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Pb and Cr Contaminations of Irrigation Water, Soils and Green Leafy Vegetables Collected from Different Areas of Colombo District, Sri Lanka

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Abstract: Excessive buildup of heavy metals in agricultural soils may contribute to environmental contamination, as well as increased heavy metal uptake by vegetable crops, which ultimately leads to adverse health consequences in mankind. A study was conducted to evaluate the Lead (Pb) and Chromium (Cr) concentrations in irrigation water, soils and green leafy vegetables ["Mukunuwenna" (*Alternanthera sessilis*), "Thampala" (*Amaranthus viridis*), "Nivithi" (*Basella alba*), "Kohila Leaves" (*Lasia spinosa*) and "Kankun" (*Ipomoea aquatica*)] collected from forty randomly selected fields of Colombo District, Sri Lanka using Graphite Furnace Atomic Absorption Spectrometry. The mean concentrations (mg/kg, dry weight basis) of Pb and Cr in the soils were reported as 39.7±32.3 and 48.4±42.9, respectively. The highest level of Pb detected in irrigation water samples was 2.01 mg/L and Cr was not detected in any of the irrigation water samples analyzed. The mean levels (mg/ kg, dry weight basis) of Cr and Pb in green leafy vegetables found as 3.36±2.76, 2.96±2.16 for Mukunuwenna, 3.58±2.80, 3.14±2.32 for Thampala, 3.28±2.45, 3.11±2.33 for Nivithi, 5.02±4.09, 4.32±3.47 for Kohila and 3.47±2.88, 3.21±2.44 for Kankun, respectively. The highest accumulations of both metals were found in Kohila leaves. Significant differences were observed in Pb and Cr levels, between both production sites and green leafy vegetables analyzed at $P<0.05$. Thus the study highlights the potential risks involved with the consumption of leafy vegetables cultivated in the contaminated areas which may adversely contribute to the food quality and safety.

Key words: Contamination, green leafy vegetables, lead, chromium

INTRODUCTION

Green leafy vegetables (GLV) are an excellent source of fiber, carotenoids, folate, vitamins C and K and minerals iron and calcium along with saponins and flavonoids (Sobukola *et al.*, 2010). In addition, they act as antioxidants by removing free radicals from the body before they become harmful. Some research has found the wide range of carotenoids (lutein, zeaxanthin etc.) present in GLV can prevent the growth of certain types of breast, skin, lung and stomach cancer (American Institute for Cancer Research, 2015). Recently there is an increased trend of consumption of GLV among the urban community of Sri Lanka due to the awareness of nutritional benefits, low cost and easy accessibility associated with the product. However GLV contains both essential and toxic elements over a wide range of concentrations.

Heavy metals are imperative environmental contaminants, predominantly in areas with high anthropogenic pressure (Mahmood *et al.*, 2012; Ondo *et al.*, 2014). Presence of these metals in water, soil and air even in trace amounts can cause detrimental effects to all organisms and the heavy metal accumulation through food chains specifically can be hazardous to the human health (Sharma *et al.*, 2009). They are natural components of the earth's crust which cannot be degraded or destroyed and enter the human bodies through food, drinking water and air. As trace minerals, certain heavy metals (e.g., copper, selenium, zinc) are vital to maintain the metabolism of the human body. Nevertheless, at higher concentrations heavy metals can lead to poisoning. Some of these elements are actually necessary for humans in minute amounts (cobalt, copper, chromium, manganese, nickel) while the others are toxic, affecting, among others, the central nervous system (manganese, mercury, lead, arsenic), the kidneys or liver (mercury, lead, cadmium, copper) or skin, bones, or teeth (nickel, cadmium, copper, chromium) (Hogan, 2010).

Rapid and unorganized metropolitan activities have contributed to the elevated levels of heavy metals in the urban surroundings of developing countries like Sri

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Lanka (Jayasinghe *et al.*, 2005; Rathnayaka *et al.*, 2004; Premarathna *et al.*, 2010), India (Khillare *et al.*, 2012; Sharma *et al.*, 2009) as well as in developed countries (Kachenko and Singh, 2006). Since heavy metals are non-biodegradable and persistent environmental contaminants, they are capable of depositing on the surfaces of plant tissues which are exposed to the polluted environment. Then the crops have the ability of absorbing these harmful metals from those deposits, as well as from contaminated soils (Shuaibu *et al.*, 2013). Heavy metal contamination of vegetables may also occur due to irrigation with contaminated water (Aweng *et al.*, 2011; Singh *et al.*, 2010; Arora *et al.*, 2008). Incessant waste water irrigation to the agricultural fields have resulted ample buildup of toxic metals in soil. Emissions from the industries and vehicles may also cause heavy metal depositions on the vegetable surfaces during their production, transport and marketing (Sharma *et al.*, 2009).

