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RESEARCH

Health Risk Assessment of Heavy Metals in Marine Fish Caught from the Northwest Persian Gulf

Solaleh Torabi[1] · Mohammad Gholizadeh[1] · Mahsa Yazarlo[2] · Zahra Riahi[3]

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Abstract
Marine fish may become contaminated as a result of environmental pollution including hazardous metals. Due to the presence of metalloids and toxic metals such as cadmium, lead, copper, and zinc in fish tissue, it may endanger health, considering the countless benefits of consuming fish, which can harm the human body if consumed in toxic amounts. Therefore, it is vital to monitor the concentration of metals in fish meat to ensure compliance with food safety regulations and protect the consumer. We considered the levels of Ni, Zn, Cu, Pb, and Cd in 60 marine fish samples (3 species) collected from coastal areas of the northwestern coast of the Persian Gulf and estimated their health risk. Mean concentrations of Ni, Zn, Cu, Pb, and Cd were 1.88 ± 0.07 µg/g, 27.16 ± 8.11 µg/g, 11.55 ± 4.12 µg/g, 14 ± 0.06 µg/g, and 0.19 ± 0.03 µg/g wet weight. Estimated average daily intakes (EDIs) for adults and children of Ni, Zn, Cu, Pb, and Cd were 0.89–4.15 µg/kg bw/day, 12.89–60.02 µg/kg bw/day, 5.47–25.53 µg/kg bw/day, 0.54–2.51 µg/kg bw/day, and 0.09–0.42 µg/kg bw/day. Our analysis revealed elevated levels of Ni and Pb in the fish samples, raising concerns about potential health hazards associated with their consumption. This study provides critical insights into heavy metal contamination in marine fish, highlighting the need for ongoing monitoring and proactive measures to ensure safe seafood consumption in the northwest Persian Gulf.

Keywords Fish · Heavy metals · Target hazard quotient · Risk assessment · Persian Gulf

Introduction

Fish is of interest to consumers due to its polyunsaturated fatty acids, vitamin B, high-quality protein, and other nutrients. However, with the rapid development of industry and urbanization in some estuaries and coastal areas, the problem of environmental pollution has become more serious. These pollutants can accumulate in the muscle tissues of marine organisms and bring potential health risks. In recent years, the association of heavy metals with environmental pollution has caused ecological concerns and severe environmental threats. Marine fish can absorb pollutants such as toxic metals indirectly through food and directly from the water.

For example, Esmaeilbeigi et al. [1] found the Pb with a mean level of 1.47 ± 0.33 (µg/g ww) in *Atropus atropos* from the Persian Gulf, Iran. Sadeghi et al. [2] observed the Ni with a mean level of 81.1 µg/g in *Otolithes ruber* from the Oman Sea, Iran. Keshavarzi et al. [3] described a range level of Cd (1.37–3.14 mg/kg) in *Anodontostoma chacunda* and *Cynoglossurs arel* from the Musa estuary Mahshahr harbor, Iran (Persian Gulf). Saadatmand et al. [4] found the level of Cu (8.62 mg/kg) in *Siganus javus* from the Persian Gulf. All these studies showed the possibility of heavy metal contamination in marine fish.

All ecosystems on earth exhibit metals and metalloids of natural or artificial origin [5, 6]. Both natural and artificial

✉ Mohammad Gholizadeh
Gholizade_mohammad@yahoo.com

Solaleh Torabi
solaleh.torabi1368@gmail.com

Mahsa Yazarlo
mahsayazarlo@gmail.com

Zahra Riahi
gh.model09@gmail.com

1 Department of Fisheries, Faculty of Agriculture and Natural Resources, Gonbad Kavous University, Gonbad Kavous, Iran

2 Department of Fisheries and Aquatic Sciences, Faculty of Fisheries and Environmental Sciences, Gorgan University of Agricultural Sciences and Natural Resources, Gorgan, Iran

3 Department of Biological Sciences, Faculty of Basic Sciences and Technical Engineering, Gonbad Kavous University, Gonbad Kavous, Iran

factors can introduce heavy metals into aquatic ecosystems [7]. Due to their high toxicity, bio-accumulation, long-term stability, and biomagnification, anthropogenically produced metals in marine environments severely threaten the food chain [1]. Over the past ten years, significant progress has been made in the identification of metal pollution sources, in the discovery of metal sinks, and in the decoding of pollution input chronologies. Significant progress has also been made in determining the biotoxicity of various natural and inorganic substances that humans have released into the environment.

Aquatic ecosystems, such as seas and coastlines, are vulnerable to various environmental pollutants, including those released by natural sources and those caused by human activity, such as heavy metals, organic and oil compounds, and herbicides. The most critical human-caused sources of heavy metals are irrigation with wastewater from cities and businesses, solid waste, hydrocarbon fuels, chemical fertilizers, and pesticides [8, 9]. Due to their toxicity, trace elements persist in the environment, contaminate food chains, and result in various health issues [7, 10].

