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Health risk assessment of the heavy metal levels in marketed *Liza aurata* (Risso, 1810) from the Urla Coast (Eastern Aegean Sea, Türkiye)

by

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Abstract

Heavy metal pollution in the coastal areas is a widespread environmental problem that may threaten seafood safety. This study aimed to determine Cd, Pb, Cu, and Zn concentrations in the gill, liver, and muscle tissues of marketed *Liza aurata* and to evaluate the potential health risks for consumers. Fish samples were seasonally collected during 2017–2018 from the Urla coast of Izmir Bay. Metal concentrations in all tissues followed the order Zn > Cu > Pb > Cd. Consumer health risks were assessed using estimated weekly intake (EWI), estimated daily intake (EDI), target hazard quotient (THQ), total target hazard quotient (ΣTHQ), and CR indices. The EWI values for Cu and Zn were within safe limits, whereas Cd exceeded the provisional tolerable weekly intake (PTWI) based on a 70 kg adult in both years. THQ values for all metals were below 1, and ΣTHQ values were 0.144 in 2017 and 0.182 in 2018, indicating no non-carcinogenic risk from consumption. In addition, CR values for Cd and Pb were acceptable according to US EPA guidelines. Pb levels approached the 1×10^{-6} threshold, indicating negligible risk, while Cd showed low acceptable risk between 1×10^{-6} and 1×10^{-4}. Overall, the results suggest that *L. aurata* can be considered a useful bioindicator species for monitoring heavy metal pollution in İzmir Bay.

Key words: Eastern Aegean Sea, heavy metal, health risk assessment, *Liza aurata*, mullet

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1. Introduction

Heavy metals are constantly being introduced into marine environments through natural inputs and anthropogenic inputs and can cause global concern owing to their toxicological nature, chronic build-up in the environment, and ecological hazards (Shah, 2021). They are perceived as being an integral part of the environmental pollution issues because of their toxicity, bioaccumulating, and biomagnifying potential throughout the food chain (Edo et al., 2024). Heavy metals can be classified into two groups: potentially toxic metals (Cd, Pb, and Ni) and physiologically essential metals (Cu, Zn, and Fe).

Long-term exposure to toxic metals, even at low concentrations, and excessive intake of essential metals can lead to severe toxic effects on human health (Jomova et al., 2025). Such prolonged heavy metal exposure can cause various health problems such as organ dysfunction, skeletal deformities, cardiovascular diseases, and neurological disorders. Since fish are at the top of the aquatic food chain, they can accumulate heavy metals through water, nutrition, sediment, and suspended particulate matter (Kamidis et al., 2024). For this reason, fish are frequently used bioindicators to both biologically monitor the pollution level of aquatic environments and to assess risks in the food chain (Iyiola et al., 2024; Kadim & Risjani, 2022).

Metal absorption in fish occurs via two main pathways: the digestive system and the gill surface (Kwong, 2024). The normal cellular metabolism of fish requires the uptake of essential metals (e.g., Cu and Zn), which can be taken up into the tissues by these pathways, while non-essential metals (e.g., Cd and Hg) can also be absorbed and accumulated in the tissues by similar pathways (Chandrapalan & Kwong, 2021; Lall & Kaushik, 2021). Thus, measuring metal accumulation in various tissues such as the gills, liver, and muscle in fish provides more realistic information about the pollutant burden in aquatic ecosystems (Sharma et al., 2024). The liver is the principal site of accumulation, biotransformation, and excretion of pollutants, which also include metals (Shahjahan et al., 2022). As they are involved in gas exchange, acid–base balance, and ion movement, the gills are directly exposed to water, and the metal levels accumulated in the gills can reflect to the metal levels in the surrounding water (Kwong, 2024). The control and follow-up of metal levels in fish muscle tissue are very important, from the viewpoint of fish health and also in terms of public health risks due to fish consumption (Ustaoğlu & Yüksel, 2024; Varol et al., 2022). Toxic metals accumulate in the fish body and their gills are the primary route of uptake of these metals, which can be passed into the human body when consumed through the food chain. Many of these toxic metals are dangerous to human health (Sigamani et al., 2024).

The release of heavy metals into the aquatic system from industrial and agricultural activities, mostly found in the near-shore marine waters, have the potential risk of affecting the health of populations that consume locally caught seafood (Nyarko et al., 2023; Saleem et al., 2022). Hence, numerous studies have been previously carried out to explore the metal contamination in various edible fish species (Naeem et al., 2021). Various studies have been conducted over the years on metal accumulation in fish species from the Aegean Sea by researchers such as Taş et al. (2011, 2024), Kontas et al. (2022), Bilgin et al. (2023), Artar et al. (2024), and Yuvka et al. (2025).

Liza aurata, which is the species in focus in this study, is a globally distributed fish species extensively found at different coastal localities worldwide from the Aegean Sea, Mediterranean Sea, and Black Sea to the Eastern Atlantic Ocean. *L. aurata*, also known as the Golden head mullet or Yellow eared mullet, is one of the target commercial fishing species in the Aegean coast, which mainly lives in the coastlines and lagoons, and rarely migrates to freshwater (İlkyaz et al., 2006). Adult fish can grow to a length of 60 cm, and their meat and caviar have a high commercial value (Kaya, 2017). *L. aurata* acts as a good bioindicator of heavy metals pollution and affects human health as it is consumed by the local inhabitants (Aydın-Önen & Öztürk, 2017). Urla-İzmir Bay is a commercially and ecologically important fishing area where coastal pollution may pose a potential risk. The aim of this study is to determine the levels of Cd, Pb, Cu, and Zn in the gill, liver, and muscle of marketed *L. aurata* from the Eastern Aegean Sea. These metals are commonly studied because they can accumulate in fish tissues and pose risks to human health. The study also aims to evaluate the possible health risks for consumers by using the estimated weekly intake (EWI), estimated daily intake (EDI), target hazard quotient (THQ), and CR indicators.

