



Risk assessment of cadmium intake via food among residents in the mining-affected areas of Nandan County, China

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Abstract This study investigated the dietary structure, Cadmium (Cd) contents in foods and exposure to Cd through diets of the residents in the mining-affected areas of Nandan County in summer 2013 (July to August) and winter 2014 (November to December). The weighing of foods and the chemical analysis of foods were applied to determine the dietary structure, and the concentration of trace element Cd in the diets, respectively, of the residents in the mining-affected areas (Chehe town, Dachang town, and Zhanglao town) and a control area (Liuzhai town), and subsequently the Cd exposure from the diets was estimated. In the mining-affected areas, the geometric mean of Cd in rice and rice products was the highest (0.29 µg/g) among all food types, and it exceeds the value of 0.2µg/g from the China Food Safety National Standard for Maximum Levels of Contaminants in Foods (GB2762-2017). The Cd contents in rice and rice products, vegetables, and beans in the mining-affected areas were significantly higher than those in the control area. The estimated daily food intakes of Cd in the mining-affected areas were higher than the intake in the control area. The THQ in the mining-affected areas of Chehe town, Dachang town, and Zhanglao town was 3.03, 2.31, and 3.27, respectively.

All of which were higher than the value of 1.44 in the control area. Thus, the high level of dietary cadmium intakes of residents in this area deserves our attention.

Keywords Cadmium · Mining areas · Diet · Exposure · Risk assessment

Introduction

Cadmium (Cd) is a toxic element of worldwide concern for years, because it has chronic toxicities on renal tubules and then disturbs mineral metabolism in the bones, as well as damage to the respiratory and cardiovascular systems (Ikeda et al., 2018; Wang et al. 2021). Cd also increases the incidence of cancer. Cd is a relatively hazardous environmental pollutant. It is often associated with naturally occurring metal ores such as lead and zinc (Chen et al., 2018; Filippini et al., 2018; Perosevic et al., 2018; Shi et al., 2018; Zhou et al., 2018), and the mining, smelting, and processing of ore are often associated with Cd entering the soil environment (Buaisha et al., 2020; Cortada et al., 2018; Sako et al., 2018). In the late 1940s, serious epidemics occurred in the Shentongchuan watershed in Toyama Prefecture, Japan, where patients suffered from severe osteomalacia, osteoporosis, and fractures. Later studies showed that these symptoms were related to excessive Cd in the body. Cd in the soil enters the body through the food chain (Jean et al.,

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2018; Moayedi et al., 2019; Yu et al., 2017). The USA Environmental Protection Agency (EPA) and the World Health Organization (WHO) all regard Cd as a priority or focus pollutant (EPA, 2014; WHO, 2011).

Guangxi, China, is known as the “hometown of non-ferrous metals.” The tin–polymetallic metallogenic belt contains very rich metal mineral resources (Cheng, 2011, 2016), and Nandan is an important source of non-ferrous metal minerals in Guangxi. Nandan County is located in the northwestern part of Guangxi. The elevation is high in the north and the south areas of the county. This county is in a semi-rocky area with rich mineral resources. More than 20 kinds of heavy metal ores have been identified in the area, including tin, antimony, zinc, aurum, silver, copper, and ferrum. The available reserves of tin and arsenic are 1,440,000 tons and 478,000 tons, respectively—the highest in China. However, the waste water, dust, and waste slag generated by the mining process enter the soil through processes such as percolation and atmospheric deposition, contaminating the surrounding farmland to varying degrees.

The mining and smelting of non-ferrous metal mineral are the main sources of Cd in the environment. These activities produce water, air, soil, and biological pollution, thereby harming the health of the exposed (Xue et al., 2017; Yu et al., 2017). The Total Dietary Study, also known as the Market Basket Study (Beidokhti et al., 2019; Koch et al., 2016; Liu et al., 2010), is internationally regarded as the most universal and best method for evaluating chemical pollutants and nutrient intake in the diets of a large-scale population (e.g., in a country or region). The present study selected villages with relatively frequent mining activity to investigate the diet structure of residents in Nandan County. Cd contents in different foods and exposure of the residents to Cd in the mining-affected areas of Nandan County in summer 2013 and winter 2014 were studied. The study is of great importance for health evaluation among the local residents.

Materials and methods

Study areas

The study areas of this investigation consist of some mining-affected areas and a control area. The mining-affected areas include some representative villages in

Chehe Town, Dachang Town, and Zhanglao Town (In Chehe Town and Dachang Town, villages which are 3–5 km away from the major mining areas were chosen (Fig. 1). In Zhanglao Town, villages along the Diao River where the effluents of the mining activities in the upstream might have affected the irrigation water were selected). Chehe Town and Dachang Town locate in the center of the polymetallic ores. They have dozens of mining enterprises, and the “Three Wastes” (waste water, waste gas, and solid waste) seep into the soil and rivers through atmospheric precipitation and surface runoff, etc., which greatly threatened the surrounding environments. Zhanglao Town locates in the middle and upper reaches of the Diaojiang River. The flood water carries tailings containing pollutants into the farmland, which affect its agricultural productivity. Liuzhai Town was chosen as the control area because it is far from mining areas, located in the north of Nandan country, and its dietary habits are similar to those of the mining-affected areas.