While necessary for the development and growth of organisms, these materials are toxic and dangerous when used in excess. Living things are seriously threatened when exposed to trace elements in the environment regularly [2]. Fish species, mainly, are among the most significant marine species regarding their ecological and economic importance [11, 12]. Fish consumption has reportedly increased worldwide since 1990 [13]. To evaluate the potential health risk to consumers and the preservation of the marine environment, it is crucial to measure the concentration of trace elements (such as Hg, Pb, Cd, and As). The accumulation of heavy metals in the bodies of aquatic animals living in polluted marine environments has been the subject of several investigations [3]. Due to their resilience and bio-accumulation, reduced bio-degradability, and potential for biomagnification in the food chain, heavy metals are two assemblages of impurities in the sea environment [10].

Some heavy metals are essential to life as trace elements, but the biotoxic effects of many of them on human biochemistry are incredibly problematic. Therefore, it is necessary to thoroughly understand the factors, such as concentrations and oxidation states, that render them harmful and how biotoxicity occurs. Natural and manufactured sources, particularly mining and industrial operations and vehicle exhausts (for lead), are responsible for releasing these metals into the environment. Any metallic element with a moderately high density and is toxic or poisonous even at low concentrations is called a "heavy metal" [14].

The following substances are classified as heavy metals: lead (Pb), cadmium (Cd), zinc (Zn), arsenic (As), silver (Ag), copper (Cu), chromium (Cr), mercury (Hg), iron (Fe), and platinum group elements [15]. While Zn and Cu are among the essential metals for properly operating biological systems, Pb and Hg are generally regarded as the most critical pollution indicators. Through effective biomagnification in the food chain, mercury (Hg) accumulates in both aquatic systems and humans [16]. The term "pollutant" refers to any environmental substance that has unfavorable effects, degrades environmental welfare, decreases human well-being, and may finally result in death. Any substance in the environment with adverse effects that impair the environment's welfare lowers human well-being and may eventually cause death called a "pollutant." Since they cannot be degraded or destroyed, heavy metals are persistent environmental contaminants that are naturally present in the earth's crust. They are slightly ingested through food and the air, and over time, they bio-accumulate in the body [17]. Most of the time, there are no significant environmental or public health risks from heavy metals filtered through soil and rocks into aquatic systems. At least some anthropogenic sources, like mining, agriculture, and aquaculture, cause metal burdens to rise above natural levels [18].

Some heavy metals, including Zn, Fe, Mg, and Ca, have been described as essential to human biology and daily health. Others, however, have been shown to have no known biological significance for human physiology and biochemistry and can even be toxic at low concentrations (such as Pb, Cd, As, and methylated forms of Hg). Dietary intakes must be maintained within administrative limits, even for those of biological importance, because excesses can cause poison or toxicity [19]. Concern over the quality of food is growing in several global regions. The assurance has prompted studies on the toxicological effects of these elements in food that they are present. Due to their toxicity and accumulation by marine organisms, heavy metals are considered the most critical type of pollution in the aquatic environment [20]. Metal contamination in water systems typically takes the form of dissolved and suspended particles, which eventually settle and are absorbed by living things. Being at the top of the food chain and able to accumulate high concentrations of a few metals, fish is one of the crucial aquatic organisms in the food chain [21]. Depending on the level of development, age, and other physiological factors, metal distribution varies between fish species [16].

The Persian Gulf is regarded as one of the world's most significant closed aquatic ecosystems. It has been impacted by the growing population and industrialization of its bordering countries, and it has discovered a worrying situation due to the pollutants entering the water bodies in the Persian Gulf and the aquatic organisms that live there [22]. *Psettodes erumei*, *Sphyraena jello*, and *Sillago sihama* are a few indicator species that can be used to gauge the extent of pollution. The species, found in the northern parts of the Persian Gulf and valued for their marketability and consumer appeal, contribute significantly to the southern

Iranian fishing industry. Specialists in nutrition, medicine, and environmental sciences face a significant challenge in monitoring heavy metals because they do not decompose naturally through chemical or biological processes, unlike organic compounds [3, 22]. Based on this, the current study's objective is to measure heavy metals such as nickel, zinc, cadmium, copper, and lead in three commercial fish species of the Persian Gulf: *Psettodes erumei*, *Sphyraena jello*, and *Sillago sihama*. After determining the health risks associated with the metals, the study will then determine the maximum amounts that can be consumed.

Materials and Methods

Study Area and Sampling

In the spring of 2022, trawl nets were used to collect samples from the four coastal communities of Asaluyeh, Dayyer, Deylam, and Bandar Bushehr in the Bushehr province (Fig. 1, Table 1). Sixty aquatic specimens (20 of each species), *Psettodes erumei, Sphyraena jello*, and *Sillago sihama*, were studied after placing them in acid-washed plastics and frozen until analysis. In polyethylene bags, samples were returned to the Persian Gulf University lab and kept frozen (− 20 °C) until analysis.

Sample Analysis, Digestion, and Metal Analysis

In the tissues of the species, the pollution caused by high concentrations of zinc, lead, nickel, copper, and cadmium was examined. In the spring of 2022, in the province of Bushehr, sampling was done randomly among the fish caught and prepared for the market from a particular area of the pier. The samples were cleaned with distilled and city water, and the total length and weight were determined using a ruler and a scale, respectively, with an accuracy of 0.1 cm and 0.01 g. Following the biopsy, the muscle tissue was isolated and cleaned with distilled water.

