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RESEARCH ARTICLE

Assessment of health risks due to toxic metals in demersal fish captured from Saros and Edremit Bays, Northern Aegean Sea

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Abstract
Bays are vulnerable ecosystems generally located near densely populated areas where toxic metals tend to accumulate and stay longer, affecting marine life. This study aimed to investigate the age-based health risks arising from Hg, Cd, Pb, and As in demersal fish captured from two major bays in the Aegean Sea. For this purpose, red mullet, whiting, piper gurnard, and tub gurnard, frequently consumed species, were caught from Saros and Edremit Bays. Toxic metal concentrations were determined from the muscle tissue of fish. Health risk assessments were conducted by the estimation of weekly intake (EWI), provisional tolerable weekly intake (PTWI), target hazard quotient (THQ), total THQ (TTHQ), and target carcinogenic risk (TR). Red mullet from Edremit Bay was the species with the highest toxic metal levels, which were 1.597 mg/kg, 0.041 mg/kg, 0.070 mg/kg, and 19.351 mg/kg for Hg, Cd, Pb, and As, respectively. Whiting from Edremit Bay had higher mean concentrations of Hg and As than those from Saros Bay. The levels of Hg, Pb, and As (0.328, 0.043, and 0.574 mg/kg) in the tub gurnard were higher in comparison with the piper gurnard (0.252, 0.020, and 0.382 mg/kg) caught in the same station in Saros. TTHQs of red mullet and whiting from the same bay were found to be > 1, indicating potential health risks for all nine age categories studied. On the other hand, TTHQs of all species from Saros Bay were determined to be > 1 for the first four age categories, which might trigger health risks for children and adolescents. According to the TR index for Pb, no risk was determined for the fish from both bays. However, TR calculations for inorganic As indicated high cancer risk in most of the age categories for red mullet and whiting from Edremit Bay. To sum up, the results revealed that the fish captured from Edremit Bay posed serious health risks in terms of Hg and As concentrations for all nine age categories. Surveillance and monitoring of toxic metal levels in demersal fish and population-based health risk evaluation are vital in heavily populated bays.

Keywords Toxic metals · Demersal fish · Risk assessment · Fish consumption · Aegean Sea · Saros Bay · Edremit Bay

Introduction

Pollution caused by potentially toxic inorganic elements significantly impacts various marine areas worldwide. These pollutants, also known as toxic metals, are non-biodegradable and accumulate up to trophic levels on the food chain, causing severe adverse effects on the marine ecosystem and consumers. Anthropogenic activities are the primary source of these pollutants, posing a significant threat to the sustainability of the ecosystem (Rhind 2009; La Torre et al. 2020). Pollution becomes a significant concern, especially in coastal areas with high urbanization rates, surrounded by many industrial zones or in proximity to agricultural and mining areas. Toxic metals can persist in sediments, marine, and freshwater systems for many years, potentially impacting human health (Akçay and Moon 2004; Alkan et al. 2015;

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Kortei et al. 2020). Mercury (Hg), cadmium (Cd), lead (Pb), and arsenic (As) are the most critical toxic metals, and serious health risks may occur in cases of prolonged exposure due to the consumption of seafood contaminated with them, even at low concentrations (Blanco et al. 2008).

The Aegean Sea is home to commercially important demersal fish species, such as red mullet (*Mullus barbatus*), whiting (*Merlangius merlangus*), piper gurnard (*Trigla lyra*), and tub gurnard (*Chelidonichthys lucerna*), which are extensively caught and consumed. In 2021, the amount of red mullet, whiting, and gurnard species caught in Türkiye was 1358.7 tonnes, 10,379.9 tonnes, and 34 tonnes (TurkStat 2023), respectively, while the amounts of the same species captured in Greece were 986.27 tonnes, 24.66 tonnes, and 72.58 tonnes, respectively (FAO 2023). These species live on the bottom with tight muscle structure and white meat and are consumed intensely by children and people who are sensitive to fish smells (Trondsen et al. 2003; McManus et al. 2007).

Demersal fish living in the sediment structure do not leave their areas unless sharp changes occur in the environmental conditions (Pihl et al. 1991). Toxic metals are one of the most critical pollutants in the marine environment and tend to remain in aquatic systems for long periods, accumulating in marine organisms (Töre et al. 2021). Pollutants in aquatic systems enter the organism's tissue through direct or indirect absorption through the biological barrier. Toxic metals accumulate in high concentrations in fish residing in these environments, also via trophic factors. Consequently, demersal fish pose a high consumer risk concerning toxic metal contamination in the food chain and serve as the primary reference in environmental assessment programs (Kadim and Risjani 2022). Therefore, monitoring is essential, and a comprehensive risk assessment should be undertaken annually for seafood consumers in coastal areas (La Torre et al. 2020).

Considering Edremit and Saros, two major bays on the Turkish coasts of the Northern Aegean Sea, previous studies emphasized the importance of these regions both economically and environmentally. On the shores of Edremit Bay, the presence of different mineral deposits is known in the region, where there are hot water outlets both in the sea and near the coast. As a consequence, geological mineral deposits or groundwater in contact with various aboveground streams cause the sea to be polluted with toxic elements (Önce 2014). Toxic metal levels in Saros Bay are also affected by mining and industrial activities in the Meriç Basin via the Meriç, Tunca, and Ergene rivers. Besides this effect, fertilizers and pesticides used in large agricultural areas also cause an increase in metal levels (Erbay 2010). Red mullet (Tepe et al. 2008; Kontas et al. 2022) and whiting (Tepe et al. 2008; Güngör and Kara 2018) were the mainly investigated fish species in these bays. Yet, there were substantially limited studies on piper gurnard (Türkmen et al. 2009) and tub gurnard (Ateş et al. 2015). In this study, it was aimed at filling the gap in the detection and evaluation of toxic metal concentrations in demersal fish captured from Edremit and Saros Bays. Uniquely, this investigation revealed the human health risks that may arise from their consumption.

