academicJournals

Vol. 8(1), pp. 66-74, January 2014
DOI: 10.5897/AJEST2013. 1573
ISSN 1996-0786 © 2014 Academic Journals
http://www.academicjournals.org/AJEST

African Journal of Environmental Science and Technology

Full Length Research Paper

Heavy metal content of selected African leafy vegetables planted in urban and peri-urban Nairobi, Kenya

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Accepted 14 November, 2013

African indigenous vegetables planted along Nairobi Rivers are suspected to absorb metals from industrial and domestic effluent. Ten (10) of the commonest vegetables in Kenyan markets grown along these rivers and the soils in their rhizosphere from 25 sites were analyzed for Pb, Cu, Zn, Cd and Cr. Soils were air-dried then leached using 0.05 M EDTA, filtered and analysed in AAS. Vegetables were oven-dried, ground, ashed then analysed in AAS. In both soil and vegetables, the metal concentration was generally in the order Zn > Cu > Pb > Cd >Cr. In soil the concentrations were Pb 0.57 - 20 mg/kg, Cu 3.59 - 75.37 mg/kg, Zn 14.62 - 198.3 mg/kg, Cr 0.03 - 1.4 mg/kg and Cd 0 - 2.6 mg/kg. In vegetables the values were Pb 0 - 2.4 mg/kg, Cu 0.52 - 21.34 mg/kg, Zn 20.13 - 89.85 mg/kg, Cd 0 - 3.02 mg/kg and Cr 0 - 1.24 pp. There were significant differences within vegetables at each site (P<0.05). In most sites, there was a positive correlation of soil metal content with that in vegetables. The metal concentrations in soil were within permissible levels allowable by WHO/FAO except for a few instances in Cd. In vegetables all metals except Cu were in a few sites higher that the recommended limits. Government clean-up activities and monitoring of waste disposal is recommended for potential agricultural land.

Key words: African Indigenous vegetables, heavy metals, pollution, urban and peri - urban agriculture, Nairobi.

INTRODUCTION

Nairobi, like other cities in the developing countries is expanding tremendously without proper planning of utilities, safety and regard to environment, making residents dump waste into rivers and on land (Yebpella et al., 2011). Wastes may contain heavy metals among other contaminants (Olowoyo et al., 2011; Tiwari et al., 2011; Sinha et al., 2010). Toxic metal sources include ordinary activities of industrialization, civilization, agriculture and natural sources (Olowoyo et al., 2011; Kisamo, 2003). Heavy metal contaminants in soil can be absorbed by plants that are consumed by humans (Mutune et al., 2013; Ghosh and Singh, 2005; Salt et al., 1995). Heavy metals such as cadmium, chromium, lead, copper and zinc have been obtained in vegetables planted or consumed within urban areas sometimes in more than allowable limits (Yebpella et al., 2011; Salariya et al., 2002). Some plants such as *Brassica* vegetables have been shown to hyperaccumulate metals in their edible parts (Kumar et al., 2007). Copper and zinc are essential micronutrients obtained from vegetables (Sinha et al., 2010; Iyaka, 2007) but at high levels they cause oxidative stress through redox reactions (Sinha et al., 2010; Ghosh and Singh, 2005). Lead also causes oxidative stress and in young children it causes mental retardation (ATSDR,

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Table 1. Sites from where vegetables and soils were collected for metal analysis.

Code	Site description	Code	Site description
S1 (IA)	Mukurwa Kwa Njenga along river	S14 (RR)	Githurai Bridge
S2 (IA)	Kware	S15 (SA)	Nairobi West Prison Farm
S3 (IA)	Donholm bridge	S16 (SA)	Langata Estate
S4 (SA)	Kayole farm	S17 (OF)	Kawangware
S5 (RR)	Komarock Junction road	S18 (OF)	Kikuyu town
S6 (OF)	Saika	S19 (OF)	Karura forest
S7 (SA)	Njiru bridge	S20 (OF)	Kiambu town
S8 (SA)	Ruai	S21 (SA)	Ruiru river near town
S9 (SA)	Ruai near treatment plant	S22 (SA)	Ruiru river near town
S10 (RR)	Kariobangi bridge	S23 (RR)	Juja bridge
S11 (OF)	Korogocho	S24 (OF)	Juja farm
S12 (RR)	Mwiki River bridge	S25 (OF)	KM
S13 (OF)	Mwihoko		

IA - Industrial area; SA - sewer area; RR - road reserve; OF - ordinary farm.

2007). Chronic exposure to cadmium causes glomerula damage and also alters Zn, Cu and Se metabolism (ATSDR, 2012) while some oxidative forms of chromium (Cr VI) are carcinogenic.

In addition to toxicity, heavy metal deficiencies also occur therefore knowledge of their amounts in vegetables for dietary supply is imperative (Iyaka, 2007). The high population of the Nairobi City and high cost of living has forced urbanites to farm within the city for consumption and income generation (Shackleton et al., 2009). Water and soil in cities are rich in nutrients such as N, P, K, S and Mg from waste which makes vegetables large and appealing. Making urban agriculture environmentally and health wise sustainable is a major constraint. There is need for research to address the constraint and help to inform relevant policy interventions. The present study aims at investigating the concen-trations of selected heavy metals in ten common vegetables and the soil where they are planted in.

METHODOLOGY

The chemicals used during this study were of analytical grade and water used for rinsing glassware was distilled.

