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REVIEW

Food Safety

Heavy metals and food safety in Sri Lanka: A review

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Summary: Entry of heavy metals to the food chain leads to food safety hazards. The origins of possible food safety hazards in Sri Lanka due to metalloid arsenic and the heavy metals cadmium, lead, and mercury are reviewed. Of them, arsenic and cadmium draw attention as contaminants in rice. Of the four heavy metals, cadmium in agricultural soils is of anthropogenic origin. Arsenic is of lithogenic origin. In some locations lead appears to be of anthropogenic origin, especially in commercial leafy vegetable cultivating soils. Marine fish, particularly swordfish and yellow fin tuna, occasionally carry cadmium and mercury concentrations above the tolerance limits established by the Codex and European Food Safety Authority. Heavy metals in well water are far below tolerance limits and are safe. Patterns of annual cancer incidences in Sri Lanka do not provide evidence to consider arsenic as a food safety hazard. Food safety hazards may occur with arsenic in the long term if attention is not paid to the quality of fertilizers or the current daily rice consumption level is not reduced. Arsenic being of lithogenic origin, unhealthy exposures cannot be prevented without affecting the food security of the country. High consumption of cadmium containing rice exposes Sri Lankans to health problems. Signs of hotspots of lead are visible. Food safety hazards are predicted by assessing exposure of humans based on their body weight and daily intake of hazardous constituents. Provincial Tolerable Weekly Intakes (PTWI) are calculated for Sri Lanka using information on heavy metals in foods from research publications. International food regulatory limits on heavy metals in foods are summarized. Horizontal standards for heavy metals in foods are developed to minimize food safety hazards in Sri Lanka.

Keywords: Arsenic, cadmium, food chain, lead, mercury.

INTRODUCTION

Entry of harmful agents through the food chain into the human body results in food safety hazards. Heavy metals have drawn scientific attention as a potential food safety hazard entering the human food chain. Of the heavy metals in the soils and the environment, cadmium (Cd), lead (Pb), mercury (Hg), and the metalloid arsenic (As) are of concern globally. Heavy metals are also described as toxic trace metals in the literature. The exposure of humans to heavy metals is linked to their presence in foods, as free metal particles, inorganic compounds, or organic compounds. Exposure of humans to heavy metals in agri-foods depends on the food processing, preparation, and consumption patterns associated with food cultures. Heavy metals of lithogenic origin may be naturally present in the soil and water, or get added to agricultural soils through anthropogenic activities, especially through fertilizers and pesticides. Heavy metals also may enter the agri-foods from organic waste, compost, animal dung, sewage sludges, irrigation water *etc*. used as manure. There are no mining activities, volcanic emissions, or glacial activities in Sri Lanka that could bring heavy metals from the core of the earth to surface soils. Sri Lankan agriculture depends totally on rain fed and irrigated water. Water from deep aquifers which may carry high concentrations of heavy metals are not used in agriculture. Deep well water in Sri Lanka is free of heavy metals. Heavy metals in foods is suspected

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as one of the probable causes of chronic diseases of unknown aetiology (CKDU) among Sri Lankans. Similar diseases are reported in a few other countries. Understanding the presence of heavy metals in the agronomic soils, their appearance in foods, and cause-effect relationship with chronic diseases in the country need in-depth multidisciplinary scientific studies. This publication examines the presence of heavy metals in Sri Lankan agricultural soils and food production environment, their probable origins, opportunities for them to enter the food chain, the Sri Lankan food consumption patterns and incidences of related effects on health. This review proposes regulatory standards to minimize food safety hazards. The focus is on arsenic, cadmium, and lead entering the food chain during crop production and mercury entering through marine fish.

HEAVY METALS IN AGRICULTURE AND FOOD SAFETY

Heavy metals are present naturally in varying concentrations in soils. They are distributed heterogeneously in the Earth's crust, resulting in differing views of their presence, and mapping of heavy metal hotspots. The heavy metal concentrations the Earth's crust is different from that of the core. The heavy metal concentrations on the crust change continuously due to environmental, agronomic, and natural factors. The suitability of soils for cultivation are decided based on the "threshold values" of heavy metals, above which there is a risk of heavy metals entering food crops. The aim is to ensure public health through a safe food supply. The average concentrations of heavy metals in the Earth's crust, their threshold values based on information from European and Indian studies, and those established by Finland, are presented in Table 1 (Ministry of Environment, Finland, 2007).

Most heavy metals of concern in Sri Lanka have been established to arise mainly from weathering of rocks and soils and not from agrochemical contamination of soil surfaces or from deep well water (Jayawardene *et al*., 2012). The homogeneity of arsenic in Sri Lankan paddy soils is evident from the presence of similar concentrations in 70 locations of 14 villages (Chandrajith *et al*., 2005). In a study comparing the trace metals in Sri Lankan soils from agricultural and non-agricultural highlands and lowlands of the Anuradhapura district by principal component analysis, calculating the geo-accumulation index and pollution loading index, it is established that copper, nickel, zinc, and lead in agricultural soils are of lithogenic origin and cadmium is of anthropogenic origin (Sanjeevani *et al*., 2017). Cadmium is one of the problematic heavy metals in human food chains in many countries.

Entry of heavy metals into the food chain

Every atom of a heavy metal or every molecule containing a heavy metal in soil does not end up in the food plate. The physical properties of the soil, the ability of soil particles to absorb, desorb or bind heavy metals, the redox potential of soils governed by oxygen availability, the soil pH, and biological properties of the plants govern the entry of heavy metals into plants. Redox potentials of paddy soils have opposing effects on the absorption of arsenic and cadmium by plants, whereas soil pH affects the bioavailability of arsenic and cadmium (Zhao & Wang, 2019). It is thus challenging to work towards food safety through adjustment of soil conditions. The heavy metals should be available in the soil at depths down to 30 cm on average, for them to be absorbed by food crops. The depth of extension of roots in the soils limit the opportunity for the heavy metals to enter plants. The plants are selective in up-taking heavy metals and in translocating them to the edible components of crops. These complexities make it difficult to scientifically predict the extent of movement of heavy metals from soil to food of plant origin. The entry of each toxic heavy metal into the human food chain needs to be understood in working towards food safety.

Table 1: Abundance of As, Cd, Pb and Hg in the Earth's crust and their threshold values (mg/kg)

Distribution	As	Cd	Pb	Hg	References
Average on Earth's crust*	1.8**	0.15	10	0.05	*https://en.wikipedia.Earth%crust*
Natural abundance	8.93	0.48	29.9	0.13	Arunakumara *et al*., 2013
Thresholds for agricultural soils	5	1	60	0.5	Govt. Decree 214.2007.doc (finlex.fi) of Finland
After sewage sludge applications in agriculture	50	3	300	1	EC Directive 86/278/EEC

*The values vary in different publications; **Range 0.1 - 40 mg/kg

Arsenic in Sri Lankan food chain

The average concentration of arsenic in the earth crust is 1.8 mg/kg with a possible range of 0.1 – 40 mg/kg in non-contaminated soils. The threshold value for arsenic in agricultural soils is 5 mg/kg. Arsenic could be present in 200 different forms in soil of which 60% are arsenates, 20% are arsenites, oxides, arsenides, silicates etc., and 20% as sulphosalts and sulphides (Lim *et al.*, 2014). Arsenites are more toxic than arsenates. Out of these, only a few forms of arsenic enter the rice grain. Though total arsenic in foods was used in assessing food safety hazards in the past, current toxicological studies focus on inorganic arsenic in foods. Of the total arsenic content in rice, 60-80% is inorganic arsenic which may increase up to 90% (Jose *et al*., 2009).

Organic arsenic, mainly present as arsenobetaine, forming more than 90% of total arsenic in fish, pose no recognizable threat to human health. Organic arsenic is not absorbed in the human gut. No regulatory limits are established for inorganic arsenic in fish in the food regulatory system in developed countries, as its presence is low and negligible (Codex, 2015; EC- 2006; FDA, 2021).

The food safety hazards through arsenic in rice occurs due to following reasons.

1. High volumes of rice consumed by Sri Lankans make rice a major entry pathway.
2. Arsenic exists in rice as the toxic inorganic form constituting 60 – 90% of total arsenic.
3. Removal of arsenic in rice is limited to polishing and washing prior to cooking. Each washing takes away 15% of arsenic in rice.
4. There is no mechanism to avoid food safety hazards from rice cultivated in areas where arsenic content in soil or irrigation water is naturally high.
5. Reduction of arsenic regulatory limit of 0.2 mg/kg for rice to 0.1 mg/kg would eliminate 70% of rice in the market leading to food security problems culminating in undernutrition of the populations (FDA, 2016).

Absorption of arsenic by plants from soil and its accumulation finally in the edible tissues occur along a concentration gradient (Jose *et al*., 2009). With 7.19 - 18.63 mg/kg of arsenic in rice plant roots in Bangladesh, the observed arsenic content in rice grains was 0.25 - 0.73 mg/kg (Bhattacharya *et al*., 2009). In rice plants, the arsenic content in roots is reported to be 28-fold higher than in the shoot, and 75-fold higher than raw rice grains (Raman *et al*., 2002). Approximately 1% of arsenic in the soil ends up in the rice grains. Raman *et al*., (2002) postulate that rice in soils containing less than 14 mg/kg of arsenic could be considered safe for human consumption. West Bengal in India and Bangladesh continue to face food safety hazards due to higher concentrations of arsenic in rice and water. The main source of arsenic in Bangladesh is the deep well water used for irrigation, resulting in contamination of the rice soils over years. A comparison of total arsenic concentrations in soil, water, and rice from West Bengal, India, where severe exposure of populations to arsenic occurs, with that of Sri Lanka are given in Table 2.

Table 2: Total As in soil, water and rice grains in West Bengal, India and in Sri Lanka

Location	Soil arsenic (mg/kg)	Irrigated water arsenic[a] (µg/L)	Rice grain arsenic[b] (mg/kg)	References
West Bengal	1.38 - 12.27	110 - 760	0.25 - 0.73	Battacharya *et al*., 2009
Dry zone Sri Lanka	0.45 - 1.04 Dry zone; 0.5 – 24 (tank sediments)	0.015 - 0.361 Nikawewa, Girandurukotte	0.09 - 0.26 Girandurukotte, Nikawewa	Chandrajith *et al*., 2011 Chandrajith *et al*., 2005 Chandrajith *et al*., 2008
Dry zone paddy soils	1.18 ± 0.59			Balasooriya *et al*, 2021
Wet zone paddy soils	1.32 ± 0.85			Balasooriya *et al*, 2021
CKDU hotspot soils	1.33 ± 0.60			Balasooriya *et.al*, 2021

a = FAO permissible limit for irrigation water is 0.10 mg/L (= 100 µg /L); Value for drinking water is 10 µg /L; b = Codex limit for arsenic in rice is 0.2 mg/kg

Arsenic in Sri Lankan soils are reported to originate from sulphide minerals of the basement rocks and the concentrations are insignificant to affect plant growth (Jayawardena, 2012). The concentrations of arsenic in well water in Sri Lanka are far below the internationally accepted maximum tolerance limit of 10 µg/L (Table 22). The concentrations are reported by Herath *et al*., 2018 (Table 3) and in the WHO report on CKDU, 2016 (Figure 1).

