HEAVY METAL OCCURRENCE WITHIN URBAN AGRICULTURE PRACTICES IN EASTERN ZONES OF NAIROBI CITY

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Abstract

Urban agriculture, although growing in importance, farmer practices have to continually adapt to the dynamics of urbanization having implication on quality of produce and public perception. The objective of this research was to assess heavy metal incidence in inputs and food crops for urban farms in eastern zone of Nairobi, determine differences in element uptake by crops and to examine influence of environmental quality of the surrounding spaces. A quasi research design approach was used to identify farm plots for field survey in three locations. Samples of tomatoes (*Lycopersicon esculentum*), arrowroots (*Colocia esculenta*), and kales (*Brassica oleraceae* var. Acephala), water and soil samples were obtained according to standard procedures. Contents of cadmium, manganese, zinc and lead were analysed using Atomic Absorption/Flame Emission Spectrophotometer. One way ANOVA was applied to examine differences in means of heavy metals between locations and to compare transfer factor (TF) index of the crops. Elements that were above allowable limits in the crops were Cd, Mn, Pb and Zn in arrowroots; Cd and Mn in kales and Cd, Mn and Pb in tomatoes. Cadmium content was highest in farm plots within Kasarani (2.44±0.86 mk/kg) and was significantly different from other two locations ($p<0.05$, Tukey HSD test). Between the neighbourhood qualities, heavy metal contents were different but not significant ($p>0.05$) between classes. The mean TF index for the heavy metals decreased in the order Cd>Pb>Zn>Mn. Transfer factor index of > 1 for cadmium was recorded in arrowroots, kales and tomatoes. Based on FAO/WHO standards, the measured heavy metal contents were high for health concern. Produce from areas designated as of low environmental quality, were not necessarily contaminated as perceived. Urban agriculture producers in Nairobi need technical risk reduction measures and legislative support to guarantee quality produce and valuable participation in the urban food system framework.

Key words: urban farming, environmental quality, cadmium, lead, transfer factor, edible produce, health risk

Introduction

In Sub-Saharan Africa, urban growth rates are expected to be fastest in the world by 2050, as urban population increases from 37 to 56 percent (United Nations, 2014). Soaring inflation and space adequacy are factors fostering growth and importance of urban and peri-urban agriculture in southern countries (MacRae *et. al*, 2010; Martelozo, 2015). A key concern of this growth has been the risk of pathogen and heavy metal contamination to consumers (de Neergaard *et al*, 2009) due anthropogenic effects. Extended use of wastewater such as sewage sludge, animal slurry, contaminated manure, excess fertilizers and pesticides for irrigation may cause accumulation of heavy metals in soils leading to bio-availability and phyto-availability of toxic elements, (Gopi *et al*., 2015), requiring adoption of risk-reduction measures (Ndunda and Mungatana, 2013).

Metal accumulation in plant is a dynamic process influenced by combination of factors such as plant species, growth stage, soil properties, weather and environment (Mirecki, 2016). Dietary intake of pollutants through contaminated crop products leads to human diseases, disorders, malfunction and malformation of organs due to heavy metal toxicity (Raheem *et al*., 2014). To mitigate the adverse effects, regulatory bodies such as Food and Agricultural Organization (FAO), World Health Organization (WHO), the European Union, Environmental Protection Agency (EPA) and the Codex Alimentarius Commission (CAC) continually provide guides for maximum permissible contents of heavy metals for various food chain products, (FAO/WHO, 2005). In Kenya, the Kenya Bureau of Standards (KBS) is the main regulator of the various food chain standards and is the National Codex Contact Point. Closer by, critically high heavy metal concentrations have been reported in production materials within urban farming systems in cities such as Benin, Harare (for soils mg/kg; 0.5 to 3.4 Cd, 14 to 228 Zn), Kampala (for soils in mg/kg; 0.8 to 1.40 Cd, 30.0 to 64.6 Pb, 78.4 to 265.6 Zn) and Benue (for tomatoes in ug/g; 0.09 Cd, 4.79 Mn and 0.22 Pb), (Mapanda *et al*, 2005; Brock and Foeken, 2006; Nabulo *et al*., 2006; Odoh and Adebayo, 2011). Previous studies on heavy metal incidence in urban areas such as Nairobi, concentrated on soils and irrigation water and effect on single crops. The current study considered heavy metal incidence in main materials utilized in production together with variety of edible crop products common in urban farms of Nairobi.

