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HEAVY METAL ACCUMULATION IN LEAFY VEGETABLES GROWN IN INDUSTRIAL AREAS UNDER VARYING LEVELS OF POLLUTION

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Abstract

The concentration of lead (Pb), cadmium (Cd), nickel (Ni), cobalt (Co) and chromium (Cr) in three popular leafy vegetables such as spinach (*Spinacia oleracea*), red amaranth (*Amaranthus tricolor*) and amaranth (*Amaranthus oleraseus*) and that in the respective soils were assessed. These crops and soils were collected from two industrial areas (Kalakoir and Zorun, Konabari, Gazipur), and one non-industrial area (Bangladesh Agricultural Research Institute-BARI) under Gazipur district. The concentration of heavy metal in different parts of plant followed the roots>leaves>stem and in soils the order was Kalakoir (pollution)> Zorun (medium pollution) > BARI (low/non-pollution). In all three leafy vegetables similar trend of metal contents was observed i.e. Ni>Cr>Pb>Co>Cd. In the highly pollution area (Kalakoir) the Pb and Ni concentration was found in the order of amaranth>spinach>red amaranth. The Cd concentration was in the order of spinach>amaranth>red amaranth whereas for Cd it was amaranth>red amaranth>spinach and for Cr it was red amaranth>amaranth>spinach. The Pb, Cd, Ni, Co and Cr concentrations in the studied vegetables grown in the low polluted area were below the maximum acceptable levels proposed by the Joint FAO/WHO Expert Committee on Food Additives, except, Cd in spinach and amaranth. However, the higher concentrations of Pb, Cd, Ni, Co and Cr in vegetables grown in the industrial areas indicates that industrial discharge causes heavy metals contamination of soil and eventually their accumulation in plants.

Keywords: Leafy vegetables, heavy metal, industrial areas.

Introduction

Anthropogenic activities have altered the environment significantly throughout the world including mining, industry and agriculture as well as increase of the urbanization level (Wang *et al.*, 2008). Disposal of sewage water and industrial wastes is a great problem. Often it is drained to the agricultural lands where it is used for growing crops including vegetables. These sewage effluents are considered not only a rich source of organic matter and some nutrients, but these also elevate the level of heavy metals like iron (Fe), manganese (Mn), copper

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(Cu), zinc (Zn), lead (Pb), chromium (Cr), nickel (Ni), cadmium (Cd), and cobalt (Co) in soils (Singh *et al.,* 2004).

In the low concentrations, many metals are essential to life (Kashif *et al.,* 2009). Trace quantities of certain heavy elements such as Co, Cu, Mn and Zn are essential micronutrients for higher animals and for plants (Somers, 1974). However, excessive accumulation of trace elements in agricultural soils through wastewater irrigation may not only result in soil contamination, but it also affects food quality and safety (Muchuweti *et al.,* 2006; Sharma *et al.,* 2007). Some trace elements are essential in plant nutrition, but plants growing in the nearby zone of industrial areas accumulate increased concentration of heavy metals, serving in many cases as bio monitors of pollution loads (Mingorance *et al.,* 2007).

Vegetables are an important part of human's diet. It is potential source of nutrients which have marked health effects (Arai, 2002). Vegetables are plants that are eaten raw or cooked. It is described as shrubs or herbaceous annual or perennial plants that are eaten by man (Longman, 2005). There are different kinds of vegetables ranging from edible roots, stems, leaves, fruits or seeds. Each group contributes to diet in its own way (Hanif *et al.,* 2006). Vegetables cultivated in soils polluted with toxic metals due to industrial activities take up heavy metals and accumulate them in their edible and non-edible parts in quantities high enough to cause clinical problems both to animals and human beings consuming these metal-rich plants because there is no good mechanism for their elimination from the human body (Alam *et al.,* 2003; Arora *et al.,* 2008). Trace elements are harmful because of their nonbiodegradable nature, long biological half-lives, and their potential to accumulate in different body parts.

Vegetables, especially those of leafy vegetables grown in heavy metals contaminated soils, accumulate higher amounts of metals than those grown in uncontaminated soils (Al Jassir *et al.,* 2005). Previous study revealed that the concentrations of metal in vegetables varied with the locations, showing the trend: high-level of pollution> medium-level of pollution> low-level of pollution (Naser *et al.,* 2009). The present study was carried out in industrial areas of Turag River vicinity, Gazipur, Bangladesh, where irrigation of vegetable crops with polluted river water is a common practice. Knowledge about contamination of vegetables with heavy metals from industrial areas of Turag River vicinity is yet to be obtained. In this context, the present study was undertaken to investigate the concentration of heavy metals (Pb, Cd, Ni, Co and Cr) in commonly grown leafy vegetables and their level in respective crop-soils.

