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RESEARCH ARTICLE

Exposure to heavy metal contamination and probabilistic health risk assessment using Monte Carlo simulation: a study in the Southeast Iran

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Abstract

The rice contamination to heavy metals and its associated health risks have been less addressed in the southeast of Iran. In the present study, in the mentioned region, we assessed the concentration of nine elements in rice, and the health risk related to the measured elements was determined using the data which were gathered by a questionnaire. For this purpose, 36 samples of the 12 most widely consumed rice brands were collected. Using ICP-MS, the concentrations of Ni, Cr, Hg, Sr, Mn, Fe, Se, Ba, and Zn were measured in the studied samples as 0.599 ± 0.124, 0.483 ± 0.28, 0.0157 ± 0.005, 0.85 ± 1.307, 11.5 ± 1.97, 178.46 ± 67.27, 0.212 ± 0.083, 0.845 ± 0.62, and 8.416 ± 1.611 mg/kg, respectively. We found that, regarding the other studies, the levels of Ni, Cr, Hg, Fe, and Ba were higher. Besides, using 258 distributed questionnaires among citizens, the daily rice consumption was determined to be 295.66 ± 171.005 g/person/ day. Based on this consumption rate and Monto Carlo uncertainty simulation, Fe (0.741 ± 0.54 mg/kg/day) and Se (8.95E-04 ± 6.33E-04 mg/kg/day) showed the highest and lowest daily intake, respectively. Also, using Hazard Quotient (HQ), the non-carcinogenic risk effects of the surveyed elements were estimated. The obtained results of HQ revealed that Fe (2.48) and Mn (1.06) could pose non-carcinogenic health risks to consumers. Moreover, the calculated hazard Index showed that the overall health risk of the surveyed elements is in an unsafe range.

Keywords Heavy metal · Risk assessment · Rice · Iran

Introduction

Nowadays, a huge consideration goes to these contaminants because they are toxic and non-biodegradable and have a persist nature which severely threaten the health of human beings and the other creatures [1]. Also, food contamination to these elements is a worldwide problem [2]. It has been found that application of untreated wastewaters, pesticide use, sewage sludge, manure, and organic composts in farmlands are among the primary sources of introducing heavy metals and the other elements into the farmland products [3]. Some metals and metalloids such as Zn, Mo, and Se are indispensable in biological systems, but most of these elements are toxic and have adverse metabolites and physiologic effects including cancer, neurological disorders, genetic, and congenital disorders on organism [4, 5]. The ingestion of the contaminated food (oral route) is considered one of the most pivotal pathways for exposure of human to these elements [6]. Among various staple food, rice is a substantial cereal crop around the globe and also highly consumed in Asia [7]. For instance, in China and Bangladesh, the average consumption of rice was determined between 340 and 650 g/day [8, 9]. Due to physiologic structure of rice, previous studies have shown the bioaccumulation of different toxic elements in this plant [5, 8, 10]. Therefore, it is probable that rice consumers could be exposed to high concentrations of metals and metalloids from contaminated sites. Unfortunately, there are no accurate data available on rice consumption in Iran, particularly in the southeast region. Because of the vicinity to Southeastern Asian countries that are known to consume rice in large quantities, the daily

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consumption of rice among people of southeast Iran is high. On the other hand, most available rice brands in the market of southeast Iran are smuggled from Pakistan into the this area because the southeast Iran shares a long border with Pakistan [11], and since there is no effective monitoring system to control quality for health safety issues, the high-levels exposure to toxic elements through rice ingestion could be critical. The current research was carried out to evaluate the concentration of nine elements including Ni, Cr, Hg, Sr, Mn, Fe, Se, Ba, and Zn in the distributed rice in the southeast markets of Iran. Also, the health risk level related to consumption of evaluated rice samples were estimated by determining the daily rice consumption of people in this region.

Material and methods

Sampling

In order to specify the most commonly used rice brands in the southeast of Iran, 258 questionnaires were distributed among women who referred to five health centers in Sistan and Balouchestan province. Also, the mean daily rice consumption in families was determined through this questionnaire. By analyzing the collected data, 12 most common consumed rice brands were gathered from the marketplace of the southeast of Iran. Three samples (about 100 g) of each brand were collected randomly from three separate packages, and each package was chosen from three separate shops.

Sample preparation and analysis

To remove dust or any impurity, samples were rinsed by deionized water and then were kept at 70 °C for 72 h. The samples were then grounded and passed through a 1 mm-mesh sieve. The digestion of samples was done according to the conducted study by Djahed et al. [12]. Afterward, the concentrations of elements were determined using inductively coupled plasma mass spectrometry (7500cx, Agilent Scientific Technology, USA). We utilized certified reference materials of NIST-SRM-1566b and NIST-SRM-1568b to confirm the accuracy of the analytical procedures. In Table 1, the limit of detection (LOD), mean of recoveries from the analysis of certified reference material are shown.