Table 3: Average As, Cd and Pb concentrations in well waters from the 25 districts in Sri Lanka (µg/L) (Herath *et al*., 2018) Values are computed from district averages

Metal	Country average	SD	Range	MTL (µg/L)	Below MTL	High district averages ± SD & (maximum) µg/L
Total arsenic	1.38	2.68	0 - 66	10	21/25 districts	Batticaloa = 3 ± 3.2 (14) Mannar = 7 ± 11.7 (66) Mullativu = 3 ± 3.7 (13) Puttalam = 4 ± 4.1 (15)
Cadmium	0.008	0.007	0 - 0.05	3	All	
Lead	0.133	0.155	0 - 0.5	50	All	Galle: one sample had 228

Concentrations of 0.5 – 24 mg/kg of arsenic and 10 – 33 mg/kg of lead have been reported from the sediments at different levels in Malagane Tank, Deduruoya. The values probably reflect accumulation of arsenic from weathering rocks (Chandrajith, 2008). These concentrations do not reflect alarming anthropogenic contributions from paddy cultivations in the surroundings.

In pot experiments with arsenic concentrations of 60 mg/kg in soil, the corresponding arsenic concentrations in cultivated rice plants were 21 mg/kg in panicles at initiation stage and 23 mg/ kg in the panicles at maturity stage (Rahman *et al*., 2008). At these artificially high exposure levels to soil arsenic, less than 50% appears to enter the rice grains. The information in Table 2 indicates that the exposure of rice plants to arsenic through soils

Table 4: Average As, Cd, and Pb in rice from CKDU endemic and non-endemic areas (mg/kg) (Herath *et al*., 2018)

Heavy metal [Sample number]	Average ± SD	Maximum	Average ± SD	Maximum	Area related to CKDU	Codex mg/kg
	Polished rice		Unpolished rice			
Total arsenic [67]	0.03 ± 0.04	0.20	0.03 ± 0.04	0.20	Endemic	0.2
Cadmium [67]	0.12 ± 0.19	0.87	0.16 ± 0.17	0.52	Endemic	0.4
Lead [67]	0.01 ± 0.02	0.08	0.00 ± 0.02	0.08	Endemic	0.2
Total arsenic [24]	0.03 ± 0.03	0.00	0.04 ± 0.03	0.09	Non endemic	0.2
Cadmium [24]	0.21 ± 0.24	0.65	0.18 ± 0.36	1.43	Non endemic	0.4
Lead [24]	0.00 ± 0.00	0.00	0.00 ± 0.00	0.02	Non endemic	0.2

Table 5: As, Cd and Hg in Sri Lankan rice (mg/kg) (Jayasekara & Fretas, 2005)

Heavy metals	Raw polished grains		Parboiled grains		Rice flour	
	Producer 1	Producer 2	Producer 1	Producer 2	Producer 1	Producer 2
Total arsenic	0.034 ± 0.006	0.034 ± 0.001	0.065 ± 0.012	0.092 ± 0.001	0.035 ± 0.001	0.061 ± 0.006
Cadmium	0.192	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5
Mercury	< 0.01	< 0.01	0.033	< 0.01	< 0.01	< 0.01

[Codex tolerance limits for rice As = 0.2, Cd = 0.4 mg/kg] in Sri Lanka is far below that of the pot experiments and in West Bengal. The soils and agronomic practices in Sri Lanka do not seem to result in entry of hazardous arsenic concentrations into the rice production-processing chain. Independent studies reported in Tables 4 and 5 by different groups of scientists support the view that rice arsenic concentrations cannot cause food safety hazards in Sri Lanka as the concentrations are well below Codex maximum tolerance limits.

The presence of arsenic in rice is a global phenomenon. Rice arsenic concentrations in USA and in several countries are given in Tables 6 and 7. A study of 901 polished white rice samples from 10 countries has shown 7-fold variation from the median. The lowest values were 0.04 mg/kg in Egypt and 0.07 mg/kg in India. The highest values were 0.25 mg/kg in USA and 0.28 mg/kg in France (Meharg *et al*., 2009).

The arsenic concentrations in rice in Sri Lanka (Tables 2 and 4) are notably less than what is in Tables 6 and 7 indicating a low exposure. The arsenic concentrations reported in Tables 2 and 4 are less than the Codex tolerance limit of 0.2 mg/kg.

Correlation of the information on arsenic in the WHO study (2016) in Sri Lanka is given in Figure 1. The figure presents the food chain in blue boxes and arrows. The values given above the food chain (in red) indicate potential food safety hazards and outcomes associated with arsenic. The values given below the food chain (in green) represent values that do not point towards food safety hazards.

The evidence does not suggest a food safety hazard or health effects on humans arising from arsenic in agricultural soils or water. A long-term risk may arise from pesticides and excessive use of phosphate fertilizers containing arsenic on continuous application. The long-term effects are generally predicted by examining the exposure of agricultural lands to contaminated fertilizers over a period of 45 years. Arsenic available in added phosphate fertilizers may get diluted in the soil allowing only a fraction to reach rice as discussed by Raman *et al.,* (2002). The pesticides along with arsenic in them are absorbed through leaves and panicles leading to increased risk. However, the current evidence does not indicate food chain (rice and water) as a pathway for exposure of humans to arsenic in Sri Lanka.

Table 6: Concentrations of As in rice products in USA (Meharg *et al*., 2009)

No	Rice type	No of samples	Mean (mg/kg)	SD (mg/kg)	Range (mg/kg)
1	All samples tested	193	0.194	0.144	0.006 - 0.723
2	Rice (non-organic)	88	0.205	0.122	0.047 - 0.559
3	Rice (organic)	13	0.174	0.142	0.086 - 0.526
4	Rice products (non- organic)	67	0.214	0.171	0.010 - 0.723
5	Rice products (organic)	25	0.125	0.142	0.006 - 0.620

Table 7: Concentrations of As in rice from several countries (Duxbury & Zavala, 2005)

Country	No. of samples	Arsenic (mg/ kg)	Country	No. of samples	Arsenic (mg/kg)
Argentina	1	0.136	Korea	2	0.045
Bangladesh	3	0.046	Lebanon	1	0.169
Bhutan	1	0.032	Pakistan	3	0.033
China	2	0.146	Spain	2	0.186
Egypt	2	0.032	Thailand	9	0.093
Greece	1	0.114	USA	22	0.181
India	16	0.037	Venezuela	12	0.084
Italy	7	0.158	TOTAL	84	Mean 0.107

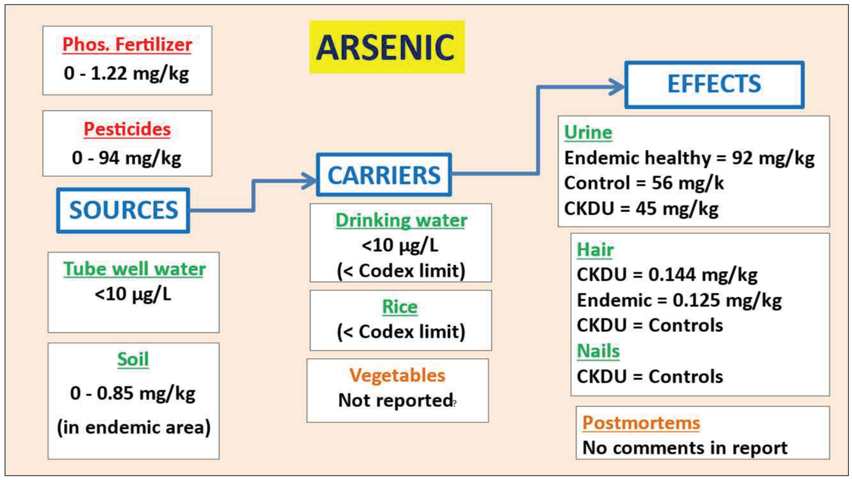

Figure 1: Concentrations of As linked to agronomic practices, appearing in food chain and in tissues of persons affected by CKDU.

While precaution is important, haste does not seem to be scientifically justifiable in assessing food safety hazards.

The major concern that may arise in Sri Lanka is the increased exposure to arsenic due to higher consumption of rice compared to developed nations, rather than high concentrations of arsenic in rice. The comparable per capita consumption values for rice in kg are Bangladesh 268; Vietnam 220; Thailand 178; Sri Lanka 160; China 125; India 98; Australia 13; USA 10; UK 8 and World average of 80 (Helgi library, 2017). The effects of volumes of rice consumed is addressed in Table 17.

Among other food sources, concerns about arsenic in canned fish has been expressed at times. Assessment of weekly, monthly or daily exposure to arsenic in foods is used in recognizing risks leading to food safety hazards. The average consumption of rice by a Sri Lankan is 438 g per day. The corresponding value for fish in Gampaha district, which get plenty of fish from Negombo is 43 g per day (Jayasinghe *et al*., 2018). With a 10-fold lower consumption of fish than rice, there is extremely low possibility of food safety risks through arsenic in fish. The arsenic in fish is 90% arsenobetaine and other organic forms which are non-toxic. Organic arsenic is not absorbed by the human gut. The European Food Safety Authority (EFSA), Joint Expert Committee of FAO/WHO (JECFA) guidelines used by Codex Alimentarius Commission (Codex), and the Food and Drugs Administration of USA (FDA) have not established regulatory limits for arsenic in fish, considering the insignificant contribution of toxic inorganic arsenic in fish to human diet. Arsenic in fish, fruits and vegetables are 90% organic (Mandel & Suzuki, 2005).

Cadmium in Sri Lankan food chain

Cadmium could enter the human body through food and water. The average concentration of cadmium in the Earth's crust is 0.15 mg/kg. The threshold value for agricultural soils is 1 mg/kg (Table 1). Cadmium compounds contaminate agricultural soils from sewage, manure, and phosphate fertilizers. Soils naturally contain low concentrations of cadmium. Gunadasa *et al*., (2021) reported that the cadmium and arsenic concentrations in paddy soils and in rice are less than 0.1 mg/kg. The soil cadmium concentrations observed in uncultivated soils in Sri Lanka is 25 - 50% below the threshold value (Sanjeevani *et al*., 2017) and vegetable soils reach threshold values (Table 8).

