Heavy Metal Status in Sri Lanka

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Abstract: The growing phenomenon of environmental contamination mainly due to heavy metals have gained considerable attention of both scientific and public communities. Heavy metals are natural constituents of the environment. Indiscriminate human interventions, such as agriculture and related industries have changed the atmospheric geochemical cycles and biochemical balance of heavy metals. It is well established that excess exposure to heavy metals causes adverse effects on both plants and human beings. The present review is based on the current research evidence on the reported levels of toxic heavy metals such as Cadmium (Cd), Lead (Pb), Arsenic (As), Nickel (Ni), Zinc (Zn), Copper (Cu), Mercury (Hg) Manganese (Mn) and Chromium (Cr) in the Sri Lankan geo-environment.

Keywords: Contamination, Geo-environment, Heavy metals, Sri Lanka, Toxic

1. WHAT IS A HEAVY METAL?

The term "heavy metal" refers to a metal or metalloid with a density greater than 5g /cm^3 and is usually associated with pollution and toxicity, although some of these elements are actually required by organisms at minute quantities (Jarup *et al*., 2003). Heavy metals enter the environment through natural processes, especially *via* weathering of bed rock and relevant parental materials (Damodaran *et al*., 2003) and through anthropogenic sources such as industrial waste, agrochemicals, sewage sludge, and traffic emissions (Bell *et al*., 2001; Passariell *et al*., 2002).

Metallic elements are classified into two groups as essential and non-essential elements. Essential metal elements are those which are required in significant amounts by the body and are vital for metabolic activities. Essential elements such as Copper (Cu), Iron (Fe), Zinc (Zn) and Selenium (Se) are required in trace amounts by the body. However, deficiencies of these elements could be fatal to human. Non-essential elements such as Lead (Pb), Arsenic (As), Cadmium (Cd) and Mercury (Hg) can be harmful to biological life if they are present in higher levels than the maximum allowable concentrations in the environment (Cobbett *et al*.,2002; Farrag *et al*.,2013; Razzaq *et al*.,2017). Those non-essential elements are non-degradable and have the ability to accumulate in the body *via* the food chain.

Usually heavy metals are released into the environment from weathering of mineral ores naturally or artificially (Razzak *et al*., 2017). As shown in Alloway, 2012, most of the heavy metal ores exist as sulphides in nature and their natural oxidation process give rise to acidic soils which stimulate the solubility and mobility of heavy metals. By artificial mining of ores, large amount of heavy metals is released to the environment as waste. For example, in gold mining, metals such as copper (Cu), lead (Pb), and silver (Ag) are released as waste. (Fashola *et al*., 2016).

Industrialization mainly via auto mechanic industries, iron and steel mills, coal fired power plants, building material production factories have contributed to the heavy metal pollution in the urban areas (Yang *et al*., 2009; Adeleken; Abagunde, 2011). In addition to the above major categories, several industries including stainless steel welding, battery and ceramic production, pigments used in textiles and pharmaceuticals can be mentioned as minor sources for heavy metals (Tchounwou *et al*., 2012).

Main sources of heavy metal pollution in agricultural soils are routine practices such as irrigation, livestock manure application, inorganic fertilizer usage and the application of pesticides. Heavy metals accumulate in livestock manure as a result of feed supplements (Nicholson *et al*., 2003). Similarly, traces of heavy metals get deposited on plant leaves and then leach into soil with rain water as a result of foliar sprays that contain Co, Cu, Fe and Mn (Raymond *et al*., 2011).

2. EVIDENCES OF HEALTH AND ENVIRONMENTAL IMPLICATIONS OF HEAVY METAL ACCUMULATION

Heavy metal contamination in the environment can cause harmful effects for both plants and animals, including humans. Heavy metals are not degradable and remain in the soil for a considerable time duration (ZhaoK *et al*., 2015).

Cadmium (Cd) is one of the most toxic elements to which people could be exposed at working place or in the environment. The outbreak of itai-itai disease, which is the most severe stage of Cd poisoning, occurred in the Cd-polluted Jinzu River Basin in Toyama (Aoshima, 2012). The Jinzu River Basin in Japan is known to be the most heavily polluted area of Cd coming from an upstream zinc mine, and its inhabitants have long suffered from kidney damage related to Cd pollution (Nogawa, 1981). The ingested Cd accumulates selectively in the kidneys and liver, especially in the renal cortex, after long-term exposure. Patients suffer from bone pain, especially in the pelvic girdle and legs while walking. (Friberg *et al*. 1974).