A 50-ml Erlenmeyer flask was filled with 3 g fish muscle tissue wet weight. The samples were given a dose of 4 mg of nitric acid (65 percent), and they were then placed under the hood at room temperature for at least an hour to begin the initial digestion process. The samples were mixed with 1.5 ml of perchloric acid (70%) and then placed on a hot plate (sand bath) at 140 °C for 6 h to finish the digestion process. The samples were digested and then left to cool at room temperature. The samples were then diluted with deionized water to a volume of 25 ml, the solutions were filtered through Whatman filter paper (40 microns), and the samples were stored in a polyethylene container in a frigid environment (4°C) until analysis [23]. The level of heavy metals in fish muscle was determined using an ICP-OES instrument made by Liberty RL.

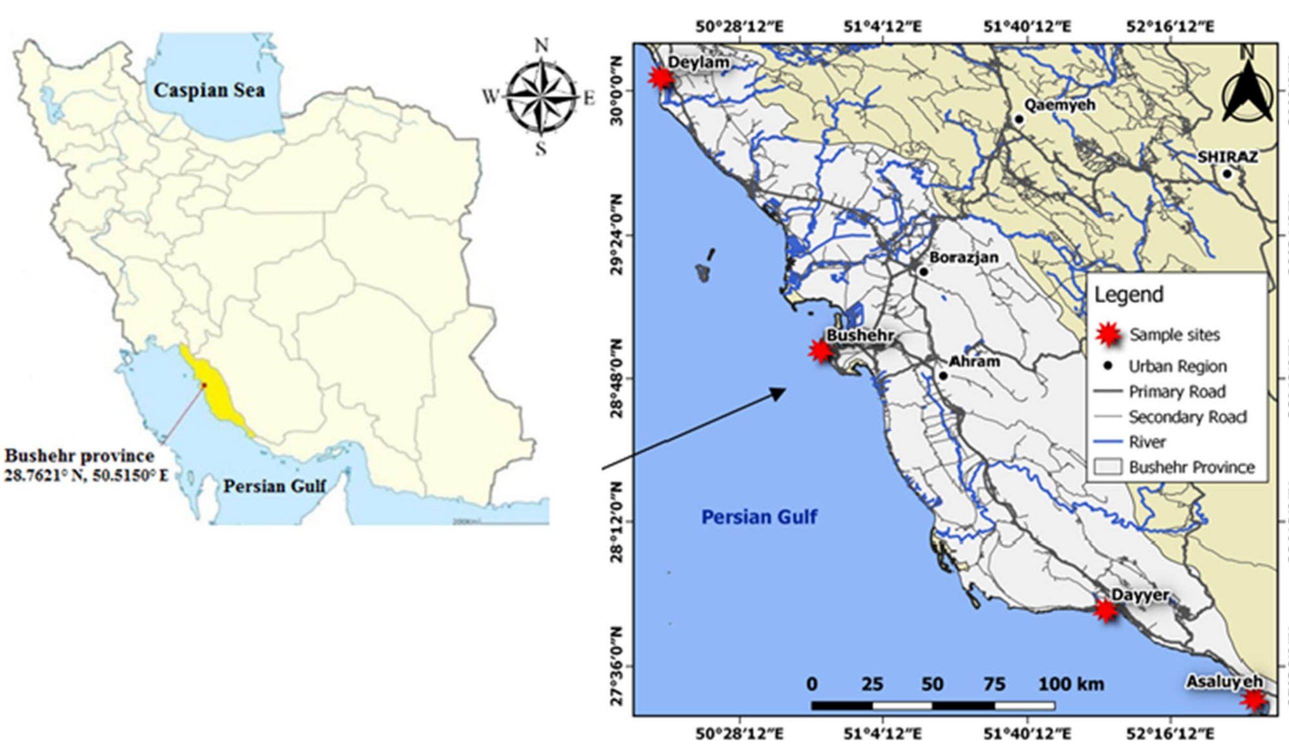

Fig. 1 Location map of the studied area (Iran, location of sampling stations in Bushehr province)

Table 1 Characteristics of sampling stations in Bushehr province

Site	Geographic position	Characteristics
Deylam	30°03′30″ N, 50°08′20″ E	Deylam port with a sandy beach with various coastal activities (tourism and fishing activities)
Bushehr	28°55′06″ N, 50°48′30″ E	The province's seat has high population density, a high rate of municipal sewage and the traffic of commercial and fishing vessels, no agricultural pollution, tourism activities, several swimming beaches, and is adjacent to the Bushehr nuclear power plant.
Dayyer	27°49′54″ N, 51°56′13″ E	Iran's largest fishing port, the leading supplier of fish and shrimp, the traffic area of commercial vessels and municipal sewage and the nearest city to Asaluyeh and a relatively suitable index for comparison with the relatively clean area and the highly contaminated area of Asaluyeh
Asaluyeh	27°28′01″ N, 52°36′35″ E	The most industrialized and polluted part of the province in the presence of enormous gas and petrochemical plants, a platform of massive vessels carrying chemical and petrochemical materials, gas extraction, and desalination plants related to the mentioned industries

Risk Assessment and Calculations

Based on the national per capita consumption (average daily fish consumption for adults of 31.92 g), the following equations estimate the CR, EDI, and THQ as well as the carcinogenic risk potential of heavy metals introduced into the human body as a result of fish consumption was calculated daily per person [13].

$$\mathrm{EDI} = \frac{\mathrm{C} \times \mathrm{FIR_D}}{\mathrm{BW}}$$

In this context, EDI stands for estimated daily intake of metals by the body, C for identified metal concentration in consumed food, and FIRD for determined daily food intake rate in grams. The target hazard quotient (THQ), used to express non-toxic effects, is the ratio between the amount of exposure metals' amount and their reference dose. If this rate is less than one, no risk can be seen.