Collection of vegetables

The vegetables collected were African nightshade (*Solanum villosum* V1), Swiss chard (*Beta vulgaris* V2), African kale (*Brassica carinata* V3), spiderplant (*Cleome gynandra* V4), Amaranths (*Amaranthus sp* V5), pumpkin leaves (*Curcubita moschata* V6), cowpea leaves (*Vigna unguiculata* V7), jute mallow (*Corchorus olitorius* V8), slenderleaf (*Crotalaria* sp. V9) and kale (*Brassica oleracea* var. Acephala V10). Collection was done in 25 sites which were ranked into four categories: industrial area (IA), road reserve (RR), sewage area (SA) and ordinary farm (OF). The industrial area was along Nairobi River and its tributaries, and all vegetables planted there were watered from these rivers which are adjacent to high manufacturing and other industrial activities. The road reserve sites were areas near roads, at least within 100 m from the roads. Sewage area sites were evidently watered with river water that contained lots of sewage effluent. Ordinary farms were far from any source of contamination, where activities are low. The sites are represented in Table 1. The vegetables were packed in polythene bags and packed in cooler boxes. In the laboratory, samples were thoroughly washed and rinsed with distilled water before drying at 70°C for three days, then powdered using a miller.

Soil collection

Top soil (0-15 cm depth) samples were obtained from each of the points where vegetables were collected. Sampling was done in a zigzag (Okalebo et al; 2002) of 5 cores across the field, avoiding areas of obvious interference like litter, manure and rocks. The sites ranged from 50 to more than 100 m^2. The five samples from each site, each about 0.5 kg, were composted and air dried at 25°C for about 1 month, sieved to <2 mm, then 3 replicates were obtained from each composite for analysis.

Digestion of samples

Soil mineral extraction was done using 0.05 M EDTA disodium salt according to Gupta (1999). Five grams of soil were vortexed with 25 ml EDTA for 60 min at 120 rpm. The supernatant was filtered through Whatman No. 42 paper, and topped up to 50 ml using distilled water and stored in a cold room at -20°C. Soil was extracted using EDTA because only extractable metal is bioavailable and mobile in reference to plants (Sinha et al., 2010). EDTA has a strong chelating ability for different heavy metals (Tandy et al., 2004).

Five grams of vegetable powder was weighed into a silica crucible. It was charred to remove carbon in a block digester at 200°C

Table 2. Heavy metal content (ppm) of soils from the sites where vegetables were collected.

Site	Pb	Zn	Cu	Cr	Cd
S1 (IA)	1.70[e*]	42.96[e]	6.43[d]	0.03[c]	0.222[d]
S2 (IA)	20.94[a]	196.00[a]	70.96[a]	1.41[a]	2.644[a]
S3 (IA)	16.33[b]	198.30[a]	75.37[a]	0.23[b]	1.731[b]
S4 (SA)	9.43[c]	190.05[a]	45.61[b]	0.12[c]	0.2279[d]
S5 (RR)	0.66[e]	29.42[e]	9.22[d]	0.05[c]	0.5571[d]
S6 (OF)	0.57[e]	43.45[e]	8.29[d]	0.09[c]	0.0333[d]
S7 (SA)	0.94[e]	40.34[e]	10.47[d]	0.14[bc]	0.00[d]
S8 (SA)	0.67[e]	13.01[h]	5.77[e]	0.18[b]	0.2629[d]
S9 (SA)	5.40[d]	105.08[c]	18.17[c]	0.17[b]	0.7146[c]
S10 (RR)	2.40[e]	110.14[c]	21.97[c]	0.09[bc]	0.1279[d]
S11 (OF)	1.88[e]	127.87[b]	12.61[d]	0.07[c]	0.0108[d]
S12 (RR)	0.78[e]	16.63[h]	11.18[d]	0.06[c]	0.0758[d]
S13 (OF)	2.42[e]	88.77[d]	18.08[cd]	0.06[c]	0.07[d]
S14 (RR)	2.83[e]	47.65[f]	3.59[e]	0.11[bc]	0.08[d]
S15 (SA)	1.28[e]	49.81[f]	6.54[d]	0.18[b]	0.1671[d]
S16 (SA)	2.18[e]	125.79[b]	18.04[c]	0.07[bc]	0.0084[d]
S17 (OF)	1.22[e]	14.62[h]	10.58[d]	0.10[bc]	0.0129[d]
S18 (OF)	0.75[e]	55.68[g]	15.70[c]	0.07[bc]	0.00**[d]
S19 (OF)	1.75[e]	42.99[g]	6.38[d]	0.25[b]	0.00[d]
S20 (OF)	2.12[e]	117.72[b]	17.45[c]	0.08[bc]	0.00[d]
S21 (SA)	2.20[e]	109.13[c]	22.00[c]	0.16[bc]	0.105[d]
S22 (SA)	1.91[e]	133.57[b]	15.62[cd]	0.20[b]	0.041[d]
S23 (RR)	0.86[e]	20.20[h]	12.56[d]	0.13[bc]	0.0458[d]
S24 (OF)	0.83[e]	17.42[h]	11.98[d]	0.21[b]	0.0675[d]
S25 (OF)	1.93[e]	111.62[c]	13.78[d]	0.15[bc]	0.1154[d]
S.E.	0.043	3.28	1.18	0.03	0.09

*Alphabetical letters indicate significance of variation within each metal among the collection sites; **0 value means below detection limit.

until all smoke had gone. The sample was then dry-ashed at 550°C in a muffle furnace for 14 h (method adapted from Okalebo et al., 2002). To the ash, 15 ml of 6 N HCl was added and the mixture heated for about 10 min at 250°C on a hot plate in order to digest the minerals in the ash. The resulting digest was filtered using Whatmans No. 42 filter paper. The filtrate was topped up to 50 ml using distilled water and stored in plastic bottles in a cold room till analysis.