Rice, potatoes, grains, and vegetables tend to absorb cadmium from soil more readily than other plants. Green vegetables appear to possess a tendency to accumulate cadmium. Unacceptable cadmium concentrations have been reported in sword fish from most oceans. Entry of cadmium to plants is reported to be 2-fold higher than arsenic. Cadmium accumulate in kidneys over long periods, and its half-life in the human body is around 30 - 38 years, and is 10 years in the kidney. Cadmium is a Group 1 carcinogen affecting mainly the kidneys, followed by bones (IARC, 2018).

Table 8: Cd and Pb in low-country and up-country vegetable soils (Premarathna *et al*., 2011)

Area	Sub area	No. fields	Cadmium (mg/kg)	Lead (mg/kg)
Low country	Sedawatta	4	0.61-3.28	39-113
	Welewatta	3	0.46-1.37	34-66
	Kotuwilla	3	0.98-1.31	20-56
	Kahathuduwa	10	0.49-1.55	17-33
	Bandaragama	2	0.53-0.89	15-15
	Mean ± SD		1.18 ± 0.82	54 ± 29
	Control soil		0.26	49
Up country	Sithaeliya	4	0.51-0.88	56-311
	Kandapola	6	0.39-1.96	27-97
	Haputale	3	0.51-3.86	26-242
	Bogahakumbura	3	1.30-1.42	45-75
	Rahangala	2	1.22-1.29	97-116
	Mean ± SD		1.21 ± 0.80	88 ± 75
	Control soil		0.51	40

Concentrations of cadmium observed in water and rice in Sri Lanka are below the Codex tolerance limit of 3 µg/L and 0.4 mg/kg respectively (Tables 3, 4, and 5). Meharg *et al.* (2013) reported the highest quantities of rice consumption in Sri Lanka and Bangladesh, among 12 countries, and the concentration of cadmium is the highest in Sri Lankan rice. The mean cadmium concentration reported by them is 0.081 ± 0.024 mg/kg, with the highest value of 0.80 mg/kg in the range for Sri Lanka. Though the concentration of cadmium in Sri Lankan rice is below the Codex tolerance limits (Table 9), the exposure of Sri Lankans appears high. The study has estimated the exposure of Sri Lankans and Bangladeshis to be 100 µg/kg of body weight per week.

Table 9: Concentrations of Cd in market rice and projected maximum weekly exposures in several countries including Sri Lanka. (Meharg *et al*., 2013)

Country	Number of samples	Mean (mg/kg)	Range (mg/kg)	Max weekly Cd intake in µg/kg body weight
Bangladesh	260	0.099	< 0.0005 – 1.31	100
Cambodia	14	0.006	0.0010 – 0.03	5
France	37	0.010	0.0030 – 0.10	1
Ghana	428	0.020	<0.005 – 0.27	10
India	58	0.078	0.0020 – 1.00	12
Italy	114	0.038	0.0030 – 0.16	10
Japan	18	0.059	0.0101 – 0.14	10
Nepal	12	0.050	0.0139 – 0.08	10
Spain	92	0.024	0.0008 – 0.14	10
Sri Lanka	75	0.081	<0.0005 – 0.80	100
Thailand	18	0.027	0.0057 – 0.07	8
USA	21	0.018	0.0095 – 0.04	7

Leafy vegetables possess a higher tendency to accumulate cadmium than other plants (Westfall *et al*., 2005; Gupta *et al*., 2019). Vegetables from commercial plots with long term cultivations and vegetables available along the roadside on the Kesbewa – Kalutara road are reported (Premarathna, *et al*., 2011; Kananke *et al*., 2014) to carry cadmium concentrations above the Codex tolerance limit and EU tolerance limit of 0.2 mg/kg for leafy vegetables and 0.1 & 0.05 mg/kg for other vegetables (Table 10 and Figure 2).

Premarathna *et al*., (2011) also reported high concentrations of cadmium in upcountry and low country vegetable soils, indicating the probable origin of cadmium in leafy vegetables (Table 8). The reported concentrations are 8-fold higher than the average cadmium concentrations in earth crust and 10-20% higher than the threshold values for agricultural soils indicated in table 1.

Table 10: Cd and Pb in low-country and up-country vegetables (Premarathna, *et al*., 2011[a]; Kananke *et al*., 2014[b])

Area	Vegetable	Cd[a] (mg/kg)	Cd[b] (mg/kg)	Pb[a] (mg/kg)	Pb[b] (mg/kg)
Low country	*Kankun*	0.28 - 0.53	0.09 - 0.19	7.4 - 11.3	0.27 - 0.45
	Mukunuwenna	0.17 - 1.10	0.08 - 0.90	5.6 - 10.36	0.18 - 1.32
	Sarana	0.48 - 0.65		8.3 - 12.7	
	Niwithi	0.30 - 0.51	0.18 - 0.72	6.6 - 12.3	0.44 - 0.97
	Thampala	0.55 - 0.62	0.11 - 0.54	8.15 - 11.72	0.54 - 1.04
	Gotukola	0.54		8.75	
	Kohila		0.24 - 0.97		1.37 - 1.59
Up country	Potato	0.22 - 0.86		3.66 - 9.95	
	Lettuce	0.3		10.12	
	Cabbage	0.37 - 2.02		5.68 - 10.10	
	Leeks	0.48 - 0.54		3.84 - 10.45	
	Carrot	0.41 - 2.05		3.81 - 10.10	
	Knol-khol	1.28		7.65	

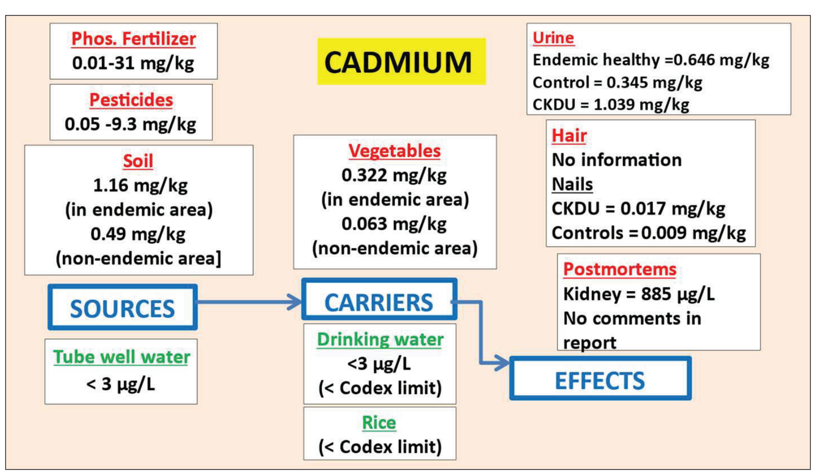

Figure 2: Concentrations of Cd linked to agronomic practices appearing in the food chain and in tissues of persons affected by CKDU.

The concentrations of cadmium in the market triple super phosphate (TSP) from locations in Anuradhapura, Medawachchiya, Medirigiriya, Girandurukotte, and Kandy are reported to be above the acceptable limits and vary widely compared to other fertilizer components urea and Nitrogen – Phosphorus – Potassium mixtures (NPK) (Chandrajith *et al*., 2010). The results are summarized in Table 11.

Reports on cadmium concentrations in other possible sources of fertilizers and manures clearly indicate the probable origin of cadmium toxicity in Sri Lankan foods leading to food safety hazards (Table 12).

The extremely heavy concentrations of cadmium in imported triple superphosphate, against local rock phosphate and other sources of phosphate fertilizers of

Table 11: Summary of Cd and Pb concentrations in market fertilizers in 6 locations of Sri Lanka.

Fertilizer	Cadmium (mg/kg)		Lead (mg/kg)	
	Mean ± SD	Range	Mean ± SD	Range
Urea	0.3 ± 0.2	n.d – 0.4	4.2 ± 0.9	3.7 – 6.0
NPK	0.5 ± 0.1	0.4 – 0.5	3.6 ± 0.5	2.6 – 3.9
TSP	49.9 ± 29.2	39.8 – 80.2	79.2 ± 53.5	58.2 – 166.0
Tolerance limits, Texas, USA	39		300	

Table 12: Cd and Pb in phosphate fertilizers and manures in Sri Lanka (Premarathna *et al*., 2011)

Fertilizer / manure	Number of samples	Cd (mg/kg)	Pb (mg/kg)
Triple super phosphate	5	23.50	5.15
Eppawala rock phosphate	4	1.92	13.00
Rock phosphate (USA)	2	13.54	12.00
Rock phosphate (India)	2	12.18	13.50
Rock phosphate (Bi Ru – China)	2	14.1	14.20
Rock phosphate (Lucille)	2	15.8	12.00
Dolomite	2	9.06	16.9
Poultry manure	12	0.97	3.20
Cattle manure	10	0.43	1.10

Table 13: Pb, Cd, and As in household foods in CKDU endemic area (Ananda Jayalal *et al*., 2019) and Codex tolerance limits

Food item	Number	As (mg/kg)	Cd (mg/kg)	Pb (mg/kg)
Rice	65	0.046	0.022	0.236
Flower vegetables	88	0.045	0.018	0.232
Leafy vegetables	43	0.066	0.019	0.212
Legume vegetables	19	0.020	0.019	0.185
Fruits	24	0.020	0.015	0.188
Fat and oil	6	0.020	0.027	0.154
Inland fish	2	0.020	0.015	0.057
Root & tuber crops	27	0.020	0.015	0.186
Codex MTL		0.20	0.40	0.20

Note: These foods represent farmer cultivations for their use global origin, indicate the possible entry of cadmium at unsafe concentrations into the food chain in Sri Lanka. Contrary to the above observations on cadmium in foods, a study on heavy metals in household foods in farmer families indicated low arsenic and cadmium concentrations, and high lead concentrations (Table 13). The samples tested perhaps represent foods produced under controlled agronomic practices for family consumption by farmers.

Correlation of the information in the WHO study (2016) points towards unacceptable cadmium concentrations in soils, in vegetables, and the tissues from persons exposed in CKDU endemic and non-endemic areas (Figure 2).

Cadmium tends to accumulate in marine fish. A study on heavy metals in fish in Sri Lanka has revealed high cadmium concentrations in sword fish compared to other fish (Table 14). Sword fish accumulates more cadmium than others. The values also represent fish ready to be exported.

