973

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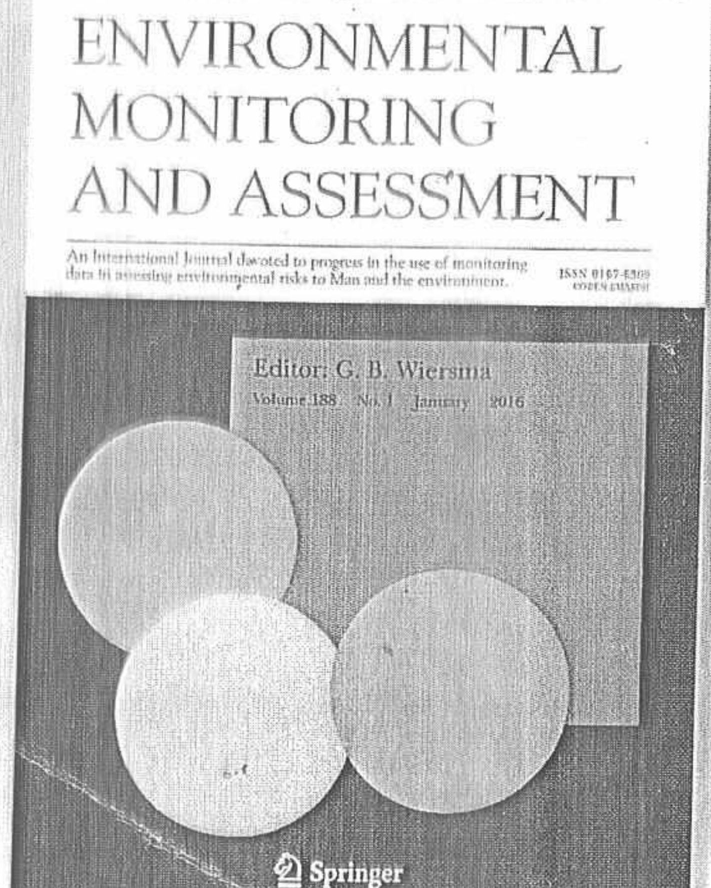

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275

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Detection of Ni, Cd, and Cu in green leafy vegetables collected from different cultivation areas in and around Colombo District, Sri Lanka

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Abstract Five types of green leafy vegetables ["Kankun" (*Ipomoea aquatica*), "Mukunuwenna" (*Alternanthera sessilis*), "Thampala" (*Amaranthus viridis*), "Nivithi" (*Basella alba*), and "Kohila leaves" (*Lasia spinosa*)] were randomly collected from six different locations (Wellampitiya, Kolonnawa, Kottawa, Piliyandala, Bandaragama, and Kahathuduwa) in and around Colombo District, Sri Lanka, and subjected to analysis of three heavy metals [nickel (Ni), cadmium (Cd), and copper (Cu)] by atomic absorption spectrometry. Soils from green leafy vegetable cultivation lands and irrigated water were also tested. The average concentrations of heavy metals Ni, Cd, and Cu in soils were 51.5 ± 45.5, 1.4 ± 1.1, and 66.5 ± 59.5 mg kg^{-1}, respectively. The highest Ni contamination was detected in the irrigated water samples from Wellampitiya (2.02 mg L^{-1}) followed by Kolonnawa (1.02 mg L^{-1}) and Kahathuduwa (0.25 mg L^{-1}) areas. This has exceeded the WHO/FAO guideline (0.2 mg L^{-1}). However, Cd and Cu contents in all tested irrigated water samples were well below the detection limits. Significant differences were observed in Ni, Cd, and Cu levels, between both production sites and green leafy vegetables analyzed ($P < 0.05$). The mean concentrations (mg kg^{-1}, dry weight basis) of heavy metals in all green leafy vegetable samples collected from six areas varied as 0.23 ± 0.15 for Cd, 12.60 ± 9.01 for Cu, and 7.62 ± 8.41 for Ni. Maximum Ni, Cd, and Cu contaminations were found in the green leafy vegetables collected from Kolonnawa area. Among the green leafy vegetables analyzed, "Kohila leaves" have the highest tendency to accumulate Ni, Cd, and Cu from the environment.

Research highlights

- Green leafy vegetables collected from Colombo area were tested for Ni, Cd, and Cu.
- Soils and irrigated water were also tested.
- Mean Ni and Cd levels in green leafy vegetables exceeded WHO/FAO safe limit.
- Highest accumulations of heavy metals were reported in *Lasia spinosa*.

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Introduction

Food safety and security is a foremost public concern in global context. Recently, the increasing demand for food

276

safety has inspired more research concerning the risks associated with the consumption of foods polluted by pesticides, heavy metals, and/or toxins. The implication associated with heavy metal contamination is of great concern, particularly in agricultural production systems. The term heavy metal refers to any metallic chemical element that has a relatively high density and is toxic or poisonous at low concentrations.

However, the usage of the term has centered on the behavior of certain metallic elements which have an impact upon plants or animals when discharged into the natural environment in relatively high concentrations (Lenntech 2004). Living organisms require trace amounts of some heavy metals, including chromium (Cr), manganese (Mn), iron (Fe), cobalt (Co), copper (Cu), zinc (Zn), and selenium (Se), but excessive levels of them can be detrimental to the organism causing several degenerative diseases of central nervous function, the cardiovascular and gastrointestinal (GI) systems, lungs, kidneys, liver, endocrine glands, and bones (Jang and Hoffman 2011; Adal and Wiener 2013). Among the nonessential metals, mercury (Hg), lead (Pb), cadmium (Cd), and arsenic (As) are recognized as most toxic to humans, even at exposure to low concentrations causing major health problems associated with neurotoxic and carcinogenic actions (Jomova and Valko 2010; Tokar et al. 2011).

