Environmental Health Engineering and Management Journal. 2026;13:1503 10.34172/EHEM.1503
http://ehemj.com

Environmental Health
Engineering and
Management Journal

Review Article

Open Access
Publish Free

The Concentration of Potentially Toxic Elements in *Shrimp* (*Caridea*) Fillet from Iran: A Systematic Review and Potential Dietary Health Risk Assessment

Yadolah Fakhri[1*], Zohreh Kamari[1], Maryam Sarkhosh[2], Nayera Naimi[3,4], Abotaleb Bay[5*]

[1]Food Health Research Center, Hormozgan University of Medical Sciences, Bandar Abbas, Iran
[2]Department of Environmental Health Engineering, School of Health, Mashhad University of Medical Sciences, Mashhad, Iran
[3]Department of Environmental Health Engineering, School of Public Health, North Khorasan University of Medical Sciences, Bojnurd, Iran
[4]Student Research Committee, Department of Environmental Health Engineering, School of Public Health, Mashhad University of Medical Sciences, Mashhad, Iran
[5]Environmental Health Research Center, Golestan University of Medical Sciences, Golestan, Iran

Abstract

Background: Pollution by potentially toxic elements (PTEs) have adverse effects on aquatic ecosystems. They may accumulate in sediments, plants, and aquatic organisms, disrupting the delicate balance of the ecosystem.

Methods: This study attempted to estimate the concentration of PTEs in shrimp tissue and estimate potential health risks in consumers among international databases, including Scopus, PubMed, Embase, and Web of Science, from January 2000 to March 20 2023. Furthermore, non-carcinogenic and carcinogenic risks for Iranian adult and child consumers were calculated using the Target hazard quotient (THQ) and Cancer Risk (CR).

Results: The rank order of PTEs due to THQ in adults was Methyl Hg (0.27) > Cd (0.13) > Ni (0.07) > Inorganic As (0.04) > Cu (0.03) > Pb (0.02), and for children Methyl Hg (1.28) > Cd (0.62) > Ni (0.35) > Inorganic As (0.20) > Cu (0.15) > Pb (0.11). TTHQ for the adults and children was 0.58 and 2.73, respectively. Besides, the mean CR in adults and children regarding inorganic As was 2.00E-5 and 7.98E-6, respectively. On the other hand, the total non-carcinogenic risk showed that children could be at considerable risk.

Conclusion: The carcinogenic risk of inorganic As was acceptable (CR < 1E-4) for adults and children. As a result, health and environmental authorities in Iran and other nearby regions must continually monitor the levels of PTEs in shrimp muscle tissue and implement policies to reduce the PTE pollution of the Persian Gulf and the Sea of Oman.

Keywords: Carcinogens, Cadmium, Shrimp, Heavy metals, Risk assessment

Citation: Fakhri Y, Kamari Z, Sarkhosh M, Naimi N, Bay A. The concentration of potentially toxic elements in *Shrimp* (*Caridea*) fillet from Iran: A systematic review and potential dietary health risk assessment. Environmental Health Engineering and Management Journal 2026;13: 1503. doi: 10.34172/EHEM.1503

Article History:
Received: 25 December 2024
Revised: 31 July 2025
Accepted: 1 August 2025
ePublished: 28 April 2026

***Correspondence to:**
Yadolah Fakhri,
Email: Ya.fakhri@gmail.com
and Abotaleb Bay,
Email: Abotaleb_bay@yahoo.com

Introduction

Water pollution due to Persistent Toxic Elements (PTEs) is a critical issue plaguing our global water systems, posing significant threats to environmental integrity and human health. PTEs such as lead (Pb), methyl mercury (Hg), cadmium (Cd), chromium (Cr), arsenic (As), and others are naturally occurring elements with high atomic weights, which can be toxic even at low concentrations (1,2). PTEs pollution of aquatic bodies may come from various sources, including mining, processing metal, and manufacturing, causing PTEs pollution. PTEs may enter water sources when industrial waste and wastewater are improperly discharged (1). Moreover, agricultural practices that use fertilizers, pesticides, and livestock waste can introduce PTEs into water systems(1).

The PTEs pollution can have adverse effects on aquatic ecosystems. They may accumulate in sediments, plants, and aquatic species, disrupting the ecosystem's delicate balance (3). The reduced biodiversity may result from PTEs affecting the development and reproduction of aquatic plants and animals (1). Additionally, they may impact an organism's physiology and behavior, harming its immune system's capacity for reproduction (4). A notable historical example is the Minamata Bay incident in Japan, where industrial discharge led to severe mercury contamination, significantly impacting aquatic life. Methylmercury, a type of mercury found in water, accumulates in fish, causing deformities, neurological harm, and reproductive problems in various species, including fish and shellfish. This pollution affected higher predators, such as birds and mammals, leading to compromised reproduction and population declines, notably affecting species like the endangered black-footed albatross. Furthermore, PTEs can potentially enter the food chain, posing risks to human health. When aquatic organisms, such as fish and shellfish, are contaminated with PTEs, consuming these contaminated organisms can lead to human exposure. Chronic exposure to PTEs through contaminated water or the consumption of contaminated food can lead to various health issues. PTEs can accumulate in human tissues and organs, leading to organ damage, neurological disorders, developmental abnormalities, and even cancer.

In Africa, as in other regions of the World, the continuous release of contaminants, including PTEs, PAHs, PCBs, plastics, pharmaceuticals, and other waste substances, into the marine ecosystem poses significant challenges for management solutions. Due to the stable, non-biodegradable, and persistent nature of these pollutants, which can accumulate in organs and tissues over time, human exposure to PTEs should be a significant concern. Reported health risks associated with human metal toxicity include kidney and skeletal damage, endocrine disruption, neurological disorders, cardiovascular dysfunction, and various cancers (5). Despite increasing evidence of PTEs pollution in the coastal waters of developing countries, there is a need for more data on PTEs levels in fish, daily intake levels, and the potential health risks to humans (6,7).

Based on an article published by the Food and Agriculture Organization (FAO), the production of various shrimp species worldwide exceeded 7.7 million tons in 2020 (8). In 2021, the global shrimp market reached USD 53.91 billion. Experts anticipate it will expand at a compound annual growth rate (CAGR) of 5.3% from 2022 to 2030. Economic progress, population growth, and cultural preferences for seafood have all impacted the trajectory of shrimp consumption in the Persian Gulf nations. These countries, including Iran, Saudi Arabia, Kuwait, the United Arab Emirates, and Qatar, have witnessed an increase in shrimp consumption as part of their diverse culinary traditions and growing demand for seafood products. Different species of shrimp have different benefits for consumption. White leg shrimp (*Litopenaeus vannamei*), Black tiger shrimp (*Penaeus monodon*), and Pink shrimp (*Farfantepenaeus duorarum*) are some different types of shrimp (9). Consuming shrimp offers several benefits due to its nutritional profile. It has few calories, includes essential vitamins and minerals, such as selenium and omega-3 fatty acids, and is a rich source of high-quality protein (10,11). Additional health advantages of shrimp include enhanced heart health, enhanced cognitive function, and antioxidant properties (12).

Various studies and research have documented PTEs in fish and marine organisms in the Persian Gulf (13). These studies investigated the levels of PTEs in different fish species and other marine organisms collected from the Persian Gulf region. The concentrations of lead (Pb) and arsenic (As) in the muscles of shrimp from the Persian Gulf were found to exceed the guidelines set by the Food and Agriculture Organization/World Health Organization (FAO/WHO) (14). The mean concentrations of zinc and copper were lower than the international standards for the highest permissible limits (MPL)(15). A study by Al-Yamani et al. (2004) analyzed the concentrations of PTEs, including mercury (Hg), lead (Pb), cadmium (Cd), and copper (Cu), in different fish species from Kuwaiti waters, which are located in the northern part of the *Persian Gulf*. They found varying levels of these PTEs in the analyzed fish species (16). The concentrations of PTEs can vary depending on factors such as the species of marine organisms, their habitat, and the specific location within the *Persian Gulf*. In addition, the contamination of marine ecosystems and the accumulation of PTEs in organisms may be attributed to shipping, urbanization, and industrial activity along the Persian Gulf coastlines(16). The Persian Gulf stands out as one of the Middle East's most environmentally compromised marine ecosystems due to significant urbanization, industrial growth, and extensive development. The region faces heightened exposure and strain from oil exploration, extraction, and transportation (15). Additionally, the discharge of wastewater from nearby coastal cities, alongside petroleum refineries and fisheries operations, further exacerbates its environmental challenges. 33 Researching PTEs in the Persian Gulf is crucial for understanding the extent of environmental pollution, identifying its sources and pathways, and assessing its potential impacts on the ecosystem and human health. Vigilant oversight and effective control of PTEs in this area are crucial for fostering sustainable growth, safeguarding marine biodiversity, and ensuring the welfare of communities that depend on the Gulf's resources. Several studies have been conducted on the concentration of PTEs in the Persian Gulf shrimps (17-21), but no systematic review study was found. This study aimed to determine the concentration of PTEs in the Persian Gulf shrimps and assess the associated health risks to consumers.