Materials and Methods

Soil and plant sampling

Soil and leafy vegetables samples were taken from three cropping areas exposed to different degrees of pollution. Area 1– high-level of pollution: Pollution by irrigation water (Kalakoir, Konabari, Gazipur- 23°59′32.65″N, 90°19′43.43″E), the vegetable samples in this area were taken from the site irrigated with the Turag river water. The river Turag is highly polluted by industrial effluents, sewage sludge, municipal waste water and urban pollution (Islam *et al.,* 2012b). Area 2– medium-level of pollution: Pollution by pond and kennel's water (Zorun, Konabari, Gazipur- 23°59′53.38″N, 90°19′21.77″E), which is polluted by industrial effluents, sewage sludge, municipal waste water and urban pollution. During rainy season pond and canals are over flown by rain water and submerse the adjacent cultivable land where the farmers grow their vegetables in winter. Area 3– low-level of pollution: The same vegetables samples and soils were collected from BARI (Bangladesh Agricultural Research Institute- 23°59′31.15″N, 90°24′50.95″E), experimental field, regarded as low-level pollution area. The collected plant samples included spinach (*Spinacia oleracea*), red amaranth (*Amaranthus tricolor*) and amaranth (*Amaranthus oleraseus*). Plant samples were collected from 6 week olds plants. Soil and vegetable samples were collected from different sites of each location. The plant samples represented different parts of plant roots, stem and leaves. Soil samples of 0–15 cm depth were collected by a stainless steel auger at the same time when vegetable samples were collected, and samples were taken to the laboratory.

Preparation and preservation

In the laboratory, all vegetables were washed with fresh running water to remove dust, dirty materials, possible parasites or their eggs and then were again washed with deionized water. The clean vegetable samples were air-dried and placed in an electric oven at 65 °C for 72–96 h depending on the sample size. The samples were homogenized by grinding using a ceramic coated grinder. All soil samples were spread on plastic trays and allowed to dry at ambient temperature for one week. Soil pH was determined by glass electrode pH meter and electricity conductivity (EC) was measured by conductivity meter in 1:5 ratio of soilwater suspension (Yong *et al.,* 2011). The dry samples of soils were ground with a ceramic coated grinder and sieved through a nylon sieve. The final samples were kept in labeled polypropylene containers at ambient temperature before analysis.

Digestion and determination

The samples were digested with HNO_3 and $HClO_4$ (5:1 volume) for total metal estimation, as described by Misra and Chaturvedi (2007). One gram of each sample was weighed into 50-ml beaker, followed by the addition of 10 ml mixture of analytical grade acids HNO_3: $HClO_4$ in the ratio 5:1, and left overnight for complete contact of material. Next day, the digestion was performed at a temperature of about 190 ºC for 1.5 h. After cooling, the samples were transferred into 50 ml volumetric flask and solution was made up to a final volume raised up to the mark with distilled water. The metal concentrations were determined by atomic absorption spectrometry using a VARIAN model AA2407

Atomic Absorption Spectrophotometer (AAS). Analysis of each sample was carried out three times to obtain representative results and the data reported in µg g^{-1} (on a dry matter basis). Statistical differences were judged by Tukey's multiple comparisons test by using Excel Statistics version 4.0 (Esumi Co. Ltd., Tokyo, Japan).

Results and Discussion

Chemical properties of soils

The pH of soil samples from high-level and medium-level pollution area was 6.58 and 6.60, respectively, which indicates that the soils were slightly acidic to neutral. On the other hand pH from low-level pollution area was slightly alkaline in reaction pH (7.43). These pH values from polluted area (either high-level or medium-level) were within the range of the pH of the surface soils (ranged from 6.10 to 6.98) from the solid waste dumping site near to the present study area (Islam *et al.*, 2012a). The study revealed that the EC of the high-level polluted soils receiving irrigation with industrial effluents was higher (3.26 deciSiemens per meter – dS m^{-1}) than the soils of medium-level polluted (1.15 dS m^{-1}), and the value of EC was lowest in low-level polluted area (0.61 dS m^{-1}). The presence of large amount of ionic substance and soluble salts have resulted in increased value of EC in the industrial effluents contaminated irrigated soil samples in comparison to the others (Islam *et al.*, 2012a).