Heavy metals are introduced to the environment by natural and anthropogenic sources such as natural weathering of the earth's crust, mining, soil erosion, industrial and traffic emissions, untreated sewage effluents, fertilizer, pesticides, and other disease control agents applied to plants, atmospheric pollution fallout, etc. (Ming-Ho 2005). One of the major routes of human exposure to these toxic elements is through the diet (food and water). According to the research conducted over the previous decades, plant crops have the ability to concentrate toxic metals in their edible and nonedible parts through contaminated soil, irrigation water sources, and atmospheric deposition. Trace metal accumulation in plants depends on plant species, growth stage, type of soil and metals, soil condition, weather, and environment (Madyiwa et al. 2002).

Consumption of green leafy vegetables (GLVs) in fresh and cooked forms are becoming very popular among Sri Lankans, particularly among the urban community since they are well aware of the nutritional benefits (fiber, vitamins C and K, carotenoides, folate, minerals iron and calcium, wide range of antioxidants and flavonoides, etc.), cheap price, and the easy accessibility associated with the product (Kananke et al. 2014). However, as reported by many previous studies conducted in other countries, leafy vegetables have more potential to accumulate heavy metals than other fruit and vegetable crops (Chang et al. 2014; Ramesh and Yogananda Murthy 2012; Gupta et al. 2013; Otitoju et al. 2012; Surukite et al. 2013). In Sri Lanka, extensive green leafy vegetable cultivation is practiced primarily in and around Colombo District which is the commercial capital of Sri Lanka. According to many previous research findings, Colombo District reported to have the highest degree of environmental pollution in Sri Lanka due to the vast number of population, industries with lack of policies to control pollution, and extensive amounts of vehicles located in the area (Country Situation Report 2013; Ileperuma 2000; Herath et al. 2013; Gunathilaka et al. 2011). Apart from this, heavy use of poor quality agro-chemicals by GLV farmers over a long time period may have also caused heavy metal contaminations of GLV in Colombo District. Further, majority of the urban community is not aware about the extent of heavy metal contamination of the GLV consumed since very scanty literature is available on heavy metal pollution of GLV obtained from the cultivation sites of Sri Lanka. In our previous investigation conducted in Colombo District, Sri Lanka, we have found high contamination of commonly consumed GLV with Pb and Cr (Kananke et al. 2015). The present study was conducted with the aim of determining the concentrations of another three toxic heavy metals (Ni, Cd, and Cu) in 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 in and around Colombo District, Sri Lanka (Fig. 1).

Material and methods

Study area

A preliminary investigation survey was carried out in and around Colombo District to identify the extensive cultivation areas of GLV. A structured questionnaire was distributed among the farmers of the selected production areas to obtain information concerning the cultivation

277

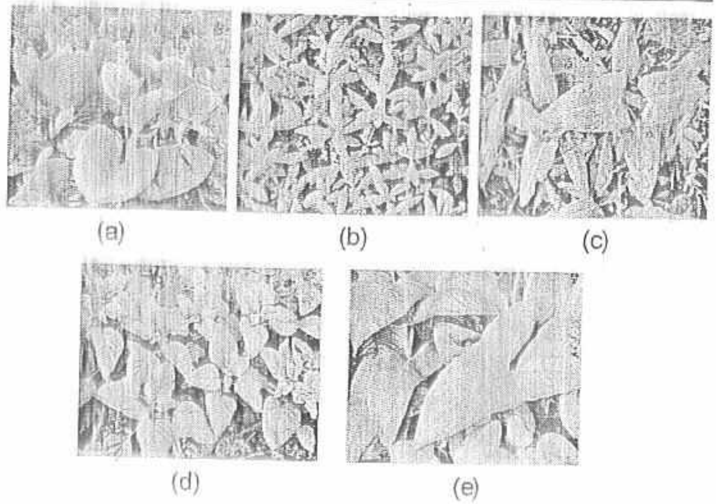

Fig. 1 Types of GLV collected from the cultivation sites **a** Nivithi **b** Mukunuwenna **c** Kankun **d** Thampala and **e** Kohila Leaves

history of selected crops. Based on that, six locations, namely, Piliyandala (9 sites), Bandaragama (5 sites), Kahathuduwa (5 sites), Wellampitiya (11 sites), Kolonnawa (5 sites), and Kottawa (5 sites), were selected for the test (Fig. 2). Irrigation water, soil, and GLV were randomly collected from the above selected sites based on the availability at the time of sampling.

GLV cultivation sites located in Kolonnawa and Wellampitiya areas are under the control of Kolonnawa Urban Council which was developed as the backyard of the Colombo City, accommodating mainly the warehousing and service sector activities. The environment of Kolonnawa is characterized by the existence of 25 % high-land and 75 % low-lying areas, which had been filled during the last three decades. Most parts of the Kolonnwa area located in the flood-plains of Kelani River, which is considered as the most polluted river in Sri Lanka. Apart from GLV cultivation, hardly any other agricultural activities exist in the unreclaimed low-lying areas. Some parts of the Kolonnawa area (Meethotamulla) used as a dumping ground for the solid waste generated in Colombo. Parallel to this process, there are major storage/utility installations/large-scale industries located in the area including Kolonnawa petroleum oil storage and refining installations, Kelanithissa electricity substation, water storage installations to South of Pothuvil Kumbura solid waste disposal site, food granaries, textile and garment industries, vehicle repair workshops, container yards, warehousing complex, garage warehouse complex, several sawmills, and timber depots. The above mentioned activities have resulted high industrial pollution in the area due to lack of enforcement of zoning and environmental regulations to ensure safe discharge of industrial effluents (City Profile-Kolnonnawa Urban Council 2002).

