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Health risk assessment of heavy metal concentrations in selected fish species from İznik Lake Basin, Turkey

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Abstract Various wastes, especially heavy metals, which are introduced to water sources in an uncontrolled manner, accumulate in aquatic organisms in the food web. Through the consumption of fish and invertebrates, those contaminants reach humans. In response to rapid industrialization, the accumulation of heavy metals in fish adversely impacts human health. The purpose of this study was to evaluate the accumulation of some heavy metals (Chromium, Cadmium, Mercury, Lead, Iron, Copper, Zinc, and Arsenic) among 11 fish species inhabiting in İznik Lake Basin (Turkey) that are threatened by anthropogenic pollution. Results showed significant differences among species with the accumulation of heavy metals ($p < 0.001$ and $p < 0.05$). Chromium, zinc, arsenic, and lead presented the highest contents in *Capoeta tinca* caught from Çakırca Stream. The contents of lead, copper, and zinc were higher than the guidelines of various authorities. The potential human health risk assessment was conducted by provisional tolerable weekly intake (PTWI). In *Rutilus rutilus* and *Cyprinus carpio*, the estimated weekly intake (EWI) for mercury was higher than the PTWI. The findings of this study are of great importance in terms of understanding the effect of fish consumption on human health in the heavy metal polluted area.

Keywords Arsenic · İznik Lake · PTWI · Accumulation · Risk assessment

Introduction

Various agricultural or industrial human activities lead to the accumulation of heavy metals in the ecosystems which is evaluated as one of the highest environmental risks (Han et al., 2002; Sandeep et al., 2019). Due to their persistence, toxicity, and lack of biodegradation, freshwater aquatic systems are being polluted by heavy metals (Adesiyan et al., 2018). Fishes are generally the organisms at the top of the aquatic food web which are the most affected by environmental pollution in aquatic environments. Since fish are more sensitive to toxic substances than other aquatic organisms, they are used as biomonitors to determine the risk potential in human consumption (Benaduce et al., 2008; Papagiannis et al., 2004). The increasing contamination with heavy metals in fish can be toxic to humans as well as to other organisms such as predator fish (Li et al., 2015) or aquatic bird species (Kanwal et al., 2020).

The discharge of pollutants threatens ecosystems through toxic effects (Monsefrad et al., 2012). Studies have shown that the metal accumulation in fish may be caused by various factors such as the type of

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metal, exposure time, environmental conditions, the ecology, feeding habits, diet and size of the fish, target tissue, or organ (Rajeshkumar et al., 2018; Varol & Şen, 2012; Wang et al., 2020; Xie et al., 2020; Yi & Zhang, 2012).

İznik Lake is the largest freshwater lake in the Marmara Basin (NW Turkey) and the fifth-largest lake in Turkey. The maximum water depth is 80 m and the surface area is about 308 km^2 (Akcaalan et al., 2009; Ozbayram et al., 2021). It has five main inlets, Orhangazi, Kırandere, Kuru, Çakırca, Sölöz, and Ekinlik streams and one outlet (Özuluğ et al., 2005). The lake is also fed by groundwater (Akbulak, 2009; Ülgen et al., 2012). Although İznik Lake has great importance both ecologically and economically, agricultural activities and anthropogenic wastes, especially olive groves and vegetable gardens, contribute significantly to the pollution in the lake. In addition, there are many industrial facilities around the Orhangazi district (Ünlü et al., 2010).

The potential risk of contaminants in fish is of particularly great importance due to human consumption. Since fish and fish products could be an important cause of human exposure to heavy metals, the main purpose of this study is to assess the pollution level of the İznik Lake Basin by determining heavy metal accumulation in fish muscles.

Material and methods

Study area and sample collection

Field surveys were conducted at monthly intervals between January and May 2014 in the lake and stream sites (Çakırca, Sölöz, and Kırandere) around the lake. The map (Fig. 1) was created using the QGIS v. 3.4 software. Fish sampling was made by backpack electrofishing (SAMUS 725G) in streams. The lake fish samples were purchased from a local fisherman on the same day of capture. All fish samples were individually stored in low-density polyethylene bags and kept at −20 °C in the freezer until the analysis.

