Heavy Metal Pollution of Vegetable Crops Irrigated with Wastewater in Accra, Ghana

I. Lente[1]*, J. Ofosu-Anim[2], A. K. Brimah[3] and S. Atiemo[4]
[1]*Institute of Environment and Sanitation Studies, University of Ghana, Legon, Accra*
[2]*School of Agriculture, University of Ghana, Legon*
[3]*Department of Chemistry, University of Ghana, Legon*
[4]*Department of Chemistry, Ghana Atomic Energy Commission, Kwabenya, Accra*
*Correspondence author; Email: *ishmaelente@yahoo.com*

Abstract

Heavy metal concentrations in irrigation water (samples =120), soil (samples =144) and edible parts of both exotic and traditional vegetables (samples = 240) irrigated with wastewater from some parts of Accra were studied. The concentrations of heavy metals in mg/l were quantified in wastewater from Accra and groundwater at Mampong as Fe (0.67; 1.00), Mn (0.78; 0.31), Cu (0.06; 0.07), Zn (0.14; 0.13), Pb (0.08; 0.12), Ni (0.06; 0.13), Cr (< 0.006), Cd (< 0.002) and Co (< 0.005), soil Fe (164.38; 162.92), Mn (39.39; 20.09), Cu (7.21; 6.13), Zn (6.03; 7.45), Pb (9.31; 7.63), Ni (5.00; 2.97), Cr (0.51;0.85), Cd (0.07;0.09) and Co (0.73;0.87), and vegetables from Accra and Mampong. The wastewater used for irrigation had the highest concentration (mg/l) of Mn (0.78), followed by Fe (0.67), Zn (0.14), Pb (0.08), Cu (0.06), Ni (0.06) while Cr, Cd and Co were below detection limits. Fe (164.38; 162.92), Mn (39.39; 20.09), Cu (7.21; 6.13), Pb (9.31; 7.63) and Ni (5.00; 2.97) levels were higher in wastewater irrigated soils than groundwater irrigated soils, respectively. However, average values were all below the FAO/WHO recommended mean levels in mg/l for wastewater and soil as Fe (5.00; 50,000), Mn (0.20; 2,000), Cu (0.20; 100), Zn (2.00; 300), Pb (5.00; 100), Ni (0.20; 50.00), Cr (0.10;50.00), Cd (0.01;3.00) and Co (0.05;100), respectively. Concentration levels of heavy metals (mg/kg) in vegetables crops analysed from all sites were not elevated except for Pb in cabbage, (10.51), lettuce (10.19), green pepper (9.44), hot pepper (7.61) and ayoyo (9.05) compared to the FAO/WHO maximum recommended limit of 0.30 mg/kg for Pb. Health risk assessments showed that hazard indexes for the crops were below 1 (USEPA), indicating that normal consumption of vegetables analysed pose no risk from heavy metal toxicities. However, to prevent any chronic health risk and extent of heavy metal contamination, steps must be taken to reduce human activities at the sites. Regular monitoring of heavy metals in the vegetables grown in wastewater irrigated areas is also necessary.

Introduction

Wastewater can contribute significantly to heavy metal accumulation in soils and crops (Mapanda *et al.*, 2005; Singh *et al.*, 2010). Other sources of heavy metals in irrigated agriculture include manures, fertilizers and pesticides (McBride, 2003), as well as airborne contamination from car traffic (Bakare *et al.*, 2004). Heavy metal contamination of agricultural soils and crops is particularly worse in developing industrialized countries such as China and India, due to extensive use of untreated industrial wastewater (Sharma *et al.*, 2009). While industrialization is less pronounced in Ghana, there is extensive use of untreated but diluted wastewater (wastewater mixed with stream/storm water) for vegetable farming in urban areas (Obuobie *et al.*, 2006). For instance, in Accra, the capital city of Ghana, it is estimated that there are 800-1000 urban vegetable farmers. The vegetables produced are sold as components of street foods eaten daily by over 200,000 urban residents (Amoah *et al.*, 2007).

West African Journal of Applied Ecology, vol. **22**(1), 2014: 41–58.

Uptake of heavy metals by crops may be done through absorption from contaminated soils through roots or by deposition on foliar surfaces (Jassir *et al.*, 2005). Uptake through roots depends on many factors such as the soluble content of heavy metals in soil, soil *p*H, plant growth stages as well as type of crops, fertilizers and soil (Sharma *et al.*, 2006). Deposition of heavy metals from industrial and vehicular emissions on crops foliar surfaces may occur during production, transportation and marketing (Jassir *et al.*, 2005). In vegetables these heavy metals accumulate in edible parts (leaves and roots). Heavy metals most often found in vegetables include cadmium, copper, arsenic, chromium, lead, zinc, cobalt and nickel. When in trace quantities, some of them are micronutrients. However, they can pose a significant health risk to humans, leading to various chronic diseases, particularly in elevated concentra-tions or in prolonged dietary intakes (Sharma *et al.*, 2009). Other than safety concerns, excessive heavy metals also contaminate soils and affect crop growth and quality (Muchuwati *et al.*, 2006). Routine monitoring of heavy metal concentrations in soils and crops is, therefore, essential to know the levels and devise strategies to minimize contamination, in order to reduce risks to human health.