Every year, the urban space of Nairobi is transforming greatly pushing potential farmers to environments constrained in space, water scarcity, pollution and hostile city by laws. Often, this situation leads to compromised farming practices that result to produce contamination (Nasinyama *et al*, 2010; Karanja *et al*, 2011) exposing consumers to potential health problems. The specific objectives of the current study were (i) to determine presence and content of heavy metals (cadmium manganese, lead and zinc) in kales, tomatoes, arrowroots, irrigation water and soil from farm plots located within low income zones of Nairobi County, (ii) to determine the relationship between heavy metal occurrence in crops and environmental quality of the surroundings and (iii) examine transmission potential of the metals in the surveyed crops.

Materials and Methods

Study Area

The study was carried out in Nairobi County, Kenya. Geographically, Nairobi is within central highlands of Kenya bounded by latitudes 1°10’ and 1°25’S and longitudes 37°00’and 36°34’E, (Figure 1). Nairobi has a population of over 3.5 million inhabitants (KNBS, 2009). The study area was selected to represent socio- economic zone of Nairobi that benefit from urban agriculture, the Eastern zones. These zones are characterized by highly populated informal settlements with poor infrastructure such as leaking sewerage and many waste dumping sites. In this social setting, urban agriculture contributes significantly to overall household income and food security compared to other zones of Nairobi and hence the issue of food safety is critical.