Collecting samples and measurement methods

A multi-stage random sampling method was used to select the survey samples from the study areas (Chehe town, Dachang town, Zhanglao towns, and Liuzhai town) in the summer (1 July–20 August 2013) and winter (1 November–10 December 2014). A dietary survey was administered at household level. During the survey, the respondents maintained their usual eating habits (including the type and amount of food and frequency of consumption) to obtain the most reliable and accurate data. The food samples collected in this study originated from the respondents homes and the nearby vegetable market, grocery, and grain stores. The survey included basic family circumstances, 24-h dietary recall, and frequency of food consumption. Kitchen scales (weighing range: 1–3 kg) were distributed to each household. For the mining-affected areas of Chehe Town, Dachang Town, and Zhanglao Town, current study investigated 24, 27, and 25 households, respectively. For the control area, 26 households living in Liuzhai Town (a town far away from the mining zones) were used. The ages of the respondents in the mining-affected areas ranged 16–101 years old (101 males with an average weight of 58.1 kg; 103 females with an average weight of 52.7 kg). Residents weigh raw (before processing at home) or processed foods (processed at home:

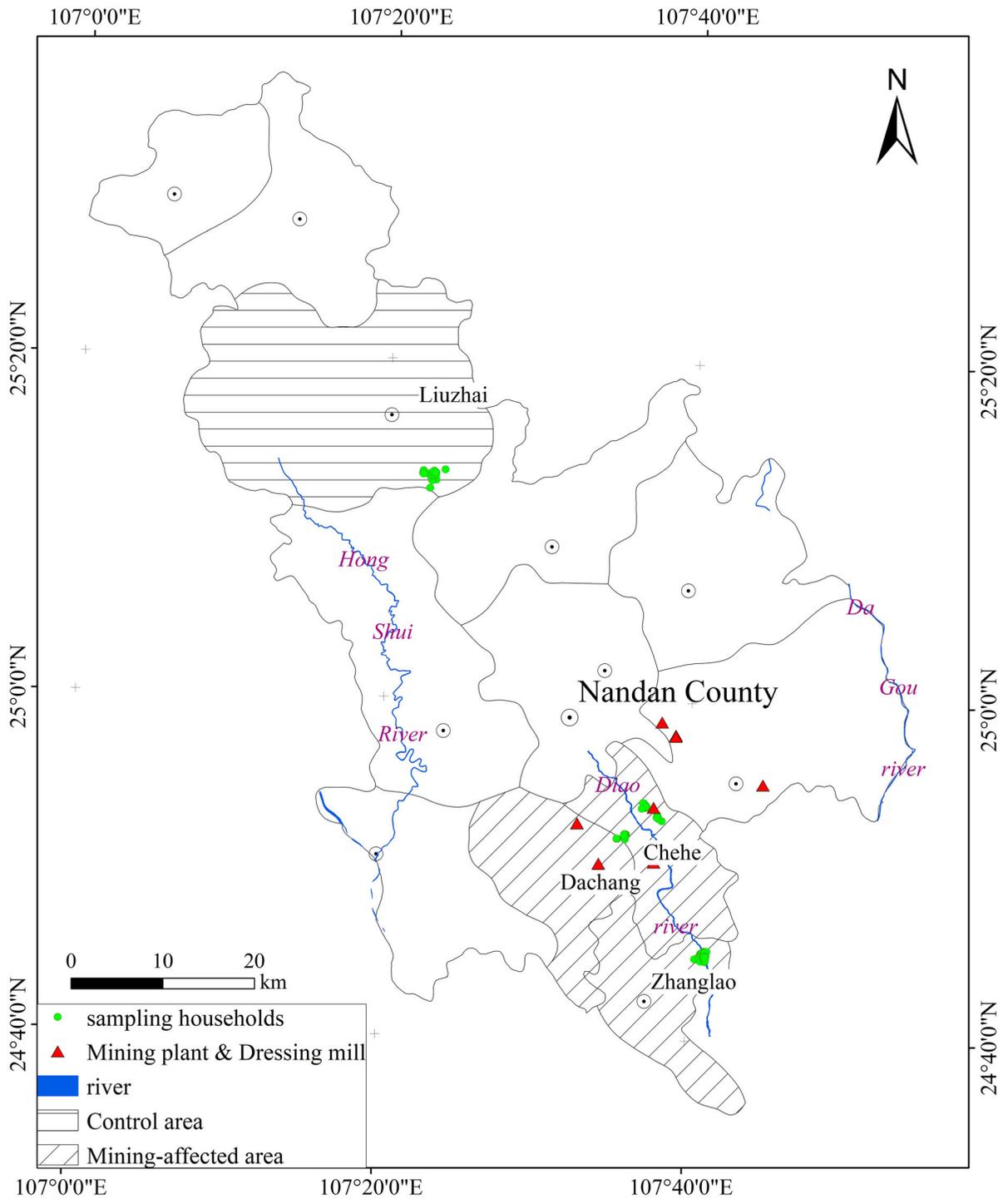


Fig. 1 Distribution map of the study area of Nandan county, China

cooking, baking, etc.), which they consumed over 3 days and recorded by researchers. Residents weighed quantities of different food types they used:

rice and its products, vegetables, meat and its products, bean and its products, fats, other grains, eggs, fishes, fruits, and others in their households consumed

over 3 days and recorded them in detail on a dietary questionnaire. The classification of food categories was made according to the China Food Safety National Standard for Maximum Levels of Contaminants in Foods (GB2762-2017). Investigators asked the respondents to keep these foods in polyethylene plastic lunch boxes provided by the investigators during the investigation; Samples were collected and numbered by the investigators, and brought to the laboratory for analysis. Notably, the researchers collected samples of perishable food, kept them warm with ice packs and foam boxes, and then brought them back to the lab to be frozen as soon as possible.

In summer (July to August), rice and its products (101 samples), vegetables (162 samples), meat and its products (9 samples), bean and its products (14 samples), fats (59 samples), other grains (103 samples; mainly corn), eggs (12 samples), fishes (2 samples), fruits (9 samples), and others (3 samples) were collected. In winter (November to December), vegetables (274 samples), meat and its products (8 samples) and other grains (30 samples; mainly corn) were collected. Over these seasons, this study collected 101 samples of rice and its products, 436 samples of vegetables, 17 samples of meat and its products, 14 samples of beans and bean products, 59 samples of fats, and 133 samples of other grains, 12 samples of eggs, 2 samples of fish, 9 samples of fruit, 3 samples of other kinds. The solid food samples (e.g., meat, poultry, bean curd) were grinded, put into the polyethylene box with cover, and stored in the freezer at $-20\text{ }^{\circ}\text{C}$; the liquid food samples (e.g., oils and eggs without shell) were filled into a polyethylene bottle (with a volume of 150 ml) and stored in the freezer at $-20\text{ }^{\circ}\text{C}$.

Samples of the collected foods (0.5 g–1.0 g) were placed in quartz containers that had been washed with MilliQ water and nitric acid (HNO_3). Before subsequent analysis, the food samples were liquid washed (6 ml $\text{HNO}_3 + 1\text{ ml H}_2\text{O}_2$) in a microwave digestion system, stored in a plastic tube, and diluted to 50 ml with deionized water. Cd were determined using a graphite furnace atomic absorption spectrometer (AA700, PerkinElmer, USA). All reagents were guaranteed reagent (GR), and deionized water was used throughout the laboratory testing. All of the analyses were performed in duplicate, and quality control was carried out using both blanks (MilliQ water) and national standard samples ((GSV-1),

(GSB-23), (GSB-29)). GSV-1 (GBW07602) is biological composition analysis-shrub branch and leaf composition analysis standard material. GSB-23 (GBW10045) is standard material for bioanalysis of rice. GSB-29 (GBW10051) is standard material for component analysis of pig liver. 10% of the samples were selected for repeated testing; the absolute error of the two independent measurements obtained under the condition of repeatability shall not exceed 20% of the arithmetic mean. LOD and LOQ were 0.001 mg/kg and 0.003 mg/kg, respectively.

Statistics and evaluation methods

SPSS 18.0 software was used for testing normality ($P_{K-S} > 0.05$ indicates that the Cd content for samples are normally distributed) and independent samples t-test for the analysis of Cd content for various food differences between mining-affected areas and control area ($P < 0.05$). Results are presented according to the distribution characteristics of the data. Original data were not normally distributed; the logarithmic transformation was used to achieve a normal distribution. Therefore, geometric means were better used to represent the mean Cd content in foods.

Using the Cd content in the food samples and data collected through the questionnaire, we obtained the actual daily food consumption per person and calculated the daily intake (DI) of Cd through food per person. Cd content in the food was compared with China Food Safety National Standard for Maximum Levels of Contaminants in Foods (GB2762-2017). For the residents of the four regions participating in the study, their daily intake from various foods was calculated by using the following formula (Ihedioha et al., 2013; Liu et al., 2010):

$$\text{DI} = F_{\text{IR}} C$$

In the formula, F_{IR} is the average daily consumption of various types of food (g), and C is the geometric mean concentration of Cd in various foods ($\mu\text{g/g}$). The total intake of Cd per person per day is the sum of dietary intakes for various food types.

The target hazard quotient (THQ) was used to evaluate the health risks of Cd to local residents through the intake of food, proposed in 2000 by the USA Environmental Protection Agency (Herrman et al. 1999; Moon et al., 1996; Speijers, 1999; Xue et al., 2017), using the following formula:

$$THQ = \frac{E_F \times E_D \times DI}{W_{AB} \times T_A \times R_{fd}} \times 10^{-3}$$

In this formula, E_F is the exposure frequency (360 d/a); E_D is the average life expectancy (73 a); DI is daily Cd intake (mg/d); R_{fd} is the reference dose (mg/[kg·d]), the Cd reference dose is 1×10^{-3} mg/[kg·d] (Liao & Ling, 2003); W_{AB} is the average body weight (kg/person; in the control area, the average body weight was 53.2 and 55.4 kg/person in the control and mining activity-affected areas, respectively), and T_A is the average exposure time (d/a). $THQ > 1$ indicates the health risk of Cd. The greater the THQ value, the higher the risk.

