Toxicology Reports 12 (2024) 578–583

Contents lists available at ScienceDirect

Toxicology Reports

journal homepage: www.elsevier.com/locate/toxrep

Evaluation of carcinogenic risk of heavy metals due to consumption of rice in Southwestern Iran

Mohammad Javad Mohammadi [a], Fatemeh Kiani [b,*], Majid Farhadi [c], Saeed Ghanbari [d], Davood Jalili [a], Leila Mirzaei [b]

[a] Department of Environmental Health Engineering, School of Public Health and Environmental Technologies Research Center, Medical Basic Sciences Research Institute, Ahvaz Jundishapur University of Medical Sciences, Ahvaz, Iran

[b] Student Research Committee, Ahvaz Jundishapur University of Medical Sciences, Iran

[c] Department of Environmental Health, School of Health and Nutrition, Environmental Health Research Center, Lorestan University of Medical Sciences, Khorramabad, Iran

[d] Department of Biostatistics and Epidemiology, School of Health, Ahvaz Jundishapur University of Medical Sciences, Ahvaz, Iran

ARTICLE INFO

Handling Editor: Prof. L.H. Lash

Keywords:
Rice
Carcinogenic risk
Heavy metals
Iran

ABSTRACT

Pollution by heavy metals is a serious global problem due to its toxicity, abiotic characteristics, abundant sources, and cumulative behavior. On the other hand, considering the importance of rice consumption as an important part of nutrition in Lordegan and Ahvaz cities, this study was conducted to evaluate the carcinogenic risk of heavy metals lead, cadmium, zinc, nickel and in local Champa rice cultivated in these two cities. 16 Champa rice samples were collected from the fields of Lordegan and Ahvaz cities. The elements were read in three replicates by Varian 710-ES atomic emission device. The results showed that the concentration of cadmium and nickel in the cultivated rice in the two studied cities was within the range of the national standard of Iran and the Codex standard. Carcinogenic risk values for lead, cadmium and nickel in Champa Lordegan and Ahvaz rice were within the safe range. Also, the non-carcinogenic risk for these heavy metals in the two studied areas was less than 1 and was in the safe range. Rice pollution in Champa in Ahvaz can be due to the industrial nature of this city, and in Lordegan, it is due to pollution through pesticides, chemical fertilizers, and transportation. Long-term consumption of contaminated rice may endanger the health of residents of these areas. It is recommended to carry out regular and up-to-date monitoring strategies in these two cities to prevent the entry of these toxic heavy metals into the human food chain. Also, more studies are needed to evaluate the complete scenario and make definitive decisions.

1. Introduction

Today, with the growing population and the expansion of urbanization, industrial globalization, and technological progress, the extent of environmental pollution has also increased. It has become an important part of the problems of human societies[1]. Heavy metals are among the most important pollutants that penetrate the environment through natural resources and human activities, including soil erosion, weathering of the earth's crust, agricultural operations using various fertilizers and pesticides, mining, industry working with metals, combustion of fossil fuels, discharge of various effluents and municipal and industrial wastewater, and irrigation of agricultural soils with polluted water [2–5]. One of the characteristics of heavy metals in nature is that they are non-biodegradable [6]. The toxicity of these metals in the human body depends on the dose absorbed, the route of exposure, and the duration of contact (acute or chronic) [2]. The most important metals are zinc(Zn), nickel(Ni), lead(Pb), and cadmium(Cd). Cadmium is a highly toxic metal that can cause kidney damage, high blood pressure, and mutagenicity [7–9]. Its compounds are known to be human carcinogens, especially in the prostate and lungs [10–12]. Increased blood pressure and kidney damage, abortion, premature babies, hemoglobin biosynthesis disorders, anemia, male infertility, brain damage, nervous system disorders, and decreased learning power are some of the effects of increasing the concentration of lead in the body. Nickel metal is toxic in high concentrations, which disrupts the biological activity of cells, delays growth, reduces hematopoiesis, and interferes with iron

* Corresponding author.
E-mail address: nazaninfatykian@gmail.com (F. Kiani).

https://doi.org/10.1016/j.toxrep.2024.05.005
Received 27 February 2024; Received in revised form 13 April 2024; Accepted 9 May 2024
Available online 13 May 2024

absorption. Nickel salts accumulate in the brain and lung tissue after entering the bloodstream, causing respiratory distress and possibly lung carcinogenesis. Contact with nickel causes skin inflammation [13]. Zinc is a metal essential for survival due to its effect on enzyme activity and protein production [6]. But above all, it accumulates in the prostate, bones, muscles, and liver [7]. The accumulation of heavy metals absorbed in plant organs in concentrations above standards, while reducing the growth and yield of agricultural products, contaminates the food chain and endangers the health of human communities [14,15]. This is why food security has become a global concern today [16]. At the same time, the issue of food safety is becoming increasingly important to consumers of agricultural products, including rice [1,17]. Rice is the staple food of more than half of the world's population, especially in Asia, Africa, and South and North America, providing about 70 percent of their daily caloric needs. Over 300 million hectares of agricultural land worldwide are under rice cultivation, 90 % located in Asia [12,13,18]. According to statistics, per capita, rice consumption in Asia is 85 kg/year, and in the world, it is equivalent to 58.8 kg/year. In Iran, this product is the second-most consumed food after wheat. Rice is one of the main ingredients in all kinds of Iranian food. Given the population growth policies in Iran, there is no doubt that the demand for rice will increase significantly annually [13,19,20]. Rice contamination with heavy metals is one of the possible cases of environmental pollution during which, under certain conditions such as water, soil, and proximity of rice fields to industrial centers and related wastewater, heavy elements are transferred to rice and accumulate in it [20]. Because of how important heavy metals are to human health and how much people want to eat rice, this study aims to evaluate the carcinogenic and non-carcinogenic risk of heavy metals due to consumption one type of rice (champa) that is grown in cities like Lordegan and Ahvaz in the southwest of Iran.

