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ESTIMATION OF BIOACCUMULATION, TRANSLOCATION AND DISTRIBUTION PATTERNS OF CADMIUM AND LEAD IN COMMONLY CONSUMED GREEN LEAFY VEGETABLES IN COLOMBO DISTRICT, SRI LANKA

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Abstract

Green Leafy Vegetables (GLV) are a key component of the Sri Lankan diet. However, GLV are identified as good heavy metal accumulators, which in turns causes potential health risks for consumers through food chain contaminations. The present study aimed to investigate the bioaccumulation, translocation and distribution patterns of cadmium (Cd) and lead (Pb) in five key Sri Lankan GLV ["Kankun" (Ipomoea aquatica), "Mukunuwenna (Alternanthera sessilis), *"Thampala" (Amaranthus viridis), "Nivithi" (Basella alba) and "Kohila" (Lasia spinosa)] grown in Colombo District, Sri Lanka. The levels of Cd and Pb in different plant parts (roots, stems and leaves) and the soil underneath were determined using the inductively coupled plasma optical emission spectroscopy (ICP-OES) and the bioaccumulation and translocation factors of heavy metals from soil to different plants parts (roots, stems, leaves), were calculated to identify the hyper accumulative species.*

Irrespective of the species and the location, GLV showed the distribution pattern for Cd and Pb as: roots>stems>leaves. In all the analyzed GLV, roots have accumulated significantly higher concentrations (at P<0.05) of Cd and Pb compared with stems and leaves. Among the two heavy metals, Cd bioavailability was higher compared with Pb. Amaranthus viridis had the lowest capacity for metal enrichment. In contrast, Lasia spinosa showed the highest bioaccumulation factors for both elements and the accumulation factor obtained for Cd (1.04) was >1. Thus, Lasia spinosa has the potential to use in phytoextraction purposes in future, though it is not safe to consume as a day to day food item.

Keywords

Green Leafy Vegetables, Distribution, Bioaccumulation, Heavy metals, Cadmium, Lead

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1. Introduction

Heavy metals can build up in soil environments and can transfer across the food chains, causing negative health impacts on human and animals. A number of studies have shown heavy metals as imperative environmental contaminants (Abbas et al. 2010; Sobukola, Adeniran, Odedairo & Kajihausa, 2010; Kaur & Goyal, 2011; Asdeo & Loonker, 2011; Hu et al. 2012; Kananke, Wansapala & Gunaratne, 2014, 2015, 2016; Haneef & Akintug, 2016 and Ngo & Tran, 2017). Through the atmospheric deposition or road runoff, metals are absorbed into the plant tissues of green leafy vegetables (GLV) which are cultivated and marketed along roadsides. The distribution of heavy metals in different plant parts (roots/stems/leaves) can be varying since translocation of heavy metals in plant body depends upon availability and concentration of heavy metals in addition to particular plant species and its population. Therefore, it might be beneficial for the consumers to know in which parts of GLV the metals are mostly accumulated.

The heavy metal contamination of agro-soils is a major apprehension, since plants can uptake metals from the contaminated soil, which in turns transfer into the food chains through consumption and ultimately resulting adverse health effects on humans and animals. According to the Environmental Protection Agency (EPA), Pb and Cd are the most concerned elements due to their high toxicity and capability to accumulate in plants and animals.

Leafy vegetables have high potential to accumulate heavy metals in their tissues (Otitoju et al., 2012; Surukite et al., 2013; Gupta, Nayek, Saha & Satpati, 2013; Chang et al., 2014; Kananke et al., 2014, 2015, 2016). Usually, the plants can uptake high quantities of heavy metals when they are grown in highly contaminated soils. Among heavy metals, Zn and Cd have more mobility and readily absorbed by plants. In contrast, Pb and Cu are less mobile as they are strongly adsorbed onto the soil particles, thus reducing their availability to uptake by plants (WHO 1998). Heavy metal uptake mechanisms by plants have been extensively studied by researchers during previous decades. As reported by Sinha et al. (2006), the plants can proceed as either “heavy metal accumulators” or “heavy metal excluders”. Accumulators are capable of concentrating the metal pollutants in aerial plant parts, which in turns biotransformed or biodegraded into static forms in plant tissues. In contrast, plant excluders hamper the uptake of metal contaminants into their biomass. Plant roots, have the ability to take up metals from soil at very low levels, even from relatively insoluble precipitates, with the help of redox reactions, plant induced pH adjustments and plant-produced chelating agents. Plants have also developed particular processes to translocate and store theses elements (Sinha et al., 2006). Frequently, the amino acids and organic acids have the potential to act as metal chelators, which in turns facilitate the movement of metal ions via the xylem (Lesage et al., 2005).

Since, there are no systematic investigations on heavy metal bioaccumulation in GLV grown in Sri Lanka, the study was aimed at determining the concentrations of two toxic elements (cadmium and lead) in soil and to investigate the bioavailability of those metals from soil to different plant parts of five popular types of GLV cultivated in fields in Colombo District, Sri Lanka.