Sample preparation

In the laboratory, the specimens were defrosted and weighed with a digital balance to 0.01 g accuracy (body weight, W), and measured to the nearest 0.1 cm (total length, TL). Approximately 1.0 g of wet muscle tissues (under the dorsal fin) from each fish specimen were weighed and deep-frozen until the metal analysis. Then, samples were homogenized and washed with distilled water. For digestion of duplicate samples, nitric acid and hydrogen peroxide (2:1) were

Fig. 1 İznik Lake and main streams flowing into the lake

used. The closed-vessel microwave (Berghoff Microwave MWS-2, Germany) system was used for digestion and performed at 150 °C for 20 min, followed by a cooling period at room temperature for 35 min in (Guhathakurta & Kaviraj, 2000). After digestion, the final volume was adjusted to 50 ml with deionized water and filtered through 0.45 µm Whatman GFC filter paper. A blank digest was processed in the same way.

Determination of metal concentrations

The concentration of heavy metals, cadmium (Cd), chromium (Cr), lead (Pb), mercury (Hg), copper (Cu), zinc (Zn), iron (Fe), and arsenic (As), was measured in the muscle of fish using a Perkin Elmer Elan-6000 inductively-coupled plasma mass spectrometry (ICP-MS). The instrumental parameters were shown in Table 1 (Chamberlain et al., 2000). The calibration curve was prepared by diluting the multi-element standard solutions (Merck) of 1000 mg L^{-1} of each element. For mercury analysis, the addition of gold solution to samples was used for preserving all forms of mercury.

The Fish Muscle European Reference Material (ERM-BB422) was used to assess the accuracy of the method. Relative standard deviation (RSD), instrumental detection (LOD), and quantification limits (LOQ) were calculated according to Mataveli et al. (2013). The recovery percentages were between 98 and 105% and were accepted to validate the calibration. The obtained RSD% values were within 0.63–8.15%. Data were represented as a mean of triplicates for each sample. LOD and LOQ of elements were Cd 0.002–0.007 µg L^{-1}; As 0.004–0.012 µg L^{-1}; Pb 0.001–0.003 µg L^{-1}; Cr 0.008–0.018 µg L^{-1}; Cu 0.006–0.012 µg L^{-1}; Zn 0.010–0.031 µg L^{-1}; Fe 0.012–0.038 µg L^{-1}, and Hg 0.005–0.015 µg L^{-1}, respectively.

Table 1 Operating parameters of ICP-MS

Characteristics	Instrument conditions
RF Power	1400 W
Nebulizer gas	Argon
Auxiliary gas flow	1.4 L min^{-1}
Nebulizer gas flow	0.99 L min^{-1}
Plasma gas flow	14.0 L min^{-1}
Number of replicates	3
Sweeps/reading	10
Sampler & skimmer cone	Nickel

Calculation of Weekly Intake (EWIs) of the metals analyzed

The potential human health risk assessment of heavy metals was calculated with the estimated weekly intake (EWI). The edible fish tissue consumption was calculated according to the consumption of fish per person in Turkey, which was 5.5 kg/person in 2017 (TUIK, 2017), and average heavy metal content. The EWI and EDI (Estimated Daily Intake) values were calculated by assuming that a 70-kg person would consume 105.5 g of fish/week. In addition, Provisional Tolerable Weekly Intake (PTWI) was computed to determine the maximum amount of pollutants that a person could be exposed to weekly over a lifetime without any additional health risk (National Academy of Science, 1989; FAO/WHO, 1996, 2010; Council of Europe, 2001; Panel & Chain, 2009).

Statistical analysis

Statistical analysis and visualizations were performed using R ver. 4.0.3 (R Core Team, 2015). Pearson's correlation method was used to reveal the correlations between heavy metal concentrations among fish species and the length and weights of fishes were identified using the R software packages. The level of statistical significance was determined at $p < 0.001$, $p < 0.05$, and $p < 0.01$. Principal component analysis (PCA) was used to examine the variation of measured parameters among samples.