It is well known that leafy vegetables accumulate more heavy metals than other food crops due to their broader leafy area. A number of studies have shown heavy metals as important contaminants of the leafy vegetables (Chang *et al.*, 2014; Ramesh and Yogananda Murthy, 2012; Gupta *et al.*, 2013; Otitoju *et al.*, 2012; Surukite *et al.*, 2013). Even though GLV constitute an important part of the Sri Lankan diet, very limited published data are available on heavy metal concentrations in the GLV from the production sites in Sri Lanka. Hence, the study was focused on determination of Pb and Cr concentrations of soil, irrigation water and five key Sri Lankan GLV ["Mukunuwenna" (*Alternanthera sessilis*), "Thampala" (*Amaranthus viridis*), "Nivithi" (*Basella alba*), "Kohila Leaves" (*Lasia spinosa*) and "Kankun" (*Ipomoea aquatica*)] grown locally in selected urban areas of Colombo District, Sri Lanka (Fig. 1).

MATERIALS AND METHODS

Preliminary survey: A reconnaissance survey was carried out in the Colombo District to identify the field sites in which the selected GLV are cultivated in large scale. A questionnaire was circulated among the farmers of the selected sites, to obtain information regarding the cultivation history of selected GLV.

Determination of heavy metal contamination in irrigation water, soil and GLV samples obtained from selected fields: Study area. Based on the results of preliminary survey, irrigation water, soil and GLV were randomly collected from forty fields located at six different areas in and around Colombo District: Piliyandala (9 sites), Bandaragama (5 sites), Kahathuduwa (5 sites), Wellampitiya (11 sites), Kolonnawa (5 sites) and Kottawa (5 sites). Sites selected at Wellampitiya and Kolonnawa areas were located closer to the Kolonnawa and Orugodawatta oil refinery and storage tanks. Further these fields are located closer to the Meethotamulla garbage dumpsite. In addition, the two areas contain lots of automobile workshops and garages as well as high population and traffic density. In Kottawa area, the selected fields were located closer to the Southern Express Highway and along the heavily traffic congested High-level Road. However the production sites selected in Piliyandala, Bandaragama and Kahathuduwa areas were suburban settings with less congested traffic and other metropolitan activities.

Water sampling and analysis: Water samples were collected in 1 L poly propylene bottles which were soaked in dilute nitric acid for overnight and rinsed with distilled water prior to use. This was done in order to avoid any possible external contamination. 1 ml of concentrated nitric acid was added to the samples to avoid microbial activity. Pb and Cr concentrations were determined by Atomic Absorption Spectroscopy (AAS) as described in APHA method (2005).

Soil sampling and analysis: Composite soil samples were collected at each site by combining small portions of soil from various locations within the plot. Soil was sampled to a depth of approximately 12 cm. At this depth, the soils sampled covered the average root system of the leafy vegetables. Unused, clear poly ethylene sampling bags were used for the collection of soil samples. Then the soil samples were analyzed by AAS to determine the Pb and Cr concentrations, according to the AOAC 965.09 method (Official methods of Analysis, 2002).

Green leafy vegetables sampling and analysis: GLV (Mukunuwenna, Thampala, Nivithi, Kohila and Kankun) samples were randomly collected in appropriately labeled polyethylene bags simultaneously with the soil samples at the same locations based on their availability at the selected site at the time.

Pre-treatment: GLV samples procured from agricultural fields were washed thoroughly with running tap water as prevalent during normal cooking process, to remove soil, dirt and other air-borne pollutants. The edible parts were chopped in to small pieces.

Drying: Test portions were dried in a drying oven, at 105°C, until obtained constant weight then cooled to ambient temperature, crushed by means of a clean pestle and mortar to obtain homogenized samples. The ground samples were then stored at room temperature in airtight sealed polyethylene bags until required for analysis by AAS after dry ashing technique as described in AOAC 975.03 (Official Methods of Analysis, 2002).