Heavy metal contents in plant parts

The mean concentrations of Pb, Cd, Ni, Co, and Cr in different parts (roots, stem, and leaves) of vegetables studied were given in Tables 1–3. The concentrations of heavy metals in these samples were quite variable such as 0.64−5.97 µg $g^{-1}$for Pb, 0.22–1.28 µg g^{-1} for Cd, 4.02–46.5 µg g^{-1} for Ni, 0.39–2.62 µg g^{-1} for Co, and 1.71–6.99 µg g^{-1} for Cr. It was observed that high contents of Cd, Ni and Cr were accumulated in roots of spinach (1.28, 46.5 and 2.62 µg g^{-1}, respectively) grown on high-level polluted area. The spinach exhibited higher levels of Pb (5.97 µg g^{-1}) in leaves followed by red amaranth, while stem of red amaranth in low-level polluted area showed low concentration of Pb (0.64 µg g^{-1}). The lowest concentration of Co (0.39 µg g^{-1}) was observed in spinach stem. On the other hand, amaranth roots showed the highest concentration of Co (2.62 µg g^{-1}). Present study revealed that all the heavy metal content was found greater in spinach grown in polluted areas (either high-level or medium-level), only Co was found greater in roots of amaranth in the same location. With few exceptions, the magnitude of heavy metals detected in various plant components particularly in roots, stems and leaves was found as roots>leaves>stem. Content of heavy metal in different parts of vegetables followed the trend as high-level of pollution> medium-level of pollution> low-level of pollution.

The mean concentrations of Pb, Cd, Ni, Co and Cr in whole plant (roots, stem and leaves) of three leafy vegetables were shown in Table 4. The concentrations of heavy metals (µg g^{-1} of dry wt.) in those vegetables quite varied, such as Pb (0.76 to 5.73 µg g^{-1}), Cd (0.29 to 1.14 µg g^{-1}), Ni (4.94 to 33.8 µg g^{-1}), Co (0.49 to 2.38 µg g^{-1}) and Cr (2.23 to 6.67 µg g^{-1}). The levels of heavy metal in all the three vegetable samples from the polluted area (either high-level or medium-level) were higher than those from the low-level polluted (BARI) area. Several studies have indicated that vegetables grown in heavy metals contaminated soils have higher concentrations of heavy metals than those grown in uncontaminated soils (Al Jassir *et al.,* 2005; Farooqet *et al.,* 2008).

Statistically significant difference ($P<0.01$) in heavy metal (Pb, Cd, Ni, Co, and Cr) contents was found between polluted (either high-level or medium-level) and non-polluted areas in both vegetables and soils. For all the three vegetables and for all locations a similar trend in metal contents was observed i.e. Ni>Cr>Pb>Co>Cd and the magnitude of heavy metal contamination was high-level of pollution> medium-level of pollution> non-pollution. However, their values in all vegetables were different. In high-level polluted area the extent of heavy metal content in vegetables can be regarded in the order of amaranth>spinach>red amaranth for Pb, spinach>amaranth>red amaranth for Cd, amaranth>spinach>red amaranth for Ni, amaranth>red amaranth>spinach for Co and red amaranth>amaranth>spinach for Cr.

Proportion of heavy metal contents increased (%) in spinach, red amaranth and amaranth in high-level polluted and medium-level polluted areas in comparison to non-polluted area showing a range from 253 to 451%, 489 to 507% and 394 to 429% for Pb; 27 to 139%, 176 to 197% and 61 to 128% for Cd; 461 to 553%, 466 to 528% and 349 to 567% for Ni, it was 188 to 227%, 134 to 177% and 65 to 95% for Co; and was 115 to 142%, 165 to 174% and 185 to 198% for Cr, respectively.