Materials and Methods

Searching strategy

The study was conducted according to the PRISMA protocol (22). The search was conducted by two authors (M. SA and Y. FA) in the international databases such as Scopus, PubMed, Embase, and Web of Science from January 2000 to March 20, 2023. Keywords used for the search of papers were «Potential toxic element» OR «Metals» OR «Heavy metals» OR «Toxic element» OR «Trace metals,» AND «SHRIMP,» OR «*Caridean Shrimp*» OR «*Penaeus Vannamei*» OR «*Penaeus Indicus*» OR «*Penaeus Semisulcatus*» OR Caridea» OR «Marine food» and «*Persian Gulf*". The other articles were downloaded, and their entire texts were evaluated; only those that met our requirements were included in the data extraction stage. The articles' references were verified to recover any missing documents. The final correspondence comment resolved a disagreement among authors regarding the selection or removal of papers (23-25).

Inclusion/exclusion criteria and data extraction

The inclusion criteria were publication within the specified time frame, availability of complete texts in English, analysis of PTEs in shrimp from the Persian Gulf, use of a reliable detection technique, and provision of the range, average, or concentration of PTEs in shrimp fillets. Books, book chapters, review studies, correspondence, theses, conferences, and letters to editors were excluded. Statistics on the concentration of PTEs (inorganic As, methyl-Hg, Cd, Ni, Pb, and Cu), including average, standard deviation, lowest and highest values, the species of shrimp, and the detection method, were extracted from papers. Some studies reported total arsenic (As) levels in shrimp. Hence, the total As was converted to inorganic As using a 5% coefficient (26-28).

Health Risk Assessment

The daily intake from the ingestion of shrimp content of PTEs was calculated using equations below:

$$\mathrm{CDI} = \frac{\mathrm{C} \times \mathrm{IR} \times \mathrm{ED} \times \mathrm{EF}}{\mathrm{BW} \times \mathrm{AT}} \qquad (1)$$

Where *CDI* is chronic daily intake; *C* is the concentration of PTEs in shrimp; *IR* is ingestion rate; *EF* is exposure frequency (350 d/y); *ED* is exposure duration (children and adults are 6 and 70 y, respectively); and *BW* is body weight (children and adults are 20 and 70 kg, respectively). The average lifetime non-carcinogenic risk for children and adults is 2190 days, and the average lifetime carcinogenic risk for both children and adults is 25550 days. The average per capita consumption of marine foods in Iran is 13.4 kg/y (29). On average, 15% of marine food consumption is dedicated to shrimp (12,30). Hence, the ingestion rate of shrimp in Iran can be as high as 2.01 kg/year. The RfD for methyl Hg, inorganic As, Ni, Cd, and Cu are 0.0001, 0.0003, 0.11, 0.001, and 0.04 mg/kg-d, respectively (31). The tolerable daily intake for Pb is 0.0036 mg/kg-d (32).

The non-carcinogenic risk was calculated by the target hazard quotient equation (32):

$$\mathrm{THQ} = \frac{\mathrm{CDI}}{\mathrm{RfD\ or\ TDI}} \qquad (2)$$

Where *THQ* is the target hazard quotient.

When THQ < 1, the exposed populations are at an acceptable non-carcinogenic risk.

The carcinogenic risk of inorganic As was calculated using the following equation (32):

$$\mathrm{CR} = \mathrm{CDI} \times \mathrm{SF} \qquad (3)$$

Where *CR* is Carcinogenic risk, *CDI* is chronic daily intake, and *SF* is slope factor.

SF for inorganic As equals 1.5 $(\text{mg/kg-d})^{-1}$. When CR < 1.00E-4 value, the exposed population is an acceptable carcinogenic risk (32).

Results

The concentration of PTEs

Of the 754 articles obtained, 673 were excluded in the initial review. According to titles and abstracts, 81 articles were identified as potentially suitable. Sixty-five articles were excluded due to the detection of other marine foods and elements; no original data were reported (review, book, chapter, letters, and conferences). After being evaluated for eligibility, 16 papers with 54 data reports published between January 2000 and March 20, 2023, were included in our study (Figure 1 and Table 1) for meta-analysis and carcinogenic risk assessment.

The highest concentration of inorganic As (1.55 mg/kg) and Cd (14.00 mg/kg) were observed in the study by Soltani et al. (Figure 2). The highest concentration of methyl-Hg (3.64 mg/kg) was observed in the study by Rahmanpour et al. (Figure 3). The highest concentration of Pb (4834 mg/kg) was observed in the study by Monikh et al. (Figure 3).

The highest concentrations of Ni (89.32 mg/kg) and Cu (97.79 mg/kg) were observed in the studies by Rahmanpour et al. and Pourang et al., respectively (Figure 4). The rank order of PTEs based on the percentage of THQ higher than 1 value was Cd (4.60%) > Methyl Hg (0%) ~ inorganic As (0%) ~ Pb (0%) ~ Ni (0%) ~ Cu (0%) for adults, and Cd (16.27%) > Ni (14.81%) > Methyl Hg (11.11%) > Inorganic As (6.60%) > Pb (0 %) ~ Cu (0%) for children (Table 2).

Risk assessment

Based on the data presented in Table 3, the rank order of PTEs based on the THQ in adults was Methyl Hg (0.27) > Cd (0.13) > Ni (0.07) > Inorganic As (0.04) > Cu (0.03) > Pb (0.02), and for children, Methyl Hg (1.28) > Cd (0.62) > Ni (0.35) > Inorganic As (0.20) > Cu (0.15) > Pb (0.11). TTHQ for adults and children was 0.58 and 2.73, respectively (Figure 5). Also, the percentage of CR higher than 1E-6 for the adults and children was equal to 0.00% and 0.00%, respectively (Table 2). The mean CR in adults

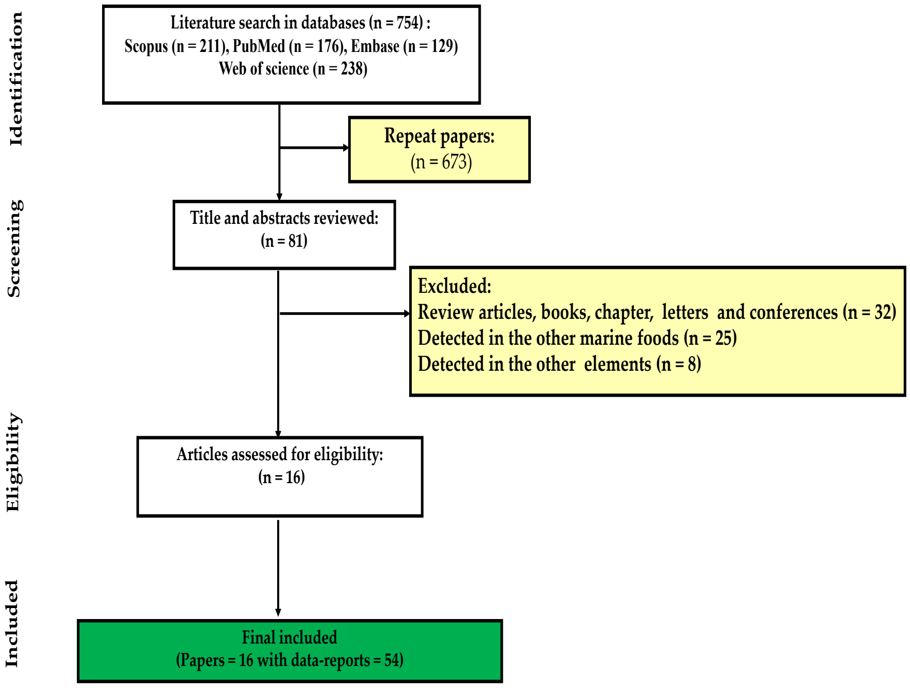

Figure 1. Process of selecting papers based on the PRISMA

and children due to inorganic As was 2.00 × 10^ (-5) and 7.98 × 10^ (-6), respectively (Figure 6).

Discussion

The highest concentration of inorganic As (1.554 mg/kg) and Cd (14.00 mg/kg) was observed in the study by Soltani *et al.* (Figure 2). These findings raise concerns about the discharge of industrial effluents caused by the activities of various industries in the region. Nevertheless, in all studies, the mean concentrations of arsenic (As) were below the Maximum Permissible Limit (MPL) of 2 mg/kg, as provided by Food Standards Australia and New Zealand (48). However, in 79% of studies, the mean concentrations of Cd exceeded the UN permissible amount by the European Commission (0.05 mg/kg) (49). These results can be attributed to human activities (e.g., oil refineries, fishing) in coastal areas (50). The major source of As in Khor Musa may be the discharge of industrial effluents from the operations of numerous enterprises in the area, particularly petrochemical complexes that employ arsenic catalysts (51). Nyarko et al. (2023) reported a higher concentration of mean As for fish species (0.8 to 8.5 mg/kg) and 0.002 mg/kg to 0.027 mg/kg of Cd in the fish species in the Gulf of Guinea that were in the MPL of the EU. The high As levels in this study may be due to the use of herbicides in mining and agricultural activities (52). However, Olmedo et al. (2013) found As and Cd levels in fresh shrimp (*Parapenaeus longirostris*) at 0.739 and 0.029 mg/kg ww, respectively (53). PTEs are considered an indicator of pollution because their exposure to water bodies leads to a decrease in the quality of water ecosystems (54). The bioaccumulation of metals in fish and shrimp may vary across species and is influenced by dietary preferences, ecological requirements, sex, age, size, physical and chemical properties of water, seasonal fluctuations, and the concentration of metals in water and sediments. Among PTEs, arsenic (As), cadmium (Cd), mercury (Hg), lead (Pb), and copper (Cu) have the highest potential for accumulation in fish tissue (55,56). Arsenic tends to accumulate in sediments, so the creatures of the deep sea are exposed to larger amounts of this pollutant due to their proximity to sediments (57). Exposure to very small amounts of arsenic may act as an endocrine disruptor. In contrast, long-term exposure to inorganic arsenic can lead to problems in the digestive, respiratory, skin, liver, vascular, and nervous systems (58).

