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Heavy Metals Uptake by Vegetables Cultivated on Urban Waste Dumpsites: Case Study of Kumasi, Ghana

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Abstract: This study was carried out to assess the concentration levels of heavy metals in vegetables grown on urban waste dumpsites. The research was carried out on three waste dumpsites in Kumasi where vegetables cultivation (cabbage, lettuce and spring onions) are practised. Experimental plots of cabbage, lettuce and spring onions were set up at these sites and harvested at complete maturity stage. Crops and soil samples were collected and analysed for the presence of four heavy metals: cadmium, lead, copper and zinc. Cadmium levels recorded were in the range of 0.68-1.78 mg kg^{-1} as against WHO/FAO recommended level of 0.20 mg kg^{-1}; lead had values in the range of 2.42-13.50 mg kg^{-1} as against the WHO/FAO recommended guideline value of 0.30 mg kg^{-1}; copper levels were in the range of 16.17-90.33 mg kg^{-1} as against the WHO/FAO recommended guideline value of 73.3 mg kg^{-1} and zinc had values between 26.77-106.83 mg kg^{-1} compared to the WHO/FAO recommended guideline value of 99.40 mg kg^{-1}. The levels of the two most toxic heavy metals, cadmium and lead, were far higher in the vegetables than the WHO/FAO recommended values and the transfer factors of these two metals were also the highest suggesting that consumption of vegetables grown on such sites could be dangerous to human health.

Key words: Heavy metals, transfer function, urban waste dumpsites, vegetables

INTRODUCTION

Due to the seemingly high organic content of waste dumpsites, some farmers choose to cultivate their vegetables on such marginal lands in order to increase yield and enhance economic gains. Solid waste management is one of the biggest challenges facing developing countries, where waste sorting and separation is usually not practised. It is therefore common that anything that loses its value is sent to waste dumpsites. Studies have shown that heavy metals concentrations from these wastes can accumulate in the soils at toxic levels hence the risk of vegetables grown in these areas getting contaminated with heavy metals and consequently endangering human health (Carlson, 1976; Alloway, 1996).

Purves (1973) discovered that municipal wastes could contain heavy metals concentrations of 44 to 352 ppm of lead; 25 to 215 ppm of copper; 7 to 21 ppm of nickel and 400 to 655 ppm of zinc. These levels of heavy metals are of concern because of the associated health risks they carry. For example, 99% of the lead that enters the adult human body and 33% that enters a child's body are excreted in about 2 weeks (ATSDR, 1999). This makes lead poisoning pose a greater threat to children. Most of the accumulated lead is sequestered in the bones and teeth leading to brittle bones and weakness in the wrists and fingers. Lead that is stored in bones can re-enter the blood stream during

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periods of increased bone mineral re-cycling (i.e., pregnancy, lactation, menopause, advancing age, etc.). Mobilized lead can be re-deposited in the soft tissues of the body and may have serious repercussive effects on human health (Todd *et al*., 1996; ATSDR, 1999).

The vegetables market in Ghana is proliferated with many products cultivated on waste dump sites (Danso *et al*., 2002), thus such vegetables could be major sources of heavy metals contamination in the food chain. A recent report on randomly sampled vegetables from markets in the two major cities of Accra and Kumasi in Ghana (Chealteau, 2007) revealed that these vegetables have excessively high concentration of heavy metals. For example carrot showed as high as 100-fold of the WHO/FAO permissible levels. Therefore there is the need to analyse soils and vegetables samples from some of these sites to determine the levels of contamination by these harmful heavy metals. To achieve this, the following objectives were set for the study (i) undertake an inventory of waste dump sites used for vegetable cultivation within the Kumasi metropolis; (ii) determine heavy metals concentrations in vegetables from these waste dump sites and compare the levels with WHO/FAO permissible levels and (iii) determine the extent of heavy metals uptake from these sites using the transfer factors.