In our previous study (Naser *et al.,* 2009), we determined the levels of Pb, Cd and Ni in samples of spinach, tomato and cauliflower 0.767-1.440 µg g^{-1}, 1.027-1.968 µg g^{-1}, 0.486-1.119 µg g^{-1}, respectively for Pb; 0.559-1.40 µg g^{-1}, 0.630-1.303 µg g^{-1}, 0.506-0.782 µg g^{-1}, respectively for Cd and 1.265-5.369 µg g^{-1}, 2.031-4.957 µg g^{-1}, 1.698-4.447 µg g^{-1}, respectively for Ni, grown in industrially (Konabari, Gazipur; Keranigonj, Dhaka), and non-industrial (Bangladesh Agricultural Research Institute-BARI, Gazipur) areas. The reported Cd concentrations were found similar to the current levels but the Pb and Ni concentrations were higher than the reported values. The higher concentrations of Pb and Ni might be due to the differences in location. On the other hand, concentrations of Pb and Ni in spinach from BARI were higher than those from previous study (Naser *et al.,* 2009). It might be due to the experimental field, which was top-dressed by foreign soil near about couple of years before. So, it is not representing the previous tested soils.

The Pb levels in vegetables in this study were higher than the reported values (Alegria *et al.*, 1991; Jamali *et al.*, 2007). For example, the levels of Pb in spinach grown in the waste water irrigation area (TVS) was 0.12 µg g^{-1} dry wt., while the cannel water irrigation area (CVS) showed 0.33 0.12 µg g^{-1} dry wt. (Jamali *et al.*, 2007). The Pb concentration in all the vegetables from polluted areas (either high-level or medium-level) was above the permissible levels (Table 4) of India (Awashthi, 2000) and was lower or similar with the maximum level as per FAO/WHO standard (FAO/WHO - Codex Alimentarious Commission, 1984), except, Pb content in amaranth from polluted area. On the other hand, the Pb levels in this study were lower than the concentrations of Pb (17.5–25.0 µg g^{-1}) in vegetables grown in wastewater treated areas of Varanasi, India (Sharma *et al.*, 2006) and the levels of Pb (6.77 µg g^{-1}) in vegetables irrigated with mixtures of wastewater and sewage from Zimbabwe (Muchuweti *et al.*, 2006).

Table1. Concentration (±, standard deviation) of Pb, Cd, Ni, Co and Cr in the roots of three leafy vegetables grown in areas with different levels of pollution by heavy metals

Vegetable	Level of pollution in the growing area	Concentration (µg $g^{-1}$of dry wt.)				
		Pb	Cd	Ni	Co	Cr
Spinach	High	4.87±0.35	1.28±0.54	46.5±2.63	1.78±0.25	6.99±0.78
	Medium	3.08±0.35	0.66±0.06	40.8±3.11	1.54±0.19	5.64±0.16
	Low	0.90±0.11	0.51±0.09	5.23±0.88	0.61±0.08	2.73±0.34
Red Amaranth	High	3.71±0.53	1.02±0.18	46.3±2.38	2.37±0.23	6.90±0.64
	Medium	3.67±0.75	0.86±0.21	40.0±2.87	2.10±0.22	6.58±0.58
	Low	0.79±0.19	0.40±0.03	5.75±0.90	1.01±0.13	3.02±0.39
Amaranth	High	5.94±0.45	1.20±0.47	37.8±2.20	2.62±0.27	6.55±0.46
	Medium	6.08±1.06	0.80±0.13	24.9±1.89	2.02±0.09	6.45±0.29
	Low	1.65±0.18	0.61±0.10	5.15±0.47	1.56±0.19	2.61±0.29

