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Heavy metal(loid)s and health risk assessment of Dambulla vegetable market in Sri Lanka

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Abstract Vegetables are essential for a healthy diet in humans. However, vegetables can carry harmful metal(loid) contaminants such as As, Cd and Pb which are deleterious to health in the long term. It has been postulated that long-term heavy metal(loid) exposure by vegetable consumption is associated with chronic kidney disease of unknown aetiology (CKDu) that prevails in North Central Province of Sri Lanka. We performed a human health risk assessment to identify if there is any link between heavy metal(loid) exposure from vegetable consumption and the prevalence of CKDu. The study includes a survey of food consumption in CKDu-impacted areas and determination of the heavy metal(loid) contents of market vegetables. We found that *Solanum tuberosum* (potato) and *Momordica charantia* (bitter gourd) accumulated Pb to a greater extent than other vegetables and exceeded the permissible concentration for foodstuffs. The Cd content of *Solanum melongena* (Brinjal) also exceeded permissible levels. However, the As content was below permissible levels for all the vegetables tested. The weekly total heavy metal(loid) intake of Cd, As and Pb in vegetables in CKDu-impacted areas was lower than permissible limits. The consumption of an average amount of vegetables does not pose a chronic health risk to the consumers. There was no evidence of a link between the consumption of heavy metal(loid)s in vegetables and CKDu. Since, few vegetables showed marked heavy metal(loid) accumulation, periodical monitoring of heavy metal(loid) concentrations in vegetables will be beneficial for avoidance of future possible health risks.

Keywords Heavy metal(loid)s · Human health risk · Food consumption survey · Health risk of vegetables

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Introduction

Vegetables are essential to the human diet because they act as the main sources of some vitamins, minerals, antioxidants and fibre (Slavin & Lloyd, 2012) that are essential for maintaining health. It has been recognised that vegetable consumption results in good health outcomes because it reduces the risks of non-communicable diseases such as cancer, stroke, diabetes and cardiovascular Alzheimer's diseases (Liu, 2003). Such non-communicable diseases have become major causes of mortality and morbidity among Sri Lankans, which might be attributed to their large intakes of carbohydrates and an imbalance of other nutrients (Ediriweera et al., 2018). The consumption of a vegetable-rich diet has been identified as a critical strategy to curtail chronic diseases (Perera & Madhujith, 2012). The low energy density of most vegetables can substantially reduce calorie intake, which can be used to better manage chronic non-communicable diseases (Blanck et al., 2008). It has been stated that more than 30% of cancer deaths in the USA could be eliminated if more fruit and vegetables were eaten (Liu, 2003). Two or more daily servings (150–200 g/day) of vegetables have been recommended for good health (Aranceta, 2004). However, studies have estimated that only 11.6% of Sri Lankans eat sufficient vegetables (Jayawardena et al., 2013), and there is overconsumption of carbohydrates.

Despite their health benefits, vegetables can phyto-accumulate As, Cd and Pb, which are harmful to consumers, due to the gradual build-up of heavy metal(loid)s in cultivated soil from the continued application of agrichemicals (Premarathna et al., 2010) or natural high background levels of cultivated area. Few studies have documented that triple supper phosphate used in Sri Lanka carry a substantial amount of toxic heavy metal(loid)s (Jayasumana et al., 2015; Jayatilake et al., 2013) which can eventually transfer to the human body by food consumption. Among the several exposure pathways of heavy metal(loid)s to the general population, contaminated food makes the most significant contribution to daily intake (Mahmood & Malik, 2014). Therefore, increased vegetable consumption should be coupled with frequent monitoring of heavy metal(loid)s in vegetables (Guerra et al., 2012).