Exposure of Sri Lankans to cadmium appears to occur through several routes with a common anthropogenic origin. Sanjeevani *et al*. (2017) identified cadmium as the only toxic heavy metal of anthropogenic origin in agricultural soils from Anuradhapura district. The distribution pattern of cadmium in agricultural soils of CKDU endemic and non-endemic regions, in commercial vegetable plots and the market vegetables (in non-endemic areas) indicates high exposure of crops to cadmium leading to food safety hazards. Evidence on fertilizer analysis further confirms this origin. Cadmium, probably arising from imported TSP threatens food safety by burdening the soil and food with cadmium. Fish does not seem to carry cadmium concentrations above the tolerance limits.

Table 14: Summary of total Hg, Cd and Pb in sea fish in Sri Lanka

Fish (number of samples)	Hg (mg/kg)	Cd (mg/kg)	Pb (mg/kg)	Reference
Cooked sword fish (11)	nd – 1.47	nd – 0.029 0.	-	Jayasinghe *et al*., 2018
Cooked yellowfin tuna (11)	nd – 0.95	007 – 0.049	-	
Cooked sardinella (11)	nd – 0.09	0.007 – 0.021	-	
Sword fish (35)	1.24 ± 0.72 (0.20 – 2.58)	0.13 ± 0.08 (0.03 – 0.36)	0.03 ± 0.04 (nd – 0.15)	Jinadasa *et al*., 2010
Yellow fin tuna (25)	0.39 ± 0.19 (0.14 – 0.88)	0.02 ± 0.02 (nd – 0.09)	0.06 ± 0.06 (nd – 0.24)	
Red snapper (12)	0.17 ± 0.06 (0.09 – 0.28)	0.02 ± 0.01 (nd – 0.04)	0.04 ± 0.05 (nd – 0.15)	
Export sword fish (176)	0.90 ± 0.51	0.09 ± 0.13	0.08	Jinadasa *et al*., 2014
Export yellow fin tuna (140)	0.30 ± 0.18	-	0.11 ± 0.16	
Export red snapper (28)	0.16 ± 0.11	0.01 ± 0.01	0.04 ± 0.04	
Export marlin (24)	0.49 ± 0.37	0.02 ± 0.02	0.05 ± 0.05	
European Commission specifications (mg/kg)	1.0 = sword fish, tuna; 0.5 = other	0.3 = sword fish; 0.1 = tuna; 0.05 = other	0.3 = tuna, sword fish	EC 1881 (2006)
Codex	Predatory fish = 1; fish = 0.5	Bivalve mollusks = 2	Fish = 0.3	Codex 193-1995

Lead in Sri Lankan food chain

The average concentration of lead in the Earth's crust is 10 mg/kg. The threshold value for lead in agricultural soils is 60 mg/kg. Sewage sludges used in agriculture elsewhere carry up to 300 mg/kg of lead. It is not possible to prevent the entry of lead naturally present in soil into the food chain through plants.

Lead in agricultural soils in Sri Lanka is mainly of lithogenic origin. Acceptable lead concentrations of 15 - 32 mg/kg have been reported from soils in Medirigiriya, Talawa and Padawiya (Jayawardene *et al*., 2012) and 4 mg/kg in rice soils recently (Balasooriya *et al*., 2021). The average lead concentrations reported in soils of vegetable plots in the low country are within, yet close to the threshold value for agricultural soils, while the ranges of lead in upcountry vegetable soils reach 2 to 5-fold higher at the maxima of the ranges (Table 8).

The lead concentrations observed in urea and NPK mixtures of market fertilizers are around 4 mg/kg indicating a low contribution (Table 11). By contrast, the market TSP contributes 15 to 40-fold higher concentrations of lead compared to urea and NPK mixtures.

Herath *et al.* (2018) reported lead concentrations below 0.03 mg/kg in rice from CKDU endemic and non-endemic areas (Table 4). The lead concentrations observed in leafy vegetables from up country and low country are 20-fold higher compared to Codex and EU regulatory limits of 0.3 mg/kg (Table 10). These observations point more towards the probable anthropogenic origin of lead in some vegetable soils. The concentrations of lead observed in agricultural inputs, vegetables, and human test materials are correlated in Figure 3.

Ananda Jayalal *et al*., (2019) observed lead concentrations of 0.20 mg/kg in rice and home-grown vegetables in CKDU affected families in the Anuradhapura district against the Codex tolerance limit of 0.3 mg/kg for leafy vegetables and 0.2 mg/kg for legume vegetables and pulses (Table 13). Table 14 shows lead concentrations below the tolerance limits for sea fish (Jinadasa *et al*., 2010; 2014a) and in Table 13 for inland fish (Ananda Jayalal *et al*., 2020).

Though the lead concentrations in rice and vegetable were notably high in home-grown vegetables, the cadmium and arsenic concentrations were low (Table 13). This may be an indicative sign of food safety hazards in the local foods due to lead hotspots.

The average lead concentrations in water from wells in 25 districts in Sri Lanka is 0.133 ± 0.155 µg/L against the Codex regulatory limit of 50 µg/L (Table 3). Though the lead concentrations in soils reported in the WHO study (2016) are within the threshold value, contribution from agricultural inputs appears high (Figure 3).

Lead concentrations in blood indicate human exposure. Madhavan *et al*. (1989) suggests that a concentration of 600 mg/kg of lead in soil contributes not more than 50 µg/L to blood in children under 12-years of age. In an indicative communication of blood lead levels, 100 - 220 µg/L has been reported in persons exposed to traffic polluted air in Kelaniya against 40 µg/L in control groups (Gunasekera *et al*., 2015). If the level in the control group is considered as normal exposure through foods, it stands below the WHO accepted limit of lead in blood of 100 µg/L for adults and 50 µg/L for children. Concentrations of lead in bones of CKDU affected persons were about 60% more compared to control groups (Ananda Jayalal *et al*., 2020) suggesting a risk through lead in diet at least to some population groups.

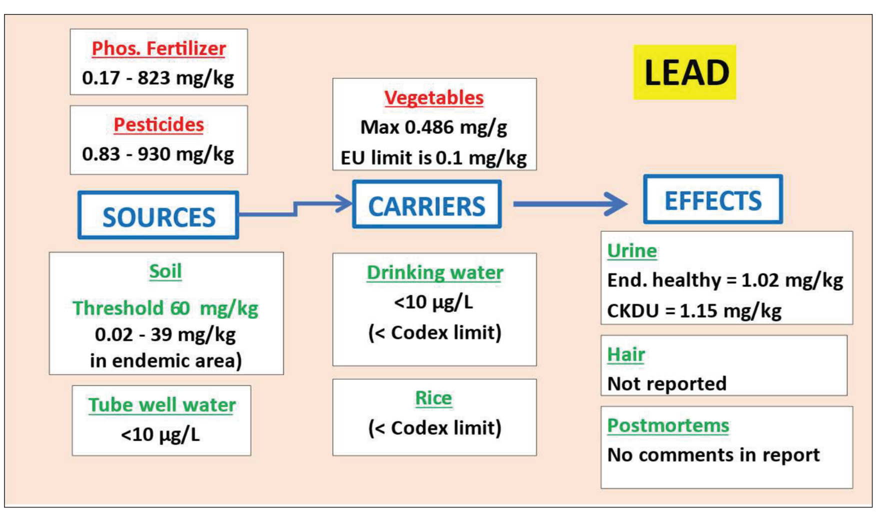

Figure 3: Concentrations of Pb linked to agronomic practices, appearing in the food chain and in tissues of persons affected by CKDU.

The high concentrations of lead observed in soils of vegetable plots (Table 8), in up-country and low-country vegetables (Table 10), in household vegetables of CKDU patients (Table 13) and the WHO study (Figure 3) together indicates probable exposure of Sri Lankans to unacceptable lead concentrations leading to food safety hazards needing attention at least in certain locations.

Mercury in Sri Lankan food chain

The average concentration of mercury in the Earth's crust is 0.05 mg/kg . The threshold value for agricultural soils is 0.5 mg/kg. Contamination of agricultural soils by mercury is not possible as there are no ores containing mercury in Sri Lanka. Mercury enters the food chain in Sri Lanka mostly through sea fish. Studies on mercury content in the Pacific and Indian Oceans have shown a mean total mercury concentration of 5.3 ng/L with a range of 3-6 ng/L in sea water with no significant variations at different depths of the oceans. Mercury occurs mostly as methyl mercury in fish and shellfish. Of the total mercury in fish, organic mercury could be 80% (Kannan *et al*., 1998). Methyl mercury is of high toxicity (Nishimura *et al*., 1983).

Of the different types of fish, swordfish and tuna are known to commonly accumulate mercury. Among four types of fish tested for mercury in Sri Lanka, swordfish is observed to carry high mercury concentrations, sometimes beyond the regulatory limits established by the Codex and EFSA (Table 14). Mercury concentrations in tuna fish also reach regulatory limits at times.

Mercury is not considered a serious food safety problem associated with rice, though the concentrations in rice are generally described to be high among grains. Mercury concentrations reported in rice in Sri Lanka are very low (Table 5). There is no tolerance limit established for mercury in rice in the Codex or EFSA. In China, mercury of anthropogenic origin has been reported in rice from districts where mercury is extracted from the ores.

Mercury could become a food safety hazard only with high consumption of swordfish and tuna.

FOOD SAFETY AND HUMAN HEALTH LINKED TO HEAVY METALS

Chronic exposure of humans to heavy metals could occur through air, water, and food, or even through skin absorption. The major health problems associated with heavy metals of interest to Sri Lanka, identified from World Health Organization information, are as follows.

Arsenic: (Arsenic key facts, WHO 2019)
Skin lesions leading to cancer, bladder cancer, and lung cancer. Increased risk of diabetes, pulmonary diseases, and cardiovascular diseases.

Cadmium: (Exposure to Cadmium, WHO 2019)
Primarily toxicity to kidney, leading to tubulointerstitial damage, affecting lung function inducing cancer, and causing bone demineralization due to interference with calcium metabolism.

Lead: (Lead poisoning – key facts, WHO 2021)
Cardiovascular effects, nervous disorders, decreased kidney function, and fertility problems

Mercury: (Mercury and Health, WHO 2017)
Toxic effects on nervous, digestive, and immune systems.

Health problems arising from exposure to heavy metals

Effects of heavy metals on public health are established by understanding the exposure dose and resulting toxicity or carcinogenicity.

