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Preliminary assessment of heavy metals intake via food in CKDu affected Uddanam region of Srikakulam, Andhra Pradesh, India

Vidhu Gupta, Kanhaiya Lal and Meena Sehgal

Environment and Health, The Energy and Resources Institute, New Delhi, India

ABSTRACT

The present study aimed to assess metal/heavy metal intake by the population via food environment of the Uddanam region, a hotspot for chronic kidney disease of uncertain aetiology (CKDu) in India. The food samples included rice/paddy, marine/freshwater fish, green gram/black gram (whole), and green leafy vegetables (GLVs, i.e. amaranth/spinach). These were analysed for metal/heavy metal (chromium, nickel, copper, arsenic, lead, magnesium, calcium, aluminium, manganese, iron, zinc, barium, cadmium, mercury, and uranium) content using standard procedures. The total heavy metal intake was calculated as a sum of the intake from each food source. The daily dietary intake was compared to safe intake levels (from the Institute of Medicine of the National Academies and National Institute of Nutrition). The intake was higher than safe levels for lead, chromium, and manganese. It is advisable to reduce heavy metal exposure by adopting agricultural practices and public health interventions in terms of diet.

KEYWORDS

CKDu; metals; food; intake; Uddanam; nephropathy

Introduction

Despite two decades of research, the root cause of chronic kidney disease (CKD) in the younger population of the Uddanam region has remained unidentified. The aetiology of CKD in the younger population is uncertain (termed CKDu) to date and is quite different from the CKD in the older population (age >60 years with a history of diabetes and prolonged hypertension). The high prevalence of CKDu in the population is clustered in some hotspot regions; one being Uddanam region of Srikakulam district in Andhra Pradesh. Here there is a 40–60% prevalence of CKDu in agricultural workers – called Uddanam nephropathy [1–3]. Heavy metals are one of the suspected causes of CKDu in the Uddanam region. Our recent study on the groundwater quality of this region showed elevated levels of environmental contaminants, including heavy metals such as lead and chromium [4].

Heavy metals are ubiquitous in the environment and mainly occur naturally. Because of socio-economic activities (industrial, agricultural, and lifestyle), deep-buried heavy metals of earth crusts are now exposed to the air, farm soil, and drinking water. Heavy

CONTACT Kanhaiya Lal kanhaiya.lal@teri.res.in Environment and Health, the Energy and Resources Institute, New Delhi, India

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metals such as arsenic, cadmium, lead, mercury, and uranium have no role in human body metabolism. Exposure to high concentration(s) of heavy metals causes acute toxicity, which is easy to monitor and hence can be easily controlled. In contrast, continuous exposures to trace levels of heavy metals over the years may cause chronic diseases such as CKDu. This is difficult to monitor and regulate.

These heavy metals can enter the human food chain via several routes. These include the metal-rich irrigation water application, improper management of industrial effluents, heavy metal-containing pesticides and fertilisers, and improper handling of poultry [5, 6]. Various detrimental health effects of heavy metals and their suspicious relation with kidney diseases have been noticed. The present study is a part of the project 'STOP CKDu AP' (details can be found in our earlier publications [3, 4]), which aimed to establish the root causes for the high burden of CKD in Uddanam. The present study focused on assessing heavy metals intake by the population via food items consumed in the Uddanam region.

Methodology

Consumption of contaminated food can be a significant source of heavy metal intake. The main cause is the cultivation of the food crops in the contaminated soils. Handling, preservation, and storage may also contribute to the burden of heavy metals. The next subsections discuss the stepwise procedure to calculate the intake levels of heavy metals by the population (adult man-weight of 60 kg, sedentary activity and in the age group of 19–50 years; Adolescents-both boys and girls of the age group of 9–13 and 14–18 years) through their diet in the Uddanam region of Srikakulam district, Andhra Pradesh.