Cd is a dangerous non-essential metal (59) that can cause chronic toxicity to various organisms, even at low concentrations (54,57). Certain environmental factors, including temperature, calcium concentration, and salinity, can influence the toxicity of this metal (59). Despite its low background concentration in the environment, exposure to cadmium (Cd) from smelting, electroplating, or even fertilizer consumption can cause kidney failure, bone softening, itai-itai disease, anemia, olfactory nerve damage, and even prostate cancer (60).

This can be caused by the accumulation of this metal in the sediments of Khuzestan province, resulting from petrochemical activities such as chlor-alkali production in the region. The Arvand River, the main source of freshwater entering the Persian Gulf, can dilute salty seawater and contribute to the formation of sediments. Therefore, mean Hg concentrations in *Metapenaus affinis* species were higher than the MPL (0.05 mg/kg) set by

Table 1. Main characteristics included in the present study (mg/kg-ww)

		Inorganic As				Cd				Methyl-Hg				Pb				Ni				Cu					
Species	**Sample size**	**Mean**	**sd**	**min**	**max**	**Mean**	**sd**	**min**	**max**	**Mean**	**sd**	**min**	**max**	**Mean**	**sd**	**min**	**max**	**Mean**	**sd**	**min**	**max**	**Mean**	**sd**	**min**	**max**	**Method of detection**	**Ref.**
shrimps (Penaeus merguiensis)	60	0.009	0.002			0.194	0.044			0.063	0.021			0.325	0.143											FIAS 4100, Perkin-Elmer	(33)
lobsters (Panulirus homarus)	60	0.005	0.003			0.163	0.077			0.053	0.012			0.641	0.084											FIAS 4100, Perkin-Elmer	(33)
Fenneropenaeus merguensis	21	0.001	0.001			0.037	0.001			0.007	0.000			0.087	0.003							1.260	0.200			Perkin-Elmer, model 4100 ZL atomic absorption spectrophotometer	(34)
Penaeus merguiensis	20					0.072	0.126											0.121	0.139			19.385	7.562			ICP-AES	(35)
Penaeus merguiensis	NM					0.381	0.207											0.129	0.179			97.798	39.042			ICP-AES	(35)
Penaeus merguiensis	NM					0.016	0.006											0.076	0.116			17.861	11.527			ICP-AES	(35)
Metapenaues affinis	20					0.098	0.231											0.231	0.179			28.198	48.838			ICP-AES	(35)
Metapenaues affinis	NM					0.171	0.314											0.446	1.084			90.526	73.466			ICP-AES	(35)
Metapenaues affinis	NM					0.023	0.013											0.245	0.361			17.369	9.868			ICP-AES	(35)
Penaeus semisulcatus	40					0.736	0.538	0.100	2.760													20.295	10.593	5.170	50.830	ICP-AES; Philips/Pye Unicam Model PU 7000 & ICP-MS; VG PlasmaQuad 3-VG Elemental	(36)
White Shrimp (Litopenaeus vannamei)	20													0.533	0.067			0.061	0.036			4.140	0.650			AAS (Perkin-Elmer Model Analyste 300)	(19)
White Shrimp (Litopenaeus vannamei)	20													0.002	0.025			0.082	0.021			0.950	0.240			AAS (Perkin-Elmer Model Analyste 300)	(19)
White Shrimp (Litopenaeus vannamei)	20													0.124	0.021			0.065	0.002			0.190	0.100			AAS (Perkin-Elmer Model Analyste 300)	(19)
White Shrimp (Litopenaeus vannamei)	20													0.069	0.029			0.080	0.002			0.060	0.010			AAS (Perkin-Elmer Model Analyste 300)	(19)
Penaeus semisulcatus	180													0.231	0.019	0.006	0.981	1.432	0.021	0.347	2.205					HR-ICP-MS	(37)
Metapenaeus affinis	27					0.021	0.000							0.004				0.025	0.000			0.810				atomic absorption	(37)
Metapenaus affinis	30	0.022	0.006			1.430	0.540			1.320	0.210			3.050	0.700			51.920	7.830							ICP–AES	(38)
Metapenaus affinis	30	0.007	0.002			0.110	0.020			0.210	0.010			0.760	0.310			52.150	13.470							ICP–AES	(38)

Table 1. Continued.

		Inorganic As				Cd				Methyl-Hg				Pb				Ni				Cu					
Species	**Sample size**	**Mean**	**sd**	**min**	**max**	**Mean**	**sd**	**min**	**max**	**Mean**	**sd**	**min**	**max**	**Mean**	**sd**	**min**	**max**	**Mean**	**sd**	**min**	**max**	**Mean**	**sd**	**min**	**max**	**Method of detection**	**Ref.**
Metapenaus affinis	30	0.053	0.017			4.920	1.050			0.620	0.160			3.940	0.630			89.320	18.610							ICP–AES	(38)
Metapenaus affinis	30	0.038	0.008			5.150	2.280			3.640	0.420			3.160	0.850			53.750	9.230							ICP–AES	(38)
Metapenaeus affinis	50					0.557	0.046							2.463	0.263			7.235	0.918			23.630	3.390			AAS	(39)
Metapenaeus affinis	50					0.647	0.038							3.629	0.470			8.875	1.560			25.610	3.640			AAS	(39)
Metapenaeus affinis	50					1.184	0.143							4.834	0.937			13.287	2.144			47.590	6.620			AAS	(39)
Metapenaeus affinis	50					0.053	0.006							1.428	0.328			6.764	0.998			16.080	2.890			AAS	(39)
Metapenaeus affinis	50					0.067	0.008							1.386	0.416			4.255	0.668			18.110	3.550			AAS	(39)
Metapenaeus affinis	50					0.032	0.063							2.898	0.544			5.200	0.363			31.750	4.620			AAS	(39)
-	NM					9.850	0.910			0.003	0.370			2.800	0.380							0.480	0.050			AA240	(40)
-	NM					10.000	0.750			0.003	0.290			2.200	0.250							0.440	0.300			AA241	(40)
-	NM					7.980	0.570			0.003	0.480			2.160	0.230							0.470	0.030			AA242	(40)
Ghost shrimp, U. pseuduchelata	7					0.720	1.060							1.500	1.200											GFAAS	(41)
Ghost shrimp, U. carinicauda	29					0.130	0.030							0.630	0.330											GFAAS	(41)
Ghost shrimp, M. indica	16					0.280	0.048							0.090	0.031											GFAAS	(41)
Ghost shrimp, P. bouvieri	23					0.210	0.020							1.026	0.420											GFAAS	(41)
Ghost shrimp, C. typa	4					0.042	0.010							0.020	0.007											GFAAS	(41)
Ghost shrimp, N. calmani	25					0.407	0.050							0.400	0.080											GFAAS	(41)
Penaeus semisulcatus	60	0.013	0.002							0.082	0.019															Perkin Elmer Model 4100 atomic absorption spectrometer	(42)
Panulirus homarus	60	0.009	0.002			0.251	0.070			0.049	0.009			0.629	0.169											Perkin Elmer Model 4100 atomic absorption spectrometer	(43)
Metapenaeus affinis	95	1.554	0.281	1.355	1.754	14.000				0.053	0.002	0.048	0.055	0.326	0.103	0.252	0.399	0.124	0.059	0.082	0.166	20.050	3.180	17.800	22.300	ICP-MS, Agilent 7700, USA	(44)
Penaeus semisulcatus	62	0.656	0.150	0.550	0.762	14.000				0.160	0.069	0.111	0.208	0.443	0.019	0.420	0.462	0.132	0.042	0.103	0.162	34.150	7.000	29.200	39.100	ICP-MS, Agilent 7700, USA	(44)

Table 1. Continued.