2. Materials and methods

2.1. Study area

Located on the Aegean coast of western Turkey and of strategic importance in terms of maritime transportation and trade, the Gulf of Izmir is also an important production area where intensive fishing activities continue. The gulf, which has a surface area of approximately 410.3 km^2, is located between 38°20′–38°40′ north latitude and 26°30′–27°10′ east longitude. Due to the large number of fishing ports and harbors, a large portion of commercial fishing in the province of Izmir is concentrated in this region. While the gulf offers breeding, feeding, and growth areas for many aquatic species, it also attracts attention with its coastal fishing activities that continue throughout the year. In this area, where coastal fishing methods are prevalent, the fish caught are usually offered for consumption in local markets, with auctions held in the morning hours (Tokaç, 2017). This situation ensures that the aquatic products obtained from the region reach consumers directly and necessitates the evaluation of the effects of possible pollutants on human health.

2.2. Sample collection, preparation, and digestion procedure

Samples were obtained seasonally between 2017 and 2018 from individuals of *L. aurata* caught within the scope of commercial fishing activities carried out on the Urla coast of Izmir Bay and offered for sale at the Urla auction (Fig. 1). The fish samples used in this study were selected to reflect the actual consumption chain in the region. Fish were taken on the first day of fishing. In each sampling period, dead fish were collected from fishermen and immediately brought to the laboratory in polyethylene containers filled with ice. In this study, a total of 80 *L. aurata*, 10 for each season, were used to determine metal concentrations. The average total length of the fish samples was 24.49 ± 1.03 cm, and the average total weight was 250.49 ± 15.73 g. Approximately 5 g pieces were separated from the dorsal surface muscle, liver, and two gills of each fish sample using clean stainless steel instruments. Each tissue sample was measured as wet weight (0.0001 g) using the XB 22OA, Precisa (Zurich, Switzerland) instrument and stored in a freezer at −20°C until analysis. The samples were dissolved in concentrated HNO_3:$HClO_4$ (5:1) (extra pure Merck) according to the method of Bernhard (1976) and filtered. Heavy metal concentrations (Cd, Cu, Pb, Zn) were analyzed using an Inductively Coupled Plasma-Optical Emission Spectrometer (ICP-OES) (Perkin Elmer 2000 DV, Waltham, MA, USA). All samples were analyzed in triplicate to measure precision. Blank samples were always analyzed under the same conditions as the samples. The results are expressed as mg kg^{-1} wet weight. Standard solutions were prepared using Merck multi-element standard solutions (Darmstadt, Germany). DORM-2 shark muscle certified reference material was analyzed as a calibration verification standard, and recovery rates for each of the four elements in fish ranged from 96% to 106%, demonstrating good accuracy of the method.

2.3. Data analysis

The normal distribution of the data was tested using the one-sample Kolmogorov–Smirnov test. The homogeneity of variances was tested using Levene's test. Tukey HSD (Honestly Significant Difference) and Tamhane Tests were applied to determine the differences between tissue samples and sampling periods. Statistically significant differences were expressed as $p < 0.05$. All analyses were performed using SPSS 25.0 (IBM Corp., Armonk, NY, USA).

2.4. Estimation of potential public health risks

Evaluation of the possible risk of pollutants to human health is mainly based on prediction or identification of the adverse effects of toxicants on human health (Babuji et al., 2023). The EDI, EWI, target hazard quotient (THQ), hazard index (HI), and carcinogenic risk (CR) are parameters normally used for evaluation of the possible impact of heavy metals on human health by the United States Environmental Protection Agency (US EPA) (2007). These evaluation parameters can vary depending on factors such as the amount of metal intake, duration of exposure, the average body weight (BW), and the reference dose from mouth (RfD), US EPA (2007). Two integrated indices were estimated based on the non-carcinogenic and carcinogenic effects of heavy metal accumulation. While the non-carcinogenic index is used to evaluate the adverse effects of heavy metals on health, the carcinogenic index is used to evaluate the potential of certain metals to increase the risk of cancer.

The EWI and EDI heavy metal exposure due to fish consumption were determined for human health risk assessment and were also compared with the provisional tolerable weekly intake (PTWI). The weekly metal consumption that is acceptable as PTWI is established by the Food and Agriculture Organization/World Health Organization (FAO/WHO) and the Joint Expert Committee on Food Additives (JECFA) (FAO/WHO, 2010, 2011). The PTWI is the estimate, from all sources, of the amount of a substance in food or drinking water, expressed as an amount per BW that can be ingested weekly over a lifetime without appreciable health risks (mg · kg^{-1} or µg · kg^{-1} BW). EWI for the intake of fish muscle (g) was estimated using the following formula, and then EDI was obtained by dividing the EWI value by 7. In Türkiye, the average per capita consumption of aquatic products was 5.5 kg

