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RESEARCH

Effects of floods resulting from climate change on metal concentrations in whiting (*Merlangius merlangus euxinus*) and red mullet (*Mullus barbatus*) and health risk assessment

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Abstract In this research, the effect of flooding caused by heavy precipitation, postulated to be one of the consequences of climate change, on toxic metal concentrations in two demersal fish species, whiting (*Merlangius merlangus euxinus*) and red mullet (*Mullus barbatus*), was investigated. For both demersal fish species, concentrations of Hg, Fe, Cd, Pb, Se, Al, Zn, Cu, Sr, B, Cr, Mn, Ni, Ba, and Li were compared between samples taken from Türkeli, Sinop, Black Sea, before and after the flood event in August 2021. Hg, Mn, Se, Li, B, and Sr metal concentrations increased in whiting and in red mullet in the post-flood samples. Estimated daily intake, target hazard quotient, cancer risk, the maximum allowable daily consumption rate and minimum daily requirements, and health risk analyses indicated that daily consumption of whiting and red mullet was risky due to the heavy metal Hg level after the flood. In addition, it was found that the samples had higher levels of Se than Hg, Se/Hg ratios were above 1, and Se-HBV were positive. Therefore, whiting and red mullet fishing should be restricted for a limited time period in the region.

Keywords Black Sea · Cancer risk · Climate change · Hazard index · Health risk assessment · toxic metals

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Introduction

Metals are naturally occurring elements in the environment. However, their concentrations can increase due to anthropogenic activities such as speedy industrialization and urbanization, enormous land-use vicissitudes, and related improved terrestrial overflow (Rahman et al., 2012; Köker, 2022).

Heavy metals, which can rise to biohazardous levels through dietary exposure, can, under certain conditions, bioaccumulate in aquatic organisms (e.g., crustaceans, molluscs, fish) in the immediate environment (Kosker, 2020; Ulusoy & Mol, 2022).

In contrast, there are also some non-essential toxic metals, such as Pb, As, and Cd, that are known to have no potential benefits to the human body (Wei et al., 2014).

Subsequently, these toxic metals can transfer to the human body through nutrition and lead to various adverse health effects, including impaired kidney function, reduced reproductive capacity, liver damage, skin and bladder cancer, disruption of mental and neurological functions, and metabolic pathways, damage to energy and neurotransmitter production, and significant alterations of the blood and cardiovascular, gastrointestinal, nervous, reproductive, and urinary systems, ultimately resulting in death (Dukes et al., 2020; Wei et al., 2014; Demir et al., 2021).

After hundreds of thousands of increasingly increasing populations, the Industrial Revolution transformed both humanity and the planet. Our meteoric rise over the earlier few centuries means that we now burn fossil fuels on an epic scale, releasing so much carbon dioxide into the atmosphere that it is quickly warming the climate, producing heatwaves, dangerous drought, and severe flooding.

Water has the ability to create and destroy. Most people experience climate change through the medium of water—droughts, floods, intensifying storms, or loss of land along the shoreline, to name a few.

The predominant pathway of human exposure to heavy metals is through ingestion, which accounts for more than 90% of cases, in contrast to other routes such as inhalation and skin contact. In many coastal communities, fish is a major component of the diet and is widely consumed, representing a significant source of heavy metal intake. Fish contribute to a healthy diet by providing high-value amino acids and essential omega-3 fatty acids in its structure (Duyar, 2016). While fish are known to be highly nutritious, their consumption in large quantities can have significant detrimental effects on human health due to the presence of toxic metals that can bioaccumulate beyond safe legal limits. So far, the balance between benefits and dangers has not been adequately understood (Saha et al., 2016). Nevertheless, within the aquatic ecosystem, fish are widely regarded as the most appropriate bioindicators due to their presence at high trophic levels (Rahman et al., 2012).

In recent years, microplastic and heavy metal pollution in the aquatic environment continues to be a significant concern and a focus of attention worldwide. However, the potential ecological hazards after devastating flood events have not been extensively studied (Atamanalp et al., 2021; Lim et al., 2021).

Heavy rains and the risk of flooding are one of the consequences of climate change. As a result, heavy metal-contaminated lands are flooded, with an increased risk of pollutants re-moving in stormwater and polluted sediment and water reaching the freshwater and marine environment (Weber et al., 2010).

The increased occurrence of extreme rainfall in recent years, attributed to climate change, has resulted in frequent flood events that not only introduce large amounts of freshwater into the Black Sea but also have a significant impact on the chemistry and hydrology of the rivers and the sea, leading to numerous negative consequences.

As a result of the heavy rains that started in the Western Black Sea region on August 11, 2021, floods and landslides occurred in the cities of Kastamonu and Sinop on the Black Sea coast. Azdavay, İnebolu, Bozkurt, Küre, and Pınarbaşı districts of Kastamonu province and Ayancık and Türkeli districts of Sinop province were affected by the flood and the sea water remained turbid for weeks.

Whiting (*Merlangius merlangus euxinus*) and red mullet (*Mullus barbatus*) are fished with gillnets in the east and throughout the Southern Black Sea region, and with bottom trawlers in the west (Satilmis et al., 2014). In Turkey, an average of 10,197 tons of whiting and 1974 tons of red mullet have been fished annually since 2000 and 2.24%, 0.43% total fishing, respectively (TUIK, 2021).

In this study, effects of heavy rain, one of the consequences of climate change, and the subsequent flood disaster, on heavy metal concentration in red mullet and whiting in the Black Sea, were investigated. Health risk analyses were conducted with the data obtained based on the consumption amount of in the human diet.

Materials and methods

Sampling and study area

This research was conducted on the coast (41° 57′ 09.90″ N, 34° 20′ 09.90″ E) of Türkeli district of Sinop province in the southern Black Sea (Fig. 1). In this study, demersal fish species whiting and red mullet were used as specimens. The pre-flood samples were obtained from commercial gillnet fisheries at the specified coordinates in June 2021. In August 2021, a flood disaster occurred in the province of Sinop, claimed to have occurred due to climate change, and the Türkeli coast was under the influence of the river floods.

In November 2021, the same fisherman of the commercial gillnet fisheries were asked to fish in the same coordinates. Whiting and red mullet samples

Fig. 1 Study area in the southern coast of the Black Sea along the Turkish coast line

were delivered to Sinop University Scientific and Technology Research Application and Research Center within 3 h by cold chain after labeling information was added.

Analyses of metal contents

In this investigation, all heavy metal analyses were conducted in triplicate groups, following the EPA Method 200.3, which outlines the sample preparation procedure for spectrochemical determination of total recoverable elements in biological tissues. Fish meat samples up to 1.5 g were digested in Teflon vessels including a mixture of concentrated supra pure grade HNO_3 and H_2O_2 (7:1) according to (HPR-FO-67) temperature and pressure profile using a microwave digestion system (Milestone SK10). Following the addition of acid to Teflon bombs, the microwave digestion system was sealed and heated at 200°C for 15 min, after which it was maintained at the same temperature for an additional 15 min. The resulting digested solutions were then transferred into 50mL polypropylene tubes and filled up to 50 ml with ultra-pure water. Standard reference material (CRM) and blank solutions were prepared using the same procedures, and the CRM materials UME CRM 1201 and SEM 2016 mix were utilized to evaluate the precision and accuracy of the analyses. Inductively Coupled Plasma Spectrometry (ICP-MS Agilent 7700X) was used to measure the concentrations of arsenic (As), aluminum (Al), boron (B), barium (Ba), lithium (Li), strontium (Sr), rubidium (Rb), copper (Cu), iron (Fe), manganese (Mn), mercury (Hg), cadmium (Cd), lead (Pb), zinc (Zn), selenium (Se), chromium (Cr), and nickel (Ni) through multi-element techniques. To avoid contamination, all glassware and Teflon bombs were soaked overnight in 10% HNO3 during the experiments, rinsed twice with distilled water, and air-dried prior to use.

