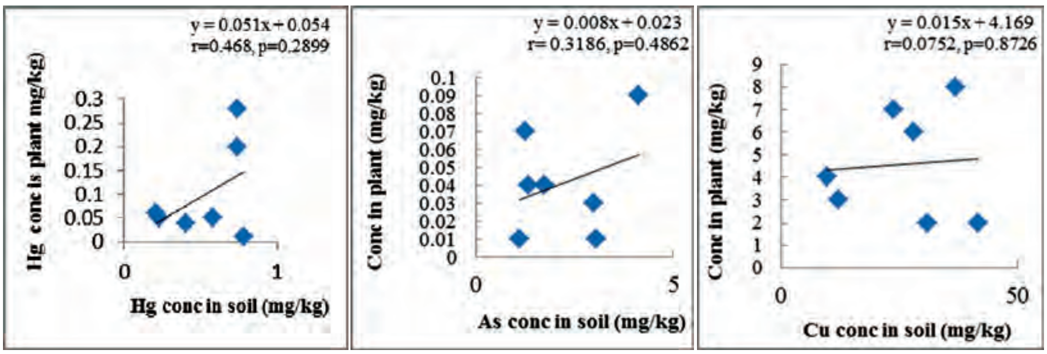

Figure 4: Scatter plots charts showing relationship between soil and cocoyam crop in Kenya locations

metallo-pesticides or herbicides, phosphate-based fertilizers, and sewage sludge–based amendments (Gall *et al.*, 2015; Lv *et al.*, 2015; Elgallal *et al.*, 2016; Woldetsadik *et al.*, 2017; El Kady and Abdel-Wahhb, 2018). In addition to natural sources, conventional/emerging anthropogenic contaminants pose major human health risks through the dietary intake of food crops contaminated by root transfer from soil to plant tissues or direct atmospheric deposition onto plant surfaces (Samsoe-Petersen *et al.*, 2002; Zhuangh *et al.*, 2009).

The heavy metal values obtained in this study for Pb and Cu were lower than those reported in other studies done in the same area by Nabulo *et al.* (2007) and Mbabazi *et al.* (2010) respectively that showed much higher heavy metal contamination in the soil sample obtained from wetland areas around lake basin. A similar increasing trend of As, Hg, Cu and Pb contents in foods has also been reported in River state, Nigeria (Hart *et al.*, 2005) and Tarkwa mining community in Ghana (Essumang *et al.*, 2007). Despite the fact that some trace metals like copper and zinc are essential for important biochemical and physiological functions necessary for maintaining health, their undue presence in the food chain especially from industrial pollution could be harmful (Hart *et al.*, 2005). The heavy metals in contaminated soils are taken up by plants via the roots and later accumulate in the stem and other edible portions of plants which eventually lead to poisoning when consumed (Rai *et al.*, 2019). They enter the human body through inhalation of dust, direct ingestion of soil and consumption of food plants grown in metal contaminated soil. Excessive content of heavy metals such as Pb, Hg and Cd in food is associated with number of diseases, especially of cardiovascular, renal, nervous and skeletal. They are also implicated in carcinogenesis, mutagenesis and teratogenesis (Rwadan and Salama, 2006; Figueiredo *et al.*, 2009; Gunney *et al.*, 2010; Farmer *et al.*, 2010; Lai *et al.*, 2010)

Heavy metals concentrations in soils were higher than those in cocoyam crops in all locations in all countries studied. It was further observed that, the As and Cr concentrations in all locations in all countries were below the maximum permitted limits 20 and 75 mg/kg (FAO/WHO, 1995). However, the Hg concentration in all locations in all countries were above the maximum permitted limits of 0.1 mg/kg while Pb and Cu concentrations in Kampala, Uganda exceeded the maximum permitted limits for soil used for agriculture of 50 and 10 mg/kg (FAO/WHO, 1995). These findings suggest presence of heavy metal contamination in the soil in these locations and thus render them unsafe for agricultural activities. The presence of heavy metals in soil can affect the quality of food, groundwater, micro-organisms activity and plant growth, thus, consumption of food grown on such soil may pose a health risk to the consumers. It is well known that plants take up heavy metals by absorbing them from contaminated soil as well as from deposits on parts of the plant exposed to the air from polluted environment (Chojnacka *et al.*, 2005; Onakpa *et al.*, 2018).

