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RESEARCH

The Bioaccumulations of Metal(loid)s in the Tissues of Invasive *Carassius gibelio* (Bloch, 1782) Fish from the Kızılırmak River (Türkiye) and Health Risk Assessment

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Abstract
The present research was an examination of the concentration levels of 10 metal(loid)s that had accumulated in the muscle, gills, and liver tissues of *Carassius gibelio* (Prussian carp) fish. The fish species, used as samples in the study, were obtained from the part of the river in Gülşehir (Türkiye). Besides, possible health risks to consumers were specified based on the daily estimated intake (EDI) of metal(loid)s in adults. Additionally, considering the inhabitants' frequency of fish consumption in the area, target hazard quotient (THQ), hazard index (HI), carcinogenic risk (CR), and maximum safe consumption quantity (MSCQ) values were assessed. All of the examined metal(loid)s in the research were determined in all of the tissues of the fish. Also, Fe and Zn had the highest levels in the tissues, and Pb had the lowest level. There were statistically significant differences of Fe, Co, Cu, Zn, As, Cd, and Pb among the tissues ($p < 0.05$). It was determined that the gender of the fish did not affect the accumulation of the metal(loid)s in the tissues. According to the research results, no significant statistical difference was found between the accumulation of the metal(loid)s (except Ni) and the size of the fish (length and weight) ($p > 0.05$). The estimated daily intake levels of the metal(loid)s accumulating in the eatable muscle of the samples were calculated to be lower than the reference dose limit. Besides, the THQ and the HI values lower than 1 were found. Carcinogenic risk values related to inorganic As were below 10^{-6}. This result specifies that consumption of the fish poses no carcinogenic risks to consumers' health. It was concluded that less than 70 g of *C. gibelio* daily consumption would not harm consumers' health.

Keywords Metal(loid)s · Kızılırmak River · Fish tissues and size · Gender · Risk assessment

Introduction

Consuming fish is very significant for an individual's healthy diet because it provides the body with essential minerals, vitamins, proteins, and unsaturated fatty acids. There are a lot of positive effects of these components on being healthy. They help people maintain their health. Besides, they protect people against illnesses [1–3]. In spite of these, fish can also threaten people's health because harmful environmental pollutants such as metal(loid)s can easily accumulate in them. Fish are exposed to metal(loid)s in their environment. Their characteristics, seasonal changes, temperature, exposure time, levels of metal(loid)s, pH, and salinity have effects on the accumulation of metal(loid)s in fish from their environment [4–6]. Metal(loid)s pose toxicological risks to humans and all other living creatures in nature. Therefore, they are considered one of the most threatening contaminants in nature [7]. Anthropogenic activities lead to harmful substances such as metal(loid)s that accumulate in aquatic creatures via the trophic level [8]. As a result, using fish that have been exposed to harmful metal(loid)s as food may pose various risks to the health of individuals [7, 9, 10]. When fish with higher levels of toxic metal(loid)s than consumption limits are eaten extensively, this may cause serious health problems in consumers such as renal complications, bone diseases, nervous system problems, and cardiovascular and liver ailments. It may even lead to cancer in consumers [11, 12]. Fish consumption is of great significance for humans to have a healthy diet because of the fact that

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it has numerous nutritional advantages. However, risks to human health created by the consumption of fish exposed to metal(loid)s should be addressed and assessed well. Studies point out that fish consumption possesses more benefits than its detriments [3, 9, 13].

Carassius gibelio, also known as the Prussian carp or Gibel carp, is a medium-sized carp. It has habitats all over the world. This fish species has come from Siberia or Central Europe and has become invasive in Europe, North America, and Asia due to its rapid reproduction [14]. It is extremely resistant to adverse environmental conditions such as low oxygen levels and fluctuating temperatures, as well as to pollution from various sources [15–17]. This omnivorous species feeds on plankton, invertebrates, plants, and detritus [14]. It is usually at the top of the food web and therefore can bioaccumulate large amounts of pollutants. It stands out due to both its expanding habitat and reproductive potential [15].