The North Central Province (NCP) of Sri Lanka, also referred to as Sri Lanka's "dry zone," is the primary agricultural region of the country and has had a devastating rise of cases of Chronic Kidney Disease (CKD) (Atapattu, 2006). Currently, over 5,000 patients are being treated for kidney failure. Athuraliya *et al*., 2003 mentioned that chronic kidney failure not associated with diabetes and hypertension was reported mostly among farmers in NCP. Senevirathna *et al.,* 2008 mentioned that The Chronic Renal Failure (CRF) prevalent in north central region of Sri Lanka is the result of chronic dietary intake of heavy metals supported by naturally high levels of fluoride in drinking water, coupled with neglect of routine sediment removal from deposits for the past 20 years.

3. STATUS OF HEAVY METALS IN AGRICULTURAL SOIL AND FOOD CROP SYSTEM

Intensive agriculture, characterized by high productivity and efficiency, has contributed to increasing food production in Sri Lanka in the past 50 years (Bandara, 2007). Excessive quantities of synthetic fertilizers are regularly added to provide N, P and K to enhance crop growth and yield. Those agrochemicals including synthetic fertilizers have been identified as the major source of heavy metals in agricultural soils (Premarathna *et al.*, 2011), especially Triple Super Phosphate (TSP) contains a considerable levels of Cd as an impurity (Pierzynski *et al*., 2000) (Table I). Chandrajith *et al* (2012) also showed that the TSP collected from Medirigiriya and some parts of Giradurukotte had higher levels of Cd than in other fertilizers. With the contamination of phosphate fertilizers by toxic metals during the manufacturing process the toxicity of the ultimate product can vary (Chandraiith *et al*., 2012). Wijewardena and Gunarathne (2004) mentioned that animal manure also contains a considerable amount of trace elements (Table II).

As shown in Table II., Cu, Ni, Pb and Zn levels were below the levels set by SLSI. Considerably high amount of Cd was recorded in IRP and TSP (Table II). According to the report, TSP contained the highest amount of Cd (23.5 ppm) while Sri Lankan ERP had a relatively low amount of Cd. According to the findings of Dissanayake and Chandrajith 2009, the mean contents of Cd in paddy, vegetable and uncultivated lands were 0.35, 0.28 and 0.26 mg kg^{-1}, respectively. It is clearly shown that Cd content of paddy lands is significantly higher than vegetable and uncultivated lands. The excessive use of TSP that containing considerable amount of Cd (Table II) may be the

Table I. – Heavy metal content (mg/kg) in chemical fertilizers from different regions of Sri Lanka

Location	Fertilizer type	Cd	Pb	Ni	Cr	Al	Reference
		Amount of Heavy Metals (ppm)					
Anuradhapura	Urea	0.40	3.80	1.40	3.90	37.00	Premarathna *et al.*, 2011
	NPK	0.40	3.80	1.40	3.90	203.00	
	TSP	3.60	50.70	35.20	52.90	9 949.00	
Medirigiriya	Urea	0.40	3.70	1.40	210.30	25.00	
	NPK	0.40	3.80	1.40	23.70	135.00	
	TSP	46.10	41.10	22.30	59.50	8 563.00	
Girandurukotte	Urea	0.40	6.00	1.40	19.60	54.00	
	NPK	0.40	3.80	1.40	22.80	143.00	
	TSP	39.80	58.20	24.20	65.90	9,016.00	
Kandy	Urea	0.40	3.90	1.40	21	52.00	
	NPK	0.60	3.80	1.40	22.10	140.00	
	TSP	4.30	80.20	27.30	62.10	10,113.00	
Padawiya, Medawachchiya	Urea	ND	0.2	1.0	ND	2.6	Jayasumana *et al*, 2015
	MOP	0.1	0.8	0.3	1.2	151.3	
	TSP	2.0	252.5	25.0	29.3	9 939.0	

Table II. – Trace metal content in fertilizers and manure

Fertilizer / Manure Source	Amount of Heavy Metals (ppm)				
	Cd	Cu	Ni	Pb	Zn
Cattle manure	0.43	8.23	4.70	1.10	57.50
Poultry manure	0.97	23.90	6.87	3.20	220.10
IRP	12.18	47.85	18.30	13.50	63.70
Lime	6.53	0.87	15.65	12.85	7.05
ERP	1.92	35.50	26.60	13	61.90
Apatite	1.32	32.35	14.20	12.20	58.60
Dolamite	9.06	0.10	9.85	16.90	20.20
TSP	23.50	9.50	20.40	5.15	130
Heavy metal levels permitted in compost by SLSI	10	400	NA	250	1000