2. Materials and methods

2.1. Study area

Lordegan city is located in the south of Chaharmahal and Bakhtiari provinces and, in terms of relative position, leads from the north to Borujen Wardel cities, from the south to Kohgoluyeh and Boyer Ahmad provinces, from the east to Isfahan province and from the west to Khuzestan province. It is located in the Zagros mountains and 1700 m above sea level (Fig. 1). Ahvaz is the capital of Khuzestan province and the largest city in this province. This city is limited to Shush, Shushtar, and Bavi cities from the north, Azadegan plain cities from the west, Khorramshahr, Shadegan, and Mahshahr cities from the south, and Ramshir, Ramhormoz, and Haftgol cities from the east. Ahvaz City is 12 m above sea level (Fig. 1). The Khersan and Armand Rivers, which are the main tributaries of the Karun River, pass through Lordegan City. Karun River is one of the most important rivers of Iran that runs a long way in Khuzestan province and is closely related to a group of essential industries such as petrochemical, metallurgy, and oil. It also has a large share of urban and agricultural wastewater. As a result, any metallic elements in the wastewater entering this river, particularly heavy metals, can be regarded as a possible concern and contaminant [21].

2.2. Data gathering and sampling

In this study, a total of 16 samples of Champa rice after harvesting and husking were collected from farmers in Lordegan and Ahvaz cities were purchased in 2021. Then local Champa rice samples were coded,