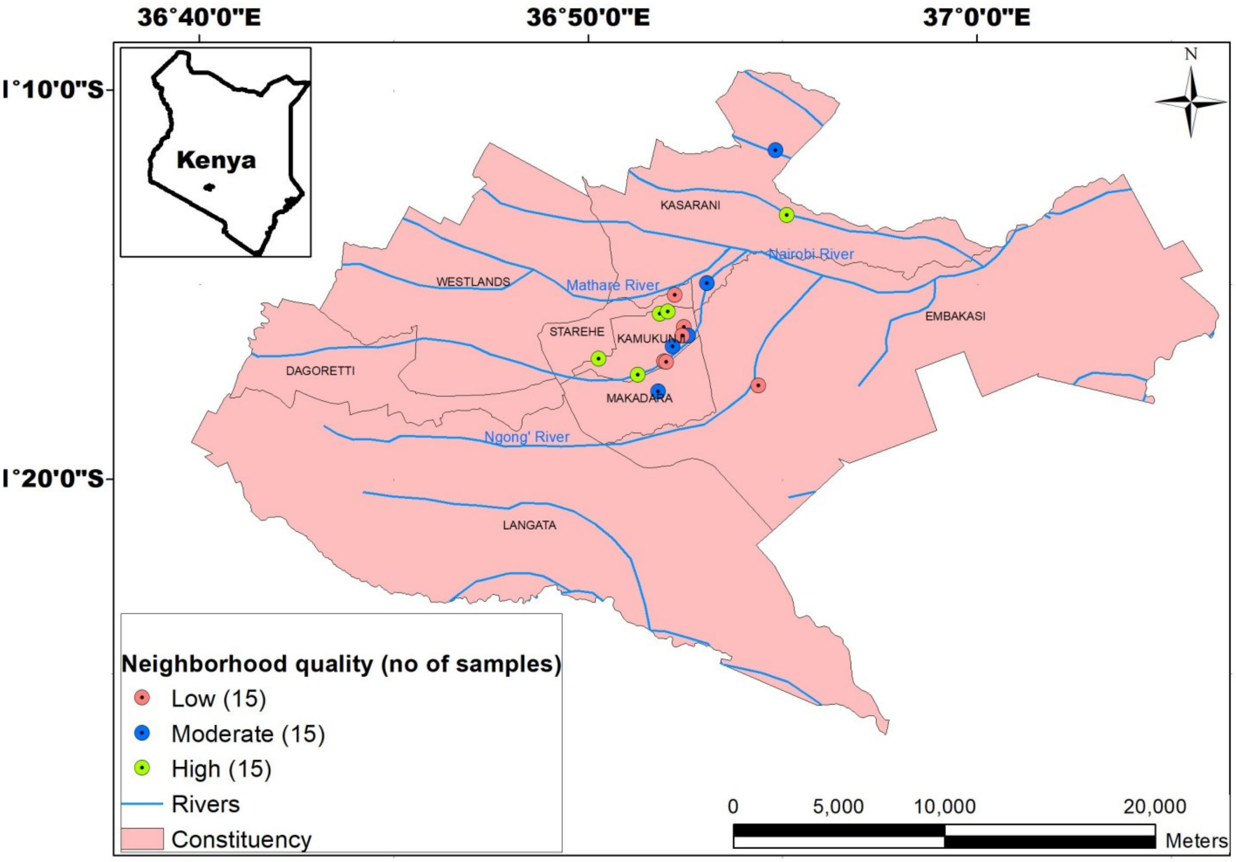

Figure 1: Location of sampled farm plots within Nairobi County and the classed categories of neighbourhood quality

Sampling and Data Collection

In this study the target population was the active urban farmers located in the eastern zone of Nairobi. A quasi-comparative study design among farm plots in three locations (Kasarani, Starehe and Kamukunji) was applied. Inclusion criteria of sample farm plots for the survey was having at least three of the target edible crops; tomatoes, kales and arrowroots growing in the farmed section. Sub-county agricultural officers helped in identification of producers who met the requirement. Farm plots were categorized according to status of environmental quality of the immediate surrounding into either low, moderate or high quality. Farms within an environment where polluted irrigation water was common or near garbage site was classified as low, one that occurred near river water on clean surroundings was classified as moderate, while one that occurred in area having both piped water and with no visible evidence of pollution was classified as high quality.

Sample Collection

Samples of the three edible crop produce, irrigation water and soil were collected in three replicates from each farm plot giving a total of fifteen samples per farm. Recently matured leaves of kales were harvested from three randomly selected plants within the farm plot and bagged in brown paper to constitute one sample. Similarly three mature, ripened tomatoes were harvested from three randomly selected plants and the procedure repeated three times. Arrow roots were dug out from a mature plant without inflicting injury to the tuber and placed in brown paper bags. Soil was obtained by making a composite sample to represent all sections of the farm plot and delivered to the laboratory in sealed 2 kg plastic bags. Closest source of irrigation water for each farm plot was identified and collected by filling the one-litre water sampling glass bottles. Samples, were stored in iced cool box, delivered to the laboratory within six hours of collection and stored in cold environmental room, totalling two hundred and twenty five.

Sample preparation and analysis were done according to procedure of Gupta, (2009). Analysis for heavy metals (cadmium, manganese, lead and zinc), was done using the Atomic Absorption / Flame Emission Spectrophotometer (AAS), (model SHIMADZU AA-630-12). Absorbance values were converted into mg/kg or mg/l based on the formulae of Gupta (2009) for a total of nine hundred data sets. The maximum allowable limits for the heavy metals by FAO and WHO and other regulatory bodies (Table 1) were used as reference to calculate the factor by which the metal content exceeded safe limits.

Table 1: Elements concentration (mg/kg) limits of different samples by different regulatory organisations

Item	Regulatory Organisation	Elements concentration (mg/kg)			
		Cd	Mn	Pb	Zn
Soil	FAO, 2011	3.00		300.00	300.00
Soil	EU standard, 2006	3.00	75.00	300.00	300.00
Water	FAO, 2011; EU, 2006	0.02	0.20	5.00	2.00
Arrowroots	FAO/WHO, 2011	0.10	2.00	0.10	47.40
Kales	FAO/WHO, 2011; EU, 2006	0.20	2.00	0.30	60.00
Tomatoes	FAO/WHO, 2011	0.05	2.00	0.10	47.40

Crop plants were further assessed on their capacity to transmit metals from soil to plant tissues using the transfer factor (TF) index. TF was calculated as ratio of concentration of a specific metal in plant tissue to the concentration of same metal in soil (Equation 1)

$$TF = \frac{Ccrop}{\mathrm{Csoil}} \qquad (1)$$

where, Ccrop and Csoil represent concentration of metal in the crop and soil, respectively.

Data Analysis

Data for the four heavy metal variables were analysed for means and ranges. One-way ANOVA was conducted to test mean differences for contents of heavy metals in crop, soil and water samples, and for the transfer factor in the edible crops. Prior to ANOVA, the homogeneities of the variances were verified using the Levene's test. Significant treatments difference were tested at $\alpha = 0.05$ using Tukey HSD test. Kruskall-Wallis test was done to estimate significance of differences between neighbourhood quality and heavy metals content. Statistical analyses were conducted using SPSS Version 25.0 (Statistical Package for Social Sciences for Windows, IBM Corporation).