Exposure assessment

Exposure assessment is a critical step considered in risk assessment [6]. In the current study, we utilized the estimated daily intake (EDI) to evaluate people's exposure to the surveyed elements by oral ingestion. We used Eq. 1 to estimate EDI [13].

$$EDI = (C_{metal} \times E_F \times E_D \times F_{IR})/(W \times T) \quad (1)$$

Where EDI presents the estimated daily intake (mg/kg/day); C_{metal} shows the level of element in the sample (mg/kg); E_F is the frequency of exposure (365 days/year); E_D is the duration of exposure (taken as 30 years for non-carcinogens effects); F_{IR} demonstrates the mean of daily rice consumption (g/person/day); W is the mean body weight (kg), and T is the mean exposure time that is approximated through multiplying E_F with E_D. Also, the value of W was regarded to be 70 kg [14].

Non-carcinogenic risk assessment

We used the qualitative method to evaluate non-carcinogenic health risks. To this end, we used the hazard quotient index (HQ) according to Eq. 2 [13, 15–17].

$$HQ = EDI/RfD \quad (2)$$

Where HQ (dimensionless), EDI (mg/kg/day), and RfD (mg/kg/day) are the hazard quotient index, the estimated daily intake, and the reference dose of the desired element, respectively. If the HQ value is calculated to be equal or lower than one, the non-carcinogenic risk is insignificant and if the amount of HQ is determined to be over one, then there could be non-carcinogenic effects [6]. Moreover, using Eq. 3, the hazard index (HI) was evaluated. This index can be employed for the total risk caused through more than one constituent in a material or the total of several risks for a specific constituent that the body is exposed to from various pathways [15, 16, 18].

$$Hazard\ Index = \sum_{k=1}^{n} \frac{EDI_k}{RfD_k} \quad (3)$$

Data analysis

Deterministic and stochastic approaches are available to perform a model of risk assessment. Variability in the response of different persons, fluctuation in the levels of toxins, and uncertainty in the approximation of different factors might cause huge uncertainty in the risk assessment process [19, 20]. Ignoring this uncertainty can lead to underestimation and/or overestimation of the results [20]. In the deterministic method, the variables are inserted into the model as point estimates which ignore the uncertainties. While in the stochastic method, the uncertainty is applied both in the input and output of the model. In the risk assessment process, in order to apply the stochastic approach, the Monte Carlo technique is a widely used method [19]. Hence, in this study, we employed the Monte Carlo simulation to assess the uncertainty in the input values. Initially, the probability of distribution was analyzed for the input variables. Then, using Monte Carlo simulation,

Table 1 Recovery of certified reference material, and limit of detection

	Element	Certified value (mg kg^{-1})	Measured value (mg kg^{-1})	Recovery%	LOD (mg kg^{-1})
NIST-SRM-1568b	Fe	7.42	7.38 ± 0.51	99.46	0.02
	Mn	19.2	18.89 ± 0.92	98.38	0.008
	Hg	0.0059	0.0056 ± 0.0008	94.91	0.0003
	Se	0.365	0.375 ± 0.007	102.73	0.005
	Zn	19.42	19.37 ± 0.09	99.74	0.008
NIST-SRM-1566b	Ni	1.04	1.02 ± 0.04	98.07	0.01
	Ba	8.6	8.68 ± 0.05	100.93	0.01
	Sr	6.8	6.71 ± 0.08	98.67	0.01

the models of exposure as well as risk assessment were simulated. To this end, we utilized 20,000 iterations. To exert the Monte Carlo simulation, ModelRisk software (V.5.0.2.1, Vose Software, Belgium) was used. Moreover, we applied the Kruskal Wallis test to survey the difference between the concentrations of elements in various rice samples. The statistical analyses were performed with IBM SPSS statistical software (version12.0).

Results and discussion

The obtained results are presented in Table 2. In addition, for every brand, the minimum, maximum, and the mean of each element are depicted in Fig. 1.

Concentration of Ni

Exposure to nickel can increase allergic skin diseases, especially in women. Also, the reproductive disorders and undesirable effects on the fetuses are from the other effects of nickel [21]. Nickel enters the body through the respiratory and intestinal system. This element can be found in many foods such as cereals, canned vegetables, spaghetti, canned and dried fruits, cocoa, and chocolate. The entered nickel might create some radical oxygen species and the other reactive compounds within the cell, which indirectly cause cell damage and cancer [22]. In the present survey, the mean content of nickel in the collected samples was 0.599 ± 0.124 mg/kg. Besides, the maximum and minimum of the measured concentrations in the samples were 0.997 and 0.318 mg/kg, respectively. The concentration levels of Ni in all the studied samples were determined over LOD value. The difference between the mean concentration among the investigated brands was not statistically significant ($x^2 = 19.52$, $p > 0.05$). According to Fig. 1, the rice brand of code 1 had the highest concentration of Ni; besides, the codes 6, 7, and 11 had a mean concentration above the overall mean of all surveyed brands. In a study on the heavy metal contamination in Indian rice supplied in the market of Iran, the mean Ni concentration was stated to be 0.019 mg/kg [23]. Moreover, in another study conducted by Pinto et al., the mean content of this element was at 0.06 mg/kg in the rice samples collected from Portugal and Spain markets [14]. In the mentioned studies, the reported concentration was much less than the values in the present research.