Comparison of heavy metals concentrations within and among countries

The observed significantly higher mean values of Hg, As and Pb concentrations in cocoyam samples and Pb and Cu concentrations in soil samples from Kampala than in other locations indicates variation in heavy metals concentrations between different locations in Uganda with Kampala being the most contaminated area. Also the overall significantly higher mean values of As and Pb in cocoyam and As, Pb and Cu concentrations in soil samples from Uganda, indicates variation in heavy metals concentrations among the 3 countries. Uganda wetlands was the most contaminated areas along the lake Victoria. These variations within and among the countries could be due to the fact that, different human activities discharge different chemicals into the environment at different levels and thus the heavy metal properties of the soil and factors promoting uptake by plants tend to differ from site to site. It was reported by Rai (2019) that due to rapid pace of population growth and industrialization, wastewater, treated effluent and sludge contaminated with heavy metals have frequently been used as low cost sources of irrigation in parts of Asia and Africa, which has resulted in negative consequences to human health. Of late, Kampala had been undergoing rapid urbanization and accelerated industrial growth (Rusongoza, 2003; Vermeiren *et al.*, 2012; World Bank, 2017). The industrial activities in Kampala include factories of batteries, soap, paint, metal fabrication, plastics, corrugated iron sheets, pharmaceuticals, breweries, tanneries, former copper smelting plant as well as municipal waste disposal (Muwanga and Barifaijo, 2006). The operations and effluent managements of these industries plus other municipal wastes and urban run-off were found to be negatively impacting on the wetlands and strongly suggest the presence of heavy metals pollution in Kampala and Uganda at large (Muwanga and Baijo, 2006). It has been reported that waste from these activities, are the main pathways of heavy metals into the lake environments (Kisamo, 2003) which in turn contaminate and adversely affect the quality of wetland resources such as water, soil, fish and food crops grown in the area (Muwanga and Barifaijo, 2006). Similar high values of heavy metals in Kampala have also been reported in studies by Nabulo *et al.* (2007) and Mbabazi *et al.* (2010).

The highest Pb concentrations have been found in aquatic and terrestrial animals that live near to Pb mining, smelting and refining facilities, storage battery recycling plants, areas with high automobile and track traffic, sewage sludge, disposal areas and sites where dredging has occurred. Moreover, the significantly higher Hg concentration in Tanzania samples could probably be due to gold mining activities in the catchment regions around the Lake Victoria in which mercury is one of the key chemicals (Kitula, 2006). A study by Mtui *et al.* (2006) revealed that increased concentration of heavy metals in the mining-impacted sites of the wetland soils was positively correlated with the bioaccumulation of such elements in plant tissues. Mercury (Hg) is used mainly for the processing of primary gold quartz veins and supergene gold mineralization. A research finding has shown that, 70–80 % of the Hg is lost to the atmosphere during processing while 20–30 % is lost to tailings, soils, stream sediments and water (Van Straaten, 2000). For every 1 g gold produced, 1.2–1.5 g Hg are lost to the environment. Cumulatively, the anthropogenic Hg released annually into the atmosphere is approximately 3–4 ton in the whole Lake Victoria Goldfields of Tanzania rendering it environmentally unstable (Van Straaten, 2000).