Results

Consumption amount in residents' diets

Using the dietary survey results, on the total amount of foods, the arithmetic means of residents' intake was calculated for the control and mining-affected areas, as shown in Table 1. The mean intake of rice and its

products by the residents of the mining-affected areas was below the recommended daily consumption amount per person. The sum of the mean intake of rice and its products and other grains reached the recommended daily consumption amount per person (250–400 g/d) (Chinese Nutrition Society 2016). The mean intake of vegetables in the mining-affected areas was below the recommended daily consumption amount per person (300–500 g/d) (Chinese Nutrition Society 2016). The mean intake of meat and its products above the recommended daily consumption amount per person (40 ~ 75 g/d) (Chinese Nutrition Society 2016). Compared with the dietary intake of urban and rural residents in study from 2002, residents of the mining-affected areas participating in the present study had higher intakes of meat and its products, fats, beans and its products, eggs, rice and its products, and other grains. There was a downward trend in the consumption of fishes and fruits.

The proportions of consumption of particular food groups among all foods were assessed. Among residents in the mining-affected areas, the top six categories for average daily consumption, listed from

Table 1 Average daily food consumption of the residents in the study areas (g/d) (g/d, average values per person.)

Food Category	Chehe Town		Dachang Town		Zhanglao Town		Mining-affected areas		Control areas (Liuzhai Town)		Guangxi Town in 2002
	N	AM	N	AM	N	AM	N	AM	N	AM	
Rice and its products	40	281.7	28	224.2	27	278	95	264.3	30	250.1	408.4
Vegetables	169	315.8	121	309.1	107	267.4	397	297.4	123	231.8	251
Meat and its products	41	154.1	38	142.8	33	165.5	112	154.6	36	105.9	158
Bean and its products	10	32.05	11	37.46	9	18.09	30	29.06	9	25.45	19
Fats	31	34.24	24	48.13	25	27.52	80	34.25	28	25.11	23.5
Other grains	23	5.54	32	8.8	18	7.96	73	7.24	16	3.3	8.9
Eggs	16	21.12	14	15.91	9	7.8	39	15.35	5	3.75	5.1
Fishes	9	20.46	5	77	4	17.92	18	31.91	6	13.1	21.6
Fruits	7	24.71	1	3.6	2	4.3	10	12.17	1	2.07	12.6
Others	92	18.64	76	0.23	62	1.29	230	7.85	65	6.62	12.2

Rice and its products: rice, paddy, and brown rice; Vegetables: Chinese cabbage, cauliflower, cabbage, green peppers, cucumbers, pumpkins, pumpkin seedlings, tomatoes, eggplants, sweet potato seedlings, bitter gourds, wax gourds, bitter herbs, onions, potatoes, green beans, spinach, ferns, fungus, loofah, leeks, carrots; Meat and its products: pork, chicken, and duck; Bean and its products: tofu, peas, and bean curd; Fats: lard, oyster sauce, animal oils, and vegetable oils; Other grains: mainly maize; Eggs: chicken eggs and duck eggs; Fishes: grass carp, frozen sea fish, and dried fish; Fruits: peaches, grapes, and watermelons; Others: sauerkraut, condiments, rice wine

N is the number of food in the sample; AM is the arithmetic mean

high to low, were as follows: vegetables (34.8%), rice and its products (30.9%), meat and its products (18.1%), fats (4.0%), fishes (3.7%), and beans and its products (3.4%) by residents. In the control area, the top six food categories in terms of average daily consumption were rice and its products (37.5%), vegetables (34.7%), meat and its products (15.9%), beans and its products (3.8%), fats (3.7%), and fishes (2.0%).

Level of Cd in foods

The results on Cd content for various foods are shown in Table 2. Rice and its products consumed in the study areas mainly produced by local residents and bought at local market. The total Cd content of rice samples in the mining-affected areas ranged from 0.001 $\mu\text{g/g}$ to 3.34 $\mu\text{g/g}$, with a geometric mean of 0.29 $\mu\text{g/g}$. The Cd content of paddy, brown rice, and other rice was 0.2 $\mu\text{g/g}$. The maximum level Cd content of ground cereals and grains in processed foods in the China Food Safety National Standard for Maximum Levels of Contaminants in Foods (GB2762-2017) is 0.1 $\mu\text{g/g}$. According to the measured results, the average content of Cd in rice and its products in the mining activity-affected areas exceeded the recommended maximum value. In the control area, the Cd content of rice and its products ranged from 0.04 $\mu\text{g/g}$ to 0.77 $\mu\text{g/g}$, with a geometric mean of 0.13 $\mu\text{g/g}$. The average Cd content of rice and its products in the control area did not exceed the recommended limit. An independent samples *t*-test showed that the Cd content of rice and rice products differed significantly between the mining activity-affected areas and the control area ($P < 0.05$).