The long-term exposure to toxic heavy metal(loid)s is harmful to human health (Jarup, 2003). Such health effects include damage to bones, reproductive biology and kidneys from exposure to Cd (Godt et al., 2006); cardiovascular disease, neurological disorders, lung cancer, skin lesion and hyperkeratosis from As exposure (Smith & Steinmaus, 2009); and neurotoxicity, damage to children's nervous system and increased blood pressure from Pb exposure (Needleman & Bellinger, 1991). Harm mainly results from heavy metal(loid) accumulation in kidneys, adrenal glands, liver, lungs, hair and the skin (Szyczewski et al., 2009), and in the long term can cause organ malfunction. More specifically, heavy metal(loid)s are a proposed risk factor for the occurrence and spread of chronic kidney disease of unknown aetiology (CKDu) in Sri Lanka (Jayatilake et al., 2013). CKDu has emerged as a serious health issue in Sri Lanka which has created greater social and economic impact to residents in disease endemic areas (Wijewickrama et al., 2019). The disease first emerged in North Central Province, and currently, it is emerging in some other villages of Uva, North-western, North, Central and Eastern provinces of country (Wijetunge et al., 2015).

The Dambulla Dedicated Economic Centre (DDEC) of Sri Lanka serves as a large-scale collection and distribution market for fruits and vegetables from producers to consumers. Approximately 3500–4000 metric tonnes/day of vegetables and fruits are sold during the major production season. Vegetables received from the main growing areas including Nuwara Eliya, Anuradhapura, Matale, Kegalle, Kurunegala, Polonnaruwa, Badulla, Puttalam, Trincomalee, Jaffna and Mannar districts are distributed to many parts of the country from this market, including CKDu endemic areas. The studies on drinking water quality in CKDu endemic areas have not found harmful amounts of heavy metal(loid)s (Chandrajith et al., 2011; Rango et al., 2015; Wimalawansa, 2019). Hence, information of heavy metal(loid) exposure through vegetable consumption is important in understanding the link between heavy metal(loid) exposure and CKDu occurrence.

The limited information on heavy metal(loid) content of vegetables in Sri Lanka limits our ability to assess human health risks associated with the consumption of commonly grown vegetables. To this end, this study aims to (1) study vegetable consumption patterns of residents in CKDu endemic areas, (2) quantify heavy metal(loid) concentrations in major vegetables and (3) investigate the daily intake of toxic metal(loid)s by humans from the consumption of vegetables in CKDu endemic areas.

Methodology

Sample collection

Three replicate samples of 23 types of vegetables were purchased from Dambulla DEC during May 2018. The 23 types of vegetables were chosen as they represent the most commonly sold vegetables. The individual samples were taken from three busy stalls to ensure the samples were independent and representative of what was being purchased. Each sample was stored separately in clean polyethylene bags, and transported on the same day to Regional Agricultural Research and Development Centre (RARDC) laboratory, Aralaganwila, Sri Lanka, for preliminary processing. Vegetables were categorised into root vegetables, *Daucus carota* (carrot), *Ipomoea batata* (sweet potato), *Beta vulgaris* (beetroot), *Brassica oleracea* (knol khol) and *Raphanus sativus* (radish), stem vegetables, *Allium cepa* (onion), *Solanum tuberosum* (potato) and *Allium porrum* (leeks), leafy vegetables, *Lactuca sativa* (lettuce), *Allium cepa* (vegetable onion) and *Brassica oleracea* (cabbage), fruit vegetables, *Cucumis sativus* (cucumber), *Solanum lycopersicum* (tomato), *Momordica charantia* (bitter gourd), *Luffa acutangular* (ridged gourd), *Solanum melongena* (brinjal), *Capsicum annuum* (capsicum), *Capsicum annuum* (green chilli), *Abelmoschus* esculentus (okra), *Cucurbita pepo* (pumpkin), and legumes, *Phaseolus vulgaris* (green beans), *Phaseolus vulgaris* (string beans) and *Psophocarpus tetragonolobus* (winged beans).

Procedure for sample preparation and chemical analysis

Vegetables were washed twice with tap water in order to remove adhered soil particles and plant debris, and then with distilled water. Non-edible parts of vegetables were removed, and the edible parts were chopped into small pieces using a stainless steel knife. The fresh weights of the samples were recorded before drying in an oven overnight at 100 °C in aluminium containers. The dry weights of samples were recorded, and the oven-dried samples ground using a clean stainless steel grinder to obtain a homogenous sample. Finely powdered samples were packed into polyethylene bags and sent to The University of Newcastle, Australia, for trace metal analyses.