Results and discussion

Heavy metal concentrations in fish tissues

A total of 108 fish samples belonging to 4 families were investigated from the lake and stream sites ($n_{Lake} = 19$; $n_{Çakırca} = 36$; $n_{Kırandere} = 24$; $n_{Sölöz} = 29$) (Table 2). The length and weight distribution of each fish species were listed in Table 2. Among these species, there were commercially important fish species such as *A. boyeri*, *R. frisii*, and *C. gibelio*, as well as non-commercial species *B. tauricus*, *C. taenia*, and *C.*

Table 2 Distributions of individual numbers (*n*), body weight (W, g), and total length (TL, cm) of fish species obtained from İznik Lake Basin

Family	Species	*n*	Body weight (W, g)		Total length (TL, cm)		Station
			Min.–max	Mean ± SD	Min.–max	Mean ± SD	
Atherinidae	*Atherina boyeri* Risso, 1810	10	2.26–4.03	3.32 ± 0.68	6.9–8.4	7.8 ± 0.6	Çakırca
Leuciscidae	*Rutilus frisii* (Nordmann, 1840)	21	1.99–535.0	124.9 ± 197.3	6.50–40.0	19.2 ± 14.3	Çakırca, Sölöz, Kırandere, Lake
	Rutilus rutilus (Linnaeus, 1758)	1	9.29	-	9.6	-	Çakırca
	Squalius cii (Richardson, 1857)	32	1.89–166.2	49.89 ± 45.88	5.7–24.3	14.9 ± 5.1	Çakırca, Sölöz, Kırandere
	Vimba vimba (Linnaeus, 1758)	3	35.3–62.5	48.9 ± 13.6	14.4–17.4	16.0 ± 1.5	Sölöz
Cobitidae	*Cobitis taenia* Linnaeus, 1758	1	2.18	-	7.0	-	Sölöz
Cyprinidae	*Barbus tauricus* Kessler, 1877	2	19.76–19.80	19.78 ± 0.03	12.2–13.2	12.7 ± 0.7	Çakırca
	Capoeta tinca (Heckel, 1843)	17	0.99–118.0	23.4 ± 28.2	4.7–22.4	11.4 ± 4.4	Çakırca, Kırandere, Lake
	Carassius gibelio (Bloch, 1782)	19	6.20–587.5	209.2 ± 230.9	6.5–30.8	17.9 ± 11.6	Çakırca, Sölöz, Kırandere, Lake
	Cyprinus carpio Linnaeus, 1758	1	679.7	-	35.3	-	Lake
Siluridae	*Silurus glanis* Linnaeus, 1758	1	431.9	-	45.8	-	Lake

tinca, which have great importance to the ecosystem due to both their consumption by predators and their ecological niches. *Carassius gibelio* which is a non-native/invasive species in İznik Lake was first reported in 2004 (Gaygusuz et al., 2005). *Atherina boyeri*, a translocated fish species, was first introduced into the lake in 1991 (Altun, 1991) and has become one of the most important commercial fish species.

All of the fish samples investigated were analyzed for heavy metal concentrations and the levels of eight heavy metals in the muscles of eleven fish species from the basin were shown in Table 3. The maximum cadmium (0.16 mg kg^{-1}) concentration was found in *S.cii* captured from Çakırca Stream. The mean concentrations of the heavy metals in the muscle of *A. boyeri*, *R. frisii*, *S. cii*, and *C. gibelio* were as follows: Zn > Fe > Cu > Cr > As > Hg > Pb > Cd. It was similar to *C. tinca* with a difference in Hg, As, and Pb. The metal bioaccumulation was in the decreasing order of Pb > As > Hg in this fish. This could be due to the fact that different metals accumulate in the tissues of different species in different ways (Akan et al., 2012).

Heavy metal concentrations in muscles of species were compared with previous studies in different ecosystems and found that *R. frisii* has a higher Cu, Zn, Cd, and Hg values in all stations than the fish investigated from the Caspian Sea (Anan et al., 2005; Monsefrad et al., 2012). These differences can be attributed to two possibilities: (i) the use of fertilizers and agricultural pesticides could be the reason for the high level of heavy metals in the İznik Lake Basin (Oktem et al., 2012) and (ii) because of the size of the catchment area of the Caspian Sea, the heavy metal concentrations may have been diluted (Carpenter et al., 2011 Oil pollution in the Caspian Sea is thought to result in higher Pb levels than in İznik Lake (Eslami et al., 2011; Monsefrad et al., 2012). However, Viehberg et al. (2012) identified the anthropogenic pollution source of Pb in Sölöz Stream. The relatively high level of Pb in tissues is related to agricultural and industrial activities (Eslami et al., 2011) which are quite prevalent in this basin. Also, our study revealed that Cd and Hg are the highest concentrations in Sölöz Stream, as well.