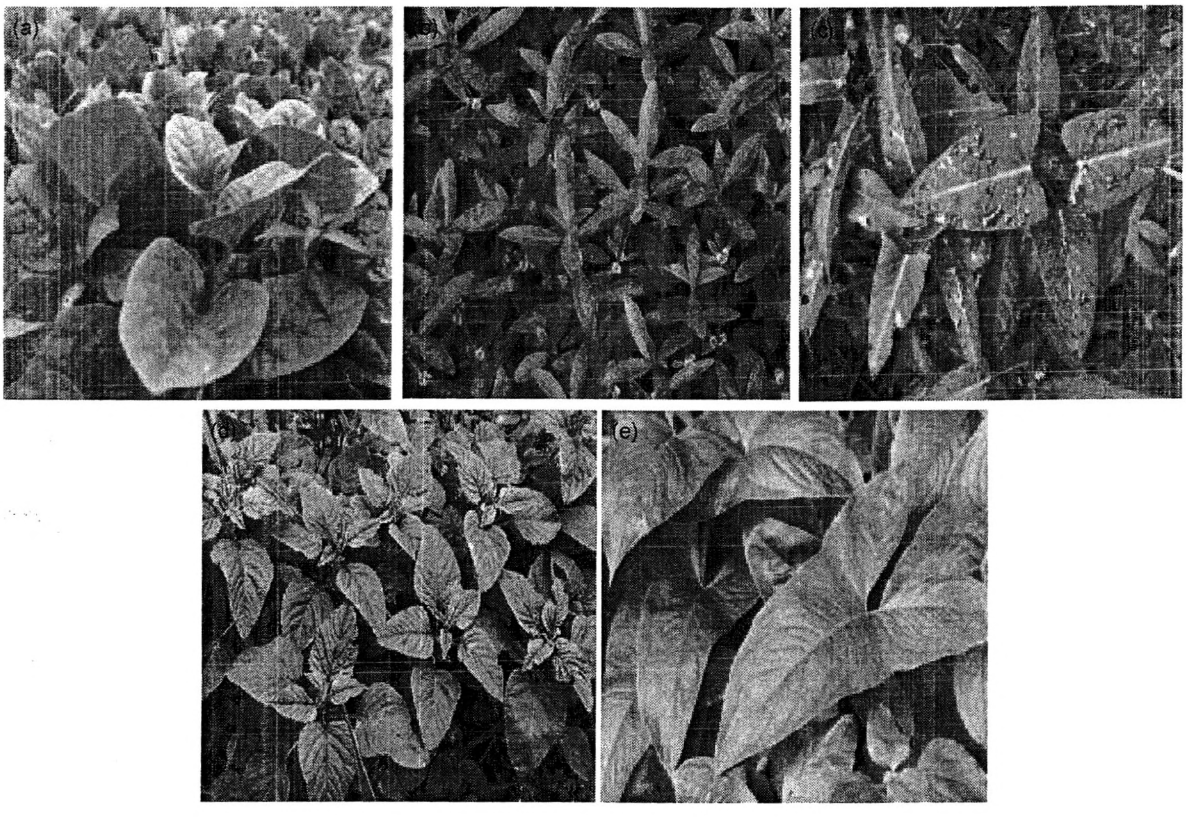

Fig. 1: Types of GLV collected from the cultivation sites (a) Nivithi (b) Mukunuwenna (c) Kankun (d) Thampala (e) Kohila

Comparison of Pb and Cr concentrations in field samples with reference samples: Reference GLV samples of Mukunuwenna, Thampala, Nivithi, Kohila and Kankun were grown in micro plots constructed in a home garden (unpolluted experimental area) without using any chemical fertilizer or pesticides. Representative samples of each GLV, a reference composite soil sample and a water sample used to irrigate the crops, were analyzed by AAS to determine the concentrations of Pb and Cr using the same methods mentioned above. Calculated values of heavy metals in soil, water and GLV samples were compared with WHO/FAO permissible limits to ensure the consumer safety (WHO/FAO, 2003; FAO/UNESCO, 1985).

Quality assurance: Appropriate quality assurance procedures and precautions were taken to ensure the reliability of the results. Samples were handled with appropriate safety measures to minimize contamination. Glass wares were cleaned properly and all the reagents used were of analytical (trace-metal) grades. Distilled water was used throughout the study. Reagent blank determinations were used to correct the instrument readings.

Statistical analysis: Descriptive statistics and statistical significance of collected data were analyzed by ANOVA using Minitab 14.0 and Excel computer packages.

RESULTS AND DISCUSSION

The study reports the Pb and Cr contamination of soil, irrigation water and GLV cultivated in Colombo District, Sri Lanka.

Lead (Pb) considered being a severe cumulative body toxin which enters into the body system through food, air and water. It cannot be detached from vegetables by washing (Kananke *et al.*, 2014). The high levels of Pb in GLV may be due to several reasons including the presence of pollutants in irrigation water, soil or vehicular emissions from heavily congested traffic areas since lead is present in fuel as an anti-knocking agent (Osundiya *et al.*, 2014). Chromium (Cr) is a trace element which is necessary for various body functions. It has the ability to stabilize blood glucose levels and help to prevent diabetes, by the efficient use of insulin. It also assists the lipid metabolism within the body and help to increase the HDL (good) cholesterol while reducing the LDL (bad) cholesterol. However the increased levels of ingestion can cause serious health effects in human body (Kananke *et al.*, 2014; Chen *et al.*, 2014; Sardar *et al.*, 2013).