Table 2 Mean, range, distribution type, and RfD related to the measured elements

Elements (NDS[a])	Mean (mg kg^{-1})	STD (mg kg^{-1})	Median (mg kg^{-1})	Range (mg kg^{-1})	95% CI for the mean (mg kg^{-1})	Type of Distribution	RfD (mg kg^{-1} day^{-1})
Ni (36)	0.599	0.124	0.582	0.318–0.997	0.557 to 0.641	Logistic	0.02
Cr (30)	0.483	0.28	0.4	0.2–1.2	0.378 to 0.588	Expon	0.003
Hg (17)	0.0157	0.005	0.015	0.01–0.0321	0.011 to 0.018	Pareto	0.0003
Sr (36)	0.85	1.307	0.5	0.2–7.1	0.407 to 1.292	Loglogistic	0.6
Mn (36)	11.5	1.978	11.5	7–16	10.83 to 12.169	Logistic	0.046
Fe (26)	178.461	67.279	166.5	104–394	132.195 to 200.902	Expon	0.3
Se (36)	0.212	0.083	0.218	0.055–0.422	0.184 to 0.24	Normal	0.005
Ba (36)	0.845	0.62	0.623	0.24–3.5	0.635 to 1.055	Loglogistic	0.07
Zn (36)	8.416	1.611	8.505	1.56–11.1	7.871 to 8.961	Laplace	0.3

[a] Number of Detectable Samples (Over LOD)