Heavy metal analysis

Atomic Absorption Flame Emission Spectrophotometer (Shimadzu AAS-6200) was used to quantify heavy metal content for soil and vegetable samples. Calibration was done by running standards at concentrations of 0, 1, 1.5, 2 and 2.5 mg/kg. Hydrochloric acid (6 N) was used as a blank to zero the AAS.

Data analysis

Data on metal content obtained from the AAS was analyzed for variance using ANOVA and multiple mean comparisons were done using Tukeys at 5% level. Pearson's Product Moment was used to correlate the amount of metal in soil to that in the plant.

RESULTS AND DISCUSSION

Heavy metals in soils

The soil metal concentrations for each element and site are listed in Table 2. Soil metal concentration was significantly different in the different sites. The trend for the mean percentage for metals was Zn > Cu > Pb > Cd > Cr. EDTA-extractable Pb ranged from 0.57 to 20.94±0.43 mg/kg. The highest levels were in industrial area (sites 2, 3 and 4). This may be explained by occasional fuel spills and other waste flowing from the industrial area. Factories in this area include paint, vehicle batteries that may contain lead oxide, glass that may contain lead, and fuel some of which still contains lead. Sewage area where the effluent from the main sewer line of the city is let into the river contained up to 5.4 mg/kg. Soil Pb levels above 20 mg/kg are toxic to plants (Audu and Lawal, 2006), the highest obtained in this study.

Cu values were 3.59 to 75.37±1.18 mg/kg, with industrial area sites registering the highest levels. Copper has extensive use in industries, domestic items and farms such as coin money, electrical wiring, water and fabric treatment and fungicides. Taber (2009) suggests a 120 mg/kg higher limit in soil. It is found in soil either from natural or anthropogenic sources through water or dumping. Soil Cu content was much less as compared to earlier studies by Kimani (2007) (0 - 198 mg/kg) working on a dumpsite area in Kenya, but higher than Yebpella et al. (2011) (2.41 - 7.39 mg/kg) working on sites along a Nigerian river. EDTA-extractable Zn content ranged between 13.01 and 198.03±3.28 mg/kg. Industrial area sites had very high Zn contents as compared to other sites. Zinc industrially is used for galvanization, in dry cell batteries, cosmetics and medicines (ATSDR, 2005). Although some soils in ordinary farm sites had deficient Zn content, none had higher content than the recommended 30 - 300 mg/kg (Taber, 2009). Values in the study were lower than that of Kimani (2007) who analyzed soil around a dumpsite (175 - 1150 mg/kg).

Extractable Cd values were 0 to 2.64±0.09 mg/kg. Similarly, the highest values were at the industrial area region. Cadmium has wide usage in batteries, PVC plastics, cigarettes and paint pigments. Chromium concentration ranged from 0.03 to 1.4±0.03 mg/kg with industrial areas as the highest; none was above the recommended 100 mg/kg. Both Cd and Cr were however below detection limit in many sites. From the results, the highest values for all metals were at industrial area, followed by sewage area implying that metal content was

Table 3. Pb content of vegetables collected from Nairobi urban and peri-urban sites.