Assessing the diet based on fish consumption and investigating the risks of metal toxicity for consumers to lead a healthy life are essential while utilizing marine resources (Meng et al. 2022). Aside from considering limit values for toxic metals, it is crucial to consider risk factors when consuming demersal fish in different age groups. Since the Aegean Sea resources are intensively consumed for food by the other two populations (Turkish and Greek), monitoring fish for toxic metals is important in determining exposure. In this study, the levels of toxic metals were examined, and health risks were assessed by calculating estimated weekly intake (EWI), target hazard quotient (THQ), and target carcinogenic risk (TR) factors for each fish species. Six stations in two regions of the Aegean Sea were sampled, focusing on four species that are known to impact the two communities in the region. The results of this study can serve as a consumption guide, enabling the assessment of the potential health effects resulting from toxic metal contamination in demersal fish inhabiting two different bays in the Aegean Sea and other coastal areas with similar physical and environmental factors.

Material and method

Sampling and experimental sites

Red mullet (*Mullus barbatus*), whiting (*Merlangius merlangus euxinus*), piper gurnard (*Trigla lyra*), and tub gurnard (*Chelidonichthys lucerna*) were captured from the Northern Aegean Sea by Istanbul University's Research Ship "Yunus-S." Sampling was carried out in the autumn of 2019. Four different stations from Saros Bay and two stations from Edremit Bay were determined as the sampling areas (Fig. 1). The coordinates of the sampling areas, trawling depths, and number of samples captured are given in Table 1. Trawling time, trawling speed, and swept area were 30 min, 3 miles/h, and 0.03 km^2, respectively.

Immediately after the fish were caught, they were frozen at – 20 °C and transported to the laboratory in polystyrene boxes at the end of the trip without breaking the cold chain. The fish were beheaded, gutted, and filleted. Fish fillets were homogenized (Retsch, GM200, Germany) and taken into sample containers for ICP-MS analysis procedures.

Fig. 1 Sampling areas and stations in Saros Bay (SB1, SB2, SB3, and SB4) and Edremit Bay (EB1 and EB2) in the Northern Aegean Sea

Table 1 Trawling coordinates and sampling depths of the fish caught from different stations

Station	Coordinates		Depth (m)
	Initial	Final	
EB1	39° 27′ 19″ N 26° 48′ 13″ E	39° 27′ 12″ N 26° 46′ 28″ E	58
EB2	39° 28′ 93″ N 26° 38′ 45″ E	39° 29′ 47″ N 26° 39′ 93″ E	80
SB1	40° 32′ 33″ N 26° 15′ 84″ E	40° 31′ 43″ N 26° 14′ 06″ E	79
SB2	40° 30′ 33″ N 26° 18′ 82″ E	40° 30′ 42″ N 26° 16′ 67″ E	183
SB3	40° 30′ 88″ N 26° 30′ 62″ E	40° 30′ 70″ N 26° 28′ 89″ E	111
SB4	40° 32′ 17″ N 26° 37′ 83″ E	40° 32′ 76″ N 26° 39′ 90″ E	107

Toxic metal analysis

The wet weight of the homogenized samples was 0.1–0.2 g. Samples were washed with distilled water and digested in a microwave (MWS-4, Berghof, Germany) after the addition of nitric acid and hydrogen peroxide (1:2 H_2O_2:HNO_3). Digestion was carried out as described by Guhathakurta and Kaviraj (2000) in duplicate. Then, the extracts were put into 50-ml sample tubes and made ready for inductively coupled plasma mass spectrometry (ICP-MS; ELAN-DRC-e, Perkin Elmer, USA). A blank sample and certified reference material (fish muscle tissue from European Reference Material-BB422) were used for each sample set. The recovery percentages of As, Cd, and Hg in reference material were 104.9%, 96.1%, and 98.7% respectively. Calibration standards were prepared from the stock solution (10,000 µg/kg) of the analyzed elements at concentrations of 0.2, 0.5, 1, 5, 10, 20, 50, 100, and 200 µg/kg for Hg, Cd, Pb, and As. Limits of detection (LODs) for As, Cd, Pb, and Hg were 0.004, 0.002, 0.001, and 0.005 µg/kg, respectively.

Health risk characterization

Health risk assessment was conducted using estimated weekly intake (EWI), target hazard quotient (THQ), provisional tolerable weekly intake (PTWI), and target carcinogenic risk (TR) as evaluation measures. Since the health risk is not the same for all age groups, the distribution of body weight (kg) by nine different age categories was used as follows (US EPA 2011): A1, 1–3 year children 14 kg; A2, 4–6 year children 21 kg; A3, 7–10 year children 32 kg; A4, 11–14 year adolescents 51 kg; A5, 15–19 year adolescents 67 kg; A6, 20–24 year adults 72 kg; A7, 25–54 year adults

77 kg; A8, 55–64 year adults 77 kg; and A9, > 65-year seniors 72 kg.