		Inorganic As				Cd				Methyl-Hg				Pb				Ni				Cu					
Species	**Sample size**	**Mean**	**sd**	**min**	**max**	**Mean**	**sd**	**min**	**max**	**Mean**	**sd**	**min**	**max**	**Mean**	**sd**	**min**	**max**	**Mean**	**sd**	**min**	**max**	**Mean**	**sd**	**min**	**max**	**Method of detection**	**Ref.**
Metapenaeus affinis	151	0.143	0.013	0.122	0.163	0.080				0.032	0.008	0.025	0.042	1.604	1.145	0.389	2.663	0.225	0.082	0.132	0.277	16.330	0.580	16.000	17.000	ICP-MS & FIMS	(45)
Penaeus semisulcatus	103	0.114	0.017	0.094	0.126	0.080				0.109	0.063	0.038	0.158	1.340	0.756	0.491	1.945	0.168	0.038	0.126	0.202	25.670	3.060	23.000	29.000	ICP-MS & FIMS	(45)
Metapenaeus affinis	80					0.027	0.001							0.032	0.001							10.000	0.060			ICP- MS, Elan 9000, Perkin Elmer, USA	(46)
Metapenaeus affinis	NM					0.021	0.001							0.025	0.001							3.000	0.030			ICP- MS, Elan 9000, Perkin Elmer, USA	(46)
Metapenaeus affinis	NM					0.021	0.002							0.017	0.001							5.500	0.090			ICP- MS, Elan 9000, Perkin Elmer, USA	(46)
Metapenaeus affinis	NM													0.002	0.001							1.100	0.040			ICP- MS, Elan 9000, Perkin Elmer, USA	(46)
Penaeus merguiensis	180													0.021	0.006			1.283	0.029							HR-ICP-MS	(47)
Penaeus semisulcatus	40					0.573	0.339	0.007	1.020													11.224	2.878	7.430	21.020	ICP-AES; Philips/Pye Unicam Model PU 7000 & ICP-MS; VG PlasmaQuad 3-VG Elemental	(36)
Penaeus semisulcatus	40					0.191	0.274	0.001	1.210													3.384	0.881	1.290	5.460	ICP-AES; Philips/Pye Unicam Model PU 7000 & ICP-MS; VG PlasmaQuad 3-VG Elemental	(36)
Penaeus merguiensis	40					0.573	0.422	0.140	2.790													22.232	13.237	6.460	83.480	ICP-AES; Philips/Pye Unicam Model PU 7000 & ICP-MS; VG PlasmaQuad 3-VG Elemental	(36)
Penaeus merguiensis	40					0.418	0.299	0.010	0.890													13.354	5.102	4.060	28.430	ICP-AES; Philips/Pye Unicam Model PU 7000 & ICP-MS; VG PlasmaQuad 3-VG Elemental	(36)
Penaeus merguiensis	40					0.076	0.051	0.010	0.180													4.873	3.671	1.420	23.520	ICP-AES; Philips/Pye Unicam Model PU 7000 & ICP-MS; VG PlasmaQuad 3-VG Elemental	(36)
Penaeus semisulcatus	60	0.013	0.002							0.082	0.017															Perkin Elmer Model 4100 atomic absorption spectrometer	(42)

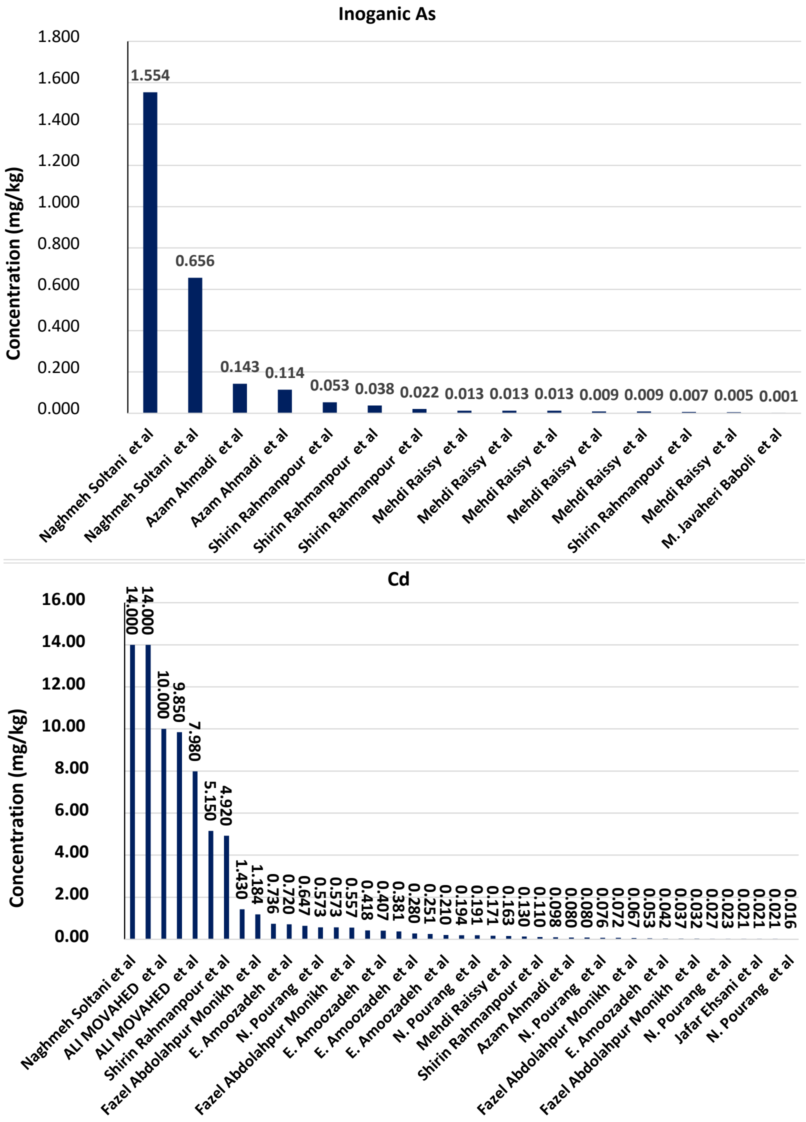

Figure 2. Concentrations of inorganic As and Cd in shrimp in the Persian Gulf

the EU. Compared to all studies, about 67% exceeded the MPL of the EU (61). Mercury is one of the rare elements, and 75-90% of the total mercury in fish is found in the dangerous organic form of methylmercury (58). Mercury in large quantities in the sediments of Khuzestan province, which serve as a trap for PTEs, is thought to cause the biological accumulation of mercury in aquatic ecosystems. Regarding differences in environmental and biological factors, PTEs in various ecosystems exhibit distinct accumulation patterns, even when similar species (62). Comparing the Kalogeropoulos et al. study, Hg levels (<0.008–0.18 mg/kg) in raw Mediterranean finfish in Greece appear to be noticeably lower than thos(63).

The highest concentration of Pb (4.83 mg/kg) was observed in the Abdolahpour et al. study (Figure 3), which was much higher than the MPLs set by the Codex Alimentarius Commission (WHO/FAO 2019) (0.300 mg/kg) (64). Approximately 36% of studies reported Pb concentrations within the WHO/FAO range. This result is consistent with the results of research by Herliwati et al. (2022), which revealed substantial Pb contamination (3.150 mg/kg) in samples taken from the Barito River estuary in Indonesia, indicating the accumulation of heavy metals from the water of the area to the sediments and finally to the shrimp (65). Pb levels in muscles, exoskeleton, and gills of the prawn *Penaeus semisulcatus* in the study by El Gendy et al. (2015) were 2.33, 17.00, and 21.33 ppm, respectively (66). One of the reasons for the increase in Pb levels in seawater may be the provision of sailing and shipping services between Ports and Islands in the region (67). Lead is an unnecessary element that is very toxic and harmful, even in small amounts. It can lead to neurotoxicity, kidney toxicity, and other negative consequences, which can negatively affect human health if consumed in terms of accumulation in the tissues of aquatic organisms (58). It may harm human health if taken, due to the accumulation in the tissues of aquatic species. Pb may cause cognitive disabilities, renal damage,