IRP; Imported Rock Phosphate, ERP; Eppawala Rock Phosphate, SLSI; Sri Lankan Institute of Standards, NA; Not Available

(Premarathna *et al*., 2011)

reason for the elevated Cd level in paddy lands (Rosemary et al., 2014). Trace metals in poultry manure are somewhat higher than those of cattle manure. Except for Cd in TSP, other trace metal levels are well below the threshold level. According to the above research findings, some fertilizer sources used currently in Sri Lanka do not contain higher levels of heavy metals. However, frequent application of such fertilizer sources in large quantities for a long time may results in the increased levels of heavy metals in the farming areas (Chandrajith *et al.*, 2010).

Rice (*Oryza sativa*) is the mostly cultivated crop throughout the year, as it is the most consumed staple food and the main source of carbohydrates in Sri Lanka (Voica *et al*., 2012). According to the WHO/FAO CODEX Alimentarius, maximum permissible levels of As, Cd, Pb, Hg and Se should be 0.2, 0.2, 0.4, 0.1 and 0.3 mg/kg respectively. Levine *et al*., 2016 mention that, the maximum measured Cd concentration in Sri Lankan rice was 0.117 mg/kg, which is below the maximum level of 0.4 mg/kg recommended by the Codex Alimentarius Commission (FAO/WHO Commission, 2011). The average concentration of As in commercial rice in Sri Lanka is 0.077 ±0.040 mg/kg which is considerably lower than the maximum Codex standard level (0.200 mg/kg) (Liu *et al*., 2020). Concentration in three samples collected from Central Northern and Western provinces for the

Table III. – Total trace metal concentrations (mg/kg) in low country region and up country region in Sri Lanka.

Region	Sub area	Cd	Cu	Ni	Pb	Zn	Reference
Low Country	Sedawatta	0.61-3.28	49-111	19-28	39-113	259-420	Premarathna *et al*., 2011
	Welawatta	0.46-1.37	33-39	20-27	34-66	171-302	
	Kotuvilla	0.98-1.31	24-28	12-16	20-56	287-302	
	Kahathuduwa	0.49-1.55	17-34	7-26	17-33	18-376	
	Bandaragama	0.53-0.89	7-14	4-13	15-15	49-121	
	Medirigiriya, Thalawa, Padawiya	NA	1.97	0.66	2.67	1.17	Jayawardana *et al*., 2014
Up country	Sitha Eliya	0.51-0.88	80-95	7-15	56-311	27-359	Premarathna *et al*., 2011
	Kandapola	0.39-1.96	34-41	7-43	27-97	178-193	
	Haputale	0.51-3.86	34-97	3-16	26-242	121-486	
	Bogahakubura	1.30-1.42	58-106	6-28	45-75	56-194	
	Rhangala	1.22-1.29	114-139	8-67	97-116	141-342	
	EU	1-3	50-140	30-75	50-300	150-300	
	USEPA	20	750	210	150	1400	
	Soil	<0.1	5-5.6	10-50	2-13	60-780	

NA – Not Available, EUa: European Union set standards for sewage sludge amended soils (McGrath et al., 1999)
USEPAb: McGrath et al., 1995. Calculated from maximum cumulative pollutant loading limits, assuming incorporation to 15-cm depth and average soil bulk density of 1.33 g cm-3, but not including background concentrations of these elements in soilsSoilb: Herrick et al., 1990

study of Liu *et al*., 2020, exceeded the Codex threshold (0.400 mg/kg) by 1.5 to 2 times. However the average Pb concentration of commercial rice was 0.031 ± 0.052 mg/kg (< 0.400 mg/kg).