Vegetables from the polluted (either high-level or medium-level) area showed higher levels of Cd than those from the low-level polluted area (Table 1–3). In fact, significant differences (P<0.01) were found in the level of Cd in all tested vegetables between polluted (either high-level or medium-level) and low-level polluted areas. The above results obtained are in line with Lone *et al.*, (2003), who studied the effect of sewage and tubewell water on heavy metal content of spinach in Pakistan, they found considerably higher concentration of Cd than those soils irrigated with tubewell water. Our study also showed that the average Cd levels measured in vegetables were higher than that in leafy and non-leafy vegetables in India (Tripathi *et al.*, 1997). Similar to Pb as reported by the group of researchers (Jamali *et al.,* 2007), the concentration of Cd in vegetables sampled from TVS was high 0.14 µg g^{-1} (spinach) on a dry wt. basis, whereas in CVS showed 0.01 µg g^{-1}. The Cd concentration was below the Indian standard (Awashthi, 2000) but above the safe levels of FAO/WHO and China (SEPA, 2005). The Ni concentrations in vegetables in this study were higher compared to the Pb and Cd concentrations, and the heavy metal concentration from industrial area was higher than that from non-industrial area (Yusuf *et al.,* 2003). The Ni concentration was below the safe level as demonstrated by FAO/WHO and it was above the safe levels of Indian standard (Awashthi, 2000) and China (SEPA, 2005). The maximum Co concentration (2.38 µg g^{-1} dry wt.) was found in amaranth whereas the mean value was 2.27 and 1.60 µg g^{-1} dry wt. for red amaranth and spinach, respectively, which was lower than the mean value 9.2 to 11.3 µg g^{-1} dry wt., for garden spinach in India (Farooq *et al.,* 1999). Cobalt concentration was below the safe levels of FAO/WHO. The mean levels of Cr in vegetables in the present study were significantly lower than the concentrations of other reported studies (Gupta *et al.,* 2008; Sharma *et al.,* 2007) in India. However, it was close to the result obtained from past study in Bangladesh (Ahmad and Goni, 2009) and in China (Liu *et al.,* 2006). Chromium concentration in all the vegetables from polluted areas (either high-level or medium-level) examined in the present study was above the permissible levels recommended by FAO/WHO and China (SEPA, 2005) but below the maximum limit for India (Awashthi, 2000).

Table 2. Concentration (±, standard deviation) of Pb, Cd, Ni, Co and Cr in the stem of three leafy vegetables grown in areas with different levels of pollution by heavy metals

Vegetable	Level of pollution in the growing area	Concentration (µg g^{-1} of dry wt.)				
		Pb	Cd	Ni	Co	Cr
Spinach	High	4.37±0.49	1.11±0.16	21.3±2.25	1.40±0.27	5.57±0.57
	Medium	3.06±0.22	0.64±0.09	20.0±2.76	1.28±0.12	5.02±0.92
	Low	0.70±0.12	0.49±0.16	4.55±0.70	0.39±0.06	2.15±0.53
Red Amaranth	High	4.53±0.47	0.74±0.15	24.1±3.33	2.14±0.20	6.34±0.77
	Medium	4.39±0.43	0.80±0.18	21.9±1.64	1.63±0.29	6.92±0.15
	Low	0.64±0.12	0.22±0.06	4.02±0.58	0.64±0.09	2.50±0.30
Amaranth	High	5.50±0.42	1.02±0.33	34.3±2.26	2.23±0.16	6.45±0.29
	Medium	4.26±0.27	0.67±0.18	22.2±3.58	1.98±0.16	6.07±0.81
	Low	0.71±0.22	0.43±0.06	5.04±0.59	0.83±0.07	2.37±0.19

Table 3. Concentration (±, standard deviation) of Pb, Cd, Ni, Co and Cr in the leaves of three leafy vegetables grown in areas with different levels of pollution by heavy metals

Vegetable	Level of pollution in the growing area	Concentration (μg g^{-1} of dry wt.)				
		Pb	Cd	Ni	Co	Cr
Spinach	High	5.97±0.30	1.02±0.15	31.9±3.38	1.63±0.24	5.70±0.36
	Medium	3.61±0.18	0.52±0.03	24.6±2.23	1.41±0.17	5.62±0.23
	Low	1.16±0.16	0.43±0.07	5.48±0.47	0.47±0.09	2.69±0.24
Red Amaranth	High	5.51±0.35	0.85±0.14	22.5±3.68	2.31±0.15	6.76±0.12
	Medium	5.29±0.65	0.77±0.12	22.1±1.79	2.02±0.30	5.82±0.51
	Low	0.85±0.15	0.23±0.02	5.04±0.62	0.80±0.07	1.77±0.22
Amaranth	High	5.75±0.38	0.78±0.22	29.3±2.48	2.30±0.15	6.93±0.40
	Medium	5.70±1.07	0.68±0.15	21.1±3.54	2.02±0.03	6.52±0.43
	Low	0.89±0.03	0.30±0.08	4.99±0.61	1.27±0.16	1.71±0.33

Table 4. Concentration (±, standard deviation) of Pb, Cd, Ni, Co and Cr in whole plant (roots, stem and leaves) of three leafy vegetables grown in areas with different levels of pollution by heavy metals