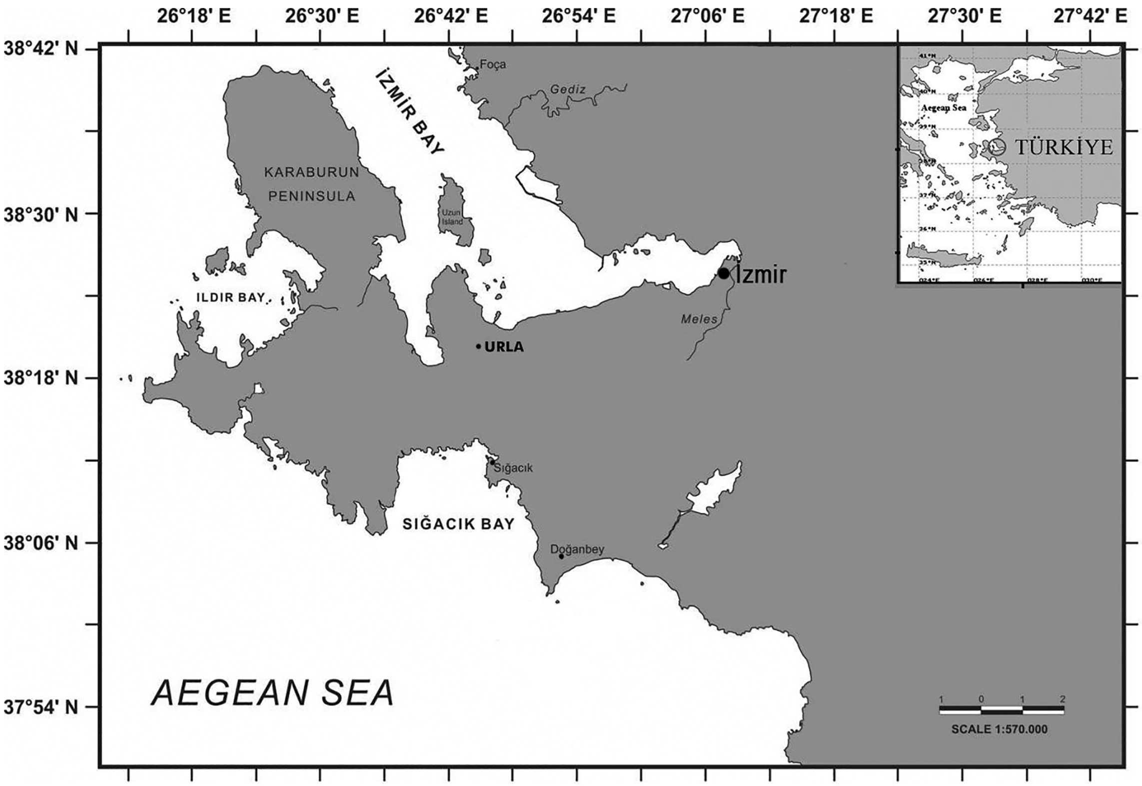

Figure 1

Sampling location.

in 2017, 6.3 kg in 2019, and 6.7 kg in 2021, while the annual per capita consumption of aquatic products was revealed as 7.3 kg in 2022, which increased by 12% in comparison to the previous year according to the data from TUIK (2023). The annual average per capita consumption of aquatic products in Türkiye is 7.3 kg or 20 g · person^{-1} · day^{-1}.

$$\mathrm{EWI} = \frac{\mathrm{WFC} \times \mathrm{MC}}{\mathrm{BW}}$$

MC: Concentration (average amount of metal in fish muscle tissue, mg · kg^{-1}) WFC: Consumption rate (g) BW: Indicates BW (kg).

Non-carcinogenic health risks posed by mullet consumption for Turkish consumers were evaluated according to the THQ. THQ expresses the non-carcinogenic risk of metal levels taken into the body. The formula used in the THQ calculation is given below (Abdel-Kader & Mourad, 2022; Korkmaz et al., 2019; Mol et al., 2017; Taş et al., 2024):

$$\mathrm{THQ} = \frac{\mathrm{EF} \times \mathrm{ED} \times \mathrm{IR} \times \mathrm{MC}}{\mathrm{RfD} \times \mathrm{BW} \times \mathrm{AT}} \times 10^{-3}$$

where EF is Exposure frequency (365 days · year^{-1}), ED is Exposure duration (year) (in case of a 70-kg adult exposed to metals through consumption for 30 years), IR is the Daily fish consumption rate, MC is the Determined metal concentration (mg · kg^{-1}), AT is the Average exposure duration (365 days × 30 years—non-carcinogenic), BW is body weight, RfD is the Oral reference dose (mg · kg^{-1}, day), and 10^{-3} is the unit conversion factor US EPA (2024). Oral reference dose (RfD) values of metals are given as 0.001; 0.04; 0.004; 0.3 (mg · kg^{-1}, day) for Cd, Cu, Pb, Zn, respectively, as per US EPA (2009). The value expressed as the total THQ value of all metals investigated is calculated as Σ THQ. A Σ THQ >1 indicates that there are non-carcinogenic health risks for consumers (US EPA, 1989):

$$\Sigma\,\mathrm{THQ} = \left(\mathrm{THQCd} + \mathrm{THQCu} + \mathrm{THQPb} + \mathrm{THQZn}\right)$$

In addition, the carcinogenic health risks associated with consuming grey mullet by Turkish consumers were evaluated according to the carcinogenic risks (CR) framework. CR refers to the increase in the risk of an individual developing cancer throughout their life as a result of exposure to a potential carcinogen.

This risk is calculated using the cancer slope factor (CSF), which determines the level of environmental exposure and the carcinogenic potential of the relevant chemical (Abbas, 2023). According to the US EPA (1989), acceptable lifetime carcinogenic risk levels for human health generally range between 10^{-4} and 10^{-6}. Carcinogenic risk is interpreted as $CR < 1 \times 10^{-6}$ insignificant risk; $1 \times 10^{-6} < CR < 1 \times 10^{-4}$ lower acceptable risk range, and $1 \times 10^{-3} < CR < 1 \times 10^{-1}$ high carcinogenic risk levels (Le et al., 2023). The specific CR value of a metal is calculated based on the CSF and the amount of exposure of the individual. Such risk assessments are critical for understanding the potential effects of heavy metal pollution on public health and for developing preventive policies. The lifetime carcinogenic risk was calculated using the formula given below (US EPA (2024); Ahmed et al., 2015). In this calculation, CSF values defined for toxic metals such as Pb and Cd were used. However, since there are no reliable CSFs defined for essential elements such as Zn and Cu and since these metals are physiologically required at certain levels in the body, CR calculations for Zn and Cu were not performed in this study. In this formula, for Cd and Pb, 0.380; 0.0085; the relevant slope factors of $mg \cdot kg^{-1} \cdot day^{-1}$ were used (Azadeh et al., 2022; Mohammadi et al., 2024; Pan et al., 2019):

$$CR = \frac{EF \times ED \times MC \times IR \times CSF}{BW \times AT} \times 10^{-3}$$

where CR is carcinogenic risk, EF is exposure frequency (365 days · $year^{-1}$), ED is exposure duration (years), MC is concentration of heavy metals in $mg \cdot kg^{-1}$ in fish muscle, IR is daily fish consumption rate, BW is body weight, AT is average exposure duration (365 days × number of exposure years, assuming 70 years for carcinogenic), 10^{-3} is the unit conversion factor, and CSF is the oral cancer slope factor provided by US EPA (1989).