We calculated the total amount of Cd in vegetables (in terms of fresh weight). The Cd content of the edible part of vegetables collected in the mining-affected areas ranged from 0.001 $\mu\text{g/g}$ to 10.85 $\mu\text{g/g}$, with a geometric mean of 0.112 $\mu\text{g/g}$. The Cd content of the edible part of vegetables collected in the control area ranged from 0.001 $\mu\text{g/g}$ to 3.24 $\mu\text{g/g}$, with a geometric mean of 0.05 $\mu\text{g/g}$. According to the “China Food Safety National Standard for Maximum Levels of Contaminants in Foods” (GB2762-2017), root vegetables (excluding celery) should contain no more Cd than 0.1 $\mu\text{g/g}$, and the Cd limit for leafy vegetables, celery, and edible mushrooms (excluding shiitake mushrooms) is 0.2 $\mu\text{g/g}$. The limit for other

vegetables and fruits is 0.05 $\mu\text{g/g}$. According to our survey results, the vegetables consumed in the survey area were mainly leafy vegetables, so the evaluation value for vegetables was 0.2 $\mu\text{g/g}$. The Cd content of vegetables was within the scope of the standard in both the control area and the mining-affected areas, but the mean level in the area affected by mining activity was only slightly lower than the standard, which requires attention. The study found that rice exceeded the standard for Cd content, whereas beans and bean products, fish, and fruits were within safe limits.

Cd exposure and health risk assessment

According to the results for residents’ food consumption (Table 1), rice and its products were the main foods consumed in the study area. In the dietary structure, the contribution rate of this type of food was high. Vegetables followed rice and rice products as the second largest contributor to daily food consumption in the study area. Table 3 summarizes residents’ dietary intake of Cd and health risks based on the average daily consumption of various food types (g/person-day) and the Cd content ($\mu\text{g/g}$) of food samples gathered from residents.

The dietary cadmium exposure in mining-affected area was 161.3 $\mu\text{g/d}$, which was higher than that in control area (76.55 $\mu\text{g/d}$). Among them, vegetables contributed the most to dietary cadmium exposure in Chehe town (40.74%), rice and its products contributed the most in Dachang town (31.43%), and rice and its products contributed the most in Zhanglao town (82.96%). In the control area, rice and its products contributed the most to dietary Cd exposure (42.79%). Therefore, rice and its products and vegetables contributed more to dietary Cd exposure.

To further analyze the health risks of Cd to the human body, the THQ was used to evaluate the health risks of heavy metals consumed by residents of mining-affected areas in Nandan through various types of food. Table 3 shows that the THQ values in the mining activity-affected areas of Chehe town, Dachang town, and Jindong village were 3.03, 2.31, and 3.27, respectively, which were all higher than the THQ value of 1.44 in Liuzhai town, the control area. The THQ values in the three mining-affected areas were all greater than one, indicating the presence of health risks in the three mining areas.

Table 2 Cd contents in the diets of the residents in the study areas (µg/g)

Food	Chehe Town			Dachang Town			Zhanglao Town			Mining-affected areas			Control areas (Liuzhai Town)		
	N	AM ± SD	GM	N	AM ± SD	GM	N	AM ± SD	GM	N	AM ± SD	GM	N	AM ± SD	GM
Rice and its products	21	0.21 ± 0.33	0.12	15	0.25 ± 0.25	0.18	47	0.78 ± 0.69	0.54	83	0.54 ± 0.617	0.29	18	0.15 ± 0.17	0.13
Vegetables	151	0.57 ± 1.02	0.22	120	0.33 ± 1.17	0.06	60	0.29 ± 0.75	0.07	331	0.44 ± 1.04	0.11	105	0.29 ± 1.15	0.05
Meat and its products	7	0.11 ± 0.07	0.09	4	0.21 ± 0.17	0.14	2	0.03 ± 0.01	0.03	13	0.1s3 ± 0.12	0.09	4	0.21 ± 0.22	0.14
Bean and its products	4	1.12 ± 1.55	0.49	5	0.45 ± 0.53	0.19	3	0.17 ± 0.05	0.17	12	0.60 ± 0.96	0.25	2	0.38 ± 0.009	0.38
Fats	15	0.09 ± 0.08	0.07	10	0.09 ± 0.11	0.09	17	0.04 ± 0.06	0.04	42	0.07 ± 0.08	0.05	17	0.04 ± 0.03	0.03
Other grains	35	0.04 ± 0.04	0.02	50	0.05 ± 0.07	0.02	23	0.18 ± 0.42	0.03	108	0.07 ± 0.21	0.02	25	0.09 ± 0.33	0.02
Eggs	8	0.19 ± 0.04	0.21	1	0.36	0.36	2	0.11 ± 0.02	0.11	11	0.19 ± 0.18	0.15	1	0.12	0.12
Fishes	1	0.13	0.13	1	0.14	0.14	-	-	-	2	0.14 ± 0.008	0.14	-	-	-
Fruits	4	0.15 ± 0.24	0.02	1	0.14	0.14	4	0.16 ± 0.29	0.009	9	0.15 ± 0.24	0.02	-	-	-
Others	3	0.12 ± 0.12	0.09	-	-	-	-	-	-	3	0.12 ± 0.12	0.09	-	-	-