Relationship between heavy metal concentration in soil and cocoyam crop

The significantly positive correlation in Pb between soil and their corresponding cocoyam crop in Kampala samples implies linear increment of the Pb concentration in crop as soil concentration increases. This may lead to conclusion that the elevated Pb pollution observed in the soil is evidently reflected in cocoyam crops grown on them. This finding is comparable to the study by Mbabazi *et al.* (2010) who observed positive correlation between elevated Pb concentrations in soil and their corresponding cocoyam crops. This could be ascribed to the fact that, when heavy metal concentrations in the soils are elevated, the total heavy metal content of food crops grown on such soils also may be elevated at a concentration causing serious risk to human health when consumed (Bortley-Sam *et al.,* 2015; Kacholi and Sahu, 2018). This is due to concentration gradient for various metals as crops utilize nutrients that are available in the soil. A study by McLaughlin *et al.,* (2011) revealed that heavy metals are transferred from soil pores to plants in ionic forms, which can vary by metal and food crop. The bio-speciation of heavy metals can also vary by food crop.

The remaining heavy metals showed insignificantly weak positive or negative correlations between soil and cocoyam crops grown. It was found in one study that although the levels of most metals in plants were highly comparable with those of soil counterparts, metals in corn and jujube grains, did not show any significant correlations with those of soils (Jung, 2008). This may be explained by the fact that high levels of heavy metals in the soil do not always indicate similar high concentration in plants. One author explained that plants develop a series of mechanisms to avoid heavy metal toxicity which include: (i) production of reactive oxygen species by auto oxidation and Fenton reaction, (ii) main functional group blocking, and (iii) displacement of metal ions from biomolecules (Clemens, 2006; Rai *et al.,* 2019). All these mechanisms operate as strategies to grow on contaminated soil. In addition, the uptake and distribution of heavy metals in crops is influenced by the availability and total concentration of metals in soil, plant parts and species concerned. Other factors are cation exchange capacity, organic matter content, soil texture, and interaction among the target elements, types and varieties of plants, and plant age (Jung, 2008), soil pH, physical and chemical soil properties (Wilson *et al.,* 2014; Wang *et al,* 2013a; Ahmad and Goni, 2010) and their forms and association in the soil, especially metals in the easily leachable and ion exchange fraction (Maimon *et al.,* 2009). Absorption and accumulation of heavy metals in plant tissues also depends upon temperature, moisture, nutrient availability (Tangahu *et al.*, 2011) and plant species, while the efficiency of plants in absorbing metals is determined by either plant uptake or soil-to-plant transfer factors of the metals (Khan *et al.,* 2008). It is however, generally accepted that the metal concentration in soil is the dominant factor (Balkhair and Ashraf, 2016). Plants are known to respond to the amount of readily mobile species of metals in soil despite differences in mechanisms involved in the elemental uptake by roots (Adbel-Sabour and Aly, 2000). The strongly bound metals to the various soil components have less mobility (leachability) to the roots systems of the plant and thus low uptake. This explains why some metals would not be up taken substantially by the crops from the soil to show significant positive correlations. Pb was reported to be taken up easily by plants under certain conditions (Maimon *et al.,* 2009). This is probably due to their easy leachability property. However, although these metals show insignificantly weak positive or negative correlations between soil and cocoyam crops in all countries, their concentrations in crops exceeded the maximum permissible limits and should not be neglected. Since heavy metals are cumulatively toxic, the prolonged production and discharge into the soils may in future show significant correlations indicating heavy contamination associated with increased danger to the health of consumers within and outside the basin.

Conclusion

Soil and cocoyam crops grown in wetland areas of around Lake Victoria basin are contaminated above maximum permissible limit mainly by anthropogenic activities which pose risk to the health of the consumers upon consumption. Hence, the soil is unfit for agriculture while crops are unsafe due toxicity nature of the metals. The level of contamination varies among location within and among countries. Kampala location and Uganda as a country were the most contaminated. With exception of Pb in Uganda, all other metals showed insignificant negative or positive correlation between soil and their corresponding heavy metal uptake by cocoyams, despite the crops having concentrations above permissible limits. Therefore, based on these findings, it can be concluded that heavy metal contamination around lake Victoria basin is of great concern which calls for quick measures to mitigate the availability and bioaccumulation of heavy metals in soils and crops.

Acknowledgement

The authors would like to thank VICRES (The Lake Victoria Research Initiative) for the financial support that made this work possible.

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