Arsenic related health problems are associated with inorganic arsenic. The patterns of cancer reported for 2019 by the National Cancer Control Program of Sri Lanka (Cancer Incidence data book, 2019), published in November 2021, provide the following information on the crude rate of new cancer cases per one hundred thousand of population in 2019 (Table 15).

Skin, bladder or lung cancer, which are the predominant health problems arising from exposure to arsenic do not appear to be high in the classified information in the Table 15. The value for skin cancer is approximately 2% of total cancers. The incidence of lung cancer is higher with males associated with smoking. The ratio of male to female CKDU patients reported in Sri Lanka is approximately 1:1 (Jayatilake *et al*., 2013). Bladder cancer and lung cancers are the other major type of cancers caused by arsenic in food. Comparison of bladder cancer rates in Colombo with the three agricultural areas is given in the Table 16.

The reported cancer patterns are not congruent with the districts where agrochemicals containing arsenic are applied. Review of the variations of the different cancers in Sri Lanka over the period 2005 to 2019 do not show relative differences in the variations of cancer incidences by types. The patterns suggest that the factors affecting cancers in Sri Lanka are common to all types of cancers. Heavy metals in the food cannot be identified as a major contributor to cancer in Sri Lanka.

The incidence of CKDU in the North Central region of the country is well studied. Its symptoms, mainly the effects on the tubular cells of the kidney, are documented (Jayatilake *et al*., 2013). It appears to be a toxicological problem different from cancer. There are no published evidence from the health sector in the country to suspect direct food safety hazards related to lead and mercury. There are mechanisms based on food safety studies to predict the possibilities of food safety hazards associated with exposure to heavy metals under discussion.

Table 15: Crude cancer rate (CR*) in Sri Lanka by major types of cancers in 2019.

Males		Females	
Type	CR	Type	CR
Lip, tongue and mouth	20.6	Breast	39.5
Trachea, bronchi and lung	12.0	Thyroid	19.6
Colon and rectum	11.9	Colon and rectum	11.1
Oesophageal	10.4	Cervix, uteri	9.9
Prostate	9.5	Uterus	8.8
Pharynx	6.3	Oesophagus	7.3
Larynx	5.9	Lip, tongue, and mouth	8.8
Lymphoma	5.8	Ovary	8.5
Bladder	5.5	Trachea, bronchi and lung	4.1
Stomach	4.3	Lymphoma	3.9

CR* = number of new cancer cases diagnosed divided by at risk population multiplied by 100,000.

Table 16: Comparison of crude rates (CR) of bladder, tracheal, and bronchial & lung cancers in 4 districts of Sri Lanka in 2019.

CR bladder cancer among males		CR Tracheal, bronchial and lung cancer among females	
District	CR	District	CR
Colombo	5.3	Colombo	5.8
Anuradhapura	0.4	Anuradhapura	0.6
Polonnaruwa	3.7	Polonnaruwa	3.6
Batticaloa	8.4	Batticaloa	1.7

Assessment of exposure of Sri Lankans to heavy metals through food chain

Assessment of safety levels of hazardous substances are done by examining the quantity of hazardous agent that would be ingested by subjects taking into consideration the quantities of contaminated food, the body weights and durations of exposure. Durations may be a month, a week, or a day. This information is examined against the adverse effects on public health to establish Provisional Tolerable Weekly Intakes (PTWI). The PTWI values are revised based on new evidence from the disease patterns associated with the hazardous component in the food. The units describing PTWI values are weight (mg / µg / ng) of the hazardous substance per kg of body weight per week. Si Lankan data on heavy metals in foods are examined using this concept to recognize the degree of food safety. The values are compared with international norms.

Risks through exposure to arsenic

A study predicted the global burden due to arsenic by applying models designed by the US Environment Protection Agency to WHO data on cancer. According to the predictions, increased incidence of bladder cancer from 9129 to 119,176, lung cancer from 11, 844 to 121,442, and skin cancer from 10,729 to 110,015 annually attributable to inorganic arsenic in food is expected (Oberoi *et al.*, 2014). The prediction represents an approximately 11-fold increase in the three types arsenic induced cancers. In contrast to the above global prediction, the information from the cancer records in Sri Lanka (Cancer Incidents data book – 2019, 2021) does not indicate an increase in lung, skin or bladder cancer patterns different from other cancers in Sri Lanka. Patterns of all cancer incidences have remained the same with only a 3-fold increase of total cancer, and each type of cancer incidences over 10 years.

A risk assessment study on exposure to inorganic arsenic in rice was done by the FDA (2016) in USA. The study assessed the risks quantitatively by examining the population affected by bladder cancer and lung cancer, as influenced by inorganic arsenic in rice consumed by pregnant mothers and infants. A parallel qualitative examination looked at exposure-effect relationships linked to other health concerns.

Important information from the USA study of relevance to Sri Lanka is as follows.

1. Heavy metal toxicity associated with rice is mainly due to inorganic arsenic, which is a large fraction of total arsenic in rice.
2. The availability of inorganic arsenic in rice is 0.092 mg/kg for white rice and 0.154 mg/kg for brown rice in the USA, which were used in the study.
3. It is noted that 28-60% of inorganic arsenic is lost during the washing of rice prior to cooking.
4. A single rinsing of rice with water removes up to 15% of inorganic arsenic in rice.
5. A selected population group in USA consuming 2-3 meals of rice per day are exposed to 435 ng inorganic arsenic per kilogram of body weight per day.
6. The regulatory limit of 0.2 mg/kg for arsenic in rice could reduce the cancer risk by 11%, and a limit of 0.075 mg/kg could reduce the risk by 79%.
7. Reducing regulatory limit arsenic from 0.2 to 0.1 mg/kg would decrease the market availability of rice by 4 - 93% depending on other factors.
8. A healthy balance between availability of rice (food security) and risk (food safety) needs to be established scientifically for consumer benefit.

To examine the exposure levels and predict the risks associated with arsenic in the Sri Lankan food chain, PTWI values were calculated (Table 17). The following assumptions were made in the calculations.

a) The average body weight of a Sri Lankan is 55 kg.
b) A Sri Lankan consumes 438 g of rice per day.
c) Inorganic arsenic (I-As) in rice is 80% of total arsenic (T-As).

The Table 17 compares the exposure of Sri Lankans against recommendations of JECFA. An attempt to compare it with the USA situation for those consuming 2-3 meals per day, as reported by the FDA, was also made. The basis used here is the calculation of PTWI in µg of inorganic arsenic per kg of body weight over one week. Calculations and predictions here involve varying amounts of uncertainty due to approximations and assumptions.

Based on above calculations, it appears that the concentrations of arsenic naturally present in rice in Sri Lanka would not pose a significant risk to human health through weekly exposure. If the PTWI value is reduced to 10 or 12 in the future by JECFA based on new exposure-effect evidence, the calculation would show a tendency towards an increased risk through rice at the maximum reported values from Girandurukotte, but not with values in the other two studies. Scientifically it is not possible to reduce the amount of natural arsenic in soil. The concentrations of arsenic naturally present in Sri Lankan soils are about 1/5 threshold value for agricultural soils. It may be possible to minimize

Table 17: Comparison of exposure of Sri Lankans to As through rice on different published data converted to PTWI.

I – As in rice (mg/kg)	Notes	Exposure µg/kg bw (I-As) [PTWI]
	JECFA exposure value withdrawn in 2015	15*
0.20 Codex limit	Applied to 438g rice / day in SL	11.1
	Based on 435 ng/kg bw/day (FDA, 2016)	3.0
0.07 = 80% T-As	Maximum reported (Jayasekara & Fretas, 2005)	3.9
0.21 = 80% T-As	Max. Girandurukotte (Chandrajith *et al*., 2011)	11.7
0.03 = 80% T-As	Mean reported (Herath *et al*., 2018)	1.7

* Protection provided by Provisional Tolerable Weekly Intake (PTWI) of 15 µg I-As/kg bw was found to be inadequate and withdrawn in 2015

risk by preventing entry of inorganic arsenic to rice soils through rigorous testing of agricultural inputs or reduction of rice consumptions perhaps from 3 meals to 2 meals a day. The fertilizer import policy needs to address this food safety issue. The arsenic, cadmium, and lead concentrations in fertilizer are concerns in most countries. The State of Texas has established a limit for arsenic as 41 mg/kg in fertilizer (Westfall *et al*., 2005). Other countries address the heavy metal concentrations in phosphate fertilizers or by examining heavy metals added to soil over 45-year period (Agriculture and agri-food Canada, 1997).

Risk through exposure to cadmium

Food safety concerns about cadmium in the Sri Lanka arise mainly due to its nephrotoxic effects. The high quantities of rice consumed in Sri Lanka and Bangladesh are known to expose the populations to unhealthy concentrations of cadmium compared to other rice consuming countries. PTWI values are used to recognize the exposure to cadmium from different food sources based on the information from published research data. The PTWI values for Sri Lanka arising from rice, vegetables and fish are presented in Table 18.

The following assumptions were made in calculating PTWI for exposure to cadmium.

a) The average body weight of humans is 55 kg.
b) The average daily consumption of rice is 438 g.
c) The average daily consumption of vegetables is 1.73 portions (approximately 130 g)
d) The average daily leafy vegetable consumption is 50 g.
e) Weekly fish consumption is 300 g.

Thresholds derived for "safe" exposure to cadmium by international regulatory agencies are given as the basis to understand the risks.

The PTWI values indicates high exposure of Sri Lankans to cadmium from rice and green leafy vegetables. Uraguchi and Fujiwara (2012) reported the intake of cadmium in Japanese population is 3.0 µg/kg bodyweight per week, which is above the PTWI limit of EFSA. In this respect the PTWI values from Sri Lankan foods in the Table 18 indicates a very high degree of food safety risk.

The high concentrations of cadmium observed in urine, hair and postmortem kidneys of CKDU affected persons further indicate the exposure of Sri Lankans to cadmium through the food chain (Figure 2). Accumulation of cadmium in bones, which is a feature of cadmium toxicity is however not detected in the WHO study (2016) or by Ananda Jayalal *et al*. (2020). Bone demineralization arising from exposure to cadmium is described more as an indirect influence via induction of renal dysfunction (Godt *et al*., 2006). The observations on relationship of cadmium with bone demineralization differ, though there is evidence supporting bone demineralization with Itai-Itai disease linked to cadmium in rice.

Patterns of daily intake of cadmium as a function of rice consumption is presented in Figure 4. The exposure due to rice consumption at 438 g per day in Sri Lanka is represented by the brown upward arrow. The red dotted line indicates the exposure of Sri Lankans to cadmium through rice at different concentrations of cadmium in rice and quantities of rice consumed.