Site	Vegetable									
	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10
S1 (IA)	0.97^{f}**	1.20^{hi}		0.86^{e}	0.61^{cdefg}		0.65^{abc}	0.67^{ab}	0.55^{a}	0.82^{bcde}
S2 (IA)	*	1.88^{j}	1.17c	2.10^{g}	2.41^{k}	2.56^{k}				0.66^{abcde}
S3 (IA)		0.70^{defg}	0.77b	2.44^{g}	1.74^{j}	1.48^{j}	1.63^{de}			0.47^{abc}
S4 (SA)	0.14^{a}	0.79^{efgh}	0.35a		1.56^{j}	0.56^{bcdefg}	0.58^{abc}	0.62^{ab}		0.61^{abcde}
S5 (RR)	0.28^{ab}	0.28^{abcd}			0.50^{bcdefg}	0.63^{cdefg}	0.78^{abc}	0.73^{ab}	0.54^{a}	0.39^{abc}
S6 (OF)	0.46^{abcd}	0.17^{ab}		0.85^{de}	0.41^{bcde}	0.60^{cdefg}	0.61^{abc}	0.95^{b}	0.58^{a}	0.94^{cdef}
S7 (SA)	0.40^{abc}	0.50^{abcdef}		0.86^{de}	0.65^{cdefg}		0.57^{abc}			0.29^{ab}
S8 (SA)	0.30^{ab}	0.92^{fghi}		0.87^{e}	0.98^{i}	1.80^{j}	0.93^{bc}	0.25^{a}		0.68^{abcde}
S9 (SA)	0.55^{bcde}	1.20^{hi}	0.61^{ab}	1.32^{f}	1.69^{j}	0.85^{ghi}	0.95^{bc}	1.97^{c}	0.94^{b}	0.37^{abc}
S10 (RR)	0.43^{abcd}	0.25^{abcd}		0.30^{ab}	0.09^{a}	1.71^{j}	2.02^{e}	1.49^{c}	0.58^{a}	1.46^{fg}
S11 (OF)	0.86^{ef}	1.04^{ghi}	1.22^{c}	1.27^{f}	1.51^{j}	1.12^{i}	1.02^{bcd}			0.55^{abcde}
S12 (RR)		0.43^{abcde}		0.24^{a}	0.27^{ab}	0.59^{bcdefg}	0.72^{abc}	0.52^{ab}		1.56^{g}
S13 (OF)	0.77^{def}	0.66^{defg}	0.42^{a}		0.41^{bcde}	2.53^{k}	0.25^{a}			
S14 (RR)	0.93^{f}				0.63^{cdefg}	0.76^{cdefg}	0.99^{bc}			0.74^{abcde}
S15 (SA)	0.49^{abcd}	0.17^{ab}		0.48^{abc}	0.41^{bcde}	0.42^{abcde}	0.64^{abc}			0.41^{abc}
S16 (SA)		1.36^{i}		0.60^{bcde}	0.96^{hi}					0.44^{abc}
S17 (OF)	0.40^{abc}	0.09^{a}			0.80^{ghi}	0.16^{a}				0.51^{abcd}
S18 (OF)	0.30^{ab}	0.41^{abcde}			0.66^{defgh}					1.05^{defg}
S19 (OF)	0.86^{ef}	1.19^{hi}	1.22^{c}	1.27^{f}	1.51^{j}	1.12^{i}	1.09^{bcd}		0.48^{a}	0.55^{abcde}
S20 (OF)	0.16^{a}	$0.55b^{cdef}$	0.45^{a}	0.29^{ab}	0.37^{abcd}	1.19^{i}	0.53^{ab}			0.18^{a}
S21 (SA)	0.24^{ab}		0.44^{a}		0.68^{efghi}					0.42^{abc}
S22 (SA)	0.72^{cdef}	0.20^{abc}			0.68^{efghi}	0.14^{a}	1.18^{cd}	0.75^{ab}		0.85^{bcde}
S23 (RR)	1.03^{f}	0.63^{cdefg}	0.39^{a}	0.65^{cde}	0.75^{fghi}	0.83^{ghi}	1.18^{cd}	0.82^{b}	0.50^{a}	1.09^{efg}
S24 (OF)	0.44^{abcd}	0.70^{defg}		0.52^{abcd}	0.34^{abc}		0.46^{ab}			1.09^{efg}
S25 (OF)	0.33^{ab}	0.43^{abcde}			0.49^{bcdef}	1.18^{hi}	0.52^{ab}	0.75^{ab}		1.56^{g}
S.E.	0.043	0.103	0.186	0.076	0.069	0.067	0.144	0.113	0.071	0.128

*Blanks indicate that the vegetable was missing in a site; **alphabetical letters indicate significance of variation within each vegetable among sites; ***0 value means below detection limit.

significantly lowered by dilution as water flows downstream and progressively reduced dumping of industrial waste.

Heavy metals in vegetables

Metal content in vegetables had a similar trend with that in soil (Zn > Cu > Cd >Pb > Cr). There was a significant difference in the amount of Pb within vegetables at all sites. The highest Pb content (Table 3) of 2.4 mg/kg was in spiderplant and Pumpkin from sites 3 and 2 (industrial area). The lowest was 0.09 mg/kg in spinach from an ordinary farm and pumpkin from sewage area.

Copper concentration was also significantly different in vegetables from different sites (Table 4). The highest was 21.34 mg/kg in pumpkin from industrial area and the lowest was 0.5 mg/kg in cowpea from a road reserve. According to Taber (2009) and Mills and Jones (1991), normal Cu content in plants should range from 2 - 20 mg/kg, and CAC (2001) sets it at 40 mg/kg therefore the concentrations in this study were within acceptable range. Many vegetables contained lower than 2 mg/kg which is the recommended lower limit of Cu in plant tissue because some soils were deficient; or when they had sufficient Cu, a pH imbalance or an excess of other nutrients such as phosphorous which were not determined in this study could have limited absorption by vegetables (Mills and Jones, 1991).

Zinc concentration in vegetables also varied significantly (Table 5). The highest was 89.85 mg/kg in African Kale from site 2 (industrial area) and the lowest was 20.13 mg/kg from Amaranth and cowpea from ordinary farms. Normal Zn content in vegetables ranges should range within 25 - 300 mg/kg (Taber, 2009). These results were slightly higher than those of Jung (2008) who found

Table 4. Cu content of vegetables collected from Nairobi urban and peri-urban sites.