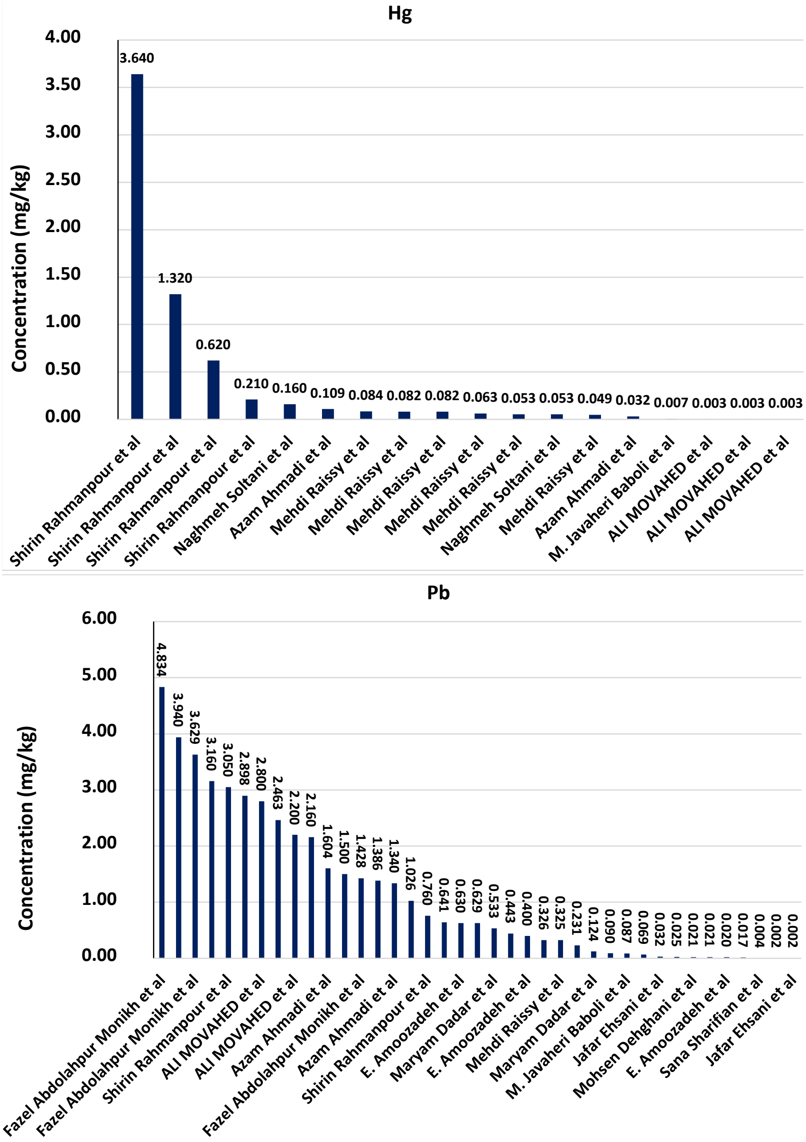

Figure 3. Concentrations of methyl Hg and Pb in shrimp in the Persian Gulf

Table 2. Percentage (%) of studies with THQ higher than one value and CR due to inorganic arsenic higher than 1E10-4 value

	THQ						CR
	Methyl Hg	**Cd**	**Inorganic As**	**Pb**	**Ni**	**Cu**	**As**
Adults	0	4.6	0	0	0	0	0
Children	11.11	16.27	6.6	0	14.81	0	0

Table 3. Mean THQ in adults and children due to heavy metals in shrimp in the Persian Gulf

	Methyl Hg	Cd	Inorganic As	Pb	Ni	Cu
Adults	0.2750	0.1330	0.0440	0.0240	0.0760	0.034
Children	1.2840	0.6210	0.2070	0.1120	0.3520	0.159

stunted development in children, and neurotoxicity. Thus, high amounts can cause death or permanent damage to the central nervous system, brain, and kidneys (54,58).

The Ni levels detected in all studies, except for the study by Rahmanpour et al which can be attributed to oil pollution in the region, were below the allowable limit of 70 mg kg^{-1} (68). Nevertheless, in 14% of studies, the Cu content exceeded the FAO permissible limit of 30 mg kg^{-1} (wet weight) (69). Suami et al. (2019) showed that the concentrations of Ni in shrimp from the Atlantic Coast varied between < LD to 0.23 mg kg^{-1}. Additionally, Copper contents ranged from 16.01 to 60.46

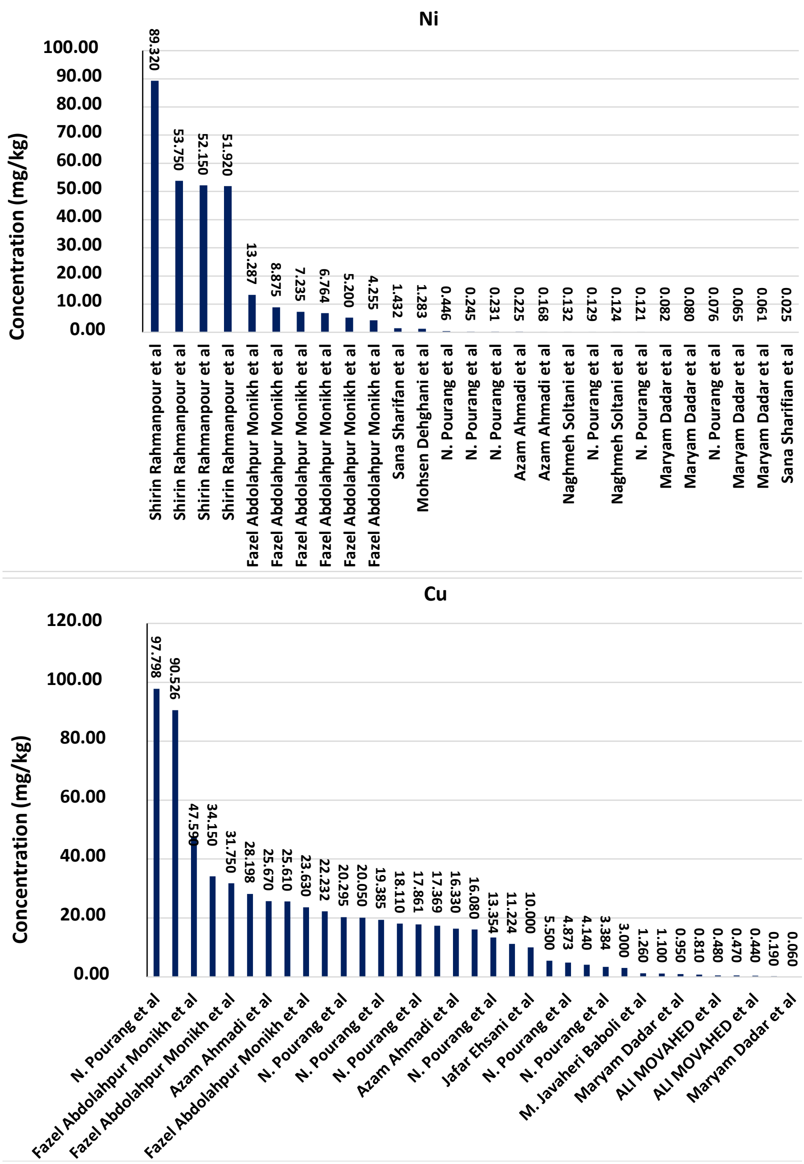

Figure 4. Concentrations of Ni and Cu in shrimp in the Persian Gulf

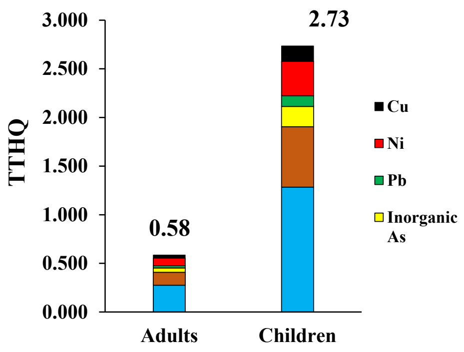

Figure 5. TTHQ in adults and children due to heavy metals in shrimp in the Persian Gulf

mg kg^{1} (70). Ezemonye et al. (2019) reported that Ni and Cu had mean values of 53.57 and 60.83 mg/kg in shrimp (*Macrobrachium macrobrachion*). Cu may have entered the water body through surface runoff and destruction of abandoned vessels near the coastlines adjacent to petrochemical fields (71). These values were lower than shrimps present in the Persian Gulf.

Copper is a significant and essential metal in cell metabolism, growth, and survival. As a result, if relatively large amounts of this metal are detected in tissues, it is necessary (72). Excessive consumption of copper can lead to kidney and liver damage, vomiting, and gastrointestinal distress (58,70,73). Food is the main source of exposure of the general population to Ni (70). Although Ni is considered an essential heavy metal, it can be toxic to humans in large amounts. One of the primary sources of high amounts of nickel is the presence of petroleum substances, such as gasoline, engine oil, and diesel fuel, that leak from motorboats on the seashore. The effects of nickel on health include hair loss and worsening of eczema, as well as adverse effects on the kidneys, cardiovascular system, immune system, and reproductive system (54).

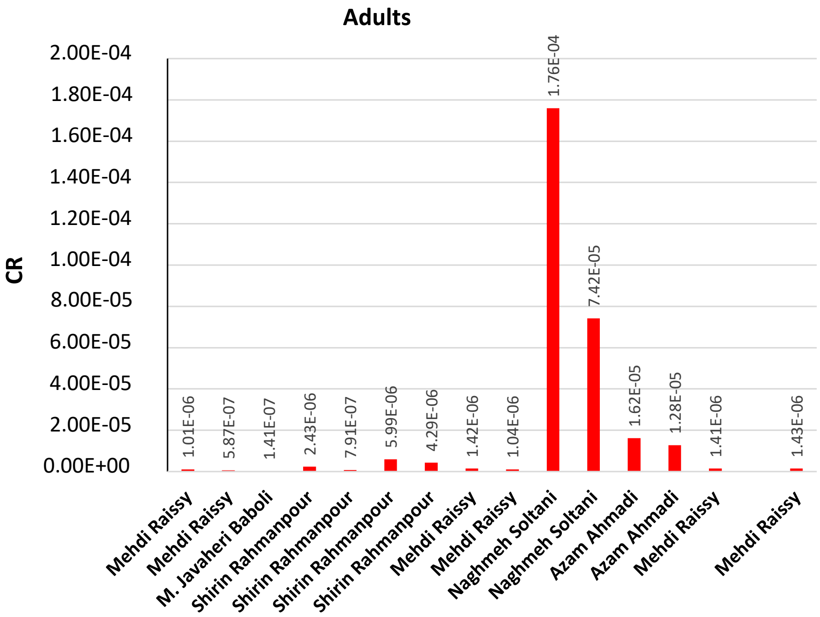

Figure 6. Mean cancer risks (CR) in adults and children due to inorganic As in shrimp of *the Persian Gulf*