Table 1: Green leafy vegetables sampled from production sites

Local name	English name	Scientific name	Edible part
Mukunuwenna	Sessile alligatorweed, Sessile joyweed	*Alternanthera sessilis*	Leaves and young stem
Nivithi	Malabar spinach	*Basella alba*	Leaves and young stem
Thampala	Chinese spinach, Green amaranth, Pig weed	*Amaranthus viridis*	Leaves and young stem
Kankun	Water morning glory	*Ipomoea aquatica*	Leaves and young stem
Kohila	Lasia	*Lasia spinosa*	Stem and young leaves

Table 2: Standard conditions of the elements analyzed by Graphite Furnace AAS

Element	Wavelength	Ash temperature	Atomize temperature	Modifier
Pb	217.0 nm	800°C	1200°C	50 µg of $Mg(NO_3)_2$
Cr	357.9 nm	1200°C	2500°C	50 µg of $Mg(NO_3)_2$

Table 3: Descriptive statistics of soil samples obtained from different areas

Area	Parameter	Cr (mg/kg)	Pb (mg/kg)
Piliyandala	Minimum	5.2	4.9
	Maximum	21.2	19.0
	Mean (n = 9)	10.6	12.0
	SD	5.0	5.3
Wellampitiya	Minimum	9.4	15.6
	Maximum	103.5	94.6
	Mean (n = 11)	78.8	56.9
	SD	28.2	22.4
Kolonnawa	Minimum	49.4	82.0
	Maximum	159.8	115.6
	Mean (n = 5)	103.5	96.9
	SD	42.4	13.4
Kottawa	Minimum	52.2	36.0
	Maximum	91.9	61.5
	Mean (n = 5)	70.0	47.7
	SD	17.7	10.1
Banadaragama	Minimum	6.9	12.0
	Maximum	14.8	19.9
	Mean (n = 5)	11.0	15.0
	SD	3.3	3.1
Kahathuduwa	Minimum	4.2	5.7
	Maximum	19.2	18.5
	Mean (n = 5)	10.0	10.9
	SD	6.01	5.68
All soils of six areas	Minimum	4.2	4.90
	Maximum	159.8	115.6
	Mean (n = 40)	48.4	39.7
	SD	42.90	32.26
Control Soil	Mean	7.6	8.0
WHO/FAO	MPL	100	100

MPL: Maximum Permissible Limit

Table 4: Descriptive statistics of irrigation water samples obtained from different areas

Area	Parameter	Cr (mg/L)	Pb (mg/L)
Piliyandala	Minimum	ND	ND
	Maximum	ND	0.01
Wellampitiya	Minimum	ND	ND
	Maximum	ND	2.01
Kolonnawa	Minimum	ND	ND
	Maximum	ND	1.01
Kottawa	Minimum	ND	ND
	Maximum	ND	ND
Bandaragama	Minimum	ND	ND
	Maximum	ND	ND
Kahathuduwa	Minimum	ND	ND
	Maximum	ND	ND
Control		ND	ND
WHO/FAO	MPL	0.1	5

ND: Not Detected, MPL: Maximum Permissible Limit

The characteristics of the five types of GLV collected from the cultivation sites included in the Table 1. The standard conditions for the Graphite Furnace AAS are shown in Table 2.

Pb and Cr concentrations in the studied soils: Heavy metals accumulations in soils are associated with biological and geochemical cycles which are affected by various anthropogenic activities including farming practices and waste removal methods (Ndiokwere and Ezehe, 1990; Zauyah *et al*., 2004; Usman *et al*., 2002). Pb and Cr concentrations in soil samples obtained from the production and control sites of this study are presented in the Table 3. When compared with the maximum allowable limits of Cr (100 mg/kg) and Pb (100 mg/kg) given by WHO/FAO guidelines, the mean concentrations of heavy metals in the soils of selected areas were found in the normal ranges, except the mean level of Cr reported in Kolonnawa area. Two sites located in Kolonnawa area showed Pb contents exceeding the safe limit, while one site located at Wellampitiya area and two sites located at Kolonnawa area showed Cr contents exceeding the WHO/FAO permissible limit.

Significantly higher Pb and Cr concentrations of the studied soils of Kolonnawa, Wellampitiya and Kottawa areas may be due to the deposition of vehicular emissions as the above farming sites are located in heavily traffic congested areas. Further, the farmers of these areas were using substantial quantities of synthetic fertilizers and pesticides, which could result in gathering of trace elements in soil as observed earlier in many other countries (Belon *et al*., 2012). Bulk quantities of fertilizers and pesticides are frequently added to the soils in intensive agricultural systems to provide sufficient N, P and K requirements for the crop growth. However, these compounds contain certain heavy metals (Cd and Pb) as impurities or as active ingredients. After long term application of fertilizer, these elements have the ability to get concentrated in the agricultural soils (Wuana and Okieiman, 2011). Therefore, fertilizers and pesticides could also be a source of Pb in the soils of the contaminated areas.