Sampling food samples for heavy metals analysis

The food samples, collected from the agricultural field and the houses, included rice/ paddy, marine fishes – Silver belly (*Photopectoralis bindicus*) and Ponyfish (*Stolephorus indicus*) and freshwater fish Rohu (*Labeo rohita*), green gram (*Vigna radiata*) whole and black gram (*Vigna mungo*) whole pulses and legumes, and green leafy vegetables, namely amaranth (*Amaranthus spp*.), and spinach (*Spinacia oleracea*) leaves. The paddy, sea fishes, and green leaves were dried under sunlight for three days before being sent to the laboratory. These food materials were further dried in a hot air oven at 60°C for 48 h to remove the moisture. In a microwave digester, the dried homogenous material was digested with aqua regia (HNO_3:HCl = 1:3, v/v). The digested solution thus obtained was subjected to heavy metals (chromium (total), nickel, copper, arsenic (total), lead, magnesium, calcium, aluminium, manganese, iron, zinc, barium, cadmium) analysis using inductively coupled plasma-mass spectrometry (ICP-MS) technique. The chromium (VI) concentration was determined using the colorimetric method [7].

Conversion of dry matter weight to fresh matter weight

As the food items are commonly cooked and consumed in their fresh form, it was necessary to convert the obtained nutrient/heavy-metal content of these food items to the fresh form value. Thus, the dry matter content of the heavy metals reported was converted to the fresh matter value for each food sample using the FAO/ INFOODS formula [8]:

$$NV\left(\frac{g}{100gEP}\right) = NV\left(\frac{g}{100gDM}\right)\frac{\left(100 - watercontent\left(\frac{g}{100gEP}\right)\right)}{100}$$

where NV is nutrient value or heavy metal content in this case; EP is the abbreviation of edible portion, and DM is dry matter, respectively. The values thus received were as mg/ kg of edible portion.

Conversion into daily intakes from different sources

The heavy-metal content from the foods expressed as mg per kg of the edible portion was then converted into the daily intakes of these heavy metals using the recommended dietary intakes [9] for those food groups (i.e. cereals and millets, pulses, fish and green leafy vegetables). The total intake of these heavy metals was calculated as a sum of the intake from each food source. Similarly, the heavy-metal intake was also calculated for the population using the reported intakes in the National Nutrition Monitoring Bureau (NNMB) survey of 10 Indian States (viz., Kerala, Tamil Nadu, Karnataka, Andhra Pradesh, Maharashtra, Gujarat, Madhya Pradesh, Orissa, West Bengal and Uttar Pradesh). We took the reported intake values for Andhra Pradesh [10].

Comparison of daily intakes with safe intake levels

The daily dietary intake of heavy metals was then compared with the safe intake levels (given by India's National Institute of Nutrition (NIN) and Institute of Medicine of the National Academies) of the heavy metals. This helped us to observe which heavy metals were consumed above the safe intake levels. The heavy metals included in the analysis were chromium (total), nickel, copper, arsenic, lead, magnesium, calcium, aluminium, manganese, iron, zinc, barium, cadmium, chromium (VI), chromium (III), mercury, and uranium.

Results

The laboratory analysis of the food items showed that heavy metals such as magnesium, aluminium, calcium, manganese, iron, zinc, and barium were contributed by cereals and pulses in the diet of the population. On the other hand, cadmium, chromium (VI), chromium (III), mercury, and uranium were contributed by fish and green leafy vegetables.

On investigating the intake of heavy metals through diet, it was found that the intake levels of an adult man (sedentary, 60 kg, 19–50 years) showed high consumption of chromium (total), manganese, arsenic, and lead with both marine and freshwater fish consumption. Chromium (total) intake was found to be higher by 16.3–20.5 times, lead intake by 3 times higher, and manganese intake by 1.3 times more than safe levels through the recommended dietary intake (i.e. the amount of different food items one should consume daily based on the gender and age as per the recommendations by the National Institute of Nutrition) of the food groups.

Comparing the intake reported through the dietary survey (i.e. the amounts of different food items actually consumed by the study population) with the safe intake levels, we observed that chromium (total) was higher by about 8 times, lead intake by 2 times, and manganese consumption by 1.3 times than safe levels. Figure 1 shows the intakes of the adult man and adolescents (both boys and girls, 9–13 years).

Figure 2 shows the intakes of the adolescents (both boys and girls, 14–18 years).