N is the number of food in the sample; AM ± SD is the arithmetic mean ± standard deviation; GM is the geometric mean

Discussion

The total Cd content of various foods varies, and, because residents have different dietary structures; the consumption of different food types by residents also varies. It is seen from Table 3 that rice and its products, vegetables, and meat were the major sources of dietary Cd intake, and they had also a high contribution rate throughout the dietary intake process. Assuming that Cd content in food is not affected by cooking, the daily food intake per resident in the mining-affected areas of Chehe town, Dachang town, and Zhanglao town were 167.4 µg/d, 127.7 µg/d, and 180.6 µg/d, respectively. These were all higher than the intake in the control area of Liuzhai town (76.55 µg/d). The Cd intake obtained in this study were higher than 69.1 µg/d reported by Hong et al. (2014) for food in Xiamen city in China and also higher than 69.52 µg/d reported by Yang et al. (2009) for foods for residents in Chongqing city in China. Clearly, the Cd intake in the studied mining-affected areas was higher than previous findings for Cd intake in mentioned areas. Our findings for Cd intake of Liuzhai town were similar to previous reports of the Cd intake in a Cd-contaminated area in the South China (Zhang, et al., 2009). THQ obtained in this study for Pb and Cd was higher than 0.42–0.90 for Cd reported by Ihedioha and Okoye (2013) for cow meat for an urban population in Enugu State, Nigeria and also were higher than 0.5 for Cd reported by Filippini et al. (2018) for dietary in a northern Italy community. Whether comparing the results with China Food Safety National Standard for Maximum Levels of Contaminants in Foods (GB2762-2017) for Cd content for food or assessing the results in terms of the health risk (THQ) for Cd, an increased degree of risk was identified in the study area. It is very important that municipalities and start implementing risk mitigation measures.

To reduce their dietary Cd exposure risk, residents of mining-affected areas should reasonably match the types of staple foods, try not to consume rice and vegetables grown on contaminated land, and increase their consumption of beans its products, fishes, and eggs. In terms of vegetables, which were in majority leafy vegetables, the THQ values for Cd in the mining-affected areas of Dachang town, and Zhanglao town were less than one. The health risks, as represented by the THQ values for Cd, were significantly higher for vegetables in Chehe town than in the other two mining

Table 3 Dietary exposure to cadmium and health risks among residents in the study areas

Food types	Chehe Town		Dachang Town		Zhanglao Town		Mining-affected areas		Control areas (Liuzhai Town)	
	Exposure (µg/d)	THQ	Exposure (µg/d)	THQ	Exposure (µg/d)	THQ	Exposure (µg/d)	THQ	Exposure (µg/d)	THQ
Rice and its products	29.86	0.54	40.13	0.73	149.84	2.71	77.44	1.4	32.76	0.62
Vegetables	68.21	1.23	18.86	0.34	19.25	0.35	33.31	0.6	10.66	0.2
Meat and its products	17.26	0.31	29.7	0.54	4.3	0.08	19.79	0.36	21.71	0.41
Bean and its products	35.89	0.65	16.86	0.31	3.06	0.06	17.55	0.32	9.75	0.18
Fats	3.32	0.06	4.48	0.08	1.18	0.02	2.54	0.05	0.9	0.02
Cereals	0.22	0	0.43	0.01	1.45	0.03	0.54	0.01	0.32	0.01
Eggs	4.01	0.07	5.71	0.1	0.84	0.02	2.92	0.05	0.45	0.01
Fishes	2.7	0.05	11.01	0.2	–	–	4.4	0.08	–	–
Fruits	3.61	0.07	0.51	0.01	0.68	0.01	1.84	0.03	–	–
Others	2.29	0.04	–	–	–	–	0.97	0.02	–	–
Total	167.4	3.03	127.7	2.31	180.6	3.27	161.3	2.92	76.55	1.44

areas and the control area. If we consider only Cd intake, the residents of Chehe town should increase their intake of eggs and fruit; Compared with these types of foods, our study results indicate that leafy vegetables had a higher Cd content. Therefore, farmers should choose to grow and eat other types of vegetables, such as beans, fruits or buying foods which are critical for Cd in another cleaner areas. Further, before eating or preparing vegetables, residents should first wash them thoroughly with clean fresh water, peel them and only then use them. It is recommended that local residents increase their intake of beans, fruits, and fruit vegetables, which do not accumulate so much Cd comparing leafy and root vegetables. In order to avoid excessive cadmium intake, residents from mining-affected areas should adjust their eating habits.

Conclusion

1. Rice and vegetables have a high contribution rate in the diet structure of residents of the studied areas. The Cd content of rice was significantly higher in the mining-affected areas than in the control area. There were no significant differences between the Cd content of vegetables in the mining-affected areas and the control area.