Results and Discussions

Level of Heavy Metals in Soil and Water

All four heavy metals were detected in soils with wide variation between farm plots (Table 2). Compared to FAO/WHO standards, contents of Cd, Pb and Zn were below unity of the allowable limits except for Mn which was high by factor of 8 (Table 2), implying that the soils could be contaminated by Mn. Highest level of Mn was recorded in a farm lot within an informal settlement of Kasarani location. There was no significance difference ($p>0.05$) in level of Cd, Mn, Pb and Zn between the localities (Kasarani, Starehe and Kamukunji), (Table 3, along column for soil).

Table 2: Heavy metal occurrence levels in soil and water samples from sampled urban farm plots in eastern zone of Nairobi (n = 15)

Analysis item	Element concentration (mg/kg)			
	Cd	Mn	Pb	Zn
Soil				
mean±sd	2.15±1.11	607.48±261.22	0.27±0.10	240.21±87.65
range	0.88- 5.47	202.55 - 1022.6	0.16 - 0.45	75.41 - 389.19
Factor of allowable	0.716	8.100	0.001	0.801
Water	Element concentration (mg/l)			
mean±sd	1.69±0.62	21.74±36.32	0.171±0.030	1.96±1.44
Range	1.17 - 3.12	1.1 - 136.86	0.16 - 0.27	0.44 - 4.95
Factor of allowable	16.922	108.684	0.034	0.982

Contents of the four heavy metals were lower in water than those recorded for soils. Cadmium and manganese were above allowable limits by factors of 16.9 and 108.7, respectively (Table 2). The high contents of Cd and Mn observed in water, were from a similar estate within Starehe. Because of water scarcity situations in urban and peri-urban regions, industrial effluent and sewerage waste water is often used to fertigate crops which, could be major source of heavy metals that cause accumulation in plants (Kumar and Chopra, 2015). Higher contents of the heavy metals were recorded in Starehe than in Kasarani or Kamukunji in all the cases (Table 3, along the water column) although the difference was not statistically different.

Level of Heavy Metals in Arrowroots

All the mean value contents for the four heavy metals in arrowroots were above allowable limits, with cadmium and manganese exceeding by factors of up to 20 and 35, respectively (Table 4). The contents varied widely among farm plots irrespective of the locality, thus for instance the maximum and minimum contents of Cd and Mn were recorded in the same localities, Kamukunji and Kasarani, respectively. Results of ANOVA showed no significance difference in mean contents of the metals between the locations (Table 3).

Table 3: Results of ANOVA for means of heavy metal contents grouped by location of the sampled urban farm plots for soil, water and crop samples in Easter region of Nairobi.

Element	Locality	Test sample				
		Soil	Water	Arrowroots	Kales	Tomatoes
Cadmium	Kasarani	2.34±0.81	1.61±0.56	1.78±0.68	2.86±0.96	2.44±0.86a
	Starehe	2.44±02.07	1.90±0.93	1.95±0.73	4.00±1.72	2.15±0.69ab
	Kamukunji	1.86±0.49	1.61±0.51	2.26±1.10	2.87±1.24	1.45±0.22b