Site	Vegetable									
	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10
S1 (IA)	1.86^{a}	2.72^{bcd}		4.82^{d}	11.35^{i}		7.11^{hi}	4.86^{b}	7.35^{c}	8.10^{j}
S2 (IA)		11.60^{h}	11.03^{e}	18.00^{h}	21.34^{l}	19.93^{i}	12.28^{k}			8.76^{i}
S3 (IA)		12.24^{h}	13.29^{f}	14.42^{g}	18.89^{k}	20.26^{i}				11.74^{k}
S4 (SA)	1.91^{a}	1.75^{ab}	1.17^{a}		2.22^{bc}	4.74^{d}	0.93^{abc}	6.47^{c}		3.28^{e}
S5 (RR)	7.74^{f}	9.40^{g}			6.79^{h}	8.16^{f}	9.21^{j}	9.81^{d}	11.34^{d}	5.11^{fg}
S6 (OF)	7.87^{f}	9.56^{g}		3.37^{c}	2.92^{cd}	2.36^{bc}	2.50^{efg}	1.91^{a}	7.31^{c}	1.97^{bc}
S7 (SA)	3.43^{bc}	7.79^{f}	4.40^{c}	6.41^{e}	1.60^{ab}					2.31^{cd}
S8 (SA)	14.88^{h}	9.11^{fg}		10.89^{f}	15.54^{j}	16.84^{h}	14.07^{l}	18.01^{f}		14.77^{l}
S9 (SA)	6.78^{e}	9.37^{g}	3.84^{c}	10.48^{f}	1.47^{ab}	10.48^{g}	1.40^{abcde}	3.92^{b}	2.5^{a}	1.22^{ab}
S10 (RR)	3.93^{c}	3.44^{cde}		2.82^{bc}	3.55^{def}	3.91^{d}	1.96^{cde}	8.70^{d}	3.24^{b}	8.66^{i}
S11 (OF)	1.72^{a}	2.07^{abc}	1.26^{a}	1.88^{ab}	2.38^{bc}	2.45^{bc}	1.88^{bcde}			5.57^{g}
S12 (RR)		1.23^{a}		10.12^{f}	1.34^{a}	0.75^{a}	0.52^{a}	3.65^{b}		2.83^{cde}
S13 (OF)	9.13^{g}	1.72^{ab}	2.16^{b}		3.92^{ef}	7.94^{f}	3.58^{g}			
S14 (RR)	5.88^{d}				3.99^{ef}	3.45^{cd}	0.63^{a}			1.96^{bc}
S15 (SA)	7.33^{ef}	2.83^{bcde}		1.32^{a}	3.09^{cde}	1.82^{ab}	0.77^{ab}			6.59^{h}
S16 (SA)		11.27^{h}		1.22^{a}	1.26^{a}					2.47^{cde}
S17 (OF)	7.21^{ef}	3.69^{de}			3.91^{ef}	6.47^{e}				2.07^{bc}
S18 (OF)	2.97^{b}	4.29^{e}	1.26^{a}		5.73^{g}					4.64^{f}
S19 (OF)	1.72^{a}	2.07^{abc}		1.88^{ab}	2.38^{bc}	2.45^{bc}	1.88^{bcde}		3.37^{b}	5.57^{g}
S20 (OF)	1.66^{a}	8.05^{fg}	6.12d	1.08^{c}	2.84^{cd}	1.67^{ab}	1.35^{abcd}			1.35^{ab}
S21 (SA)	7.80^{f}				7.54^{h}		3.40^{fg}			3.18^{de}
S22 (SA)	5.73^{d}	4.26^{de}			5.73^{g}	1.86^{ab}	6.42^{h}	15.79^{e}		0.77^{a}
S23 (RR)	9.13^{g}	1.07^{a}	3.84c	11.27^{f}	1.24^{a}	7.49^{ef}	11.27^{k}	3.79^{b}	2.37^{a}	9.13^{i}
S24 (OF)	3.80^{bc}	3.91^{de}		1.72^{ab}	4.40^{f}		7.93^{i}			9.13^{i}
S25 (OF)	1.72^{a}	2.07^{abc}			2.38^{bc}	2.45^{bc}	2.30^{def}	15.79^{e}		5.57^{g}
S.E.	0.072	0.35	0.065	0.249	0.2109	0.326	0.2556	0.331	0.173	0.2

*Blanks indicate that the vegetable was missing in a site; **alphabetical letters indicate significance of variation within each vegetable among sites; ***0 value means below detection limit.

Table 5. Zn content of vegetables collected from Nairobi urban and peri-urban sites.

Site	Vegetable									
	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10
S1 (IA)	31.23^{f}	44.43^{i}		54.46^{e}	33.76^{e}		38.12^{fgh}	43.01^{a}	38.45^{d}	54.48^{j}
S2 (IA)		59.33^{k}	89.85^{g}	81.15^{h}	80.55^{l}	61.38^{i}	55.76^{l}			55.6^{j}
S3 (IA)		43.86^{hi}	82.45^{f}	53.56^{e}	44.34^{g}	64.41^{k}				56.49^{j}
S4 (SA)	26.32^{cde}	60.62^{l}	54.43^{c}		22.44^{b}	47.76^{gh}	31.45^{cd}	32.27^{c}		33.14^{d}
S5 (RR)	29.24^{e}	47.32^{j}			43.88^{f}	44.5^{fg}	50.24^{k}	47.7^{f}	30.64^{b}	33.73^{d}
S6 (OF)	35.24^{gh}	43.76^{hi}		52.11^{d}	53.44^{i}	42.43^{ef}	45.67^{ijk}	46.54^{f}	40.52^{e}	31.11^{c}
S7 (SA)	23.15^{b}	34.02^{bcd}		26.75^{a}	26.82^{cd}		45.79^{ijk}			31.32^{c}
S8 (SA)	25.05^{bc}	34.56^{cd}		87.42^{i}	37.47^{f}	45.73^{g}	40.99^{ghi}	30.27^{c}		55.79^{j}
S9 (SA)	21.3^{a}	26.81^{a}	52.22^{c}	56.77^{f}	62.08^{k}	39.44^{cde}	35.88^{defg}	24.55^{a}	32.22^{c}	41.83^{g}
S10 (RR)	31.98^{f}	54.35^{l}	50.68^{bc}	53.88^{e}	48.73^{ij}	42.69^{ef}	44.87^{ij}			38.57^{f}
S11 (OF)	38.73^{i}	39.19^{e}	70.44^{e}	56.25^{f}	45.11^{h}	76.7^{k}	37.11^{efgh}			44.81^{h}
S12 (RR)		37.18^{de}		58.45^{f}	25.18^{c}	22.42^{a}	36.95^{efgh}	23.63^{c}		52.76^{i}
S13 (OF)	33.08^{fg}	45.68^{ij}	47.46^{b}		32.44^{de}	32.63^{b}	26.44^{cd}			33.45^{d}
S14 (RR)	35.05gh				52.55i	27.13c	32.65cde			35.77e

Table 5. Contd.