3. Results and discussion

3.1. Metal concentrations of samples

In this study, heavy metal accumulation in *L. aurata* was investigated, and it was determined that the metal concentrations varied in different tissues. The average heavy metal accumulation of Cd, Cu, Pb, and Zn in the muscle, gill, and liver tissues of *L. aurata* is presented in Table 1, and their distribution according to seasons is presented in Figs. 2–5. According to the findings, metal concentrations followed the order of Zn > Cu > Pb > Cd in all tissues. In other words, Zn was detected at the highest concentration in all sampling periods and all tissue types, followed by other metals, respectively. Although positive and statistically significant relationships have been reported between the total length, BW, and metallothionein level in the liver cytosol of fish and metal accumulation in general (Oliveira et al., 2010; Wosnick et al., 2021), no significant relationship was found between the length and weight of *L. aurata* individuals and heavy metal accumulation in this study ($p > 0.05$).

3.1.1. Zinc

Zn is an essential trace element required for human and animal health and plays a role in the regulation of cellular functions by participating in the structure of many metalloenzymes. Its deficiency can affect the carcinogenesis process through weakening of the immune system and cellular damage (ATSDR, 2005). In this study, the average Zn concentrations varied depending on the tissue type (Table 1). Zn accumulation followed the order: liver > gills > muscle. Zn concentrations varied depending on the year and season. However, according to the results of statistical analyses, the

Table 1

Average concentrations of heavy metals in muscle, gill, and liver of *L. aurata* ($mg \cdot kg^{-1}$ ww).

Tissue	Periods	Cd	Cu	Pb	Zn
		(mean ± SE)	(mean ± SE)	(mean ± SE)	(mean ± SE)
Muscle	**2017**	0.324 ± 0.019^a	0.548 ± 0.032^a	0.648 ± 0.019^a	4.709 ± 0.166^a
	2018	0.452 ± 0.013^b	0.584 ± 0.041^a	0.638 ± 0.027^a	4.795 ± 0.185^a
Gill	**2017**	0.591 ± 0.035^a	1.053 ± 0.057^a	0.844 ± 0.030^a	15.795 ± 0.673^a
	2018	0.631 ± 0.023^a	1.047 ± 0.056^a	0.912 ± 0.022^a	14.658 ± 0.493^a
Liver	**2017**	0.862 ± 0.029^a	1.650 ± 0.061^a	1.871 ± 0.111^a	23.133 ± 0.268^a
	2018	0.930 ± 0.027^a	1.792 ± 0.044^a	1.913 ± 0.083^a	23.400 ± 0.364^a

[a,b] Different letters shown for each metal in the columns indicate statistically significant difference ($p < 0.05$).
SE, standard error.

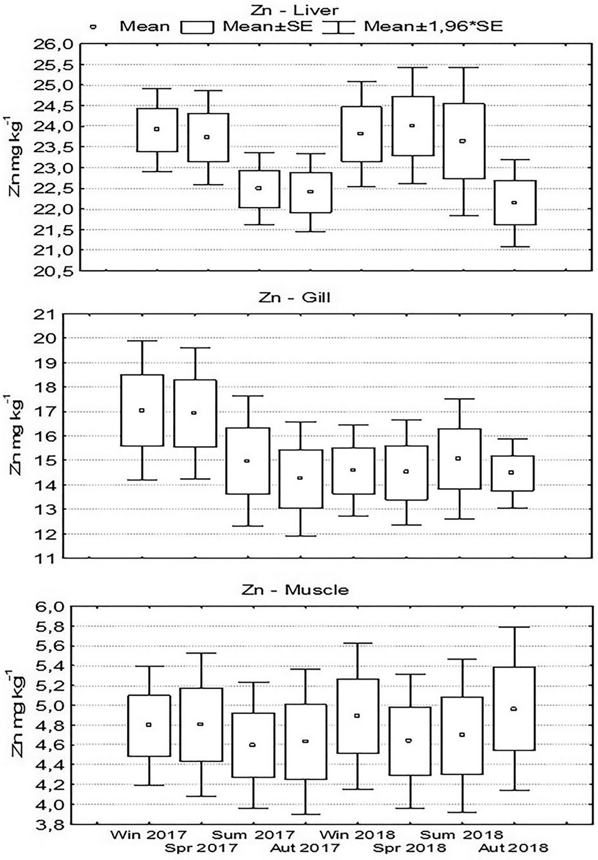

Figure 2

Seasonal distribution of Zn concentrations (mg · kg^{-1} ww) in liver, gill, and muscle tissues of *L. aurata*.

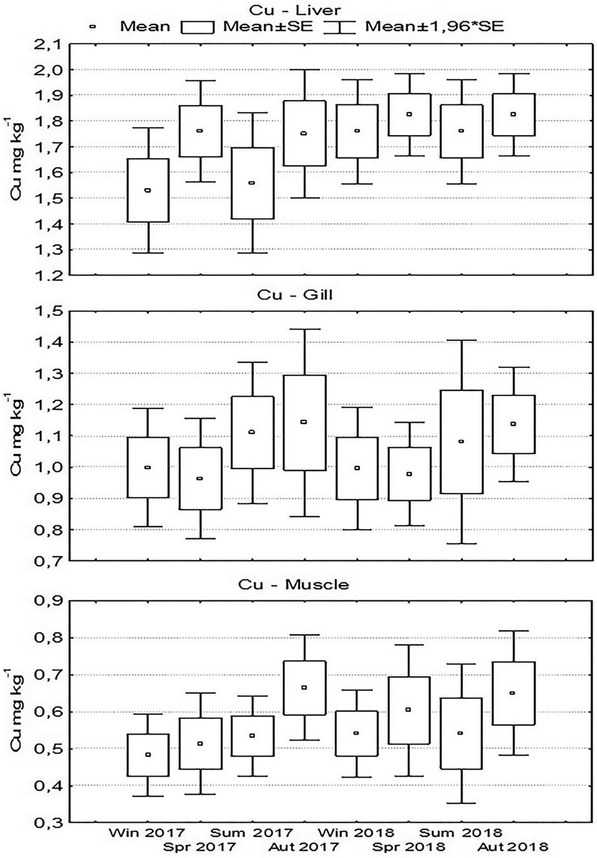

Figure 3

Seasonal distribution of Cu concentrations (mg · kg^{-1} ww) in liver, gill, and muscle tissues of *L. aurata*.