2. Methodology

2.1 Study Site and Sample Collection

The GLV [Kangkung" (Ipomea aquatica), "Mukunuwenna" (Alternanthera sessilis), "Thampala" (Amaranthus viridis), “Spinach" (Basella alba) and “Kohila” (Lasia spinosa)] samples were randomly collected at different points from selected production sites (Piliyandala, Wellampitiya, Kolonnawa, Kahathuduwa) in Colombo District, Sri Lanka (Figure 1). For each green leafy vegetable sampled, surrounding soil of a depth 0-15 cm was also collected. The composite samples of soil and GLV were brought to the laboratory using clear, unused, polyethylene bags. The GLV samples collected were washed with running tap water for several times followed by distilled water to remove the soil and other adhered contaminants.

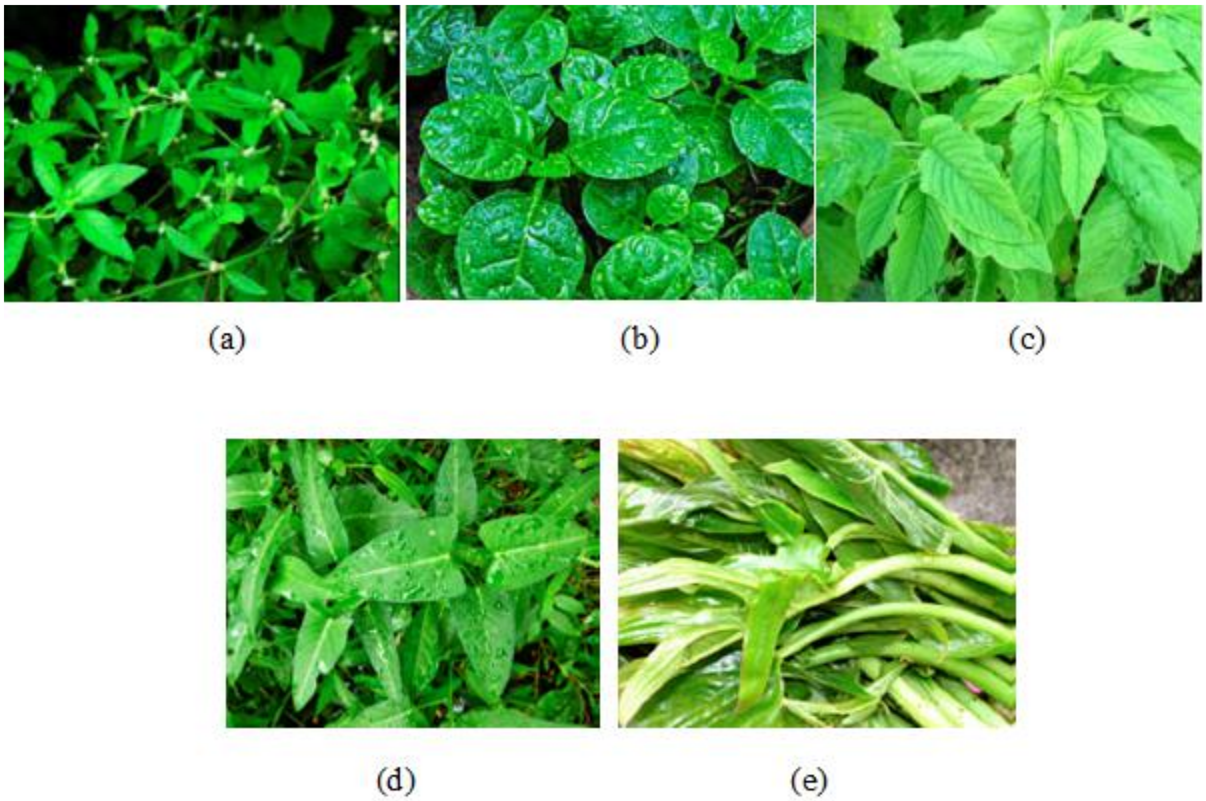

Figure 1: *Types of green leafy vegetables collected from the fields*
(a) Mukunuwenna (b) Nivithi (c) Thampala (d) Kankun (e) Kohila leaves