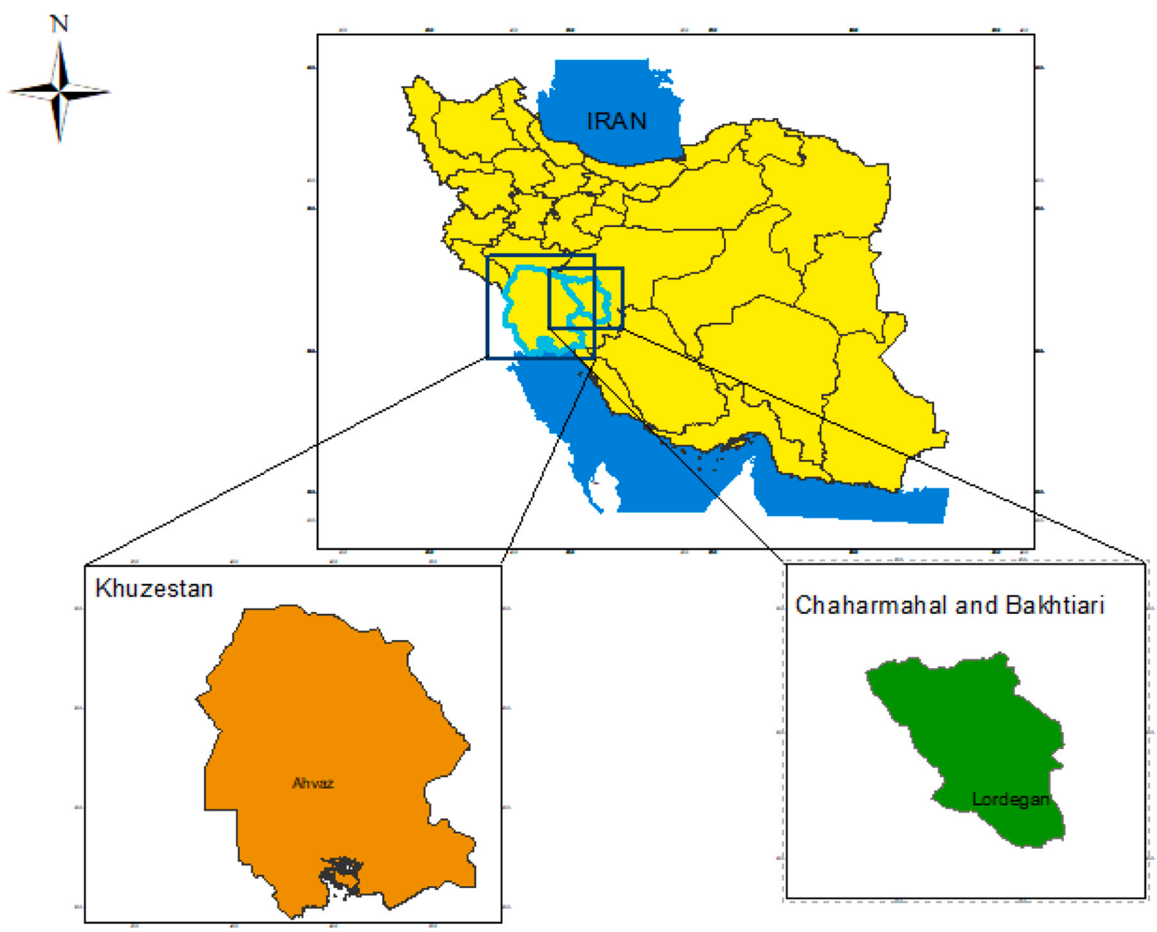

Fig. 1. The location of the study areas, Ahvaz and Lordegan cities of Iran.

recorded, and transported to the laboratory in nylon bags. After spreading the samples on clean paper in the open air to dry, the samples were dried and completely powdered by the mill and stored in polyethylene containers.

2.3. Sample preparations and chemical analysis

To determine the concentration of raw white rice's zinc, nickel, lead, and cadmium elements, collected rice samples were washed with double distilled water to remove possible contaminants. The samples were dried in the oven at a temperature of 110–120 degrees Celsius. Then the samples were placed in the oven at 151 degrees Celsius to obtain white ash without carbon. Then 1 g of each sample was powdered by an electric mill and extracted from them by acid digestion with 4 M nitric acid at a temperature of 95 °C. After filtering the extracts with Whatman 42 filter paper and making a stock solution and standards, zinc, nickel, lead, and cadmium elements were read by an atomic emission device at a concentration of 100 micrograms per liter. Finally, each sample's zinc, nickel, lead, and cadmium elements were read in three replicates by the Varian 710-ES atomic emission device in terms of micrograms per dry gram. Statistical processing of the results was done by SPSS22 software. Thus, the Kolmogorov-Smirnov test was used to ensure the normality of the data. A Mann-Withney statistical test was used to compare the average concentrations of the studied elements in different rice samples [3,7].

2.4. Assessment of carcinogenic risk

The risk of carcinogenesis indicates the probability of a person getting more cancer during a lifetime due to exposure to a potential carcinogen. In this regard, carcinogenicity is the assumption that there is a relationship between increasing the dose or exposure to the concentration of a pollutant and increasing the risk of developing cancer. There is a line. The resulting slope in this relationship is the Cancer Slope Factor, and its unit is expressed based on each milligram of the chemical substance per kilogram of body weight per day. The USEPA proposes the carcinogenic slope factor for cadmium, lead, and nickel.

The equation below is used to evaluate the risk of carcinogenesis:

$$CR = EDI*CSF \qquad (1)$$

CR: Carcinogenesis Risk

CSF: Carcinogenicity Slope Factor

The amount of pollutant received through rice per kilogram of body weight per day (Estimated Daily Intake) was calculated using the following Eq. (2):

$$EDI = (EFr \times ED \times IR \times C) / (BW \times AT) \qquad (2)$$

EDI: The amount of daily dose in mg kg-1 day^{-1}

EFr: Frequency of exposure (365 days a year)

ED: Duration of exposure (15 years for children & 70 years for adults)

IR: Rice consumption (82 mg day $^{-1}$ for adults and 25 mg day $^{-1}$ for children)

C: Metal concentration in rice (mg kg $^{-1}$ of rice)

BW: Average body weight (32.7 kg for children and 70 kg for adults)

AT: Average exposure time for carcinogenic and non-carcinogenic substances (2190 for children and 10,950 kg for adults)[22]

The carcinogenic risk (CR) is the probability that an individual will acquire cancer at some point throughout their lifespan due to exposure to carcinogenic hazards. Generally speaking, the USEPA states that a CR below 1×10^{-6} can be considered inconsequential, whereas a CR exceeding 1×10^{-4} is likely to be hazardous to human health. For social stability and human health, a CR between $1 \times 10^{-4} \sim 1 \times 10^{-6}$ is considered acceptable or bearable. In this investigation, the CR was evaluated only for Ni(1.7), Cd (0.380), and Pb (0.0085) based on the available toxicological data for SF[23–25].

2.5. Assessment of non-carcinogenic risk

In this research, the hazard quotient (HQ) was used to calculate non-carcinogenic risk (Eq. (3)). The RfD indicates the reference dose in terms of (mg kg^{-1} day^{-1}). Its value for Cd, Pb, Ni and Zn metals is 0.0005, 0.0035, 0.02 and 0.3 respectively. If its value is less than 1, there is no non-carcinogenic risk, but if its value is greater than 1, the non-carcinogenic risk is unacceptable and high [22,23]

$$HQ = ADI/RfD \qquad (3)$$

3. Results and discussion

We used the Mann–Withney test to compare Cd, Pb, Zn and Ni in Ahvaz and Lordegan. In this study, the average concentration of Zn and Ni measured in Lordegan is lower than in Ahvaza (Figs. 4 and 5). The results show that Zn (P-value <0.001) and Ni (P-value <0.001) were significantly different in the two cities (Table 1). Although the average concentration of Cd and Pb measured in Ahvaz were higher than in Lordegan (Figs. 2 and 3), the average concentration of cadmium (P-value=0.066) and lead (P-value=0.195) were not significantly different (Table 1).