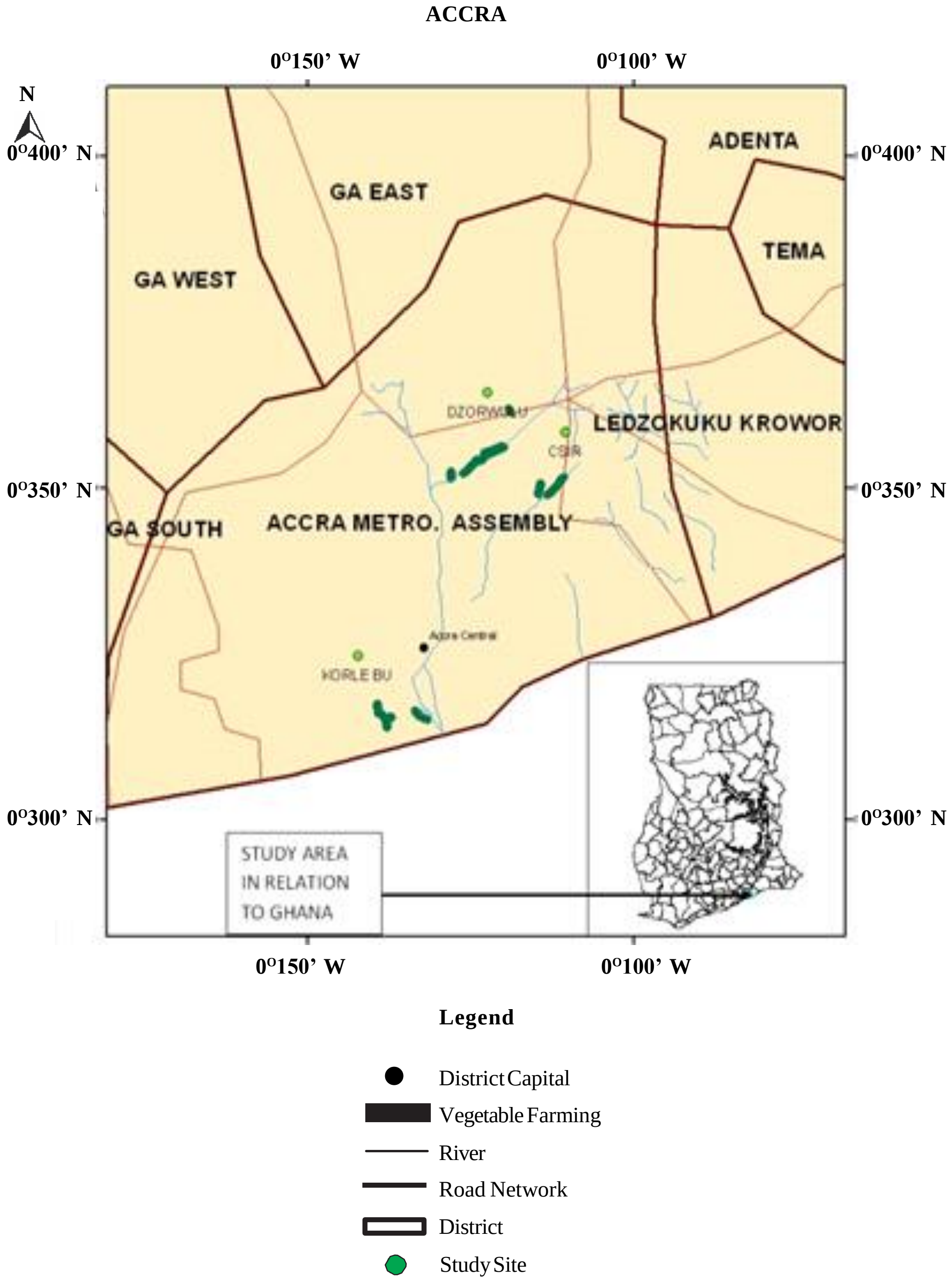
In Ghana, studies on health risks from wastewater irrigation have focused more on microbiological contamination (Amoah *et al.*, 2011). Studies on heavy metals have been limited, due to the perceived comparatively lower public health significance. However, studies in other less industrialized countries including Zimbabwe, Zambia and Nigeria have shown that heavy metal contamination can have significant environmental and health impacts (Mapanda *et al.*, 2005; Ogwuegbu & Muhanga 2005; Eriyamremu *et al.*, 2005). Also, auto emissions from over-aged vehicles are common in Ghana, as in many parts of sub-Saharan Africa (Affum *et al.*, 2008; Bakare *et al.*, 2004). In addition, there is increasing expansion of light industrial activities such as oil and gas stations, textile, electronics and plastics in Ghana, especially after the recent discovery of oil reserves.

The paper presents findings from an assessment study on heavy metal contamination in irrigated urban vegetable farming in Accra. The assessment was done to determine whether heavy metal contamination should be a present concern to public health, and also to encourage future studies as heavy metal contamination is expected to be a challenge in Ghana in the near future, if not well addressed.

Materials and methods

Study sites and farming practices

Four farming sites were selected for the study. Three sites (Dzorwulu, CSIR and Korle Bu) are in Accra and the main irrigation water sources are drains and water bodies heavily polluted with untreated wastewater (diluted wastewater) (Obuobie *et al.*, 2006), shown Fig. 1. The fourth site, used as a control, was at Mampong-Akuapem, 40 km north-west of Accra, where farmers used groundwater from shallow wells for irrigation (Fig. 2). Each of the sites was about 10 ha in size, had been cultivated for more than 10 years and less than 300 m from a road with heavy vehicular movements. In addition, there were scrap metal dealers, automobile repair and vehicle washing activities around the wastewater irrigated sites (Accra sites), while for the groundwater irrigated site


ACCRA
0°150’ W
0°100’ W
N
0°400’ N
0°350’ N
0°300’ N
GA EAST
GA WEST
ADENTA
TEMA
LEDZOKUKU KROWOR
GA SOUTH
ACCRA METRO. ASSEMBLY
DZORWULU
CSIR
Accra Central
KORLE BU
STUDY AREA IN RELATION TO GHANA
Legend
● District Capital
Vegetable Farming
River
Road Network
District
● Study Site

(a)