In Sri Lanka, vegetables are highly recommended for humans and are consumed in large quantities as part of the daily diets (Cobb *et al*., 2000). Heavy metal contamination at relatively higher levels (eg: Cd, Cu, Zn, Pb, Ni) has been reported in various food crops such as *Abelmoschus esculentus* (Okra), *Solanum melongena* (Eggplant). *Brassica campestris* (Field mustard), *Beta vulgaris* (Beetroot), *Cucumis sativus* (Cucumber), *Pisum sativum* (Pea), *Coriandrum sativum* (Coriander), *Spinacia oleracea* (Spinach), *Lycopersicon esculentum* (Tomato), and *Brassica oleracea* (Cabbage) (Chen *et al*., 2014; Ghosh *et al*., 2013; Gupta *et al*., 2013; Mubofu, 2012; Cao *et al*., 2010; Naser *et al*., 2009; Alam *et al*., 2003b;). Therefore, the accumulation of heavy metals through the edible parts of vegetables represents a direct route for their incorporation into the human food chain (Florigin, 1993).

Elevated levels of heavy metals have been reported in some parts of the intensive vegetable growing areas of the up country and the low country (Premarathna *et al*., 2011). According to the results, the highest concentration of trace metals in the soil were found in the Sedawatta area for almost all trace metals (Table III). The recorded concentration in that area is higher than the European Community set standards that allowed in agricultural soils treated with sewage sludge. However, it is lower than the United States set standards in 1993. It is mentioned that most of the fields studied in the Sedawatta area has more than 20 years of cultivation where poultry manure has been used for agricultural purposes for about 10 years, while the fields studied in Welawatta and Kotuwilla has a cultivation history of approximately 10-20 years. These results also show that the number of years under cultivation has an effect on the accumulation of trace metals in the agricultural soils of Sri Lanka (premarathna *et al*., 2011).

Vegetable cultivation is more intensive and highly commercialized in the up country intermediate zone (UCIZ) and the up country wet zone (UCWZ) of Sri Lanka. Farmers in these areas grow 2-3 crops per year on the same land. Vegetable growers in UCIZ and UCWZ use 2-3 times higher than the recommended dose of fertilizers (Wijewardena and Yapa., 1999). The use of animal manure is well adopted especially by farmers of potatoes and vegetables and, to a lesser extent, for rice and local tuber crops (Wijewardena and Gunarathna, 2004). Generally, soils of up country wet zone are acidic in nature and it is a major limitation for the agriculture in the up country of Sri Lanka (Kumaragamage *et al*., 1999). Most probably that could be the reason for adding excess amounts of poultry manure and lime to those fields (Wijewardena and Gunarathna, 2004).

The results of Kanake *et al*., 2014 indicated that the average concentrations of heavy metals in five types of green leafy vegetables increased in the order of Cd<Pb<Cr<Ni<Cu (Table IV). The selected green leafy vegetables were “Kangkung" (*Ipomoea aquatica*), "Mukunuwenna" (*Alternanthera sessilis*), "Thampala" (*Amaranthus viridis*), "Nivithi" (*Basella alba*) and “Kohila” *(Lasia spinosa*). Highest concentration of Ni (15.89 mg/kg), Cd (0.97 mg/kg), Pb (1.59 mg/kg), and Cu (18.44 mg/kg), were found in Kohila leaves, while the highest amount of Cr (5.05 mg/kg), was found in Mukunuwenna.

4. STATUS OF HEAVY METALS IN WATER AND RESERVOIRS IN SRI LANKA

The estimated groundwater potential of Sri Lanka is about 780,000 hectares per year (Mikunthan, and De Silva, 2008). Anthropogenic activities such as, the application of agrochemicals (pesticides and herbicides), manure and sewage sludge may change the natural concentrations of heavy metals at various degrees (Sanjeevani *et al*., 2013). Thus the following paragraphs review the existing status of heavy metals in water sources and reservoirs in Sri Lanka.

According to the Sri Lankan standards (Sri Lankan Standard Institute 2013) and the

guidelines of the World Health Organization (WHO) (WHO 2011), the maximum allowable level of arsenic (As) in drinking water is 0.01 ppm. Jayawardana *et al*., 2012 showed that As concentration, is less than 0.01 ppm in the groundwater system in dry (Eppawala, Talawa, Madirigiriya, Padaviya and Galgamuwa) wet (Hikkaduwa and Kandy) and intermediate (Siyabalangamuwa, Matale and Naula) zones in Sri Lanka. Figure II shows the maximum concentration of As, Cd, Pb and Cr in well water in each district (25 districts) of Sri Lanka.