Twelve hydroelectric dams have been constructed on the Kızılırmak, which is the longest river in Türkiye. Some of these dams are used to provide drinking water to the population and to irrigate agricultural lands. In addition, the Kızılırmak River is an important habitat for many fish species. As a result, good water quality of the river is very important for the continuation of its ecosystem and human health. However, as a result of domestic and industrial wastewater discharged into the river without treatment and excessive agricultural activities, it is increasingly polluted with metal(loid)s [18–21].

C. gibelio was chosen in the current study. This species was obtained from the Kızılırmak River. The current research has four aims. The first one is to find out whether there are any statistically significant differences in the accumulations of 10 metal(loid)s among the liver, gills, and muscle of *C. gibelio*. It also aims to reveal whether length or weight and gender have any effect on the accumulation of the metal(loid)s in tissues. In addition, the study aims to evaluate the risks of metal(loid)s entering the body as a result of fish consumption in terms of consumers' health. Finally, it aims to determine the safe limits within which fish consumption does not pose any health risk to consumers.

Materials and Methods

Research Area

The Kızılırmak rises in Kızıldağ in İmranlı, Sivas. It passes through 11 provinces and meets the Black Sea in Bafra, Samsun after it completes its course of 1355 km (Fig. 1). The flow of the river changes significantly through the seasons. It reaches the maximum level in April due to the melted snow and rainwater. It is at the minimum level in



Fig. 1 Map of the Kızılırmak River showing the study area and sampling site. Source: Google Maps (10.06.2024) [61]

summer. The total drainage area of the river consists of 78,180 km^2 [18–20].

Fish Collection and Metal(loid)s Analysis

The fish samples to be examined in the study were obtained from the part of the river in Gülşehir (Türkiye) in April 2023 by local fishermen and the researcher using gill nets. In total, 10 *C. gibelio* fish, 5 females and 5 males, were used as samples in the research. The samples were brought to the lab instantly and were washed carefully using distilled water. Then, the size and weight of each sample were measured cautiously. After this procedure, the gills, the liver, and the dorsal muscle (anterior to dorsal fin) were separated from the fish species. Each of them was packaged individually. They were kept at − 20 °C until analysis was implemented. Table S1 provides data regarding the characteristics of the samples such as their common name and scientific name in addition to such biometric data as size and weight and gender.

The present research is a comprehensive examination of the levels of 10 metal(loid)s (Cu, Fe, Mn, Ni, Zn, As, Cd, Co, Cr, and Pb) in the muscle, gills, and liver of *C. gibelio*. Analysis of metal(loid)s was performed using the method used in a previous study [22]. In the study, the concentrations of the metal(loid)s were determined in 30 biological samples (10 specimens × 3 tissues). The muscles, gills, and livers (about 0.5 g) that had been removed from the samples earlier were put into the digestion tubes. Each of the tubes was filled with 7 mL HNO_3 (65%, EMSURE® Reag. Ph Eur, ISO, Merck KGaA) and 1 mL H_2O_2 (30%, EMSURE® ISO, Merck KGaA). The digestion tubes were put aside for a while so that they could reach room temperature. For the implementation of the digestion procedure, a microwave digestion system (Milestone Start D, USA) was employed. The microwave digestion heating program was performed as follows: temperature 200 °C; ramp time 15 min; hold time 15 min; power 1200 W. After the digestion process, the tubes were allowed to cool to room temperature. The solutions in the digestion tubes were transferred into the falcon tubes, and ultrapure water to 25 mL was used to dilute the solutions in the tubes. Inductively coupled plasma-tandem mass spectrometry (ICP-MS/MS) (Agilent 8800, USA) was implemented for assessment of the concentration levels of the metal(loid)s in the samples that had been digested earlier. The instrument is equipped with two hyperbolic profile quadrupoles separated by the ORS (octopole reaction system) cell, allowing operation in MS/MS mode. The first quadrupole operates as a mass filter, allowing only the target analyte mass to pass through to the ORS cell and rejecting all other matrix-derived and plasma-based ions. Thus, this configuration provides the most efficient removal of polyatomic and isobaric interferences.