Table 18: Comparison of exposure of Sri Lankans to Cd through foods based on published research data converted to PTWI.

PTWI	Notes
0.7	US Agency for toxic substances and diseases registry
2.5	European Food Safety Authority (EFSA, 2012)
5.8	Equivalent for JEFCA value of 25 µg/kg PTMI (monthly intake)
9.5	Rice based on Herath *et al*., 2018 (Table 4) for 0.17 (average) mg/ kg
5.3	Vegetables based on Cd observed in endemic area (Figure 2)
1.0	Vegetables based on Cd observed in non-endemic area (Figure 2)
3.2	Leafy vegetables based on (Table 9); Approximated as 0.5 Cd mg/kg
2.5 – 7.0	Rice, vegetables and water combined based on Jayalal *et al*. (2015) 60 kg body weight (consumption: 152-419 µg Cd / week)
0.23	Fish at reported maximum value of 0.049 mg/kg (Jinadasa *et al.*, 2010); for maximum exposure with consumption of 300 g per week

The curves indicate the need to either reduce the cadmium in rice or reduce consumption of rice to levels around 2/3 of the current consumption to be in line with Codex standards or to a level of 1/3 to be in line with EFSA standards.

Evidence leading to food safety hazards through cadmium in the food chain is apparent through several studies. Sanjeevani *et al*. (2017) indicated only cadmium, among the heavy metals under discussion here, to be of anthropogenic origin. High cadmium concentrations in TSP used as a fertilizer in Sri Lanka is documented in Table 11 (Chandrajith *et al.,* 2010) and the heavy cadmium concentrations associated with vegetable production in Tables 8 and 10. The observations of Meharg *et al*., (2013) in Table 9 provide independent evidence on high exposure of Sri Lankans to cadmium. Cadmium is a known cause of tubulointerstitial damage to the kidney. Tubulointerstitial damage is the main lesion among CKDU patients.

When the contribution of cadmium from leafy vegetables (Figure 3) is added to the contribution from rice, the need to prevent the use of TSP as a fertilizer and application of better quality phosphate fertilizer becomes evident. It must be mentioned that the cadmium concentrations in Eppawala rock phosphate is much less compared to TSP detected in Sri Lankan markets (Table 11 and 12).

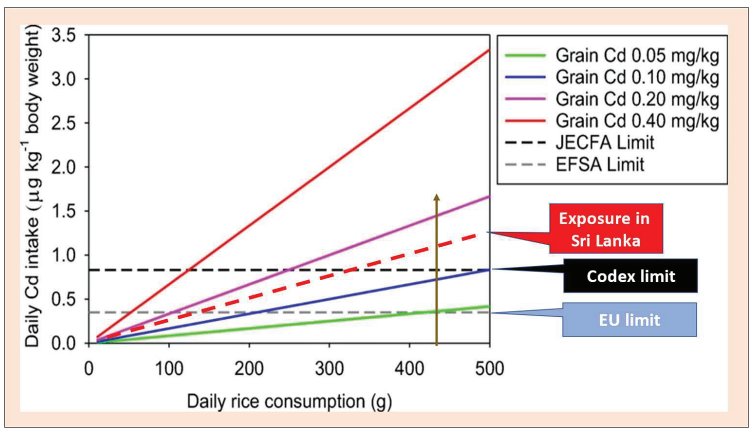

Figure 4: Daily intake of cadmium as a function of rice consumption modified from Zhao and Wang (2020).

Regulating the entry of heavy metals present in fertilizer into the human food chain is difficult. However, there are regulatory limits for heavy metals in fertilizers in other countries. California has regulations for arsenic, cadmium, and lead in fertilizers. The regulatory limits are linked with the main components in fertilizers such as 1% P_2O_5 or 1% Zn arising from minerals. The regulations in Canada specifie application limiting to accumulation over a 45-year period expressed as kg per hectare (Agriculture and Agri-foods Canada, 1997). The regulations in Texas specify the limits of arsenic, cadmium, lead, and mercury as 41, 39, 300 and 17 mg/kg of fertilizer respectively (Westfall *et al*., 2005). A mechanism to limit the entry of cadmium into agricultural soils is a need, in order to prevent food safety hazards arising through commercial agriculture. Limiting the entry of cadmium to agricultural soils is highly relevant to Sri Lanka, in the light of evidence regarding high cadmium concentrations in rice and leafy vegetables arising from use of TSP.

Risk through exposure to lead

Risks in the food chain may arise from lead present naturally in soil or added through contaminated agricultural inputs. The lead content reported in rice is less than 0.03 mg/kg on the average (Table 4), which is much below the Codex tolerance limit of 0.2 mg/kg. Norton *et al*. (2014) have reported lead concentrations of 0.020 mg/kg and 0.048 mg/kg in white and brown rice from Sri Lankan markets respectively. Based on findings of Norton *et al*. (2014) and Herath *et al*. (2018), 0.03 mg/kg was taken as a basis for estimating the contribution to the PTWI of lead from rice.

With the lead content in water reported as 0.133 µg/L in well water (Herath *et al*., 2018) against the Codex tolerance limit of 10 µg/L (WHO 2016), the risk arising from drinking water would be insignificant.

Maximum lead concentrations of 0.486 mg/kg reported in vegetables (WHO, 2016) and in leafy vegetables (Premarathna *et al*., 2011) are of concern, and used in calculating PTWI.

The following assumptions were made in calculating the PTWI and PTTI values for exposure to lead through food. Each contribution may be used to recognize cumulative contribution.

a) The average body weight of humans is 55 kg.
b) Rice consumption is 438 g per day containing 0.03 mg/kg of Pb (Herath *et al.*, 2018)
c) A mean contribution of 8.5 mg/kg from leafy vegetables (Table 10, Premarathna *et al*., 2011)
d) A weekly consumption of 300 g of fish containing a mean of 0.11 mg/kg lead.
e) The total diet of farmers from lead hot spots consists of 330 g of food with 0.200 mg/kg lead.

The analysis indicates high exposure to lead through leafy vegetables.

In estimating the provisional tolerable intake of lead through food, a factor of 10 was applied to obtain an exposure level to achieve some margin of safety based on lead concentrations in blood (Carrington & Bolger, 1992). Estimation of lead in blood is the only reasonably acceptable level of understanding exposure to lead from a variety of sources, *i.e.*, food, water and air. The FDA classifies a population into 4 groups by age. When the reported lead concentrations in Sri Lankan foods is viewed from the daily exposure angle, the resulting Provisional Tolerable Total Intake (PTTI) values could be compared (Table 20). The values reflect daily exposure in micrograms.

The risk due to lead through exposure to vegetables appear to reach the PTTI value of the FDA for adults.

Table 19: Comparison of exposure of Sri Lankans to Pb through foods based on published research data converted to PTWI

PTWI	Notes
25	This Codex value was declared inadequate in 2010
1.67	At the rate of 0.03 mg/kg in rice (Herath *et al*., 2018; Norton *et al*., 2014); Consumption of 438 g rice per day
8.04	Based on WHO, 2016 (0.486 mg/kg); consumption of 130 g vegetables per day
52.2	Based on Table 9 (approx. maximum of 8.2 mg/kg); consumption of 50 g leafy vegetables per day.
7.7	Household rice and vegetables 330 g/day from CKDU patients with approx. 0.200 mg/kg of lead (Ananda Jayalal *et al.,* 2019); 60 kg body weight.
4.2	Fish (observed mean) 0.11 mg/kg in tuna fish (Jinadasa *et al*., 2014)

Table 20: Comparison of exposure of Sri Lankans to Pb through foods based on published research data converted to PTTI

PTTI (μg/day)	Notes
6	Limit for children below 7 years
15	Limit for children above 7 years
25	Limit for pregnant women
75	Limit for adults
13.4 (Rice)	At the rate of 0.03 mg/kg in rice (Herath *et al*., 2018; Norton *et al*., 2014); Consumption 438 g rice per day
63.2 (Vegetables)	Based on WHO (2016) (0.486 mg/kg); consumption 130 g per day
410 (Leafy vegetables)	Based on Table 9 (approximate maximum lead of 8.2 mg/kg) and leafy vegetable consumption 50 g per day
66	Household rice and vegetables 330 g/day from CKDU patients approximated to 0.20 mg/kg of lead (Ananda Jayalal *et al.,* 2019)
4.4	Fish (mean) 0.11 mg/kg in tuna (Jinadasa *et al*., 2014); consumption 43 g per day [mean exposure may be 1/10 of this]

The same trend is visible when the PTWI levels of the Codex is examined in the Table 19. The risk due to leafy vegetables appears to be extremely high based on an assumption of 50 g consumption per day, at least in the study in the vegetable cultivating villages. TSP appears to be a major source of lead entering Sri Lankan foods (Figure 3). Ananda-Jayalal *et al*., (2020) reported high concentrations of lead in bones of autopsy samples of CKDU affected subjects.

Risk through exposure to mercury

Risk associated with mercury in the food chain occurs mainly on exposure to methyl mercury in fish, which is of higher toxicity than its inorganic forms. Methyl mercury accounts for 83% of total mercury in fish muscle from south Florida estuaries (Kannan *et al*., 1998). In the same location, methyl mercury in estuary sediments were only 0.77%, and that of water is less than 52% of total mercury. Separate studies by the same research group in Sri Lanka have shown mean total mercury concentrations of 0.43 in cooked, 0.90 in export, and 1.24 mg/kg in fresh swordfish, with a maximum value of 1.47 mg/kg (Table 14). These values were used in estimating the PTWI values for comparison with international norms.

The following assumptions were made in calculating the PTWI values for exposure to total mercury through fish.

a) The average body weight of humans is 55 kg.
b) The concentrations of mercury in fish is 1.24 mg/kg (mean value for sword fish) and 2.58 mg/kg (maximum reported for sword fish) (Jinadasa *et al*., 2010).
c) The average consumption of fish is 300 g per week, as observed in a study in Gampaha district (Jayasinghe *et al*., 2018).
d) The average consumption of pelagic fish, mainly swordfish, is 83 g per week (Jinadasa *et al*., 2014b).

On the above basis, PTWI levels for mercury are shown in Table 21.

Table 21: Comparison of exposure of Sri Lankans to mercury through sea fish based on published research data converted to PTWI.