The weekly fish consumption value (weekly ingestion rate: IRw) was obtained by measuring one portion as 150 g/week/person for A2, A3, A4, A5, A6, A7, A8, A9, and 50 g/week/person for A1. Estimated weekly intake (EWI) was determined by multiplying IRw with metal concentration (Cm) and dividing it by body weight (BW) related to each age category.

$$EWI = \frac{Cm * IRw}{BW} \quad (1)$$

Provisional tolerable weekly intake (PTWI) (μg/kg bw·week) values and percent PTWI (%PTWI) were also calculated in order to compare with the EWI results. PTWI values of metals (PTWI*m*) were set at 1.3 μg/kg for MeHg (EFSA 2012a) and 2.5 μg/kg for Cd (EFSA 2012b). Although the PTWI*m* values of 15.0 μg/kg for As (EFSA 2009) and 25.0 μg/kg for Pb (EFSA 2010) were declared to be invalid according to the Joint FAO/WHO Expert Committee on Food Additives (JECFA), the calculations were based on using these established intakes.

$$PTWI = PTWIm * BW \quad (2)$$

The health risks of consuming red mullet, whiting, piper gurnard, and tub gurnard were evaluated based on THQ and TR. The calculation of THQ indicates the non-carcinogenic risk due to heavy metal exposure, while TR offers the estimated risk of developing cancer in an individual exposed to a contaminant over a lifetime. All calculations were based on the assumption that inorganic arsenic ($_{i}As$) consisted of 10% of the total As detected in the species. In order to maximize the risk, it was assumed that total Hg was methylmercury (MeHg), the toxic form of Hg (Qin et al. 2015; Özden et al. 2020).

Equations were derived from US EPA (2023a):

$$THQ = \frac{EF * ED * IFR * Cm}{BW * AT * RfD} * 0.001 \quad (3)$$

$$TR = \frac{EF * ED * IFR * Cm * CSF}{BW * AT} * 0.001 \quad (4)$$

where EF is the exposure frequency (350 days/yr), ED is the exposure duration (years), IFR is the food ingestion rate (g/day) considering different age groups, Cm is the metal concentration (mg/kg), CSF is the oral carcinogenic slope factor, BW is the body weight (kg), AT is the average exposure time for non-carcinogens (365 days/yr * 70 yrs), and RfD is the oral reference dose (mg/kg/day) (US EPA 2023a).

The RfD for Hg, Cd, and $_{i}As$ was set as 0.0001, 0.0001, and 0.0003, respectively (US EPA 2023b). The CSF is 8.5×10^{-3} (mg/kg-day)$^{-1}$ for Pb and 1.5 (mg/kg-day)$^{-1}$ for As (US EPA 2023b). Considering the age categories, the ED values used in this study were 1 year (A1), 4 years (A2), 7 years (A3), 11 years (A4), 15 years (A5), 20 years (A6), 25 years (A7), 55 years (A8), and 66 years (A9) (Vieira et al. 2011).

THQ and TTHQ were calculated for Hg, Cd, and As for consumer food safety assessments. The TR of developing cancer factors was applied to Pb and As data. Statistical calculations of toxic metal levels regarding consumer safety, given as mean concentrations and standard deviation, were performed using the Microsoft Excel 365 software package.

Results and discussion

The Aegean Sea, surrounded by large agricultural areas and rich in geological resources, also encounters significant ship traffic (Burak et al. 2004; Giannakopoulos et al. 2015). The bay of Edremit is located on the Turkish Northern Aegean coast, enclosed by the Greek island of Lesbos. A high sediment load is carried by many streams to the bay. Besides basin and coastal erosion, the bay has been facing problems arising from urbanization, tourism, and olive oil production (Irtem et al. 2005; Darilmaz et al. 2019).

The distance between the Greek island of Lesbos and the Turkish coast is approximately 10–15 km. Industrial fishing is allowed inside the gulf on the Turkish side and the Greek side of the island of Lesbos. On the other hand, Saros Bay has a completely open position towards the Aegean Sea, and the region is closed to industrial fishing. It is regarded as a pristine region (Cengiz and Paruğ 2021). Only small-scale coastal fishing is permitted in the bay (BSGM 2020). Our study is critical in terms of revealing the risk levels from the consumption of demersal fish caught in these regions.

Toxic metal concentrations

In Edremit and Saros Bays, the metal concentrations were detected to be in the following order: As > Hg > Pb > Cd. The Cd levels were found to be the lowest, and the As levels were the highest (Tables 2 and 3). According to the findings of the study, the effect of anthropogenic resources was intense in Edremit Bay, considering the region. However, Saros Bay also seemed to be affected by discharges from the Meriç River and Kavak Creek, especially in terms of sediment Pb concentrations (Uluturhan et al. 2010). In our study, the fish muscle Pb levels captured from Saros Bay were similar to those from Edremit Bay (Tables 2 and 3). According to a recent monitoring study conducted between 2014 and 2019 on the Turkish coast of the Aegean Sea, there had been an increase in the Pb, Hg, and As levels in Edremit and Saros Bays in recent years. In the context of that study, the highest Pb level was found in Edremit Bay, while the highest Hg

Table 2 Toxic metal concentrations in demersal fishes captured from Edremit Bay

Edremit Bay		Mean metal concentrations mg/kg (± SD)			
Sample	Station	Hg	Cd	Pb	As
Red mullet	EB1	1.597 ± 0.220	0.041 ± 0.008	0.070 ± 0.001	19.351 ± 0.368
	EB2	1.198 ± 0.156	0.003 ± 0.000	0.010 ± 0.001	17.443 ± 1.225
Whiting	EB1	0.406 ± 0.022	ND	0.036 ± 0.010	9.884 ± 0.359
	EB2	0.419 ± 0.043	ND	0.023 ± 0.000	8.549 ± 0.601