According to Sri Lankan Standard Institute 2013 and WHO 2011 the acceptable level of cadmium (Cd), lead (Pb) and chromium (Cr) in drinking water should be 3 µg/L, 10 µg/L and 50 µg/L respectively. According to the study done by Herath *et al*., 2018, no district exceeded the maximum allowable level of Cd and Cr in well water. Galle District showed an extremely high concentration of Pb in well water at 288 µg / L. All the other districts were below the maximum concentrations of Pb (10 µg / L).

Sri Lanka as a developing country with minimum land extend, most common disposal method of municipal solid wastes is placing in open dumps or landfills (Abeynayaka and Werellagama, 2007, Perera, 2003). Landfill leachate may contain heavy metals (Alluri *et al*., 2007) and when the landfill leachate mixes with the groundwater, it forms a plume that extends in the direction of the flowing groundwater (Slack *et al*., 2005). As an example the concentration of heavy metals in leachate samples collected from the Gohagoda landfill site has been presented in Table. V (Dharmarathne and Gunatilake, 2013). According to the findings of Dharmarathne and Gunatilake, the highest average concentration of Fe indicates that Fe and steel scrap are dumped in the Gohagoda landfill. The presence of excessive Zn in the leachate samples shows that the landfill receives waste from batteries and fluorescent lamps.

Table IV. – Heavy metal concentrations (mg/kg) of food crops in Sri Lanka

Food crop	Reported heavy metal concentration (mg/kg)						Reference
	Ni	Cd	Cr	Pb	Cu	As	
Leafy Vegetables							
Mukunuwenna (*Alternanthera sessilis*)	15.89	0.90	5.05	1.32	16.25		Kananke *et al*., 2014
Nivithi (*Basella alba*)	6.39	0.72	2.82	0.97	13.49		Kananke *et al*., 2014
Thampala (*Amaranthus viridis*)	3.56	0.54	3.07	1.04	12.09		Kananke *et al*., 2014
Kankung (*Ipomoea aquatic)*	15.27	0.19	1.38	0.45	13.65		Kananke *et al*., 2014
Kohila *(Lasia spinosa*)	15.89	0.97	4.66	1.59	18.44		Kananke *et al*., 2014
Gotukola *(Centella asiatica)*	6.27	0.54	NA	8.75	6.03		Premarathne *et al*., 2005
Legumes and cereals							
Rice *(Oryza sativa)*	1.34	0.12	0.18	0.15	5.43	NA	Levine *et al*., 2016
Rice *(Oryza sativa)*	NA	0.022	NA	0.237	NA	0.046	Jayalal *et al.*, 2019
Mustard *(Cynara cardunculus)*	0.014	NA	NA	NA	NA	ND	Edirisinghe and Jinadasa, 2019
Maize *(Zea mays)*	0.010	NA	NA	NA	NA	0.091	Edirisinghe and Jinadasa, 2019
Finger Millet *(Eleusine coracana)*	0.022	NA	NA	NA	NA	0.053	Edirisinghe and Jinadasa, 2019
Sesame *(Helianthus tuberosus)*	0.038	NA	NA	NA	NA	0.105	Edirisinghe and Jinadasa, 2019
Cowpea *(Vigna unguiculata)*	0.008	NA	NA	NA	NA	0.60	Edirisinghe and Jinadasa, 2019
Foxtail Millet *(Panicum italicum)*	0.022	NA	NA	NA	NA	0.029	Edirisinghe and Jinadasa, 2019
Long bean *(Vigna unguiculata ssp. Sesquipedalis)*	0.012	NA	NA	NA	NA	ND	Edirisinghe and Jinadasa, 2019
Green gram *(Vigna radiate)*	0.028	NA	NA	NA	NA	0.047	Edirisinghe and Jinadasa, 2019