Table 3 Heavy metal contents in the tissues of the studied species: minimum/maximum and mean values (mg kg^{-1} wet W)

Fish species	Heavy metal concentrations in muscle (mg kg^{-1}) mean ± SD (min.–max.)							
	Cd	Pb	As	Cr	Cu	Zn	Fe	Hg
A. boyeri	0.03 ± 0.01	0.22 ± 0.04	0.63 ± 0.18	0.75 ± 0.12	2.44 ± 0.44	97.6 ± 16.3	51.9 ± 13.8	0.28 ± 0.02
	ND–0.04	0.19–0.31	0.40–0.84	0.58–0.92	1.79–2.99	7.7–116.5	30.4–70.7	0.26–0.31
R. frisii	0.04 ± 0.03	0.24 ± 0.15	0.43 ± 0.23	1.03 ± 0.5	2.5 ± 0.52	44.1 ± 20.2	42.0 ± 11.9	0.33 ± 0.19
	ND–0.13	0.07–.0.60	0.06–0.93	0.22–1.95	1.48–3.34	10.5–76.6	25.8–72.1	ND–0.74
R. rutilus	0.01	0.15	0.61	0.64	3.77	48.2	49.2	0.13
S. cii	0.03 ± 0.03	0.19 ± 0.31	0.22 ± 0.2	0.62 ± 0.22	3.34 ± 1.88	55.9 ± 22.9	47.96 ± 17.33	0.2 ± 0.16
	ND–0.16	ND–1.78	ND–1.00	0.09–1.12	0.87–10.3	26.0–121.8	18.4–92.3	ND–0.68
V. vimba	0.01 ± 0.004	0.13 ± 0.03	0.14 ± 0.02	0.42 ± 0.02	5.06 ± 2.66	19.11 ± 3.43	62.1 ± 22.3	0.12 ± 0.03
	0.01–0.02	0.11–0.16	0.11–0.16	0.40–0.44	2.63–7.90	16.5–23.0	41.2–85.7	0.10–0.16
C. taenia	0.05	0.72	0.48	0.71	3.23	122.7	181.7	0.25
B. tauricus	0.04 ± 0.01	0.8 ± 0.09	0.43 ± 0.08	0.68 ± 0.06	5.65 ± 1.25	76.7 ± 9.6	90.8 ± 49.3	0.18 ± 0.06
	0.04–0.04	0.74–0.86	0.37–0.49	0.63–0.72	4.76–6.54	69.8–83.5	56–125.7	0.14–0.23
C. tinca	0.03 ± 0.03	0.83 ± 0.72	0.67 ± 0.42	1.11 ± 1.56	5.48 ± 2.32	93.7 ± 55.2	66.3 ± 20.0	0.21 ± 0.11
	ND–0.09	0.09–3.48	0.20–2.02	0.49–7.14	2.93–11.5	38.5–221.9	43.4–115.1	0.08–0.53
C. gibelio	0.03 ± 0.02	0.32 ± 0.22	0.44 ± 0.23	0.74 ± 0.57	2.90 ± 1.87	65.5 ± 25.8	35.1 ± 30.1	0.43 ± 0.28
	ND–0.08	0.12–1.08	0.12–0.78	0.19–2.43	0.80–5.97	15.7–102.6	0.54–132.6	ND–0.86
C. carpio	0.02	0.16	0.38	0.29	2.43	65.6	29.1	0.11
S. glanis	0.01	0.20	0.04	0.4	1.6	27.1	37.2	0.61

ND not detected

When heavy metal accumulations were examined in 11 fish species, Cd was found in undetectable levels (< 0.05) for all fish samples. Pb (3.48 mg kg^{-1}), Cu (11.5 mg kg^{-1}), Zn (221.9 mg kg^{-1}), Cr (7.14 mg kg^{-1}), and As (2.02 mg kg^{-1}) present the maximum concentrations in *C. tinca* caught from Çakırca Stream. Also, *C. gibelio* and *S. cii* had higher Cr, Fe, Zn, Hg, and Pb concentrations than the other sites. These results may indicate a continuous pollution input along the Çakırca Stream. The observed differences between the heavy metal content in species could be related primarily to their feeding habits, the metal content of the environment, and the bioconcentration capacity of each species (Farkas et al., 2000). Ünlü and Alpar (2016) reported that heavy metal concentrations in İznik Lake sediment were similar to accumulations in fish muscles, followed as Zn > Cr > Cu > As > Pb > Fe > Cd. The fish species, especially *B. tauricus*, *C. tinca*, *C. taenia*, *C. carpio*, and *S. glanis*, are bottom feeders, and the bioaccumulation from sediment could be the reason for long-term sources of contamination (Eimers et al., 2001; Klake et al., 2012). These results also supported that the sediment is the main source of heavy metal accumulation in fish, as reported in previous studies (Burrows & Whitton, 1983; Yi et al., 2011, 2017).