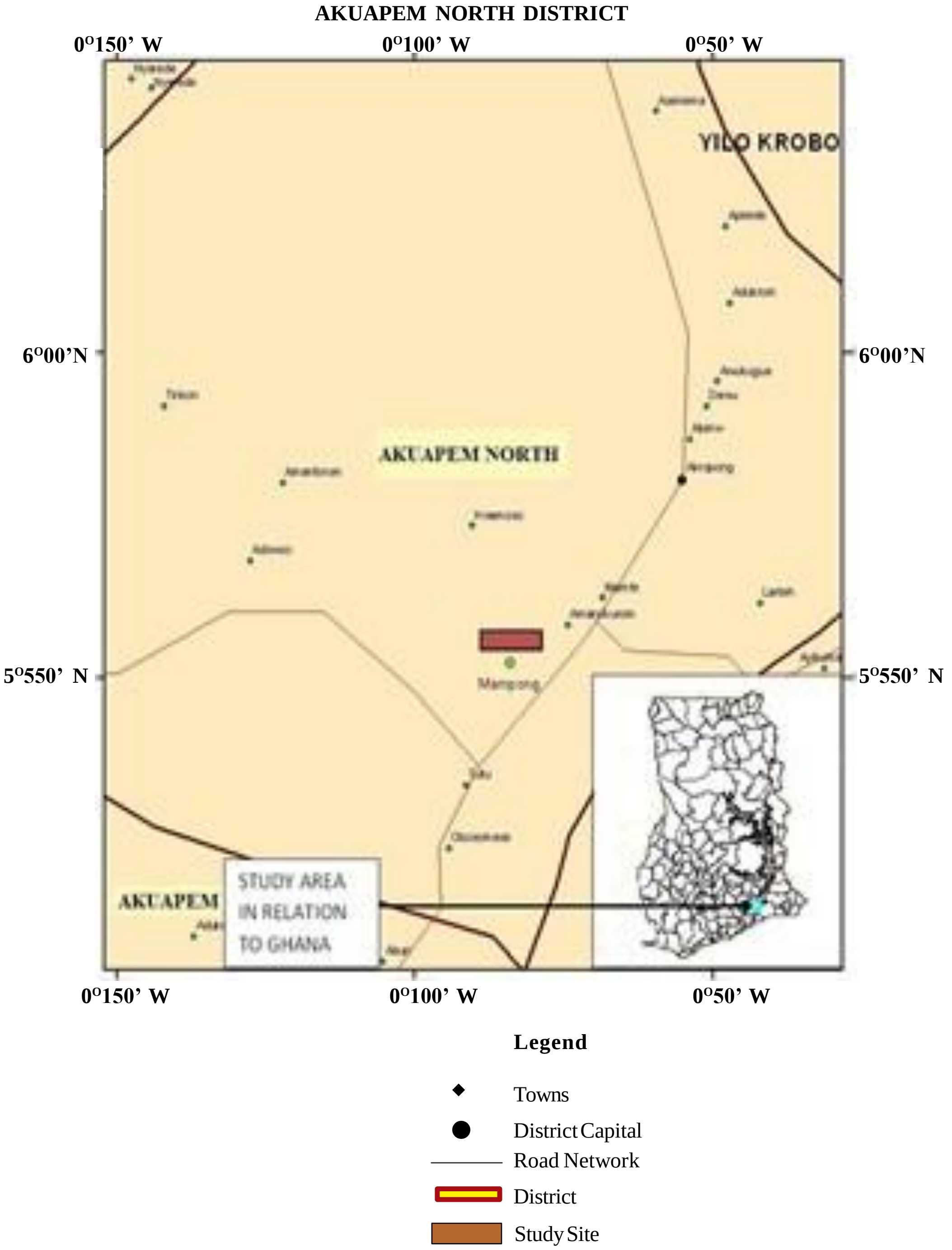


Fig. 1. Some vegetable farming sites in Accra and a site in Mampong-Akuapem

Fig. 2. Vegetable beds with and without crops on some of the farming sites in Accra

(Mampong), there was a municipal (domestic) waste dumping site in close proximity. The soil texture on study sites varied largely between clay and sand extremes.

The major vegetables at these sites were cabbage (*Brassica oleracea*), lettuce (*Lactuca sativa)*, green pepper (*Capsicum annuum*), "ayoyo" (*Corchorus olitorius*) and hot pepper (*Capsicum annuum*), which were also selected as study crops. Farming was done on vegetable beds, each measuring an average of 20 m^2 (Fig. 3). Irrigation was done mostly using watering cans so water was applied directly to the surfaces of crop leaves, usually twice a day unless it rains. A few farmers on the study sites use small motorized pumps, either for lifting water to ponds before applying it on the crops with watering cans or for applying the water directly on crops using water hoses. Organic manure from poultry was predominantly used as a source of fertilizer, though occasionally, chemical fertilizers were used whenever there was shortage of poultry manure.

Sampling

The study was conducted over a period of 3 months in the major dry season in Ghana, i.e. from December 2010 to February 2011.

Water sampling. Water samples were collected in sterilized 500-ml plastic bottles filled to the brim. About 2 ml of 10% HNO_3 was added to each bottle to avoid microbial activity (Singh *et al*., 2010). Samples were taken monthly from 10 water collection points used by farmers in each of the four study sites over the entire period of 3 months. A total of 120 water samples were collected. The water samples were labeled and kept on ice in an ice chest and then transported to the laboratory for storage in a refrigerator at about 4 °C before analysis.

Fig. 3. A drain and a river used for irrigating vegetables on a farming site in Accra

Soil sampling. Soil samples were also collected monthly from 12 randomly selected vegetable beds (one each from 12 different farmers) at a depth of 0–20 cm over the sampling period of 3 months from all study sites. A total of 144 soil samples were collected for analysis. Sampling was done with a plastic spate and packaged into transparent zipped lock plastic bags and transported to the laboratory in bigger plastic bags.

Vegetable sampling. Five different types of commonly grown vegetables (as mentioned above) were sampled from each of the four study sites. Sampling was done from the edible parts of ready-to-sell vegetables. Twelve samples were collected for each vegetable from each site, so a total of 240 vegetable samples were collected. The samples were collected from the same vegetable beds from where soil samples were taken. Sampling of vegetables was only done once when the crop was mature. Collection was done in transparent zipped lock plastic bags and transported to the laboratory in an ice chest.

Laboratory analysis

Water, soil and vegetable samples were analysed for iron (Fe), manganese (Mn), copper (Cu), zinc (Zn), lead (Pb), nickel (Ni), chromium (Cr), cadmium (Cd) and cobalt (Co). About 5 ml of water sample and 1.5 g of sieved dry soil sample were digested separately in 6 ml HNO_3 (69%), 3 ml HCl (36%) and 0.25 ml H_2O_2 (30%) for 26 min (APHA-AWWA-WEF, 2001). Analysis of vegetables was done by first washing them thoroughly with tap water followed by distilled water and then cutting them to small pieces with a stainless steel knife. They were deep-frozen and later freeze-dried and ground to powder form. About 0.5 g vegetable sample was weighed and digested in 6 ml HNO_3 (69%) and 1 ml H_2O_2 (30%) for 26 min. All the digested samples were transferred into a 20-ml measuring cylinder and made up to the mark with distilled water, and then poured into test tubes for the AAS analysis (APHA-AWWA-WEF, 2001).

The samples were digested by the Milestone-microwave laboratory system (Microwave Labstation, Ethos 900) digester using programmes 309, 308 and 18 for water, soil and vegetables, respectively (Borowski & Schmaling, 1996). The concentrations of Fe, Mn, Cu, Zn, Pb, Ni, Cr, Cd and Co were determined using atomic absorption spectrophotometer (Model AA240FS, Varian Fast Sequential), fitted with a specific lamp of the particular metal using appropriate drift blanks.

Data analysis

Factor analysis was done to ascertain the levels of enrichment and contamination in the soils as follows (a) *Enrichment factor (EF)* is used to differentiate heavy metals originating from human activities (anthropogenic sources) and those of natural sources and to assess the degree of anthropogenicinfluence.

$$EF_x = [X_s/E_{s\,(ref)}]/[X_C/E_{C\,(ref)}]$$

where EF_X is the enrichment factor for the element X, X_S is the concentration of element of interest in sample, $E_{S(ref)}$ is the concentration of the reference element, *Fe* used for normalization in the sample, X_C is the concentration of the element in the crust, and $Ec_{(ref)}$ is the concentration of the reference element used for normalization in the crust (Taylor & Meclenan, 1985). Values ranging from $0.5 \leq EF \leq 1.5$ suggest that traces of metal may come from crustal materials or natural weathering processes (Zhang & Liu, 2002**)**. Five contamination categories are recognized on the basis of the enrichment factor:

- EF < 2 states deficiency to minimal enrichment,
- EF = 2–5 moderate enrichment,
- EF = 5–20 significant enrichment,
- EF = 20–40 very high enrichment, and
- EF > 40 extremely high enrichment (Yonming *et al.*, 2006; Kartal *et al.*, 2006).

(b) Index of geoaccumulation (Igeo). A common criterion to evaluate the heavy metal pollution in soil is the index of geoaccumulation (*I*geo), which was originally defined by Muller (1979) to determine metals contamination in sediments, by comparing current concentrations with pre-industrial levels. It can also be applied to the assessment of road dust and surface soil contamination (Lu *et al.*, 2009; 2010; Gowd *et al.*, 2010). The relation used is $Igeo = log2\ (C_n/1.5{*}B_n)$. where C_n is the measured concentration of element n in the soil sample and B_n is the geochemical background for the element n, taken from the literature (average shale value described by Turekian & Wedepohl (1961). The factor 1.5 is introduced to include possible variation of the background values that are due to lithogenic variations.