S15 (SA)	35.14^{gh}	41.16^{ef}		48.46^{c}	41.33^{g}	43.56^{ef}	22.05^{b}			41.22^{g}
S16 (SA)		43.61^{ghi}		74.32^{g}	63.56^{k}					44.22^{h}
S17 (OF)	47.51^{k}	32.83^{bc}			45.56^{h}	42.46^{ef}				32.36^{cd}
S18 (OF)	35.11^{gh}	41.27^{efg}			21.56^{a}					37.39^{f}
S19 (OF)	31.98^{f}	54.35^{l}	79.88^{f}	49.63^{c}	51.39^{i}	50.24^{h}	28.41^{d}		30.28^{b}	50.38^{i}
S20 (OF)	27.24^{cde}	36.34^{d}		44.75^{b}	37.69^{f}	41.16d^{ef}	35.5^{e}	43.12^{e}	32.71^{c}	33.46^{d}
S21 (SA)	37.15^{hi}		56.27^{cd}		22.47^{b}					58.28^{k}
S22 (SA)	26.92^{cde}	59.08^{S}			28.54^{d}	35.48^{c}	20.45^{a}	36.56^{d}		21.91^{a}
S23 (RR)	33.73^{fg}	36.19^{d}	60.43^{d}	57.72^{f}	25.18^{c}	24.15^{b}	36.76^{efgh}	32.65^{c}	28.31^{a}	35.51^{e}
S24 (OF)	27.23^{cde}	43.03^{fgh}		45.68^{b}	20.13^{a}		41.46^{hi}	35.06^{d}		35.51e
S25 (OF)	42.50^{j}	31.98^{b}	61.45^{d}		50.48^{i}	50.33^{h}	38.96^{fgh}			50.38^{i}
S.E.	0.654	0.547	0.606	0.401	0.515	1.003	1.163	0.306	0.173	0.3462

*Blanks indicate that the vegetable was missing in a site; **alphabetical letters indicate significance of variation within each vegetable among sites; ***0 value means below detection limit.

that vegetables had a Zn range of 18 - 52 mg/kg, and was highest in mining sites. Mean Zn values were very high as compared to Iyaka (2007) who got 7 mg/kg Zn in spinach in a similar study, and Yebpella et al. (2011), who got the highest value of 26.7 mg/kg while working on a site irrigated with contaminated river water. Zinc is least toxic among the heavy metals in this study; its deficiency could be more detrimental than toxicity (Kumar et al., 2007). CAC (2001) sets the limit of its intake at 60 mg/kg while Nair et al. (1997) puts it at 150 mg/kg, therefore the content in this study may be acceptable.

Cadmium concentration in vegetables was significantly different in vegetables from different sites (Table 6). The highest was 3.02 mg/kg noted in African Kale followed by 2.5 mg/kg in spider plant both from Industrial area. In all vegetables, the Cd concentration was consistently highest in Industrial area and sewage area.

Although in most vegetables, Cd was not above the dietary recommended limit in vegetables (0.2 mg/kg) (Yebpella et al., 2011), continued low-intake of oral Cd may cause negative gastrointestinal, musculoskeletal, renal and neurological effects (Kumar et al., 2007). Chromium concentration was the lowest of all the metals in the vegetables (Table 7). The highest noted was 1.24 mg/kg in spider plant followed by 1.19 mg/kg in spinach both from Industrial area.

Correlation of soil and vegetable heavy metal concentrations

Simple correlation was carried out to establish whether the heavy metal concentration in vegetables was a function of the amount in soil where they were grown. At $P < 0.05$ of most metals there was a significant positive linear relationship between the heavy metal in soil and that in vegetable leaves (Table 8). There was a stronger linear relationship in Cu, Cd and Cr for most vegetables and soils. Jung (2008) through a multiple regression using several factors determined that soil metal content was the principal determinant of plant tissue metal content.

In cases where soil metal was less than vegetable content other metal sources such as dumped items could be implicated. In a few instances such as Zn in African Nightshade and Jute mallow, and Pb in kale the relationship was negative implying that the plant accumulated the metals in leaves or the amount of the metals in the field at some point were higher than at the time of sampling. Factors that were not tested in this study that would account for the negative correlation include soil pH, cation exchange capacity, organic matter content, types and varieties of vegetables, and vegetable age (Jung, 2008).

Conclusion

From this study, the most elevated soil metal concentrations were found nearest to industrial area with average of 20.94, 198.3, 75.37, 2.64 and 2.1 mg/kg for Pb, Zn, Cu, Cd and Cr, respectively. Most vegetables planted in these sites of the study area are within safe limits although some exceed.

This notwithstanding, longterm metal exposure by regular consumption of such locally grown vegetables poses potentially health problems to animal and humans. Further cleaning of the rivers needs to be done, and curtailing of all effluents and dumping of solid waste should be done to minimize contaminant leakage into water and soil that may be used for agriculture.