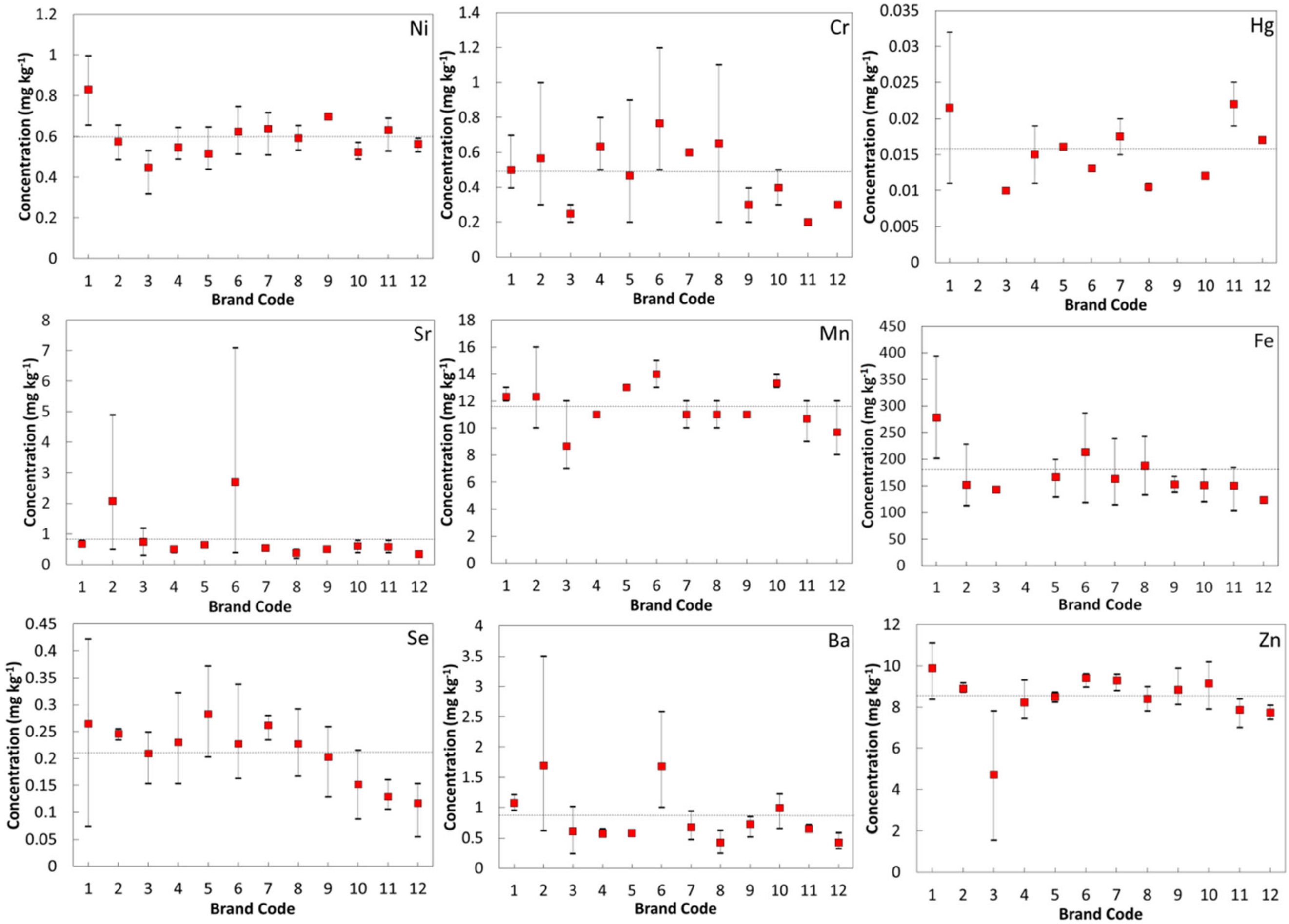

Fig. 1 Comparison of the mean, maximum and minimum concentrations of heavy metals in the surveyed brands

Concentration of Cr

For more than a century, chromium has been used in industries and is abundant in nature. Chromium is a Group 1 inorganic human carcinogen [24]. Exposure to this element can result in the generation of free oxidizing radicals, mutations in DNA, chromosomal damage, and sister chromatid exchange. These effects might lead to the development of tumors, allergic sensitization, and asthmatic responses [25]. Lung cancer is a consequence of chromium inhalation exposure. In addition, cancers of gastrointestinal and central nervous systems, skin ulceration, and dermatitis are the other complications of chromium oral exposure [26, 27]. As reported in Table 2, the mean content of chromium in surveyed samples was detected to be 0.483 ± 0.28 mg/kg, which ranged from 0.2 to 1.2 mg/kg. Further, as Fig. 1 depicts, the brand codes of 6 and 11 had the highest and lowest concentrations of Cr, respectively. Also, the results from the Kruskal Wallis test revealed that there is no statistical difference between surveyed brands ($x^2 = 14.812$, $p > 0.05$). In a study by Barbosa et al., the content of Cr in the supplied rice of Brazilian markets was reported 3 ± 0.3 mg/kg [28]. In Portugal and Spain markets, the concentration of this element was 0.11 ± 0.05 mg/kg [14]. In another study, Saha and Zaman reported the concentration of Cr 0.15 ± 0.01 mg/kg in rice cultivated in Bangladesh [29]. Besides, Lin et al. showed the Cr contents of the existing rice in Taiwan market 0.1 ± 0.39 mg/kg [30]. In comparison with the mentioned studies, the mean concentration of Cr in this investigation was higher, suggesting that the measured samples were contaminated with Cr.

Concentration of Hg

Mercury (Hg) is a toxic element for humans. Hg has toxic influences on the nervous, renal, reproductive, and cardiovascular systems and also affects the development of the fetus' brain [8, 10]. The mean concentration of Hg in the investigated samples was specified to be 0.0157 ± 0.005 mg/kg ranging from 0.01 to 0.0321 mg/kg (Table 2). As shown in Table 2, the Hg levels were detectable in 17 samples. In some brands such as codes of 2 and 9 (Fig. 1), all samples were determined under LOD. Also, the difference between Hg levels was not statistically significant ($x^2 = 10.005$, $p > 0.05$) among the surveyed brands. In the rice samples cultivated near an industrial zone in China, Cao et al. found the mean concentration of Hg 0.0057 (0.001–0.013) mg/kg [31]. In Tanzania, Machiwa measured the concentration of Hg in rice samples gathered from the wetlands of Lake Victoria basin and reported Hg concentrations in the range of 0.0005 to 0.0062 mg/kg [32]. Besides, in an E-waste recycling area in southeast China, Fu et al. found the mean concentration of Hg 0.022 ± 0.014 mg/kg [33]. By comparing the Hg concentration level of the investigated samples in the current research with other studies, we concluded that the samples with a higher concentration than LOD were probably cultivated in contaminated areas.