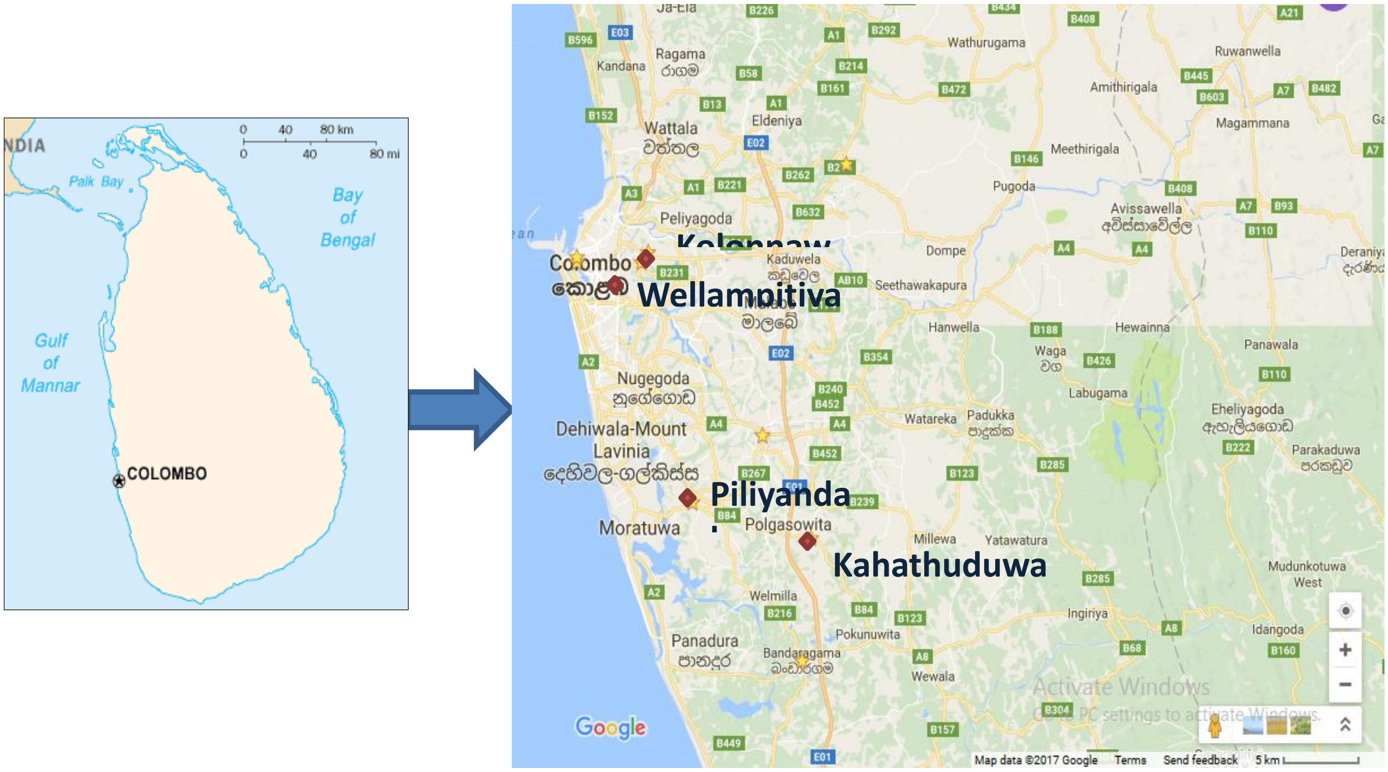

Figure 2: *Production sites selected from Colombo District, Sri Lanka*

2.2 Sample Preparation and Analysis

The GLV were cut into leaves, stems and roots separately, using a stainless steel knife. Then the test portions were dried to constant weights in an oven heated at 105°C, cooled to room temperature and mechanically ground to fine powders using a pestle and mortar. Then the ground samples were subjected to dry ashing procedure prior to elemental analysis by the ICP-OES based on the protocol AOAC 999.11 (Official Methods of Analysis, 2002).

The soil samples were air-dried, then mechanically ground using a stainless steel soil grinder and sieved to get < 2 mm fraction. Sub-sample (30g) was obtained from the bulk (< 2 mm fraction) and again ground with a laboratory mortar and pestle to acquire < 200 µm fraction. Next, soil samples were acid digested and Cd and Pb contents were estimated as described in the AOAC protocol 965.09 (Official Methods of Analysis, 2002).

Since the total heavy metal contents of soils is a poor indicator of metal availability for plant uptake, accumulation factor was calculated based on the metal availability and its uptake by a particular plant (Brooks, Lee, Reeves & Jaffre, 1977).

2.3 Determination of Soil-to-Plant Transfer Factor of Heavy Metals

The bioavailability of a particular metal to a plant can be assessed by calculating the bioaccumulation factor (BAF) values, as defined by the following equation (Wang et al., 2006).

$$BAF = \frac{C_{plant}}{C_{soil}} \quad (1)$$

Where, C_{plant} = Mean Concentration (mg kg^{-1}) of an element in the plant material (dry weight basis) and C_{soil} = Mean concentration (mg kg^{-1}) of the same element in the soil (dry weight basis) where the GLV was grown.

The higher values for transfer factors indicate more mobility or availability of a particular metal to the plants. Therefore, high BAF values may put forth the potential health risks to the consumers (Wang et al., 2006).

2.4 Determination of Mobility Index (MI) of Heavy Metals in Each Plant Level of Green Leafy Vegetables

Mobility Index (MI) or Translocation Factor (TF) was calculated to measure the relative mobility or translocation of trace elements from soils to leaves through roots and stems of GLV. To determine the translocation of heavy metals into different plant parts, the whole experiment was divided into three categories: Level 1 (Soil to Roots), Level 2 (Roots to Stems) and Level 3 (Stems to Leaves).

$$\text{Mobility Index (MI)} = \frac{\text{Concentration of metal (mg kg}^{-1}\text{) in the receiving level}}{\text{Concentration of metal (mg kg}^{-1}\text{) in the source level}} \quad (2)$$

2.5 Quality Assurance

Relevant quality assurance practices and precautions were taken to assure the reliability of the test results. All the experimental chemicals (analytical grade) were purchased from the Sigma Aldrich (Pvt.) Ltd., USA. Using the stock solutions, standards were prepared for each metal to calibrate the spectrophotometer. Properly cleaned glassware and distilled water were used throughout the research. Analysis of standard reference materials, spiking and reagent blank determinations were done to correct the ICP-OES readings.