Replicates, analytical blanks, and reference standards were utilized while carrying out the experiment to ensure quality control. To ensure the accuracy of the method, certified reference material (DORM-2) was digested with every nine samples and analyzed using the same procedure as the samples. The averages of the recoveries ranged between 90.77 and 108.83% (Table S2). Also, detection limits of the metal(loid)s were assessed (Table S2). The comparative typical deviations of replicates were assessed to be below 10%. Following the calculation, the concentrations of the metal(loid)s below were measured in the tissues of *C. gibelio*: mg/kg wet weight (ww).

Risk Assessment

In the current research, a comparative analysis was carried out between the estimated daily intake (EDI) values (μg/kg bw/day) of different metal(loid)s such as Cu, Fe, Mn, Ni, Zn, As, Cd, Co, Cr, and Pb and their equivalent reference doses (RfDs) determined by USEPA [23]. The respective reference dose specifies a tolerable amount of a toxic substance that is exposed due to human activities and enters the body through the mouth. When exposed below the reference dose, a toxic substance will not lead to any permanent risks of harmful non-carcinogenic effects [24]. The estimated daily intake values were assessed utilizing the following formula [25, 26]. Table 1 provides the details.

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

The target hazard quotient (THQ) of each metal(loid) was determined via a respective reference dose. Besides, metal(loid) concentration-related non-carcinogenic health (NCH) risks due to fish consumption were also evaluated using it [27]. For the assessment of combined health risks because of the consumption of fish exposed to metal(loid)s, the THQ or the HI was utilized [9]. When the THQ or HI values are below 1, it indicates that eating the fish species examined in the study will not pose any NCH risk to consumers' health [9]. But when the values are higher than 1, NCH effects are likely expected on consumers' health due to fish consumption [28]. For the assessment of the THQ or HI values, the following formula was used [23]. Table 1 provides the details.

$$\mathrm{THQ} = \frac{\mathrm{EF} \times \mathrm{ED} \times \mathrm{IRd} \times \mathrm{C}}{\mathrm{RfD} \times \mathrm{BW} \times \mathrm{ATnoncancer}} \times 10^{-3}$$

$$HI = \sum_{n}^{i} THQn$$

If a person is exposed to a carcinogen for a long time, it is highly potential that he will develop cancer. This potential is

Table 1 Details about the formulas used to calculate health risks

Symbols and explanations	Units and values	References
C: Mean metal(loid) level	mg/kg wet weight	This study
IRd: Average fish consumption rate	g/day: 18.4	[58]
BW: Average adult body weight	kg: 70	[9]
ED: Exposure duration	Years: 26	[59]
EF: Exposure frequency	Days/year: 350	[60]
RfD: Reference dose	mg/kg-day	[23]
ATnoncancer: Averaging time for non-carcinogens	Days: 365 × 26	[28]
CSF: Carcinogenic slope factor	$(mg/kg\text{-}day)^{-1}$: 1.5	[23]
ATcancer: Averaging time for carcinogens	Days: 365 × 70	[28]
MSCQ: Maximum safe consumption quantity	kg fish ww/day	[31]
ARL: Acceptable lifetime risk level	10^{-5}	[31]

described as carcinogenic risk (CR) [29]. Of the metal(loid)s examined in this study, only inorganic arsenic constitutes CR to consumers' health [23]. For the assessment of the CR resulting from inorganic As, the subsequent formula was utilized [30]. Table 1 provides the details.

$$CR = \frac{EF \times ED \times IRd \times C \times CSF}{BW \times ATcancer} \times 10^{-3}$$

If the values of CR are between 10^{-4} and 10^{-6}, they are the tolerable ones. If they are below 10^{-6}, they do not create any carcinogenic risks. But, if they are above 10^{-4}, they cannot be tolerated [29].

The maximum safe consumption quantity (MSCQ) specifies a daily allowable quantity of fish consumption for humans without being exposed to any harmful effects of metal(loid)s [14]. The equation below was employed to determine the MSCQ for non-carcinogenic effects [31]. Table 1 provides the details.

$$MSCQnoncancer = \frac{RfD \times BW}{C}$$

The equation below was utilized to determine the MSCQ for carcinogenic effects of inorganic As [31]. Table 1 provides the details.

$$MSCQcancer = \frac{ARL \times BW}{C \times CSF}$$

Statistical Analysis

Kolmogorov–Smirnov test was utilized to check the normality of the metal(loid)s. All of the metal(loid)s examined in the research did not have a normal distribution. Therefore, the statistical significance of differences in metal(loid) accumulation among tissues was evaluated using the non-parametric Kruskal–Wallis test, followed by post-hoc comparisons using Dunnett's test. Independent *t*-test was conducted to assess the differences between the levels of the metal(loid)s in the tissues and gender. Relationships between the levels of the metal(loid)s in the tissues and the fish size were assessed using the Spearman correlation test. All the analyses were implemented via SPSS 22.