differences in Zn accumulation levels among all tissue types (muscle, gill, liver) were not found to be statistically significant ($p > 0.05$) (Fig. 2). In this study, Zn concentrations in the liver, gill, and muscle tissues were substantially lower than those reported in the Caspian Sea of Iran (Jelodar et al., 2011), the Payas coast of Turkey (Turan et al., 2022), the Sfax coast of Tunisia (Salem & Ayadi, 2016), and the Bizerte Lagoon (Telahigue et al., 2024) (Table 2). In contrast, the Zn levels in muscle tissue were found to be higher than those reported in the Gulf of Cádiz (Usero et al., 2003), Sinop (Bat et al., 2015), and the Aegean Sea (Aydın-Önen & Öztürk, 2017) (Table 2).

3.1.2. Copper

Cu is an essential trace element for human health, but excessive intake can lead to toxic effects. High copper exposure can cause health problems such as liver damage and gastrointestinal symptoms (US EPA, 2023; ATSDR, 2023). The average Cu concentrations were lowest in muscle tissue in 2017 (0.548 ± 0.032 mg · kg^{-1} ww) and highest in liver tissue in 2018 (1.792 ± 0.044 mg · kg^{-1} ww) (Table 1). The liver plays an important role in copper accumulation and detoxification (Zaghloul et al., 2024), and the obtained data are consistent with this physiological function. According to the results of statistical analyses, the differences in Cu accumulation levels among all tissue types (muscle, gill, liver) were not found to be statistically significant ($p > 0.05$) (Fig. 3).

The Cu concentrations obtained in this study were considerably lower compared with those reported in other studies conducted on *L. aurata* worldwide (Table 2). For example, in liver tissue, significantly high concentrations have been reported from the Caspian Sea (160.39 ± 40.01 mg · kg^{-1} ww; Jelodar et al., 2011) and the Bizerte Lagoon (47.88 ± 4.66 mg · kg^{-1} ww; Telahigue et al., 2024). Similarly, studies conducted in Turkey have also reported higher Cu levels. In the Akyatan Lagoon and along the Payas coast, liver Cu concentrations were reported as 19.0 ± 3.12 mg · kg^{-1} ww (Türkmen et al., 2012) and 21.11 ± 12.20 mg · kg^{-1} ww (Turan et

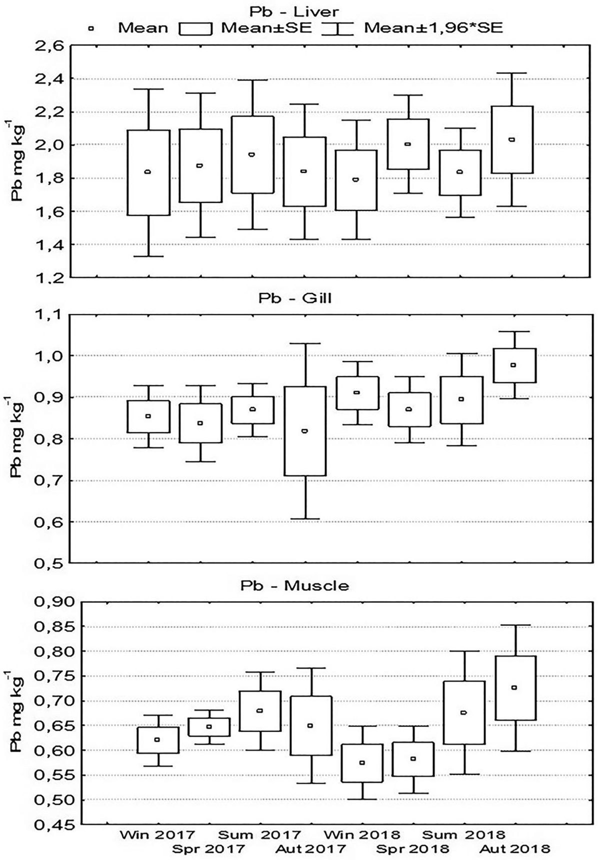

Figure 4

Seasonal distribution of Pb concentrations (mg · kg^{-1} ww) in liver, gill, and muscle tissues of *L. aurata*.

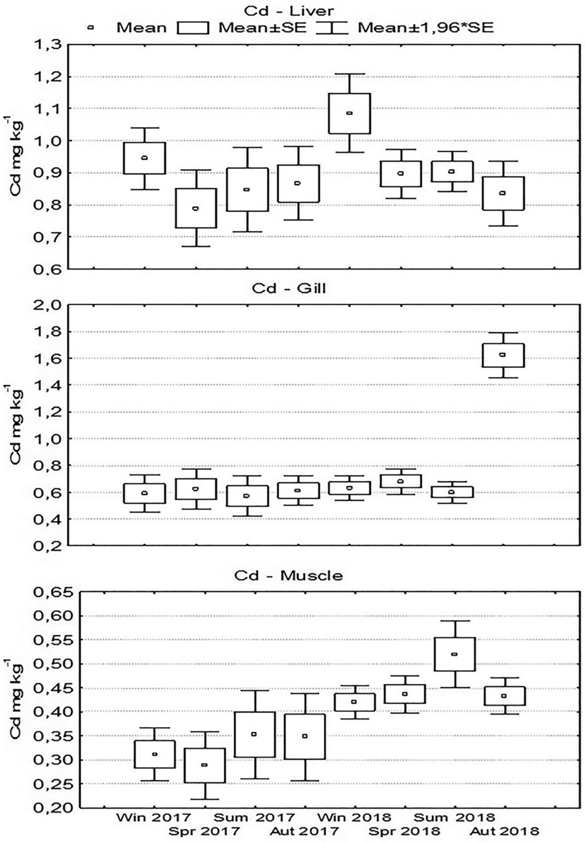

Figure 5

Seasonal distribution of Cd concentrations (mg · kg^{-1} ww) in liver, gill, and muscle tissues of *L. aurata*.

al., 2022), respectively, both substantially exceeding the levels measured in the present study. The Cu concentration of gill tissue also reported for the Akyatan Lagoon (2.27 ± 0.43 mg · kg^{-1} ww, Türkmen et al., 2012) is higher than in the present study. Similarly, the Cu concentration of muscle tissue found in the present study (0.566 ± 0.026 mg · kg^{-1} ww) was lower than that reported in the Akyatan Lagoon (Türkmen et al., 2012) and the Payas coast (Turan et al., 2022).