Table 5: Descriptive statistics of GLV samples obtained from different areas

		G1		G2		G3		G4		G5	
Area	Parameter	Cr	Pb	Cr	Pb	Cr	Pb	Cr	Pb	Cr	Pb
Piliyandala	Min	0.16	0.07	0.25	0.08	0.50	0.13	0.73	0.21	0.28	0.14
	Max	1.78	0.40	2.70	0.37	2.31	0.39	2.96	0.81	1.75	0.33
	Mean	0.85	0.20	1.33	0.20	1.29	0.22	1.82	0.34	1.01	0.24
	SD	0.50	0.12	0.92	0.10	0.64	0.09	0.77	0.18	0.54	0.06
Wellampitiya	Min	3.66	0.03	3.98	0.18	2.97	0.19	5.55	0.29	4.05	0.16
	Max	7.43	8.79	8.96	9.19	6.09	9.52	9.18	12.90	7.33	9.60
	Mean	5.58	5.87	6.02	6.17	5.10	6.25	7.46	7.85	5.82	6.24
	SD	2.59	3.46	2.66	3.56	0.88	2.86	1.15	3.65	1.13	3.09
Kolonnawa	Min	4.16	4.52	4.69	5.51	4.11	5.72	5.48	8.18	3.64	4.77
	Max	11.09	8.02	9.01	9.40	9.42	7.94	18.79	12.49	10.64	9.09
	Mean	6.51	6.22	6.39	6.82	6.48	6.66	10.99	10.00	6.47	6.27
	SD	2.82	3.44	2.75	3.59	2.38	1.04	5.46	1.74	2.70	1.87
Kottawa	Min	0.59	2.40	0.67	2.29	0.60	2.08	0.68	3.53	0.37	2.71
	Max	6.75	5.48	6.62	5.10	6.00	6.50	10.08	7.82	7.51	8.04
	Mean	4.52	3.69	5.01	3.94	4.18	3.71	6.34	6.14	5.05	4.82
	SD	2.86	3.17	2.70	3.35	2.11	1.78	3.48	1.77	2.88	2.27
Bandaragama	Min	0.66	0.11	0.27	0.10	0.17	0.10	0.88	0.19	0.01	0.09
	Max	2.20	0.32	0.88	0.39	1.66	0.31	2.30	0.36	1.34	0.27
	Mean	1.26	0.23	0.60	0.22	0.86	0.18	1.69	0.27	0.64	0.19
	SD	0.62	0.08	0.26	0.13	0.66	0.09	0.54	0.06	0.58	0.08
Kahathuduwa	Min	0.51	0.20	0.43	0.14	0.21	0.11	0.59	0.19	0.42	0.09
	Max	1.64	0.32	1.95	0.28	2.15	0.23	1.82	0.33	1.59	0.32
	Mean	0.76	0.26	1.03	0.23	1.18	0.19	1.46	0.25	0.94	0.21
	SD	0.49	0.05	0.72	0.06	0.82	0.05	0.51	0.05	0.43	0.09
All samples	Min	0.16	0.03	0.25	0.08	0.17	0.10	0.59	0.19	0.01	0.09
	Max	11.09	8.79	9.01	9.40	9.42	9.52	18.79	12.90	10.64	9.60
	Mean	3.36	2.96	3.58	3.14	3.28	3.11	5.02	4.32	3.47	3.21
	SD	2.76	2.16	2.80	2.32	2.45	2.33	4.09	3.47	2.88	2.44
Control	Mean	1.34	0.14	0.99	0.10	1.60	0.07	1.96	0.16	1.77	0.08
WHO/FAO	MPL	2.3	0.3	2.3	0.3	2.3	0.3	2.3	0.3	2.3	0.3

MPL: Maximum Permissible Limit. G1: Mukunuwenna, G2: Thampala, G3: Nivithi, G4: Kohila, G5: Kankun

Further, in the selected fields, poultry manure has been used as a fertilizer for more than 10 years. Soils receiving continuous application of poultry manure for several years could also accumulate certain trace metals, which could also be potentially bio-available (Bolan *et al.*, 2010). As shown in the Fig. 2, highest contaminations of both metals were found in Kolonnawa area followed by Wellampitiya and Kottawa areas. Comparatively other three areas (Piliyandala, Bandaragama and Kahathuduwa) reported significantly low degree of contamination for both Pb and Cr (at $p<0.05$).

The mean concentration of Pb (39.7±32.3 mg/kg) found in the studied soils of this experiment was lower than the mean concentration of Pb (49.71 mg/kg) found in soil of industrial area of Dhaka as described by Jasim and Abdul (2010), as well as the mean Pb content (42.5±25.6 mg/kg) in the agricultural soils of the Pearl River Delta, South China reported by Chang *et al.* (2014). However, as reported by Aktaruzzaman *et al.* (2013) the mean concentration of Pb (7.31±5.04 mg/kg) found in the soils along the Dhaka Aricha Highway and the concentration range (54-59 mg/kg) in the soil of Gazipur as reported by Habib *et al.* (2009) was lower than reported by our study (4.9-115.6 mg/kg).