Consumers' health will be at risk if this ratio equals or exceeds one [13]. In this case, EFr is the exposure frequency (365 days per year), EDtot is the exposure duration, total (72 years), FIR is the food intake rate (about 31.92 g per person per day for fish), C is the concentration of heavy metal in the studied food (mg/g), RfDo is reference dose, oral (mg/kg/day), BWa is weight body, adult (70 kg), and ATN is averaging time, noncarcinogens (365 days/year times the number of years of exposure is about 72 years) [13].

$$\mathrm{THQ} = \frac{\mathrm{EFr} \times \mathrm{EDtot} \times \mathrm{FIR} \times \mathrm{C}}{(\mathrm{RfDo} \times \mathrm{BWa} \times \mathrm{ATN}) \times 10^{-3}}$$

The pollutant carcinogenic risk index (CR) is obtained from the following relationship. In this regard, EDI is the body's estimated daily intake of metals, and CSF is the cancer slope factor [24].

$$\mathrm{CR} = \mathrm{EDI} \times \mathrm{CSF}$$

A cancer risk index indicates a range of anticipated potential risks for agents that cause cancer between 10^{-6} (lifetime risk of developing cancer 1 in 1,000,000) and 10^{-4} (lifetime risk of developing cancer 1 in 10,000). As a result, chemicals that contain risk factors (less than 10^{-6}) are not regarded as chemicals of concern [24]. Based on the U.S. Environmental Protection Agency (USEPA) established standard defaults, the relevant calculations were completed. Nickel compounds are categorized as class I carcinogenic elements by the International Agency for Research on Cancer (IARC).

Statistical Analysis

The Kolmogorov–Smirnov normality test was used to check the normality of the data. The Levene test was used to evaluate the homogeneity of variance. One-way analysis of variance (ANOVA) test with a significance level of 5% was used to analyze data between elements in the sampling location for the statistical analysis of the concentration of heavy metals in fish muscle tissue [25]. The software Excel 2013 was also used to create the graphs and tables. The resulting data were compared to relevant national and international standards.

Result

Ten specimens of each species were examined in the current study. The average total length (cm) of *Sillago sihama* (20.57 ± 2.50), *Sphyraena jello* (34.71 ± 5.96), and *Psettodes erumei* (44.91 ± 15.46) were based on biometric data. Table 2 lists the biometric findings and traits of the investigated species, including diet and habitat.

Table 3 displays the typical levels of the studied species' muscle tissue's heavy metal content (copper, nickel, lead, zinc, and cadmium). Based on the obtained results, the highest concentration of metals was observed respectively in the muscle tissue of *P. erumei* > *S. sihama* > *S. jello*. The FAO recommends limits of Ni and Cr for seafood of 70 mg/kg ww and 12 mg/kg ww, whereas the USFDA set the permissible levels at 80 mg/kg ww and 13 mg/kg ww, respectively. In

Table 2 Characteristics of the studied species (standard deviation ± mean)

Species	Number of species	The total weight (g)	Total length (cm)	Diet	Habitat
P. erumei	20	00.72 ± 908. 508	44.15 ± 91.46	Carnivorous	Benthic
S. jello	20	14.03 ± 224.33	71.96 ± 34.5	Carnivorous	Pelagic
S. sihama	20	21.07 ± 82.13	57.50 ± 20.2	Planktivorous	Demersal

Table 3 The average concentration of heavy metals in the muscle tissue of the studied species based on milligrams per gram of wet weight (mean ± standard deviation)

Species	Cd	Pb	Cu	Zn	Ni
P. erumei	18.06 ± 0.0	84.48 ± 0.0	60.34 ± 2.1	32.69 ± 2.3	80.3 ± 0.0
S. jello	4.02 ± 0.0	2.01 ± 0.0	90.04 ± 0.0	10.08 ± 6.10	54.58 ± 1.0
S. sihama	5.02 ± 0.0	9.01 ± 0.0	53.12 ± 0.0	60.44 ± 30.8	30.14 ± 0.0

adults, from 5.0 to 22.0 mg (WHO) and 40 mg kg^{-1} (FAO) are recommended for Zn. The mean values of metal concentrations (Zn, Cu, Cd, Pb, and Ni) for the varying parts of the Bushehr province with 3 sampled fish are presented in Fig. 2.

The estimated daily intake (EDI) of the elements under investigation was calculated for the current study and is shown in Table 4. According to the findings, the rate of estimated daily intake (EDI) and estimated weekly intake (EWI) for nickel, lead, and cadmium metals in all studied species are higher than the limit of provisional tolerable daily intake (PTDI) and provisional tolerable weekly intake (PTWI) in an adult. Estimated daily intake (EDI) and estimated weekly intake (EWI) for copper and zinc were both below the limit of the provisional tolerable weekly intake (PTWI). In addition, the daily and weekly intake rate of heavy metals in *Psettodes erumei* was as follows: copper > zinc > nickel > lead > cadmium. In *Sphyraena jello* fish, daily and weekly intake of heavy metals is in order: copper > nickel > zinc > cadmium > lead. The daily and weekly intake rates of heavy metals for *Sillago sihama* were copper > zinc > nickel > cadmium > lead.