Vegetable	Level of pollution in the growing area	Concentration (μg g^{-1} of dry wt.)				
		Pb	Cd	Ni	Co	Cr
Spinach	High	5.07±0.79c	1.14±0.31c	33.2±11.2 b	1.60±0.27b	6.09±0.85b
	Medium	3.25±0.35b	0.61±0.09b	28.5±9.74b	1.41±0.18b	5.43±0.57b
	Low	0.92±0.23a	0.48±0.10a	5.09±0.74a	0.49±0.12a	2.52±0.44a
Red Amaranth	High	4.59±0.87b	0.87±0.18b	31.0±11.8b	2.27±0.20b	6.67±0.56b
	Medium	4.45±0.89b	0.81±0.16b	28.0±9.21b	1.92±0.32b	6.44±0.63b
	Low	0.76±0.16a	0.29±0.09a	4.94±0.97a	0.82±0.18a	2.43±0.61a
Amaranth	High	5.73±0.41c	1.00±0.35c	33.8±4.20c	2.38±0.25b	6.64±0.40b
	Medium	5.35±1.13b	0.71±0.15b	22.7±3.19b	2.01±0.10b	6.35±0.52b
	Low	1.08±0.45a	0.44±0.15a	5.06±0.49a	1.22±0.35a	2.23±0.47a
Safe Limit (μg g^{-1}) [a]		5	0.3	20	50	5

Mean values in the same column followed by the same letters are not significantly different ($P < 0.01$).

[a] FAO/WHO-Codex Alimentarious Commission (1984).

Heavy metal contents in soils

Lead, Cd, Ni, Co and Cr concentrations in soil samples (Table 5) followed a trend similar to vegetables heavy metals concentrations of vegetables. Thus, the increase of metal contents (µg g^{-1}) in soils of medium-level and high-level polluted areas were 109 to 274%, 104 to 173% and 112 to 269% for Pb; 126 to 187%, 162 to 164% and 119 to 157% for Cd; 132 to 185%, 169 to 189% and 102 to 171% for Ni; it was 151 to 212%, 171 to 250% and 269 to 286% for Co; and was 142 to 174%, 151 to 178% and 154 to 159% for Cr, respectively. Comparing the metal concentration in soil with guidelines for soils showed that all metal concentration was below the safe limits for soils (Table 5).

Table 5. Concentration (±, standard deviation) of Pb, Cd, Ni, Co and Cr in soils of three leafy vegetables from areas with different levels of pollution by heavy metals

Vegetable	Level of pollution in the growing area	Concentration (µg g^{-1} of dry wt.)				
		Pb	Cd	Ni	Co	Cr
Spinach	High	17.5±0.55c	2.03±0.08c	39.9±1.10c	14.3±1.28b	32.3±1.40b
	Medium	9.75±1.23b	1.60±0.16b	32.5±1.60b	11.5±1.45b	28.6±1.71b
	Low	4.67±0.58a	0.71±0.03a	14.0±0.26a	4.59±0.84a	11.8±1.33a
Red Amaranth	High	13.5±1.87b	1.86±0.12b	38.5±0.92b	14.6±1.78b	33.4±0.17b
	Medium	10.1±0.35b	1.84±0.09b	35.7±3.62b	11.3±1.22b	30.1±1.05b
	Low	4.95±0.17a	0.70±0.03a	13.3±0.62a	4.17±1.50a	12.0±1.46a
Amaranth	High	18.7±1.20c	2.01±0.19b	41.0±2.40c	15.6±2.19b	31.9±1.91b
	Medium	10.8±0.59b	1.71±0.16b	30.7±1.79b	14.9±1.31b	31.3±1.06b
	Low	5.07±0.24a	0.78±0.17a	15.2±2.05a	4.04±0.63a	12.3±0.82a
Safe Limit (µg g^{-1}) [b]		100	3	50	50	100

Mean values in the same column followed by the same letters are not significantly different ($P < 0.01$).

[b][Ewers U (1991).

Relationship between soil and plant metal concentrations

The correlation between the heavy metal contents in soils and their corresponding contents in vegetables indicated positive correlation, the *r* values ranged from 0.599 to 0.999 (Table 6). The higher correlation between soil and plant corresponded to Cr in amaranth. On the other hand, comparatively lower correlation between soil-plant corresponded to Cr in spinach. However, the degree of relationship between soil and plant in respect of three locations was irregular.