The mean concentration of Cr (42.5±25.6 mg/kg) accumulated in the agricultural soils in the Pearl River Delta, South China (Chang *et al.*, 2014) and the average concentration of Cr (21.51 mg/kg) recorded in the studied soil of Ado Ekiti, Southwestern Nigeria (Aruleba and Ajayi, 2012) found to be much lower than the mean value of Cr (48.4±42.9 mg/kg) reported by this study. Mahmood and Malik (2013) reported the concentration ranges of Cr in the soil of waste water as 11.37-33.39 mg/kg and in the soil of tube well water as 9.27-21.39 mg/kg. Those values are lower than the range of Cr (4.2-159.8 mg/kg) found in the soils of the present study. However, Iqbal *et al.* (2011) reported much higher range of Cr (246-1980 mg/kg) in the soils collected from periurban agricultural areas of Central Punjab Province of Pakistan.

Pb and Cr concentrations in irrigation water samples: Three samples of irrigation water obtained from Piliyandala, Wellampitiya and Kolonnawa areas were detected for Pb, while Cr was not detected in any of the sites. The detected levels of Pb in irrigation water sources complied with WHO/FAO standards (Table 4). The irrigation water used in the studied fields of Wellampitiya, Kolonnawa and Kottawa areas were mostly either well water or tap water. In addition water from small streams was used in the other areas.

Pb and Cr concentrations in green leafy vegetables: Results revealed that the field samples of GLV contain markedly higher levels of Pb and Cr concentrations than

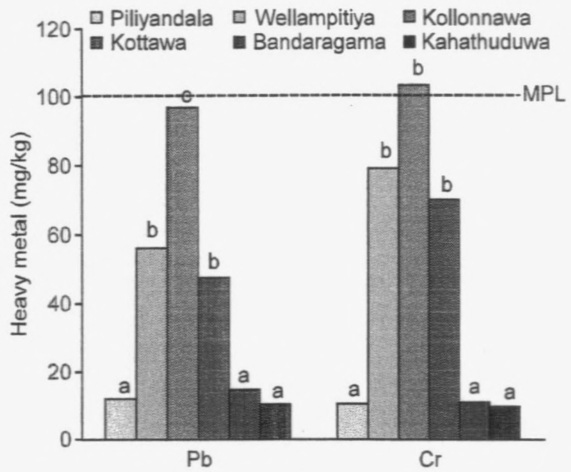

Fig. 2: Mean Pb and Cr concentrations of soil collected from different areas. Letters with same characters are not significantly different at $p<0.05$ for each metal. MPL denotes the maximum permissible limit of metals under WHO/FAO guidelines

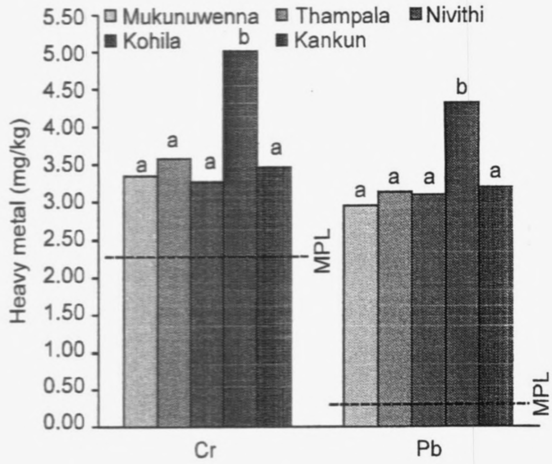

Fig. 3: Mean Pb and Cr concentrations of different GLV collected from Colombo District. Letters with same characters are not significantly different at $p<0.05$ for each metal. MPL denotes the maximum permissible limit of metals under WHO/FAO guidelines

the reference samples. The average Pb and Cr concentrations of all the five types of GLV exceeded the WHO/FAO safe limits for human consumption (Table 5). Accumulation of Cr in GLV followed the order of Nivithi <Mukunuwenna<Kankun<Thampala<Kohila, while for Pb it varied as Mukunuwenna<Nivithi<Thampala< Kankun<Kohila. Compared with other four GLV, Kohila accumulated significantly higher levels of both Pb and Cr (Fig. 3).

Significant differences were observed in Pb and Cr levels of all GLV collected from the six areas at $p<0.05$ (Fig. 4). For both metals, kolonnawa area showed the highest contamination, followed by the Wellampitiya and Kottawa areas. Comparatively the other three areas showed less contamination for both Pb and Cr and the mean levels were lower than the WHO/FAO permissible limits (WHO/FAO, 2003).

The differential concentrations of Pb and Cr in the GLV sampled from the production sites may be due to the variations of heavy metals concentrations of soil, air and irrigation water of the respective site. Further, the concentrations of heavy metals in leafy vegetables differ from one sampling location to the other and vary from one species of vegetable to the other. This may be attributed to differential uptake capacity of vegetables for different heavy metals through roots and their further translocation within the plant parts. It can also be due to soil characteristics such as acidity and organic matter contents and ability of the root type of the plants to penetrate where the heavy metals are found (Richards *et al.*, 2000; Domergue and Vedy, 1992).