Kottawa is also a suburb of Colombo City, which is located 21 km from the center of Colombo. And, it is a key landmark in Sri Lanka's road systems due to the development of highways across the area (A04 highway connecting Colombo and Batticaloa and Southern Expressway (E01) connecting Colombo and Matara). The area reported high number of population and traffic density apart from few industrial activities. Piliyanadala is another suburb of the Colombo District, which is situated about 18 km south of Colombo. It is one of the relatively high populated suburbs positioned in the Colombo City, and it is surrounded by the less urban suburbs of Kesbawa, Bandaragama, and Kahathuduwa.

Water sampling and analysis

Irrigated water samples from each production site were collected in previously cleaned, 1-L polypropylene bottles, and 1 mL of concentrated nitric acid was added to each sample to avoid microbial spoilage. Samples were prepared and analyzed for Cd, Cu, and Ni concentrations by atomic absorption spectroscopy (AAS) as described in APHA (2005).

Soil sampling and analysis

Composite soil samples were collected from each site by combining small portions of soil from various locations within the plot. Soil was sampled to a depth of

278

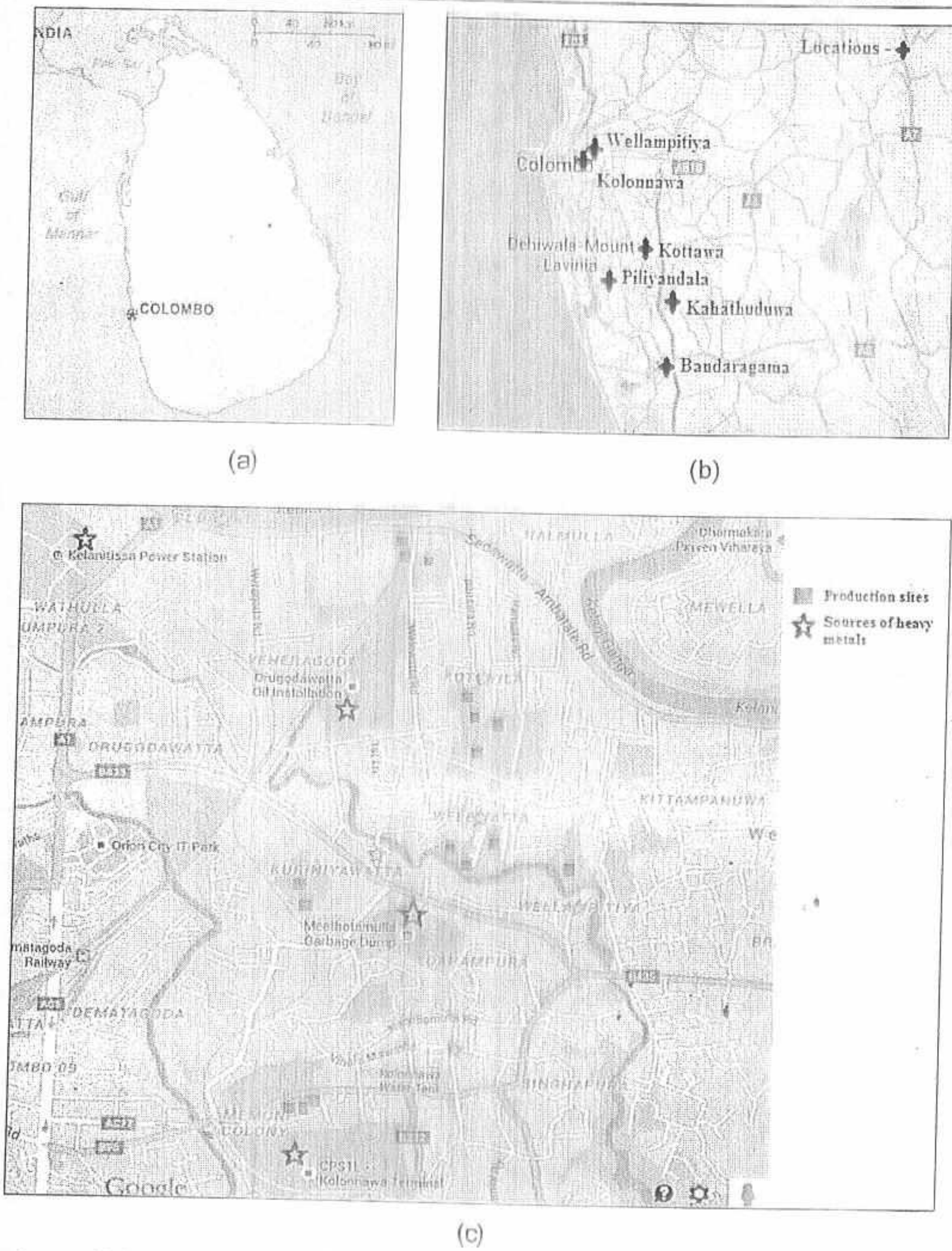

Fig. 2 **a** A map of Sri Lanka. **b** Sample locations in and around Colombo District. **c** Production sites located in Kolonnawa and Wellampitiya areas and probable sources of heavy metals

approximately 12 cm, in which the soils sampled covered the average effective root zone of the green leafy vegetables. Unused, clear polyethylene sampling bags were used to collect the soil samples into the laboratory. Then, the soil samples were prepared and analyzed for Cd, Cu, and Ni by AAS, according to the method described in AOAC 965.09 (Official Methods of Analysis 2002).