Table 6. Cd content of vegetables collected from Nairobi urban and peri-urban sites.

Site	Vegetable									
	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10
S1 (IA)	0.15^{bcd}	0.24^{h}		0.27^{cd}	0.16^{e}		0.11^{bc}	0.14^{d}	0.05^{a}	0.05^{ab}
S2 (IA)		1.95^{j}	2.04^{c}	2.54^{f}	1.77^{i}	1.81^{g}	1.53^{g}			0.36^{fg}
S3 (IA)		2.07^{k}	3.02^{d}	2.01^{e}	1.52^{h}	1.66^{f}				1.58^{h}
S4 (SA)	0.07^{abc}	0.09^{cde}	0.11^{a}		0.04^{abc}	0.06^{ab}	0.13^{cd}	0.12^{cd}		0.34^{fg}
S5 (RR)	0.21^{de}	0.32^{i}			0.32^{f}	0.42^{e}	0.21^{ef}	0.15^{d}	0.10^{b}	0.21^{de}
S6 (OF)	0.02^{a}	0.03^{ab}		0.04^{ab}	0.04^{abcd}	0.06^{ab}	0.03^{a}	0.02^{a}	0.12^{b}	0.04^{ab}
S7 (SA)	0.03^{a}	0^{a}		0^{a}	0^{a}		0.00^{a}			0.00^{a}
S8 (SA)	0.23^{de}	0.11^{cdef}		0.02^{ab}	0.02^{ab}	0.11^{bc}	0.05^{ab}	0.09^{bc}		0.00^{a}
S9 (SA)	0.22^{de}	0.33^{i}	0.39^{b}	0.43^{d}	0.42^{g}	0.24^{d}	0.19^{de}	0.32^{f}	0.31^{c}	0.40^{g}
S10 (RR)	0.03^{a}	0.16^{fg}		0.20^{bc}	0.14^{de}	0.06^{ab}	0.03^{a}	0.05^{ab}	0.07^{a}	0.05^{ab}
S11 (OF)	0.04^{a}	0.07^{bcd}	0.06^{a}	0.10^{abc}	0.15^{e}	0.03^{ab}	0.00^{a}			0.08^{ab}
S12 (RR)		0.15^{fg}		0.11^{abc}	0.16^{e}	0.19^{cd}	0.25^{f}	0.21^{e}		0.25^{ef}
S13 (OF)	0.06^{abc}	0.14^{efg}	0.06^{a}		0.08^{abcde}	0.10^{abc}	0.21^{ef}			
S14 (RR)	0.06^{ab}				0.03^{ab}	0.13^{bcd}	0.14^{cd}			0.07^{ab}
S15 (SA)	0.07^{abc}	0.09^{cde}		0.15^{abc}	0.27^{f}	0.17^{cd}	0.14^{cd}			0.20^{cde}
S16 (SA)		0.26^{h}		0.17^{abc}	0.17^{e}					0.13^{bcd}
S17 (OF)	0.30^{e}	0.03^{ab}			0.04^{abc}	0.00^{a}				0.00^{a}
S18 (OF)	0.03^{a}	0.06^{bc}			0.03^{ab}					0.00^{a}
S19 (OF)	0.01^{a}	0^{a}	0.00^{a}	0^{a}	0^{a}	0.00^{a}	0.00^{a}		0.15^{b}	0.03^{ab}
S20 (OF)	0.06^{abc}	0.00^{a}	0.00^{a}	0^{a}	0.00^{a}	0.00^{a}	0.00^{a}			0.00^{a}
S21 (SA)	0.10^{abc}		0.07^{a}		0.11^{bcde}				0.10^{b}	0.08^{ab}
S22 (SA)	0.03^{a}	0.08^{cd}			0.08^{abcde}	0.09^{abc}	0.05^{ab}	0.09bc		0.03^{ab}
S23 (RR)	0.03^{a}	0.08^{cd}	0.05^{a}	0.07^{ab}	0.10^{bcde}	0.06^{ab}	0.01^{a}	0.07b	0.04^{a}	0.05^{ab}
S24 (OF)	0.03^{a}	0.13^{defg}		0.09^{abc}	0.13^{cde}		0.06^{ab}	0.07b		0.04^{ab}
S25 (OF)	0.16^{cd}	0.16^{g}			0.13^{cde}	0.09^{abc}	0.10^{bc}			0.09^{abc}
S.E.	0.032	0.01232	0.0646	0.04104	0.0224	0.024	0.0142	0.0094	0.017	0.0261

*Blanks indicate that the vegetable was missing in a site;**alphabetical letters indicate significance of variation within each vegetable among sites; ***0 value means below detection limit.

Table 7. Cr content of vegetables collected from Nairobi urban and peri-urban sites.