MATERIALS AND METHODS

Information was first collected from the Kumasi Metropolitan Assembly on the available communal waste dumpsites in the metropolis followed by a reconnaissance visit from September to December, 2006 to locate sites used for cultivating vegetables. After the reconnaissance visit, three sites were selected out of four identified. The three are Ayigya, Buokrom Estates and Abrepo. Experimental plots were then established at these sites. With the exception of Abrepo, which is an abandoned dumpsite, the other two sites are still being used as dumpsite. The site visits also revealed that there are very shallow hand dug wells on the farms, which serve as source of water for irrigation of the vegetables. Water samples from these sources were also collected for analysis for the presence of heavy metals.

The establishment of experimental plots were done during the dry season of the year from the middle of January to early March and then the vegetables (cabbage, spring onions and lettuce) were harvested for processing and laboratory analyses.

At the end of maturity, the vegetables were collected from the sites in polyethylene bags, separating the edible parts (leaves) from the non-edible parts (stems and roots) for analysis of heavy metals concentrations. The separation of the vegetables into edible and non-edible parts is to establish the trends of heavy metals uptake from the soil to the roots/stems and to the leaves of the vegetables.

Soil samples at each of the three sites were collected to a depth of 15 cm from the same locations where the vegetable plants were sampled. The 0-15 cm depth was considered to represent the plough layer and average root zone for nutrients uptake and heavy metals burden by plants (Nyangababo and Hamya, 1986). As a means of control, soil samples in the vicinity (upstream) of dumpsites (50 m upstream) were collected for analysis.

Laboratory Analysis

Samples Preparation

Water samples of 500 mL each from sources for irrigation were collected from September to December, 2006 and filtered using filter paper with 0.45 mm pore size. The filtrate of each sample (500 mL each) was preserved with 2 mL nitric acid to precipitate organic matter present. The samples were concentrated to 10-fold on a water bath and subjected to nitric acid digestion using the microwave-assisted technique, setting pressure at 30 bars and power at 700 Watts (Clesceri, 1998).

Vegetable samples (both edible and non-edible parts) were prepared for the analysis of heavy metals (cadmium, lead, zinc and copper) concentrations (Lark *et al*., 2002). The raw samples were thoroughly washed to remove all adhered soil particles, initially with raw water and then with distilled water. The samples were then cut into small pieces and then dried in the oven at 60-70°C for 72 h. The dried samples were ground in warm condition and passed through 1 mm sieve. Well-mixed samples of 2 g each were taken and digested with 10 mL of 2% nitric acid, filtered and then diluted to 50 mL with distilled water. Well-mixed samples of 250 mL each were taken in 500 mL glass beakers and digested in the 24 mL of aqua regia on a sand bath for three days. After evaporation, the samples were filtered and diluted to 50 mL with distilled water.

Soil samples were also prepared for analysis for cadmium, lead, copper and zinc concentrations in addition to pH, texture and organic matter determinations (USA Environmental Protection Agency, 1986). The soil samples were air-dried and ground into fine powder using pestle and mortar and passed through 2 mm sieve. Well-mixed samples of 1-2 g each were taken into a beaker. Ten milliliter of 1:1 ratio of concentrated nitric acid and water was then added. The solution in the beaker was heated at 95°C for 5 min. Sequentially, 5.0 mL of concentrated nitric acid, 1.0 mL of 30% hydrogen peroxide and 5.0 mL of concentrated hydrochloric acid were added. The solution was then filtered and diluted with distilled water to a final volume of 100 mL for analysis using a flame Atomic Absorption Spectrophotometer (AAS).

Heavy Metals Analysis

Heavy metals analyses were carried out using AAS. The AAS was calibrated for all the metals by running different concentrations of standard solutions. Average values of three replicates were taken for each determination. The detection limits for Cd, Pb, Cu and Zn were 0.005, 0.10, 0.02 and 0.005 mg L^{-1}, respectively.

pH Determinations

Water Samples

After calibration of the pH meter using standard buffers of pH of 4.01 and 7.01, 50 mL of each water sample in duplicates were taken and their pH values determined at room temperature of 25°C.