Based on the concentration of heavy metals, the calculation of the maximum amount of fish that can be eaten daily (kg/day) and the maximum amount of fish that can be eaten monthly (serving/month) is shown for adults and children of the studied species (Table 5). *P.erumei* were related to zinc metal (9.07 kg/day), *S. jello* (17.21 kg/day), and *S. sihama* (18.67 kg/day) to lead metal, which is the highest permissible limit of fish consumption for two age groups of adults and children. In addition, *S. sihama* and both adult and child populations had higher permissible lead consumption rates (2503.14 servings per month) than other metals.

Table 6 provides the target hazard quotient (THQ) and total target hazard quotient (TTHQ) of nickel, zinc, copper, lead, and cadmium in the studied fishes for consumers (children and adults). The following vital presumptions were considered when calculating the risk index: (a) the amount of imported metal equals the amount absorbed in the body; (b) pollutants are unaffected by cooking; (c) Iranians live an average of 72 years; and (d) adults weigh an average of 70 kg, while children weigh an average of 15 kg. The risk index is less than one for each of the three species of metals and fish studied, which means there is no risk to consumer health. Additionally, the combined risk of the heavy metals used in *S. jello* and *S. sihama* is less than one, indicating no health risk to the consumers.

Discussion

Economic activities like refining crude oil, making aluminum and zinc, building and repairing ships, and loading and unloading various minerals and chemicals have all increased recently [9]. These have destroyed the delicate water ecosystem and increased pollution, which has developed along Iran's southern coast. The harmful effects affecting marine ecosystems, including aquatic life and humans, make identifying, measuring, and tracking heavy metal elements essential [26]. From six main ports in Bushehr province, Persian Gulf, 60 pieces of fish were examined in the spring of 2022. *P. erumei*, *S. sihama*, and *S. jello* fish were tested for their ability to absorb the five heavy metals (lead, cadmium, nickel, copper, and zinc) required by the World Health Organization and the Food and Agriculture Organization of the United Nations. Mean concentrations of Ni, Zn, Cu, Pb, and Cd were 1.88 ± 0.07 µg/g, 27.16 ± 8.11 µg/g, 11.55 ± 4.12 µg/g, 14 ± 0.06 µg/g, and 0.19 ± 0.03 µg/g wet weight. Turkmen et al. determined the metal levels in the muscles and livers of 12 fish species from the Aegean and Mediterranean Seas and reported that the levels of Cd,