Table 1 shows the intake of adolescents (boys and girls) which follows a similar pattern in both age groups.

Arsenic intake is considered harmful even in small amounts, and thus no limits have been given for it. But the present population was found to be consuming some amount of arsenic through dietary sources, as shown in Table 2.

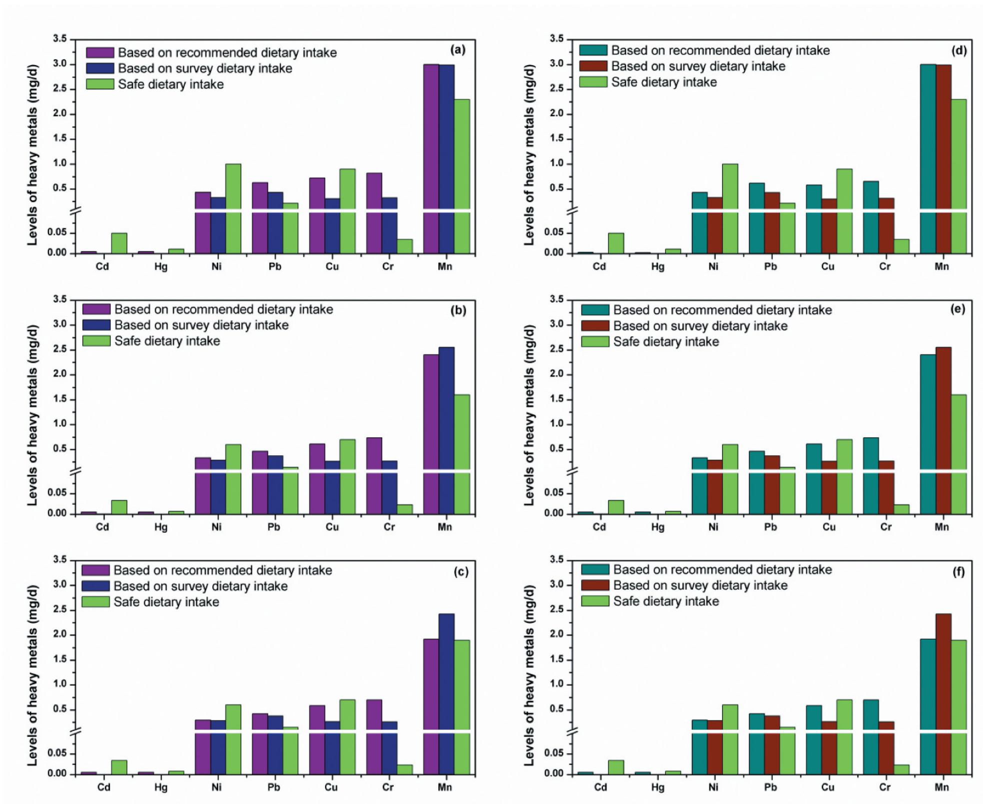

Figure 1. Heavy metals intake by Uddanam's population with (a-c) marine fish & (d-f) freshwater fish consumption [(a) & (d) – adult man (60 kg, sedentary, 19–50 years), (b) & (e) -adolescent boys (9–13 years), (c) & (f) – adolescent girls (9–13 years)]; *The intakes are dietary intakes for the specified age group as recommended in Dietary Guidelines and reported in the NNMB survey 2012; Safe intake levels are for intake of heavy metals intake for that age group (study duration: August 2018 – April 2019).