Triplicates of each sample were acid digested. Briefly, about 0.5 g of each powdered vegetable sample was accurately weighed into a glass tube; 5 ml of trace metal analysis grade HNO_3 (70%) was then added before standing overnight in a fume cupboard. Block digestion was done according to the procedure described by Rahman et al. (2013). The digest was diluted to 20 ml with Milli-Q water and mixed well using a vortex mixer. The diluted solution was then filtered through a 0.45-µm syringe filter and the filtrate analysed for trace metal(loid)s by inductively coupled plasma mass spectrometry (ICPMS 7900, Agilent Technologies, Japan) and inductively coupled plasma emission spectrometry (PerkinElmer, Avio 200). The instrument detection limits for trace metals were Cd 0.03, Co 0.01, Cu 0.02, Mn 0.02, Pb 0.05 and Zn 0.01 µg/L (Mwale et al., 2018).

Daily vegetable consumption rates and health risk evaluation

The ingestion rate of vegetables was obtained by a food consumption survey in an area where chronic kidney disease of unknown aetiology (CKDu) is prevalent (Medirigiriya Divisional Secretary in the District of Polonnaruwa). Consecutive 7-day food consumption data were obtained by diet diaries maintained by 100 participants. Human ethics clearance for the dietary survey was obtained from the Human Ethics Committee of The University of Newcastle, Australia (H-2017-0250) and Ethics Review Committee of the Faculty of Medicine, Rajarata University of Sri Lanka (ERC/2017/62). Prior to the survey, participants' information statements were explained and their consent was obtained. The diet diary survey was conducted during June–July 2018 to obtain the consumption rates of different vegetables, and data were utilized to calculate weekly vegetable intake for each type of vegetable. Average body weights of adults and children were obtained from our duplicate diet study in the same geographical area. The total weekly intake (TWI) of heavy metal(loid)s from each vegetable was calculated using Eq. 1, which is based on US EPA 2006 (Fan et al., 2017; Ullah et al., 2017; Wu et al., 2009):

$$TWI = C_M \times WI / BW_A \tag{1}$$

where C_M = metal(loid) concentration in each vegetable (µg/kg).

WI = weekly vegetable intake (kg),

BW_A = average body weight (kg) of different age groups.

BW_A = average body weight (kg) of different age groups.

The hazard quotients (HQs) for the heavy metal(loid)s, Cd, As, Pb, Mn, Zn and Cu, were calculated with

Eq. 2 based on US EPA 2011 (Ametepey et al., 2018). The oral reference dose (RfD) for these heavy metal(loid)s were 0.5, 3, 3.5, 14, 300 and 420 (μg/kg/day), respectively, as used in the calculation advised by US EPA 2008 (Ametepey et al., 2018).

$$HQ = TDI / RfD \quad (2)$$

where,

TDI = total daily heavy metal(loid) intake (μg/kg/day).

RfD = oral reference dose (μg/kg/day).

Descriptive statistical analyses of the results were compared with the safety guidelines. All statistical analyses were performed using JMP software (JMP, 2013).

Results and discussion

Heavy metal(loid)s in vegetables

The concentrations of Mn, Co, Cu, Zn, As, Cd and Pb in common vegetables collected from Dambulla DEC (wet weight basis) showed significant variation between the vegetables, with the highest concentrations recorded in *Phaseolus vulgaris* (string bean) (Table 1). Variation in the heavy metal(loid) concentrations among vegetable types may be attributed to differences in the areas they are cultivated and differences in phyto-accumulation capacity of the organs (Liu et al., 2013). For instance, phyto-accumulation of heavy metal(loids) was greater in tubers than leaves in cassava (Harrison et al., 2018). The CODEX (1995) standards for allowable limits for Cd, Pb and As were set at 0.1 mg/kg on a wet weight basis for most types of vegetables, and 0.3 mg/kg was applied to root and tuber crops. According to these allowable limits, the As and Cd content of all vegetables except *Solanum melongena* (brinjal) (Table 1) was less than the CODEX (1995) standard. The Pb content in *Ipomoea batata* (sweet potato) and *Momordica charantia* (bitter gourd) has reached to allowable limit, while all other studied vegetables had values below the allowable limits (Table 1).