2. The THQ value from rice in the mining-affected area of Zhanglao town was greater than one, indicating the presence of health risks. The total THQs from all foods considered in all three areas affected by mining activities were higher than the THQ value of in the control area. Therefore, mining activities can have an impact on the health risk of dietary intake of Cd.
3. Based on the health risks because of Cd intake identified in the study areas, the intake of beans and soybean products, eggs, and fruits should be increased in the mining-affected areas. In the area of Zhanglao town the consumption of rice should be reduced, and other types of staple foods or the rice from not contaminated areas should be consumed.

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Data Availability Statement The original data required to reproduce these findings cannot be shared at this time as the data also form part of an ongoing study.

Declarations

Conflict of interest The authors declare that they have no conflicts of interest.

Animal rights The manuscript does not contain animal research content.

Informed consent All authors consent to participate and consent to publish before reference in the manuscript.

References

- Beidokhti, M. Z., Naeeni, S. T. O., & Abdighahroudi, M. S. (2019). Biosorption of nickel (ii) from aqueous solutions onto pistachio hull waste as a low-cost biosorbent. *Civil Engineering Journal*, 5(2), 447. <https://doi.org/10.28991/cej-2019-03091259>.
- Buasha, M., Balku, S., & Yaman, E. Z. (2020). Heavy metal removal investigation in conventional activated sludge systems. *Civil Engineering Journal*, 6(3), 470–477. <https://doi.org/10.28991/cej-2020-03091484>.
- Chen, H., Yang, X., Wang, P., Wang, Z., Li, M., & Zhao, F.-J. (2018). Dietary cadmium intake from rice and vegetables and potential health risk: A case study in Xiangtan, southern China. *Science of the Total Environment*, 639, 271–277. <https://doi.org/10.1016/j.scitotenv.2018.05.050>.
- Cheng, Y. S. (2011). Ore-controlling Characteristics of devonian stratum in the Dachang Sn Ore-field, Guangxi (South China). *Procedia Earth and Planetary Science*, 2, 28–33. <https://doi.org/10.1016/j.proeps.2011.09.005>.
- Cheng, Y. S. (2016). Occurrence characteristics and enrichment regularity of indium in pyrite: A case study of Dachang tin ore-field. *Transactions of Nonferrous Metals Society of China*, 26(8), 2197–2208. [https://doi.org/10.1016/S1003-6326\(16\)64336-4](https://doi.org/10.1016/S1003-6326(16)64336-4).
- Chinese Nutrition Society. (2016). The Chinese dietary guidelines. People's Medical Publishing House (PMPH).
- Cortada, U., Hidalgo, M. C., Martínez, J., & Rey, J. (2018). Impact in soils caused by metal(loid)s in lead metallurgy. The case of La Cruz Smelter (Southern Spain). *Journal of Geochemical Exploration*, 190, 302–313. <https://doi.org/10.1016/j.gexplo.2018.04.001>.
- EPA. (2014). Priority pollutant list, 40 CFR Part 423, Appendix A.
- Filippini, T., Cilloni, S., Malavolti, M., Violi, F., Malagoli, C., Tesauro, M., Bottecchi, I., Ferrari, A., Vescovi, L., & Vinceti, M. (2018). Dietary intake of cadmium, chromium, copper, manganese, selenium and zinc in a Northern Italy community. *Journal of Trace Elements in Medicine and Biology*, 50, 508–517. <https://doi.org/10.1016/j.jtemb.2018.03.001>.
- Herrman, J. L., & Younes, M. (1999). Background to the ADI/TDI/PTWI. *Regulatory Toxicology and Pharmacology*, 30(2), S109–S113. <https://doi.org/10.1006/rtph.1999.1335>.
- Hong, H. R., Zhang, X. D., Chen, J. F., Wang, J., & Rong, B. (2014). Evaluation of dietary lead and cadmium exposure in Xiamen residents. *Journal of Hygiene Research*, 43(6):1009–1012 (in China).
- Ihedioha, J. N., & Okoye, C. O. B. (2013). Dietary intake and health risk assessment of lead and cadmium via consumption of cow meat for an urban population in Enugu State, Nigeria. *Ecotoxicology and Environmental Safety*, 93, 101–106. <https://doi.org/10.1016/j.ecoenv.2013.04.010>.
- Ikeda, M., Nakatsuka, H., Watanabe, T., & Shimbo, S. (2018). Estimation of dietary intake of cadmium from cadmium in blood or urine in East Asia. *Journal of Trace Elements in Medicine and Biology*, 50, 24–27. <https://doi.org/10.1016/j.jtemb.2018.05.019>.
- Jean, J., Sirot, V., Hulin, M., Le Calvez, E., Zinck, J., Noël, L., Vasseur, P., Nesslany, F., Gorecki, S., Guérin, T., & Rivière, G. (2018). Dietary exposure to cadmium and health risk assessment in children—Results of the French infant total diet study. *Food and Chemical Toxicology*, 115, 358–364. <https://doi.org/10.1016/j.fct.2018.03.031>.
- Koch, W., Karim, M. R., Marzec, Z., Miyataka, H., Himeno, S., & Asakawa, Y. (2016). Dietary intake of metals by the young adult population of Eastern Poland: Results from a market basket study. *Journal of Trace Elements of Medical Biology*, 35, 36–42. <https://doi.org/10.1016/j.jtemb.2016.01.007>.
- Liao, C. M., & Ling, M. P. (2003). Assessment of human health risks for arsenic bioaccumulation in Tilapia (*Oreochromis mossambicus*) and large-scale mullet (*Liza macrolepis*) from Blackfoot Disease Area in Taiwan. *Archives of Environmental Contamination and Toxicology*, 45, 264–272. <https://doi.org/10.1007/s00244-003-0107-4>.
- Liu, P., Wang, C. N., Song, X. Y., & Wu, Y. N. (2010). Dietary intake of lead and cadmium by children and adults—Result calculated from dietary recall and available lead/cadmium level in food in comparison to result from food duplicate diet method. *International Journal of Hygiene and Environmental Health*, 213(6), 450–457. <https://doi.org/10.1016/j.ijheh.2010.07.002>.
- Moayed, A., Yargholi, B., Pazira, E., & Babazadeh, H. (2019). Investigated of desalination of saline waters by using dunaliella salina algae and its effect on water ions. *Civil Engineering Journal*, 5(11), 2450–2460. <https://doi.org/10.28991/cej-2019-03091423>.
- Moon, C. S., Zhang, Z. W., Shimbo, S., Hokimoto, S., Shimazaki, K., Saito, T., Shimizu, A., Imai, Y., Watanabe, T., & Ikeda, M. (1996). A comparison of the food composition table-based estimates of dietary element intake with the values obtained by inductively coupled plasma atomic emission spectrometry: An experience in a Japanese Population. *Journal of Trace Elements in Medicine and Biology*, 10(4), 237–244. [https://doi.org/10.1016/S0946-672X\(96\)80041-1](https://doi.org/10.1016/S0946-672X(96)80041-1).
- Perosevic, A., Joksimovic, D., Durovic, D., Milasevic, I., Radomirovic, M., & Stankovic, S. (2018). Human exposure to trace elements via consumption of mussels *Mytilus galloprovincialis* from Boka Kotorska Bay, Montenegro. *Journal of Trace Elements of Medical Biology*. <https://doi.org/10.1016/j.jtemb.2018.03.018>.
- Sako, A., Semdé, S., & Wenmenga, U. (2018). Geochemical evaluation of soil, surface water and groundwater around the Tongon gold mining area, northern Côte d'Ivoire, West Africa. *Journal of African Earth Sciences*, 145(SEP.), 297–316. <https://doi.org/10.1016/j.jafrearsci.2018.05.016>.