	mean±s.d.	2.14±1.11	1.69±0.62	2.05±0.88	3.17±1.30	1.90±0.70
	p-value	0.69	0.757	0.699	0.481	0.041
	Tukey HSD	0.74	0.777	0.717	0.522	0.055
Manganese	Kasarani	675.24±245.18	16.67±12.68	74.70±12.82	10.10±3.98	7.94±2.44
	Starehe	611.68±227.98	40.77±64.83	69.28±2.64	17.08±7.52	7.72±4.03
	Kamukunji	566.36±313.26	7.54±10.95	70.09±5.04	16.37±9.07	7.12±4.75
	mean±s.d.	607.48±261.22	21.74±36.32	71.11±7.26	14.88±7.73	7.50±3.82
	p-value	0.824	0.477	0.540	0.374	0.943
	Tukey HSD	0.823	0.481	0.526	0.378	0.950
Lead	Kasarani	0.25±0.08	0.16±0.00	0.31±0.16	0.24±0.12	0.42±0.36
	Starehe	0.22±0.06	0.19±0.05	0.24±0.08	0.21±0.06	0.17±0.00
	Kamukunji	0.31±0.12	0.17±0.02	0.31±0.13	0.18±0.03	0.34±0.14
	mean±s.d.	0.27±0.10	0.17±0.03	0.29±0.12	0.21±0.07	0.32±0.19
	p-value	0.307	0.454	0.640	0.384	0.459
	Tukey HSD	0.334	0.398	0.671	0.382	0.391
Zinc	Kasarani	240.22±110.26	2.09±1.77	34.44±1.84	26.85±13.30	20.08±18.34
	Starehe	275.38±100.21	2.17±1.86	74.56±62.68	30.26±9.85	24.35±13.79
	Kamukunji	220.11±74.35	1.77±1.20	98.09±46.30	36.50±20.90	56.61±45.61
	mean±s.d.	240.21±87.65	1.96±1.44	74.84±49.98	32.26±16.26	38.27±36.37
	p-value	0.637	0.904	0.123	0.648	0.192
	Tukey HSD	0.823	0.521	0.526	0.378	0.950

[a]Mean values assigned with different letters indicate significance difference ($p < 0.05$; Tukey HSD test)

Level of Heavy Metals in Kales

In kales, Cd and Mn registered high mean values at factors of 15 and 7, respectively, above the allowable limits as compared to Pb and Zn which were below unity (Table 4). ANOVA test returned a no significance difference between localities ($P>0.05$) for all the heavy metals (Table 3). However, among the three crops, Cd content was highest in kales, a common occurrence for leafy vegetables. The highest mean values for Cd and Mn were observed in Starehe.

Table 4: The overall of heavy metal occurrence levels in arrowroots, kales and tomatoes from the sampled urban farm plots in Eastern Nairobi (n = 15)

	Element concentration (mg/kg)			
Analysis item	Cd	Mn	Pb	Zn
Arrow root				
Mean±sd	2.5±0.88	71.12±7.26	0.29±0.13	74.84±49.98
Range	1.17 - 4.49	62.54 - 89.15	0.161 - 0.56	0.44 - 4.95
Factor of allowable	20.50	35.55	2.94	1.58
Kales				

Mean±sd	3.18±1.30	14.89±7.73	0.21±0.07	32.26±16.26
Range	1.76 - 5.27	3.65 - 26.86	0.16 - 0.43	12.86 - 69.77
Factor of allowable	15.13	7.44	0.48	0.68
Tomatoes				
Mean±sd	1.90±0.70	7.50±3.82	0.32±0.19	38.27±36.37
Range	1.17 - 3.51	2.38 - 13.52	0.17 - 0.68	8.70 - 136.84
Factor of allowable	38.01	3.75	3.17	0.81

Level of Heavy Metals in Tomatoes

In all cases except for Zn, the measured contents in tomatoes were above allowable limits, with cadmium exceeding by up to 38 times (Table 4). ANOVA test showed high significance difference between localities in the content of Cd (Tukey HSD = 0.055, $p \leq 0.05$) but none for Mn, Pb and Zn (Table 3). The highest mean Cd content recorded in Kasarani was not statistically different from Starehe but different from Kamukunji. This showed that tomatoes within Kasarani and Starehe from around Soweto and Kiamaiko villages, respectively, were likely contaminated with cadmium during the survey season due to usage of water loaded with industrial effluents and animal slurry. Farm plots from Kasarani also recorded the highest amounts of Mn and Pb in tomatoes while Zn was highest in Kamukunji (Table 3).

Level of Heavy Metals between Neighbourhood Classes

Results of Kruskal-Wallis test showed that there was no significant effect of neighbourhood quality of farm plots on amount of the four heavy metals in soil, (H'(2), $p > 0.05$). In water, there was significant effect of neighbourhood quality on content of Zn, (H'(2) = 6.388, $p < 0.05$) being highest in moderate quality class. This results showed that although neighbourhood environmental condition could portray a polluted environment, farm practices at the individual farm plot such as using clean manure and precaution on use of contaminated water could guarantee safety of crop produce.