Results and Discussion

Concentrations of Metal(loid)s in *C. gibelio*

The results of Dunnett's test, highlighting statistical differences in the concentration levels of metal(loid)s among tissues (muscle, gills, liver), are presented in Table 2. Based on the results, statistically significant differences related to all the other metal(loid)s except for Mn, Ni, and Cr were found among the tissues of *C. gibelio* ($p < 0.05$). In the examined samples of *C. gibelio*, 8 of the metal(loid)s (Cu, Fe, Ni, Zn, Cd, Co, Cr, and Pb) had higher concentrations in the liver, and 2 of them (Mn and As) showed higher concentrations in the gills (Table 2). The analysis of the relevant data pointed out that there were statistically higher levels of means of Cu and Pb in the liver than in the muscle and the gill of *C. gibelio* ($p < 0.05$). Yet the results did not report any statistically significant differences between the mean concentrations of Fe, Zn, Cd, and Co in the liver and in the gill ($p > 0.05$). They were found to be higher than the levels in the muscle ($p < 0.05$) (Table 2). Besides, it was inferred that there was a statistically significant difference between the mean of As in the gill and the means in the liver and in the muscle ($p < 0.05$) (Table 2). There is a similarity between these results, and the results of previous studies that reported concentrations of metal(loid)s were commonly lowest in fish muscles and highest in fish liver and gills [32–37]. The average As (0.351 mg/kg), Mn (0.622 mg/kg), Ni (1.117 mg/kg), Cu (2.607 mg/kg), and Cd (0.086 mg/kg) values in the muscle tissues of *C. gibelio*obtained from the Tigris River (Türkiye) by [38] were assessed to be higher than the current

Table 2 Metal(loid) concentrations **(units mg/kg wet weight)** in tissues of the examined *C. gibelio*

Species		N		Cu	Fe	Mn	Ni	Zn	As	Cd	Co	Cr	Pb
C. gibelio	Muscle	30	Mean	0.704[b]	8.041[b]	0.421	0.511	7.670[b]	0.232[b]	0.010[b]	0.016[b]	0.315	0.008[b]
			S.D	0.418	8.147	0.113	0.468	5.406	0.092	0.014	0.023	0.346	0.009
	Gills	30	Mean	0.988[b]	42.714[a]	5.542	0.610	24.958[a]	0.924[a]	0.038[a]	0.036[ab]	0.521	0.015[b]
			S.D	0.499	21.782	10.155	0.303	20.691	0.425	0.029	0.021	0.463	0.013
	Liver	30	Mean	10.206[a]	54.385[a]	1.337	1.041	39.815[a]	0.471[b]	0.048[a]	0.058[a]	0.549	0.034[a]
			S.D	7.705	25.529	0.675	1.084	19.686	0.315	0.033	0.050	0.569	0.028

The different letters in the same column indicate statistical difference among the tissues (muscle, gills, liver) for *C. gibelio*

S.D. standard deviation, *N* number of samples

study. The current study was compared with a previous study conducted with the same fish species in Marmara Lake (Türkiye) [39]. It was determined that the average Cr, Ni, and Cu concentrations in the liver, muscle, and gills of *C. gibelio* were higher, and the average As, Cd, and Pb concentrations in the muscles were lower.