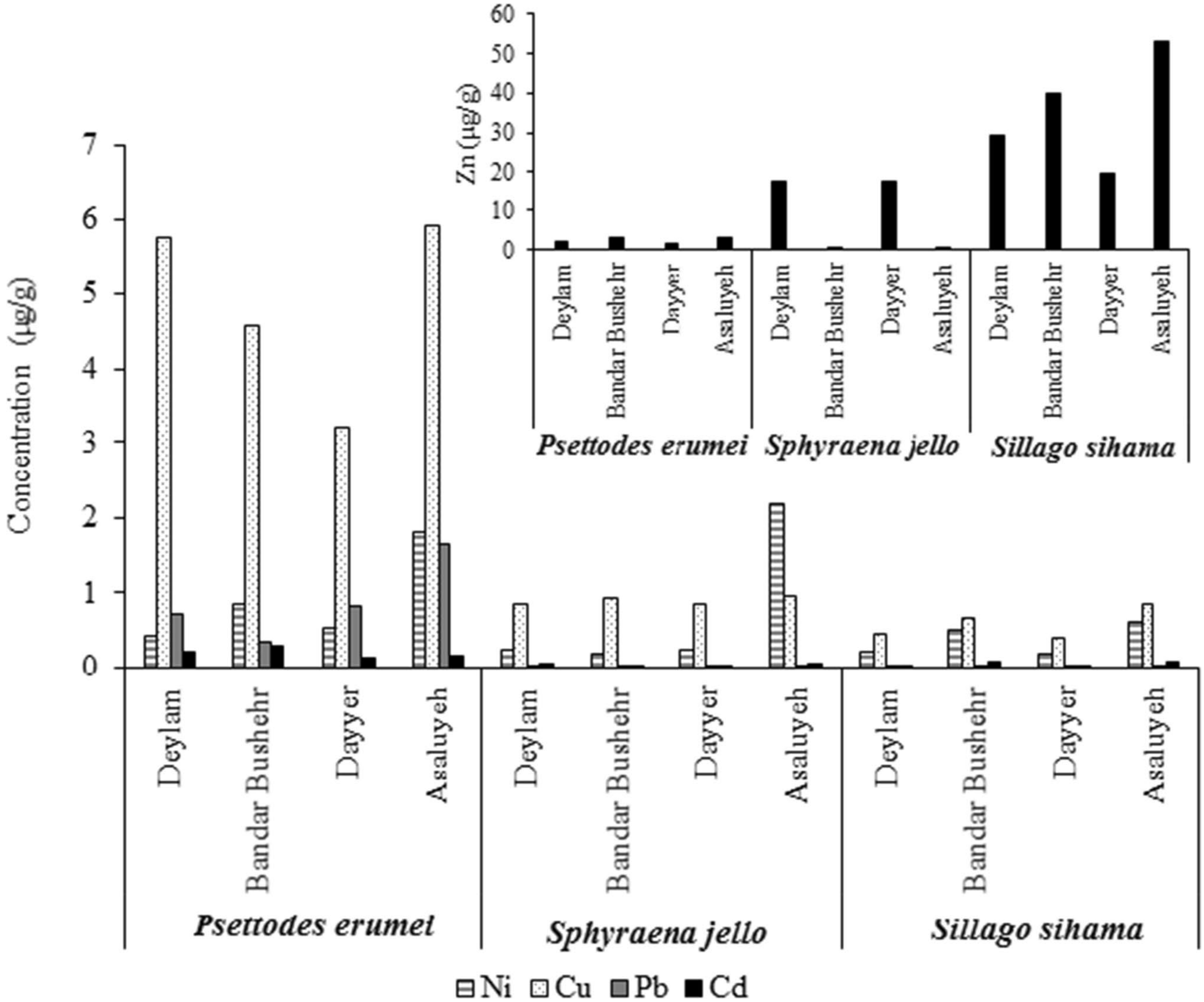

Fig. 2 Mean concentrations (μg metal/g dw) of heavy metals in the sampling sites

Mn, Pb, and Zn in muscles of fish were < 0.01–0.39 mg/kg, 0.18–2.78 mg/kg, 0.21–1.28 mg/kg, and 3.51–53.5 mg/kg, respectively [27].

It should be illustrious that coastal areas of the Persian Gulf are now facing great challenges in regard to heavy metal contamination. The Bushehr province coastal area is a typical transitional zone between land and ocean, receiving a large amount of anthropogenic pollutants, such as water discharge from ship balance tanks, discharge of industrial, agricultural, and domestic sewage, and soil erosion [28], and fish may take in some heavy metals from the environment via the food chain or water [29]. The results of the ANOVA analysis revealed a significant difference in the number of metals present in the fish muscle tissue in the sampling area ($p < 0.05$). Applying different management and environmental conditions, sewage discharge, and aquaculture activities in the investigated regions may cause a significant difference in the concentration of heavy elements in other species and areas. Dural et al. [30] demonstrated that there are differences in the concentration of heavy metals in the bodies of aquatic organisms in various areas (the Persian Gulf, the Egyptian Gulf, the Scandinavian Gulf, and the California wetlands) as a result of multiple environmental factors, including temperature, light, and human activity. The current study used the spring season to examine 60 pieces of fish. In a study by Shahri and Velayatzadeh [31], the length and the total weight of 48 fish were used to study the impact of seasons on the buildup of metals in the muscle of *Acanthopagrus latus* and *Platycephalus indicus* in the Oman Sea. In the present study, the concentration of metals was observed in the muscle of *P. erumei* > *S. sihama* > *S. jello*.

Table 4 Estimation of daily and weekly intake of heavy metals due to consumption of studied fishes by consumers (adults and children)

Species	Metals	EWI[e] (adults – children)	EDI[d] (adults – children)	PTDI[c]	PTWI[b]	PTWI[a]
P. erumei	Ni	12.41 – 2.66	0.38 – 1.77	0.012	2.45	0.035
	Cu	35.83 – 7.68	5.1 – 12.10	0.5	245	3.5
	Zn	40.19 – 8.61	5.1 – 74.23	1	490	7
	Pb	13.2 – 03.79	1.0 – 86.40	0.0035	1.75	0.025
	Cd	2.0 – 82.60	0.0 – 40.09	0.001	0.49	0.007
S. jello	Ni	23.5 – 88.12	3.0 – 41.73	0.012	2.45	0.035
	Cu	94.20 – 42.23	13.2 – 49.89	0.5	245	3.5
	Zn	13.2 – 87.97	1.0 – 98.42	1	490	7
	Pb	0.0 – 25.05	0.0 – 4.01	0.0035	1.75	0.025
	Cd	0.54 – 0.12	0.0 – 8.02	0.001	0.49	0.007
S. sihama	Ni	4.64 – 0.99	0.0 – 66.14	0.012	2.45	0.035
	Cu	101.44 – 473.38	14.49 – 67.63	0.5	245	3.5
	Zn	8.1 – 13.74	1.16 – 0.25	1	490	7
	Pb	0.23 – 0.05	0.03 – 0.01	0.0035	1.75	0.025
	Cd	0.81 – 0.17	0.12 – 0.02	0.001	0.49	0.007

[a]Provisional tolerable weekly intake (PTWI) in µg/week/kg of body weight

[b]Provisional tolerable weekly intake (PTWI) for an adult with an average body weight (70 kg) in µg/g/week for a 70-kg person

[c]Provisional tolerable daily intake (PTDI) in µg/day for a 70 kg person

[d]Estimated daily intake (EDI) in µg/day for a 70-kg person and a 15-kg child

[e]Estimated weekly intake (EWI) in µg/day for a 70-kg adult and a 15-kg child

Table 5 The amount permissible limit (kg per day) and the permissible rate of consumption (number of servings per month) of heavy metals in studied fishes