The following classification is given for index of geoaccumulation (Huu *et al.*, 2010; Muller, 1969):

(a) < 0 = practically unpolluted,
(b) 0–1 = unpolluted to moderately polluted,
(c) 1–2 = moderately polluted,
(d) 2–3 = moderately to strongly polluted,
(e) 3–4 = strongly polluted,
(f) 4–5 = strongly to extremely polluted, and
(g) > 5 = extremely polluted.

The Igeo class 0 indicates the absence of contamination while the Igeo class 6 represents the upper limit of the contamination.

Health risk assessment

Daily intake of heavy metals through vegetables. An assessment of the human health risk posed by heavy metals from consumption of irrigated vegetables was made by comparing the concentration of the heavy metals recorded with international safe limits, i.e. Potential Tolerable Daily Intakes (PTDIs) and Reference Dose (RfD). The daily intake of heavy metals through the consumption of the vegetables tested was calculated according to the given equation, also used by Sharma *et al.*, (2009):

$$\text{EDI} = \frac{C_{\text{metal}} \times \text{DVC}}{\text{BW}}$$

where EDI = estimated daily intake of heavy metals (µg/day), DVC = daily vegetable consumption (g/day), C_{metal} = concentration of heavy metal (µg/g), BW = body weight. Daily vegetable consumption was obtained through estimations from key informants who have conducted several surveys on urban vegetable farming in the study area (Amoah *et al*., 2007).

Hazard index. The hazard index (HI) was calculated to determine the overall risk of exposure to all the heavy metals *via* the ingestion of a particular vegetable crop (USEPA, 1996). To get HI, the hazard quotients (HQ) need to be obtained.

$$\text{HQ} = \text{DIR}/\text{RfD},$$

i.e. ratio of daily intake rate to the reference intake rate (RfD) or (PTDI).

HI is the sum of all the HQs of all the elements in each vegetable crop. HI < 1 indicates that the predicted exposure is unlikely to pose potential health risks. However, a hazard index >1 does not necessarily indicate that a potential adverse health effects will result, but only indicates a high probability of posing health risks. When interpreting the magnitude of HI, especially HI values that are marginally different from 1, it is important to consider the sources of uncertainty.

Quality assurance

Appropriate quality assurance procedures and precautions were taken to ensure the reliability of the results. Samples were carefully handled to avoid contamination. Glassware were properly cleaned, and reagents were of analytical grades. Deionized water was used throughout the study. Reagent blank determinations were used to correct the instrument readings. For validation of the analytical procedure, repeated analysis of the samples against internationally certified IAEA soil – 7 and plant (spinach) standard reference material (SRM-1570) of IAEA were used, and the results were found below 10% of the certified values.

Results and discussion

Heavy metals in irrigation water

All heavy metals analysed in irrigation water (both diluted wastewater and groundwater) were not elevated except Mn, which was elevated in both wastewater and groundwater (Table 1). On average, the levels of Mn were about 1.5 times higher in groundwater and 4 times higher in wastewater than the recommended 0.2 mg/l. The concentrations of Cr, Cd and Co were below detection limits, therefore, should not be of any concern for irrigation water. Other trace elements measured (Cu, Zn and Pb) in the irrigation water sources were not significantly different.

It is common to have such low levels of heavy metals in wastewater, especially where the water is diluted by stream water or on sites with no localized industrial activities like the study areas, where most wastewater is from domestic sources. Related studies on wastewater irrigation in two cities in India

TABLE 1
Concentration of heavy metals in irrigation water (N = 120 samples)

Element	*Wastewater (mg/l)*	*Groundwater (mg/l)*	*RML FAO (mg/l)*	*RML WHO (mg/l)*
Fe	0.67 ± 0.09	1.00 ± 0.023	5.00	5.00
Mn	0.78 ± 0.73	0.31 ± 0.001	0.20	0.20
Cu	0.06 ± 0.01	0.07 ± 0.003	0.20	0.20
Zn	0.14 ± 0.05	0.13 ± 0.108	2.00	2.00
Pb	0.08 ± 0.04	0.12 ± 0.017	5.00	5.00
Ni	0.06 ± 0.03	0.13 ± 0.009	0.20	0.20
Cr	BDL	BDL	0.10	0.10
Cd	BDL	BDL	0.01	0.01
Co	BDL	BDL	0.05	0.05

BDL = below detection limit of instrument; Cr = 0.006, Cd = 0.002, Co = 0.005, RML = recommended maximum limit, source: FAO/WHO, 2001, Ayers and Westcot (1985).

have shown similar trends. In Varanasi, Singh *et al.* (2010) reported equally low levels of Cd (0.02 mg/l), Pb (0.0.09 mg/l), Zn (0.13 mg/l), Ni (0.06 mg/l) and Cr (0.05 mg/l) in wastewater. However, when irrigation water is from urban streams, downstream of industrial activities, elevated levels have been reported. For example, studies from a number of streams flowing through Addis Ababa and its neighborhoods have reported elevated values of Cd, Co, Cu, with levels as high as Cd (0.033 mg/l), Co (0.219 mg/l) and Cu (0.37 mg/l) (Weldegebriel *et al.*, 2012).

Continuous application of irrigation water from urban streams could contribute to heavy metal accumulation in soils and, hence, crops. While levels are still low in Ghana, care should be taken especially when using more polluted urban streams receiving wastewater from different sources with higher concentrations of heavy metals such as waste dumping sites, car washing bays, fuel stations and from the increasing light industries such as textile, paint (dyes) and plastics.

Heavy metals in soil

Levels of Fe, Mn, Cu, Pb and Ni appeared tangentially higher in wastewater irrigated soils than groundwater irrigated soils (Table 2). However, average values were all below the recommended maximum levels (Pendias & Pendias, 1992; Ewers, 1991). The highest value of Cr was 1.64 mg/kg recorded at Korle-Bu, while the lowest value recorded was 0.85 mg/kgat Mampong (Table 8). For Co, the highest mean value of 1.81 mg/kg was recorded at Dzorwulu, while the lowest value of 0.87 mg/kg was recorded at Mampong. Similarly, the highest and lowest mean values of Cd were recorded at Dzorwulu (0.24 mg/kg) and Mampong (0.09 mg/kg), respectively.