Estimations of consumer health risks

Health risks for consumers exposed to metals through oral intake have been assessed as non-carcinogenic and carcinogenic risks in the present study for adults with body weights of 70 kg provided by IOM (2006). The average consumption of fish in the European population is about 23 kg per capita annually (Failler et al., 2007). Estimated daily intake (EDI, mg/kg body weight/day) of metals through fish consumption were calculated using the following formula reported earlier by Copat et al. (2013), Yigit et al. (2018), and Bayrakli (2021):

$$EDI = \frac{MC \times MS}{BW}$$

where:

MC stands for metal concentration (mg kg^{-1} ww) in fish meat.
MS is the meal size (kg/day), the average daily intake rate of fish in the EU population.
BW represents body weight (kg) for adults (men 70 kg).

Non-carcinogenic risk

Non-carcinogenic risk has been evaluated via comparison of the exposure level over a specific time period (lifetime) with reference dose suggested for the same exposure duration. The target hazard quotient (THQ), which represents the non-carcinogenic risk, is calculated as the ratio of the estimated daily intake (EDI) to the reference dose (RfD). The RfD is an assumption of an exposure level that is unlikely to cause health risks, even for sensitive populations. If the exposure level exceeds this threshold, there may be a concern for potential non-cancer health effects. The risk evaluation was made assuming that the toxic inorganic arsenic constituted 3% of the total (FSA, 1999). The mathematical explanation of the potential risk described as THQ caused by a single element within a single exposure route over a lifetime duration of 70 years was estimated using the following equation reported by US-EPA (1989):

$$THQ = \frac{EDI}{RfD} \, x \, 10^{-3}$$

where:

EDI is estimated daily intake (mg/kg body weight/day).
RfD represents the reference doses (mg kg^{-1} day^{-1}) for metals according to EFSA (2010) and US-EPA (2013).

The acceptable standard value for THQ has been reported as “1” (US-EPA 1989). If the calculated THQ value is below “1” (<1), no harmful effect might be expected for human consumers. However, human exposure to metals over “one” (>1) may affect in cumulative reaction (Hallenbeck, 1993). In other words, when the sum of all the THQ values exceeds 1, it indicates a potential health risk due to exposure to multiple chemicals. It is important to note that even if the exposure level of each individual chemical is below its RfD, the cumulative effect of multiple chemical exposures can still result in a hazard index exceeding unity and pose a health risk. Therefore, it is essential to consider the combined effects of multiple chemicals in risk assessments to ensure the safety of human health and the environment. The mathematical equation for non-cancer hazard index (HI) as the arithmetic sum of each THQ values was used in the present study according to US-EPA (1989) as described earlier by Bonsignore et al. (2018), Yigit et al. (Murat Yigit et al., 2020), and Bayrakli (2021), for the evaluation of the risks from multiple metals (the *n* value was “15” in the present study).

$$HI\ (TTHQ\ \Sigma n) = \left(EDI_1/RfD_1\right) + \left(EDI_2/RfD_2\right) + \left(EDI_3/RfD_3\right) + \ldots\ldots\cdots + \left(EDI_n/RfD_n\right)$$

$$HI = \Sigma_n\ THQ_m$$

where:

EDI_n is the estimated intake level for the *n*th metal.

Carcinogenic risks for toxic metals

The International Agency for Research on Cancer (IARC) has classified arsenic, cadmium, chromium, nickel, and lead as potential carcinogens to humans. The cancer slope factor (CSF) is a unitless value that estimates the increased risk of cancer per unit of exposure to a carcinogenic substance over a lifetime. It is used to estimate the cancer risk associated with exposure to these heavy metals (IARC, 2012). The lifetime cancer risk (CRR) was estimated using the equation provided by US-EPA (1989, 2010), as earlier described by Liang et al. (2017):

$$CRR = EDI \, x \, CSF$$

where:

EDI is the estimated daily intake (mg/kg/day).
CSF stands for the cancer slope factor for As (1.5 mg/kg/day), Cd (6.3 mg/kg/day), Cr (0.5 mg/kg/day), Ni (0.84 mg/kg/day), and Pb (0.0085 mg/kg/day) (Liang et al., 2017; US-EPA, 1996).

Although methylmercury (MeHg) is classified as a possible carcinogen to humans (IARC, 2012), the cancer slope factor for Hg has not been issued by the US-EPA. Therefore, this study did not estimate cancer risks associated with Hg. The level of cancer risk for carcinogens ranges between 10^{-4} and 10^{-6}, which presents risk of developing cancer for the entire human lifetime of 1 in 10,000, and 1 in 1,000,000, respectively. It means that a risk lower than 10^{-6} is an acceptable risk and can be ignored, but a risk exceeding 10^{-4} is considered as unacceptable. Hence, an average cancer benchmark of 10^{-5} was considered as the threshold in this study (US-EPA 2010).

Safe consumption limits

The maximum allowable daily consumption rate that is the safe daily consumption limit has been defined as ADC, and calculated using the following formulae (US-EPA, 2000):

$$ADC = \frac{\text{RfD x BW}}{\text{MC}}$$

where:

RfD is the reference doses (mg kg^{-1} day^{-1}) for metals (EFSA, 2010; US-EPA, 2013).
BW represents body weight (kg) for adults (men 70 kg).
MC represents metal concentration (mg kg^{-1} ww) in fish meat.

The maximum safe weekly consumption rate or allowable weekly consumption (AWC, meals per week) was calculated by converting the allowable daily consumption rate (ADC) into the food meal size (MS) that is 0.227 kg/day for adults, a default data provided by US-EPA (2000, 1989). The allowable weekly consumption (AWC, meals per week) was calculated according to the calculation stated in a previous study by Yigit et al. (2018)):

$$AWC = \frac{\text{ADC x 7}}{\text{MS}}$$

where:

ADC is the maximum allowable daily consumption rate (US-EPA, 2000).
MS is the meal size (0.227 kg/day).

Compensation of daily requirements for essential trace elements

Percent compensation of minimum daily requirements (CDRmin) for essential trace elements in human consuming mollusc was calculated using the following equation according to Yigit et al. (2020):

$$CDRmin = \frac{EDI\ x\ 100}{EAR}$$

where:

EDI represents the assessed daily intake (mg/kg/day).
EAR stands for the estimated average daily requirement for a healthy human (IOM, 2001, 2006).

Statistical analysis

Linear relationships between elements for each fish species were appraised using Spearman's rank correlation test. Principal component analysis (PCA) was used to reduce dimensionality in the data set for both fish species. In addition, paired sample *t*-test was utilized to compare the means of the data obtained for each element in pre- and post-flood for both fish species. Before applying this test to the data, it was checked with the Shapiro-Wilk normality test whether the assumption that the pairwise differences were normally distributed for each element was satisfied. In paired sample *t*-test application, firstly, two-way hypotheses were used to examine the difference between the pre- and post-flood. Then, one-way hypotheses were tested to determine in which periods the flood effect occurred pre- and post-flood. All statistical analyses used in this study were performed with statistical software packages R (v4.0.5, http://www.r-project.org) and the significance level was accepted as 0.05.

Eta squared was calculated here using the test statistic t.

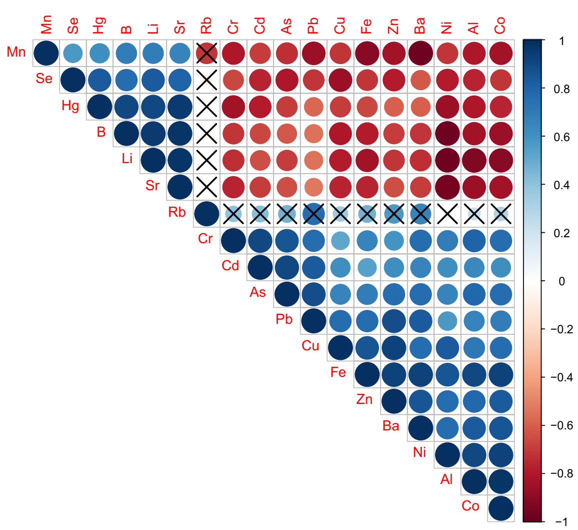
Eta squared $= \frac{t^2}{t^2+df}$

where t is the test statistic and df is the degrees of freedom.