2.6 Statistical Analysis

Descriptive statistics (mean, standard deviation and range) and the statistical significance of collected data were analyzed by ANOVA and the mean separations of the data were conducted by the Tukeys Range Test, using the Minitab 17.0 computer package.

3. Results and Discussion

3.1 Heavy Metal Distribution Pattern in GLV

The distribution patterns of Cd and Pb in different GLV parts are shown in Table 3.1. According to analyzed results, GLV species showed noticeable variations in uptake and distribution of metals to the different plant parts. The reasons might be the diverse morphological characteristics, location of the edible plant parts and selective uptake of metal by each crop.

Table 1: *Mean Cd and Pb concentrations (mg kg^{-1}) in different plant parts of GLV*

GLV	n	Plant part	Cd	Pb
Mukunuwenna	8	Roots	0.98^{a}	8.32^{a}
		Stems	0.51^{ab}	4.94^{a}
		Leaves	0.27^{b}	5.30^{a}
Nivithi	8	Roots	0.67^{a}	8.00^{a}
		Stems	0.29^{b}	3.70^{a}
		Leaves	0.37^{ab}	4.18^{a}
Thampala	8	Roots	0.57^{a}	4.06^{a}
		Stems	0.31^{a}	1.93^{a}
		Leaves	0.22^{a}	1.50^{a}
Kankun	8	Roots	1.05^{a}	7.76^{a}
		Stems	0.65^{a}	5.73^{a}
		Leaves	0.57^{a}	3.93^{a}
Kohila	8	Roots	1.63^{a}	15.82^{a}
		Stems	1.08^{ab}	7.47^{ab}
		Leaves	0.78^{b}	3.48^{b}
All GLV	40	Roots	0.98^{a}	8.79^{a}
		Stems	0.57^{b}	4.75^{b}
		Leaves	0.44^{b}	3.68^{b}

Values in the same column with a same superscript letter are not significantly different from each other at ($P < 0.05$), for each GLV. n=number of samples

The magnitude of heavy metal contaminations (mg kg^{-1}) found in the roots of GLV were as for Cd: Kohila (1.63) > Kankun (1.05) > Mukunuwenna (0.98) > Nivithi (0.67) > Thampala (0.57); and for Pb: Kohila (15.82) > Mukunuwenna (8.32) > Nivithi (8.00) > Kankun (7.76) > Thampala (4.06). Therefore Kohila roots have the highest capability of accumulating both metals from the soil, while the Thampala roots have the least capability. When consider the heavy metal accumulation in stems of different GLV the highest amounts (mg kg^{-1}) of Cd (1.08) and Pb (7.47) were found in Kohila stems. In contrast the least amounts (mg kg^{-1}) Pb (1.93) were found in Thampala stems, while the least Cd (0.29) were found in Nivithi stems. The distribution of heavy metals in the leaves of different GLV species also showed that Kohila leaves accumulated the highest Cd (0.78 mg kg^{-1}), while Mukunuwenna leaves showed the highest Pb concentration (5.3 mg kg^{-1}). Conversely Thampala leaves have reported the least Cd (0.22 mg kg^{-1}) and Pb (1.50 mg kg^{-1}) levels (Table 3.1).

In Mukunuwenna, the Cd in roots was significantly higher than in leaves. Nivithi, roots reported significantly higher (at $p<0.05$) Cd level than stems or/and leaves. In Thampala and Kankun none of the analyzed heavy metals reported significant differences between roots, stems and leaves at $P<0.05$. However in Kohila, significant differences ($p<0.05$) were observed between roots and leaves for Cd and Pb (Table 1). In all the analyzed GLV the highest amounts of trace elements were accumulated in roots. Because, roots are in direct contact with the toxic metals present in the soil and consequently absorb and mobilize these heavy metals in to other plant parts. The presence of high levels of toxic metals in roots and stems might be an advantage for the consumers, since the roots and matured stems are usually discarded during processing and cooking of GLV. Irrespective of the species and the location, all the collected GLV showed the distribution pattern for the five heavy metals as: roots>stems>leaves.

During the past decades, many similar research studies were conducted to investigate the heavy metal distribution patterns in various vegetable crops in different parts of the world. Onyedika and Okon (2014) studied the bioaccumulation and mobility of Cd, Pb and Zn in Green Spinach grown on dumpsite soils in Gombe, Nigeria. The results showed that Green Spinach accumulated Cd, Pb and Zn at varying concentrations, where the roots showed highest metal concentration while the stem showed least. In this study also the highest metal contents were found in roots of the GLV, however the least metal concentrations were mostly found in the leaves, with few exceptions. The authors have explained high metal contents found in roots probably due to the fact, that roots are the origin which is in direct contact with the toxic elements in soil. Further they have found high concentrations of Cd in the leaves of green spinach and suggest that may be due to atmospheric deposition of metal (from anthropogenic activities conducted closer to the sites) which in turns absorbed by the foliage and translocated through the plants tissues.