279

Green leafy vegetable 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. A complete description of the GLV collected from the study area was given in Table 1.

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 airborne pollutants. The edible parts were chopped into small pieces.

Drying Test portions were dried in a drying oven, at 105 °C, until a constant weight was obtained, then cooled to ambient temperature, and crushed by means of a clean pestle and mortar to obtain homogenized samples. Then, the ground samples were 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).

Comparison of Cd, Cu, and Ni concentrations in field samples with reference samples

Reference GLV samples of Mukunuwenna, Thampala, Nivithi, Kohila, and Kankun were grown in experimental plots constructed in a home garden in an unpolluted area, without using any chemical fertilizer or pesticides. Representative samples of each GLV, a reference composite soil sample and an irrigated water sample, were analyzed by AAS to determine the concentrations of Cd, Cu, and Ni 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 1985).

Quality assurance

Appropriate quality assurance procedures and precautions were followed to ensure the reliability of the results. All chemicals used in the experiment were purchased from the Sigma Aldrich Company, USA, and all the reagents used were of analytical (trace metal) grades. Standards were prepared for each metal using the stock solutions to calibrate the equipment. Glasswares were properly cleaned and distilled water was used throughout the study. Reagent blank determinations were used to correct the instrument readings.

Statistical analysis

Descriptive statistics (mean, minimum, maximum, and standard deviation) and statistical significance of collected data were analyzed by ANOVA using Minitab 14.0 and Excel computer packages.

Results and discussion

Heavy metal contamination in studied soils

The nature of the soil is one of the influential factors which determine the heavy metal levels of agricultural crops (Madyiwa et al. 2002). Heavy metal pollution of agro-soils can create long-term ecological problems, as well as numerous health consequences in human (Muchuweti et al. 2006). Soils can act as filters of toxic chemicals. However, continuous loading of pollutants or changes in pH can reduce the capacity of soils to retain toxic metals. Consequently, soils release heavy metals into the groundwater or soil solution, which in turn available for plant uptake. Trace metals in soil originally arise from the geochemical cycling and soil-forming processes, and the amount of trace elements in soil depends on the parent material, climate, topography,

Table 1 Green leafy vegetables sampled from production sites

Local name	English name	Scientific name	Edible part
Mukunuwenna	Sessile alligatorweed and sessile joyweed	*Alternanthera sessilis*	Leaves and young stem
Nivithi	Malabar spinach	*Basella alba*	Leaves and young stem
Thampala	Chinese spinach, green amaranth, and 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

280

etc. Further accumulation of metals in soil may occur by long-term application of pesticides, fertilizers, composts, and manure; sewage sludge; and other anthropogenic activities (Alloway and Ayres 1993).

The results of the concentrations of heavy metals in the soils collected from six different production areas in and around Colombo District are given in Table 2. Average concentrations of Cd, Cu, and Ni in agricultural soils showed larger variations in the analyzed fields. Mean levels of Cd, Cu, and Ni in field soil samples were higher than the control soil sample obtained from the unpolluted experimental area. When compared with the maximum allowable limits of Cd (3 mg kg^{-1}), Cu (100 mg kg^{-1}), and Ni (50 mg kg^{-1}) established by the WHO/FAO guidelines, the mean concentrations of Cd in Kolonnawa area (3.56 mg kg^{-1}); Cu in Wellampitiya (113.0 mg kg^{-1}) and Kolonnawa (142.7 mg kg^{-1}) areas; and Ni in Wellampitiya (79.9 mg kg^{-1}), Kolonnawa (118.9 mg kg^{-1}), and Kottawa (74.1 mg kg^{-1}) areas exceeded the safe limits. The highest contaminations of Cd, Cu, and Ni 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 Cd, Cu, and Ni (at $P<0.05$).

High levels of heavy metals were found in the soils of Kolonnawa, Wellampitiya, and Kottawa areas possibly due to several reasons. Some of the cultivation sites of these areas were located in heavily traffic-congested areas and subjected to frequent deposition of vehicular emissions. 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 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 Okieimen 2011).

In addition, farmers in the study areas are using bulk quantities of poultry manure for longer periods of time. Several trace metals including As, Co, Cu, Fe, Mn, Se, and Zn were added to poultry diet for various purposes. Soils receiving continuous application of poultry manure for several years could accumulate such trace metals, which could also be potentially bioavailable (Han et al. 2000). Premarathna et al. (2011) reported the levels (mg kg^{-1}) of trace metal impurities in major