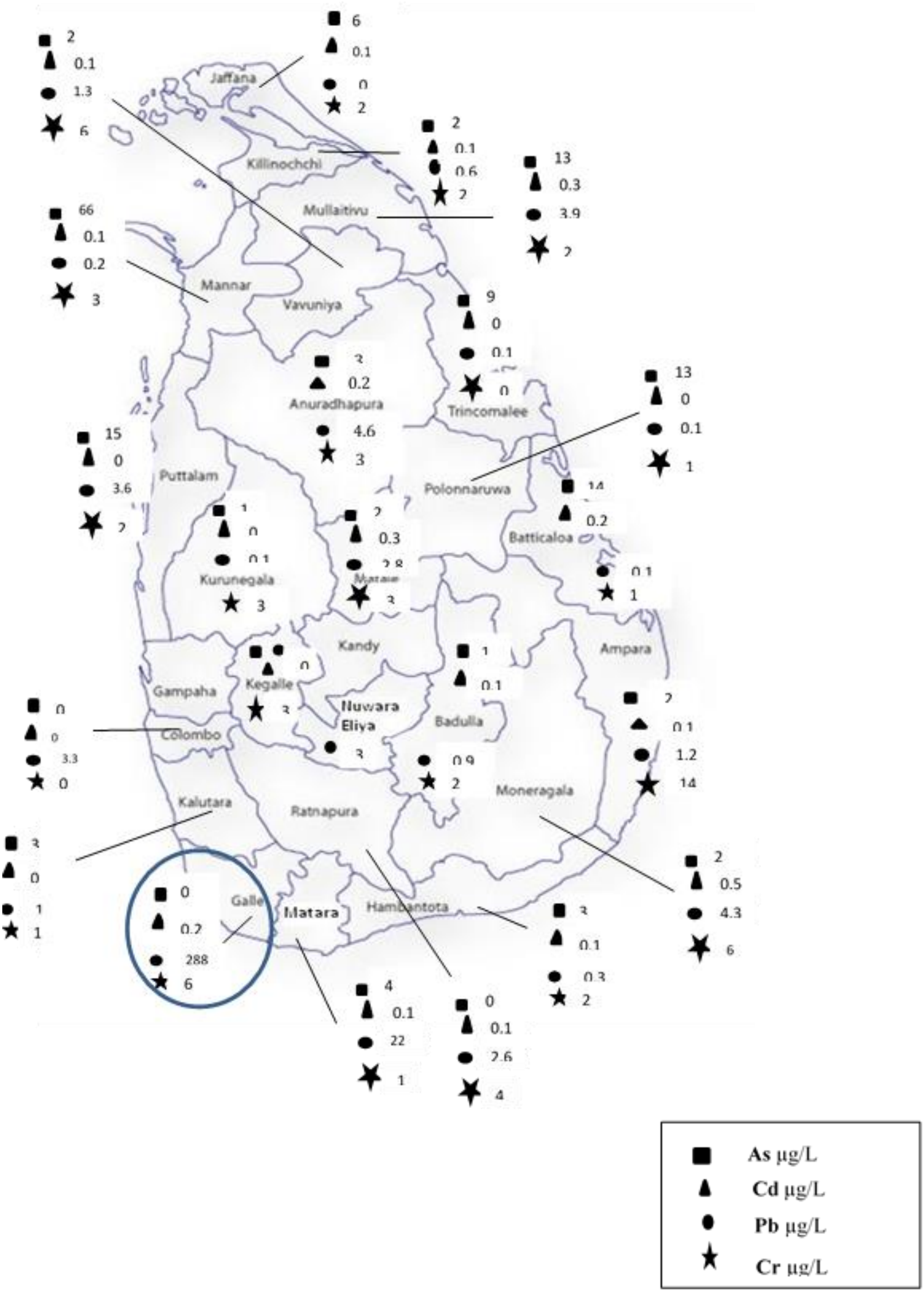
NA – Not Available, ND – Not Detected

Table V. Average heavy metals concentration in leachate samples collected from the Gohagoda landfill site

	Zn	Cu	Fe	Mn	Cr	Ni	Cu
Average element concentration in leachate samples (mg/kg)	1.72	1.69	15.07	1.14	0.04	0.36	0.26
Standard deviation	3.09	4.24	29.32	1.00	0.09	0.22	0.32