±SD, standard deviation; ND, not in detectable limits (limits of detection Cd: 0.002; Pb: 0.001 μg/kg). Number of sample for red mullet:*n*=42. Number of sample for whiting:*n*=21

Table 3 Toxic metal concentrations in demersal fishes captured from Saros Bay

Saros Bay		Mean metal concentrations mg/kg (± SD)			
Sample	Station	Hg	Cd	Pb	As
Red mullet	GS4	0.310 ± 0.044	0.003 ± 0.001	0.049 ± 0.011	0.341 ± 0.132
Whiting	GS1	0.363 ± 0.036	ND	0.039 ± 0.001	0.720 ± 0.354
	GS3	0.135 ± 0.007	0.003 ± 0.000	ND	0.022 ± 0.006c
Piper gurnard	GS1	0.272 ± 0.075	ND	0.040 ± 0.001	0.525 ± 0.145
	GS2	0.347 ± 0.015	0.002 ± 0.000	0.004 ± 0.000	0.610 ± 0.084
	GS3	0.252 ± 0.049	0.003 ± 0.001	0.020 ± 0.009	0.382 ± 0.077
	GS4	0.266 ± 0.030	0.003 ± 0.001	ND	0.496 ± 0.071
Tub gurnard	GS3	0.328 ± 0.071	0.002 ± 0.001	0.043 ± 0.012	0.574 ± 0.079

±SD, standard deviation; ND, not in detectable limits (limits of detection Cd: 0.002; Pb: 0.001 μg/kg). Number of sample for red mullet:*n*=26. Number of sample for whiting:*n*=14. Number of sample for piper gurnard:*n*=17. Number of sample for tub gurnard:*n* =2

concentration was determined in Saros Bay, in red mullet (ÇŞİDB TUBİTAK-MAM 2021).

Concerning demersal fish species, only red mullet and whiting were captured from Edremit Bay. It was observed that fewer species were caught by the trawler than by Saros Bay (Tables 2 and 3). According to the analyses of Hg, Cd, Pb, and As carried out on these two species, the highest levels of toxic metals were found in red mullet at levels of 1.597 mg/kg, 0.041 mg/kg, 0.070 mg/kg, and 19.351 mg/kg, respectively. It was also observed that the determined mercury level was higher than the existing national and CAC norm limit values. The Codex Alimentarius Commission (CAC) has established legally permitted maximum levels (ML) for certain contaminants in specific foods. According to the CAC, the ML for Pb in fish is set at 0.30 mg/kg, MeHg in tuna is set at 1.2 mg/kg, and Cd in marine bivalve mollusks and cephalopods is set at 2 mg/kg. However, there is no specific limitation for As in any kind of seafood (CAC 2019).

In a study conducted in Edremit Bay, the toxic metal concentrations of red mullet varied according to season. The Hg, Cd, and Pb values were 0.872, 0.004, and 0.481 mg/kg in spring and 0.447, 0.003, and 0.151 mg/kg in autumn, respectively (Kontas et al. 2022). Tepe et al. (2008) determined that metal levels ranged between 0.041 and 0.165 mg/kg for Cd and 0.289 and 2.354 mg/kg for Pb in red mullet caught from the mid-North Aegean coasts of Türkiye. Unlike our study, Yabanli and Alparslan (2015) reported that the Hg, Cd, and Pb levels of red mullet obtained from the Eastern Aegean Sea were 0.10, 0.03, and 0.10 mg/kg, respectively. Uluozlu et al. (2007) examined the metal levels of red mullet, which were 0.45 mg/kg for Cd and 0.84 mg/kg for Pb. Tecimen et al. (2023) also examined the Cd and Pb levels in red mullet caught from Kuşadası Bay (Aegean Sea). Pb levels in fish ranged between 0.21 and 0.78 mg/kg; however, cadmium was not detected in the fish samples. In another study, Fındık and Çiçek (2011) presented the mean Cd level as 0.11 mg/kg (0.02–0.55) and the Pb level as 1.11 mg/kg (0.09–7.00) for red mullet from the western coast of the Black Sea. Additionally, As concentration of 0.551 mg/kg of red mullet captured from the Aegean Sea was similar to our results from Saros Bay (Kuplulu et al. 2018). Higher As levels were reported in intensely industrialized fishing areas. Guerra-García et al. (2023) reported 59.05 mg/kg As concentration of red mullet from the Bay of Cadiz—Iberian Peninsula. Kucuksezgin et al. (2014) reported As concentrations of 3.6–22.1 mg/kg from Izmir Bay (Aegean Sea) between 2009 and 2011, surpassing the As levels observed in our study.

The average Hg and As concentrations of whiting from Edremit Bay were found to be higher than those in Saros Bay, as expected (Tables 2 and 3). Unlike our study, Güngör and Kara (2018) determined higher As levels which were 3.563 mg/kg in September and 4.403 mg/kg in March, from Saros Bay. Whiting caught from Iskenderun Bay also presented higher mean metal levels compared to our study (As: 10.320 mg/kg; Cd: 0.006 mg/kg; and Pb: 0.087 mg/kg) (Kaya and Turkoglu 2017). In contrast to our study, whiting obtained from commercial fishing in Türkiye had higher Cd (0.55 mg/kg) and Pb (0.93 mg/kg) concentrations (Uluozlu et al. 2007). Fındık and Çiçek (2011) also reported elevated mean Cd (0.40 mg/kg) and Pb (6.80 mg/kg) of whiting from the western coast of the Black Sea.