Bioconcentration factor

Bioconcentration factor (BCF) of different heavy metals from soil to vegetables are one of the key components of human exposure to metals through the food chain (Table 7). It is calculated as the ratio between the concentration of heavy metals in the vegetables and that in the corresponding soil (all based on dry weight) for each vegetable separately (Liu *et al.*, 2006). The TF values were below 1, and more TF values were obtained for Ni whereas it was less for Co as compared to Pb, Cd and Cr. The trend of TF for heavy metals in different leafy vegetables studied were in the order of Ni>Cd>Pb>Cr>Co. The TF values ranges were: Pb 0.153 – 0.500, Cd 0.383 – 0.675, Ni 0.340 – 0.878, Co 0.110 – 0.309, and Cr 0.181 – 0.215. These values were higher than those observed (Ahmad and Goni, 2009). The degree of TF showed irregular pattern in high-level polluted, medium-level polluted and low-level polluted areas, however the trend of TF for location were polluted (either high-level or medium-level)>low-level polluted.

Table 6. Correlations between heavy metal content§ in soils and in vegetables (§=µg g^{-1} of dry wt., *=$p < 0.05$, **=$p < 0.01$, ns=not significant)

Vegetable	Level of pollution in the growing area	Pb	Cd	Ni	Co	Cr
Spinach	High	0.8538ns	0.8350ns	0.9965**	0.9934*	9690*
	Medium	0.9944**	0.9087ns	0.9402ns	0.9794*	8039ns
	Low	0.6547ns	0.9920**	0.8232ns	0.8846ns	8975ns
Red Amaranth	High	0.9707*	0.9824*	0.9440ns	0.9665*	0.9381ns
	Medium	0.8496ns	0.9839*	0.9902**	0.8181ns	0.9709*
	Low	0.9041ns	0.6698ns	0.9868*	0.9687*	0.9992**
Amaranth	High	0.9983**	0.9278ns	0.9186ns	0.6833ns	0.9813*
	Medium	0.9498ns	0.9877*	0.9864*	0.9933**	0.9931**
	Low	0.8992ns	0.9317ns	0.5989ns	0.9331ns	0.9813*

Table 7. Bioconcentration factor (±, standard deviation) of Pb, Cd, Ni, Co and Cr for the soils to vegetables species

Vegetable	Level of pollution in the growing area	Pb	Cd	Ni	Co	Cr
Spinach	High	0.290±0.014	0.563±0.041	0.833±0.002	0.112±0.017	0.189±0.014
	Medium	0.337±0.046	0.383±0.043	0.878±0.072	0.124±0.020	0.190±0.013
	Low	0.200±0.033	0.675±0.033	0.363±0.032	0.110±0.032	0.215±0.087
Red Amaranth	High	0.345±0.054	0.466±0.005	0.806±0.053	0.156±0.007	0.200±0.006
	Medium	0.441±0.044	0.439±0.036	0.788±0.083	0.170±0.016	0.214±0.016
	Low	0.153±0.007	0.415±0.025	0.373±0.043	0.227±0.124	0.201±0.019
Amaranth	High	0.307±0.027	0.500±0.087	0.825±0.056	0.156±0.017	0.209±0.020
	Medium	0.500±0.049	0.412±0.016	0.742±0.032	0.135±0.003	0.203±0.007
	Low	0.213±0.020	0.575±0.067	0.340±0.073	0.309±0.075	0.181±0.035

The river Turag is highly polluted by industrial effluents, sewage sludge, municipal waste water and urban pollution. Vegetable lands irrigated with this water are contaminated, because more industrial effluents from various industrial sources enter into river. Additionally, little or no treatment is applied to the industrial discharges to detoxify the wastewater draining into rivers. However, the higher concentrations of Pb, Cd, Ni Co and Cr in the polluted (either high-level or medium-level) area indicates that industrial discharges add heavy metals into the soil.

Conclusions

Industrial effluents and urban pollution associated with sewage sludge, municipal waste water increased the levels of Pb, Cd, Ni, Co and Cr intake of the vegetables and soils. To avoid entrance of metals into the food chain, industrial discharges should not be drained into rivers and farmlands without prior treatment. Considering human health hazard, it is recommended that these types of plants should not be cultivated in farms and fields irrigated by industrial waste water or water contaminated by heavy metals. These findings suggest further work by more controlled experiment, which should take into consideration of variations in uptake between different plant species, cropping history, fertilization and the levels of metals present in the soils and atmosphere.

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