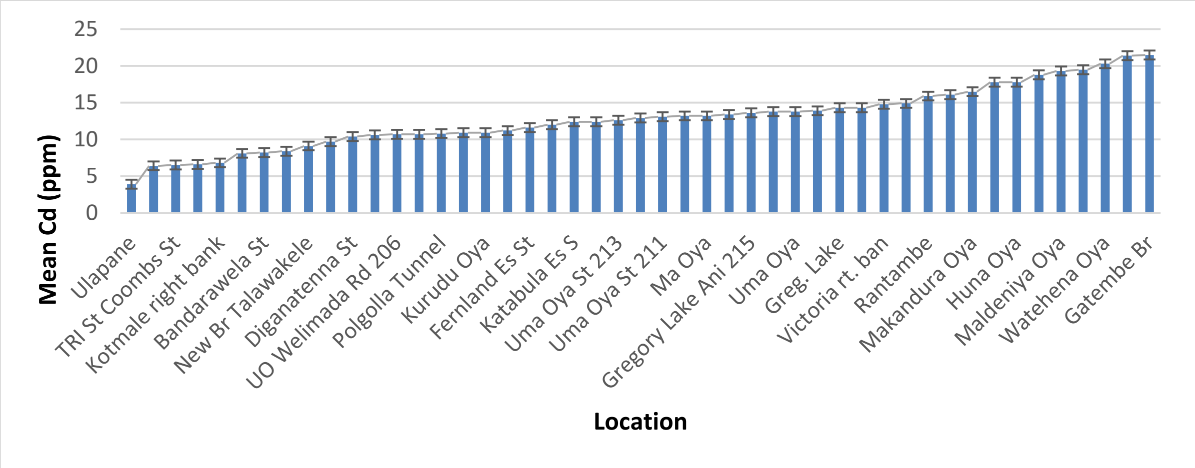
(Dharmarathne and Gunatilake, 2013)

Figure I. – Heavy metal concentration in the well water of each district in Sri Lanka



(Ayala *et al*., 2018, Herath *et al*., 2018)

Figure II. - Mean cadmium levels (ppm) in waters of tributaries of river Mahaweli, the main river, and its reservoirs in the upper catchment from the Polgolla diversion



(Bandara *et al*., 2011)

Artificial water structures, such as reservoirs are extremely important as ecological and economic sources of drinking water and agriculture. These reservoirs can be used as the main water source for several irrigation methods in agricultural fields. (Wetzel, 2001). The dry zone of Sri Lanka consists of a large number of inland valleys resulting in the cascade irrigation systems with small tanks (Pannabokke, 2002). Athuraliya *et al*., 2003 reported that, 90 – 94.5% of chronic renal failure (CRF) patients were found from farming communities under Mahaweli irrigation scheme. In a more comprehensive study on water quality in Sri Lankan reservoirs, Bandara *et al*., 2011 presented mean cadmium levels (µg Cd/l) in waters of tributaries of river Mahaweli, the main river, and its reservoirs in the upper catchment from the Polgolla diversion (Fig .II).

5. HEAVY METALS IN FOOD ITEMS AND HYPER-ACCUMULATING PLANTS IN SRI LANKA

It is said that a plant is a hyper-accumulator if it can accumulate considerable levels of metals: 100-1000 times of the normally accumulated levels in most species. Several plant families contain an unusually large number of hyperaccumulators. These plant families include Asteraceae, Brassicaceae, Euphorbiaceae, Fabaceae, Flacourtiaceae and Violaceae (Weerakoon and Somaratne, 2010). For heavy metals Ni, Cu, Co, Cr and Pb, a hyper-accumulating plant must contain more than 1000 µg / g of dry leaf weight. For Zn and Mn, hyper-accumulative plants should contain more than 10,000 µg / g (Baker and Brooks, 1989).

One of the most promising and well-tested candidate for hyper-accumulation is a plant familiar to many Sri Lankans, the Indian mustard, *Brassica juncea* (Brassicaceae) (Rajakaruna *et al*., 2006). Mustard is capable of producing 18 tons of biomass per hectare per crop and is able to simultaneously accumulate and translocate high levels of Cu, Cr, Cd, Ni, Pb and Zn into the shoots.

The most common large plant found in all reservoirs in the dry zone is the species *Nelumbo nucifera* (Lotus) which has been cultivated in reservoirs for over thousands of years for phyto-remedial purposes (Bandara *et al*., 2008). Chandrajith *et al*., 2012 mentioned that, the average Cd content in lotus rhizomes in the dry zone is 7.47 mg / kg ranging from 6.79 to 8.57 mg / kg. The species *Lacia aculeata* (kohila), which grows in wetlands and on waterways, is another popular food product in Sri Lanka. The average content of Cd in kohila rhizomes is 6.06 mg / kg (5.30-6.82 mg / kg) (Chandrajith *et al*., 2012).

6. CONCLUSION

Excessive use of agrochemicals has been identified as the major source of heavy metals in agricultural soil of Sri Lanka. Current researches have pointed out that Cd, As, and Pb accumulation in rice in Sri Lanka is below the acceptable level. The rise in evidence of increasing heavy metal contamination in Sri Lankan agricultural soil emphasizes the necessity of careful monitoring and research to mitigate health risks and adverse environmental effects.

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