	CR_{mm} (number of servings per month)		CR_{lim} (kg per day)		
Species	Children	Adults	Children	Adults	Metals
P. erumei	50.16	243.08	0.37	1.75	Ni
	260.55	1215.90	1.94	9.07	Cu
	30.97	144.52	00.23	1.08	Zn
	9.56	44.59	0.07	0.33	Pb
	11.05	51.58	0.08	0.38	Cd
S. jello	26.07	121.6	0.19	0.91	Ni
	98.87	461.39	0.74	3.44	Cu
	89.73	418.74	0.67	3.12	Zn
	494.62	2308.23	3.69	17.21	Pb
	57.47	268.19	0.43	2.00	Cd
S. sihama	134.10	625.79	4.67	1.00	Ni
	19.72	92.03	0.15	0.69	Cu
	153.03	714.16	1.14	5.33	Zn
	536.39	2503.14	4.00	18.67	Pb
	38.31	178.80	0.29	1.33	Cd

P. erumei (9.07 kg per day), *S. jello* (17.21 kg per day), and *S. sihama* (18.67 kg per day) have the highest daily limits for zinc consumption for two age groups of fish: adults and children. Additionally, compared to other metals, the acceptable lead consumption rate for *S. sihama* (2503.14 monthly servings) was higher. Cu and Zn are crucial for most animals' growth, cell metabolism, and survival. As a result, their necessity can be attributed to the generally high levels of these metals [32]. A crucial component of the human glucose tolerance factor, Cr is a fundamental micronutrient trace metal with a pattern similar to Zn and Ni [33]. However, its excess may cause diabetes or contribute to diabetes. Cd may not be a significant metal for organisms, but it is highly toxic to wildlife and humans. This can increase the risk to aquatic animals and local human health [34]. Present findings showed that Ni and Pb concentrations in detected seafood species were relatively high for human consumption. Acute exposure to high Pb levels can cause gastrointestinal, renal, and brain damage along with other toxic effects [35]. Zinc, an element essential for metabolic processes, was also found in all samples. Most Zn concentrations in all species were below the permissible of 100 mg/kg ww and 1000 mg/kg ww set by WHO for fish and crustaceans, respectively.

The risk index is less than one for all metals and the three studied fish species, indicating no risk to consumer health. There is no risk to consumers' health because the combined risk index for heavy metals in *S. jello* and *S. sihama* is less than one. Most investigated organisms are benthic, with a 5- to 80-m depth range, and can feed close to the bed. Being carnivores, they frequently eat fish and crustaceans for food [36], therefore, if the amount of heavy metal accumulation in the fish was more significant than that in the muscle of

Table 6 Target hazard quotient (THQ) of non-cancerous diseases and hazard index (HI) of studied heavy metals in adults (a) and children (c) based on consumption of aquatic species muscle

Species	THQ(target hazard quotient)										Hazard index (HI)	
	Cd		Pb		Cu		Zn		Ni			
	c	a	c	a	c	a	c	a	c	a	c	a
P. erumei	0.4	0.09	0.47	0.1	0.14	0.031	0.02	0.004	0.09	0.02	1.12	0.24
S. jello	0.08	0.02	0.009	0.002	0.05	0.01	0.05	0.01	0.17	0.04	0.35	0.08
S. sihama	0.12	0.03	0.008	0.002	0.03	0.006	0.23	0.05	0.03	0.01	0.41	0.09

S. jello fish, then it is one of the species that is placed above the food web. The bio-accumulation of heavy metals occurs in the muscles of the fishes. According to an assessment of the risk of heavy metal accumulation in green tiger shrimp (*Penaeus semisulcaus*) in the waters of Bushehr provinces, the amount of metal accumulation was 0.40 µg/g and 25.43 µg/g, respectively. The calculated risk index for adults and children was less than 1, indicating no risk to the health of shrimp consumers in terms of heavy metals [37]. The variations in heavy metal concentrations among marine species could thus come from several factors, including feeding strategies, metabolic activities, and rich metal affinity for specific organs [38]. Exposure of various marine species to heavy metals, mainly Cd, Cu, and Zn, is associated with the induction of metallothionein. Metallothionein (MT) is a cysteine-rich, low-molecular weight protein that plays a special part in regulating the intracellular homeostasis of essential and non-essential metals and their detoxification [38]. Thus, the excess heavy metals will be detoxified by metallothionein and stored in tissues including the liver, kidneys, and muscle.

The body's ability to control the concentrations of some metals and the fact that body size and biochemical components have little to no bearing on variability may help to explain why there is no relationship between some metal concentrations and length [37]. The findings indicated a correlation between the concentration of copper, zinc, and cadmium elements and total fish length in the study area,as the fish's total length increases, so does the concentration of the elements, as mentioned earlier in fish muscle tissue. Dadolahi et al. [39] found that the amount of lead and cadmium metals in the muscle and gill tissue of *Arabibarbus grypus* have a direct linear relationship with total length and weight. Shirvani [40] demonstrated that there is a statistically significant relationship between the concentration of metals and body size by examining the number of heavy metals in the muscle and liver tissues of two species of *Terapon jarbua* and *Sillago sihama* on the coast of the southern basin of Qeshm Island; in other words, the intensity of pollution increases with an increase in fish length and body weight.