In this study, a tub gurnard was only captured from one station in Saros Bay. The mean levels of Hg, Cd, Pb, and As in the samples were 0.328, 0.002, 0.043, and 0.574 mg/kg, respectively. Similar mean Hg values of 0.22 mg/kg were reported from the Adriatic Sea. Higher Cd and lower Pb levels (0.02 and 0.02 mg/kg) were also stated (Storelli 2008). Unlike our study, Ersoy and Çelik (2010) examined tub gurnard samples from Iskenderun Bay throughout four seasons. The Pb and Cd levels ranged 0.12–0.42 mg/kg and 0.04–0.07 mg/kg, respectively. This may be because of the location of Iskenderun Bay, which is known to be one of the heavily industrialized gulfs with high anthropogenic inputs and is situated on the eastern Mediterranean coast of Türkiye. Ateş et al. (2015) also reported higher metal levels than our study for tub gurnard from the Northern Aegean Sea (Cd: 0.05 mg/kg and Pb: 0.36 mg/kg), Yalova region of the Marmara Sea (Cd: 0.01 mg/kg and Pb: 0.27 mg/kg), and Iskenderun Bay (Cd: 0.46 mg/kg and Pb: 1.26 mg/kg). In another study on tub gurnard from the Portuguese Northwest Atlantic coast, Hg concentration ranged from < 0.020 to 1.044 mg/kg, Cd ranged from < 0.002 to 0.089 mg/kg, and Pb ranged from < 0.005 to 0.403 mg/kg (Reis et al. 2020).

Piper gurnard, caught from four stations in Saros Bay, exhibited mean Hg, Cd, Pb, and As levels of 0.284, 0.002, 0.016, and 0.503 mg/kg, respectively. Another study conducted on piper gurnard to determine the presence of toxic metals, captured from the central Aegean Sea, Northern Aegean Sea, and Iskenderun Bay, revealed higher Cd and Pb levels compared to our results. The fish from the Northern Aegean Sea had a Cd level of 0.04 mg/kg and a Pb level of 0.31 mg/kg (Türkmen et al. 2009). Since there are limited studies on whiting, tub gurnard, and piper gurnard regarding the detection and risk assessment of metal concentrations in these types of gulfs in the Aegean Sea, our study provided important data.

The toxic metal concentrations of edible demersal fish caught from important bays around the world in recent years were compared with the data obtained in this study (Table 4). Although the fish species in the table are various, recent studies reveal the situation of bottom-dwelling fish in the world in terms of toxic metals.

Health risk assessment

Exposure characterization is an element of risk assessment that defines the objective, analyzes exposure for specific populations, synthesizes data, evaluates confidence to draw conclusions, and integrates with other assessment factors (US EPA 2019). In this study, the toxic metal concentrations in each fish from two Northern Aegean bays were used to demonstrate the potential health risk. The weekly designation is important in terms of limiting the intake of contaminants over a specific period of time. Therefore, the Joint FAO/WHO Expert Committee on Food Additives (JECFA) established provisional tolerable weekly intake (PTWI) (μg/kg bw·week) values for certain toxic substances in order to estimate weekly risks.

Concerning EWI, the highest metal exposure emerged from the red mullet obtained from Edremit Bay (Table 5). At all age groups, the Hg risk was found to be more than 100% of PTWI. The dietary intake calculations for MeHg ranged between 209.4 and 768.3%. On the other hand, red mullet captured from Saros Bay had %PTWIs of 170.33% and 111.78% for the A2 and A3 age groups, respectively. The maximum intakes of MeHg in whiting were also higher than the recommendations for A1, A2, and A3 from Edremit Bay and A2 from Saros Bay. The %PTWIs of both the piper gurnard and tub gurnard from Saros Bay exceeded the EWI for A2 and A3. As for the EWI calculations of Cd, Pb, and As, none of the fish posed a risk in terms of established PTWI at any age group. Hg seemed to be a significant contaminant in both bays, and the children were more likely to be affected. Also, the population living around Edremit should be aware of the risks of consuming a 150-g portion of red mullet per week. Likewise, Kontas et al. (2022) reported that Hg concentrations of red mullet from Edremit Bay were higher than the PTWI value retrieved from FAO/WHO, regarding weekly average fish consumption of 105 g in Türkiye. Therefore, it was speculated that health risks could arise due to Hg concentrations. For piper gurnard, it was stated that the EWI of Hg, Cd, As, and Pb were less than the set values according to 70 kg BW, similar to our study (Türkmen et al. 2009). Tub gurnard from the Eastern Mediterranean Sea was also regarded as safe in terms of the weekly intake of Cd and Pb (Ersoy and Çelik 2010). Unlike our study, Mol et al. (2017) reported lower EWI values of the same metals than the established PTWI in red mullet and whiting captured from the Southwest Black Sea. Ateş et al. (2015) also determined that whiting did not pose any health risks according to weekly intake recommendations.