3.1. Comparison of measured heavy metal concentration with standard concentration

According to the national standard of Iran No. 12968, the maximum permissible cadmium in rice equals 0.06 [26]. The study results are in Table 1, and the figure shows that the amount of Cd in Lordegan (0.0165) and Ahvaz (0.0295) rice is lower than the national and Codex standards. Based on the statistical analysis, there was no significant difference (P-Value = 0.066) between the amounts of Cd in the Champa rice of Lordegan and Ahvaz. According to the national standard of Iran No. 12968, the maximum allowable Pb in rice is equal to 0.15 [26]. The results of the present study in Table 1 and Fig. 3 show that the amount of Pb in the rice of Champa Lordegan (7 times) and Ahvaz (9 times) is significantly higher than the national standard of Iran. Although its amount is slightly lower in Lordegan than in Ahvaz, based on the statistical analysis, there was no significant difference between the lead values of the two cities (P-Value = 0.195).

In the case of rice, the standard limit for nickel and zinc has not been defined. However, the permissible limit of nickel for cereals in the Codex standard is 10 mg kg^{-1}. The concentration of Ni in Ahvaz (0.1876) and Lordegan (0.0196) is within the standard range. The amount of Zn and Ni measured in the rice of Ahvaz is significantly higher than that of Lordegan. According to the statistical analysis, there is a significant difference between the amounts of Zn (P-Value<0.001) and Ni (P-Value<0.001) in the rice of the two cities. So far, several studies have investigated the concentration of heavy metals in rice consumed in Iran and other countries. Among them, we can mention the study of Parisa Ziarati in 2016, who investigated the number of heavy metals Pb, Cd, and Ni in Iranian and imported rice consumed in Tehran.The results showed that Cd and Pb exceeded the permissible limit. In the current study, the amount of Pb is more than the national limit [26]. In 2012, Shekarzadeh and his colleagues measured Cr, Cd, and Pb in irrigation water and Tarem rice cultivated in three cities of Mazandaran province. Cd and Pb metal were above the permissible limit, and Cr metal was below the standard limit [27]. In another study, Azad Bakht et al. investigated the concentration of Pb, Cd, and As in 108 Iranian and imported rice samples in Yazd province. The Pb concentration in the samples was more than the permissible limit, but the concentration of Cd and As was lower than the permissible limit [28]. Zazouli et al. investigated the Cd concentration in Mazandaran province rice in 2008. The Cd concentration in rice samples exceeded the FAO limit [29].

Table 1
Result of the Mann–Withney test to compare the concentration of heavy metals in Champa rice of Ahvaz and Loredgan.

	City	Mean(mg kg^{-1})	Std. Deviation	Min	Max	CV	Test statistic	P-value
Cd	Ahvaz	0.0295	0.0157	0.0131	0.0580	0.533	-1.839	0.066
	Lordegan	0.0165	0.0035	0.0129	0.0207	0.211		
Pb	Ahvaz	1.3496	0.4860	0.9800	2.4870	0.360	-1.365	0.195
	Lordegan	1.1265	0.0634	0.0200	0.2100	0.501		
Zn	Ahvaz	29.455	12.4346	17.8900	50.6000	0.422	-3.361	< 0.001
	Lordegan	1.5651	0.5406	1.0500	2.7600	0.345		
Ni	Ahvaz	0.1876	0.0679	0.1100	0.3100	0.362	-3.361	< 0.001
	Lordegan	0.0196	0.0053	0.0120	0.0270	0.272		

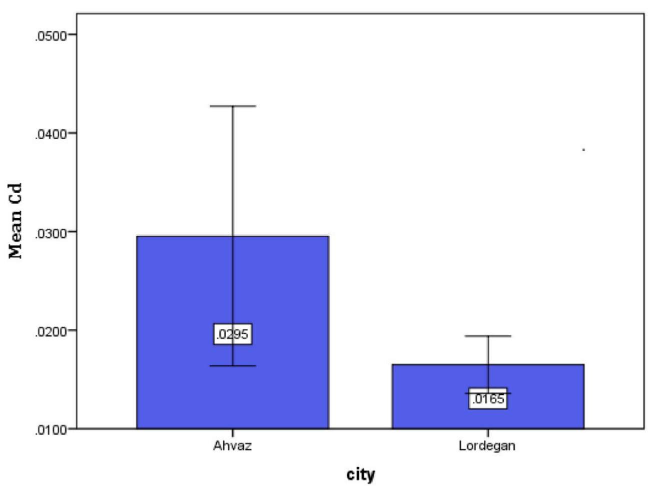

Fig. 2. The average concentration of cadmium in the Lordegan and Ahvaz regions.