Concentration of Sr

Sr is known as a potent human toxin that causes brain damage and mental disabilities [34]. Sr can substitute the calcium in bones because it has similar biochemical characteristics to calcium. Hence, at high concentrations, Sr can lead to disorders in normal bone development [10]. Besides, the white cells are destroyed when Sr enters the bone marrow that consequently causes immune system impairment. In this condition, different types of diseases such as cancer might develop [35]. Also, in plants, Sr can be exchanged with calcium, which is an essential element for plant growth while Sr is an unnecessary element [36]. The findings of current research revealed that the content of Sr in the rice samples ranged from 0.2 to 7.1 mg/kg with a mean concentration of 0.85 ± 1.307 mg/kg. According to Fig. 1, Sr element in all brands was detectable, and in two rice brands of code 6 and 2, the measured concentration was higher than the overall mean. Based on the Kruskal Wallis test, it was found no statistical difference between the Sr contents in the surveyed brands ($x^2 = 15.153$, $p > 0.05$). In a study on the existing rice in the Jamaican market, Antoine et al. reported the mean Sr level to be 1.93 ± 0.348 mg/kg [10]. Also, in another investigation in Spain and Portugal markets, Pinito et al. determined the content level of Sr as 0.2 ± 0.14 mg/kg [14]. The obtained level of Sr in the present study was in the range of the mentioned studies.

Concentration of Mn

Manganese (Mn) works as an enzyme activator and also is a necessary element for bone growth and fat metabolism; therefore, lack of this element can lead to extreme skeletal and reproduction disorders in mammals [37]. However, manganese deficiency in humans is rare because it is present in almost all foodstuffs. Exposure to high concentrations of Mn causes side effects such as neurotoxicity [3]. In this study, the mean content of Mn in the rice brands was 11.5 ± 1.976 mg/kg. Also, the concentration range for Mn was 7–16 mg/kg (Table 2). According to Fig. 1, the highest mean for Mn was obtained in the brands of code 6, but one of the brands of code 2 had the highest level among all the studied brands. According to the observed results from the Kruskal Wallis test, a statistical difference in the content of the investigated brands was determined ($x^2 = 21.8$, $p < 0.05$). Antoine et al. found the concentration of Mn equal to 10.5 ± 3.68 mg/kg in the rice available in the Jamaican market [10]. In another study, Barbosa et al. reported the level of Mn to be 12.2 ± 6.4 mg/kg in the Brazilian rice market [28]. Considering the results of the mentioned researches and the level of Mn in the planted rice in an industrial area in China (28.639 ± 5.57 mg/kg) [33], it was concluded that our samples were not contaminated with Mn.

Concentration of Fe

Iron (Fe) is an essential element but could be toxic in high concentrations [38]. Free Fe accelerates the production of toxic radicals that will damage DNA, proteins, lipids, and mitochondria, and these damages might be a major cause of aging [38, 39]. The liver, heart, central nervous systems, pancreatic beta cells, and blood are among the organs and cell types, which are affected by Fe overload [40]. Also, Fe causes atherosclerosis, neurodegeneration, Parkinson's, and Alzheimer's disease [38, 39]. Based on Table 2, the mean of Fe content in the surveyed samples was 178.461 ± 67.279 mg/kg. Figure 1 shows the highest as well as the lowest level of this element that belonged to brand codes 1 and 12. Also, all samples of the brand code 4 were below LOD. The Kruskal Wallis test revealed that there was no statistical difference between the Fe concentrations of the surveyed brands ($x^2 = 8.14$, $p > 0.05$). Compared to other studies, our findings showed that the concentration of Fe in the investigated samples was in a high range; for instance, in separate studies in Swedish and Brazilian markets, the mean concentration of Fe was determined to be 2.2 (1.2–3.7) and 3.6 ± 3 mg/kg, respectively [5, 28]. Also, in another survey in Portugal and Spain markets [14], the mean concentration of this element was reported as 6.8 ± 1.5 mg/kg, which was lower than our result.

Concentration of Se

Selenium (Se) is an essential element for humans. It has a major role in metabolic activity in the human body [41]. Investigations have shown that the use of Se increases biochemical resistance against cancer and infection and reported it as a natural anti-carcinogenic agent [41, 42]. However, a high-level intake of Se might lead to selenosis [41], which can cause symptoms such as nausea, vomiting, garlic-like breath odor, gastrointestinal, skin lesions, tooth decay, nail and hair deformities, liver damage, and peripheral nerve damage [43]. In the current study, the mean concentration of Se in the investigated brands was 0.212 ± 0.083 mg/kg. The highest and lowest measured concentrations were 10.055 and 0.422 mg/kg, respectively. According to Fig. 1, the highest measured mean in the studied brands was detected in the brands with code 5; however, one of the surveyed samples of code 1 had the highest measured value. Moreover, based on the obtained results from the Kruskal Wallis test, no significant difference was observed in the concentration of Se in the studied brands ($x^2 = 15.64$, $p > 0.05$). In a research, Jorhem et al. determined the mean content of Se in the Swedish market as 0.1 (<0.1–0.2) mg/kg [5]. Also, the concentration of this metal in Portugal and Spain markets was 0.2 ± 0.19 mg/kg [14]. We found that the concentration of Se in the investigated samples was lower than the mentioned studies.