Satpathy& Reddy (2013) analyzed metal concentrations in roots, stems and leaves of Indian mustard (*Brassica juncea L.*) grown in Puducherry, India and found the ranking order of heavy metals levels in roots: Pb > Zn > Cu > Cd > Mn, in stems: Mn > Pb > Zn > Cd > Cu and in leaves: Mn > Pb > Cd > Zn > Cu. Further the magnitude of order of heavy metal accumulation in different plant parts were reported as root>stem>leaves for Pb, Cd, Zn and Cu. It showed the affinity of roots to accumulate considerable amount of elements from soil and transfer a small amount to above ground vegetative shoots. The results of the present study also confirmed the findings of Jarvis, Jones & Hooper (1976), who observed that heavy metal accumulation was more in roots than the aerial parts.

Increased levels of heavy metals detected in various parts of crops, as reported in the current study also verify the previous findings of other researchers (Allinson & Dzialo 1981; Barman et al. 2000; Kumar, Soni, Kumar & Bhatt, 2009; Singh, Zacharias, Kalpana & Mishra, 2012). As similar to the present results, heterogeneous accumulation and distribution of trace metals in different plant species were also stated by Barman et al. (2000), Singh & Aggarwal (2006) and Singh et al. (2012) and the reason behind this attributed to their different morphological characteristics, selective uptake of heavy metals by plants and the position and distance between the edible plant parts and the roots (Mohamed & Rashed 2003). Less heavy metal accumulations were found in fruit type vegetables than in leafy vegetables and also low metal contents were observed in reproductive organs than in vegetative shoots by several authors (Allinson & Dzialo 1981; Singh & Aggarwal 2006; Singh et al. 2012). Such variations observed in metal accumulation and their distribution between different plant parts could be useful in selecting green leafy vegetable species appropriate for planting in metal polluted lands to decrease the transfer of toxic heavy metals across the food chains.

3.2 Bioaccumulation and Translocation Factors of Heavy Metals in GLV

Bioaccumulation factor (BAF) is an important indicator used in the fields of environmental toxicology and risk assessment (Badr, Fawzy & AlQahtani, 2012) in determination of the degree of intake and storage of toxic substances in animals and plants (Connell, 1997). In plant crops, the BAF defines as the ratio of plant metal concentration to the corresponding soil metal concentration [Metal (plant)/ Metal (soil) or (substrate)]. This ratio supposed to be greater than one (>1) to include a particular plant in the hyperaccumulator category (Badr et al., 2012). Several authors (McGrath & Zhao, 2003; Sun, Zhou & Diao, 2008) have explained the bioaccumulation factor as an indicator for classification of hyper-accumulator species.

Apart from that, several researchers (Baker, 1981; Srivastava, Ma & Santos, 2006; Usman & Mohamed, 2009) have mentioned that the hyper accumulator potential of plants can be characterized by another factor called "Translocation Factor (TF) or Mobility Index (MI)", which is referred to as the ratio between the metal concentration in the aerial tissues to the roots tissues [Metal (shoot)/ Metal (root)]. Mobility Index can be used to identify the bio-mobility and transportation of metals across different levels: Level 1 (Soil-to-Roots), Level 2 (Roots-to-Stems) and Level 3 (Stems-to-Leaves) in vegetable crops, which in turn become useful to comprehend the transport mechanisms of heavy metals in different plant components (roots, stems and leaves). The crops with the translocation factors greater than one (TF>1) are classified as hyper-accumulators for metal translocation from roots to the shoots of plants (Ma et al., 2001). The hyper-accumulative plants have the capability of accumulating unusually high levels of metals, which attributed to the genetic potential of those plants to clean up the contaminated soil. In contrast non-hyper accumulator plants generally have more metal levels in the roots than in the shoots (Al-Qahtani, 2012).

Accumulation and distribution of trace elements in the plants rely upon the plant species, genetic factors and other morphological characteristics of the plants, metal concentrations found in the surrounding environment (soil, water and air), the metal species and their bioavailiability, soil characteristics (pH, organic matter, cation exchange capacity etc.), vegetation period, climacteric conditions, and multiple other factors. The continuous uptake and mobilization of metals inside plants can increase the levels of metals in plant tissues than that of the soil which has relatively low metal concentrations (Kachenko & Singh, 2004). Such results are attributed to the root uptake mechanisms, as well as the foliar absorption potential of atmospheric metal deposits on plant surfaces. Further, the previous research evidences have suggested that the green leafy vegetables are specifically having high capability of up taking trace elements from the soil ecosystems (Ali, Naseer & Sajeed, 2013).

Table 2: *Mean Cd and Pb concentrations (mg kg^{-1}) in soils from different areas*

Site	Number of samples	Cd	Pb
Piliyandala	5	1.18	17.00
Kolonnawa	5	1.79	56.75
Wellampitiya	5	1.58	37.50
Kahathuduwa	5	0.71	14.40
WHO/FAO safe limit		3	100

Table 2 presents the average Cd and Pb concentrations detected in the soils of four GLV cultivation areas selected for the study. In comparison to Piliyandala and Kahathuduwa areas, Kolonnawa and Wellampitiya areas showed higher metal contaminations. Further the metal contents in all soil samples complied with WHO/FAO safe limits. Generally the soils collected showed higher metal concentrations than the GLV collected from the respective sites.