PTWI	Notes
1.6	JECFA PTWI for methyl mercury (2003)
5.0	JECFA PTWI for total mercury (1978)
2.3	Assuming consumption of 300 g per week of cooked fish containing 0.43 mg/kg total mercury (Jayasinghe *et al*., 2018)
6.7	For a mean value of 1.24 mg/kg of total mercury in swordfish (Jinadasa *et al*., 2010)
3.9	Maximum of 2.58 mg/kg of total mercury in swordfish (Jinadasa *et al*., 2014b) with a weekly consumption of 83 g.

Table 22: Summary of food standards for heavy metals in developed countries (mg/kg)

Regulator	Arsenic	Cadmium	Lead	Mercury
Codex - food	0.1 [rice 0.2]	0.05-0.2	0.001 – 0.3	0.5 -1.0
Codex - water	10 μg/L	3 μg/L		0.1 μg/L
European Commission (ESFA)	0.1-0.3 [rice products]	0.05 -0.5 [meats] 0.05 [root vegetables] 0.2 [leafy vegetables]	0.02 – 0.5 0.1 [vegetables]	0.5 – 1.0 [fish]
USA - FDA	10 achievable in apple juice	50 ppb suitable for juices		
USA - EPA - water	10 μg/L	7 μg/L for tap water	0 μg/L for tap water	1 μg/L for tap water
FAO/WHO	10 μg/L for water	0.2 for food	0.3 for food 100 μg/L water for adults 10 μg/L water Canada	1 μg/kg body weight per week other than seafoods

If the data in the Table 21 are examined assuming that methyl mercury is 75% of total mercury (Florida estuaries showed 80%), the calculated PTWI values would be almost the same as JEFCA value for cooked fish, and would exceed that for fresh swordfish. Jinadasa *et al*. (2014a), in a study of 140 and 176 samples of yellow fin tuna and swordfish, concluded that they contribute only 9% and 27% total mercury respectively to the PTWI of JCEFA, based on consumption of 83 g large pelagic fish per week. They also reported that 32% of swordfish samples exceeded the EU tolerance limit of 1 mg/kg for mercury, but not any of the tuna fish samples.

The results suggest that there is a food safety risk to persons consuming tuna or swordfish as the only type of fish in Sri Lanka in high volumes.

Regulations on heavy metals in foods

Each country decides on the level of protection needed for its population from food safety hazards. This results in variations in food standards. A summary of the food standards by major food safety authorities in the World is given in Table 22.

Table 23 : Proposed horizontal food standards for heavy metals in Sri Lanka.

Heavy metal	Commodities	MTL mg/kg	Notes
Arsenic (Total)	Rice and rice- based products for adults	0.2	Recommendations take into consideration what is agronomically possible based on reported levels of arsenic in soil and water, leaving out what may be contributed by agricultural inputs, and accepting what is recognized internationally as safe.
Arsenic (Total)	Rice and rice -based products for infants	0.1	Risk reductions need to be addressed for more vulnerable groups, the infants, children, and pregnant mothers consuming special foods through rice-based cereals *etc*.
Arsenic (Total)	Drinking water	10 µg/L	Codex limit would be satisfactory under Sri Lanka conditions as total arsenic levels are 7 to10-fold less than the limit.
Arsenic (Total)	Vegetables and fruits	0.2	General Codex limit for arsenic in foods as there is no evidence of arsenic in vegetables and fruits in Sri Lanka
Arsenic (Inorganic)	Fish and fish products	0.2	The bulk of arsenic in fish is in a non-toxic form as arsenobetaine.
Cadmium	Rice and rice products	0.1	This appears achievable under current cultivation conditions and would prevent development of cadmium hot spots. The need is linked with observed high consumption of rice in Sri Lanka
Cadmium	Water	3 µg/L	Codex standard
Cadmium	Vegetables and fruits	0.2	Stringent conditions are needed considering current field observations. Controls through fertilizer and pesticides is possible. The suggested value is the Codex limit.
Cadmium	Fish & fish products	0.1	In line with the limits in many countries. It is achievable.
Lead	Rice & rice products	0.1	A more reasonable tolerance limit to discourage use of contaminated agricultural inputs while accommodating natural soil concentrations.
Lead	Water	10 µg/L	This low limit is suggested as it is already reflected in reports and would be beneficial to be used as a mechanism to reduce the overall exposure and the risk through lead
Lead	Vegetables and fruits	0.3	A low tolerance limit for vegetables to discourage use of agricultural inputs contaminated with lead. Same as Codex limit
Lead	Fish & fish products	0.3	Achievable. It is in line with EFSA limits.
Mercury	Rice & rice products	0.02	Mercury is not a food safety hazard associated with rice. It is best to use the Codex standard
Mercury	Water	1 µg/L	Same as Codex standard
Mercury	Vegetables and fruits	0.02	Mercury is not a food safety problem associated with vegetables. It is best to use the Codex standard.
Mercury	Fish & fish products	1.0 methyl mercury	For predatory fish (shark, swordfish, tuna). 0.5 for other fish. Same as Codex standards

All developed countries and most of the Southeast Asian countries moved to new food safety authorities and horizontal food safety standards during 2012 to 2020. Preparation of country specific standards needs deep understanding of the exposure levels and risks arising from heavy metals in foods and dietary patterns.

Recommendations

Considering this national need, the recommendations given in Table 23 are made to develop Horizontal Food Safety Standards in Sri Lanka.

CONCLUSION

Sri Lanka needs to understand the critical points in the food chain where controls should be introduced to ensure the food safety of the nation without affecting its food security. It requires addressing the problems with deep scientific understanding. This review is meant to provide the analyzed scientific information for Sri Lanka in its efforts to ensure a safe food supply.

REFERENCES

Agriculture and Agri-Food Canada. (1997). Standards for methods in fertilizers and supplements, memorandum. T-4-93. *Fertilizer Act Regulations*. Government of Canada.

Ananda-Jayalal T.B. (2015). Chronic kidney disease of uncertain aetiology; adding vital piece of information to the national project team report of Sri Lanka. *BioMedical Central Nephrology* **16**(216): 1–3.
DOI: https://doi.org/10.1186/s12882-015-0211-5

Ananda-Jayalal T.B., Jayaruwan Bandara T.W.M.A., Mahawithanage S.T.C., Wansapala J.M.A. & Galappaththi S.P.L. (2019). A quantitative analysis of chronic exposure of selected heavy metals in a model diet in a CKD hotspot in Sri Lanka. *BioMedical Central Nephrology* **20**: 208.
DOI: https://doi.org/10.1186/s12882-019-1371-5

Ananda-Jayalal T.B., Mahawithanage S.T.C., Senanayaka S.M.H.M.K. & Dasanayaka P.B. (2020). Evidence of selected nephrotoxic elements in Sri Lankan human autopsy bone samples of patients with CKDU and controls. *BioMedical Central Nephrology* **21**: 384.
DOI: https://doi.org/10.1186/s12882-020-02049-4

Arunakumara K.K.I.U., Walpola B.C. & Yoon M-H. (2013). Current status of heavy metal contamination in Asia's rice lands. *Reviews in Environmental Science and Biotechnology* **12**: 355–377.
DOI: https://doi.org/10.1007/s11157-013-9323-1

Balasooriya S., Diyabalanage S., Yatigammana S.K., Ileperuma O.A. & Chandrajith R. (2021). Major and trace elements in paddy soils in Sri Lanka with special emphasis on chronic kidney disease of undetermined origin. *Environmental Geochemical Health*. **44**: 1841–1855
DOI: https://DOI.oog/10.1007/s.10653-021-01036-4

Bhattacharya P., Samal A.C., Majumdar J. & Santra S. (2009). Transfer of arsenic from groundwater and paddy soil to rice plant (*Oryza sativa L.*): A micro level study in West Bengal, India. *World Journal of Agricultural Sciences* **5**(4): 425–431.

Ministry of Health (2021). *Cancer Incidence and Mortality Data, Sri Lanka.* National Cancer Control Programme, Ministry of Health, Colombo, Sri Lanka.

Carrington C.D. & Bolger P.M. (1992). An assessment on the hazards of lead in food. *Regulatory Toxicology and Pharmacology* **16**(3): 265–272.
DOI: https://doi.org/10.1016/0273-2300(92)90006-U

Chandrajith R., Dissanayake C.B. & Tobschall H.J. (2005). The abundance of rarer trace elements in paddy (rice) soils of Sri Lanka. *Chemosphere* **58**: 1415–1420.
DOI: https://doi.org/10.1016/j.chemosphere.2004.09.090

Chandrajith R., Mahatantila K., Jayasena H.A.H. & Tobschall H.J. (2008). Geochemical characteristics of sediments from a reservoir (tank) ecosystem in Sri Lanka. *Paddy Water Environment* **6**: 363–371.
DOI:https://doi.org/10.1016/j.chemosphere.2004.09.090

Chandrajith R., Seneviratna S., Wickramaarachchi K., Attanayake T., Aturaliya T.N.C. & Dissanayake C.B. (2010). Natural radionuclides and trace elements in rice field soils in relation to fertilizer application: study of a chronic kidney disease area in Sri Lanka. *Environmental Earth Science* **60**:193–201.
DOI:https://doi.org/10.1007/s12665-009-0179-1

Chandrajith R., Nanayakkara S. K., Aturaliya T.N.C., Dissanayake C.B., Abeysekera T., Harada, K., Watanabe T. & Koizumi A. (2011). Chronic kidney diseases of uncertain etiology (CKDU) in Sri Lanka: geographic distribution and environmental implications. *Environmental and Geochemical Health* **33**: 267–268.
DOI:https://doi.org/10.1007/s10653-010-9339-1

FAO (2015). *Codex General Standard For Contaminants and Toxins in Food and Feed (CODEX STAN 193-1995)*. FAO, Rome, Italy.

Commission Regulations (EC) (2006). *Commission Regulations 1881/2006 Setting Maximum Levels for Certain Contaminants in Foodstuffs.* European Union.

Duxbury J.M. & Zavala Y.J. (2005). What are safe levels of arsenic in food and soils. *Term Paper,* Cornell University, Ithaca, NY, USA.

EFSA (2012). Cadmium dietary exposure in the European population. *European Food Safety Authority Journal* **10**(1): 2551.
DOI: https://doi.org/10.2903/j.efsa.2012.2551

FDA (2016). *Arsenic in Rice and Rice Products; Risk assessment report (Version released for public comments).* Center for Food Safety and Applied Nutrition. FDA, Maryland, USA.

FDA (2021). *Fish and Fishery Product Hazards and Control Guidelines*. Center for Food Safety and Applied Nutrition. FDA, Maryland, USA.