In an integrated risk assessment that compares the exposed contaminant to a standard reference dose, the US EPA recommends that THQ be taken into account. This approach has been broadly adopted to assess the levels of toxic elements

Table 4 Comparison of toxic metal concentrations found in bottom-dwelling fish in recent studies from major bays around the world

Bay	Species	Toxic metals (mg/kg)				Reference
		Hg	Cd	Pb	As	
Saros Bay (Aegean Sea)	*Mullus barbatus*	0.31	0.003	0.05	0.34	This study
	Merlangius merlangus euxinus	0.25	0.001	0.02	0.37	
	Trigla lyra	0.28	0.002	0.02	0.50	
	Chelidonichthys lucerna	0.33	0.002	0.04	0.57	
Edremit Bay (Aegean Sea)	*Mullus barbatus*	1.40	0.022	0.04	18.40	This study
	Merlangius merlangus euxinus	0.41	n/d	0.03	9.22	
Edremit Bay (Aegean Sea)	*Mullus barbatus*	0.447	0.003	0.151	-	Kontas et al. (2022)
	Merluccius merluccius	1.92	0.004	0.135	-	
	Pagellus erythrinus	6.83	0.01	0.344	-	
Kuşadası Bay (Aegean Sea)	*Mullus barbatus*	-	n/d	0.78	-	Tecimen et al. (2023)
Iskenderun Gulf (Mediterranean Sea)	*Solea solea*	-	6.83	79.5	-	Aytekin et al. (2019)
	Sparus aurata	-	3.44	40.00	-	
Mersin Bay (Mediterranean Sea)	*Mullus barbatus*	-	n/d	n/d	6.36	Korkmaz et al. (2019)
	Mullus surmuletus	-	n/d	n/d	7.96	
	Mugil cephalus	-	n/d	n/d	1.08	
Almería Bay (Mediterranean Sea)	*Merluccius merluccius*	-	0.01	n/d	9.60	Ramos-Miras et al. (2019)
	Mullus surmuletus	-	0.02	n/d	53.74	
Bay of Biscay (Cantabrian Sea)	*Maurolicus muelleri*	0.01	0.08	0.02	2.25	Zhu et al. (2023)
Gorgan Bay (Caspian Sea)	*Mugil cephalus*	-	2.11	0.69	0.21	Bagheri et al. (2023)
Kuwait Bay (Persian Gulf)	*Acanthopagrus latus*	-	0.23	0.12	4.67	Ali & Chidambaram (2021)
	Sparidentex hasta	-	1.05	0.16	7.29	
	Pomadasys argenteus	-	0.78	0.24	7.20	
Bandar Abbas (Persian Gulf)	*Sillago arabica*	1.93	0.13	1.71	13.52	Barani et al. (2023)
	Sillago attenuata	1.29	0.17	1.80	11.87	
	Sillago sihama	1.57	0.20	1.83	16.09	
Chabahar Bay (Gulf of Oman)	*Sillago indica*	0.75	0.08	1.24	8.37	Barani et al. (2023)
	Sillago sihama	0.65	0.05	1.64	7.43	
	Sillaginopodys chondropus	0.86	0.10	1.31	5.51	
Chabahar Bay (Gulf of Oman)	*Otolithes ruber*	0.17	0.01	0.12	0.47	Agah (2021)
Gadani Area (Arabian Sea)	*Acanthopagrus australis*	1.57	-	2.74	-	Kakar et al. (2020)
Bay of Bengal (Indian Ocean)	*Arius africanus*	-	n/d	0.30	-	Pandion et al. (2023)
	Epinephelus undulosus	-	n/d	0.10	-	
	Zebrias quagga	-	n/d	0.20	-	
Bay of Bengal (Indian Ocean)	*Lates calcarifer*	-	0.05	1.33	0.02	Tahity et al. (2022)
Banten Bay(Java Sea)	*Planiliza subviridis*	0.05	-	0.08	-	Nirari et al. (2022)
Butuan Bay (Bohol Sea)	*Lutjanus malabaricus*	n/d	17.00	3.83	-	Cabuga Jr. et al. (2020)
	Nemipterus japonicus	n/d	9.50	3.50	-	
	Selar crumenophthalmus	n/d	13.17	2.00	-	
Laizhou Bay (Bohai Sea)	*Platycephalus indicus*	0.21	4.25	-	-	Liu et al. (2019)
	Lateolabrax japonicus	1.04	4.36	-	-	
	Paralichthys olivaceus	0.35	4.47	-	-	
Haizhou Bay (Yellow Sea)	*Jaydia lineata*	1.27	-	0.87	5.62	Zhang et al. (2023)
	Lophius litulon	0.50	-	n/d	32.65	
	Sebastes schlegelii	0.92	-	0.15	8.00	
Hangzhou Bay (East China Sea)	*Collichthys lucidus*	0.01	0.02	0.06	0.21	Noman et al. (2022)
	Cynoglossus joyneri	0.003	0.01	0.06	0.35	
Delaware Bay (Atlantic Ocean)	*Morone saxatilis*	0.740	0.001	0.016	-	Burger et al. (2019)