Concentration of Ba

Barium (Ba) can be deposited in bone and substitute calcium. Moreover, Ba causes smooth, striated, and cardiac muscle stimulation, and blood pressure elevation [44]. In our investigation, it was found that the determined values of barium were higher than the limit of detection in all the studied samples (Fig. 1). As presented in Table 2, the lowest and the highest measured concentrations in the studied samples were 0.24 and 3.5 mg/kg, respectively. Also, as Fig. 1 depicts, the concentration of Ba is maximum in the brand of code 2 (1.69 ± 1.56 mg/kg). The mean Ba concentration in the investigated rice samples was 0.84 ± 0.62 mg/kg. Besides, a significant difference was found between the levels of the surveyed brands ($x^2 = 22.02$, $p < 0.05$). Fu et al. studied rice planted in the E-waste recycling area and reported the mean content of Ba in the investigated samples as 2.586 mg/kg, which was much more than the obtained results in the present study. They also concluded that the high concentrations of this element were attributed to the high concentration of barium in the soil of the studied area [33]. In another study in Brazil, Barbosa et al. reported the mean barium content in rice as 0.32 ± 0.28 mg/kg [28], whereas the obtained average amount in this study was about 3 times more than the mentioned studies.

Concentration of Zn

Zinc plays a significant role in the adjustment of metabolic activities. Nevertheless, long-term consumption and high concentration of Zn in the diet may lead to vomiting, nausea, fever, headache, and stomachache [37]. The highest and lowest concentrations of Zn in the investigated samples were observed in the rice brands of codes 1 and 3, respectively (Fig. 1). As presented in Table 2, the mean concentration of Zn was 8.416 ± 6.11 mg/kg. Besides, a significant difference was found in Zn concentration in the investigated brands ($x^2 = 21.8$, $p < 0.05$). In separate studies conducted in Taiwan, Jamaica, and Sweden, Zn levels were reported to be 13.1 ± 19.4, 15.6 ± 19, and 17 (15–18) mg/kg, respectively [5, 10, 30], suggesting that the mean concentration of Zn in the current research was lower than the mentioned studies.

Exposure assessment

The intake level of the toxic agent into the human body is determined in the exposure assessment process. In the present research, 258 questionnaires were distributed among the southeast citizens of Iran to investigate their mean rice consumption. A total of 240 questionnaires were completed. The respondents answered the questions including the mean frequency of daily rice consumption, the type of devices (cup/glass) that respondents may use to measure the quantity of rice for cooking, and the mean number of glasses/cups of rice that they cook for each individual in each meal. Table 3 presents the results of the distributed questionnaire analysis.

For more precise calculations, we selected 5 glasses and 5 cups in different figures to approximate the capacities of cups as well as glasses (in terms of g/cup and g/glass). We filled them with rice several times and, subsequently, determined a mean of 118.04 ± 16.73 g and 178.52 ± 0.32 g for capacities of cups and glasses, respectively. Furthermore, we estimated the mean daily rice consumption as 295.66 ± 171.005 g/person/day through multiplying the parameters of the frequency of rice consumption per day, the number of cups or glasses of rice cooked for each person in each meal, and the capacity of a glass or a cup. The estimated daily rice consumption in the present research was obtained higher than the other investigations in Iran. For instance, the daily consumption of rice levels in the research conducted by Bakhtiarian and Zazouli was calculated to be 116.16 and 165 g/person/day, respectively [45, 46]. The authors of the present study believe that the obtained results are more accurate because of estimating daily rice consumption using questionnaires directly.

Regarding the estimated daily consumption of rice, the EDI was calculated using Eq. 1. For this purpose, Monte Carlo analysis through 20,000 iterations was utilized. The results are presented in Table 4.

As presented in Table 4, Fe with a mean of 0.741 ± 0.54 mg/kg/day was estimated as the greatest EDI. In addition, Se intake among the surveyed elements with a mean of 8.95 ± 6.33 mg/kg/day was determined as the lowest one. As Table 4 shows, the mean estimation of the EDI for the surveyed elements ranked in the following order: Fe > Mn > Zn > Ba>Sr > Ni > Cr > Se.

Risk characterization

The qualitative risk assessment of the non-carcinogenic effects of the investigated elements was done using Eq. 2. For this purpose, the Monte Carlo analysis, the calculated EDI (Table 3), and RfD (Table 2) were used. Figure 2 presents the distribution of HQ obtained through Monte Carlo