For arrowroots, only Mn, Pb and Zn were low in the high quality neighbourhood consistent with our classification but no significance difference ($p > 0.05$) between classes (Table 5). In kales, distribution of Mn content agreed with the neighbourhood quality classification while in tomatoes, although there was no significant effect of neighbourhood class on metals (H' (2), $p > 0.05$), contents of Cd, Pb and Zn were high in the low quality neighbourhood consistent with the classification. For all the crops, Kruskal-Wallis test showed no significant effect of neighbourhood quality on the level of Cd, Mn, Pb and Zn (H' (2), $p > 0.05$) (Table 5). Our criteria for classifying vicinities as high, moderate or low quality relied on visual observations and working experience of agricultural staff and researchers. However, heavy metal occurrence contents fluctuated between the neighbourhood qualities. This implied that agricultural practices at the farm level were more critical in influencing quality of food produce than the nature of the surrounding environment.

Table 5: Heavy metal content in crop samples from urban farm plots of Nairobi classed by environmental quality of the vicinity.

Env. quality class	Metal element concentration (mg/kg)			
	Cd	Mn	Pb	Zn
Arrow root				
L	1.99±0.51	71.92±9.70	0.40±0.15	84.56±47.89
M	1.74±0.66	70.79±7.77	0.25±0.08	85.81±50.09
H	2.42±1.32	70.61±5.38	0.24±0.07	54.15±56.00
mean	1.99±0.51	71.10±7.26	0.29±0.12	74.84±49.98
H'	0.994	0.06	3.512	1.94
p	0.608	0.97	0.173	0.379
Kales				
L	2.78±1.48	19.11±5.64	0.18±0.04	42.95±21.56
M	3.03±0.52	12.86±7.27	0.24±0.11	23.56±10.46
H	3.91±1.88	12.68±9.54	0.21±0.05	30.28±10.43
mean	2.78±1.48	14.89±7.73	0.21±0.07	32.26±16.26
H'	1	1.52	2.23	4.22
p	0.607	0.468	0.328	0.121
Tomatoes				
L	1.84±0.68	8.44±5.35	0.51±0.24	36.27±21.56
M	2.11±0.98	5.81±2.91	0.23±0.10	49.64±51.47
H	1.76±0.44	8.23±2.91	0.28±0.19	28.89±15.74
mean	1.83±0.68	7.50±3.82	0.32±0.19	38.26±36.36
H'	0.112	0.857	2.661	0.245
p	0.945	0.652	0.264	0.885

Where L, M, and H are qualities of low, medium and high, respectively; n = 15; H'= Kruskal-Wallis test statistics.

Transfer Factor Index

Results of transfer factor index (TF) analysis, also called the bioaccumulation factor, for the four heavy metals in the three crop types is shown in figure 3. Significant differences were found in the TFs of Mn and Pb in the edible parts of the surveyed crops; arrowroots, chi-square, Mn (H' (2) = 31.08 and Pb (H' (2) = 6.82, $p<0.05$). Overall, mean TF index for the heavy metals decreased in the order Cd>Pb>Zn>Mn. The mean TF of Mn in arrowroots was significantly higher than in kales and tomatoes (Figure 3). Similarly, TF of Pb in arrowroots was significantly higher than in tomatoes. When the TF ratio is > 1, the plants have accumulated elements, ratios around 1 indicate no influence by the elements, and ratios < 1 show that plants exclude the elements from uptake (Mirecki et al, 2015). Transfer factor index of > 1 for cadmium was recorded in arrowroots, kales and tomatoes while the other TF above 1 for lead was in arrowroots (Figure 3). This indicated high likelihood for bio-accumulation of Cd and Pb in the surveyed sites. The mean TF index in crops decreased in the order arrowroots>kales>tomatoes. Thus, arrowroots had high capacity to accumulate the heavy metals, especially Cd and Pb.