Gunadasa S.G., Tighe M.K. & Wilson S.C. (2021). Arsenic and cadmium and associated risk in farm soils of the dry zone Sri

Lanka where chronic kidney disease of unknown etiology (CKDU) is endemic. *Exposure and Health* **14**: 543–556. DOI: https://doi.org/10.1007/s12403-021-00433-5

Gunasekera D., Amarasinghe K.K.H.A. & Deeyamulla M. (2015). Determination of lead exposure in humans by biomonitoring of selected Sri Lankan population. *Postgraduate Research Conference, University of Kelaniya.*

Godt J., Scheidig F., Grosse-Siestrup C., Esche V., Brandenburg P., Andrea Reich R. & Groneberg D.A. (2006). The toxicity of cadmium and resulting hazards for human health. *Journal of Occupational Medicine and Toxicology* **1**:22. DOI:https://doi.org/10.1186/1745-6673-1-22

Gupta N., Yadav K.K., Kumar V., Kumar S., Chadd R.P. & Kumar A. (2019) Trace elements in soil-vegetables interphase: Translocation, bioaccumulation, toxicity and amelioration – A review. *Science of the Total Environment* **651**: 2927–2942. DOI:https://doi.org/10.1016/j.scitotenv.2018.10.047

Helgi Library (2017). *Rice Consumption Per Capita in World.* Helgi Library, Czech Republic. Available at *https://www.helgilibrary.com/indicators/rice-consumption-per-capita*.

Herath H.M.A.S., Kawakami T., Nagasawa S., Serikawa Y., Motoyama A., Chaminda T., Weragoda G.G., Yatigammana S.K. & Amarasooriya A.A.G.D. (2018). Arsenic, cadmium, lead, and chromium in well water, rice, and human urine in Sri Lanka in relation to chronic kidney disease of unknown etiology. *Journal of Water Health* **16**(2): 212–222. DOI: https://doi.org/10.2166/wh.2018.070

IARC (2018). *IARC Monographs: Cadmium and Cadmium Compounds.* IARC, Lyon, France. Available at *https://monograph.iarc.who.int/wp-content.*

Jayasekara R. & Fretas M.C. (2005). Concentration levels of major and trace elements in rice from Sri Lanka as determined by the k_0 standardization method. *Biological Trace Elements Research* **103**: 83–95. DOI: https://doi.org/10.1385/BTER:103:1:083

Jayasinghe G.D.T.M., Sandaruwan K.P.G.L., Silva D.W.L.U. & Jinadasa B.K.K.K. (2018). Total diet study approach in estimating mercury and cadmium levels using selected fish: A case study from Sri Lanka. *Ceylon Journal of Science* **47**(3): 275–279. DOI: https://doi.org/10.4038/cjs.v47i3.7534

Jayatilake N., Mendis S., Maheepala P. & Mehta F.R. (2013). Chronic kidney disease of uncertain aetiology: prevalence and causative factor in a developing country. *BioMedical Central Nephrology* **14**: 1–13. DOI: https://doi.org/10.4038/cjs.v47i3.7534

Jayawardena D.T., Pitawala H.M.T.G.A. & Ishiga H. (2012). Geochemical assessment of arsenic and selected elements in agricultural and non-agricultural soils in Sri Lanka. *Tropical Agriculturist* **20**: 1–19.

Jinadasa B.K.K.K., Edirisinghe E.M.R.K.B. & Wickramasinghe I. (2014a) Total mercury, cadmium and lead levels in main export fish of Sri Lanka. *Food Additives and Contaminants: Part 2* **7**(4): 309 –314. DOI: https://doi.org/10.1080/19393210.2014.938131

Jinadasa B.K.K.K., Ahmad S.B.N., Edirisinghe E.M.R.K.B. & Wickramasinghe I. (2014b). Mercury content in yellowfin tuna (*Thunnus albacores*) and swordfish (*Xiphias gladius*) and estimation of mercury intake. *Journal of Food Security* **2**(1): 23–26.

Jinadasa B.K.K.K., Rameesha L.R.S., Edirisinghe E.M.R.K.B. & Rathnayake R.M.U.S.K. (2010). Mercury, cadmium and lead levels in three commercially important marine fish species of in Sri Lanka. *Sri Lanka Journal of Aquatic Science* **15**: 39–43. DOI: https://doi.org/10.4038/sljas.v15i0.5481

Jose R., Peralta-Videa., Lopez M. L., Narayan M., Saupe G. & Gardea-Torresdey J. (2009). The biochemistry of environmental heavy metal uptake by plants: Implications for the food chain. *The International Journal of Biochemistry and Cell Biology* **41**(8): 1665–1677. DOI: https://doi.org/10.1016/j.biocel.2009.03.005

Kananke T., Wansapala J. & Gunaratne A. (2014). Heavy metal contamination in green leafy vegetables collected from selected market sites of Piliyandala area, Colombo District, Sri Lanka. *American Journal of Food Science and Technology* **2**(5): 139–144. DOI: https://doi.org/10.12691/ajfst-2-5-1

Kannan K., Smith R.G., Jr., Lee R.F., Windom H.L., Heitmuller P.T., Macauley J.M. & Summers J.K. (1998). Distribution of total mercury and methyl mercury in water, sediment, and fish from south Florida estuaries. *Archives of Environmental Contamination and Toxicology* **34**(2):109–18. DOI: https://doi.org/10.1007/s002449900294

Lim K. T., Shukor M.Y. & Wasoh H. (2014). Physical, chemical, and biological methods for the removal of arsenic compounds. *Biomed Research International*. 2014 DOI: https://doi.org/10.1155/2014/503784

Madhavan S., Roseman K.D. & Skehata T. (1989). Lead in soil: recommended permissible levels. *Environmental Research* **49**(1): 136–142. DOI: https://doi.org/10.1016/S0013-9351(89)80028-3

Mandal B.K. & Suzuki K.T. (2002). Arsenic round the world – a review. *Talanta* **58**: 201–235. DOI: https://doi.org/10.1016/S0039-9140(02)00268-0

Meharg *et al.* (16 authors) (2013). Variation in rice cadmium related to human exposure. *Environmental Science and Technology* **47**: 5613–5618. DOI: https://doi.org/10.1021/es400521h

Meharg A.A., Williams N.P., Adomako E..E., Lawgali Y.Y., Deacon C., Villada A., Robert C., Cambell J., Sun G., Y-G., Feldmann J., Raab A., F-J., Rafiqul Islam R., Hossain S., & Yanai J. (2009). Geographic variation of total and inorganic arsenic content of polished white rice. *Environmental Science and Technology* **43**(5): 1612 –1617.

Ministry of Environment (2007). *Government Decree on the Assessment of Soil Contamination and Remediation Needs 214/2007.* Ministry of the Environment, Finland. Available at *http://extwprlegs1.fao.org/docs/pdf/fin113198.pdf.*

Nishimura M, Konishi S., Matsunaga K., Hata K. & Kosuga T. (1983). Mercury concentration in the ocean. *Journal of the Oceanographical Society of Japan* **39**: 295–300.

DOI: https://DOI.org/10.1007/BF02071824

Norton *et al.* (17 authors) (2014). Lead in rice: Analysis of baseline lead levels in market and field collected rice grains. *Science of the Total Environment* **485**: 428–434. DOI: https://doi.org/10.1016/j.scitotenv.2014.03.090

Oberoi S., Barchowsky A. & Wu F. (2014). The global burden of disease for skin, lung, and bladder cancer caused by arsenic in food. *Cancer Epidemiol Biomarkers Prev*ention **23**(7):1187–1194. DOI: https://doi.org/10.1158/1055-9965.EPI-13-1317

Premarathna H.M.P.L., Hettiarachchi G.M. & Indraratne S.P. (2011). Trace metal concentration in crops and soils collected from intensively cultivated areas of Sri Lanka. *Pedologist* 230–240.

Rahman M.A., Hasegawa H., Rahman M.M., Mazid-Mia M.A. & Tasmin A. (2008). Arsenic accumulation in rice (*Oryza sativa* L.): human exposure through food chain. *Ecotoxicology and Environmental Safety* **69**: 317–324. DOI: https://doi.org/10.1016/j.ecoenv.2007.01.005

Rahman M.A., Hasegawa H., Rahman M.M., Rahman M.A. & Miah M.A. (2007). Accumulation of arsenic in tissues of rice plant (*Oryza sativa* L.) and its distribution in fractions of rice grain. *Chemosphere* **69**(6): 942–948. DOI: https://doi.org/10.1016/j.chemosphere.2007.05.044

Sanjeevani U.K.P.S., Indraratne S.P., Weerasooriya R., Vitharana U.W.A. & Kumaragamage D. (2017). Identifying the sources and contamination status of potentially toxic trace elements in agricultural soils. *Communications in Soil Science and Plant Analysis* **48**(8): 865–877. DOI: https://doi.org/10.1080/00103624.2017.1299168

Toth G, Hermann T., Da Silva M.R. & Montanarella L. (2016). Heavy metals in agricultural soils of the European Union with implications for food safety. *Environment International* **88**: 299–309. DOI: https://doi.org/10.1016/j.envint.2015.12.017

Uraguchi S. & Fujiwara T. (2012). Cadmium transport and tolerance in rice: Perspectives for reducing grain cadmium accumulation. *Rice* **5**: 1–8. DOI: https://doi.org/10.1186/1939-8433-5-5

Westfall D.G., Mortvedt J.J., Peterson G.A. & Gangloff W.J. (2005). Efficient and environmentally safe use of micronutrients in agriculture. *Communications in Soil Science and Plant Analysis* **36**(1-3): 169–182, DOI: https://doi.org/10.1081/CSS-200043024

WHO (2016). *Investigation and Evaluation of Chronic Kidney Disease of Uncertain Aetiology in Sri Lanka – Final Report.* Ministry of Health, Colombo Sri Lanka.

WHO (2017). *Mercury and Health, Fact Sheet.* WHO, Geneva, Switzerland.. Available at *https://www.who.int/news-room/fact-sheets/detail/mercury-and-health.*

WHO (2018) *Arsenic: Key Facts.* WHO, Geneva, Switzerland. Available at *https://www.who.int/news-room/fact-sheets/detail/arsenic.*

WHO (2019). *Preventing Disease Through Healthy Environments: Exposure To Cadmium: a Major Public Health Concern.* WHO., Geneva, Swtzerland.

WHO (2021), Lead Poisoning: Key Facts, WHO, Geneva, Switzerland. Available at *https://www.who.int/news-room/fact-sheets/detail/lead-poisoning-and-health.*

Zhao F.J. & Wang P. (2020). Arsenic and cadmium accumulation in rice and mitigation strategies. *Plant Soil* **446**:1–21.