–, not investigated; n/d, not detected

Table 5 EWI, THQ, and TR indexes for the fish species captured from Edremit Bay

Edremit Bay	EWI (μg/kg week)				THQ				TR	
Age	Hg	Cd	Pb	As	Hg	Cd	As	TTHQ	Pb	$_i$As
Red mullet										
A1	4.993	0.079	0.143	6.570	6.840	0.108	3.000	9.947	2.40E-09	1.90E-05
A2	9.986	0.157	0.286	13.141	13.679	0.215	6.000	19.895	1.90E-08	1.50E-04
A3	6.553	0.103	0.188	8.624	8.977	0.141	3.938	13.056	2.20E-08	1.80E-04
A4	4.112	0.065	0.118	5.411	5.633	0.089	2.471	8.192	2.20E-08	1.70E-04
A5	3.130	0.049	0.090	4.119	4.287	0.067	1.881	6.236	2.20E-08	1.80E-04
A6	2.913	0.046	0.083	3.833	3.990	0.063	1.750	5.802	2.80E-08	2.30E-04
A7	2.723	0.043	0.078	3.584	3.731	0.059	1.636	5.426	3.20E-08	2.60E-04
A8	2.723	0.043	0.078	3.584	3.731	0.059	1.636	5.426	7.10E-08	5.80E-04
A9	2.913	0.046	0.083	3.833	3.990	0.063	1.750	5.802	9.10E-08	7.40E-04
Whiting										
A1	1.475	0.000	0.107	3.292	2.021	0.000	1.503	3.523	1.80E-09	9.70E-06
A2	2.950	0.000	0.214	6.584	4.041	0.000	2.992	7.032	1.40E-08	7.70E-05
A3	1.936	0.000	0.141	4.320	2.652	0.000	1.963	4.615	1.60E-08	8.80E-05
A4	1.215	0.000	0.088	2.711	1.664	0.000	1.232	2.896	1.60E-08	8.70E-05
A5	0.925	0.000	0.067	2.064	1.267	0.000	0.938	2.204	1.70E-08	9.00E-05
A6	0.860	0.000	0.063	1.920	1.179	0.000	0.873	2.051	2.10E-08	1.10E-04
A7	0.805	0.000	0.058	1.796	1.102	0.000	0.816	1.918	2.40E-08	1.30E-04
A8	0.805	0.000	0.058	1.796	1.102	0.000	0.816	1.918	5.30E-08	2.90E-04
A9	0.860	0.000	0.063	1.920	1.179	0.000	0.873	2.051	6.90E-08	3.70E-04

in contaminated shellfish (Bogdanovic et al. 2014). The non-carcinogenic risk arising from exposure to heavy metals via the consumption of fish was determined by using the THQ index. The amount of the consumed food and the body weight of the consumer group are determinative factors in the formation of health risks. Therefore, the effects of toxic metals on health are estimated by using THQ calculations. The THQ value greater than 1 implies a potential risk for health (Ulusoy 2023). Regarding this index, red mullet was found to exceed the safe consumption limits for Hg and As across all age groups in Edremit Bay (Table 5). On the other hand, the THQ of Hg in whiting exceeded 1 for all age groups, as did the THQ of As in A1–A4. While the toxic metals, particularly Hg, were lower than the ML in whiting, THQs were still found to be high, as indicated in Tables 5 and 6. Table 3 indicates that the Hg and As levels in the four demersal fish species caught by the research trawler from Saros Bay were found to be lesser compared to those from Edremit Bay. The results obtained for Hg levels in Saros Bay ranged between 0.135 and 0.363 mg/kg. Although these values were below the current limits, total THQ (TTHQ) was found to exceed 1 for A1 to A4 consumers in Saros Bay for all species. The A5 group was also at risk in terms of consuming tub gurnard from the same bay (Table 6). Kontas et al. (2022) also found that TTHQ values for red mullet captured from Edremit Bay were over 1 throughout the year (1.802 in spring and 1.398 in autumn). Unlike our study, Özden and Erkan (2016) calculated THQs of demersal fish from Türkiye's seas for three different age groups and found no risks (THQ < 1). Storelli (2008) determined the TTHQ index for tub gurnard as 0.27. Furthermore, no potential health risk was calculated for whiting. Mol et al. (2017) also report THQs lower than 1 for whiting from the Southwest Black Sea.

When the calculated TR index, or estimated cancer risk due to exposure to a contaminant over a lifetime, is lower than 10^{-6}, the cancer risk is predicted to be negligible. On the contrary, if it is greater than 10^{-4}, then the risk is unacceptable. The values between 10^{-6} and 10^{-4} indicate acceptable cancer risk (Qin et al. 2015; Karimi et al. 2020; Bristy et al. 2021). In this study, the Pb levels of the fish from both bays did not pose a cancer risk to any consumer group (Tables 5 and 6). However, TR calculations for $_i$As indicated a high cancer risk for red mullet captured from Edremit Bay for A2 to A9 consumers. Furthermore, $_i$As calculations of whiting captured from the same bay exhibited cancer risk in the A6 to A9 age groups (Table 5). Likewise, red mullet captured from Iskenderun Bay posed a carcinogenic risk due to $_i$As contamination (Varol et al. 2019). Erkan et al. (2020) also stated that health risks related to As in various fish species varied according to different age groups and body weights. Children and adolescents were more at risk in comparison to adults and seniors. Vieira et al. (2011) also calculated TR for pelagic fish captured from the Northeast and Eastern Central Atlantic Oceans in Portuguese and found it higher than 10^{-6} for As. Yet, they brought forward that, according to As TR levels, the youngest (A1 and A2) and the oldest (A9) seemed to be affected more than the rest of the population, primarily because of the duration of their lifetime exposure.