Health risk assessment

Microbial and chemical contamination in food can have detrimental effects on consumer health (25). The non-carcinogenic and carcinogenic effects on humans can be due to their toxic nature, stable properties, and the accumulation of toxic metals due to their biological accumulation properties. As mentioned earlier, if the THQ > 1, it implies the non-carcinogenic health threats for the exposed population (74)

As can be seen, the non-cancer risk caused by cadmium is more evident in the studies, which can be in terms of relatively high concentration and the very high toxicity of cadmium. The percentage of THQ > 1 in children was higher than in adults, likely due to their lower body weight, which may lead them to take risks. These findings imply that children's and adults' long-term ingestion of mercury and cadmium from shrimp poses the most significant non-cancer health hazards because of their increased toxicity. Our findings align with those of Nyarko et al, who also reported elevated As and Cd levels in fish from the Gulf of Guinea. The estimated THQ of As for *P. notialis* (Southern pink shrimp) in both children and adolescents, as well as the case of Cd in children, exceeded 1 (52). However, Kalogeropoulos et al reported that THQ for Pb, Cd, and Hg in Pan-fried shrimp had no health risks to consumers (63). TTHQ for children was higher than 1, indicating a potential risk to children's health from consuming shrimp. Ezemonye et al. found a similar TTHQ (above 1) in their study for shrimp consumption (*Macrobrachium macrobrachion*) (71). However, the study by Ahmed et al showed TTHQ levels below the permissible level of 1 for shrimp (*Macrobrachium rosenbergii* and *Metapenaeus monoceros*) (75). This difference can be attributed to different concentrations of elements in shrimp and their different per capita consumption. Usually, Cancer Risks (CR) higher than 1E-4 are considered considerable (76). These results showed that the CR values of As were not considerable for adults and children. These results are based on the research by Ahmed et al which showed that the CR was between 10^{-7} and 10^{-5} for all shrimp samples (75). Although children are lighter than adults, adults still have a higher chance of developing cancer because children's contact time with the environment is estimated to last 70 years, making children's carcinogenesis risk significantly lower.

Conclusion

This study attempted to collect studies related to the concentration of PTEs in shrimp consumed in Iran and estimate the potential health risk. The concentration of PTEs in shrimp was observed to be different. In some studies, the concentrations exceeded the standard limits, while in others, they were below them. This difference in concentration is attributed to variations in shrimp genus and species, sampling location, and sampling season. According to the health risk assessment, Methyl Hg and Cd may pose a larger non-carcinogenic risk than other PTEs. On the other hand, the overall non-carcinogenic risk demonstrated that youngsters may be exposed to a high level of danger. Thus, the carcinogenic risk of inorganic As was acceptable (CR < 1E-4) in adults and children. In future studies, the difference in the concentration of PTEs in the Persian Gulf and Sea of Oman shrimps and other pollutants, such as antibiotics, pesticides, and PAHs in shrimp tissue, can be considered.

Acknowledgements

We want to thank Masume Abedinejad (Molecular

Medicine Research Center, Hormozgan University of Medical Sciences, Bandar Abbas, Iran) for her technical assistance.

Authors' contributions

Conceptualization: Yadolah Fakhri, Zohreh Kamari
Data curation: Yadolah Fakhri, Zohreh Kamari
Formal Analysis: Yadolah Fakhri
Funding acquisition: Nayera Naimi
Investigation: Yadolah Fakhri
Methodology: Yadolah Fakhri, Zohreh Kamari
Project administration: Yadolah Fakhri, Abotaleb Bay
Resources: Yadolah Fakhri and Zohreh Kamari
Software: Yadolah Fakhri
Supervision: Yadolah Fakhri
Validation: Yadolah Fakhri, Abotaleb Bay
Visualization: Zohreh Kamari
Writing – original draft: Yadolah Fakhri, Zohreh Kamari, Maryam Sarkhosh, Nayera Naimi, Abotaleb Bay
Writing – review & editing: Yadolah Fakhri, Zohreh Kamari, Maryam Sarkhosh, Nayera Naimi, Abotaleb Bay

Competing interests

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.

Ethical issues

All methods were carried out in accordance with relevant guidelines and regulations, and all participants have read and declared their consent in accordance with relevant guidelines. Written informed consent was obtained from the participants before data collection.

Funding

This study was self-funded by the authors and received no external financial support from any funding organization.

References

1. Mahino F, Nazura U, Hossain MM. Heavy metal in aquatic ecosystem emphasizing its effect on tissue bioaccumulation and histopathology: a review. Jou of Environ Scien and Techno 2014;7(1):1-15. doi:10.3923/jest.2014.1.15
2. Ortiz-Moriano MP, Machado-Schiaffino G, Garcia-Vazquez E, Ardura A. Traceability challenges and heavy metal risks in commercial shrimp and prawn. Food Control 2024;157:110193. doi:10.1016/j.foodcont.2023.110193
3. Sarkar T, Alam MM, Parvin N, Fardous Z, Chowdhury AZ, Hossain S, et al. Assessment of heavy metals contamination and human health risk in shrimp collected from different farms and rivers at Khulna-Satkhira region, Bangladesh. Toxicology Reports. 2016;3:346-50.https://doi.org/10.1016/j.toxrep.2016.03.003.
4. Jaishankar M, Tseten T, Anbalagan N, Mathew BB, Beeregowda KN. Toxicity, mechanism and health effects of some heavy metals. Interdiscip Toxicol 2014;7(2):60–72. doi:10.2478/intox-2014-0009
5. Fu Z, Xi S. The effects of heavy metals on human metabolism. Toxicol Mech Methods 2020;30(3):167–76. doi:10.1080/15376516.2019.1701594
6. Mahu E, Nyarko E, Hulme S, Swarzenski P, Asiedu DK, Coale KH. Geochronology and historical deposition of trace metals in three tropical estuaries in the Gulf of Guinea. Estuarine, Coastal and Shelf Science 2016;177:31–40. doi:10.1016/j.ecss.2016.05.007
7. Adokoh CK, Obodai EA, Essumang DK, Serfor-Armah Y, Nyarko BJ, Asabere-Ameyaw A. Statistical evaluation of environmental contamination, distribution and source assessment of heavy metals (aluminum, arsenic, cadmium, and mercury) in some lagoons and an estuary along the coastal belt of Ghana. Arch Environ Contam Toxicol 2011;61(3):389–400. doi:10.1007/s00244-011-9643-5
8. Wang H, Teng M, Liu P, Zhao M, Wang S, Hu J, et al. Selection Signatures of Pacific White Shrimp Litopenaeus vannamei Revealed by Whole-Genome Resequencing Analysis. Frontiers in Marine Science 2022;9:844597. doi:10.3389/fmars.2022.844597
9. Delgado E, Valles-Rosales DJ, Flores NC, Reyes-Jáquez D. Evaluation of fish oil content and cottonseed meal with ultralow gossypol content on the functional properties of an extruded shrimp feed. Aquaculture Reports 2021;19:100588. doi:10.1016/j.aqrep.2021.100588
10. Liu B, Lv L, An M, Wang T, Li M, Yu Y. Heavy metals in marine food web from Laizhou Bay, China: Levels, trophic magnification, and health risk assessment. Science of The Total Environment. 2022;841:156818.https://doi.org/10.1016/j.scitotenv.2022.156818
11. Hayat M, Khan B, Iqbal J, Ahmad MN, Khan AA, Haq TU, Aziz T, Albekairi TH. Evidence of microplastic contamination in the food chain: an assessment of their presence in the gastrointestinal tract of native fish. Italian Journal of Food Science 2024;36(3):40-49. doi:10.15586/ijfs.v36i3.2532
12. Hossain MB, Bhuiyan NZ, Kasem A, Hossain MK, Sultana S, Nur A-AU, et al. Heavy metals in four marine fish and shrimp species from a subtropical coastal area: accumulation and consumer health risk assessment. Biology. 2022;11(12):1780. https://doi.org/10.3390/biology11121780
13. Yu B, Wang X, Dong KF, Xiao G, Ma D. Heavy metal concentrations in aquatic organisms (fishes, shrimp and crabs) and health risk assessment in China. Mar Pollut Bull 2020;159:111505. doi:10.1016/j.marpolbul.2020.111505
14. Sharifian S, Mortazavi MS, Nozar SLM. Health risk assessment of commercial fish and shrimp from the North Persian Gulf. J Trace Elem Med Biol 2022;72:127000. doi:10.1016/j.jtemb.2022.127000
15. Fakhri Y, Mohseni-Bandpei A, Oliveri Conti G, Ferrante M, Cristaldi A, Jeihooni AK, et al. Systematic review and health risk assessment of arsenic and lead in the fished shrimps from the Persian gulf. Food Chem Toxicol 2018;113:278–86. doi:10.1016/j.fct.2018.01.046
16. Loghmani M, Tootooni MM, Sharifian S. Risk assessment of trace element accumulation in two species of edible commercial fish Scomberoides commersonnianus and Cynoglossus arel from the northern waters of the Oman Sea. Mar Pollut Bull 2022;174:113201. doi:10.1016/j.marpolbul.2021.113201
17. Al-Yamani FY, Bishop JM, Al-Rifaie K, Ismail W. The effects of the river diversion, Mesopotamian Marsh drainage and restoration, and river damming on the marine environment of the northwestern Arabian Gulf. Aquatic Ecosystem Health & Management 2007;10(3):277–89. doi:10.1080/14634980701512384
18. Pourang N, Amini G. Distribution of Trace Elements in Tissues of Two Shrimp Species from Persian Gulf and Effects of Storage Temperature on Elements Transportation.