The highest As, Zn, Cu, and Cr concentrations were found in *C. tinca*, the highest concentrations of Cd and Pb in *S. cii*, the highest concentration of Fe in *C. taenia*, and the highest Hg concentration found in *C. gibelio*. Additionally, the correlograms showing significant correlations among heavy metals and length/weight parameters of each fish species are presented in Fig. 2. Chromium was the only heavy metal having a strong positive correlation with the size of *C. tinca* ($p < 0.05$). The results indicated a strong negative correlation between length/weight and Cu, Fe, and Zn concentrations in *S. cii* and *R. frisii* ($p < 0.05$ and $p < 0.001$, respectively). Although the general opinion is that the heavy metal concentration will increase as the length/weight increases, studies show that the metabolic rate and the dilution of metals may cause a negative correlation (Anan et al., 2005; Gašpić et al., 2002; Monsefrad et al., 2012).

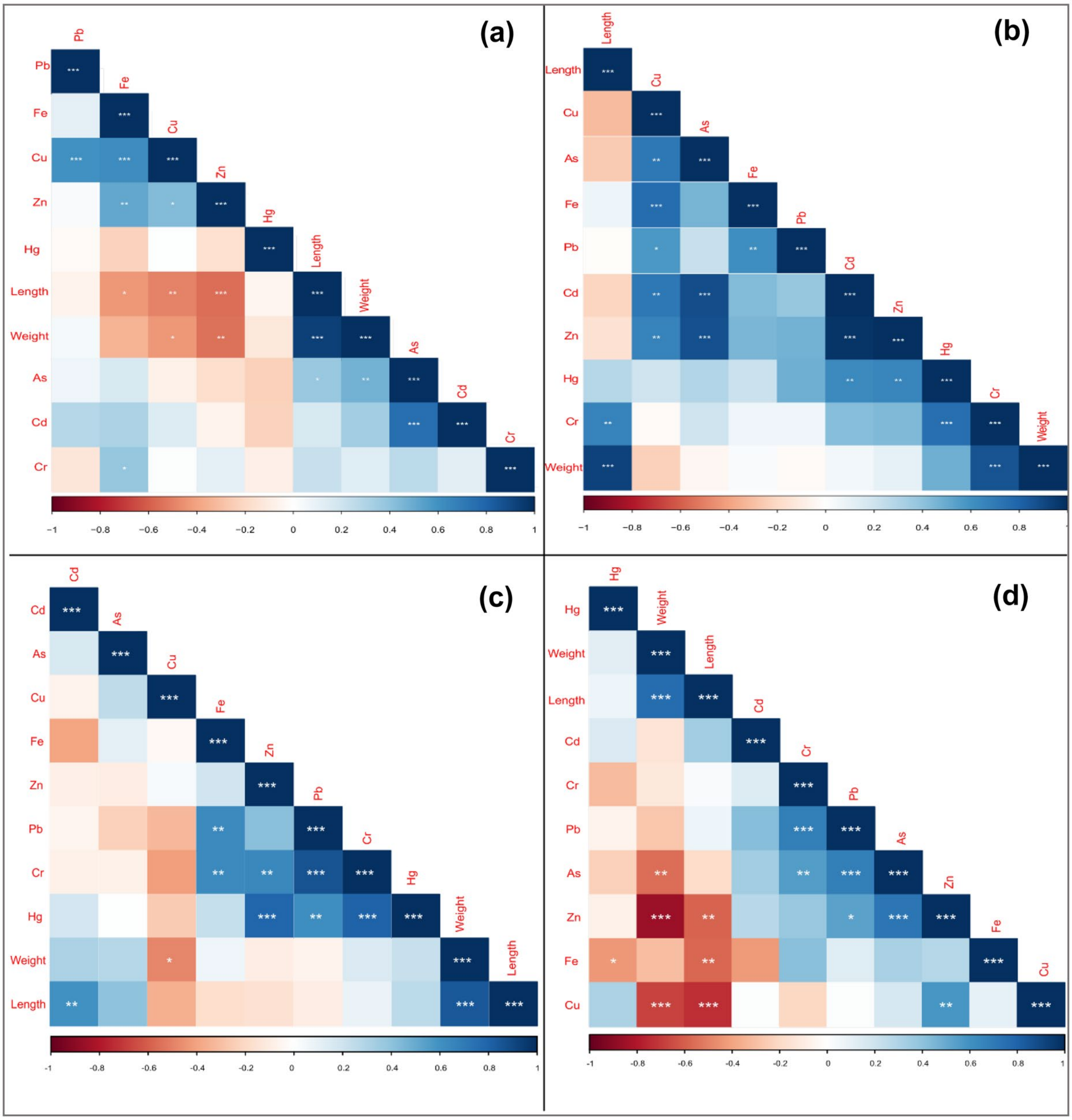

Fig. 2 The correlograms represent the correlations for all pairs of heavy metals for **a** *S. cii*; **b** *C. tinca*; **c** *C. gibelio*; **d** *R. frisii*. Red color represents negative and blue color represents positive correlations. The color intensity is proportional to the correlation coefficients (*$p<0.1$, **$p<0.05$,***$p<0.001$). Pb: Lead; Fe: Iron; Cu: Copper; Zn: Zinc; Hg: Mercury; As: Arsenic; Cd: Cadmium; Cr: Chromium

The heavy metal concentrations in the tissue of *S. cii* and *R. frisii* showed a negative correlation between fish size and iron ($p<0.1; <0.05$); zinc ($p<0.001$) and copper ($p<0.05$; $p<0.001$). The negative correlation between heavy metal levels and fish size depends on sex, age, and metal metabolism of fish species (Canli & Atli, 2003; Douben, 1989; Liang et al., 1999; Widianarko et al., 2000).

Results of statistical comparisons of heavy metal concentrations among four stations are given in Fig. 3. Although the general distribution showed that the fish were clustered according to the stations, it