The figure 2 illustrates the average heavy metal bioaccumulation factors in different GLV collected from all the four cultivation areas. Accordingly, Kohila showed the highest accumulation factors for both elements (significant at $p<0.05$) and the accumulation factor obtained for Cd (1.04) was >1. Thus, Kohila can be used for phytoextraction of Cd, as well as for the phytoremediation purposes to clean the metal contaminated environments. The magnitude of the order of Cd and Pb accumulation factors for different GLV shows that GLV have the highest accumulation factor for Cd, compared with Pb (except in Nivithi).

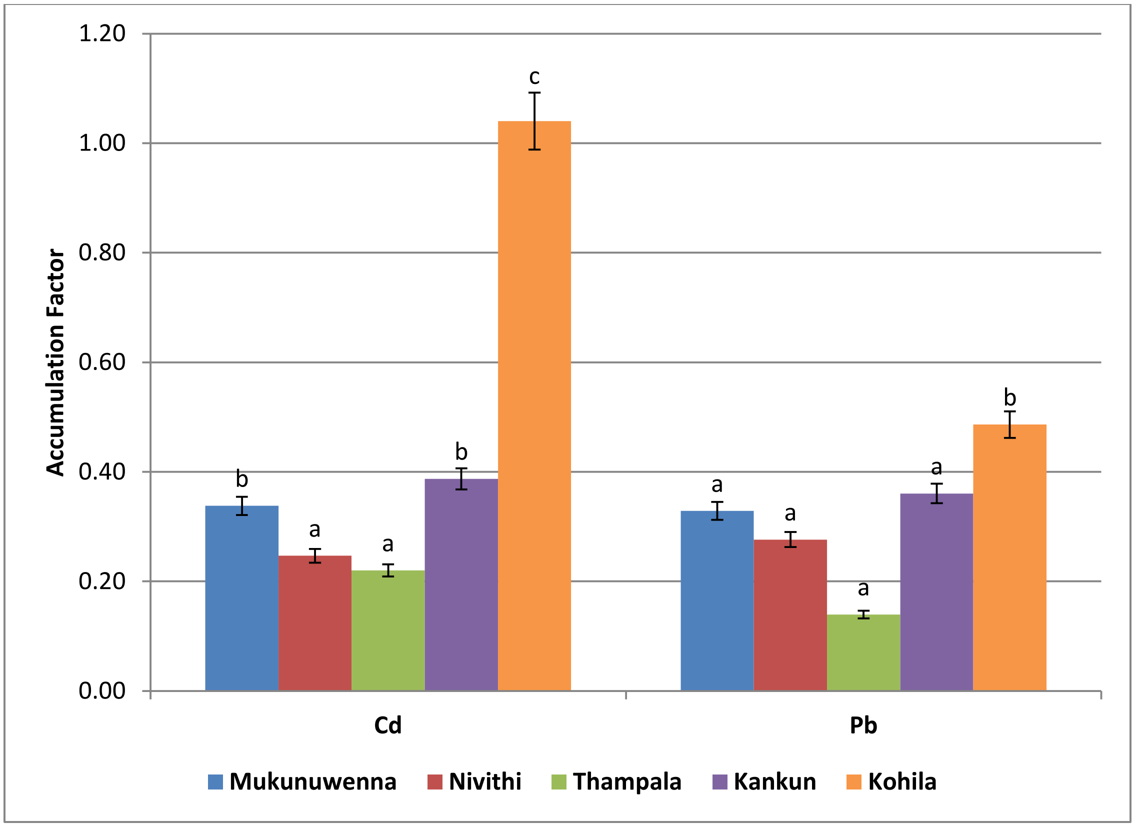

Figure 3: *Cd and Pb accumulation factors in different GLV.*
Letters with same characters are not significantly different at P<0.05 for each metal.

Gupta et al. (2008) observed that the mean BAF of heavy metals (Cd, Cu, Mn, and Zn) showed < 1 in tomato plants, which suggested less uptake of heavy metals from soil. In the present study also the GLV reported BAF<1 for all the analyzed heavy metals, except for Cd (1.04) found in Kohila. Radulescu et al. (2013) investigated the heavy metal accumulation and translocation in different parts of *Brassica oleracea L.* in Romania and the results revealed that the plant was a poor accumulator of Fe, Cd, Ni, Cu, and Pb (BAF <1), and a good accumulator of Mn (BAF >1).

3.3 Mobility index (MI) or Translocation Factor (TF) of Heavy Metals in GLV

MI or TF is an essential indicator that allows the assessment of mobility or translocation of heavy metals in plants. The mobility indices of Cd and Pb in the sampled GLV were presented in Table 3.