Results and discussion

Whether the concentrations of elements were affected by flooding, principal components analysis and paired sample t-test were used for both fish species and the results obtained are provided below. When the Spearman rank correlation test results and the correlogram were analyzed (Fig. 2) for each element for whiting, strong positive significant correlations were observed between Hg-Sr, B-Sr, Li-Sr, and Al-Co (p-value < 0.05). Moreover, strong negative significant correlations were revealed between Mn-Ba, B-Ni, Li-Ni, and Sr-Ni. In addition to, the relationships between Mn-Rb, Rb-Cr, Rb-Cd, Rb-As, Rb-Pb, Rb-Cu, Rb-Fe, Rb-Zn, Rb-Ba, Rb-Al, and Rb-Co were not statistically important. There were no relationships between Rb-Se, Rb-Hg, Rb-B, Rb-Li, Rb-Sr, and Rb-Ni.

According to PCA analysis performed between elements for whiting (Fig. 3), it was determined that the size of the data could be represented by two components. Dim 1 (PC1) and Dim 2 (PC2) principal components explained 94% and 5% of the total variation in data, respectively. In order to interpret PCA, it is necessary to examine the standardized loads based on the correlation matrix. All elements except Rb were highly positively and negatively correlated with PC1, respectively. Thereby, these elements were the most important in PC1. It was experiential that the amount of common variance (community) was high for all elements, and it seemed which there was a high level of correlation between elements with a common variance close to 1 and other elements. In this study, element density in whiting meat was found as Fe>Al>Zn>As>Sr>Rb>Se>Cu>B>Cr>Mn>Ni>Ba>Li>Hg>Pb>Cd before flooding. After the flood, the element density changed as Zn>Fe> Sr>As>Al>Se>Rb>Mn>B>Cu>Li>Hg>Ba>Ni> Pb>Cr>Cd (Table 1). It was reported that Zn, Al, Fe, Cu, As, and Mn elements were high in studies conducted in whiting meat in the Black Sea (Table 3). However, it is important to note that the concentrations of Fe, As, Al, Cr, Ni, Pb, and Zn were observed to decrease after the flood event. These findings require further explanation and analysis. Possible factors contributing to the decrease in these elements could include the dilution effect caused by the floodwaters, changes in sedimentation patterns, or other environmental processes that might have influenced the distribution and behavior of these elements. Future studies should focus on investigating the mechanisms behind these observed decreases in order to provide a comprehensive understanding of the effects of the flood on the concentrations of these elements. The variation in all other elements, except the Rb element, can be explained by PC1 (Fig. 3).



The symbol 'X' in Figure 2 shows that the correlations between the elements are not statistically significant at p<0.05. In this graph, blue color indicates a strong positive (+) correlation, and red color indicates a strong negative (-) correlation.

Fig. 2 Correlogram of Spearman correlation results for each element in whiting

For each element investigated on the red mullet, the Spearman rank correlation test results and the correlogram (Fig. 4) revealed that strong positive significant correlations between B-Cr, Fe-Hg, B-Rb, Al-Fe, Cr-Rb, Ni-Zn, Cu-Se, and Rb-Sr (p-value<0.05) existed. Strong negative significant correlations were observed between Al-Cd, Fe-Cd, Hg-Cd, Al-Cd, As-Cd, Co-Cu, Co-Se, and Li-Pb (p-value<0.05). Conversely, the connection between Li-Cu was not statistically significant.

In accordance with PCA analysis actualized between elements for red mullet (Fig. 5), one component was statistically sufficient to model the data. Dim 1 (PC1) explained 97% of the total variation in the data,

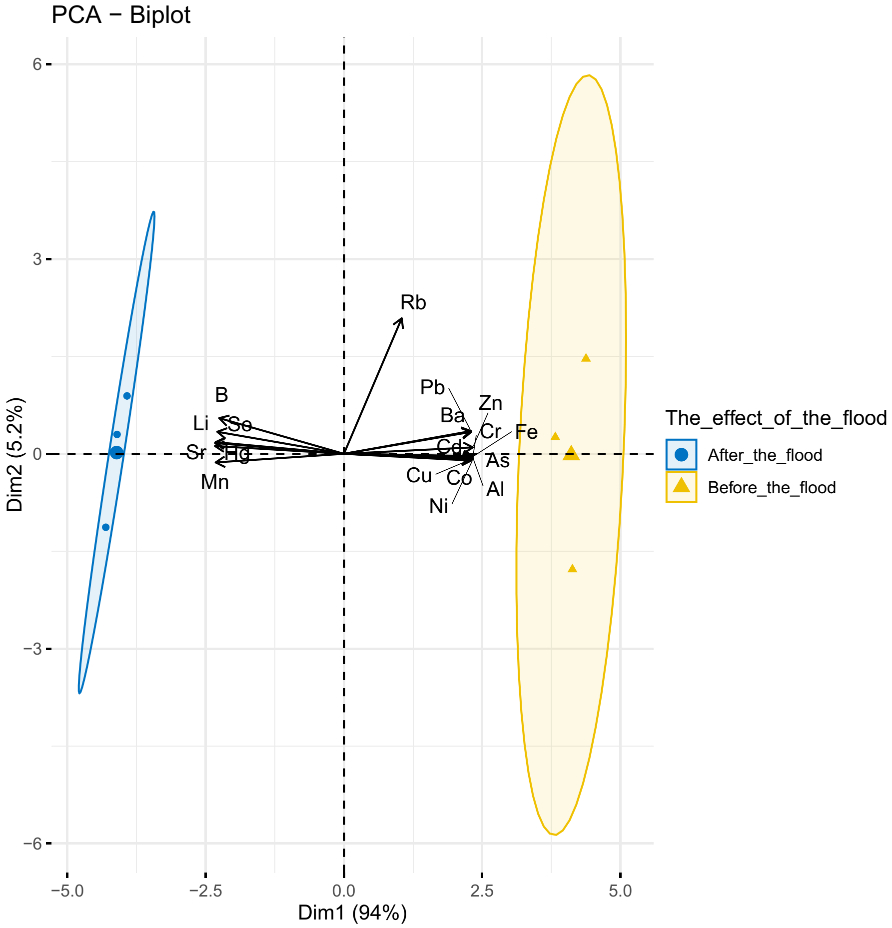
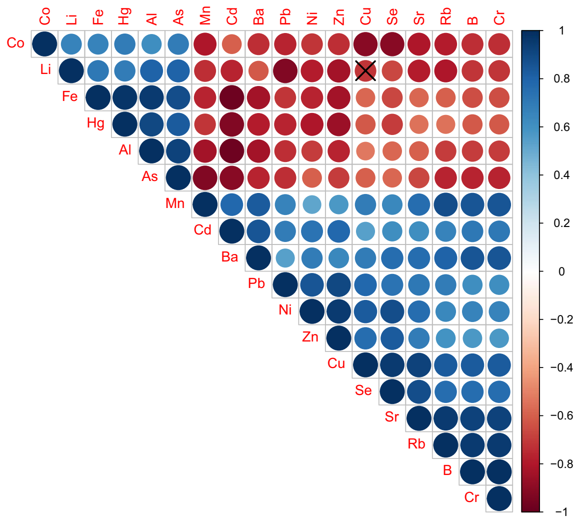


Fig. 3 Biplot of principal component analysis of elements represented with the flood factor for whiting

Table 1 Trace metals of before and after flood for both fish species (mg kg^{-1} ww)

	Whiting						Red mullet					
	Before flood			After flood			Before flood			After flood		
Al	9.91	±	0.138	2.47	±	0.082	3.03	±	0.073	7.70	±	0.193
As	7.29	±	0.018	2.91	±	0.010	2.15	±	0.023	5.87	±	0.040
B	0.52	±	0.012	0.58	±	0.004	0.95	±	0.005	0.38	±	0.011
Ba	0.13	±	0.004	0.10	±	0.001	0.30	±	0.002	0.03	±	0.001
Cd	0.00	±	0.000	0.00	±	0.000	0.01	±	0.000	0.00	±	0.000
Cr	0.42	±	0.004	0.00	±	0.001	0.25	±	0.004	0.01	±	0.001
Cu	0.61	±	0.006	0.55	±	0.006	0.63	±	0.011	0.55	±	0.015
Fe	20.65	±	0.165	4.54	±	0.036	6.19	±	0.016	6.47	±	0.021
Hg	0.05	±	0.001	0.15	±	0.007	0.04	±	0.001	0.17	±	0.005
Li	0.08	±	0.005	0.16	±	0.001	0.10	±	0.001	0.10	±	0.004
Mn	0.39	±	0.020	0.74	±	0.032	1.27	±	0.006	0.38	±	0.003
Ni	0.23	±	0.002	0.06	±	0.002	0.35	±	0.003	0.05	±	0.002
Pb	0.04	±	0.002	0.02	±	0.002	0.04	±	0.001	0.02	±	0.001
Rb	0.98	±	0.016	0.97	±	0.011	0.76	±	0.002	0.56	±	0.008
Se	0.95	±	0.050	1.27	±	0.022	1.00	±	0.040	0.60	±	0.021
Sr	1.70	±	0.048	3.77	±	0.023	7.66	±	0.074	1.95	±	0.063
Zn	9.23	±	0.061	7.70	±	0.118	9.26	±	0.181	7.24	±	0.171