Previous studies conducted in some of the sites studied, i.e. Korle-Bu and Dzorwulu, also showed that most heavy metals were not elevated and had similar trends (Akrong, 2009). Results from other cities in Africa and India show comparatively much higher levels of heavy metals in wastewater irrigated soils. To illustrate this, four metals (Cd, Ni, Cr

TABLE 2

Concentration of heavy metals in soil (N= 144 samples)

Element	*Wastewater irrigated soil (mg/l)*	*Groundwater irrigated soil (mg/l)*	*RML FAO(mg/l)*	*RML WHO(mg/l)*
Fe	164.38 ± 5.55	162.92 ± 1.52	50000	50000
Mn	39.39 ± 21.80	20.09 ± 12.62	2000	2000
Cu	7.21 ± 3.83	6.13 ± 2.62	100	100
Zn	6.03 ± 1.67	7.45 ± 3.91	300	300
Pb	9.31 ± 2.23	7.63 ± 2.79	100	100
Ni	5.00 ± 2.48	2.97 ± 1.68	50	50
Cr	0.51 ± 1.53	0.85 ± 0.52	50	50
Cd	0.07 ± 0.17	0.09 ± 0.03	3	3
Co	0.73 ± 1.28	0.87 ± 0.55	100	100

Sources of RML values: FAO/WHO (2001); Pendias and Pendias (1992); Ewers (1991).

and Pb) were selected and compared to the Accra results with three other cities (Harare, Zimbabwe; Addis Ababa, Ethiopia and Varanasi, India), based on findings reported by Mapanda *et al.* (2005) for Harare, Weldegebriel *et al.* (2012) for Addis Ababa and Singh *et al.* (2010) for Varanasi. Cd levels (mg/kg) in Harare ranged between 0.5–2.5, in Addis Ababa between 1.4–1.8 and in Varanasi the mean value was 3.1, just exceeding the allowed threshold. Pb levels reported from the three other cities ranged between 6.7–49.7 mg/kg, and, on average, these levels were 2–3 times higher than levels reported in Accra, but also still below the threshold.

Similarly, Ni levels from other cities were 2–6 times higher. However, while chromium levels were 30–40 times higher in Addis Ababa and Varanasi, in Harare, levels reported ranged between 50–145 mg/kg, which was on average 200 times the 0.5 mg/kg reported in Accra and above the threshold of 50 mg/kg. As deduced in the other studies, vehicular emissions and fertilizers could have contributed more to heavy metals in soils than in irrigation water. In general, Accra soils were less contaminated with heavy metals than the other cities. However, due to the potential for accumulation of heavy metals in soils, crop samples were also analysed .

Enrichment factors and index of geoaccumulation

Enrichment factors (EF) ranged from significant to extreme values, an indication that the study sites were points of anthropogenic input. According to Zhang & Liu (2002), EF values between 0.5 and 1.5 indicate the metal is entirely from crust materials or natural processes, whereas EF values greater than 1.5 suggest that the sources are more likely to be anthropogenic. Table 3 shows that the general trend for total enrichment at the sites was highest at the Dzorwulu farming site (823.28) followed by Korle-Bu (756.82), CSIR (559.62) and least in the groundwater irrigated Mampong site (476.60). The high values at Dzorwulu could be attributed to vehicle washing activities, scrap metal burning and its closeness to high tension plants.

TABLE 3

Enrichment factors and index of geoaccumulation of mean heavy metal concentrations in soil for the study sites

Element	*Dzorwulu*		*CSIR*		*Korle–Bu*		*Mampong*	
	EF	*Igeo*	*EF*	*Igeo*	*EF*	*Igeo*	*EF*	*Igeo*
Fe	1.00	-8.99	1.00	-9.03	1.00	-9.00	1.00	-9.02
Mn	10.78	-5.56	12.96	-5.33	11.66	-5.46	7.31	-6.15
Cu	52.83	-3.26	32.64	-4.00	48.93	-3.39	38.53	-3.75
Zn	32.53	-3.96	24.03	-4.44	31.86	-4.01	36.79	-3.82
Pb	269.96	-0.91	221.71	-1.23	274.88	-0.90	210.99	-1.30
Ni	29.10	-4.12	20.24	-4.69	18.98	-4.76	13.70	-5.24
Cr	5.17	-6.62	4.99	-6.71	5.60	-6.52	2.92	-7.47
Cd	397.38	-0.35	227.48	-1.20	350.65	-0.55	153.26	-1.76
Co	24.53	-4.37	14.57	-5.16	13.26	-5.27	12.10	-5.43

Sources of the Igeo and enrichment classes: Yonming *et al.*, 2006; Kartal *et al.*, 2006, Huu *et al.*, 2010; Muller, 1969. EF = enrichment factors, Igeo = index of geoaccumulation.

At the Korle-Bu site, automobile repairs and a gas filling station is located within it. It is also close to the sea where raw sewage is disposed and the largest hospital in Ghana is situated. The CSIR site is associated with vehicle washing activities; scrap metal burning, domestic waste containing sewage and detergents mostly from Golden Tulip Hotel, whereas Mampong site receives releases from the major road as a result of the wear of tyre, brake lining and vehicle parts and combustion of fossil fuels (Thorpe & Harrison, 2008). All the study sites were close to major roads with heavy traffic. The geoaccumulation factor values were all negative, showing that the soils at all the four study sites were practically unpolluted (Igeo < 1) (Huu *et al*., 2010; Muller, 1969).

Heavy metals in vegetables

Table 4 shows the concentrations of heavy metals on vegetables. Most levels reported for chromium and cadmium were below detectable limits, with only leafy vegetables, i.e. lettuce and *ayoyo* having slightly elevated levels (1–2.5 times higher than the MRL). Similar levels of elevation (1–5 times higher than the MRL) were reported for cadmium in studies conducted in Varanasi, Harare and Addis Ababa (Sharma *et al.*, 2007; Mapanda *et al.*, 2007; Weldegebriel *et al.*, 2012). However, Muchuweti *et al.* (2006), in a study done in Harare, reported that local vegetables *Tsunga* leaves irrigated with wastewater contained 3.68 mg Cd per kg, over 18 times EU standards. In Kumasi, a study done on vegetables grown on waste dumping sites showed high cadmium contamination of 0.68–1.78 mg/kg (Odai *et al.*, 2008) Cadmium is becoming an increasing health concern in wastewater irrigated agriculture, especially due to its association in the damage of kidneys and bones and its potential carcinogenic nature (Suruchi & Khanna, 2011).