Soil Samples

The pH metre was again calibrated as above. Deionised water of volume 25 mL was added to 25 g of the prepared soil samples taken in duplicates. The mixture was then stirred for 10 min and allowed to stand for 30 min and again stirred for 2 min. The pH values of the suspensions were then determined using the pH metre at room temperature of 25°C.

Organic Matter Content Determination

The Walkley and Black method (1934) was used to determine the organic matter content. Organic carbon was determined using sulphuric acid and aqueous potassium dichromate ($K_2Cr_2O_7$) mixture. After complete oxidation from the heat of solution and external heating, the unused or residual $K_2Cr_2O_7$ (in oxidation) was titrated against ferrous ammonium sulphate. The used $K_2Cr_2O_7$, (the difference between added and residual $K_2Cr_2O_7$), gave a measure of organic carbon content of the soil.

RESULTS AND DISCUSSION

Heavy Metals Concentrations

The tables below show the respective heavy metals concentrations in the edible and non-edible parts of vegetables from the three experimental sites (Ayigya, Buokrom and Aprepo). Table 1 shows heavy metals concentrations in vegetables at Ayigya. The cadmium concentrations ranged between 0.68 mg kg^{-1} in cabbage to 1.78 mg kg^{-1} in lettuce and these values were far higher than the

Table 1: Heavy metals concentration in vegetables at Ayigya

	Heavy metals concentration (mg kg^{-1})			
Vegetables	Cd	Pb	Cu	Zn
Edible parts				
Cabbage	0.68	7.50	16.17	26.77
Lettuce	1.78	9.20	23.67	106.83
Spring onions	0.73	6.77	16.67	37.23
**WHO/FAO	0.20	0.30	73.30	99.40
Non-edible parts				
Cabbage	1.02	8.63	28.20	62.35
Lettuce	1.97	16.35	57.50	124.00
Spring onions	0.92	8.72	24.00	74.00

**WHO/FAO (1989): Guidelines for heavy metals concentration in leafy vegetables

Table 2: Heavy metals concentrations in vegetables at Buokrom

	Heavy metals concentration (mg kg^{-1})			
Vegetables	Cd	Pb	Cu	Zn
Edible parts				
Lettuce	0.92	2.42	90.33	59.50
Spring onions	1.10	13.47	89.50	48.33
**WHO/FAO	0.20	0.30	73.30	99.40
Non-edible parts				
Lettuce	1.42	6.70	151.67	76.67
Spring onions	1.63	16.63	136.67	104.00

**WHO/FAO = Guidelines for heavy metals concentration in leafy vegetables

recommended WHO/FAO (1989) guidelines of 0.20 mg kg^{-1}. For lead concentrations, the values ranged from 6.77 mg kg^{-1} in spring onions to 9.20 mg kg^{-1} in lettuce and again were far higher than the WHO/FAO recommended value of 0.30 mg kg^{-1}. One-Sample t-test at 95% confidence interval showed differences in variation of these values around the mean and the WHO/FAO permissible levels were significant.

For copper, the values ranged from 16.17 mg kg^{-1} in spring onions to 23.67 mg kg^{-1} in lettuce, which were found to be well below the WHO/FAO recommended values of 73.3 mg kg^{-1}. In the case of zinc, it was only lettuce, which had a value of 106 mg kg^{-1}, which was slightly higher than the recommended WHO/FAO guidelines of 99.40 mg kg^{-1}. However, this was not statistically significant.

According to Warner (1993), there is normally more heavy metal concentration in roots than in leaves and even less in fruits and seeds. This may explain why high metals concentrations were found in the non-edible parts (roots and stems) than in the edible parts (leaves) of all the vegetables from this site.