3.1.3. Lead

Pb is a nontarget, nonessential, toxic, and carcinogenic heavy metal lacking any essential roles for the human body. Although it occurs naturally at low levels, it is released in the environment primarily through anthropogenic uses like mining, industrial activities, and leaded gasoline, paint, and solder. Such heavy metal released into the aquatic environment can contaminate aquatic organisms through ingestion and enter into the food chain, and in the long run can be potentially dangerous to human health. Prolonged exposure may cause serious health effects like neurological disorders, hematological effects, cardiovascular diseases, renal failure, hypertension, and fertility problems in adult people (Telahigue et al., 2024) and retarded cognitive development and poor mental performance in children (Ramírez Ortega et al., 2021).

The mean Pb concentrations were lowest in muscle tissue in 2018 (0.638 ± 0.027 mg · kg^{-1} ww) and highest in liver tissue in the same year (1.913 ± 0.083 mg · kg^{-1} ww) (Table 1). Pb accumulation levels followed the order: liver > gill > muscle. According to the results of statistical analyses, the differences in Pb accumulation levels among all tissue types (muscle, gill, liver) were not found to be statistically significant ($p > 0.05$) (Fig. 4).

In the present study, the mean Pb concentration determined in muscle tissue (0.643 ± 0.016 mg · kg^{-1} ww) was found to be lower than the Pb levels reported in four separate studies on *L. aurata* from the Caspian Sea, Iran (Hosseini et al., 2022; Jelodar et al., 2011), Bizerte Lagoon, Tunisia (Telahigue et al., 2024), and

Table 2

Levels of heavy metals in mullet species from different regions of the world (mean ± SE mg · kg^{-1} ww).

Tissue	Species	Study Area	Cd	Cu	Pb	Zn	Reference
Liver	*L. aurata*	Ca'diz Bay (Spain)	0.14–0.51	13.7–64.0	0.25–0.48	30.6–81.8	Usero et al. (2003)
	L. aurata	*Caspian Sea (Iran)	1.07 ± 0.68	160.39 ± 40.01	2.60 ± 0.76	78.97 ± 29.93	Jelodar et al. (2011)
	L. aurata	Akyatan Lagoon (Türkiye)	0.07 ± 0.01	19.0 ± 3.12	0.53 ± 0.06	23.9 ± 1.88	Türkmen et al. (2012)
	L. aurata	*Sfax Coast (Tunisia)	0.55 ± 0.01	7.28 ± 1.12	0.57 ± 0.14	127.5 ± 0.06	Salem and Ayadi, (2016)
	L. aurata	Payas Coast, (Türkiye)	0.66 ± 0.14	21.11 ± 12.20	2.74 ± 1.50	46.09 ± 25.69	Turan et al. (2022)
	Mugil cephalus	*Damietta Port (Egypt)	1.08 ± 0.15	1.90 ± 0.08	2.31 ± 0.15	21.42 ± 1.56	Monier et al. (2023)
	L. aurata	Bizerte Lagoon (Tunisia)	1.44 ± 0.27	47.88 ± 4.66	2.04 ± 0.27	127.29 ± 13.8	Telahigue et al. (2024)
	L. aurata	Bardawil Lake (Egypt)	0.48 ± 0.43	19.64 ± 17.12	0.43 ± 0.37	9.17 ± 5.51	Zaghloul et al. (2024)
	Mullet	Rabat Estuary (Morocco)	0.0439	0.1806	0.0272	3.586	Aarabi et al. (2024)
	L. aurata	Urla, İzmir (Türkiye)	0.896 ± 0.02	1.721 ± 0.038	1.892 ± 0.006	23.266 ± 0.22	This study
Gill	*L. aurata*	*Caspian Sea (Iran)	0.90 ± 0.59	5.53 ± 1.01	3.61 ± 0.70	60.14 ± 2 6.60	Jelodar et al. (2011)
	L. aurata	Akyatan Lagoon (Türkiye)	0.08 ± 0.00	2.27 ± 0.43	0.40 ± 0.06	14.2 ± 1.45	Türkmen et al. (2012)
	L. aurata	*Gasthani Estuary (India)	0.7	-	1.8	252.7	Gawade et al. (2013)
	L. aurata	*Sfax Coast (Tunisia)	0.30 ± 0.03	0.04 ± 0.00	1.97 ± 0.35	171.2 ± 0.02	Salem and Ayadi (2016)
	L. aurata	Bizerte Lagoon (Tunisia)	0.88 ± 0.07	8.92 ± 0.76	1.94 ± 0.31	117.44 ± 1 9.9	Telahigue et al. (2024)
	Mullet	Rabat Estuary (Morocco)	0.0064	0.0712	0.0193	2.506	Aarabi et al. (2024)
	L. aurata	Urla, İzmir (Türkiye)	0.741 ± 0.043	1.050 ± 0.04	0.878 ± 0.019	15.226 ± 0.41	This study
Muscle	*L. aurata*	Ca'diz Bay (Spain)	0.013–0.030	0.20–0.60	0.03–0.05	3.10–8.41	Usero et al. (2003)
	L. aurata	*Caspian Sea (Iran)	0.35 ± 0.23	4.54 ± 1.07	1.50 ± 0.53	13.69 ± 7.23	Jelodar et al. (2011)
	L. aurata	Akyatan Lagoon (Türkiye)	0.06 ± 0.00	0.80 ± 0.13	0.41 ± 0.05	7.16 ± 0.98	Türkmen et al. (2012)
	L. aurata	*Gasthani Estuary (India)	0.7	-	1.8	252.7	Gawade et al. (2013)
	L. aurata	Tagus Estuary (Portugal)	0.01–0.02	<dl	0.11–0.30	16–19	Maulvault et al. (2015)
	L. aurata	Sinop (Türkiye)	<0.02	<0.5	<0.05	2.9	Bat et al. (2015)
	L. aurata	*Sfax Coast (Tunisia)	0.10 ± 0.05	nd	0.17 ± 0.05	106 ± 0.21	Salem and Ayadi (2016)
	L. aurata	*Aegean Sea (Türkiye)	0.001–0.004	nd—0.058	nd—0.039	0.138–0.555	Aydın-Önen and Öztürk (2017)