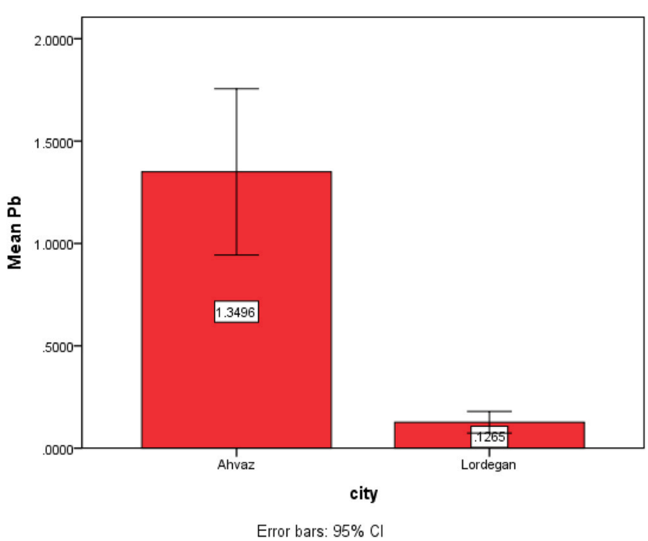

Fig. 3. The average concentration of lead in the Lordegan and Ahvaz regions.

Malkutian investigated Pb, Cd, Ni, and Cr concentrations in 2010. The results showed that the lead exceeded the permissible limit of FAO/WHO [30]. The number of samples and different sampling points, as the type of cultivated rice, can be the reason for the difference in some of the results of these studies. Since Ahvaz is a metropolis with various industries, the Pb concentration exceeding the standard can be caused by the use of pesticides, pollution caused by industrial wastewater, and pollution of irrigation water, transportation, paint factories, and industries iron and steel, non-ferrous metal industries, garbage, and residues containing burnt lamps and used batteries enter the environment [31,32]. Lordegan contains small and few industries. Its heavy metals can be caused by human pollution related to these industries, agricultural activities, and transportation.

3.2. Carcinogenic risk (CR) and non-carcinogenic risk

The results in Table 2 show that the average risk of carcinogenesis (CR) and non-carcinogenic risk in children and adults, respectively, for the lead element in Champa Lordegan rice, is 1.152E-09 and 2.694E-09, so it is in the safe range. CR for lead element in Champa rice of Ahvaz is 9.619E-10 and 2.249E-09, respectively, which is in the safe range. CR for cadmium metal in children and adults in Champa Lordegan rice was estimated as 1.118E-09 and 2.615E-09, respectively, and in Ahvaz 6.299E-10, and 1.472E-09, respectively. CR of cadmium in two cities is within the probable range. CR for nickel in Champa Lardegan rice in children and adults is 3.204E-08 and 7.489E-08, which is in the safe range for children and adults. Nickel CR in Champa Ahvaz rice is for children and adults, respectively, 3.347E-09 and 7.825E-09, so it is in the safe range. Nickel in agricultural soils is probably of human origins, such as precipitation caused by greenhouse gas emissions, industrial activities, and refinery dust, which has been mentioned in many studies [23,24]. The Table 2 shows that HQ less than 1,and therefore non-cancerous risks are also acceptable.

In the study of Khoshnaz Payandeh and his colleagues, the carcinogenic risk of cadmium, lead, and nickel metals was higher than 10^{-4} in cultivated rice samples of Khuzestan province. These results were consistent with the present study on nickel. Carcinogenic risk values of nickel and cadmium metals in rice of the Hunan region in China have been reported as 0.00393 and 0.0343, respectively, which were higher than 10^{-4}, and the consumption of this rice has the potential to cause cancer in humans [33]. In the study of Nehreen Majed, the carcinogenic risk of cadmium metal (7.33E−03) was in the range of carcinogenicity, and lead, nickel, and zinc metals were in the permissible range [24]. In the study of Ting Huan et al. the carcinogenic risk of Cr, As, and Cd exceeded the 10–4 risk index threshold, indicating the carcinogenic risk for the human body [34]. The number of samples and different sampling points, as the type of cultivated rice, can be the reason for the difference in some of the results of these studies.

4. Conclusion

This study investigated the concentration of heavy metals nickel, lead, cadmium, and zinc in Champa rice grown in Lordegan and Ahvaz cities and the carcinogenic ana non-carcinogenic risk assessment of these heavy metals. The concentration of cadmium and nickel in the cultivated rice in the two studied cities was within the range of the national standard of Iran and the Codex standard. However, the lead concentration in Lordegan and Ahvaz was higher than the standard. There was no significant difference between lead and cadmium concentrations of Champa rice grown in the two cities. However, there was a significant difference between rice's zinc and nickel concentrations. Also, the concentration of heavy metals measured in Ahvaz was higher than in Lordegan. Carcinogenic risk values for lead, cadmium and nickel in Champa Lordegan and Ahvaz rice were within the safe range. Also,