Detailed studies of heavy metal(loid) concentrations in vegetables grown in Sri Lanka have been limited, and only a few published analyses are available for a few selected vegetables, such as lotus rhizomes (Bandara et al., 2008; Jayatilake et al., 2013) and leafy vegetables (Kananke et al., 2014). Consequently, heavy metal(loid) concentrations found in the present study were compared with studies undertaken in neighbouring countries and grown in uncontaminated agricultural lands, to assess heavy metal(loid) status.

Among the vegetables in the present study, *Phaseolus vulgaris* (string beans) contained the highest Mn concentrations, while *Cucumis sativus* (cucumbers) had the lowest (Table 1). However, on a dry weight basis, the Mn concentration was lowest in *Ipomoea batata* (sweet potato) (5.51 mg/kg), while *Lactuca sativa* (lettuce) (65.8 mg/kg) showed the highest. A similar result was reported for market vegetables in Saudi Arabia, where Mn was in the range of 5.3 mg/kg on a dry weight basis (root vegetables) to 65.5 mg/kg (leafy vegetables) (Ali & Al-Qahtani, 2012). A study in Pakistan also found similar Mn concentrations (dry weight basis) in *Luffa acutangular* (ridged gourd) (18.7 mg/kg), *Solanum melongena* (brinjal) (23.2 mg/kg) and *Cucurbita pepo* (pumpkin) (33.8 mg/kg) (Latif et al., 2018). In the present study, Mn values in these vegetables were 39.0, 21.6 and 25.6 mg/kg, respectively, and not markedly different from those of other countries.

The concentration of Cu was lowest in leeks and highest in *Solanum melongena* (brinjal) (Table 1). Market vegetables in Bangladesh reportedly had much higher Cu concentrations of 2.25 to 9.71 mg/kg wet weight basis (Shaheen et al., 2016). In the study by Islam et al. (2015), the minimum and maximum Cu concentrations in market vegetables were 1.5 and 5 mg/kg, respectively, and greater than those reported here. On a dry weight basis, the lowest Cu value was reported for *Brassica oleracea* (cabbage) (1.92 mg/kg) and the highest in *Psophocarpus tetragonolobus* (winged beans) (14.4 mg/kg) in the Bangladeshi study. In Saudi Arabian market vegetables, the Cu concentration ranged between 2.8 mg/kg and 12.5 mg/kg (Ali & Al-Qahtani, 2012). Yang et al. (2018) reported that the average Cu concentration of vegetables grown in China was 6.67 mg/kg, close to the 6.33 mg/kg reported in the current study, while the Cu content in Pakistani vegetables (Latif et al., 2018) was higher (22.3 to 65.2 mg/kg). In Indian market vegetables, the mean concentration for Cu was reported as 9.5 mg/kg (dry weight basis) (Sharma et al., 2009). In general, the vegetables from Dambulla DEC had smaller concentrations of Cu than those found elsewhere.

Table 1 The heavy metal(loid) content in vegetables (mg/kg fresh weight basis)

Vegetable	Metal						Moisture%
	Mn	Cu	Zn	As	Cd	Pb	
Root							
Carrot	4.11	0.62	2.32	-	0.01	0.09	96
Sweet potato	1.19	0.66	0.62	-	-	**0.10**	**78**
Beetroot	2.50	0.53	1.97	0.01	-	0.03	91
Knol khol	1.83	0.41	1.83	0.01	-	0.03	94
Radish	2.85	0.33	2.53	0.01	-	0.03	93
Stem							
Onion	1.70	0.76	2.12	-	0.01	0.03	88
Potato	1.32	0.72	1.30	0.01	0.03	0.09	84
Leeks	1.09	0.22	0.97	-	-	0.03	96
Leafy							
Lettuce	3.96	0.45	2.39	0.01	0.02	0.08	95
Vegetable onion	2.08	0.42	1.13	0.01	-	0.02	95
Cabbage	1.69	0.15	1.22	-	0.01	0.06	93
Fruits							
Cucumber	0.93	0.23	0.76	-	-	0.06	97
Tomato	2.12	0.41	1.37	-	0.01	0.03	93
Bitter gourd	2.47	0.48	2.18	-	-	**0.11**	93
Ridged gourd	2.54	0.63	1.61	-	-	0.02	95
Brinjal	2.48	1.43	1.64	0.01	**0.15**	-	90
Capsicum	1.49	0.60	1.32	-	0.01	0.04	94
Green chilli	3.74	1.05	2.49	0.01	0.01	0.06	87
Okra	2.58	0.87	4.36	0.01	0.01	0.05	90
Pumpkin	2.68	0.38	0.64	-	-	0.02	92
Legume							
Green beans	5.50	0.71	2.87	-	0.04	-	90
String beans	6.19	0.84	3.68	0.01	-	0.04	92
Winged beans	4.52	1.10	1.86	0.01	-	0.03	95