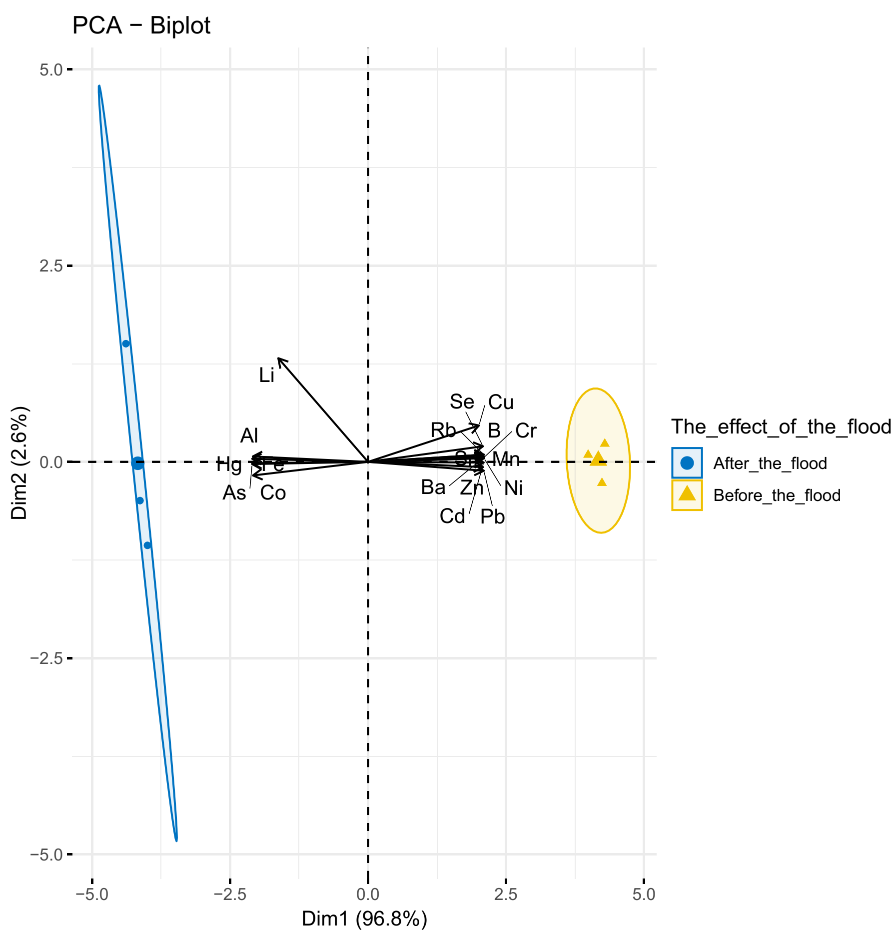


The symbol "X" in Figure 4 shows that the correlations between the elements are not statistically significant at p<0.05. In this graph, blue color indicates strong positive (+) correlation and red color indicates strong negative (-) correlation.

Fig. 4 Correlogram of Spearman correlation results for each element in red mullet

confirming the convenience of PCA. All elements except Li were highly positively and negatively correlated with PC1 (Fig. 4). It emerged that there was a high level of correlation between elements with a common variance close to 1 and other elements. In this study, the element density in red mullet meat was found as Zn> Sr>Fe>Al> As> Mn> Se> B> Rb>Cu> Ni> Ba>Cr> Li> Pb>Hg> Cd before the flood. After the flood, the element density changed as Al>Zn>Fe> As>Sr> Se> Rb>Cu>Mn> B> Hg>Li> Ni>Ba> Pb>Cr> Cd (Table 1). It was reported that Zn, Fe, Al, Cu, As, and Mn elements were higher than the other elements in the investigations conducted in the Black Sea region of red mullet meat (Table 3). However, it is noteworthy that while the concentrations of B, Se, Hg, Sr, and Mn elements in whiting were higher after the flood compared to pre-flood concentrations, there was a decrease in the concentrations of Fe, As, Al, Cr, Ni, Pb, and Zn. These contrasting trends in element concentrations necessitate further investigation and clarification. Potential

Fig. 5 Biplot of principal component analysis of elements represented with the flood factor for red mullet



factors contributing to the observed decrease in Fe, As, Al, Cr, Ni, Pb, and Zn concentrations could include various environmental processes, such as changes in sedimentation patterns, chemical interactions, or other factors that may have influenced the mobility and fate of these elements in the aftermath of the flood. Future studies should focus on elucidating the mechanisms behind these changes to provide a more comprehensive understanding of the observed variations in element concentrations.

To determine whether there were differences in the concentrations of each element examined for both fish species before and after the flood, a paired sample *t*-test was utilized (Table 2). The normality of the differences in the concentrations of each element obtained pre- and post-flood was assessed using the Shapiro-Wilk goodness-of-fit test of normality. The results showed that the differences in the mean concentrations of all elements examined in whiting before and after the flood followed a normal distribution (Shapiro-Wilk p-value > 0.05; Table 2). However, the differences in the mean concentrations of all elements, except for the Rb element, before and after the flood were statistically significant (Table 2). The mean concentrations of Hg, Mn, Se, Li, B, and Sr elements examined in whiting significantly increased after the flood compared to before the flood, and this increase was statistically significant. For red mullet, it was observed that the differences in the mean concentrations of all the elements examined before and after the flood followed a normal distribution. However, the differences in the mean concentrations of all elements before and after the flood were statistically significant. The mean concentrations of Li, Al, Fe, Co, As, and Hg elements investigated on red mullet increased significantly after the flood compared with before the flood, and this increase was statistically significant (Sig (one-tailed) p-value < 0.05; Table 2).

We could obtain a different mean for each element than mean of the differences in measurement before and after the flood if we were to take additional samples besides the samples considered in this study that is why it is very significant to look at the 95% confidence interval (95% CI). In our case, for example, the 95% CI for mean of the measurement differences obtained before and after the flood for the element Li studied in whiting is (0.077, 0.089). This indicates that although the difference in Li concentration is statistically significant, the difference is actually relatively small. It remains to be considered whether this difference in the concentration of element Li is not only statistically significant, but also practically significant.

The mean change for each element was calculated as a percentage of the mean initial concentration to aid in decision-making (Table 1). When these percentages were examined for the post-flood period, the concentrations of Li, Mn, Sr, and Hg elements increased significantly in whiting compared to the pre-flood concentrations. Among these elements, the highest increase was observed in Hg element. Concentrations of Al, Cr, Fe, Ni, Co, As, Cd, and Pb elements showed a high decrease after the flood. Among them, the highest decrease was observed in Cr element. While a high increase was observed in the concentrations of Al, Co, As, and Hg elements in red mullet after the flood, the highest percentage of increase was seen in Hg. A high decrease was detected in the density of B, Cr, Mn, Ni, Sr, Cd, Ba, and Pb elements after the flood, and it was revealed that the highest decrease was observed in the Cr element concentration. These emerging outcomes were statistically significant and are considered to be important practically as well as.

So as to calculate the magnitude of the existing mean change, the effect sizes for the investigated elements in each fish species were computed using eta squared, one of the most commonly used effect size statistics. The instructions for interpreting this value are 0.01=small effect, 0.06=moderate effect, and 0.14=large effect (Cohen, 1988). Considering eta squared values greater than 0.14, we can conclude that there is a large effect with a significant difference in the concentrations obtained for all elements considered for both fish species studied before and after the flood (Table 2).

When all statistical results were examined, principal component analysis and paired sample *t*-test applied for both fish species were found to give consistent results with each other. For this reason, it may be preferable to use both methods together in future studies.