Internal regulatory mechanisms and functions of fish possess very significant roles in the bioaccumulation of metal(loid)s [36]. For instance, fewer metabolic activities are available in muscle than gills and liver. This prevents high concentrations of metal(loid)s from accumulating in muscle. Additionally, the muscle tissue of a fish makes up the largest portion of its weight. As a result, metal(loid) concentrations in muscle are more dilute than concentrations in other organs or tissues [1, 40, 41]. The gills and liver are very active in the metabolism of fish. They also have physiological roles in fish metabolism. Therefore, metal(loid)s mostly target these organs [42, 43]. The gills of fish constantly contact with water. They also filter large amounts of water. Therefore, they are exposed to large amounts of metal(loid)s, and thus, metal(loid)s can easily enter the fish body through them. There is also a relationship between metal(loid) levels accumulated in the gills and metal(loid) levels accumulated in the water where the fish live. Metal(loid) levels accumulated in gills provide important clues about metal(loid) levels in water [40, 44]. The liver of fish is of vital significance because it stores, excretes, and detoxifies metal(loid)s through the induction of metal(loid)-binding proteins like metallothioneins (MTs). MTs play an important role in the transport and storage of base metal(loid)s. Additionally, they provide a protection shield against the toxic effects of metal(loid)s [36, 41, 45].

The current research concluded no statistically significant difference related to gender in terms of the concentrations of the metal(loid)s in the muscle, gill, and liver of *C. gibelio* ($p > 0.05$) (Table S3). It can be expressed that fish gender does not have any role in the accumulation of metal(loid)s in tissues. There is consistency between this study and previous studies that concluded that there was no significant difference between the levels of the metal(loid)s in fish tissues and gender [1, 46, 47]. Different factors, such as life cycle stage, ecological needs, and metabolic activities may influence gender-induced differences in concentrations of metal(loid)s in fish tissues [48, 49]. For example, during the spawning period, the metabolic activities of a fish are fast, but when the spawning period ends, the metabolism slows down [50]. The spawning period of *C. gibelio* fish examined in this research begins in mid-spring and continues until mid-summer. For this study, *C. gibelio* samples were collected in late spring. It is known that gonads are in the recovery phase during this period. This can be attributed to the fact that fish gender has no effect on the accumulation of most metal(loid)s in tissues.

Table S4 gives information about the correlations among the levels of the metal(loid)s measured in the tissues (muscle, gills, and liver) and the fish size (length and weight). The conclusions indicated no statistically significant relationship between the concentrations of the metal(loid)s in the muscle and the liver and the fish size in *C. gibelio* ($p > 0.05$). Similarly, no statistically significant relationship was found between most of the metal(loid)s in the gills and the fish size ($p > 0.05$). The results pointed out that only Ni concentration measured in the gills had a positive relationship with the fish size ($p < 0.05$). It cannot be said that there is consistency between this finding and the results of previous studies that found an inverse correlation between levels of metal(loid)s in tissues and fish size [51, 52].

Risk Assessment

For human health and food safety, it is essential to measure the levels of metal(loid)s in the muscle tissue of fish and monitor them at regular intervals. The highest levels allowed for metal(loid)s in fish muscle tissue by international organizations are 2.0 mg/kg for Cr and 0.1 mg/kg for inorganic As, Chinese Health Ministry [53]; 0.05 mg/kg for Cd and 0.3 mg/kg for Pb, European Commission Regulation [54]; and 30 mg/kg for Cu and Zn, Food Agriculture Organization [55] (Table 3). The highest metal(loid) levels in the muscle tissue of *C. gibelio* examined in the study were determined

as 0.010 for Cd, 0.315 for Cr, 0.704 for Cu, 7.670 for Zn, and 0.008 mg/kg for Pb (Table 3). The mean levels (0.232) of inorganic As in the muscle tissues of the examined samples, which is required to be 3% of the total As were found to be lower than the acceptable limit of 0.1 mg/kg. These results show that the levels of the metal(loid)s found in the muscle tissue of *C. gibelio* are below the maximum allowable metal(loid) levels set by the abovementioned organizations. Varol et al. [56] measured and evaluated the levels of the metal(loid)s in the muscle tissues of *Carassius gibelio*, *Cyprinus carpio*, and *Tinca tinca* fish species obtained from the Kızılırmak River. Similar to the present research, they reported that the mean Cd (1.4 µg/kg for *C. gibelio*, 5.4 µg/kg for *C. carpio*, 1.8 µg/kg for *T. tinca*); Cr (99.9 µg/kg for *C. gibelio*, 54.3 µg/kg for *C. carpio*, 85 µg/kg for *T. tinca*); Cu (0.48 mg/kg for *C. gibelio*, 0.296 mg/kg for *C. carpio*, 0.235 mg/kg for *T. tinca*), and Zn (9 mg/kg for *C. gibelio*, 6.1 mg/kg for *C. carpio*, 4.2 mg/kg for *T. tinca*) levels in the muscle tissues of the samples did not exceed the acceptable borders.