(Continued)

Table 2

Continued

Tissue	Species	Study Area	Cd	Cu	Pb	Zn	Reference
	L. aurata	Payas Coast, (Türkiye)	0.091 ± 0.05	1.553 ± 0.31	0.579 ± 0.25	20.18 ± 6.97	Turan et al. (2022)
	L. aurata	Caspian Sea (Iran)	0.036	1.87	0.971	7.41	Hosseini et al. (2022)
	M. cephalus	*Damietta Port (Egypt)	0.64 ± 0.01	1.28 ± 0.07	1.48 ± 0.39	16.02 ± 1.01	Monier et al. (2023)
	L. aurata	Bizerte lagoon (Tunisia)	0.59 ± 0.09	9.44 ± 0.85	1.15 ± 0.13	70.98 ± 7.86	Telahigue et al. (2024)
	L. aurata	Bardawil Lake (Egypt)	0.38 ± 0.09	0.59 ± 0.08	0.36 ± 0.12	5.28 ± 4.32	Zaghloul et al. (2024)
	Mullet	Rabat Estuary (Morocco)	0.0046	0.0103	0.0088	0.1648	Aarabi et al. (2024)
	M. cephalus	Manzala Lake (Egypt)	0.12 ± 0.02	-	0.87 ± 0.15	-	Abd-Elghany et al. (2024)
	L. aurata	Urla, İzmir (Türkiye)	0.388 ± 0.013	0.566 ± 0.026	0.643 ± 0.016	4.750 ± 0.123	This study

*mg · kg^{-1} dw.
dl, detection limit; nd, non-detection; SE, standard error.

Gasthani Estuary, India (Gawade et al., 2013), as well as in two studies on *Mugil cephalus* from Damietta Port (Monier et al., 2023) and Manzala Lake (Abd-Elghany et al., 2024), Egypt (Table 2). These variations in Pb levels are attributed to factors such as the age, size, and feeding habits of the fish, habitat characteristics, regional pollution levels, and interspecies differences in the bioaccumulation capacity of heavy metals (Wei et al., 2014).

3.1.4. Cadmium

Cd is a hazardous heavy metal that has no biological function and can have toxic effects even at low concentrations. By accumulating in the body, it can cause health problems such as kidney damage, skeletal system deformations, reproductive and digestive system disorders, and pulmonary emphysema. It can also trigger the development of various types of cancer by disrupting the epigenetic mechanisms in cells (Farhat et al., 2025; Telahigue et al., 2024).

The average Cd concentrations were lowest in muscle tissue in 2017 (0.324 ± 0.019 mg · kg^{-1} ww) and highest in liver tissue in 2018 (0.930 ± 0.027 mg · kg^{-1} ww) (Table 1). The tissue distribution of Cd followed the order: liver > gills > muscle. This distribution is related to the organism's regulatory capacity, behavioral characteristics, and feeding habits (Jelodar et al., 2011), and it results from the higher tendency of cadmium to accumulate in organs such as the liver and kidneys compared with muscle tissue (Barone et al., 2015). The gills function as the primary organ responsible for the excretion of cadmium from the body (Zaghloul et al., 2024). Evaluation of seasonal data showed that Cd levels in all tissue types varied seasonally, and these differences were statistically significant ($p < 0.05$) (Fig. 5).

In this study, the Cd levels detected in tissues were compared with those reported in other studies on mullet fish. The Cd concentration determined in the liver tissue (0.896 mg · kg^{-1} ww) was higher than those reported for regions such as Cádiz Bay, Spain (0.51 mg · kg^{-1} ww; Usero et al., 2003), Akyatan Lagoon (0.07 mg · kg^{-1} ww; Türkmen et al., 2012), Payas Coast (0.66 ± 0.14 mg · kg^{-1} ww; Turan et al., 2022), and Rabat Estuary (0.043 mg · kg^{-1} ww; Aarabi et al., 2024), but lower than the levels reported in highly polluted areas such as the Caspian Sea (1.07 mg · kg^{-1} dw; Jelodar et al., 2011), Damietta Port (1.08 mg · kg^{-1} dw; Monier et al., 2023), and Bizerte Lagoon (1.44 mg · kg^{-1} ww; Telahigue et al., 2024) (Table 2). Similarly, Cd levels in muscle tissue were found to be lower compared with studies conducted on *L. aurata* and *M. cephalus* in regions such as the Caspian Sea (Hosseini et al., 2022;

Jelodar et al., 2011), Bizerte Lagoon (Telahigue et al., 2024), Damietta Port, and Lake Manzala (Abd-Elghany et al., 2024; Monier et al., 2023) (Table 2).

3.2. Potential health risk assessment

For a long time, the examinations have been used to estimate the health risk to humans from heavy metal content in numerous fish species. Although toxicological limits may not have been surpassed for the average consumer, the health risk of heavy metal exposure may appear for heavy consumers of a particular fish species (Leblanc et al., 2005). Consequently, the weekly (EWI) and daily (EDI) dietary exposures were calculated for *L. aurata* and compared with the PTWI. Moreover, non-carcinogenic health risks (THQ and Σ THQ) and carcinogenic health risks (CR) were estimated for consumers, and the results are listed in Table 3.