Table 2 Descriptive statistics of soil samples obtained from different areas

Area	Parameter	Cd (mg kg^{-1})	Cu (mg kg^{-1})	Ni (mg kg^{-1})
Piliyandala	Range	0.02–0.94	4.1–18.3	1.1–18.7
	Mean ± SD ($n=9$)	0.55 ± 0.31^{a}	12.5 ± 4.7^{a}	11.6 ± 6.7^{a}
Wellampitiya	Range	0.26–3.20	20.6–158.4	9.1–102.5
	Mean ± SD ($n=11$)	1.95 ± 0.82^{b}	113.0 ± 41.7^{bc}	79.9 ± 26.6^{b}
Kolonnawa	Range	2.81–4.25	108.1–195.6	59.1–174.3
	Mean ± SD ($n=5$)	3.56 ± 0.58^{c}	142.7 ± 35.3^{b}	118.9 ± 43.2^{c}
Kottawa	Range	0.54–2.70	50.8–119.8	47.6–90.7
	Mean ± SD ($n=5$)	1.47 ± 0.92^{ab}	94.1 ± 26.4^{c}	74.1 ± 17.0^{b}
Banadaragama	Range	0.45–1.16	8.4–17.3	11.7–16.9
	Mean ± SD ($n=5$)	0.71 ± 0.27^{a}	12.1 ± 3.8^{a}	14.2 ± 2.1^{a}
Kahathuduwa	Range	0.35–1.07	5.1–18.8	2.1–18.1
	Mean ± SD ($n=5$)	0.60 ± 0.30^{a}	11.7 ± 5.04^{a}	8.7 ± 6.67^{a}
All soils	Range	0.02–4.25	4.1–195.6	1.1–174.3
	Mean ± SD ($n=40$)	1.45 ± 1.15	66.5 ± 59.52	51.5 ± 45.51
Control soil	Mean	ND	9.7	7.6
WHO/FAO	MPL	3	100	50

Values in the same column with the same superscript letter are not significantly different from each other ($P<0.05$)

ND not detected, *MPL* maximum permissible limit types of animal manure and fertilizers used in the green leafy vegetable cultivation areas of Colombo District, Sri Lanka, poultry manure (0.97, 23.9, and 6.87), urea (0.4, 0.2, and 1.4), triple super phosphate (23.5, 9.5, and 20.4), and imported rock phosphate (12.18, 47.85, and 18.3) for Cd, Cu, and Ni, respectively. Accordingly, the levels of Cd found in triple super phosphate and imported rock phosphate have exceeded the trace metal levels permitted in compost by Sri Lanka Standards Institute guidelines (10 mg kg^{-1} for Cd and 400 mg kg^{-1} for Cu).

Han et al. (2000) showed that Cu and Zn had accumulated considerably in the poultry waste-amended soil over 25 years. Majority of the studied fields in Kolonnawa and Wellampitiya areas have more than 15 years of cultivation history, while the studied fields in Piliyandala and Bandaragama areas have a cultivation history of about 5–10 years. Earlier research findings have also suggested that the number of years of cultivation had an effect on trace metal accumulation in soils. Therefore, the increased and repeated use of poultry manure and fertilizer could be one reason for the observed increases in Cd, Ni, and Cu concentrations of soils.

Besides, several fields of Wellampitiya area are located in the floodplains of the Kelani River which is frequently subjected to flooding. The Kelani River is also the most polluted river in Sri Lanka because it receives untreated industrial effluents directly from the Colombo and Gampaha Districts and also indirectly from tributary streams and canals (Herath 2002). Therefore, polluted water can enter the closer by agricultural fields. Thus, the river water could also have contributed to the accumulation of trace metals in these areas.

As reported by Premarathna et al. (2011), the mean concentrations (mg kg^{-1}) of Cd (1.18±0.82), Cu (51 ±26), and Ni (20±5) concentrations of the studied soils of green leafy vegetable cultivation sites of low country areas in Sri Lanka found to be little less than the levels (mg kg^{-1}) of Cd (1.45±1.15), Cu (66.5±59.52), and Ni (51.5±45.51) reported in the present study. According to Harmanescu et al. (2011), the Cu (229.15 ±10.27 mg kg^{-1}) contamination of soils collected from vegetable cultivation sites of an old mining area (Moldova Noua) of Banat County, Romania, found to be much higher than the value reported by the present study (66.5±59.52 mg kg^{-1}). However, the Cd (0.40 ±0.02 mg kg^{-1}) and Ni (18.40±0.40 mg kg^{-1}) contaminations of the soils in their study are far less compared to our study (1.45±1.15 mg kg^{-1} Cd and 51.5±45.51 mg kg^{-1} Ni). Ekpo et al. (2014) studied the heavy metal concentrations on soil and some economic crops grown within an abandoned Peacock Paints Industry environment in Ikot Ekan, Nigeria, and found the mean level of Cd (12.34±1.30 mg kg^{-1}) in the topsoils, which is far greater than the value reported by the present study (1.45±1.15 mg/kg Cd). However, the Cu (36.29±2.32 mg kg^{-1}) and Ni (25.27 ±1.21 mg kg^{-1}) levels were low in comparison to our values.