Zinc and copper concentrations on vegetables were below permissible limits. Mean concentrations were below 10 mg/kg. Studies in other cities have shown mixed

TABLE 4

Concentration of heavy metals in vegetable crops (n = 240)

Levels of heavy metals on vegetables (mg kg^{-1}dry weight)

		Fe	*Mn*	*Cu*	*Zn*	*Pb*	*Ni*	*Cr*	*Cd*	*Co*
Wastewater irrigated	cabbage	37.19 ± 7.39	13.69 ± 3.77	3.33 ± 1.44	9.55 ± 1.37	10.51±3.02	1.77 ± 1.03	< 0.006	< 0.005	0.44 ± 0.0
	lettuce	108.07 ± 17.58	63.96 ± 11.34	6.26 ± 1.39	10.61 ± 3.48	10.19±2.49	2.78 ± 0.46	< 0.006	0.01±0.01	1.07 ± 0.81
	green pepper	43.31 ± 9.28	5.18 ± 1.98	7.80 ± 2.05	6.94 ± 2.00	9.44±1.51	1.75 ± 0.76	< 0.006	< 0.005	0.24 ± 0.01
	hot pepper	29.57 ± 5.48	4.41 ± 0.10	5.25 ± 2.80	5.06 ± 1.52	7.61±1.78	1.68 ± 0.93	< 0.006	< 0.005	0.40 ± 0.01
	ayoyo	70.48 ± 27.82	16.82 ± 2.38	8.12 ± 1.93	7.96 ± 1.30	9.05±2.42	1.43 ± 0.47	< 0.006	0.28±0.01	< 0.005
Groundwater irrigated	cabbage	83.52 ± 0.01	13.12 ± 8.21	2.65 ± 0.36	9.55 ± 1.54	6.68±4.15	1.44 ± 0.06	< 0.006	< 0.005	1.00 ± 0.0
	lettuce	75.58 ± 9.14	11.94 ± 6.08	3.32 ± 2.74	9.84 ± 1.02	7.99±5.23	2.79 ± 3.16	1.12±0.01	0.50±0.01	1.45 ± 0.0
	green pepper	31.61 ± 17.85	10.26 ± 5.16	6.15 ± 0.35	6.06 ± 2.10	5.59±3.52	2.05 ± 0.21	< 0.006	< 0.005	0.79 ± 0.01
	hot pepper	77.11 ± 49.07	4.59 ± 1.87	7.38 ± 2.48	9.29 ± 2.25	6.68±0.65	4.05 ± 0.01	< 0.006	< 0.005	< 0.002
	ayoyo	23.40 ± 0.06	4.47 ± 2.07	5.89 ± 6.99	5.41 ± 4.95	8.33±1.16	1.30 ± 0.05	< 0.006	< 0.005	1.51 ± 0.07
	MRL	425.50	500	40	60	0.30	67.90	2.30	0.20	–

MRL = maximum recommended limit; conversion to wet weight done at mean 90% moisture content for all crops. All units are in mg/kg (same as µg/g) dry weight, Source; FAO/WHO, 2007 and adapted from Singh *et al*, 2010.

results. In Varanasi, Singh *et al*. (2010) showed elevated levels of Zn and Cu while Sharma *et al*. (2007) showed that the two elements were not elevated compared to the MRL. Similarly in Harare, while Muchuwati *et al.* (2006) showed the two elements were elevated (4–5 times higher than the MRL), Mapanda *et al*. (2007) showed the two elements were within permissible limits. These four studies show that some contamination can be location specific.

No reliable reference levels were obtained for Co. However, levels obtained were < 2 mg/kg, which seem tolerable. Similarly, though present in all vegetables, levels obtained for Ni were much lower than MRLs. In any case Ni concentrations should not be of much concern as higher threshold levels have been reported in other studies e.g. 68 mg/kg by Weigert (1991), based on the argument that more than 90% of Ni taken in is held in the organic form that can be safely excreted. Thus, the risk of exposure to Ni at the studied sites is low.

However, the concentrations of Pb on vegetables should be of concern as they were high and were found in 100% of samples collected. Mean Pb levels ranged between 5.59–10.51 mg/kg, with highest levels reported in cabbage and lettuce. This was 1.8–3.5 times higher than the MRL standards used. Similar ranges were obtained by studies done in Kumasi (2.42–13.50 mg/kg) and in Harare, where mean Pb concentrations of 6.77 mg/kg were obtained (Odai *et al.*, 2008; Muchuwati *et al.*, 2006). High Pb levels in Ghana could probably be attributed more to vehicular exhaust fumes (Affum *et al.*, 2008) than to irrigation water or contaminated soils. Kylander *et al.* (2003) analysed in Accra a Pb distribution following traffic density with levels reflecting a pre-catalyst situation in Europe and the US. This present study and that of Odai *et al.* (2008) show that some vegetables sold in Ghanaian urban markets have elevated levels of heavy metals, from localized contamination.

Estimation of daily intake of heavy metals

The degree of toxicity of heavy metals to human beings depends upon their daily intake and concentration of heavy metals (Table 5).

Amount of vegetables consumed. Estimates were based on expert knowledge and previous studies of the consumption behavior of the urban population of Accra (Amoah *et al.,* 2007).

(a) Lettuce: Mostly eaten as raw salad. Estimate of 30 g per person eaten 3 times in a week = 12.86 g/person/day

(b) Cabbage: Consumed as raw salad and stew. Frequently eaten in Ghana. Estimate of 50 g per person eaten 5 days in a week = 35.71 g/person/day.

(c) Hot pepper: Usually eaten with local diets like kenkey and banku. Can be added to stews also for flavor. These can be eaten about 5 days in a week and about 5 g each time = 3.57 g/person/day.

(d) Green pepper: Green pepper is sometimes also eaten as salad and to make stews. Estimate of 10 g per person eaten 5 times in a week = 7.14 g/person/day

(e) *Ayoyo:* Typical in local diets to make stew. Not frequently eaten, so about 2 times in a week but amounts consumed are high, on average about 200 g = 57.14 g/person/day

Since these estimates are in wet weights, to translate them to dry weights, estimated (conservative) moisture content of 90% was

TABLE 5

Estimated daily intake (ug/day) of heavy metals from consumption of irrigated vegetable crops in Accra.

		Fe	*Mn*	*Cu*	*Zn*	*Pb*	*Ni*	*Cr*	*Cd*	*Co*
Wastewater	cabbage	2.21	0.81	0.20	0.57	0.63	0.11	0.00	0.00	0.03
irrigated	lettuce	2.32	1.37	0.13	0.23	0.22	0.06	0.00	2.14E-4	0.02
	green pepper	0.52	0.06	0.09	0.08	0.11	0.02	0.00	0.00	2.86E-3
	hot pepper	0.18	0.03	0.03	0.03	0.05	1.00E-4	0.00	0.00	2.38E-3
	ayoyo	6.71	1.60	0.77	0.76	0.86	0.14	0.00	0.03	0.00
Groundwater	cabbage	4.97	0.78	0.16	0.57	0.40	0.09	0.00	0.00	0.06
irrigated	lettuce	1.62	0.26	0.07	0.21	0.17	0.06	0.02	1.07E-3	0.03
	green pepper	0.38	0.12	0.07	0.07	0.07	0.02	0.00	0.00	9.40E-3
	hot pepper	0.46	0.03	0.04	0.06	0.04	0.02	0.00	0.00	0.00
	ayoyo	2.23	0.43	0.56	0.52	0.79	0.12	0.00	0.00	0.14
PTDI/RfD		48^a	11^b	300^a	60^a	214^a	1^b	10^c	60^a	–

RfD = reference dose for 60 kg person; conversion to wet weight done at mean 90 % moisture content for all crops. PTDI = provisional tolerable daily intake ([a]WHO/FAO – JECFA, 199; 2004 as reported by Singh *et al.*, 2010), [b]IOM (2001), [c]Lake (1987).