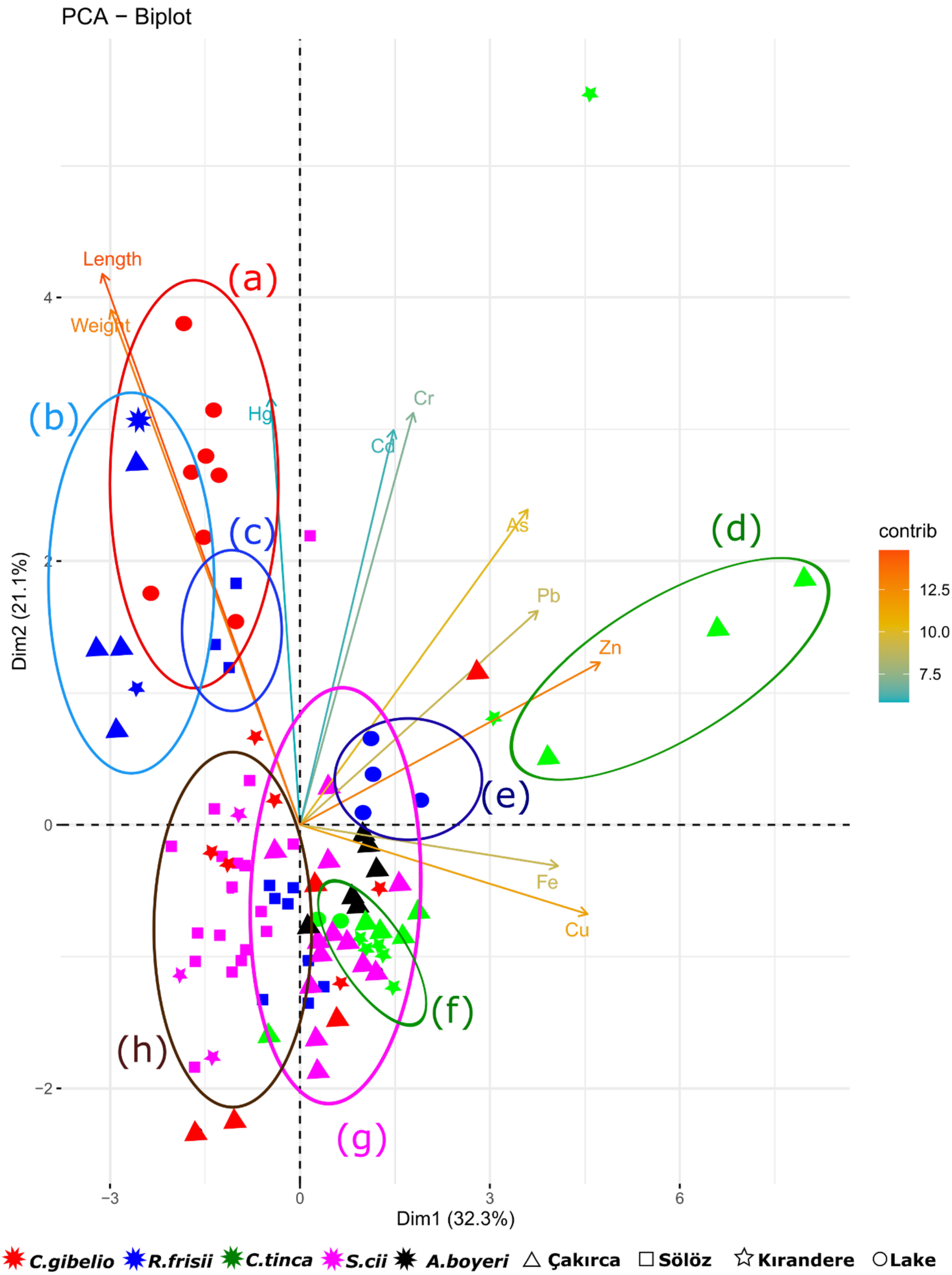

Fig. 3 The PCA plot of heavy metal concentrations in muscle of five studied fish species in different stations

was observed that some fish species were grouped according to the length and weight distributions (Fig. 3a–c) and heavy metal concentrations as well (Fig. 3d–f). The PCA analysis showed that the lake *C. gibelio* population was clustered depending on the size distribution while *R. frisii* population clustered depending on As, Pb, and Zn. *Squalius cii* populations had a similar pattern to the Sölöz and Çakırca streams which were affected by heavy metals negatively (Fig. 3g, h). In Çakırca Stream, the largest inlet feeding İznik Lake, it has been determined that the amount of pollutant input was very high. Although there were a decrease in the flow rates in Çakırca (1.032 m^3 sn^{-1}) and Kırandere (0.289 m^3 sn^{-1}) streams, the flow continued during the sampling period in all stations (TUBİTAK 112Y209 et al., 2015).

Since İznik Lake is surrounded by agricultural lands, the lake received agricultural wastes which were contaminated by heavy metals (Albay & Aykulu, 2002). Approximately 10,000 tonnes of fertilizer and 2550 tonnes of pesticides are used annually for agriculture (Albay & Aykulu, 2002; Katip, 2020; TÜİK, 2020). Nitrogen and phosphorus-based fertilizers containing high concentrations of Cd, Pb, As, and Cu caused accumulation in the freshwater system (Sönmez et al., 2008). In this study, the higher heavy metal concentrations found in fishes were