Heavy metal contamination of irrigation water

As shown in the Table 3, Cd and Cu were not detected in any of the irrigated water samples collected from the six areas. However, Ni was present in the irrigated water samples collected from all six areas, and the maximum levels of Ni detected in the Wellampitiya (2.02 mg L^{-1}), Kolonnawa (1.02 mg L^{-1}), and Kahathuduwa (0.25 mg L^{-1}) areas exceeded the safe limit (0.2 mg L^{-1}) established by the WHO/FAO guideline. Farmers in the cultivation areas are mostly utilizing shallow groundwater for irrigation purposes, using the agro-wells constructed on the fields. In addition, they are using the water of small tributary streams and canals

Table 3 Descriptive statistics of irrigation water samples obtained from different areas

Area	Parameter	Cd (mg L^{-1})	Cu (mg L^{-1})	Ni (mg L^{-1})
Piliyandala	Minimum	ND	ND	ND
	Maximum	ND	ND	0.05
Wellampitiya	Minimum	ND	ND	ND
	Maximum	ND	ND	2.02
Kolonnawa	Minimum	ND	ND	ND
	Maximum	ND	ND	1.02
Kottawa	Minimum	ND	ND	ND
	Maximum	ND	ND	0.06
Bandaragama	Minimum	ND	ND	ND
	Maximum	ND	ND	0.10
Kahathuduwa	Minimum	ND	ND	0.05
	Maximum	ND	ND	0.25
Control		ND	ND	ND
WHO/FAO	MPL	0.001	0.2	0.2

ND not detected, *MPL* maximum permissible limit

282

of Kelani River for irrigation purposes. In 2002, Gunawardhana et al. investigated the heavy metal concentrations in shallow groundwater in Colombo South area and similarly found high concentrations of Ni (0.1 mg/L) unlike Cu (0.01 mg/L) and Cd (not detected). As the authors have mentioned, the groundwater pollution occurs on a different timescale than the surface water contamination. Therefore, nonpoint source pollution can take years or even decades to appear in wells and just as long to be dissipated or to be converted. These distinctions depend on the topography, hydrology, and the sources of groundwater recharge and have implications for limiting as well as remediating groundwater contamination.

Heavy metal contamination of GLV

Table 4 represents the Cd, Cu, and Ni concentrations of GLV collected from six cultivation areas and the control site. Results revealed that the field samples of GLV contain markedly higher levels of Cd, Cu, and Ni contents than the reference samples. The average Cd and Ni concentrations of all the five types of GLV exceeded the permissible limits for human consumption, while the Cu level remained under the permissible limit. Accumulation of Cd in GLV followed the order of Mukunuwenna < Nivithi < Kankun < Thampala < Kohila, while for Cu, it varied as Thampala < Nivithi < Mukunuwenna < Kankun < Kohila and for Ni as Thampala < Mukunuwenna < Nivithi < Kankun < Kohila. Compared with other four GLV, Kohila accumulated significantly higher levels of all the three metals ($P < 0.05$).

Significant differences were observed in Cd, Cu, and Ni levels of all GLV collected from the six areas ($P < 0.05$). For all three metals, Kolonnawa area showed the highest contamination, followed by the Wellampitiya and Kottawa areas (Fig. 3). Comparatively, the other three areas showed less contamination for Cd, Ni, and Cu, and the mean levels were lower than the permissible limits (WHO/FAO 2003).

The differential concentrations of Cd, Cu, and Ni in the GLV sampled from the production sites may be due to the variations of heavy metal 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).

Colombo District is the most polluted city in Sri Lanka due to high urban population, traffic congestion, and vast number of unplanned industries located in the area. Some of the industries with lack of policies to control pollution have been established in Colombo for more than two decades, and heavy use of agrochemicals by farmers over long time may suggest that the historical pollution related to past and present activities contribute to the contaminations of GLV (Country Situation Report 2013; Ileperuma 2000; Herath et al. 2013; Gunathilaka et al. 2011). The obtained data reported that the concentrations of heavy metals were higher in the GLV samples collected from Kolonnawa and Wellampitiya areas. Fields of these two areas are located very closer (approximately 500 m) to the Kolonnawa and Orugodawatta oil refinery and storage plants and additionally to the Meethotamulla garbage dumpsite (Fig. 2). This site is used for the disposal of solid waste collected from Kolonnawa area. The extent of the dumpsite is about 18 ac, and 45,500 kg of waste is disposed daily. The open dump is more than 30 m high and created poor sanitary conditions due to lack of maintenance. When the untreated leachate travels downward from the landfill to the groundwater table, both soil and water gets contaminated as a result of infiltrated precipitation (Perera et al. 2014). In addition, Sewwandi et al. (2013) evaluated the leachate contamination potential of municipal solid waste dumpsites in Sri Lanka using leachate pollution index (LPI) and found the highest overall LPI from Kolonnawa dumpsite followed by Bandaragama and Rathnapura sites. According to them, Kolonnawa landfill leachate is contaminated with organic pollutants and heavy metals and it has the highest potential of pollution.

Ni, Cd, and Cu contaminations of GLV were also higher in Kottawa area. The cultivation sites selected here were located closer to the traffic-congested high-level (A04) road and to the Southern Expressway (E01). 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