In this study, fish samples were assessed for potential impact of the heavy metals on human health; the EWI for heavy metals was compared with the PTWI of individuals with a BW of 70 kg (adult). The EWI of Cd was above the 70 kg adult PTWI. The EWI for 2017 was 0.648 mg · week^{-1}, whereas the PTWI limit is 0.49 mg · week^{-1}. This difference became even larger in 2018: the EWI value was calculated to be 0.904 mg · week^{-1}. This indicates that exposure to Cd in both years was higher than the permissible levels in the short term. The rise in Cd accumulation with time also suggests that Cd requires careful surveillance on health perspectives. The estimated EWI values of Pb in 2017 and 2018 were 1.296 mg · week^{-1} and 1.276 mg · week^{-1}, respectively, which were also lower than the PTWI (1.75 mg · week^{-1}). These findings indicate that exposure to Pb was not excessive during the time frame studied. Although the determined ones are below the admissible ones for public health, the values obtained, which are relatively closer to the limit values, do not exclude carrying them out carefully for the purpose of monitoring Pb contamination. The EWI of Cu in 2017 and 2018 was computed as 1.096 mg · week^{-1} and 1.168 mg · week^{-1}, respectively. These levels are substantially lower than the PTWI of 245 mg · week^{-1}. The values obtained indicate that the ingestion of *L. aurata* is safe in relation to Cu, and the levels of exposure do not pose any

Table 3

Guideline-based estimated exposures and human health risks of heavy metals in muscle tissue of *L. aurata*.

		Metals				ΣTHQ[h]
		Cd	Cu	Pb	Zn	
PTWI[a]		0.007	3.5	0.025	7	
PTWI[b]		0.49	245	1.75	490	
PTDI[c]		0.07	35	0.25	70	
Mean. Cons. (mg · kg^{-1})	2017	0.324	0.548	0.648	4.709	
	2018	0.452	0.584	0.638	4.795	
EWI[d]	2017	0.648	1.096	1.296	9.418	
	2018	0.904	1.168	1.276	9.590	
EDI[e]	2017	0.092	0.156	0.185	1.345	
	2018	0.129	0.166	0.182	1.370	
CR[f]	2017	3.52×10^{-5}	-	1.58×10^{-6}	-	
	2018	4.91×10^{-5}	-	1.55×10^{-6}	-	
THQ[g]	2017	0.092	0.004	0.044	0.004	0.144
	2018	0.129	0.004	0.045	0.004	0.182

[a] PTWI (tolerable weekly intakes) mg · week^{-1} · kg^{-1} BW FAO/WHO (2004).
[b] PTWI for an adult individual weighing 70 kg (mg · week^{-1} · kg^{-1} BW).
[c] PTDI, mg · day^{-1} · 70 kg^{-1} BW.
[d] EWI, mg · week^{-1} · kg^{-1} BW.
[e] EDI, mg · day^{-1} · kg^{-1} BW.
[f] CR, USEPA, 1995.
[g] THQ.
[h] ΣTHQ.

ΣTHQ, total target hazard quotient; BW, body weight; CR, carcinogenic risk; EDI, estimated daily intake; EWI, estimated weekly intake; PTDI, provisional tolerable daily intake; PTWI, provisional tolerable weekly intake; THQ, target hazard quotient.

health risk. The estimated EWI values for Zn in both years were well below the PTWI limit (490 mg · week^{-1}) Cd, in particular, was found to exceed the permissible limits more frequently than other metals. In this regard, strategies for environmental monitoring and source control of Cd are crucial.

When non-carcinogenic health risks (THQ and Σ THQ) for consumers were examined, the THQ values for 2017 were calculated as Cd: 0.092, Cu: 0.004, Pb: 0.044, and Zn: 0.004, respectively. In 2018, these values were Cd: 0.129, Cu: 0.004, Pb: 0.045, and Zn: 0.004. The THQ value of no metal exceeded 1 in both years. These results reveal that consumption of the examined fish is within acceptable limits in terms of non-carcinogenic health risks. Total Target Hazard Quotient (ΣTHQ) was found to be 0.144 for 2017 and 0.182 for 2018. The fact that ΣTHQ values are below 1 indicates that the combined toxic effects resulting from the combined effect of metal accumulation do not pose a significant risk to public health. However, Cd is seen to have the highest THQ contribution in both years; this is an indicator that will require regular monitoring of cadmium in fish in this region.

In this study, carcinogenic risk (CR) was assessed for Cd and Pb, representing the potential long-term carcinogenic effects of these metals. CR reflects the probability of developing cancer from lifetime exposure. The values were Cd: 3.52×10^{-5} and Pb: 1.58×10^{-6} in 2017, and Cd: 4.91×10^{-5} and Pb: 1.55×10^{-6} in 2018. Although the CR values calculated for Pb slightly exceeded the threshold of 1×10^{-6} in both years and technically fall into the "low acceptable risk" category, they remain very close to the 'negligible risk' level. This indicates that under current conditions, Pb does not pose a significant public health risk, although long-term exposure should be monitored. The CR values calculated for Cd fall within the range of $1 \times 10^{-6} < CR < 1 \times 10^{-4}$, which is interpreted as a "low acceptable risk". Overall, since the CR values for both metals remain below the maximum lifetime risk threshold of 1×10^{-4} accepted by the US EPA, they do not indicate a significant carcinogenic risk to public health. However, Cd is identified as a critical metal that should be carefully monitored under long-term exposure scenarios.

4. Conclusion

This study examined the levels of heavy metal accumulation in different tissues of *L. aurata* caught from the Urla coast, Eastern Aegean Sea, and evaluated the possible health risks for human consumption. The study showed that essential metals (Zn, Cu) accumulated at higher levels than toxic metals (Cd, Pb) in all tissues, which reflects the biological needs of the fish. Regarding human health, the calculated risk indices (THQ and CR) indicate that consuming *L. aurata* from the Urla coast does not pose a significant health risk to the public. The results show that consuming this fish species does not cause a major health risk, but the cadmium levels should be checked regularly. Finally, the clear differences observed between seasons and tissues support the use of *L. aurata* as a useful biological indicator for monitoring pollution in the Eastern Aegean Sea. The outcomes of this study can contribute to future risk assessments and monitoring plans for different coastal ecosystems.

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