Zn, Fe, and Cu. Similar to our results, Heiny and Tate (1997) reported that Cd, Cu, Ag, and Zn concentration increased in fish due to chemicals used in agriculture. Chaisemartin (1983) also determined that the use of fertilizers containing heavy metals caused accumulation in fish. Considering the pesticides and fertilizers used in İznik Lake, it is seen that these pollutants are the leading source of heavy metals in fish.

Health risk assessment from fish consumption

While comparing with national and international standards, the concentrations of all heavy metals were below the permissible limits for TKB and EPA (Table 4). The mean concentration levels of Cd, As, and Cu in fish muscles studied were below recommended limits for all fish species. Since the WHO permissible limits are lower than other regulations, some heavy metals were determined higher. In *B. tauricus* and *C. tinca*, Pb concentrations (0.8 mg kg^{-1} and 0.83 mg kg^{-1}, respectively) were higher than the

Table 4 The permissible content of heavy metals in fish (mg kg^{-1})

	TKB mg kg^{-1}	EPA	WHO
Pb	0.3		0.5
Cd	0.05	1,4	0.5
As	1		1,8
Cr		4,1	0.15
Hg	0.5		0.5
Cu		54	30
Zn		410	30
Fe		410	100

EPA Environmental Protection Agency, *TKB* Turkish Fisheries Laws and Regulations, *WHO* World Health Organization

maximum permissible limits. Chromium concentrations (0.29–1.11 mg kg^{-1}) exceed the limits for all species. Zinc also has high concentrations between 44.1 and 122.7 mg kg^{-1} in all fishes except *V. vimba* and *S. glanis* (Nyingi et al., 2016).