283

Table 4 Descriptive statistics of GLV samples obtained from different areas

GLV	Parameter	Cd (mg kg^{-1})	Cu (mg kg^{-1})	Ni (mg kg^{-1})
Sampling areas				
Piliyandala ($n=9$)	Mean ± SD	0.15 ± 0.06^{a}	6.67 ± 2.84^{a}	2.50 ± 1.97^{a}
	Range	0.04–0.29	1.74–13.83	0.01–9.02
Wellampitiya ($n=11$)	Mean ± SD	0.29 ± 0.16^{b}	18.13 ± 6.48^{b}	10.06 ± 7.46^{b}
	Range	0.11–0.78	6.08–34.01	1.39–38.26
Kolonnawa ($n=5$)	Mean ± SD	0.39 ± 0.20^{c}	21.97 ± 13.59^{b}	21.73 ± 10.73^{c}
	Range	0.16–0.88	3.79–45.30	3.65–38.73
Kottawa ($n=5$)	Mean ± SD	0.22 ± 0.11^{ab}	13.73 ± 7.57^{c}	7.15 ± 3.61^{b}
	Range	0.06–0.58	3.29–31.73	1.73–14.75
Bandaragama ($n=5$)	Mean ± SD	0.16 ± 0.04^{a}	7.72 ± 3.01^{a}	3.15 ± 1.72^{a}
	Range	0.07–0.25	2.58–11.90	1.34–8.61
Kahathuduwa ($n=5$)	Mean ± SD	0.16 ± 0.04^{a}	5.28 ± 2.22^{a}	2.33 ± 1.58^{a}
	Range	0.11–0.26	2.03–11.06	0.45–6.18
Field samples				
Mukunuwenna ($n=40$)	Mean ± SD	0.20 ± 0.11^{a}	11.85 ± 7.51^{a}	6.48 ± 6.74^{ab}
	Range	0.06–0.51	2.03–33.74	0.04–26.84
Nivithi ($n=35$)	Mean ± SD	0.20 ± 0.13^{a}	10.07 ± 8.75^{a}	6.53 ± 7.97^{ab}
	Range	0.06–0.62	1.74–41.62	0.01–26.87
Thampala ($n=35$)	Mean ± SD	0.23 ± 0.11^{a}	9.19 ± 7.25^{a}	5.95 ± 7.18^{a}
	Range	0.04–0.55	2.29–37.63	0.01–29.16
Kankun ($n=40$)	Mean ± SD	0.21 ± 0.12^{a}	14.13 ± 8.90^{ab}	7.90 ± 8.61^{ab}
	Range	0.04–0.71	4.47–38.84	0.50–34.22
Kohila ($n=30$)	Mean ± SD	0.33 ± 0.20^{b}	17.73 ± 10.03^{b}	11.24 ± 10.36^{b}
	Range	0.12–0.88	4.78–45.30	0.70–38.73
All samples ($n=180$)	Mean ± SD	0.23 ± 0.15	12.60 ± 9.01	7.62 ± 8.41
	Range	0.04–0.88	1.74–45.30	0.01–38.73
Reference samples				
Mukunuwenna	Mean	ND	3.88	0.89
Nivithi	Mean	ND	2.34	1.17
Thampala	Mean	ND	3.84	1.45
Kankun	Mean	ND	9.14	0.96
Kohila	Mean	ND	11.34	1.62
WHO/FAO	MPL	0.2	40	4*

Values in the same column with a same superscript letter are not significantly different from each other ($P < 0.05$)

MPL maximum permissible limit

*According to the Food and Nutrition Board, Institute of Medicine (2010)

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 2011; Kananke et al. 2015).

It is well known that leafy vegetables are heavy metal accumulators. Therefore, if they grow in contaminated soil, and if plant and soil factors are favorable for the transfer of trace metals from soil to plant, contamination can occur. Bioavailability of trace metals for plant