Table 3: *Translocation Factors of Cd and Pb in GLV from different cultivation sites*

Site	GLV	Translocation Factors					
		Cd			*Pb*		
		(S-R)	*(R-S)*	*(S-L)*	*(S-R)*	*(R-S)*	*(S-L)*
1	Mukunuwenna	0.56	0.49	0.38	0.54	0.89	0.92
	Nivithi	0.53	0.45	1.72	1.07	0.35	1.41
	Thampala	0.45	0.27	1.32	0.29	0.28	1.38
	Kankun	0.87	0.34	0.42	0.63	1.11	0.52
	Kohila	1.07	0.83	0.78	1.39	0.56	0.38
2	Mukunuwenna	0.88	0.59	0.40	0.16	0.51	1.04
	Nivithi	0.49	0.33	1.30	0.08	0.49	1.52
	Thampala	0.53	0.42	0.81	0.07	0.44	1.42
	Kankun	0.68	0.63	0.76	0.08	0.59	0.62
	Kohila	1.27	0.57	0.68	0.26	0.52	0.44
3	Mukunuwenna	0.73	0.49	0.87	0.46	0.47	1.35
	Nivithi	0.45	0.76	1.04	0.29	0.71	0.77
	Thampala	0.27	1.15	0.30	0.27	0.69	0.45
	Kankun	0.83	0.90	0.99	0.54	0.91	0.86
	Kohila	1.40	0.71	0.68	0.76	0.42	0.51
4	Mukunuwenna	0.89	0.33	0.59	0.03	0.62	1.71
	Nivithi	0.69	0.35	1.44	0.02	0.73	1.12
	Thampala	0.45	0.54	1.09	0.01	0.70	1.15
	Kankun	1.01	0.46	0.99	0.02	0.51	1.75
	Kohila	1.30	0.56	0.86	0.03	0.47	1.27

Site 1=Piliyandala, Site 2=Kolonnawa, Site 3=Wellampitiya, Site 4=Kahathuduwa; S-R=Soil to Root, R-S=Root to Stem, S-L=Stem to Leaves

TF greater than 1 indicates high mobility of such heavy metal from the source level to the receiving level (plant parts). From the analyzed GLV, Kohila showed TF>1 at the Level 1 (soil-to-root) for Cd and Pb in different areas; Piliyandala: Cd (1.07), Pb (1.39), Kolonnawa: Cd (1.27); Wellampitiya: Cd (1.40); Kahathuduwa: Cd (1.30). Therefore Kohila have high translocation ability of Cd from the soil to the roots of the plants. Generally, in all the four cultivation areas least mobility of Cd and Pb at the Level 1 (soil-to-root) was reported in Thampala, only with few exceptions.

The Figure 3 (a) shows the average heavy metals TF at the level 1 (soil-to-roots) in different GLV. Significant differences ($P<0.05$) were observed in the TF for both heavy metals for the analyzed GLV. Kohila have reported significantly higher levels of TF for Cd (1.26) and Pb (0.61) compared with Thampala which was detected for the least amounts of TF for Cd (0.42) and Pb (0.15).

As shown in Table 3.3, Level 2 TF (root-to-stem) of Cd and Pb shows great variation between the GLV. In Piliyandala area, Pb (1.11) in Kankun shows TF>1. In addition Wellampitiya area showed higher TF (>1) for Cd (1.15) in Thampala. As illustrated in Figure 3 (b), the highest average TF (root-to-stem) of Pb was detected for Kankun, while the highest Cd found in Kohila. The least mobility (from roots to stem) of Cd was found in Nivithi and Pb was found in Kohila. Compared with the TF at the other two levels, translocation of Cd and Pb at Level 3 (stem to leaves) of GLV showed increased values in different cultivation areas (Table 3.3). Nivithi showed higher TF (>1) for Cd and Pb in Piliyandala, Kolonnawa, Kahathuduwa and Wellampitiya areas. Thampala also had TF>1 for Cd and Pb in Piliyandala and Kahathuduwa areas. For Mukunuwenna also Pb in Kolonnawa, Kahathuduwa and Wellampitiya areas showed higher mobility from stem to the leaves of GLV. The Figure 3 (c) shows the average translocation factors (stem-to-leaves) of different GLV for each metal. For Pb, highest TF were identified in Mukunuwenna and for Cd highest TF reported by Nivithi. However for each metal, the TF were not significant (at $P<0.05$) between the analyzed GLV. Thus the data show that the heavy metal contents in the GLV tissues differed among species at the cultivation sites indicating their different capacities for metal uptake. Further, the TF>1 at level 3 indicates the possibility of foliar metal absorption due to atmospheric deposition of heavy metals on GLV surfaces, in addition to the root uptake mechanism.