The Colombo district, where two-thirds of the population is urban, accounts for over 60% of the manufacturing

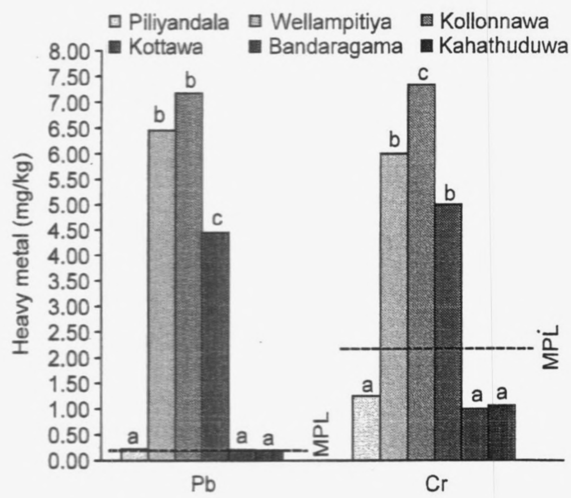

Fig. 4: Mean Pb and Cr concentrations of GLV collected from different areas. Letters with same characters are not significantly different at $p<0.05$ for each metal. MPL denotes the maximum permissible limit of metals under WHO/FAO guidelines

industries, 60% of registered vehicles and two diesel power plants. Hence, the most significant air pollution is generated primarily in this region (Country Situation Report, 2013). Worldwide, about 90 percent of the lead in urban air comes from motor vehicles. The obtained data reported that the concentrations of both Pb and Cr were higher in the GLV samples collected from Kolonnawa and Wellampitiya areas.

Further, the fields of these two areas located very closer (approximately 500 m) to the Kolonnawa and