.

used for all the vegetables as also reported by Sharma *et al.* (2009). For example, dry weights of lettuce will be 21.43 × (1.0-0.9) = 2.14 g.

Daily intake of heavy metals. The degree of toxicity of heavy metals to humans depends on the daily intake of the elements. Table 5 shows the calculated daily intake of heavy metals. The calculated values were compared with the provisional tolerable daily intake (PTDI) as provided by the WHO/FAO -JECFA (1999, 2004 and IOM as reported by Singh *et al.* (2010).

Levels obtained from this study were all below the MRLs and PTDIs obtained in literature. In a related study done on wastewater irrigated vegetables in Harare, Zimbabwe, where similar heavy metal elements were analyzed, Mapanda *et al.* (2007) showed that all heavy metal elements were below MRLs, except Cd, which was 333% of the MRL, which could only point to a specific Cd source in the study area. A study conducted in Varanasi, India, found contributions of these irrigated vegetables to daily intake of Cu, Zn, Cd and Pb to be 13%, 1%, 47% and 9%, respectively, of their corresponding provisional tolerable daily intake (PTDI) values (Sharma *et al.*, 2009).

Hazard index values. All heavy metals analyzed had a hazard quotient of less than one (HQ < 1), showing that vegetables pose no potential health risks from heavy metal toxicities to consumers (USEPA, 1996). On average, cadmium had the lowest HQ, with iron having the highest (Co < Cd < Cr < Cu < Pb < Zn < Fe < Mn < Ni). These values of HQs obtained in Accra, which is typical of a developing country with low industrial development, shows clear differences with HQs obtained from developing industrial economies like China and India, where studies have shown HQs of more than 1 (Singh *et al.*, 2010; Cui *et al.*, 2004). The Hazard Index values were also less than 1 (HI < 1) (Fig. 1) also showing that the consumption of all the vegetables did not pose potential health risks to consumers through the intake of the heavy metals.

Conclusion

Wastewater irrigation can lead to accumulation of heavy metals in the soil and, consequently, in the vegetables, which when consumed in excessive quantities can pose health risks. This study shows that irrigated soils and crops irrigated with diluted wastewater had slightly higher but not significantly different levels of heavy metals, compared to control site where groundwater was used. Heavy metal concentrations in irrigation water, soils and vegetables were below permissible levels, except Pb on vegetables, which was 1.8–3.5 higher than the safe limits. Health risk assessments done show that normal consumption of vegetables assessed poses no risk from heavy metal toxicities since daily intake rates and the hazard indices obtained were all below the minimal risk levels.

Ayoyo, cabbage and lettuce showed highest hazard indices but remained well under the respective thresholds. In general, levels obtained in Accra were much lower than those reported in other countries but should continue to be monitored in the envisaged industrial growth in Ghana due to the development of many light industries. The possible risk from Pb should alert policy makers to address the dangerous synergy of leaded petrol meeting an over-aged car pool on Accra's roads. Compared with previous studies which focused on microbial hazards from using the same water sources (Amoah *et al.*, 2011), the current study showed that the risk from heavy metals is of lower significance than that from pathogens. For the field of study, developing comprehensive and universally acceptable guidelines and standards on heavy metal contamination will be helpful to make sound inter-study comparisons and risk estimations.

References

Affum H. A., Oduro-Afriyie K., Nartey V. K., Adomako D. and **Nyarko B. J. B.** (2008). Bio-monitoring of airborne heavy metals along a major road in Accra, Ghana. *Envir. Monit. Assess.* **137**: 15–24.

Akrong O. M. (2009). The Influence of quality of irrigation water and post harvest handling on bacterial contamination and heavy metal accumulation on lettuce cultivated in urban Accra. (PhD Thesis.) Department of Env'tal Sci, University of Ghana, Legon.

American Public Health Association, American Water Works Association, Water Environment Federation (APHA, AWWA, WEF) (2001). *Standard methods for the examination of water and wastewater,* 22nd edn. Washington, D.C.

Amoah P., Keraita B., Drechsel P., Abaidoo R., Konradsen F. and **Akple M.** (2011). *Low cost options for health risk reduction where crops are irrigated with polluted water in West Africa*. IWMI research Report No 141, Colombo, Sri Lanka.

Amoah P., Drechsel P., Abaidoo R. C. and **Henseler M.** (2007). Irrigated urban vegetable production in Ghana: Microbiological contamination in farms and markets and associated consumer risk groups. *J. Wat. Hlth*. **5**(3): 455–466.

Ayers R. S. and **Westcot D. W.** (1985). *Water quality for Agriculture.* FAO Irrigation and Drainage Paper 29. Rome.

Bakare S. Denloye A. A. and **Olaniyan F. O.** (2004). Cadmium, lead and mercury in fresh and boiled leafy vegetables grown in Lagos, Nigeria. *Envir. Tech.* **25 12:** 1367–1370.

Borowski K. and **Schmaling A.** (1996). *An integrated microwave digestion system for the modern laboratory.* Milestone Inc. America laboratory.

Cui Y. J., Zhu Y. G., Zhai R. H., Chen D. Y., Huang Y. Z., Qui Y. and **Liang J. Z.** (2004). Transfer of metals from near a smelter in Nanning, China. *Envir. Int.* **30**: 785–791.

Eriyamremu G. E., Asagba S. O., Akpoborie A. and **Ojeabur S. I.** (2005). Evaluation of lead and cadmium levels in some commonly consumed vegetables in the Niger-Delta oil area of Nigeria. *Bull. Envir. Cont. Toxicol.* **7**5: 278–283.

Ewers U. (1991). Standards, guidelines and legislative regulations concerning metals and their compounds. In Metals and their compounds in the environment, Relevance. (E. Merian, ed.), pp. 458–468. VCH, Weinlein.

FAO/WHO (2007). *Expert Committee on Food Additives.* Cambridge University Press, Cambridge. pp. 329–336.

FAO/WHO (2004).*Codex Alimentarius Commission. Food additive and contaminants*. Joint FAO/ WHOFood Standards Programme, ALINORM.

FAO/WHO (1994).*Codex Alimentarius Commission. Food additive and contaminants*. Joint FAO/ WHOFood Standards Programme, ALINORM.

FAO/WHO (2001). *Codex Alimentarius Commission. Food additive and contaminants*. Joint FAO/ WHOFood Standards Programme, ALINORM 01/ 12A. pp 1–289.

Gowd S. S., Reddy M. R. and **Govil P. K.** (2010). Assessment of heavy metal contamination in soils at Jajmau (Kanpur) and Unnao industrial areas of the Ganga Plain, Uttar Pradesh, India. *J. Hazardous Mat.* **174**: 113–121.

Huu H. H., Rudy S. and **Van Damme.** (2010). Distribution and contamination status of heavy metals in estuarine sediments near CauOngharbor, Ha Long Bay, Vietnam. *Geology Belgica.***13**(1–2): 37–47.