Table 3 The obtained results from the collected questionnaires

Parameters	Value	
The brands of consumed rice were belonged to	Pakistan	75.6%
	India	13.4%
	Iran	0.6%
	I don't know	10.2%
Average frequency of daily rice consumption	Once a day	84.3%
	Twice a day	15%
	Three times a day	0.7%
Frequency of devices which were utilized for rice measurement	Cup	78.8%
	Glass	21.2%
Average of number of cups that were cooked for each individual	2.1 ± 0.4 (min = 1, max = 4)	
Average of number of glasses that were cooked for each individual	1.8 ± 0.77 (min = 2, max = 5)	
Average capacity of cup	118.04 ± 16.73 (g cup^{-1})	
Average capacity of glass	178.52 ± 0.32 (g $glass^{-1}$)	
Average daily of rice consumption	295.66 ± 171.005 (g $person^{-1}$ day^{-1})	

simulation. To determine the HQ distribution, 20,000 iterations were done. As shown in Fig. 2, according to Monte Carlo analysis, just 90% of iterations for Cr, Fe, and Mn ranged over 1 while it was below 1 for the rest of the elements. Furthermore, the data about the HQ stochastic analysis are shown in Table 5. As can be seen in Table 5, Fe with a mean of 2.48 ± 1.98 and Sr with a mean of 4.66E-3 ± 6.55E-3 had the highest and lowest estimated HQ, respectively. Moreover, the mean for the calculated HQ of the surveyed elements was obtained in the following order: Fe > Mn > Cr > Hg > Se > Ni > Zn > Ba>Sr. According to Table 4, the mean HQ for Mn and Fe elements was over 1, suggesting that the consumption of investigated rice brands can cause the rise of non-carcinogenic effects, arising from exposure to the mentioned elements. Also, the 90th percentile of iterations related to Cr was over 1 but their mean was estimated below 1. This result suggests the non-carcinogenic adverse effects of Cr are possible in the consumers of the studied brands; however, its probability is low. According to Table 4, the other surveyed elements had the HQ below 1, indicating their rare non-carcinogenic effects. Also, using Eq. 3, the amount of HI was calculated to be 4.92, which revealed that the overall risk related to the consumption of the studied rice brands was high. As presented in Table 4, elements such as Fe, Mn, and Cr had the most contribution level in HI.

Conclusion

Rice is among the most important resources for heavy metal intake. Thus, monitoring heavy metals in foodstuff is critical, especially in countries with high rice consumption. Although rice is considered as a staple food in the southeastern region of Iran, there is no accurate information related to the rate of daily rice consumption as well as the level of toxic elements in the rice which is supplying in the marketplace of this region. In the current research, the concentrations of nine important elements were determined in 36 collected samples (12 brands) of rice from the markets of southeastern, Iran. Furthermore, health risk arising from the consumption of these rice brands

Table 4 Stochastic calculation of EDI (mg/kg/day)

Element	Minimum	Maximum	Mean	SD	Median	90th Percentile
Ni	0	8.58E-02	2.50E-03	1.59E-03	2.19E-03	3.89E-03
Cr	3.10E-04	4.35E-02	2.00E-03	1.75E-03	1.51E-03	3.72E-03
Hg	1.51E-05	3.00E-03	7.03E-05	7.58E-05	5.30E-05	1.19E-04
Sr	3.30E-04	0.760683	2.82E-03	6.28E-03	2.07E-03	4.96E-03
Mn	3.52E-03	1.823295	4.89E-02	3.05E-02	4.27E-02	7.58E-02
Fe	0.172166	16.99389	0.74172	0.541727	0.602651	1.271397
Se	0	2.88E-02	8.95E-04	6.33E-04	7.78E-04	1.54E-03
Ba	3.08E-04	0.127533	3.53E-03	3.67E-03	2.64E-03	6.41E-03
Zn	0	1.358918	3.60E-02	2.23E-02	3.15E-02	5.48E-02

Table 5 Stochastic calculation of HQ and estimated HI for evaluated elements

Element	Mean	SD	Median	90th Percentile	Contribution to HI (%)	HI
Ni	1.25E-01	7.45E-02	1.09E-01	1.96E-01	2.543808	4.92E+00
Cr	6.66E-01	5.68E-01	5.01E-01	1.26E+00[a]	13.53807	
Hg	2.35E-01	2.61E-01	1.77E-01	4.00E-01	4.769865	
Sr	4.66E-03	6.55E-03	3.43E-03	8.27E-03	0.094789	
Mn	1.06E+00[a]	6.25E-01	9.31E-01	1.63E+00[a]	21.59974	
Fe	2.48E+00[a]	1.98E+00	2.00E+00	4.27E+00[a]	50.35444	
Se	1.79E-01	1.27E-01	1.55E-01	3.07E-01	3.644492	
Ba	5.01E-02	4.98E-02	3.76E-02	9.09E-02	1.019361	
Zn	1.20E-01	7.02E-02	1.05E-01	1.85E-01	2.435445	