The combined effects of the rainy season's (July to September) dilution of water salinity and spawning, which affect metal levels by lowering concentrations, may be to blame for the loss of metals in soft tissue. Under specific environmental or physiological conditions, increasing the levels of some organisms in various tissues may have a detrimental effect on the normal operations of various organs and tissues [41]. Esmaeilbeigi et al. [1] mentioned that although metallothionein's metal binding is steady, it is also dynamic due to quick

Table 7 Comparison of the concentration of studied metals (µg/g) in the muscle of fishes with international standards (µg/g)

Species	Metals	Mean	Minimum	Maximum	USEPA	FDA	WHO
P. erumei	Ni	80.3 ± 0.0	0.39	1.83	0.5	–	60–80
	Cu	60.34 ± 2.1	1.32	4.84	120	–	10
	Zn	32.69 ± 2.0	1.44	3.11	120	–	100
	Pb	84.48 ± 0.0	0.34	1.64	0.5	5	0.4
	Cd	18.06 ± 0.0	0.13	0.28	2	2	0.2
S. jello	Ni	54.58 ± 1.0	0.2	4.18	0.5	–	60–80
	Cu	90.04 ± 0.0	0.86	0.94	120	–	10
	Zn	10.08 ± 6.10	2.26	11.74	120	–	100
	Pb	0.2.01 ± 0.0	0.013	0.023	0.5	5	0.4
	Cd	04.02 ± 0.0	0.02	0.05	2	2	0.2
S. sihama	Ni	30.14 ± 0.0	0.19	0.51	0.5	–	60–80
	Cu	53.12 ± 0.0	0.4	0.66	120	–	10
	Zn	60.44 ± 30.8	19.9	40.1	120	–	100
	Pb	09.01 ± 0.0	0.07	0.1	0.5	5	0.4
	Cd	05.02 ± 0.0	0.04	0.08	2	2	0.2

metal exchanges within and between proteins. The latter property enables metal exchange within and between metallothionein molecules and between metallothionein and donor or acceptor ligands. Fish organs generally respond poorly to heavy metal poisoning. Due to its crucial function in human nutrition and the need to ensure its safety for consumption, fish muscle tissue was examined in this study. Although it is clear that muscles are not a biologically active site for the transfer and accumulation of metals, there is a severe risk to human health in polluted aquatic habitats where the concentration of metals in fish muscles may be higher than is safe for human consumption. The World Health Organization (WHO) and the US Food and Drug Administration (FDA) set acceptable standards for heavy metals, and the values of the results of this study were compared with those standards (Table 7). The comparison of the results revealed that the lead concentration in the muscle tissue of *P. erumei* is higher than the reference standards. Other metal concentrations in fish are below the World Health Organization's permissible limit. The potential hazard quotient (THQ) was used to calculate the risk of dietary intake of heavy metals from seafood consumption (Table 6).

Tahsini et al. [42] assessed the concentration of heavy metals in the fish breeding ponds of Sanandaj City and the risk of their ingestion in rainbow trout. Additionally, Tahsini et al. [42] determined that adults should consume 888.7 g of food daily, while children should consume 177.7 g. The findings demonstrated that fish muscle tissue has an average concentration of iron, nickel, zinc, copper, and magnesium metals that is lower than the permitted limit according to international standards. The existence of numerous industries along the coasts, the discharge of industrial and urban wastewater, which contains all kinds of heavy metals, and causes an increase in the concentration of this metal in this area are the reasons why the maximum concentration of nickel metal in fish muscle tissue is higher than the USEPA standard [43]. Additionally, the THQ index results for the studied region's fish muscle tissue were calculated to be less than one. The THQ is less than one in the risk assessment, which means there will be no adverse health effects for the consumer and no threat to the consumer's natives. Fish with a considerable length had a higher cancer slope index in the metals under investigation. Other findings demonstrated that the amount of CR in element exposure carries a negligible risk of carcinogenesis.

Conclusion

The concentration of nickel, zinc, copper, lead, and cadmium metals in the muscle of fish with different length classes show a notable difference and a positive correlation, according to the study's findings and measurement of metals in the studied fishes in Bushehr Province. With increasing body length, the concentration of these metals also rises. The mean concentration of five heavy metals analyzed in the sampling fish was as follows: copper > zinc > nickel > cadmium > lead with different spatial distributions along the study sites. The concentration of nickel metal was higher than the permissible limit compared to the standard of the World Health Organization, which could be problematic for consumers. Fish consumption poses no risks to consumers, according to the findings of research into THQ levels in adults. Finally, it is suggested to offer management solutions to improve the current conditions after considering the results and realizing the Bushehr coastal area's relative pollution and ecological significance.

Author Contribution All authors contributed to the study's conception and design. **S. T**: conceptualization, methodology, writing – original draft, review, and editing, visualization; **M. Gh**: supervision, writing – original draft, review, and editing, project administration, funding acquisition; **M. Y**: investigation, resources, data curation; **Z. R**: writing – original draft.

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Data Availability All the data are within the article.

Declarations

Ethical Approval In the current study, fish were caught by fishermen not specifically for the project.

Consent to Participate This is a review study, so there is no need for consent to participate.

Consent for Publication The participant has consented to the submission of the case report to the journal.

Competing Interests The authors declare no competing interests.

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