The EDI values of the metal(loid)s calculated for *C. gibelio* are given in Table 4. In this study, inorganic As values were used to calculate the health risk of arsenic. Inorganic As values were calculated as 3% of total As [13, 46]. Among the metal(loid)s examined, it was determined that inorganic As, Cd, Co, and Pb had the lowest EDI values, while Fe and Zn had the highest EDI values (Table 4). The EDI values of Cu, Fe, Mn, Ni, Zn, inorganic As (3% of total), Cd, Co, Cr, and Pb were found to be much lower than the reference doses (RfD) determined by USEPA [23] (Table 4). Consequently, it can be said that daily metal(loid) intake in *C. gibelio* species does not pose a health risk to consumers. Studies on fish species in other large reservoirs in Türkiye have reported similar results [15, 57].

Table 4 shows the estimated THQs for the metal(loid)s to which consumers are exposed through *C. gibelio* consumption. The THQs calculated for each metal(loid) in the muscle tissues of *C. gibelio* were found to be much lower than 1 (Table 4). These results point out that there are no non-carcinogenic risks to consumers due to the intake of individual metal(loid)s or combined metal(loid)s through fish consumption. There is consistency between this conclusion and the conclusions of the study conducted by Varol et al. [56]. They reported that the metal(loid) concentrations in the muscle of the samples from Kızılırmak River and the THQs of all the metal(loid)s in all the samples were < 1. The hazard index (HI) value in *C. gibelio* was found to be (0.038) (Table 4). If an HI value is below 1, consumers are unlikely to experience adverse health effects due to consumption of fish with combined metal(loid)s. For *C. gibelio*, Co has the highest THQ value, and its contribution to HI was determined as 34.99% (Table 4).

Table 4 shows that the carcinogenic risk (As-CR) value of inorganic As is 9.77×10^{-7} for *C. gibelio*. As-CR value is lower than 10^{-6}. This result points out that there is no carcinogenic health risk arising from fish consumption in terms of consumers' health.

The maximum safe consumption quantity (MSCQ) refers to the daily allowable quantity of fish consumption for a 70 kg adult without being exposed to any harmful effects of metal(loid)s. The MSCQ values were found to be sufficiently high for all the metal(loid)s in *C. gibelio* in terms of non-carcinogenic health effects (Table 4). Of all the metal(loid)s, Co indicated the least MSCQ values in *C. gibelio* (Table 4). The least MSCQ values specify that if an adult that weighs 70 kg consumes more than 1310 g of *C. gibelio* daily, this has the potential to lead to non-carcinogenic health effects (Table 4). Besides, the MSCQ values related to inorganic As (3% of the total As) in the fish species were found to be sufficiently high, which means that consumers will not experience any health risks (2.71 kg/day in *C. gibelio*) (Table 4). In terms of carcinogenic effects, the MSCQ value for inorganic As in *C. gibelio* was found to be 70 g (Table 4). All the MSCQ values regarding all the metal(loid)s in *C. gibelio* samples in terms of both non-carcinogenic and carcinogenic health effects were calculated to be higher than 18.4 g/day. This rate shows the average fish consumption in Türkiye. As a result, there are no non-carcinogenic or carcinogenic health risks arising from fish consumption for consumers' health.

USEPA [31] states that using the lower MSCQ values for both health effect categories will protect consumers from the carcinogenic and non-carcinogenic health effects of metal(loid)s. According to the research findings, the MSCQ values for carcinogenic effects are lower than for non-carcinogenic effects. This suggests that a 70 kg person can eat less than 70 g of *C. gibelio* per day without experiencing any health problems.