[a] Estimated HQ over the hazard quotient threshold (over 1)

was evaluated. The results showed that the mean concentration of elements were 0.599 ± 0.124 (Ni), 0.483 ± 0.8 (Cr), 0.0157 ± 0.005 (Hg), 0.85 ± 1.307 (Sr), 11.5 ± 1.978 (Mn), 178.461 ± 67.279 (Fe), 0.212 ± 0.083 (Se), 0.845 ± 0.62 (Ba), and 8.416 ± 1.611 (Zn) mg/kg. Additionally, our findings revealed that the mean concentrations of metals, such as Ni, Cr, Hg, Fe, and Ba were higher than the reported levels in other studies. Also, Fe with a mean of 0.741 ± 0.45 mg/kg/day and Se with a mean of 8.95E-04 ± 6.33E-04 mg/kg/day had the highest and lowest exposure level, respectively. We estimated the HQ value for Mn and Fe over 1, which showed a high probability of non-carcinogenic effects on the

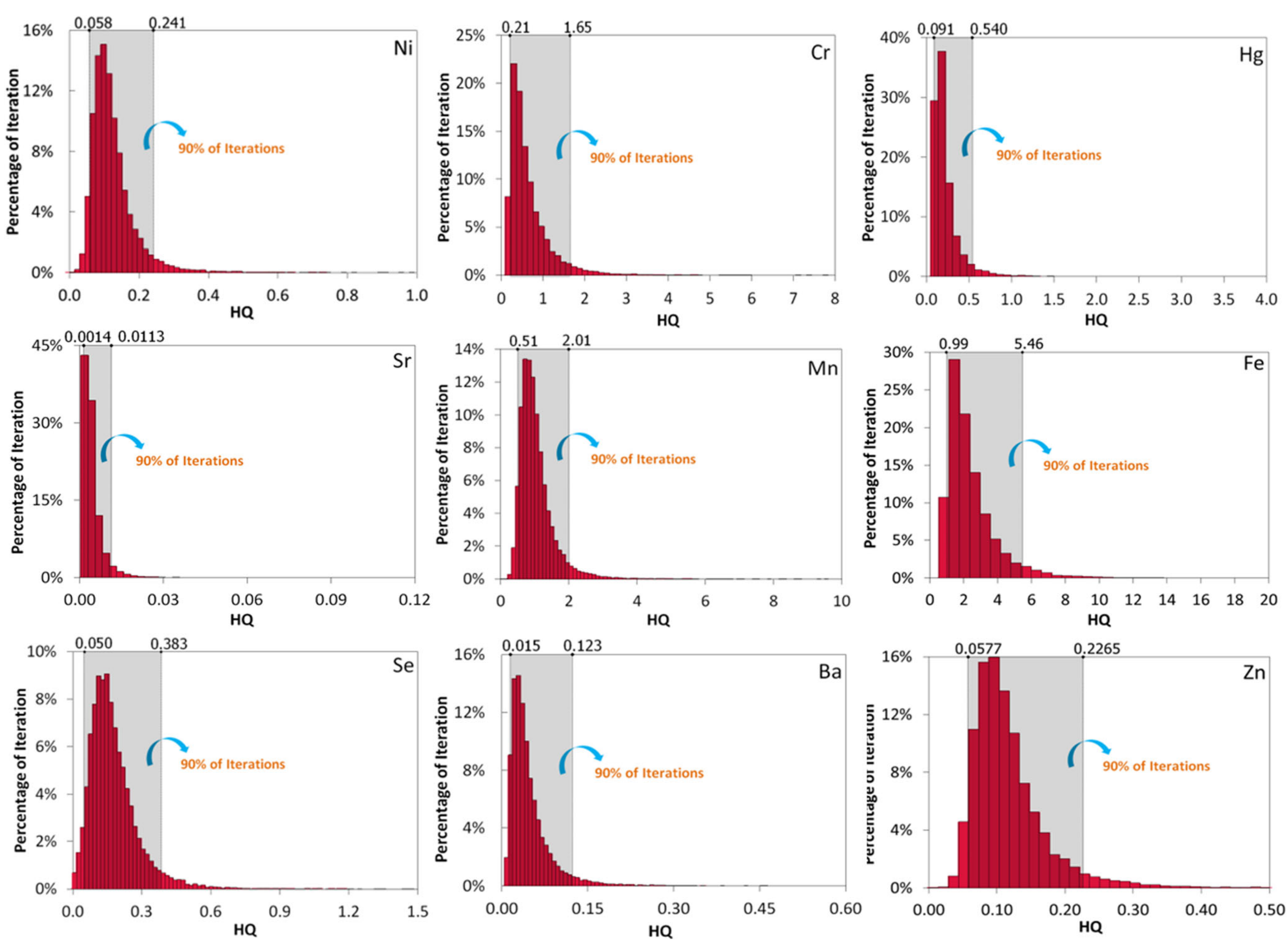

Fig. 2 HQ distribution for Ni, Cr, Hg, Sr, Mn, Fe, Se, Ba, and Zn through Monte Carlo simulation

consumers. Moreover, the HI index was estimated at 4.92, which supports the surveyed rice samples in this study to be unsafe for consumers.

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Compliance with ethical standards

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

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