Table 6 EWI, THQ, and TR indexes for the fish species captured from Saros Bay

Saros Bay	EWI (µg/kg week)				THQ				TR	
Age	Hg	Cd	Pb	As	Hg	Cd	As	TTHQ	Pb	$_i$As
Red mullet										
A1	1.107	0.011	0.175	0.122	1.517	0.015	0.056	1.587	2.90E-09	3.60E-07
A2	2.214	0.021	0.350	0.244	3.033	0.029	0.111	3.174	2.30E-08	2.90E-06
A3	1.453	0.014	0.230	0.160	1.991	0.019	0.073	2.083	2.70E-08	3.30E-06
A4	0.912	0.009	0.144	0.100	1.249	0.012	0.046	1.307	2.60E-08	3.20E-06
A5	0.694	0.007	0.110	0.076	0.951	0.009	0.035	0.995	2.70E-08	3.40E-06
A6	0.646	0.006	0.102	0.071	0.885	0.009	0.032	0.926	3.40E-08	4.20E-06
A7	0.604	0.006	0.095	0.066	0.827	0.008	0.030	0.865	4.00E-08	4.90E-06
A8	0.604	0.006	0.095	0.066	0.827	0.008	0.030	0.865	8.70E-08	1.10E-05
A9	0.646	0.006	0.102	0.071	0.885	0.009	0.032	0.926	1.10E-07	1.40E-05
Whiting										
A1	0.889	0.007	0.071	0.133	1.218	0.01	0.061	1.288	1.20E-09	3.90E-07
A2	1.779	0.014	0.143	0.265	2.436	0.02	0.121	2.577	9.50E-09	3.10E-06
A3	1.167	0.009	0.094	0.174	1.599	0.013	0.079	1.691	1.10E-08	3.60E-06
A4	0.732	0.006	0.059	0.109	1.003	0.008	0.05	1.061	1.10E-08	3.50E-06
A5	0.557	0.004	0.045	0.083	0.764	0.006	0.038	0.808	1.10E-08	3.70E-06
A6	0.519	0.004	0.042	0.077	0.711	0.006	0.035	0.751	1.40E-08	4.50E-06
A7	0.485	0.004	0.039	0.072	0.664	0.005	0.033	0.702	1.60E-08	5.30E-06
A8	0.485	0.004	0.039	0.072	0.664	0.005	0.033	0.702	3.60E-08	1.20E-05
A9	0.519	0.004	0.042	0.077	0.711	0.006	0.035	0.751	4.60E-08	1.50E-05
Piper gurnard										
A1	1.014	0.007	0.057	0.18	1.389	0.01	0.082	1.481	9.50E-10	5.30E-07
A2	2.029	0.014	0.114	0.359	2.779	0.02	0.164	2.963	7.60E-09	4.20E-06
A3	1.331	0.009	0.075	0.236	1.824	0.013	0.108	1.944	8.70E-09	4.80E-06
A4	0.835	0.006	0.047	0.148	1.144	0.008	0.068	1.22	8.60E-09	4.80E-06
A5	0.636	0.004	0.036	0.113	0.871	0.006	0.051	0.929	8.90E-09	5.00E-06
A6	0.592	0.004	0.033	0.105	0.811	0.006	0.048	0.864	1.10E-08	6.20E-06
A7	0.553	0.004	0.031	0.098	0.758	0.005	0.045	0.808	1.30E-08	7.20E-06
A8	0.553	0.004	0.031	0.098	0.758	0.005	0.045	0.808	2.90E-08	1.60E-05
A9	0.592	0.004	0.033	0.105	0.811	0.006	0.048	0.864	3.70E-08	2.00E-05
Tub gurnard										
A1	1.171	0.007	0.154	0.205	1.605	0.010	0.094	1.708	2.60E-09	6.00E-07
A2	2.343	0.014	0.307	0.410	3.209	0.020	0.187	3.416	2.00E-08	4.80E-06
A3	1.538	0.009	0.202	0.269	2.106	0.013	0.123	2.242	2.30E-08	5.50E-06
A4	0.965	0.006	0.126	0.169	1.322	0.008	0.077	1.406	2.30E-08	5.50E-06
A5	0.734	0.004	0.096	0.129	1.006	0.006	0.059	1.071	2.40E-08	5.70E-06
A6	0.683	0.004	0.09	0.12	0.936	0.006	0.055	0.997	3.00E-08	7.00E-06
A7	0.639	0.004	0.084	0.112	0.875	0.005	0.051	0.931	3.50E-08	8.20E-06
A8	0.639	0.004	0.084	0.112	0.875	0.005	0.051	0.931	7.70E-08	1.80E-05
A9	0.683	0.004	0.09	0.12	0.936	0.006	0.055	0.997	9.80E-08	2.30E-05

Conclusion

This study rectifies a shortage by offering insight into the Hg, Cd, Pb, and As concentrations in fish from Edremit and Saros Bays. Health risks for nine age categories associated with the consumption of red mullet due to Hg contamination were substantial, especially for those captured from Edremit Bay. According to the results of TR calculations of As and TTHQs, the alarm bells were ringing for the red mullet and whiting from the same bay. Also, the Hg pollution clearly could affect the population, which consumes 150 g of these fish per week. Considering the EWI, the health risk was found to be notably higher in children in both bays. Therefore, health risk assessments of toxic metals should focus on age groups instead of only the average body weight of adults. The limitation of this study was the lack of seawater and sediment sampling. Species and their environments posing risks need to be sampled frequently and investigated in the future research, and legal monitoring programs should be established by the authorities. It is crucial to periodically determine the toxic metal concentrations of frequently consumed white-fleshed demersal fish in such bays and to conduct age- and population-based health risk assessments in terms of public health.

Author contribution All authors contributed to the study conception and design. Data collection was carried out by Firdes Saadet Karakulak. Material preparation and analysis were performed by Hande Dogruyol, Idil Can Tuncelli, and Özkan Özden. The first draft of the manuscript was written by Hande Dogruyol. Reviewing and editing was done by Nuray Erkan. All authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Data availability The data will be made available on request from the corresponding author.

Declarations

Ethical approval Not applicable.

Consent to participate Not applicable.

Consent for publication Not applicable.

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