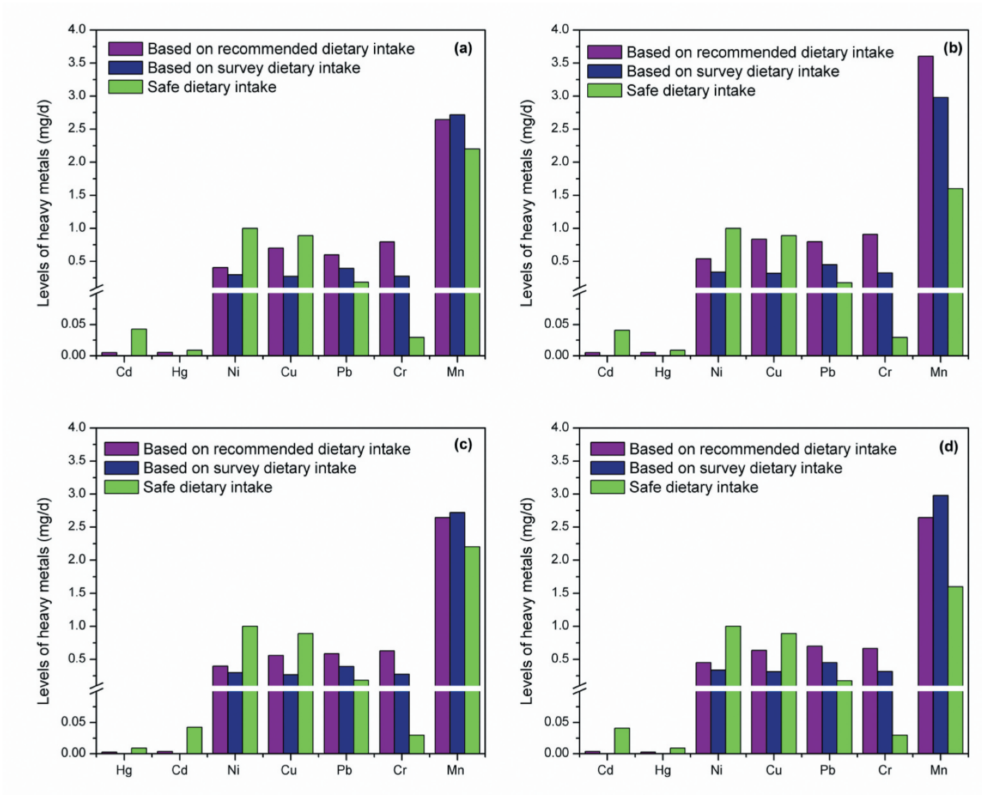

Figure 2. Heavy metals dietary intake by adolescent boys and adolescent girls from survey (age = 14–18 years) [(a &b) marine fish, (c & d) freshwater fish consumption]; *The safe intake levels are the safe levels for heavy metals intake for that age group; study area: Uddanam region, Srikakulam, Andhra Pradesh, India, duration: August 2018 – April 2019).

Table 1. Heavy metals intake by adolescents in Uddanam region Srikakulam, calculated based on recommended dietary intakes and intakes reported in survey (duration: August 2018 – April 2019).

	No. of times heavy metals intake is higher than safe levels							
	9–13 years				14–18 years			
	Based on recommended dietary intake*		Based on intake reported in dietary survey**		Based on recommended dietary intake		Based on intake reported in dietary survey	
Heavy metal	Girls	Boys	Girls	Boys	Girls	Boys	Girls	Boys
Pb	2.7–2.8	2.9–3.4	2.3–2.5	2.6	3.3	3.9–4.4	2.2	2.5
Cr (total)	26.5–35	26.5–37	13	13–13.5	21–26.3	22.3–30.3	9–9.3	10.7–11
Mn	1.0	1.2–1.5	1.3	1.6	1.2	1.7–2.25	1.2	1.9

*Recommended dietary intake: the amounts of different food items one should consume daily based on their gender and age as per the recommendations by the National Institute of Nutrition (NIN)
**Dietary Survey: the amounts of different food items actually consumed by the study population

Therefore, all the age groups consumed chromium (total) in higher amounts, especially adolescents.

Table 2. Arsenic intake by population in Uddanam region Srikakulam, calculated based on recommended dietary intake and on intake reported in survey (duration: August 2018 – April 2019).