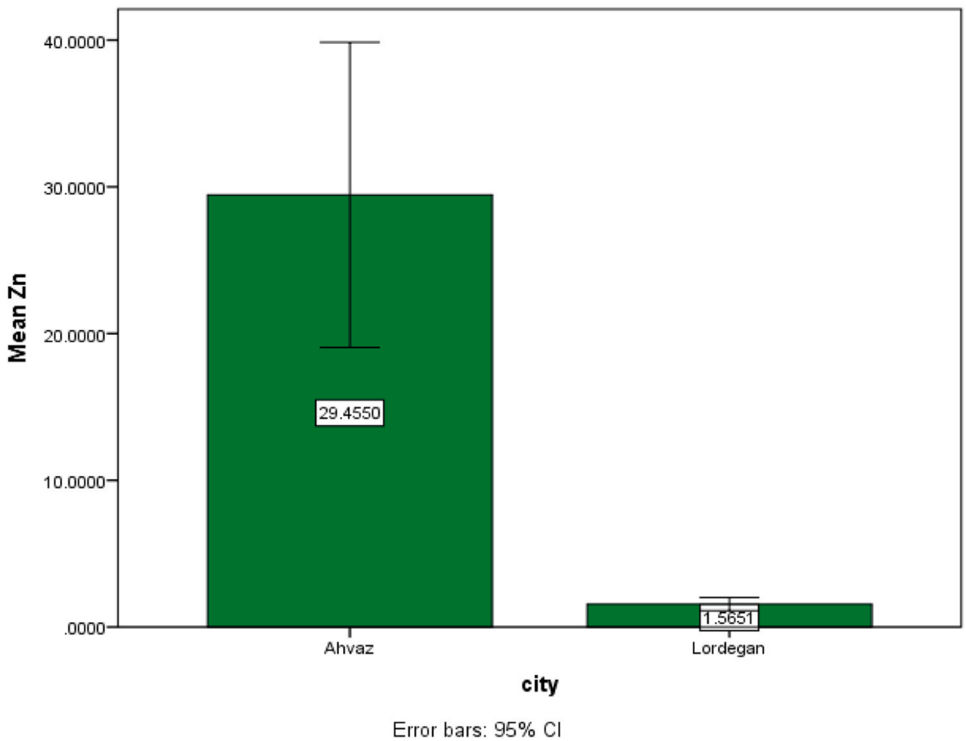

Fig. 4. The average concentration of zinc in the Lordegan and Ahvaz regions.

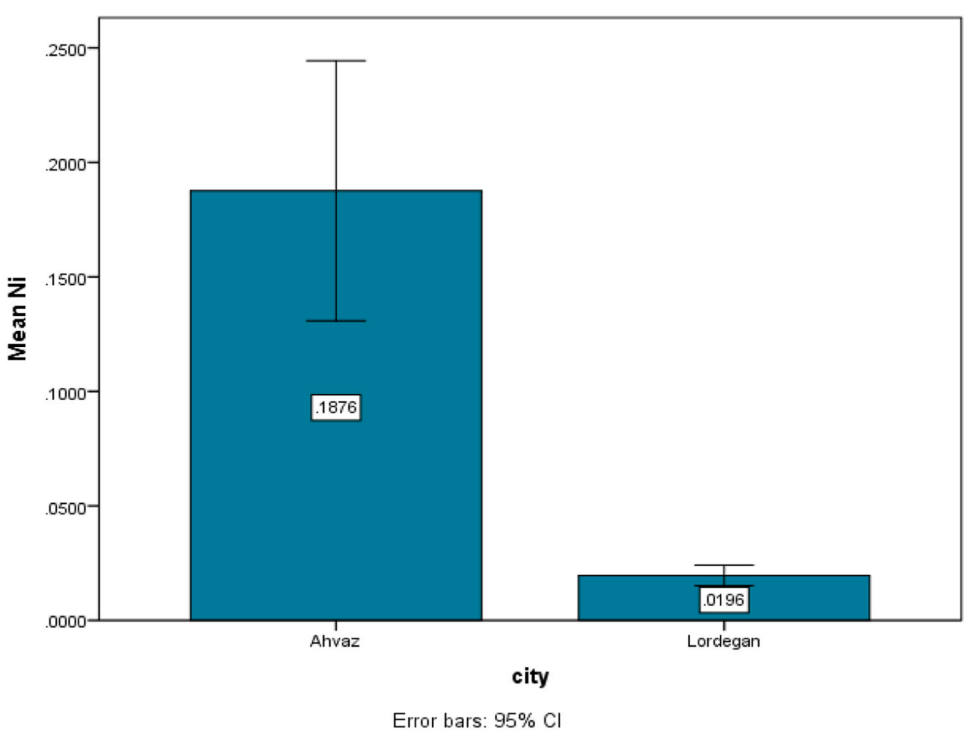

Fig. 5. The average concentration of nickel in the Lordegan and Ahvaz regions.

the non-carcinogenic risk for these heavy metals in the two studied areas was less than 1 and was in the safe range. Rice pollution in Champa in Ahvaz can be due to the industrial nature of this city, and in Lordegan, it is due to pollution through pesticides, chemical fertilizers, and transportation. Considering the measured levels and amounts of heavy metals, long-term consumption of contaminated rice may endanger the health of the residents of these areas. On the other hand, more studies should be done to evaluate the complete scenario and make definitive decisions. Also, to prevent the entry of these toxic heavy metals into the human food chain in these two cities, careful monitoring and regularly updated monitoring strategies are needed.