Water, Air, and Soil Pollution 2001;129(1):229–43. doi:10.1023/A:1010371713798
19. Pourang N, Dennis JH. Distribution of trace elements in tissues of two shrimp species from the Persian Gulf and roles of metallothionein in their redistribution. Environ Int 2005;31(3):325–41. doi:10.1016/j.envint.2004.08.003
20. Dadar M, Peyghan R, Memari HR. Evaluation of the bioaccumulation of heavy metals in white shrimp (Litopenaeus vannamei) along the Persian Gulf coast. Bull Environ Contam Toxicol 2014;93(3):339–43. doi:10.1007/s00128-014-1334-2
21. Sharifian S, Taherizadeh MR, Dehghani M, Nabavi M. Food safety of the green tiger shrimp Penaeus semisulcatus from the Persian Gulf. Environ Sci Pollut Res Int 2022;29(16):23861–70. doi:10.1007/s11356-021-17620-1
22. Rahmanpour S, Ghorghani NF, Lotfi Ashtiyani SM. Heavy metal in water and aquatic organisms from different intertidal ecosystems, Persian Gulf. Environ Monit Assess 2014;186(9):5401–9. doi:10.1007/s10661-014-3788-4
23. Moher D, Shamseer L, Clarke M, Ghersi D, Liberati A, Petticrew M, et al. Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015 statement. Syst Rev 2015;4(1):1. doi:10.1186/2046-4053-4-1
24. Bahardoust M, Dehkharghani MZ, Ebrahimi P, Najafirashed M, Mousavi S, Haghmoradi M, et al. Effect of ABO blood group on postoperative overall survival and recurrence-free survival rate in patients with hepatocellular carcinoma after hepatectomy: a multi-center retrospective cohort study. BMC Surg 2023;23(1):324. doi:10.1186/s12893-023-02236-8
25. Bahardoust M, Mousavi S, Dehkharghani MZ, Arab M, Rashidi H, Gorgani H, et al. Association of Tramadol Versus Codeine Prescriptions with all-cause mortality and cardiovascular diseases among patients with osteoarthritis: a systematic review and meta-analysis of propensity score-matched population-based cohort studies. Adv Rheumatol 2024;64(1):80. doi:10.1186/s42358-024-00417-4
26. Tavakoli Pirzaman A, Sepidarkish M, Alizadeh F, Al-Obidy S, Ebrahimi P, Kianifard N, et al. Prevalence of human Schistosoma mansoni infection in endemic regions (2010-2024): a systematic review and meta-analysis. EClinicalMedicine 2024;77:102855. doi:10.1016/j.eclinm.2024.102855
27. Vu CT, Lin C, Yeh G, Villanueva MC. Bioaccumulation and potential sources of heavy metal contamination in fish species in Taiwan: assessment and possible human health implications. Environ Sci Pollut Res Int 2017;24(23):19422–34. doi:10.1007/s11356-017-9590-4
28. Fakhri Y, Sarafraz M. Refer to Evaluation of Possible Human Health Risk of Heavy Metals from the Consumption of Two Marine Fish Species Tenualosa ilisha and Dorosoma cepedianum by Ullah et al. (2019)*. Biological Trace Element Research 2021;199(3):1090-1. doi:10.1007/s12011-020-02198-5
29. Fakhri Y, Mousavi Khaneghah A. Refer to the investigation of toxic elements in Carassius gibelio and Sinanodonta woodiana and its health risk to humans by Arumugam et al. (2020). Environmental Science and Pollution Research 2020;27(24):30901–2. doi:10.1007/s11356-020-09940-5
30. Head of Iran Fisheries Organization. Fish Per capita consumption in Iran. Head of Iran Fisheries Organization. Accessed 2019. Available from:https://www.tehrantimes.com/news/449572/Fish-consumption-per-capita-stands-at-13kg-in-Iran. 2019.
31. Fan Y, Schneider KR, Sarnoski PJ. Determining spoilage of whiteleg shrimp (Litopanaeus vannemei) during refrigerated storage using colorimetric strips. Food Chem X 2022;14:100263. doi:10.1016/j.fochx.2022.100263
32. United States Environmental Protection Agency (EPA). Reference Dose (RfD): Description and Use in Health Risk Assessments. United States Environmental Protection Agency. Accessed 2021. Available from: https://www.epa.gov/iris/reference-dose-rfd-description-and-use-health-risk-assessments. 2021.
33. Ghane ET, Poormohammadi A, Khazaei S, Mehri F. Concentration of Potentially Toxic Elements in Vegetable Oils and Health Risk Assessment: a Systematic Review and Meta-analysis. Biol Trace Elem Res 2022;200(1):437–46. doi:10.1007/s12011-021-02645-x
34. Raissy M. Assessment of health risk from heavy metal contamination of shellfish from the Persian Gulf. Environ Monit Assess 2016;188(1):55. doi:10.1007/s10661-015-5071-8
35. Baboli MJ, Velayatzadeh M, Branch A. Determination of heavy metals and trace elements in the muscles of marine shrimp, Fenneropenaeus Merguiensis from Persian Gulf, Iran. Journal of animal and plant sciences. 2013;23(3):786-91
36. Salam MA, Dayal SR, Siddiqua SA, Muhib MI, Bhowmik S, Kabir MM, et al. Risk assessment of heavy metals in marine fish and seafood from Kedah and Selangor coastal regions of Malaysia: a high-risk health concern for consumers. Environ Sci Pollut Res Int 2021;28(39):55166–75. doi:10.1007/s11356-021-14701-z
37. Mok JS, Kwon JY, Son KT, Choi WS, Kang SR, Ha NY, et al. Contents and Risk Assessment of Heavy Metals in Marine Invertebrates from Korean Coastal Fish Markets. Journal of Food Protection. 2014;77(6):1022-30.https://doi.org/10.4315/0362-028X.JFP-13-485.
38. Wu X-Y, Yang Y-F. Heavy metal (Pb, Co, Cd, Cr, Cu, Fe, Mn and Zn) concentrations in harvest-size white shrimp Litopenaeus vannamei tissues from aquaculture and wild source. Journal of Food Composition and Analysis. 2011;24(1):62-5.https://doi.org/10.1016/j.jfca.2010.03.030
39. Ray S, Vashishth R. From water to plate: Reviewing the bioaccumulation of heavy metals in fish and unraveling human health risks in the food chain. Emerging Contaminants. 2024;10(4):100358.https://doi.org/10.1016/j.emcon.2024.100358
40. Monikh FA, Maryamabadi A, Savari A, Ghanemi K. Heavy metals' concentration in sediment, shrimp and two fish species from the northwest Persian Gulf. Toxicol Ind Health 2015;31(6):554–65. doi:10.1177/0748233713475498
41. Movahed A, Dehghan AV, Haji Hosseini R, Akbarzadeh S, Zendehboudi AA, Nafisi Behabadi M, et al. Evaluation of heavy metals in the tissues of different species of shrimps collected from coastal waters of Bushehr, Persian Gulf. Iranian South Medical Journal 2013;16(2):100-9.
42. Amoozadeh E, Malek M, Rashidinejad R, Nabavi S, Karbassi M, Ghayoumi R, et al. Marine organisms as heavy metal bioindicators in the Persian Gulf and the Gulf of Oman. Environ Sci Pollut Res Int 2014;21(3):2386–95. doi:10.1007/s11356-013-1890-8
43. Raissy M, Rahimi E, Nadeali V, Ansari M, Shakerian A. Mercury and arsenic in green tiger shrimp from the Persian Gulf. Toxicol Ind Health 2014;30(3):206–10. doi:10.1177/0748233712452608
44. Raissy M, Ansari M, Rahimi E. Mercury, arsenic, cadmium and lead in lobster (Panulirus homarus) from the Persian Gulf. Toxicol Ind Health 2011;27(7):655–9. doi:10.1177/0748233710395346
45. Soltani N, Moore F, Keshavarzi B, Sorooshian A, Javid R. Potentially toxic elements (PTEs) and polycyclic aromatic hydrocarbons (PAHs) in fish and prawn in the Persian Gulf, Iran. Ecotoxicol Environ Saf 2019;173:251–65. doi:10.1016/j.ecoenv.2019.02.005.