Category	Based on recommended dietary intake (in mg/d)	Based on intake reported in dietary survey (in mg/d)
Adult man	0.30–0.35	0.15–0.16
Adolescents (9–13 years)		
Girls	0.20–0.25	0.15
Boys	0.20–0.25	0.14
Adolescents (14–18 years)		
Girls	0.30–0.35	0.14
Boys	0.39–0.45	0.17

Discussion

Heavy metals may enter food materials through contaminated soils, irrigation water, and air. Consumption of food items contaminated by heavy metals is a significant route for heavy metal exposure in human beings [11, 12]. Heavy metals are non-biodegradable and their bio-accumulation increases in the nutrition-deprived state. Therefore, developing countries with a higher prevalence of undernutrition are at a greater risk of heavy-metal toxicity. Haiyan and Stuanes reported that vegetables could absorb metal toxins from soils and those parts exposed to the polluted environment [13].

The present study analysed the commonly consumed foods in the Uddannam region, viz., rice, pulses (green gram and black gram), green leafy vegetables (amaranth and spinach), and fish (including marine fishes, Silver belly and Ponyfish, and freshwater fish Rohu) for heavy-metal content. On conversion to daily intakes from these food sources and comparing the same with the safe heavy metal intake levels, we observed a higher intake for lead, chromium, and manganese by the population. A recent Kolkata-based study reported higher daily intakes of lead than the prescribed maximum tolerable (0.2 mg/day) daily intake through consumption of rice, red lentil, vegetables, fish, and chicken consumption. But, arsenic, copper, chromium, manganese, and zinc intake were within the prescribed limits [14]. Another study done in Vadodara reported that cereals are the major contributors to the daily intake of cadmium, lead, and arsenic in the study population [15]. Similar findings on the contribution of arsenic, lead and cadmium from rice were reported in a study done in Sri Lanka [16]. A higher chromium intake in the consumption of vegetables and fruits (100 g) than the limit of daily dietary intake was reported in a study done in and around the Tummalapalle uranium mining site in Andhra Pradesh [17]. Another study done in Sri Lanka showed the contribution of fish to the intake of heavy metals like arsenic, cadmium, and lead [18].

Recent studies in Sri Lanka showed elevated levels of lead (Pb) in Potato (*Solanum tuberosum*), bitter gourd (*Momordica charantia)*, and cadmium (Cd) in Brinjal (*Solanum melongena*) [19]. Another study by Fernando et al. found a higher intake of chromium through cooked rice in CKDu prevalent areas of Sri Lanka [20]. Therefore, various studies done in Sri Lanka have reported that the disease is mainly caused by one or other environmental agents such as drinking water, agricultural practices, heavy metals, and many more [21], which has been observed in Indian cities as well.

Agricultural practices such as the cultivation of crops having low heavy metal uptake tendency, crop rotation and soil treatment measures can reduce the heavy metal content in food crops [22]. Further, food preparation practices like boiling the food items in water followed by draining the excess water and frying in fresh edible oil have reduced the heavy metals in the cooked food items. Moreover, adequate intake of dietary supplements (i.e. essential micronutrients and vitamins) and enhanced consumption of vegetables and fruits help reduce heavy metals exposure [23].

Conclusion and recommendation

The present study showed that dietary intake contributes to heavy metal intake by the people of the Uddanam region, Srikakulam district, Andhra Pradesh. The dietary intake of metals through the food items decreased in the order of Ca> Zn> Mn> Fe> Al> Mg> Ba> **Cr> Cu> Pb> Ni> As**> Cd> Hg> U through recommended dietary intakes. This highlights the importance of exploring heavy metals content in other vegetables and food items of the Uddanam region in future studies. This evidence will further help to find the root cause of CKDu in Uddanam. It is advisable to reduce heavy metal exposure by adopting agricultural practices and public health interventions in terms of diet.

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Disclosure statement

No potential conflict of interest was reported by the author(s).

Author contributions

Meena Sehgal contributed to the study concept and design. Sample and data collection and analysis was performed by Kanhaiya Lal and Vidhu Gupta. The first draft of the manuscript was prepared by Vidhu Gupta and Kanhaiya Lal, and reviewed by Meena Sehgal. All the contributing authors read and approved the final draft.

Data availability statement

The datasets generated during and/ or analysed during the current study are not publicly available as we need consent from the funding agency but are available from the corresponding author on reasonable request. Processed data used in this study is provided as supplementary material.

ORCID

Kanhaiya Lal http://orcid.org/0000-0002-3288-3050

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