Table 2
Estimated carcinogenic risk and non-carcinogenic risk for Cd, Pb, Zn, and Ni in Champa rice samples.

Carcinogenic risk				Non- Carcinogenic risk
Pb	Lordegan	children	1.152E-09	0.000542
		Adult	2.694E-09	0.000254
	Ahvaz	children	9.619E-10	0.000453
		Adult	2.249E-09	0.000212
Cd	Lordegan	children	1.118E-09	4.12E-05
		Adult	2.615E-09	1.93E-05
	Ahvaz	children	6.299E-10	2.32E-05
		Adult	1.472E-09	1.08E-05
Ni	Lordegan	children	3.204E-08	1.3192E-05
		Adult	7.489E-08	6.16767E-06
	Ahvaz	children	3.347E-09	1.37826E-06
		Adult	7.825E-09	6.44384E-07
Zn	Lordegan	children	-	0.000138
		Adult	-	6.46E-05
	Ahvaz	children	-	7.34E-06
		Adult	-	3.43E-06

Funding

This work was part of a funded at Ahvaz Jundishapur University of Medical Sciences (AJUMS), and the financial support of this study (IR. AJUMS.REC.1400.349) was provided by AJUMS.

CRediT authorship contribution statement

majid farhadi: Resources, Methodology, Investigation. **fatemeh kiani:** Data curation, Conceptualization. **Mohammad Javad Mohammadi:** Writing – original draft, Supervision, Funding acquisition, Formal analysis. **Leila mirzaei:** Methodology, Investigation. **Davood Jalili:** Resources, Data curation. **Saeed Ghanbari:** Software, Methodology.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

All data generated or analyzed during this study are included in this published article.

Acknowledgment

This work was funded by Student Research Committee Ahvaz Jundishapur University of Medical Sciences (AJUMS), and the financial support of this study (00s35) was provided by Student Research Committee, AJUMS.

References

[1] Skandari A., Mohammadi R.M. Health assessment of heavy metals pollutions in some of imported and cultivated rice of Karoon River (Case study: Shadegan city). 2019.

[2] M. Jaishankar, T. Tseten, N. Anbalagan, B.B. Mathew, K.N. Beeregowda, Toxicity, mechanism and health effects of some heavy metals, Interdiscip. Toxicol. 7 (2) (2014) 60–72.

[3] S. Akbari, M. Cheraghi, The concentration of heavy metals Zn, Pb and Cd in rice supplied in the consumer market in Hamadan, J. Environ. Sci. Technol. 21 (8) (2019) 13–22.

[4] N. Khan, K.Y. Ryu, J.Y. Choi, E.Y. Nho, G. Habte, H. Choi, et al., Determination of toxic heavy metals and speciation of arsenic in seaweeds from South Korea, Food Chem. 169 (2015) 464–470.

[5] E. Idani, S. Geravandi, M. Akhzari, G. Goudarzi, N. Alavi, A.R. Yari, et al., Characteristics, sources, and health risks of atmospheric PM10-bound heavy metals in a populated middle eastern city, Toxin Rev. 39 (3) (2020) 266–274.

[6] C. Xu, H. Yan, S. Zhang, Heavy metal enrichment and health risk assessment of karst cave fish in Libo, Guizhou, China, Alex. Eng. J. 60 (1) (2021) 1885–1896.

[7] S. Nazemi, Concentration of heavy metal in edible vegetables widely consumed in Shahroud, the North East of Iran, J. Appl. Environ. Biol. Sci. 2 (8) (2012) 386–391.

[8] J.O. Duruibe, M. Ogwuegbu, J. Egwurugwu, Heavy metal pollution and human biotoxic effects, Int. J. Phys. Sci. 2 (5) (2007) 112–118.

[9] S. Mishra, R.N. Bharagava, N. More, A. Yadav, S. Zainith, S. Mani, P. Chowdhary, Heavy metal contamination: an alarming threat to environment and human health, Environ. Biotechnol.: Sustain. Future (2019) 103–125.

[10] T. Sanders, Y. Liu, V. Buchner, P.B. Tchounwou, Neurotoxic effects and biomarkers of lead exposure: a review, Rev. Environ. Health 24 (1) (2009) 15–46.

[11] M.A. Davis, D. Gilbert-Diamond, M.R. Karagas, Z. Li, J.H. Moore, S.M. Williams, H. R. Frost, A dietary-wide association study (DWAS) of environmental metal exposure in US children and adults, PLoS One 9 (9) (2014) e104768.

[12] M. Abtahi, Y. Fakhri, G. Oliveri Conti, H. Keramati, Y. Zandsalimi, Z. Bahmani, et al., Heavy metals (As, Cr, Pb, Cd and Ni) concentrations in rice (Oryza sativa) from Iran and associated risk assessment: a systematic review, Toxin Rev. 36 (4) (2017) 331–341.

[13] Ziarati P., Moslehisahd M. Determination of heavy metals (Cd, Pb, Ni) in Iranian and imported rice consumed in Tehran. 2017.