In the studies of whiting in the Black Sea, it was reported as As 0.17–9.67, Cd <0.01–4.05, Cr 0.04–1.62, Ni 0.09–2.87, Pb 0.01–17.11, Hg <0.05–0.084, Se 0.29–0.40, Al 5.53–25.88, Cu 0.26–11.83, Fe 0.69–150, Mn 0.18–8.7, and Zn 3.4–152 mg kg^{-1} in whiting meat. In Red mullet meat, it was reported as As 0.11–3.40, Cd

Table 2 Paired sample *t*-test consequences for each element in comparing the means of before and after flood for both fish species

Elements for whiting									
	Li	B	Al	Cr	Mn	Fe	Co	Ni	Cu
Mean difference	0.083	0.059	−7.447	−0.413	0.354	−16.106	−0.017	−0.178	−0.060
95% CI	(0.077, 0.089)	(0.043, 0.074)	(−7.651, −7.243)	(−0.421, −0.406)	(0.294, 0.414)	(−16.426, −15.787)	(−0.021, −0.012)	(−0.182, −0.175)	(−0.078, −0.041)
Mean change %	105.78%	11.30%	−75.11%	−99.59%	91.27%	−78.0%	−50.69%	−76.21%	−9.92%
Shapiro-Wilk *p*-value	0.789*	0.687*	0.796*	0.763*	0.304*	0.791*	0.743*	0.196*	0.768*
$t_{(3)}$-statistic	45.387	12.085	−116.250	−175.04	18.756	−160.390	−10.891	−164.920	−10.300
Sig (two-tailed)	2.3e-05**	1.2e-03**	1.4e-06**	4.1e-07**	3.3e-04**	5.3e-07**	1.6e-03**	4.9e-07**	1.9e-03**
Sig(one-tailed)	1.2e-05**	6.1e-04**	7.0e-07**	2.0e-07**	1.6e-04**	2.7e-07**	8.3e-04**	2.4e-07**	9.7e-04**
Eta squared	0.99	0.98	0.99	0.99	0.99	0.99	0.97	0.99	0.97
	Zn	As	Se	Rb	Sr	Cd	Ba	Hg	Pb
Mean difference	−1.532	−4.380	0.321	−0.011	2.074	−0.003	−0.026	0.098	−0.017
95% CI	(−1.752, −1.311)	(−4.400, −4.361)	(0.234, 0.407)	(−0.029, 0.006)	(2.034, 2.114)	(−0.004, −0.003)	(−0.032, −0.019)	(0.087, 0.109)	(−0.017, −0.016)
Mean change %	−16.59%	−60.06%	33.71%	−1.17%	122.25%	−85.32%	−20.33%	204.55%	−46.46%
Shapiro-Wilk *p*-value	0.689*	0.781*	0.437*	0.526*	0.796*	0.209*	0.599*	0.793*	0.796*
$t_{(3)}$-statistic	−22.130	−717.930	11.801	−2.053	164.790	−28.075	−12.306	28.656	−143.670
Sig (two-tailed)	2.0e-04**	5.9e-09**	1.3e-03**	1.3e-01	4.9e-07**	9.9e-05**	1.1e-03**	9.3e-05**	7.4e-07**
Sig (one-tailed)	1.0e-04**	2.9e-09**	6.5e-04**	-	2.4e-07**	4.9e-05**	5.8e-04**	4.6e-05**	3.7e-07**
Eta squared	0.99	0.99	0.97	0.58	0.99	0.99	0.98	0.99	0.99
Elements for red mullet									
	Li	B	Al	Cr	Mn	Fe	Co	Ni	Cu
Mean difference	0.006	−0.561	4.663	−0.246	−0.895	0.280	0.018	−0.297	−0.077
95% CI	(−0.002, 0.015)	(−0.578, −0.544)	(4.397, 4.929)	(−0.251, −0.240)	(−0.909, −0.879)	(0.272, 0.288)	(0.015, 0.020)	(−0.303, −0.290)	(−0.096, −0.059)
Mean change %	6.78%	−59.40%	153.72%	−97.83%	−70.24%	4.53%	226.72%	−84.68%	−12.35%
Shapiro-Wilk *p*-value	0.627*	0.787*	0.208*	0.774*	0.508*	0.607*	0.741*	0.436*	0.712*
$t_{(3)}$-statistic	2.380	−103.170	55.812	−135.150	−190.070	108.300	19.699	−138.580	−13.279
Sig (two-tailed)	9.7e-02**	2.0e-06**	1.2e-05**	8.9e-07**	3.2e-07**	1.7e-06**	2.8e-04**	8.3e-07**	9.2e-04**
Sig (one-tailed)	4.9e-02**	1.0e-06**	6.3e-06**	4.4e-07**	1.6e-07**	8.6e-07**	1.4e-04**	4.1e-07**	4.6e-04**
Eta squared	0.65	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.98

Table 2 (continued)

Elements for whiting

	Li	B	Al	Cr	Mn	Fe	Co	Ni	Cu
	Zn	As	Se	Rb	Sr	Cd	Ba	Hg	Pb
Mean difference	−2.020	3.718	−0.396	−0.199	−5.703	−0.006	−0.267	0.136	−0.018
95% CI	(−2.525, −1.516)	(3.626, 3.810)	(−0.477, −0.315)	(−0.211, −0.187)	(−5.741, −5.664)	(−0.007, −0.006)	(−0.271, −0.264)	(0.129, 0.142)	(−0.021, −0.016)
Mean change %	−21.83%	173.17%	−39.70%	−26.21%	−74.48%	−94.69%	−90.10%	384.69%	−47.85%
Shapiro-Wilk *p*-value	0.419*	0.410*	0.183*	0.457*	0.523*	0.411*	0.797*	0.204*	0.764*
$t_{(3)}$-statistic	−12.746	128.300	−15.528	−51.972	−472.120	−95.116	−221.380	63.515	−24.641
Sig (two-tailed)	1.0e-03**	1.0e-06**	5.8e-04**	1.5e-05**	2.1e-08**	2.5e-06**	2.0e-07**	8.5e-06**	1.4e-04**
Sig (one-tailed)	5.2e-04**	5.2e-07**	2.9e-04**	7.8e-06**	1.0e-08**	1.2e-06**	1.0e-07**	4.3e-06**	7.3e-05**
Eta squared	0.98	0.99	0.98	0.99	0.99	0.99	0.99	0.99	0.99

<0.01–3.38, Cr 0.02–1.70, Ni 0.09–5.76, Pb <0.05–7.0, Hg <0.05–0.11, Se 0.45–1, Al <0.5–10.98, Cu <0.5–9.21, Fe 2–107, Mn 0.13–4.41, and Zn 3.4–40.72 mg kg^{-1}. The values presented reflect the range of minimum and maximum concentrations reported in the literature references cited in Table 3. These values provide an overview of the variability in element concentrations found in the meat of whiting and red mullet.

Based on the findings of this study, it was observed that the concentrations of the examined elements in both whiting and red mullet were consistent with the values reported in the existing literature. All metal levels, except As, found in the present study were below the acceptable maximum values described by Millward (2012), the EU Commission (1881/2006), and Turkish Food Codex (TFC 2011). Arsenic is a relatively common heavy metal in the marine environment, and it is frequently found in seafood (Moreda-Piñeiro et al., 2012). Arsenic can exist in organic or inorganic forms in nature (Raknuzzaman et al., 2016), with the inorganic form being highly toxic, while the organic form has relatively low toxicity (Sarkar & Paul, 2016). International organizations such as the Department of Health and Human Services (DHHS), the International Agency for Research on Cancer (IARC), and the Environmental Protection Agency (EPA) have classified inorganic arsenic as a human carcinogen (Chou et al., 2007). Studies have reported that the proportion of inorganic arsenic in fish ranges from 1 to 10% of the total arsenic (Kalantzi et al., 2016). In this study, it was found that the amount of inorganic As in whiting and red mullet was calculated as 3% of the total arsenic amount, which is between 0.01 and 0.10 mg/kg ww. This value is below the permissible values reported by Food Standards Australia and New Zealand (FSANZ 2013) and the Chinese Health Ministry (MHPRC 2013), which are 2 mg/kg ww and 0.1 mg/kg ww, respectively.