- Shi, Z., Taylor, A. W., Riley, M., Byles, J., Liu, J., & Noakes, M. (2018). Association between dietary patterns, cadmium intake and chronic kidney disease among adults. *Clinical Nutrition*, 37(1), 276–284. <https://doi.org/10.1016/j.clnu.2016.12.025>.
- Speijers, G. J. A. (1999). Precision of estimates of an ADI (or TDI or PTWI). *Regulatory Toxicology and Pharmacology*, 30(2), S87–S93. <https://doi.org/10.1006/rtp.1999.1331>.
- Wang, X., Cui, W., Wang, M., Liang, Y., Zhu, G., Jin, T., Chen, X. (2021). The association between life-time dietary cadmium intake from rice and chronic kidney disease. *Ecotoxicology and Environmental Safety*, 211, 111933.
- WHO. (2011). Evaluation of certain food additives and contaminants:seventy-third report of the Joint FAO/WHO expert committee on Food additives.WHO Technical Report Series, No.960.
- Xue, S., Shi, L., Wu, C., Wu, H., Qin, Y., Pan, W., Hartley, W., & Cui, M. (2017). Cadmium, lead, and arsenic contamination in paddy soils of a mining area and their exposure effects on human HEPG2 and keratinocyte cell-lines. *Environmental Research*, 156, 23–30. <https://doi.org/10.1016/j.envres.03.014>
- Yang, W., Jiang, D. M., & Wang, D.Y. (2009). Investigation on dietary intake of heavy metals intaken by inhabitants in Chongqing. *Asian Journal of Ecotoxicology*, 4(1):50–56 (in China).
- Yu, G., Zheng, W., Wang, W., Dai, F., Zhang, Z., Yuan, Y., & Wang, Q. (2017). Health risk assessment of Chinese consumers to Cadmium via dietary intake. *Journal of Trace Elements in Medicine and Biology*, 44, 137–145.<https://doi.org/10.1016/j.jtemb.07.003>.
- Zhang, W. L., Li, Q. J., Shi, L. J., Lu, K., Shang, Q., Yao, L. S., & Ye, G. L. (2009). Investigation of dietary intake of cadmium in certain polluted area of south in China. *Journal of Hygiene Research*, 38(5), 552–557 (in China).
- Zhou, Z., Chen, Z., Pan, H., Sun, B., Zeng, D., He, L., Yang, R., & Zhou, G. (2018). Cadmium contamination in soils and crops in four mining areas, China. *Journal of Geochemical Exploration*, 192,72–84. <https://doi.org/10.1016/j.gexplo.06.003>.

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