46. Ahmadi A, Moore F, Keshavarzi B, Soltani N, Sorooshian A. Potentially toxic elements and microplastics in muscle tissues of different marine species from the Persian Gulf: Levels, associated risks, and trophic transfer. Mar Pollut Bull 2022;175:113283. doi:10.1016/j.marpolbul.2021.113283
47. Ehsani J, Roomiani L. Study bioaccumulation of heavy metals (Zn, Cu, Cd, Pb) in metapenaeus affinis in bahrekan, west-north of persian gulf. FAO AGRIS - International System for Agricultural Science and Technology 2015. Available from: https://agris.fao.org/search/ar/records/66743f4eeb5a381a3380fbc9
48. Dehghani M, Sharifian S, Taherizadeh MR, Nabavi M. Tracing the heavy metals zinc, lead and nickel in banana shrimp (Penaeus merguiensis) from the Persian Gulf and human health risk assessment. Environ Sci Pollut Res Int 2021;28(29):38817–28. doi:10.1007/s11356-021-13063-w
49. FSANZ (Food Standards Australia and New Zealand) Australia New Zealand Food Standards Code S, contaminants and natural toxicants. 2013. Avaiable from: https://faolex.fao.org/docs/pdf/nze208919.pdf
50. Commission of the European Communities. Commission regulation (EC) no. 2021/1323 of 10 August 2021 aRENarmlo; 2021. Available from: https://eur-lex.europa.eu/eli/reg/2021/694/oj/eng
51. Yang C, Zhang Z, Liu Y, Shan B, Yu W, Li H, et al. Heavy metal pollution and stable isotope ratios (δ(13)C and δ(15) N) in marine organisms from the Northern Beibu Gulf, South China Sea. Mar Pollut Bull 2021;166:112230. doi:10.1016/j.marpolbul.2021.112230
52. Safahieh A, Monikh FA, Savari A. Heavy metals contamination in sediment and sole fish (Euryglossa orientalis) from Musa estuary (Persian Gulf). World Journal of Fish and Marine Sciences 2011;3(4):290–7
53. Nyarko E, Boateng CM, Asamoah O, Edusei MO, Mahu E. Potential human health risks associated with ingestion of heavy metals through fish consumption in the Gulf of Guinea. Toxicol Rep 2023;10:117–23. doi:10.1016/j.toxrep.2023.01.005
54. Olmedo P, Pla A, Hernández AF, Barbier F, Ayouni L, Gil F. Determination of toxic elements (mercury, cadmium, lead, tin and arsenic) in fish and shellfish samples. Risk assessment for the consumers. Environ Int 2013;59:63–72. doi:10.1016/j.envint.2013.05.005
55. Udoinyang EP, Anne G, Ekpo ND, Akpan II, Iwekumo A, Okon AO. Temporal Survey of Heavy Metal Loads in Surface Water, Sediments and Shrimps from Iko River Estuary, Eastern Obolo L.G.A, Nigeria. Asian Journal of Environment & Ecology 2022;17(1):63–77. doi:10.9734/ajee/2022/v17i130282
56. Khazali Majid. An Overview of Persian Gulf Environmental Pollutions. E3S Web of Conferences 2021;325:03013. doi:10.1051/e3sconf/202132503013
57. Ra WJ, Yoo HJ, Kim YH, Yun T, Soh B, Cho SY, et al. Heavy metal concentration according to shrimp species and organ specificity: Monitoring and human risk assessment. Mar Pollut Bull 2023;197:115761. doi:10.1016/j.marpolbul.2023.115761
58. Sultana S, Hossain MB, Choudhury TR, Yu J, Rana MS, Noman MA, et al. Ecological and Human Health Risk Assessment of Heavy Metals in Cultured Shrimp and Aquaculture Sludge. Toxics 2022;10(4). doi:10.3390/toxics10040175
59. Oudainia SE, Derbal F, Alik O, Bourehail N. Seasonal and Sexual Variations of Trace-Metal Elements (Cd, Pb, Cu, Zn, Fe) in Muscle and Eggs of the Deep-Water Pandalid Shrimp Plesionika edwardsii (Brandt 1851) from Northeast Algeria. Thalassas: An International Journal of Marine Sciences 2023;39(1):263–71. doi:10.1007/s41208-022-00512-7
60. Schaefer HR, Flannery BM, Crosby LM, Pouillot R, Farakos SMS, Van Doren JM, et al. Reassessment of the cadmium toxicological reference value for use in human health assessments of foods. Regulatory Toxicology and Pharmacology 2023;144:105487. doi:https://doi.org/10.1016/j.yrtph.2023.105487
61. Inaba T, Kobayashi E, Suwazono Y, Uetani M, Oishi M, Nakagawa H, et al. Estimation of cumulative cadmium intake causing Itai-itai disease. Toxicol Lett 2005;159(2):192–201. doi:10.1016/j.toxlet.2005.05.011
62. Yabanlı M, Şener İ, Yozukmaz A, Öner S, Yapıcı HH. Heavy metals in processed seafood products from Turkey: risk assessment for the consumers. Environ Sci Pollut Res Int 2021;28(38):53171–80. doi:10.1007/s11356-021-14569-z
63. Kalogeropoulos N, Karavoltsos S, Sakellari A, Avramidou S, Dassenakis M, Scoullos M. Heavy metals in raw, fried and grilled Mediterranean finfish and shellfish. Food Chem Toxicol 2012;50(10):3702–8. doi:10.1016/j.fct.2012.07.012
64. Food and Agriculture Organization of the United Nations;World Health Organization. (2019). General standard for contaminants and toxins in food and feed CXS 193-1995. Avialble from: https://www.fao.org/fao-who-codexalimentarius/sh-%E2%80%8Eproxy/en/?lnk=1&url=https%253A%252F%252Fworkspace.fao.org%252Fsites%252Fcodex%252Fstandards%252FCXS%2B193-1995%252FCXS_193e.pdf
65. Herliwati H, Rahman M, Hidayat A, Amri U, Sumantri I. The Occurrences of Heavy Metals in Water, Sediment and Wild Shrimps Caught from Barito Estuary, South Kalimantan, Indonesia. HAYATI Journal of Biosciences 2022;29(5):643–7. doi:10.4308/hjb.29.5.643-647
66. El Gendy A, Farraj S, Hedeny M. Heavy Metal Concentrations in Tissues of the Shrimp Penaeus semisulcatus (De Haan, 1844) From Jazan, Southern Red Sea Coast of Saudi Arabia. Pakistan Journal of Zoology 2015;47(3):671–7.
67. Alnashiri HM. A Brief Review on Heavy Metal Bioaccumulation Studies from Red Sea. Adsorption Science & Technology 2022;2022:6201299. doi:10.1155/2022/6201299
68. US FDA bFaDAGDfNiSDPFCOoS, Washington, D.C. Food and Drug Administration Guidance Document for Nickel in Shellfish DHHS/PHS/FDA/CFSAN/Office of Seafood, Washington, DC. 1993b.Abailable from: https://www.ahajournals.org/doi/full/10.1161/CIRCULATIONAHA.111.028381
69. FAO CoLLfHSiFaFP, pp. 5–100. FAO Fishery Circular No. 464. Compilation of Legal Limits for Hazardous Substances in Fish and Fishery Products,. FAO Fishe Circu 1983(464):5–100. 65474474555/56651440. Available from: https://www.fao.org/inland-fisheries/topic/detail/ar/c/1150083/
70. Suami RB, Al Salah DMM, Kabala CD, Otamonga JP, Mulaji CK, Mpiana PT, et al. Assessment of metal concentrations in oysters and shrimp from Atlantic Coast of the Democratic Republic of the Congo. Heliyon 2019;5(12):e03049. doi:10.1016/j.heliyon.2019.e03049
71. Ezemonye LI, Adebayo PO, Enuneku AA, Tongo I, Ogbomida E. Potential health risk consequences of heavy metal concentrations in surface water, shrimp (Macrobrachium macrobrachion) and fish (Brycinus longipinnis) from Benin River, Nigeria. Toxicol Rep 2019;6:1–9. doi:10.1016/j.toxrep.2018.11.010
72. Araya M, Olivares M, Pizarro F. Copper in human health. International Journal of Environment and Health 2007;1(4):608–20. doi:10.1504/IJENVH.2007.018578
73. Ewool J, Sakyi NAA, Aryee NAT, Asante J, Acquah NAA, Blankson ER. Bioaccumulation of heavy metals in fish and shrimp from the Atlantic Ocean off the coast of Accra, Ghana, and their associated health risks. Marine Pollution Bulletin. 2025;221:118524.https://doi.org/10.1016/j.marpolbul.2025.118524

74. Fakhri Y, Nematollahi A, Abdi-Moghadam Z, Daraei H, Ghasemi SM, Thai VN. Concentration of Potentially Harmful Elements (PHEs) in Trout Fillet (Rainbow and Brown) Fish: a Global Systematic Review and Meta-analysis and Health Risk Assessment. Biol Trace Elem Res 2021;199(8):3089–101. doi:10.1007/s12011-020-02419-x
75. Ahmed S, Uddin MF, Hossain MS, Jubair A, Islam MN, Rahman M. Heavy metals contamination in shrimp and crab from southwest regions in Bangladesh: Possible health risk assessment. Toxicol Rep 2023;10:580–8. doi:10.1016/j.toxrep.2023.05.001
76. U.S. Environmental Protection Agency. Regional Screening Levels (RSLs) - Generic Tables. Accessed June 2017. Available from: https://www.epa.gov/risk/regional-screening-levels-rsls-generic-tables