Potential health risk evaluation

Seafood is a nutritious and healthy food choice that can provide various health benefits when included in a balanced diet (Bayraklı & Duyar, 2019; Oztekin et al., 2018). Nevertheless, contamination from industrial and domestic waste is one of the primary sources of pollution in coastal zones, causing detrimental impacts on the environment and human health. Climate change exacerbates the issue as flood events can result in the transportation of pollutants from land to coastal areas. Benthic organisms, including red mullet and whiting, are typically found in coastal zones and are a crucial source of food for humans. However, these organisms can accumulate metals and other contaminants in their tissues, which can be risky to human health if consumed in large quantities.

Table 3 Literature information on trace metal contents determined for whiting and red mullet (mg kg^{-1})

	As	Cd	Cr	Ni	Pb	Hg	Se	Al	Cu	Fe	Li	Mn	Zn		
ww	**2.91–7.29**	**0.001–0.004**	**0.001–0.420**	**0.053–0.237**	**0.017–0.038**	**0.048–0.155**	**0.89–1.30**	**2.41–10.02**	**0.54–0.61**	**4.51–20.83**	**0.073–0.163**	**0.37–0.78**	**7.54–9.31**	21	*
dw		0.002±0.00		3.78±0.38	0.58±0.03				3.72±0.59	28.84±1.69		6.92±0.71		1	*
dw		0.192±0.02	0.144±0.05	1.363±0.50	0.502±0.10			86.301±11.77		4.488±0.44	3.061±0.15	0.079±0.02	6.029±0.55	2	*
dw	0.17±0.01	0.21±0.02	0.86±0.07	1.14±0.10	0.53±004	0.084±0.01	0.29±0.02		1.32±0.11	98.1±7.7		7.63±0.45	65.4±4.2	3	*
ww		0.12 ± 0.04	0.29 ± 0.06		1.02 ± 0.29			5.53 ± 1.46	1.93 ± 0.91	5.80 ± 1.39		1.10 ± 0.76	6.14 ± 1.65	6	*
ww		0.05–0.68	0.04–0.47	0.25–2.66	0.56–2.06				1.62–4.21	8.16–111		0.18–1.78	3.77–12.8	8	*
ww		0.10–0.25	0.55–1.1		0.28–0.71				1.3–2.8	9.6–58.6		1.3–8.7	16.1–28.8	9	*
dw	3.76–9.67	0.02–0.04	0.45–1.02	0.09–1.19	0.01–0.05				1.03–1.71			0.77–1.19	19.57–25.5	10	*
ww	0.82±0.02	4.05±0.14		<LOD	0.02±0.00		0.40±0.01			0.69±0.01		0.23±0.01		11	*
ww		0.09–0.10	0.51–0.55	1.60–2.53	0.16–0.57				0.26–0.69			0.21–0.45	4.69–9.4	12	*
dw		0.2±0.03			0.9±0.2				2.3±0.7	9.9±2.1		4.3±0.7	58.0±3.5	14	*
dw		0.02–0.18			0.02–1.51				0.19–7.74				6.95–34.3	15	*
dw	1.24	<0.02			<0.05	<0.05		<0.5	<0.5	0.87			3.4	16	*
ww		0.027±0.01	0.63±0.16		0.69±0.34				1.20±0.31	62.80±19.61			16.34±3.8	17	*
ww		0.15–0.89	0.63–1.62	1.25–2.87	2.69–17.11			11.67–25.88	6.30–11.83	59.97–150.74		1.85–2.60	37.96–152.67	20	*
	2.12–5.90	**0.001–0.007**	**0.004–0.254**	**0.052–0.353**	**0.019–0.040**	**0.034–0.175**	**0.58–1.05**	**2.94–7.95**	**0.53–0.64**	**6.16–4.49**	**0.095–0.11**	**0.37–1.28**	**7.05–9.48**	21	
		0.10–0.62	0.34–1.70		0.17–0.82				0.56–2.00	16.10–107.20		1.10–4.10	6.40–30.00	9	**
WW		0.035±0.018	0.62±0.16		0.82±0.34				0.95±0.41	34.34±13.12			17.15±3.78	17	**
ww		0.04–0.12	0.09–0.35	1.73–2.54	0.45–1.30				1.74–1.99	30.5–49.5		0.24–0.43	5.00–7.15	8	**
ww		0.08–0.10	0.49–0.74	1.24–5.76	0.13–0.18				0.32–0.39			0.41–4.41	7.92–8.55	12	**
ww	3.40±0.03	3.38±0.06		<LOD	<LOD		0.55±0.01			4.00±0.01		0.13±0.01		11	**
dw	13.43–14.47	0.01–0.04	0.54–0.69	0.14–0.24	0.09–0.12	0.11	1.87–3.54		1.10–1.14				26.13–28.58	10	**
ww		0.02–0.55	0.02–0.65	0.09–2.84	0.09–7.00			0.9–10.98	1.23–9.21	7.90–39.88		0.31–1.53	3.48–40.72	20	**
dw		0.017–0.023		2.43–2.50	0.72–1.12				2.88–3.40	27.51–30.83		5.00–8.92	23.47–23.95	1	**
ww		0.14 ± 0.005	0.23 ± 0.11		0.72 ± 0.08			0.89 ± 1.54	1.27 ± 0.46	7.9 ± 1.14		0.98 ± 0.37	7.85 ± 3.36	6	**
dw		0.208±0.017	1.055±0.289	0.658±0.333	0.727±0.141			9.850±1.439		21.272±1.476	3.120±0.095	0.005±0.018	7.573±0.389b	2	**
dw		0.02			0.09–0.31				4.93–7.74				6.95–18.43	15	**
dw	1.3	<0.02			<0.05	<0.05		<0.5	<0.5	2.3			3.2	16	**
dw	0.11±0.01	0.17±0.02	1.35±0.12	1.55±0.12	0.36±0.03	0.036±0.002	0.45±0.04		0.96±0.08	53.2±2.8		2.76±0.17	75.5±5.3	3	**

1 (Nisbet et al., 2009), 2 (Turan et al., 2009), 3 (Tuzen, 2009), 4 (Kulpulu et al., 2018), 5 (Korkmaz et al., 2012), 6 (Mutlu, 2021a), 7 (Mutlu, 2021b), 8 (Türkmen and Akaydin, 2017), 9 (Mendil et al., 2010), 10 (Alkan et al., 2012), 11 (Aydın and Tokalıoğlu, 2015), 12 (Türkmen and Öğütçü, 2020), 13 (Ergül and Aksan, 2013), 14 (Aygun and Abanoz, 2011), 15- (Bat et al., 2013), 16 (Bat et al., 2015), 17 (Ergönül and Altindağ, 2014), 18 (Turan et al., 2019), 19 (Baki, 2021), 20 (Fındık and Çiçek, 2011), 21 this study

Bold entries are used to highlight the findings of this study. By emphasizing certain data points, we aim to draw attention to the key results and their significance within the context of our research

The arithmetic sum of each THQ values for the investigated metals in adults upon consuming whiting and red mullet collected from Sinop Türkeli coast of Black Sea is provided in Fig. 1.

The prediction daily intake per meal size (EDI, mg kg^{-1} day^{-1}), maximum allowable daily consumption rates (ADC, kg day^{-1}), allowable monthly consumption (AMC, meal/month), target hazard quotients (THQ) and hazard index (HI), the total target hazard quotient (TTHQ), and cancer risks (CRR) for the studied metals in an adult human upon consuming whiting and red mullet meat, along with reference dose and cancer slope factor, are presented in Table 4. For this reason, acceptable reference doses (RfD) of trace metals in foods taken daily diet have been reported by international health organizations (US-EPA, 2013).

In addition, the estimated daily intake (EDI) is a crucial tool used to assess the level of trace metal ingestion in a typical meal size (Copat et al., 2013). Similarly, the calculation of cancer risk levels (ADC) helps identify the maximum meal intake that poses no cancer risk through food consumption (US-EPA, 2000).

When examining the EDI values, it was found that all the detected elements in the sampled red mullet and whiting before the flood were below the reference dose (RfD) level. However, following the flood, the EDI_{Hg} value exceeded the RfD level in both fish species (Table 4).

The target hazard quotient (THQ) serves as an essential risk assessment tool to evaluate the potential non-carcinogenic health effects associated with exposure to a chemical substance. It is important to note that THQ values are utilized as a preliminary screening tool, and if the THQ value exceeds 1, further evaluation and risk management strategies may be necessary (Bayrakli, 2021).