(a)
(b)
(c)

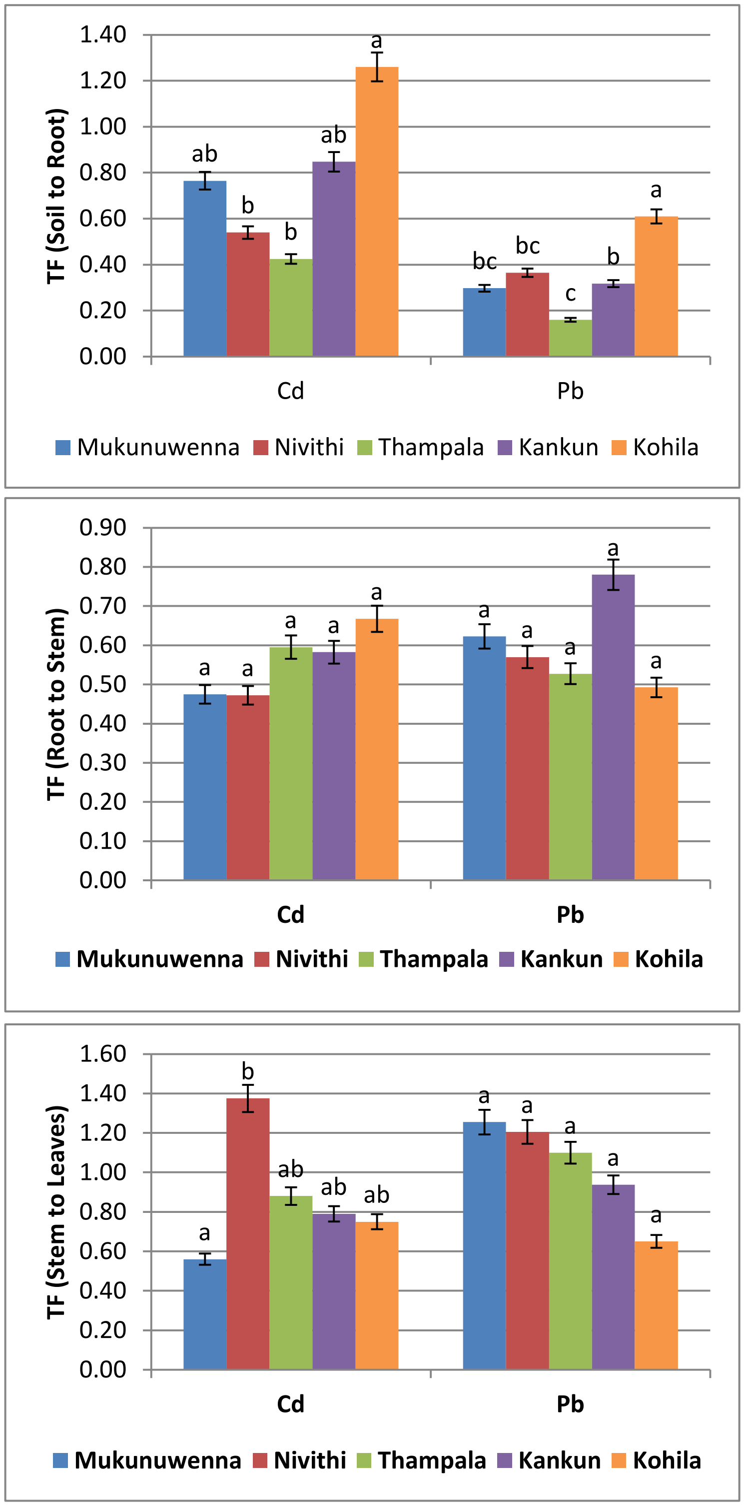

Figure 4: *Translocation factors of Cd and Pb from (a) Soil to Root, (b) Root to stem and (c) Stem to Leaves in different GLV*
Letters with same characters are not significantly different at P<0.05 for each metal.

Eze & Ekanem, (2014) have found the mean mobility index of heavy metals for Green Spinach grown in dumpsites of Nigeria, was in the order of Cd>Pb>Zn. The comparatively high mobility of Cd in Green Spinach was attributed to the fact that Cd can be easily absorbed by the plant roots. The study has also shown that Cd is readily transferred in to the other plant parts after absorption. The present study also found high TF for Cd in the analyzed GLV.

According to the research findings of Satpathy & Reddy (2013), translocation of heavy metals in Indian mustard (*Brassica juncea L.*) at Level 1(soil to root) showed high mobility rate for Pb, Cd, Zn and Cu than at Level 2 (root to stem) and Level 3 (stem to leaf). The analysis also revealed that the translocation of elements in different levels barely followed any specific pattern; and mostly varied with the metal species.

Gupta et al. (2008) described that the translocations of heavy metals from soil to roots were in the order of Fe (0.96) > Cd (0.77) > Cu (0.52) >Zn (0.37) > Mn (0.28) > Cr (0.25) where the TF < 1. This suggests that the transportation of metals from soil to the plant may controlled by certain soil factors (pH, organic matter, CEC etc.) and specific intrinsic resistive mechanisms exist within the plant body (eg. Phytochelation).

4. Conclusion

The studied GLV species showed noticeable variations in heavy metal uptake and distribution to different plant parts, owing to their diverse morphological characteristics, position of edible parts on GLV and selective uptake of metals by each plant. Interestingly, irrespective of the species and the location, all the collected GLV showed a similar distribution pattern for both Cd and Pb as: roots>stems>leaves. The presence of high contents of heavy metals in roots and stems might be an advantage for the consumers, since the roots and matured stems are usually discarded during processing and cooking of GLV. According to the average heavy metal bioaccumulation factors estimated in different GLV, Kohila showed the highest accumulation factors for both elements and the bioaccumulation factors obtained for Cd were >1. Thus, Kohila can be effectively used for phytoextraction, though it is not safe to consume as a day to day food item.

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