Table 2 contains heavy metals concentrations of vegetables from Buokrom. The situation at Buokrom was not any different. Cadmium levels exceeded WHO/FAO guidelines of 0.2 mg kg^{-1} by 0.72 mg kg^{-1} in lettuce and by 0.90 mg kg^{-1} in spring onions and these differences were found to be statistically significant. Lead values were also found to exceed the guidelines by 2.12 mg kg^{-1} in lettuce and 13.17 mg kg^{-1} in spring onions and again, these variations were statistically significant.

For copper, lettuce recorded 90.33 mg kg^{-1} and spring onions 89.50 mg kg^{-1}. These values were higher than the WHO/FAO guideline value of 73.3 mg kg^{-1}. None of the zinc concentrations exceeded that of the recommended guidelines. The concentrations in the non-edible parts were higher than in the edible parts similar to the situation in Ayigya.

On the third waste dumpsite at Abrepo both lead and cadmium exceeded the recommended guidelines significantly in excesses of at least 0.77 mg kg^{-1} for cadmium and 10.89 mg kg^{-1} for lead (Table 3). None of the values for both copper and zinc exceeded the WHO/FAO recommended guidelines. The trends of the metals levels in the non-edible parts and edible parts showed similar trends as those from the previous sites, confirming the findings of Warner (1993).

Table 3: Heavy metals concentrations in vegetables at Abrepo

Vegetables	Heavy metals concentration (mg kg^{-1}) Cd	Pb	Cu	Zn
Edible parts				
Lettuce	0.97	13.50	22.67	44.33
Spring onions	1.18	11.19	27.50	35.83
**WHO/FAO	0.20	0.30	73.30	99.40
Non-edible parts				
Lettuce	1.63	20.57	29.00	57.23
Spring onions	1.55	12.97	83.17	50.00

**WHO/FAO = Guidelines for heavy metals concentration in leafy vegetables

Table 4: Heavy metals concentrations in soils and water samples

Samples	Heavy metals concentrations (ppm) Cd	Pb	Cu	Zn
Ayigya				
Soil at site	2.87	54.67	1376.67	2606.00
Control-soil	0.20	17.50	806.17	746.00
Water sample	0.02	0.23	0.02	0.02
Buokrom				
Soil at site	2.10	50.67	1631.67	1230.00
Control-soil	0.76	16.83	816.33	566.67
Water sample	0.02	0.24	0.05	0.01
Abrepo				
Soil at site	1.86	51.83	1400.00	1476.67
Control-soil	0.93	25.17	752.50	701.67
Water sample	0.01	0.22	0.11	0.01

Soil and Water Samples

Table 4 shows the heavy metals concentration of the control soil and the water from the wells used for irrigation by the farmers at these sites. These wells are so close to all the dumpsites, within a distance of 1-20 m and downstream of the dumpsites. The metals' levels in the water samples are far higher than the recommended acceptable levels in fresh water. According to Ward (1995), the levels should be cadmium: 0.00003 ppm, lead: 0.001 ppm, copper: 0.003 ppm, zinc: 0.015 ppm. The levels recorded from the three sites are all above the fresh water levels. This could be attributed to the pollution from the soils at the respective waste dumpsites due to contamination from leachate flow.

Table 4 shows also that the heavy metals concentrations in the control soil samples (50 m upstream from the dumpsites) were far lower than those at the sites. It may therefore be inferred that the heavy metals concentrations recorded in the vegetables are as a result of the pollution from the various waste dumpsites, since the plots for cultivating these vegetables are just downstream of the dumpsites and the control sites are upstream of the dumpsites.

Organic Matter Content of Soils

Organic matter content describes the levels of mineral elements for plants development and growth. Enwezor *et al.* (1988) classified organic matter for cultivation as follows: less than 2.0% as low (values below critical limits); 2.1-3.0% as medium (values above critical level) and greater than 3.1% as high. Hence Ayigya having 3.43% and Buokrom 3.1% could be considered as high. This could be expected because waste dumpsites receive much organic wastes. Abrepo had a medium value of 2.59%. The organic content of the soils confirm why farmers consciously choose to farm on such sites (Table 5).