Numbers in bold are at the maximum permissible limit

Zinc concentrations were low in *Ipomoea batata* (sweet potato) and *Cucurbita pepo* (pumpkin), but high in *Abelmoschus esculentus* (okra) (Table 1). The zinc concentrations were comparable with those reported in Bangladeshi vegetables (Shaheen et al., 2016) and ranged from 0.07 to 4.75 mg/kg on a wet weight basis. On a dry weight basis, the lowest value for Zn was 2.88 mg/kg (*Ipomoea batata*—sweet potato) and the highest was 61.74 mg/kg *Daucus carota* (carrot) in the current study. In contrast, the highest concentration of Zn was observed in *Ipomoea batata* (sweet potato) (28.6 mg/kg) and the least value reported in *Daucus carota* (carrot) (8.3 mg/kg) from Saudi Arabian market vegetables (Ali & Al-Qahtani, 2012). Pakistani market vegetables ranged from 19.5 to 41 mg/kg (Latif et al., 2018). Further, on dry weight basis, 29.6 mg/kg of Zn content was reported in Indian market vegetables (Sharma et al., 2009). It is evident that Dambulla DEC market vegetables are relatively rich in Zn, which is an essential mineral.

Vegetables of Dambulla DEC had As concentrations (Table 1) that were much lower than those of Bangladesh (0.04 – 0.8 mg/kg wet weight basis) (Islam et al., 2015). However, As detected by Shaheen et al. (2016) in Bangladeshi vegetables varied from 0.004 to 0.018 mg/kg, which is comparable to Dambulla DEC vegetables. High As concentrations in irrigation water and soils used for cultivation are common in many parts of Bangladesh (Islam et al., 2017; Juhasz et al., 2003), and result in high As concentrations in Bangladesh-grown food crops (Khan et al., 2010; Rahman et al., 2014).

Dambulla DEC vegetable Cd concentrations were small in *Phaseolus vulgaris* (string beans) and *Ipomoea batata* (sweet potato), and the highest in *Solanum melongena* (brinjal) (Table 1). Results for the analyses of Cd in market vegetables in Bangladesh ranged from 0.03 to 0.3 mg/kg on a wet weight basis (Islam et al., 2015), which is much higher than the vegetables analysed here. In contrast, Shaheen et al. (2016) reported that the Cd concentrations of Bangladeshi market vegetables ranged from 0.008 to 0.056 mg/kg on a wet weight basis, which is slightly higher than those in Table 1. On a dry weight basis, the concentrations of Cd in Saudi Arabian market vegetables varied from 1.1 to 3.89 mg/kg, which was much higher than the current study, in which the concentration ranged from 0.002 (*Ipomoea batata*—sweet potato) to 0.28 mg/kg in *Lactuca sativa* (lettuce). Market vegetables in Pakistan and India also exhibited higher levels of Cd compared to 0.001 mg/kg found in Dambulla DEC vegetables. The Cd levels in the market vegetables in Parkistan ranged from 0.04 to 0.39 mg/kg (Latif et al., 2018), while in Indian market vegetables, the mean value was 0.5 mg/kg dry weight basis (Sharma et al., 2009). In general, the concentrations of Cd in Dambulla DEC vegetables were smaller than those in other South Asian countries or Saudi Arabia.