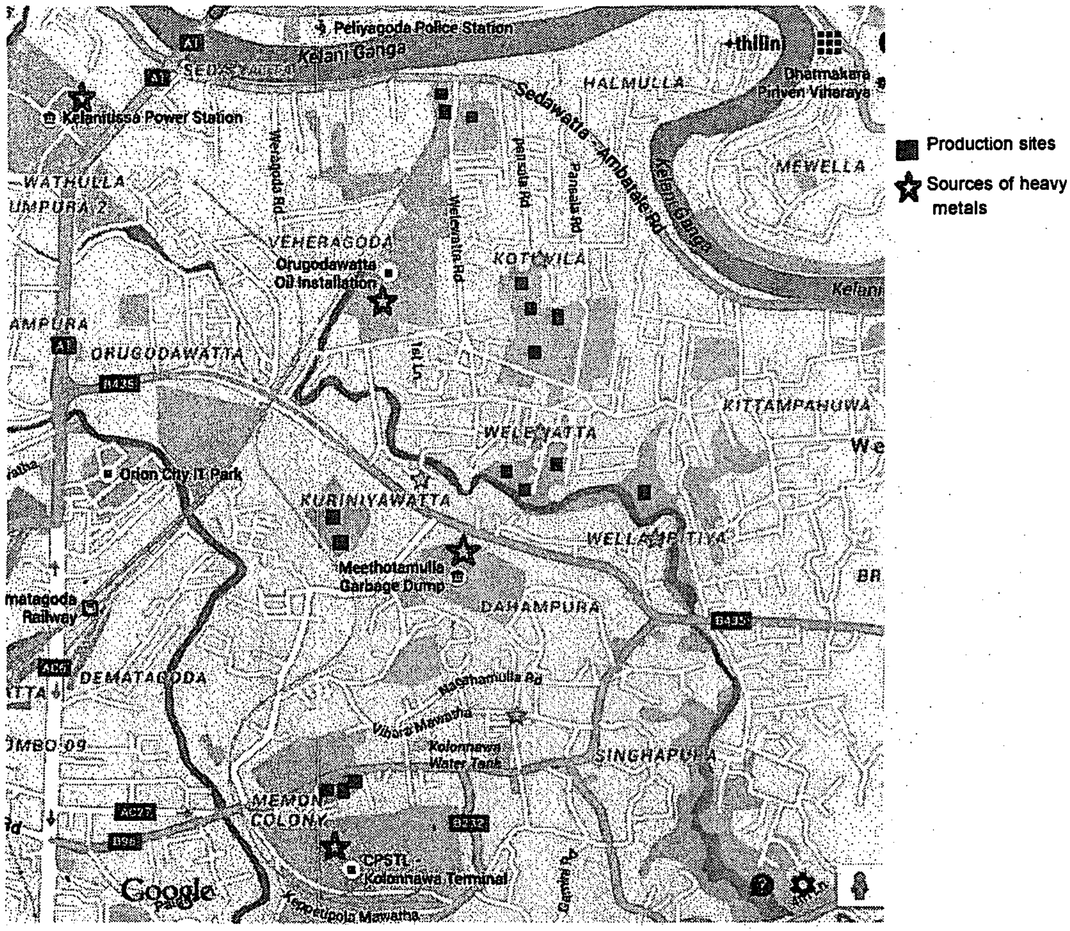

Fig. 5: Selected production sites of GLV in Kolonnawa and Wellampitiya area

Orugodawatta oil refinery and storage plants (Fig. 5). Additionally, the Meethotamulla garbage dumpsite is also situated closer to the selected production sites of Kolonnawa and Wellampitiya areas (Fig. 5). The site is used for the disposal of solid waste collected from Kolonnawa area. The extent of the dump site is about 16 acres and 45,500 kg of waste is disposed daily. The open dump is higher than 30 m and due to poor maintenance, it has created most unhealthy sanitary conditions. The untreated leachate flows to a stagnated water body which is situated closer to the dump. When leachate travels downwards from the landfill to the ground water table, both water and soils get contaminated as a result of infiltrated precipitation (Perera *et al.*, 2014).

The fields selected at Sedawatta of Wellampitiya area located closer to the flood plains of the Kelani River (Fig. 5). It is considered as the most polluted river in Sri Lanka due to the discharge of untreated effluents from the numerous industries located closer to the river Unilevers, Poogoda textile factory, Oruwala iron etc. Hence the polluted river water may leach into the soils of the cultivation sites.

Pb and Cr levels of GLV also found to be higher in Kottawa area. The cultivation sites selected here were located closer to the Southern Express Highway and along the roadsides of the High-Level Road where highly congested traffic can be observed. The transport sector, accounting for 12% of Sri Lanka's energy consumption and 60% of all petroleum consumption, causes the most serious air pollution due to its concentration in populated areas. Consumption rates recorded by the Ceylon Petroleum Corporation show that petrol consumption has declined marginally, but consumption of diesel has doubled due to the increased number of private buses. Concern is also growing about the impacts of the small particulates emitted from diesel engines. Uncontrolled diesels' emit about 30 to 70 times more particulates than petrol engines. Studies indicate that these particulates have caused increased tumors in animals and may be carcinogenic to exposed human body (Natural Resources of Sri Lanka, conditions and trends, 2011).

Chang *et al.* (2014), analyzed the Pb and Cr levels of six types of leafy vegetable grown in the Pearl River Delta, South China. According to the results, the analyzed leafy vegetables reported less heavy metal contents with apparent variations between different species. The ranges of Pb concentrations found in leafy vegetables of this experiment were comparatively low than the levels of Pb contamination showed by the GLV analyzed in our study (0.009-0.22 mg/kg (Flowering Chinese Cabbage), 0.006-0.65 mg/kg (Lettuce), 0.008-0.37 mg/kg (Pakchoi), 0.022-0.43 mg/kg (Chinese Cabbage), 0.028-0.79 mg/kg (Loose-leaf Lettuce) and 0.008-0.13 mg/kg (Chinese Leaf Mustard)). Additionally, the Cr levels of all vegetable samples reported by Chang *et al.* (2014) were below the FAO/WHO standard value unlike in our research.

As described by Aktaruzzaman *et al.* (2013), the Pb and Cr concentration ranges in leafy vegetables grown along the Dhaka Aricha Road were 0.695-3.155 and 1.173-3.83 mg/kg, respectively. These values are less compared with the Pb and Cr ranges reported in the analyzed GLV of the present study (Table 5). Ramesh and Murthy (2012) investigated the degree of heavy metal pollution in two leafy vegetables viz., Palak (Beta vulgaris) and Coriander (*Coriandrum sativum*) collected from five different stations of Bangalore Urban District. Results showed that, Pb concentration was exceedingly high in Palak (28.43 to 149.50 ppm) and Coriander (54.69 to 75.50 ppm) in all sampling stations. Cr content in Palak (70.79 ppm) and Coriander (127.27 ppm) found to be disturbingly high at the station 2. These values are much higher than the Pb and Cr levels reported in the six different areas considered in our study. Gupta *et al.* (2013) recorded heavy metal concentrations among different vegetables collected in the vicinity of Raipur city, India. According to them, mean concentrations of Cr and Pb in analyzed leafy vegetables were as follows: *Amaranthus virdis* (1.1 and 2.56 mg/kg), *Spinacia oleracea* (0.31 2.78 mg/kg), *Trigonella foenum graecum* (1.1 and 1.55 mg/kg) and *Coriandrum sativum* (1.1 and 2.49 mg/kg). These values are lower compared to the Cr and Pb concentrations of the GLV estimated in the present study.

Conclusion: The present findings provide proof that the key GLV cultivated and consumed in Colombo District, Sri Lanka were contaminated with Pb and Cr. Hence, it emphasizes the necessity of systematic and extensive investigation of heavy metal contaminations in GLV obtained from other agricultural fields as well as from markets. This research also highlight the importance of investigating the sources of trace metals in Sri Lankan GLV and possible control measures to reduce the associated risk due to food chain transfer of toxic trace metals. Furthermore, the results obtained in this study would go a long way in fortifying the scanty literature available regarding the assessment of heavy metals in GLV, within Sri Lanka.

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