Table 3 Mean concentrations of metal(loid)s detected in muscle of *C. gibelio* in this study and maximum permissible levels for fish (units mg/kg ww)

	iAs	As	Cd	Cr	Cu	Zn	Pb	
C. gibelio (the current study)	0.00696	0.232	0.010	0.315	0.704	7.670	0.008	This study
Maximum acceptable values								
Chinese Health Ministry	0.1			2.0				[53]
European Commission Regulation			0.05				0.3	[54]
Food and Agriculture Organization					30	30		[55]

iAs inorganic As (3% of total arsenic)

Table 4 Estimation of health risk from consumption of *C. gibelio* due to their metal(loid) contents

	Target hazard quotient (THQ)										**HI**	**CR**
	Cu	**Fe**	**Mn**	**Ni**	**Zn**	**As[a] (3%)**	**Cd**	**Co**	**Cr**	**Pb**		
C. gibelio	4.44E − 03	2.89E − 03	7.58E − 04	6.44E − 03	6.44E − 03	5.85E − 06	2.52E − 03	1.34E − 02	5.29E − 05	1.34E − 03	3.83E − 02	9.77E − 07
	Contribution of the THQ each metal(loid) to the HI (%)											
	Cu	**Fe**	**Mn**	**Ni**	**Zn**	**As[a] (3%)**	**Cd**	**Co**	**Cr**	**Pb**		
C. gibelio	11.59	7.54	1.98	16.81	16.81	0.01	6.58	34.99	0.14	3.50		
	Estimated daily intake (EDI) (µg/kg bw/day)											
	Cu	**Fe**	**Mn**	**Ni**	**Zn**	**As[a] (3%)**	**Cd**	**Co**	**Cr**	**Pb**		
C. gibelio	1.85E − 01	2.11E + 00	1.11E − 01	1.34E − 01	2.01E + 00	1.83E − 03	2.63E − 03	4.20E − 03	8.28E − 02	2.10E − 03		
RfD (µg/kg bw/day)	40	700	140	20	300	0.3	1	0.3	1500	1.5		
	Maximum safe consumption quantity (MSCQ) for noncancer effects (kg fish ww/day)										MSCQ for cancer effects (kg fish ww/day)	
	Cu	**Fe**	**Mn**	**Ni**	**Zn**	**As[a] (3%)**	**Cd**	**Co**	**Cr**	**Pb**	**As[a] (3%)**	
C. gibelio	3.98	6.09	23.3	2.74	2.74	2.71	7	1.31	333	13.12	0.07	

[a]Inorganic arsenic

Conclusions

The current research was an investigation into the levels of 10 metal(loid)s in the tissues (muscle, gills, and liver) of *C. gibelio* in the Kızılırmak River and was an evaluation of the health risks of metal(loid)s created by fish consumption. The findings of the research concluded lower levels of the metal(loid)s in the muscle of *C. gibelio*, but the gills and liver had higher concentrations. It was determined that the gender of the fish did not affect the accumulations of the metal(loid)s in the tissues. The values of the EDI, THQ, HI, and CR pointed out that there were no health risks from exposure to the metal(loid)s in *C. gibelio* due to consumption. It was concluded that an adult's consumption of less than 70 g of *C. gibelio* per day would not pose any health risk. In addition, in terms of food safety and human consumption, the mean concentrations of Cd, Cr, Cu, Zn, Pb, and inorganic As in the muscle tissue of *C. gibelio* appear to be below the legally permitted limits. Consequently, the consumption of *C. gibelio* does not have any risk to consumers' health. Also, the Kızılırmak is an important water and nutrient source of Türkiye. Thus, it is envisaged that periodic monitoring of the pollution of this river through studies on other fish species and different regions will be important for both the future of this water mass and the health of aquatic creatures and local people.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s12011-024-04355-6.

Author Contribution EK designed the study, collected the fish samples, and performed laboratory analyses of the samples. EK and EK completed the interpretation of the data, made the health risk assessments, and prepared and finalized the design.

Data Availability Data are available on request from the authors.

Declarations

Ethics Approval and Consent to Participate Before this study, we applied to our university for the ethical permission. However, Nevşehir Hacı Bektaş Veli University Ethics Committee stated that approval was not required as no experimental study was conducted with alive fish samples in this study.

Competing Interests The authors declare no competing interests.

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