The study findings revealed a significant increase in the mean concentrations of Hg in both whiting and red mullet after the flood compared to before the flood. This elevation in Hg levels surpassed the threshold value of 1 for THQ. Moreover, the THQHg values for red mullet and whiting accounted for 28.19% and 34.29% of the total hazard index (HI) before the flood, and 67.55% and 67.18% after the flood, respectively. These results strongly suggest that the flood event potentially caused heightened levels of Hg contamination in these fish, posing a considerable health risk to individuals who consume them. Therefore, continuous monitoring of Hg levels in these fish is crucial to ensure that they remain within safe limits for human consumption. Given the adverse effects that high Hg levels can have on human health, regular monitoring is indispensable to guarantee the safety of fish intended for consumption.

The CRR (cancer risk ratio) analysis is a valuable tool for assessing the risk of cancer development resulting from exposure to specific substances or environmental factors. It compares the estimated lifetime cancer risk between exposed and unexposed individuals (Ahmed et al., 2015). The findings of this investigation revealed that before the flood, the CRR_{As}, CRR_{Cr}, and CRR_{Ni} values in both fish groups exceeded tolerable levels ($>10^{-4}$). However, after the flood, these values decreased below tolerable levels ($10^{-4}>$ fish$>10^{-6}$), except for the CRR_{As} ($>10^{-4}$). These results underscore the importance of monitoring and regulating harmful substance levels, especially in aquatic ecosystems, to ensure the well-being of wildlife and human populations that depend on them.

To mitigate cancer risks, it is crucial to determine the maximum allowable daily consumption rates (ADC, kg day^{-1}) for fish. These rates specify the safe amount of fish meat that can be consumed in a day. The evaluation based on ADC_{As} and ADC_{Hg} revealed that both fish groups were not suitable for daily consumption before and after the flood. Specifically, the lowest daily consumption value, ADC_{Hg}, was used for assessment. For whiting, it was determined that consuming a maximum of 20 portions before the flood and 6 portions per month after the flood posed no health risk in terms of AMC_{Hg}. As for red mullet, it was considered safe to consume a maximum of 26 portions before the flood and 5 portions after the flood. The analysis of other metal levels indicated no cancer risk for individuals consuming contaminated whiting and red mullet. However, it is important to note that prolonged excessive mercury consumption can lead to health issues, including nervous system damage. Therefore, adhering to recommended consumption limits is vital to avoid potential health risks.

While other nutritional sources were not considered in the calculations, it is noteworthy that the estimations in this study suggest a high risk associated with Hg and As exposure. Inorganic arsenic has been linked to various cancers, including skin, lung, bladder, and kidney cancers (Copat et al., 2013). Methylmercury

Table 4 Estimated daily intake per meal size, maximum safe daily consumption rate, allowable weekly consumption, target hazard quotient, total target hazard index, and cancer risk rate for the studied metals in adults consuming fish meat based on cancer slope factor and reference dose

	RfD (mg/kg/day)	CSF (mg/kg/day)	*	EDI (mg/kg/day, ww)		THQ		ADC (kg/day)		Cancer Risk (CRR)	
				Mezgit	Barbun	Mezgit	Barbun	Mezgit	Barbun	Mezgit	Barbun
As	0.0003	1.5	1	2.0×10^{-4}	5.8×10^{-5}	0.657	0.193	**0.10**	0.33	**3.0**$\times10^{-4}$	**8.7**$\times10^{-5}$
			2	7.9×10^{-5}	1.6×10^{-4}	0.262	0.528	0.24	**0.12**	**1.2**$\times10^{-4}$	**2.4**$\times10^{-4}$
Cd	0.001	6.3	1	3.4×10^{-6}	6.3×10^{-6}	0.003	0.006	18.33	9.94	2.2×10^{-5}	4.0×10^{-5}
			2	5.0×10^{-7}	3.4×10^{-7}	0.001	0.000	124.91	187.22	3.2×10^{-6}	2.1×10^{-6}
Cr	0.003	0.5	1	3.7×10^{-4}	2.3×10^{-4}	0.125	0.075	0.51	0.84	1.9×10^{-4}	1.1×10^{-4}
			2	1.5×10^{-6}	4.9×10^{-6}	0.001	0.002	124.16	38.53	7.6×10^{-7}	2.5×10^{-6}
Ni	0.02	0.84	1	2.1×10^{-4}	3.2×10^{-4}	0.011	0.016	5.98	3.99	1.8×10^{-4}	2.7×10^{-4}
			2	5.0×10^{-5}	4.8×10^{-5}	0.003	0.002	25.15	26.07	4.2×10^{-5}	4.1×10^{-5}
Pb	0.002	0.0085	1	3.3×10^{-5}	3.5×10^{-5}	0.016	0.018	3.87	3.59	2.8×10^{-7}	3.0×10^{-7}
			2	1.7×10^{-5}	1.8×10^{-5}	0.009	0.009	7.22	6.88	1.5×10^{-7}	1.6×10^{-7}
Hg	0.0001		1	4.3×10^{-5}	3.2×10^{-5}	0.433	0.318	**0.15**	**0.20**	For carcinogenic exposure; no cancer risk if value: > 0.000001 (10^{-6}) cancer risk if value: < 0.000001 (10^{-6}) benchmark: < 0.00001 (10^{-5}) (US-EPA 2010)	
			2	1.3×10^{-4}	1.5×10^{-4}	**1.319**	**1.540**	**0.05**	**0.04**		
Se	0.005		1	8.6×10^{-4}	9.0×10^{-4}	0.172	0.180	0.37	0.35		
			2	1.1×10^{-3}	5.4×10^{-4}	0.229	0.108	0.27	0.58		
Al	1		1	8.9×10^{-3}	2.7×10^{-3}	0.009	0.003	7.06	23.08		
			2	2.2×10^{-3}	6.9×10^{-3}	0.002	0.007	28.37	9.09		
Cu	0.04		1	5.5×10^{-4}	5.6×10^{-4}	0.014	0.014	4.62	4.47		
			2	4.9×10^{-4}	4.9×10^{-4}	0.012	0.012	5.13	5.10		
Fe	0.7		1	1.9×10^{-2}	5.6×10^{-3}	0.027	0.008	2.37	7.92		
			2	4.1×10^{-3}	5.8×10^{-3}	0.006	0.008	10.79	7.57		
Li	0.002		1	7.1×10^{-5}	8.6×10^{-5}	0.035	0.043	1.78	1.46		
			2	1.5×10^{-4}	9.2×10^{-5}	0.073	0.046	0.86	1.36		
Mn	0.14		1	3.5×10^{-4}	1.1×10^{-3}	0.002	0.008	25.23	7.69		
			2	6.7×10^{-4}	3.4×10^{-4}	0.005	0.002	13.19	25.85		
Ba	0.2		1	1.2×10^{-4}	2.7×10^{-4}	0.001	0.001	109.50	47.14		
			2	9.2×10^{-5}	2.6×10^{-5}	0.000	0.000	137.45	476.52		
B	0.2		1	4.7×10^{-4}	8.5×10^{-4}	0.002	0.004	26.75	14.81		
			2	5.2×10^{-4}	3.5×10^{-4}	0.003	0.002	24.03	36.49		
Sr	0.6		1	1.5×10^{-3}	6.9×10^{-3}	0.003	0.011	24.75	5.49		
			2	3.4×10^{-3}	1.8×10^{-3}	0.006	0.003	11.14	21.50		
Zn	0.3		1	8.3×10^{-3}	8.3×10^{-3}	0.028	0.028	2.27	2.27		
			2	6.9×10^{-3}	6.5×10^{-3}	0.023	0.022	2.73	2.90		
			1	50.36[a]	71.85[a]	1.54[c]	0.92[c]	**4.49**[e]	**6.11**[e]		
			2	22.13[a]	8.94[a]	1.95[c]	2.29[c]	**1.47**[e]	**1.26**[e]		
			1	12.07[b]	12.64[b]	28.19[d]	34.29[d]	**19.22**[f]	**26.20**[f]		
			2	16.12[b]	7.53[b]	67.55[d]	67.18[d]	**6.31**[f]	**5.41**[f]		