Analyses of Dambulla DEC vegetables showed the highest Pb concentrations in *Momordica charantia* (bitter gourd) while the lowest was in *Solanum melongena* (brinjal) (Table 1). Lead concentrations in Bangladeshi market vegetables varied between 0.03 and 1.2 mg/kg (Islam et al., 2015) and 0.005 to 0.011 mg/kg (Shaheen et al., 2016) on a wet weight basis, indicating that the Dambulla DEC vegetables had less Pb. On a dry weight basis, *Cucurbita pepo* (pumpkin) (0.16 mg/kg) has the least Pb and *Solanum melongena* (brinjal) (1.37 mg/kg) the highest Pb concentrations, as in the present study. On the dry weight basis, the concentration of Pb in Indian market vegetables was 0.3 mg/kg (Sharma et al., 2009). Analyses of Pakistani market vegetables (Latif et al., 2018) did not detect Pb, and in China, market vegetables ranged from 0 to 1.47 mg Pb/kg on a dry weight basis (Yang et al., 2018). The mean As, Cd and Pb concentrations in 28 different market vegetables of Zhejiang Province in China were 0.013, 0.017 and 0.034 mg/kg, respectively (fresh weight basis) (Liu et al., 2013). Means of As, Cd and Pb concentrations in the present study were 0.004, 0.007 and 0.05 mg/kg (fresh weight basis), respectively, indicating that the DEC vegetables were not contaminated by these toxic heavy metal(loid)s.

Vegetables grown in the areas supplying the DEC are relatively low in heavy metal(loid)s compared to neighbouring countries (Islam et al., 2015; Latif et al., 2018; Shaheen et al., 2016). The vegetable cultivation areas are not highly industrialised and this may explain the low heavy metal(loid) concentrations found here. The possible sources of contamination are fertilisers or geological sources such as ultramafic rocks (e.g. serpentine). Fertilisers used in Sri Lanka have been reported to have impurities of heavy metal(loid)s (Jayasumana et al., 2015; Jayatilake et al., 2013). However, vegetables grown in major growing areas of Sri Lanka are not contaminated with heavy metal(loid)s to hazardous levels.

Weekly intake of vegetables

According to survey data, the most frequently consumed vegetables (number of time per week per person) were in the following order: potato (1.96) > brinjal

Table 2 Weekly vegetable ingestion rate (kg fresh weight/week) of female adults (FA), male adults (MA), male children (MC) and female children (FC)

Vegetables	Categories			
	FA	MA	MC	FC
Green Beans	0.06	0.04	0.05	0.04
Beet root	0.07	0.07	0.07	0.07
Bitter gourd	0.10	0.08	0.10	0.10
Brinjal	0.14	0.14	0.14	0.15
Cabbage	0.06	0.03	0.06	0.05
Capsicum	0.08	0.13	0.08	0.06
Carrot	0.07	0.06	0.06	0.06
Cucumber	0.05	0.08	0.07	0.04
Knol Khol	0.08	-	0.07	-
Leeks	0.10	-	0.06	0.05
Ridged gourd	0.10	0.07	0.11	0.14
Okra	0.08	0.08	0.07	0.04
Potato	0.11	0.08	0.13	0.11
Pumpkin	0.09	0.14	0.20	0.14
Radish	0.08	0.10	0.06	0.07
String bean	0.10	0.09	0.09	0.07
Sweet potato	0.10	-	0.08	-
Winged bean	0.04	0.04	0.05	0.06