284

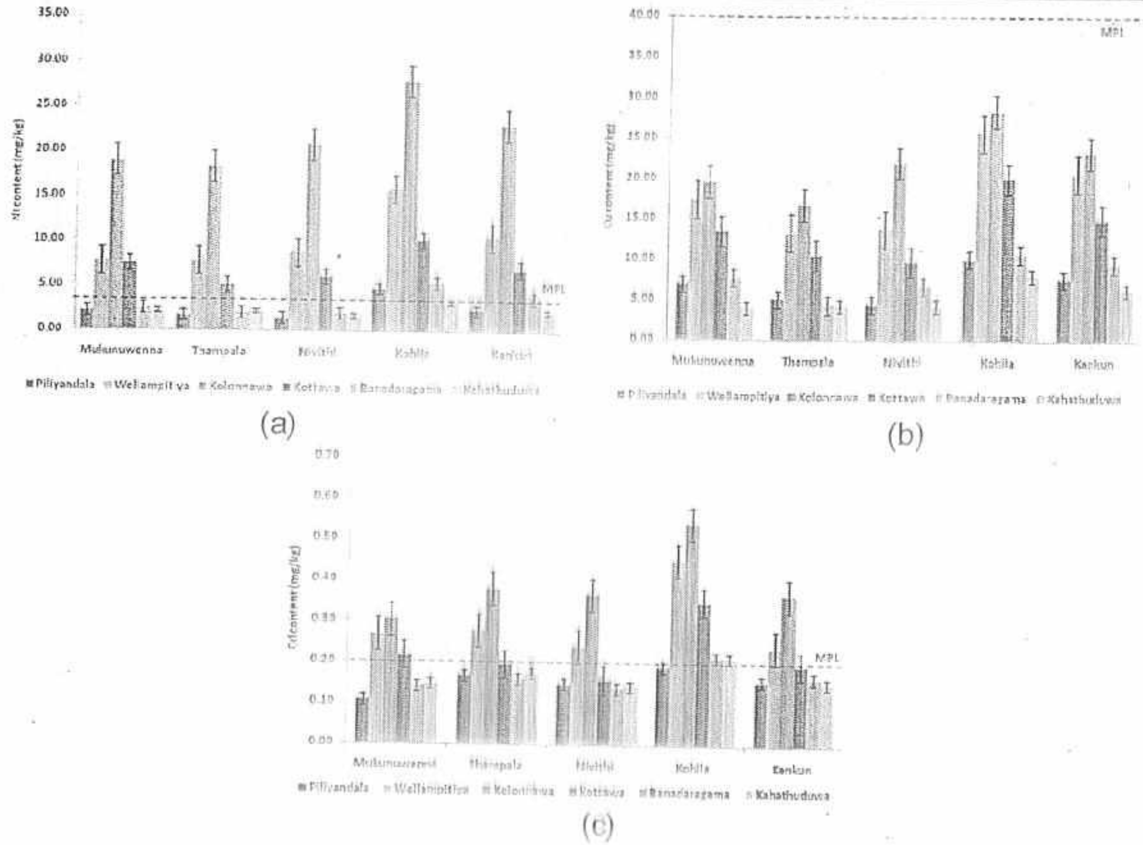

Fig. 3 Mean concentrations of a Ni, b Cu, and c Cd concentrations of GLV collected from different areas. MPL denotes the maximum permissible limit of each metal

uptake in soils can be affected by not only total trace metal concentration but by soil pH, organic matter, cation exchange capacity, etc. (Blaster et al. 2000). In addition to soil factors, climatic and agronomic practices also influence the mobility and bioavailability of metals in the soil. Uptake and translocation of metals in different plant parts are controlled by the plant genotype. GLVs are having broader leafy surfaces which serve as points of heavy metal uptake into the plant either by stomatal or cuticle pathways. According to previous studies, pronounced differences were observed in cuticular uptake rates for different heavy metals. For instance, Cu, Zn, and Cd were taken up at high rates by cuticles of many plants, whereas Pb is transmitted in very low quantities. Further, it was found that Cd and Zn were much more mobile compared to Cu or Pb. Moreover, the young plants found to be more efficient on internal transportation of heavy metals than the mature plants (Blaster et al. 2000).

Premarathna et al. (2011) studied the trace metal concentrations in GLV collected from intensively cultivated areas of low country, Sri Lanka, and found that the mean values (mg kg^{-1} dry weight) of the trace metals in the plants were as 0.59 ± 0.44 for Cd, 11 ± 6 for Cu, and 13 ± 9 for Ni. Comparatively, in the present study, the average concentrations of elements were reported as 0.23 ± 0.15 for Cd, 12.60 ± 9.01 for Cu, and 7.62 ± 8.41 for Ni. In both studies, the mean Cd levels of the studied GLV have exceeded the WHO/FAO safe limit (0.2 mg kg^{-1}), while Cu (40 mg kg^{-1}) levels were under the permissible limits. According to Oluwole et al. (2013), Cu and Cd levels in leafy vegetables cultivated by the roadside, Ojo local government area, Lagos, Nigeria, ranged from 0.3944 to 1.6559 mg kg^{-1} and 0.0854 to 0.2563 mg kg^{-1}, respectively. These values were quite low compared to the Cd (0.04–0.88 mg kg^{-1}) and Cu (1.74–45.30 mg kg^{-1}) ranges found in the GLV analyzed in the present study and considered safe for human consumption without the risk of environmental toxicants. Jacob and Kakulu (2012) assessed the heavy metal bioaccumulation in spinach, jute mallow, and tomato in farms within Kaduna Metropolis, Nigeria, and found the mean ± SD (mg kg^{-1}) of trace elements of vegetable samples as Cd 3.2 ± 1.0 and Ni 9.6 ± 2.5. Mean levels of both Cd and Ni found in the analyzed vegetables of their study were higher compared with us (0.23 ± 0.15 for Cd and 7.62 ± 8.41 for Ni). According to them, high concentrations of Cd in vegetable samples were attributed to high levels of industrial activities, metal works, vehicular emissions, small-scale tanning operations, and other anthropogenic activities prevailing in the area. Spinach accumulated more metals, followed by jute mallow, and then tomato. This is in agreement with some earlier reports that leafy vegetables have greater potential for accumulating heavy metals in their edible parts than other grains and fruit crops, due to their higher transpiration rate. Kalagbor et al. (2014) revealed the mean concentrations and ranges (mg kg^{-1}) of Ni 17.69 (15.75–19.25), Cu 9.13 (7.75–11.00), and Cd 1.44 (1.25–1.50) in four edible vegetables, bitter leaf (*Vernonia amygdalina*), scent leaf (*Ocimum gratissimum*), water leaf (*Talinum triangulare*), and fluted pumpkin (*Telfairia occidentalis*) from a cottage farm in Port Harcourt. The leaves analyzed in their study revealed high concentrations (mg kg^{-1}) of Cd and Ni compared with our study (0.23 ± 0.15 for Cd, 12.60 ± 9.01 for Cu, and 7.62 ± 8.41 for Ni), and these high values were attributed to the atmospheric pollution by a major highway, burning of fossil fuels, and use of machinery closer to the farm area.

Conclusion

The present study revealed that the GLVs (total 180) collected from Colombo area, Sri Lanka, with 43 % (Cd), 52 % (Ni), and 1.5 % (Cu) were exceeding the maximum permissible limits established for human consumption. Dietary intake of foods contaminated with heavy metals results in long-term low-level body accumulation of these elements, and the detrimental impacts become apparent only after several years of exposure. Thus, regular monitoring of these toxic heavy metals in leafy vegetables and in other food materials is essential to prevent their excessive buildup in the food chain. Studies are in progress to assess the other types of heavy metals (Hg, As, Zn, Co, and Mn) present in the commonly consumed GLV, as well as to find the particular sources of heavy metals in respective GLV cultivation areas.

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286

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