IOM, Food and Nutrition Board. (2001). *Dietary Reference Intakes for Vitamin A, Vitamin K, Arsenic, Boron, Chromium, Copper, Iodine, Iron, Manganese, Molybdenum, Nickel, Silicon, Vanadium and Zinc.* National Academy Press, Washington, D.C.

Jassir M. S., Shaker A. and **Khalip M. A.** (2005). Deposition of heavy metals on green leafy vegetables sold on roadsides of Riyadh city, Saudi Arabia. *Bull. Envir. Cont.Toxicol.* **75**: 1020–1027.

Kartal S. Aydýn Z. and **Tokalýoglu S.** (2006). Fractionation of metals in street sediment samples by using the BCR sequential extraction procedure and multivariate statistical elucidation of the data. *J. Haz. Mat.* **132**: 80–89.

Kylander M. E., Rauch S., Morrison G. M. and **Andam K.** (2003) Impact of automobile emissions on the levels of platinum and lead in Accra, Ghana. *J. Envir. Monit.* **5**: 91–95.

Lake D. L. (1987). Chemical speciation of heavy metals in sewage sludge and related matrices. In *Heavy Metals in Wastewater and Sludge Treatment Process.* (J. N. Lester, ed.), pp. 15–40. CRC Press Inc., Boca Raton, USA,

Lu X. Wanga L. Li L.Y. Lei K. Huang L. and **Kang D.** (2010). Multivariate statistical analysis of heavy metals in street dust of Baoji, NW China. *J. Haz. Mat.* **173**: 744–749.

Lu X. Wang L. Lei K. Huang J. and **Zhai Y.** (2009). Contamination assessment of copper, lead, zinc, manganese and nickel in street dust of Baoji, NW China. *J. Haz. Mat.* **161**: 1058–1062.

Mapanda F., Mangwayana E. N., Nyamangara J. and **Giller K. E.** (2005). The effect of long term irrigation using wastewater on heavy metal contents of soils under vegetables in Harare, Zimbabwe. *Agric. Ecosyst. Envir.* **107:** 151–165.

Mapanda F., Mangwayana E. N., Nyamangara J. and **Giller K. E.** (2007). Uptake of heavy metals by vegetables irrigated using wastewater and the subsequent risks in Harare, Zimbabwe. *Phys. Chem. Earth Part. A/B/C* **32**:15–18, 1399–1405.

McBride M. B. (2003). Toxic metals in sewage sludge-amended soils: has promotion of beneficial use discounted the risks? *Adv. envir. Res.* **8**: 5–19.

Muchuwati M., Birkett J. W., Chinyanga E., Zvauya R., Scrimshaw M. D. and **Lester J. N.** (2006). Heavy metal content of vegetables irrigated with mixtures of wastewater and sewage sludge in Zimbabwe: Implications for human health. *Agric. Ecosys. Envir.* **112**: 41–48.

Muller G. (1969). Index of geoaccumulation in sediments of the Rhine River. *Geo. J.* **2** (3): 108–118.

Obuobie E., Keraita B., Danso G., Amoah P., Cofie O. O., Raschid-Sally L. and **Drechsel P.** (2006). *Irrigated Urban Vegetable Production in Ghana: Characteristics, benefits and risks.* IWMI, Accra; Accessedon18/7/2012 at *www.cityfarmer.org/GhanaIrrigateVegis.html*

Odai S. N., Mensah E., Sipitey D., Ryo S. and **Awuah E.** (2008). Heavy Metals Uptake by Vegetables Cultivated on Urban Waste Dumpsites: Case Study of Kumasi, Ghana. *Res. J. envir. Toxicol.* **2**: 92–99.

Ogwuegbu M. O. C and **Muhanga W.** (2005). Investigation of lead concentration in the blood of people in the copper belt province of Zambia. *J. Envir.* **1**: 66–75.

Pendias A. K. and **Pendias H.** (1992).Elements of group VIII. In *Trace Elements in Soils and Plants.* pp. 271–276. CRC Press, Boca Raton.

Sharma R. K., Agrawal M. and **Marshall F. M.** (2006). Heavy metals contamination in vegetables grown in wastewater irrigated areas of Varanasi, India. *Bull. envir. Contam. Toxicol.* **77**: 312–318.

Sharma R. K., Agrawal M. and **Marshall F. M.** (2007) Heavy metals contamination of soil and vegetables in suburban areas of Varanasi, India. *Ecotox. envir. Saf.* **66**: 258–266.

Sharma S. and **Prasad F. M.** (2009). Accumulation of Lead and Cadmium in Soil and Vegetable Crops along Major Highways in Agra, India. *E-J. Chem.* **74**: 1174–1183.

Singh A., Sharma R. K., Agrawal M. and **Marshall F. M.** (2010). Risk assessment of heavy Metal toxicity through contaminated vegetables from wastewater irrigated areas in Varanasi, India. *Trop. Ecol.* Iss 51. **2**: 375–387.

Suruchi and **Khanna P.** (2011). Assessment of heavy metal contamination in different vegetables grown in and around urban areas. *Res. J. envir. Toxicol.* **5**: 162–179.

Taylor S. R. and **McLennan S. M.** (1985). *The Continental Crust: Its Composition and Evolution.* Blackwell Scientific Publications, Oxford.

Thorpe A. and **Harrison R. M.** (2008). Sources and properties of non-exhaust particulate matter from road traffic: A review, *Sci. Tot. Envir.* **400**: 270–282.

Turekian K. K. and **Wedepohl K. H.** (1961). Distribution of the elements in some major units of the Earth's crust. *Bull. Geol. Sot. Am.* **72**: 175–192.

Umweltbundesamt (1992). Klaerschlammverordnung *www.umweltbundesamt.de/boden-und-altlasten/boden/downloads/Klaerschlammverordnung.pdf* (accessed 18 July 2012).

US Environmental Protection Agency (USEPA) (1996). *Review of National Air Quality Standards for Ozone, Assessment of scientific technical information.* OAQPS Staff Paper, EPA 452/R-96-007; USEPA Air Quality Criteria for Ozone and related Photochemical Oxidants EPA/600/P-93/004Af.

Weigert P. (1991). Metal loads of food of vegetable origin including mushrooms. In *Metals and Their Compounds in the Environment, Occurrence, Analysis and Biological Relevance.* (E. Marian, ed.), pp. 458–468. VCH, Weinheim.

Weldegebriel Y., Chandravanshi B. S. and **Wondimu T.** (2012). Concentration levels of metals in vegetables grown in soils irrigated with river water in Addis Ababa, Ethiopia. *Ecotox. envir. Saf.* **77**: 57–63.

Yongming H., Peixuan D., Junji C. and **Posmentier E. S.** (2006). Multivariate analysis of heavy metal contamination in urban dusts of Xi'an, Central China, *Sci. Tot. Envir.* **355**: 176–186.

Zhang J. and **Liu C. L.** (2002). Estuarine. *Coastal and Shelf Sci.* **54:** 1051.