Transfer Factors

Transfer factor is the ratio of the heavy metal concentration in the crop to the total heavy metal concentration in the soil at the site (Chamberlain, 1983; Harrison and Chirgawi, 1989; Smith, 1996). It signifies the amount of heavy metals in the soil that ended up in the vegetable crop.

Table 5: Organic matter contents of soil samples

Samples	Soil organic matter contents (%)
Ayigya	
Soil at site	3.43
Soil for control	1.31
Buokrom	
Soil at site	3.10
Soil for control	2.05
Abrepo	
Soil at site	2.59
Soil for control	1.95

Table 6: Transfer factors for vegetables at Abrepo

	Transfer factors of metal (%)			
Vegetables	Cd	Pb	Cu	Zn
Edible parts				
Lettuce	52	26	2	3
Spring onions	64	22	2	2
Non-edible parts				
Lettuce	88	40	2	4
Spring onions	83	25	6	3

Table 7: Transfer factors for vegetables cultivated at Ayigya

	Transfer factors of metal (%)			
Vegetables	Cd	Pb	Cu	Zn
Edible parts				
Cabbage	24	14	1	1
Lettuce	62	16	2	4
Spring onions	26	12	1	1
Non-edible parts				
Cabbage	36	16	2	2
Lettuce	69	30	4	5
Spring onions	32	16	2	3

Table 8: Transfer factors for vegetables at Buokrom

	Transfer factors of metal (%)			
Vegetables	Cd	Pb	Cu	Zn
Edible parts				
Lettuce	44	5	6	5
Spring onions	52	27	5	4
Non-edible parts				
Lettuce	67	13	9	6
Spring onions	78	33	8	8

From the three waste dumpsites, spring onion from Abrepo recorded the highest transfer factor of 64% for cadmium in the edible part (Table 6). This goes to buttress the research by Alloway (1996) that cadmium tends to be more mobile in soil systems and therefore more available to plants than many other heavy metals. The least value of 1% was recorded for copper and zinc by cabbage and spring onions from Ayigya (Table 7).

The most toxic heavy metals, cadmium and lead recorded the highest transfer factors at all the three sites. The transfer factors for these two metals are all higher than 10% except in lettuce from Buokrom, which recorded 5% (Table 8). Copper and zinc recorded transfer factors less than 10% from the three sites. There was also a general trend of all the transfer factors of the non-edible parts of vegetables being higher than their corresponding edible parts.

Table 9: pH for soil and water samples

Samples	pH
Ayigya	
Soil at site	6.9
Soil for control	6.9
Buokrom	
Soil at site	6.4
Soil for control	6.7
Abrepo	
Soil at site	6.4
Soil for control	6.9
Water samples	
Ayigya	5.1
Buokrom	6.6
Abrepo	7.0

pH of Soils and Water at Sites

The pH values at all the sites were found to be almost neutral. According to Perk (2006), bio-availabilities of most of these heavy metals, copper, lead, etc., are low at these neutral pH ranges. Hence the transfer factors may actually be low under the circumstances since these values could rise if the acidity of the soil increases.

The values of cadmium and lead in particular that ended up in the crops are dangerous to human consumption (Table 9). Generally, uptake in basic conditions is lower, thus technologically, liming the soils could raise the pH values higher and hence liming could be used to mitigate this high transfer rates. However, it will be more expedient to ban farming in these areas.

CONCLUSIONS

The study was able to successfully show that heavy metals in soils at waste dumpsites eventually end up in the vegetables cultivated on such lands. The four heavy metals, lead, cadmium, copper and zinc, were present at all the three waste dumpsites in measurable quantities. The concentrations of the two most toxic heavy metals, cadmium and lead that ended up in the vegetables from the soils far exceeded the WHO/FAO recommended guidelines. Since the levels of the two most toxic heavy metals are very alarming, farmers at these sites should be banned by the metropolitan authorities and the Environmental Protection Agency from using waste dumpsites in the metropolis for vegetables cultivation.

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