Site	Vegetable									
	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10
S1 (IA)	0^{a}	0.02^{a}		0.02^{a}	0.02^{a}		0^{a}	0.02^{a}	0.02^{a}	0.03^{ab}
S2 (IA)		1.19^{e}	1.08^{b}	1.24^{c}	0.96^{i}	0.26^{g}	0.34^{g}			0.07^{bcd}
S3 (IA)		0.12^{abc}	0.12^{a}	0.20^{a}	0.16^{cdef}	0.12^{cde}				0.00^{a}
S4 (SA)	0.11^{bc}	0.18^{bcd}	0.14^{a}		0.29^{g}	0.13^{def}	0.08^{bcde}	0.11^{cd}		0.07^{bcd}
S5 (RR)	0^{a}	0.05^{ab}			0.08^{abc}	0.08^{bcd}	0^{a}	0.12^{cd}	0.07^{b}	0.06^{bc}
S6 (OF)	0.1^{abc}	0.07^{ab}		0.07^{a}	0.10^{abcd}	0.11^{cde}	0.04^{abc}	0.06^{ab}	0.13^{c}	0.06^{bcd}
S7 (SA)	0.04^{ab}	0.24^{cd}		0.03^{a}	0.05^{ab}		0.05^{bcd}			0.07^{bcd}
S8 (SA)	0.023^{ab}	0.05^{ab}		0.23^{a}	0.18^{def}	0.07^{abc}	0^{a}	0.03^{a}		0.08^{cde}
S9 (SA)	0.06^{ab}	0.14^{abc}	0.50^{ab}	0.13^{a}	0.17^{cdef}	0.13^{cdef}	0.05^{bcd}	0.14^{d}	0.04^{ab}	0.04^{abc}
S10 (RR)	0.02^{ab}	0.16^{abcd}		0.03^{a}	0.13^{bcde}	0.05^{ab}	0.03^{ab}	0.06^{ab}	0.12^{c}	0.05^{bc}
S11 (OF)	0.06^{ab}	0.04^{ab}	0.00^{a}	0.06^{a}	0.10^{abcd}	0.09^{bcde}	0.04^{abc}			0.04^{abc}
S12 (RR)		0.04^{ab}		0.02^{a}	0.12^{bcd}	0.07^{abcd}	0.09^{de}	0.03^{a}		0.05^{bc}
S13 (OF)	0.03^{ab}		0.05a		0.08^{abc}	0.07^{abcd}	0^{a}			
S14 (RR)	0.09abc	0.04ab			0.17cdef	0.14ef	0.03ab			0.06bc

Table 7. Contd.

S15 (SA)	0.17^{c}	0.14abcd		0.18^{a}	0.21^{efg}	0.18^{f}	0.16^{f}			0.10^{def}
S16 (SA)		0.04^{ab}		0.09^{a}	0.11^{abcd}					0.03^{ab}
S17 (OF)	0.03^{ab}	0.13^{abc}			0.14^{bcdef}	0.05^{ab}				0.35^{g}
S18 (OF)	0.05^{ab}	0.07^{ab}			0.09^{abcd}					0.00^{a}
S19 (OF)	0.09^{abc}	0.19^{bcd}	0.10^{a}	0.17^{a}	0.23^{fg}	1.09^{h}	0.06^{bcde}		0.08^{b}	0.11^{def}
S20 (OF)	0.08^{abc}	0.17^{abcd}	0.10^{a}	0.75^{b}	0.08^{abc}	0.08^{bcd}	0.03^{ab}			0.03^{ab}
S21 (SA)	0.04^{ab}		0.09a		0.23f^{g}					0.07^{bcd}
S22 (SA)	0.09^{abc}	0.29^{d}		0.10^{a}	0.47^{h}	0.01^{a}	0.10^{e}	0.11^{cd}		0.13^{f}
S23 (RR)	0.53^{d}	0.13^{abc}	0.16^{a}	1.22^{c}	0.10^{abcd}	0.05^{ab}	0.07^{bcde}	0.09^{bc}	0.07^{b}	0.05^{bc}
S24 (OF)	0.09^{abc}	0.09^{ab}			0.09^{abcd}		0.08^{bcde}	0.13^{d}		0.08^{cde}
S25 (OF)	0.08^{abc}	0.10^{abc}			0.11^{abcd}	0.12^{cde}	0.09^{cde}			0.12^{ef}
S.E.	0.023	0.0123	0.065	0.05	0.0218	0.014	0.0114	0.0094	0.0093	0.001

*Blanks indicate that the vegetable was missing in a site; **alphabetical letters indicate significance of variation within each vegetable among sites; ***0 value means below detection limit.

Table 8. Correlation between heavy metals in soil and vegetables.

Heavy metal	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10
Pb										
R	-0.0192	0.551	0.4326	0.8249	0.7064	0.6122	0.4571	0.0304	0.4024	-0.2055
P value	0.9341	0.0059	0.2118	<0.001	<0.001	0.0053	0.0427	0.9293	0.5018	0.3469
Cd										
R	0.5777	0.9518	0.887	0.9858	0.9752	0.9692	0.9639	0.7537	0.8874	0.949
P value	0.0061	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.0074	0.0446	<0.001
Cr										
R	0.2679	0.9683	0.9199	0.6866	0.9173	0.2115	0.8964	0.6736	0.5583	0.1188
P value	0.2404	<0.001	<0.001	0.0033	<0.001	0.3848	<0.001	0.0231	0.3281	0.5892
Cu										
R	0.6121	0.6358	0.9324	0.7538	0.8518	0.9053	0.6356	0.5962	0.8119	0.5817
P value	0.0032	0.0011	<0.001	<0.001	<0.001	<0.001	0.0026	0.0529	0.0951	0.0036
Zn										
R	-0.4961	0.0385	0.6797	0.49	0.3507	0.174	0.4965	-0.0357	0.1459	0.5341
P value	0.0222	0.8615	0.0306	0.054	0.0856	0.4762	0.026	0.9171	0.8149	0.0087

P is at 5% and R is the correlation coefficient.

ACKNOWLEDGEMENT

This research was financed by the National Council of Science and Technology, Ministry of Education, Kenya.

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