RfD, (mg kg^{-1} day^{-1}): reference dose (EFSA, 2010; US-EPA, 2013); *CSF*, cancer slope factors for As, Pb (US-EPA, 1996), Cd, Cr, and Ni (Liang et al., 2017); EDI, (mg kg^{-1} day^{-1}): estimated daily intake per meal size; *ww*, wet weight basis; *THQ*, target hazard quotient; *ADC*, (kg day^{-1}): maximum allowable daily consumption rate; *CRR*, cancer risk rate; [a]Se/Hg; [b]*HBV Se* [c]*HI*, hazard index representing arithmetic sum of THQs; [d]THQ_{Hg}*100/HI; [e]AWC_{Hg}, (meal/week) allowable weekly consumption for only Hg; [f]$AM\text{-}C_{Hg\ (meal/month)}$, allowable month consumption for only Hg

Bold entries are utilized to highlight values that may pose potential risks to human health. By emphasizing these specific data points, we aim to underscore the importance of recognizing and addressing these potentially hazardous levels from a health perspective

(MeHg), the toxic form of Hg, is known to have detrimental effects. Furthermore, the level of risk can be influenced by factors such as bioavailability of heavy metals, dietary habits, nutritional status, and individual metabolism. Cooking methods can also impact the bioavailability of MeHg in fish, with boiling and frying reported to decrease MeHg bioavailability by 40% and 60%, respectively (Ouedraogo and Amyot, 2011). Additionally, selenoproteins, important compounds of selenium (Se), have been identified as potential mitigators of Hg's toxic effects (Osman et al., 1998).

The Se:Hg molar ratio above 1 provides protection against Hg toxicity and reduces its adverse effects (Ralston, 2009). The Se-HBV ratio is a reliable indicator for assessing the risk of methylmercury (MeHg) exposure (Ralston, 2009). Studies have suggested that Se in the diet mitigates Hg toxicity and positively affects the health of fish consumers (Bjerregaard et al., 2011; Gochfeld et al., 2012).

In this study, the Se/Hg ratios in whiting before and after the flood were 50.36 and 22.13, respectively, while in red mullet, the ratios were 71.85 and 8.94. The flood event significantly impacted the Se:Hg molar ratios, resulting in a decrease for whiting. The Se HBV ratio improved after the flood in the whiting group (12.07, 16.12) but decreased in the red mullet group (12.64, 7.53). Moreover, the Se/Hg ratios were above 1, indicating a protective effect against mercury toxicity. The flood event likely increased the mercury concentration in the fish, possibly due to factors such as increased runoff from agricultural fields or other sources of pollution. Overall, the study suggests that these fish species pose no health risk to consumers due to the protective effect of Se on Hg toxicity. However, it is important to note that the health risks associated with fish consumption depend on various factors, including species, geographical location, and environmental conditions. Further studies should evaluate the potential health risks considering parameters such as Se-HBV ratios, Se/Hg ratios, and fish consumption frequency and amount.

The International Organization for Standardization (IOM) (2006) has published dietary reference intakes for various nutrients, including trace elements like Cr, Cu, Fe, Mn, Se, and Zn, which are essential for maintaining human health. These reference intakes provide estimates of the minimum daily requirement levels of these elements for individuals, which can serve as a guide for ensuring adequate intake. According to IOM, whiting might only meet about 1.068% of the minimum daily requirement level for Cr, 0.078% for Cu, 0.310% for Fe, 0.015% for Mn, 1.906% for Se, and 0.088% for Zn before the flood. After the flood, these values might meet about with 0.004% for Cr, 0.070% for Cu, 0.068% for Fe, 0.029% for Mn, 2.540% for Se, and 0.074% for Zn through consuming whiting. (Table 5), based on estimated daily average requirement levels provided by IOM (2001, 2006). Only 1% of the daily requirement amounts are met for whiting before and after the flood, respectively. For red mullet, these values were 0.646 to 0.014 % of the minimum daily requirement level for Cr, 0.080 to 0.0.071 % for Cu, 0.093 to 0.097 % for Fe, 0.050 to 0.015% for Mn, 1.996 to 1.203 % for Se, and 0.089 to 0.069 % for Zn through consuming. Similar to our results in this study, Yigit et al. (2018) indicated that a separation would compensate only 0.013 to 0.94% of the minimum daily necessity level for Cu, Zn, Fe, or Mn when consuming Mediterranean mussels (*Mytilus galloprovincialis*) exposed to a cage farm with copper alloy mesh pens.

Conclusions

According to this study, benthic organisms such as whiting and red mullet, commonly found in coastal zones, have the ability to accumulate metals and other contaminants in their tissues, which can pose a risk to human health when consumed in high quantities. Our study revealed a significant increase in Hg levels in both fish species following a flood event, exceeding the threshold value of 1 for THQ. The elevated THQ value suggests the potential for non-carcinogenic health effects, with the probability of these effects increasing as the THQ value rises. Additionally, we found that all elements detected in the fish samples were below the acceptable reference dose (RfD) level before the flood. However, after the flood, the EDI_{Hg} value exceeded the RfD level in both fish species. Furthermore, our CRR analysis indicated that the CRR_{As}, CRR_{Cr}, and CRR_{Ni} values were determined to be above the tolerable range ($>10^{-4}$) in both fish groups before the flood. These values fell below the tolerable range after the flood ($10^{-4}>$ fish$>10^{-6}$), except for the CRR_{As} ($>10^{-4}$). Overall, our study suggests that consuming whiting and red mullet from the Sinop Türkeli coast of the Black Sea may pose a significant health risk to individuals, particularly when consumed in high quantities.

Continuous monitoring of harmful substance levels in these fish is crucial to ensure their safety for human consumption. Promoting public awareness and education regarding the potential health risks associated with fish consumption is essential. Providing

Table 5 Percent compensation of minimum daily requirements (CDRmin) for essential trace elements in adult men (AM), adult women, and children (C) via consuming whiting and red mullet, based on estimated daily average requirement levels according to IOM (2001, 2006)

	EAR (mg/day, person ww)	EDI (mg/kg/day, ww)		CDRmin (%)	
				Mezgit	Barbun
Cr	0.035	3.7×10^{-4}	1	1.068	0.646
		1.5×10^{-6}	2	0.004	0.014
Cu	0.700	5.5×10^{-4}	1	0.078	0.080
		4.9×10^{-4}	2	0.070	0.071
Fe	6.000	1.9×10^{-2}	1	0.310	0.093
		4.1×10^{-3}	2	0.068	0.097
Mn	2.300	3.5×10^{-4}	1	0.015	0.050
		6.7×10^{-4}	2	0.029	0.015
Se	0.045	8.6×10^{-4}	1	1.906	1.996
		1.1×10^{-3}	2	2.549	1.203
Zn	9.400	8.3×10^{-3}	1	0.088	0.089
		6.9×10^{-3}	2	0.074	0.069

EAR, estimated average daily requirement (mg/day) for a healthy human; *ww*, (wet weight) basis; *EDI*, (mg kg^{-1} day^{-1}) estimated daily intake per meal size; *CDRmin (%)*, compensation of minimum daily requirement calculated according to Yigit et al. (2020)

information about CRR analysis, safe consumption guidelines, and strategies to minimize exposure to harmful substances can empower individuals to make informed decisions. Collaboration among public health authorities, environmental agencies, and relevant organizations is necessary to safeguard the health and well-being of the population and preserve aquatic ecosystems.

In conclusion, this study contributes to the identification of potential health risks associated with fish consumption and paves the way for future measures and research. Further sampling and comprehensive investigations will enhance our understanding of the impact of pollutants on fish and aid in the development of appropriate strategies to protect public health.

Data availability The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Author contributions Hünkar Avni Duyar: conceptualization, methodology, preparation, writing original draft, resources, writing, review and editing, finalizing manuscript

Baris Bayrakli: conceptualization, methodology, formal analysis and investigation, writing original draft preparation, resources, finalizing manuscript

Mutlu Altuntaş: statistical analysis, writing, review and editing, finalizing manuscript

Declarations

All authors have read, understood, and have complied as applicable with the statement on "Ethical responsibilities of Authors" as found in the Instructions for Authors and are aware that with minor exceptions, no changes can be made to authorship once the paper is submitted.

Ethics approval Not applicable for this study.

Consent to participate Informed consent was obtained from all individual participants included in the study.

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