To evaluate health risks from fish consumption, provisional tolerable weekly intake (PTWI) (mg/week/70 kg, body weight) and estimated weekly intake (EWI) values in the muscle of studied fishes were calculated (Table 5). According to the Turkish Statistical Instıtute (TUIK), the per capita fish consumption in Turkey is 105.5 gr day^{-1} (TÜIK, 2017). The EWI's of mercury were calculated to range from 0.16 to 0.93 mg per person. Except for *R. rutilus* and *C. carpio*, all the EWI values of mercury were found higher than the permissible limits. İznik Lake and its basin are polluted with anthropogenic pollutants, such as the use of fertilizers and agricultural pesticides composed of arsenic and mercury (Oktem et al., 2012). Studies have shown that mercury-containing pesticides can be detected in fish muscles even after 30 years of exposure (Chen & Gao, 1993; Yang et al., 1994). Barut et al. (2018) recorded that according to geoaccumulation index, the lake was polluted by Hg from moderately to highly polluted. The rest of the heavy metals were below the recommended PTWI. Data showed that metal intake in an adult person consuming commercial fish species in the İznik Lake basin is generally lower than recommended values for human consumption (FAO/WHO, 2006). Also according to Ünlü & Alpar, 2016, Cu, Pb, Zn, and Cd in the sediment had no harmful effect on living organisms in İznik Lake sediment.

Table 5 Estimated weekly intakes (EWI) of examined species

	Cr	Fe	Cu	Zn	As*	Cd	Pb	Hg
Atherina boyeri	1.13	78.13	3.67	147.04	0.95	0.04	0.33	0.42
Rutilus frisii	1.55	63.28	3.77	66.52	0.65	0.04	0.37	0.50
Rutilus rutilus	0.96	74.06	5.68	72.68	0.92	0.01	0.23	0.20
Squalius cii	0.94	72.26	5.03	84.28	0.33	0.05	0.29	0.30
Vimba vimba	0.64	93.54	7.62	28.80	0.20	0.02	0.20	0.28
Cobitis taenia	1.07	273.79	4.87	184.92	0.72	0.07	1.08	0.37
Barbus tauricus	1.02	136.87	8.51	115.49	0.65	0.06	1.21	0.28
Capoeta tinca	1.62	99.88	8.26	141.16	1.01	0.04	1.08	0.31
Carassius gibelio	1.11	52.89	4.37	98.72	0.66	0.04	0.49	0.65
Cyprinus carpio	0.44	43.87	3.65	98.86	0.58	0.03	0.25	0.16
Silurus glanis	0.61	56.0	2.41	40.82	0.06	0.02	0.31	0.93
Guidelines for PTWI (mg/week/kg)	0.02	5.6	3.5	7.0	0.02	0.01	0.03	0.004
PTWI (mg/week/ 70 kg bw)	1.63	392	245	490	1.05	0.49	1.75	0.28

EWI estimated weekly ıntake, *PTWI* provisional tolerable weekly ıntake

*Total arsenic concentrations were converted to inorganic arsenic (Panel & Chain, 2009)

Conclusion

As a result of this study, significant differences were identified among species in view of the accumulation of heavy metals. The content of the studied heavy metals in the edible muscle is generally lower than the maximum permitted contents recommended by FAO/WHO. *Capoeta tinca* was found to have a higher ability to accumulate heavy metals compared to fish species (such as *A. boyeri*, *C. carpio*, and *S. glanis*) consumed by humans. However, periodic monitoring of heavy metals content in İznik Lake fishes must be performed to reduce the health hazards both in humans and the ecosystem associated with fish consumption.

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Data availability statement The author confirms that the data supporting the findings of this study are available within the article. Raw data that support the findings of this study are available from the corresponding author, upon reasonable request.

Declarations

Conflict of interest The author declares no competing interests.

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