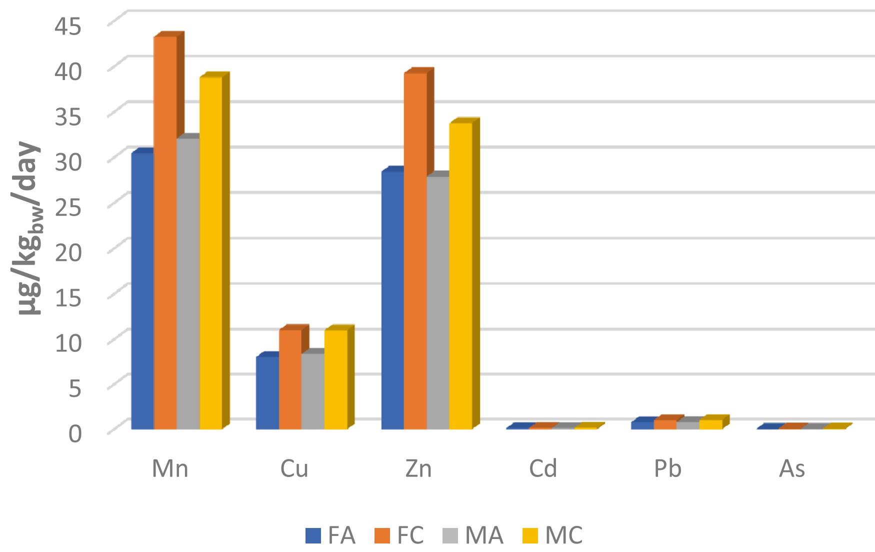

Fig. 1 Estimated weekly intake of heavy metal(loid)s from vegetables (FA = female adults, FC = female children, MA = male adults and MC = male children)

(1.45) > string bean (1.22) > pumpkin (0.83) > beans (0.70) > ridged gourd (0.70) > cabbage (0.67), whereas the least frequently consumed vegetables were knol khol > (0.09), leeks (0.09) and sweet potato (0.07).

Table 2 presents a summary of the survey data on the weekly intake of each vegetable. The total weekly vegetable intake according to diet diary survey for an adult females, adult males, female children and male children were 0.81, 0.85, 0.65 and 0.68 kg (fresh weight), respectively. No differences were found for ingestion rates of these vegetables between age and gender groups. The daily vegetable intake of young adults of Sri Lanka was reported as 127 g fresh weight (Perera & Madhujith, 2012), so the adult population in CKDu endemic areas had similar vegetable consumption rate as other parts of the country.

Estimation of weekly intake of heavy metal(loid)s

Estimated weekly intakes (EWIs) of Cd, As, Cu and Pb from consumed vegetables were calculated using the respective concentrations of metal(loid)s in vegetables, and weekly average intake of adults and children is stated in Fig. 1. EWI for nephrotoxic heavy metal(loid)s of Cd, Pb and As ranged from 0.11 to 0.15, 0.77 to 1.03 and 0.04 to 0.06 µg/kg_{bw}/week, respectively. Hence, EWIs of those metal(loid)s were well below the allowable weekly intakes of Cd, Pb and As of 7, 25 and 14 µg/kg_{bw}/day, respectively (FAO/WHO, 2011).

The EWI was higher for children than adults, which may be due to their lower body mass (Tajdar-Oranj et al., 2018). EWI from the consumption of vegetables follows the decreasing order of Mn > Zn > Cu > Pb > As > Cd. Health risks from individual metal(loid) exposure were assessed by calculating hazard quotients (HQ, Table 3). All the measured heavy metal(loid) HQ values were less than 1, confirming that the health risk from consuming metal(loid)s present in vegetables was minimal. Therefore, the consumption of vegetables at the measured frequencies and quantities will not pose an adverse health risk.

Table 3 HQ for Mn, Cu, Zn, Cd, Pb and As from vegetable intake of an adult female (AF), female children (FC), male adult (MA) and male children (MC)

Gender	Metals					
	Mn	Cu	Zn	Cd	Pb	As
AF	0.311	0.003	0.014	0.031	0.031	0.002
FC	0.441	0.004	0.019	0.037	>0.042	0.003
MA	0.327	0.003	0.013	0.031	0.032	0.002
MC	0.396	0.004	0.016	0.043	0.042	0.003

Conclusions

Heavy metal(loid) concentrations of vegetables consumed in Dambulla DEC did not differ greatly from this found in comparable countries. It was found that consuming Dambulla DEC-sourced vegetables at the measured rates does not pose a health risk for people as the EWI for toxic-heavy metal(loid)s were below the permissible levels. The potential to bio-accumulate heavy metal(loid)s differed according to the type of vegetable. Typically, legume vegetables had a greater tendency to accumulate Mn, Cu and Zn than other kinds of vegetables. Carrot, which is a root vegetable, tended to accumulate more Mn than other vegetables, and okra—a fruit vegetable—accumulated more Zn than other vegetables. However, some vegetables in this study accumulated Cd and Pb at greater than their permissible levels. Therefore, regular monitoring of heavy metal(loid) concentrations of vegetable is necessary, particularly if intensification of agricultural practices lead to increased metal concentrations.

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Data availability The datasets generated during and/or analysed during the current study area available from the corresponding author on reasonable request.

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