[14] A. Alengebawy, S.T. Abdelkhalek, S.R. Qureshi, M.-Q. Wang, Heavy metals and pesticides toxicity in agricultural soil and plants: ecological risks and human health implications, Toxics 9 (3) (2021) 42.

[15] M.M. Uddin, M.C.M. Zakeel, J.S. Zavahir, F.M. Marikar, I. Jahan, Heavy metal accumulation in rice and aquatic plants used as human food: a general review, Toxics 9 (12) (2021) 360.

[16] P.K. Rai, S.S. Lee, M. Zhang, Y.F. Tsang, K.-H. Kim, Heavy metals in food crops: health risks, fate, mechanisms, and management, Environ. Int. 125 (2019) 365–385.

[17] F.P. Carvalho, Agric., Pestic., Food Secur. Food Saf. Environ. Sci. Policy 9 (7-8) (2006) 685–692.

[18] S. Sharma, A.K. Nagpal, I. Kaur, Heavy metal contamination in soil, food crops and associated health risks for residents of Ropar wetland, Punjab, India and its environs, Food Chem. 255 (2018) 15–22.

[19] M. Naseri, A. Vazirzadeh, R. Kazemi, F. Zaheri, Concentration of some heavy metals in rice types available in Shiraz market and human health risk assessment, Food Chem. 175 (2015) 243–248.

[20] F. Mosaferi, M. Ahmadi, F. Porramezan, M. AbediArani, Investigation of heavy metals content including lead, arsenic, and cadmium in imported rice in Hormozgan province in 2015-2016, J. Prev. Med. 5 (2) (2018) 65–73.

[21] V. Diagomanolin, M. Farhang, M. Ghazi-Khansari, N. Jafarzadeh, Heavy metals (Ni, Cr, Cu) in the karoon waterway river, Iran, Toxicol. Lett. 151 (1) (2004) 63–67.

[22] A. Neisi, M. Farhadi, K.A. Angali, A. Sepahvand, Health risk assessment for consuming rice, bread, and vegetables in Hoveyzeh city, Toxicol. Rep. (2024).

[23] M. Fouladi, M. Mohammadi Rouzbahani, S. Attar Roshan, S. Sabz Alipour, Health risk assessment of potentially toxic elements in common cultivated rice (Oryza sativa) emphasis on environmental pollution, Toxin Rev. 40 (4) (2021) 1019–1034.

[24] M.I.H. Real, H.M. Azam, N. Majed, Consumption of heavy metal contaminated foods and associated risks in Bangladesh, Environ. Monit. Assess. 189 (2017) 1–14.

[25] S. Onuoha, P. Anelo, K. Nkpaa, Human health risk assessment of heavy metals in snail (Archachatina marginata) from four contaminated regions in Rivers State, Nigeria, Am. Chem. Sci. J. 11 (2) (2016) 1–8.

[26] P. Ziarati, M. Moslehisahd, Determination of heavy metals (Cd, Pb, Ni) in Iranian and imported rice consumed in Tehran, Iran. J. Nutr. Sci. Food Technol. 12 (2) (2017) 97–104.

[27] M. Shokrzadeh, M.A. Rokni, Lead, cadmium, and chromium concentrations in irrigation supply of/and tarom rice in central cities of Mazandaran Province-Iran, J. Mazandaran Univ. Med. Sci. 23 (98) (2013) 234–242.

[28] R. Morekian, M. Mirlohi, L. Azadbakht, M.R. Maracy, Heavy metal distribution frequency in Iranian and imported rice varieties marketed in central Iran, Yazd, 2012, Int. J. Environ. Health Eng. 2 (1) (2013) 36.

[29] M.A. Zazouli, M. Shokrzadeh, H. Izanloo, S. Fathi, Cadmium content in rice and its daily intake in Ghaemshahr region of Iran, Afr. J. Biotechnol. 7 (20) (2008).

[30] M. Malakootian, M. Tahergorabi, M. Daneshpajooh, K. Amirtaheri, Determination of Pb, Cd, Ni, Zn concentration in canned fish in south of Iran, Hormozgan Med J. 16 (2013) 445–451.

[31] G. Mausi, G. Simiyu, S. Lutta, Assessment of selected heavy metal concenteration in Eldoret town, Kenya, Environ. Earth Sci. 4 (3) (2014).

[32] H. Wu, F. Yang, H. Li, Q. Li, F. Zhang, Y. Ba, et al., Heavy metal pollution and health risk assessment of agricultural soil near a smelter in an industrial city in China, Int. J. Environ. Health Res. 30 (2) (2020) 174–186.

[33] F. Zeng, W. Wei, M. Li, R. Huang, F. Yang, Y. Duan, Heavy metal contamination in rice-producing soils of Hunan province, China and potential health risks, Int. J. Environ. Res. Public Health 12 (12) (2015) 15584–15593.

[34] T. Huang, Y. Deng, X. Zhang, D. Wu, X. Wang, S. Huang, Distribution, source identification, and health risk assessment of heavy metals in the soil-rice system of a farmland protection area in Hubei Province, Central China, Environ. Sci. Pollut. Res. 28 (2021) 68897–68908.