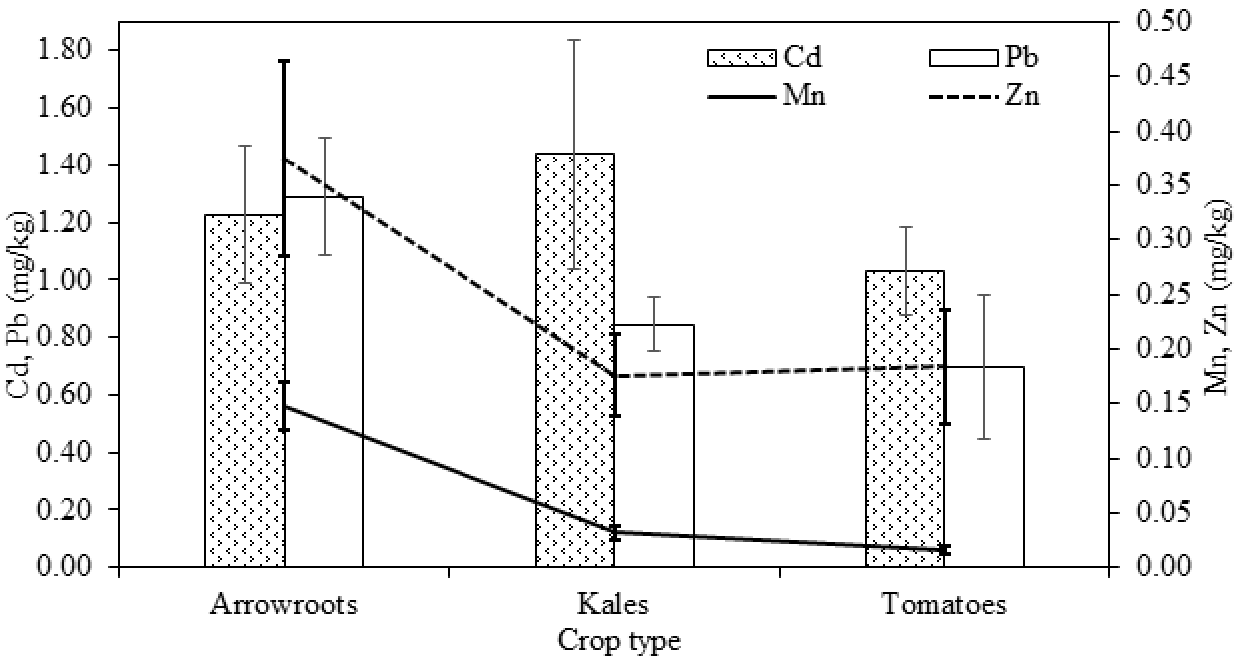

Figure 3: Transfer factor index of heavy metals in three vegetable crops sampled from urban farm plots of Eastern Nairobi. Error bars indicate standard error of fifteen replicates.

Participation in urban agriculture impacts dietary adequacy (Zezza and Tasciotti, 2010), implying that engagement in farming by urban households allows them consume better, more nutritious diets. However, the urban farmer grows plants under strong stresses caused by character of city environment such as, being near industrial areas, dumping and exposed municipal refuse sites that contaminate air, soils and water (Chaoua et al, 2018). This study indicates heavy metal pollution in growing media, irrigation water and produce particularly of cadmium. Soils had higher contents of the heavy metals and so it is likely most of the contamination occurred through the soils or soil amending materials from where it accumulates in crops posing a risk to human health when consumed (Kumar et al, 2015; Olowoyo, 2016). Concentration of heavy metal was found to be crop specific attributable to variation in uptake efficiency, the transfer factor, of different species. Cadmium was high in kales (sukuma wiki), a leafy vegetable widely grown in urban neighbourhoods and indispensable in daily diet of many of urban households especially in the low-income informal settlements of Nairobi. Production of arrow roots in marshy areas of the city is common practice irrespective of water source yet it showed high tendency to accumulate the heavy metals. Although urban dwellers in this part of the city may be aware of health risks from unsafe farming practices (Lee-Smith, 2006), they are, forced by the reality of low incomes and socio-economic status to overlook them. Techniques and measures to mitigate health risk need to be scaled-up such as treatment of waste water (NEMA, 2006; Gweyi et al, 2011), community self-regulation (Community Gardens, 2011) and building on good practice frameworks Cole et al, (2006).

Conclusion

Crops with low transfer factors of heavy metals should be proposed for production in such urban environments. Technical, organizational and financial support to urban farmers is needed for Nairobi, to reduce risks and promote positive perception in urban agriculture. Through research and implementation relevant policies, Nairobi County government, through the Departments of Agriculture, Public Health and Urban Planning, can improve competitive status and level of participation of the urban farmer in the wider economic web of the urban food system.

Acknowledgement
We thank the urban farmers of Nairobi and staff at the Department of Agriculture, Nairobi City County for collaboration and appreciate support for the research by Regional Universities Forum for Capacity Building in Agriculture (RUFORUM), Grant No. RU/2012/GRG-80.

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