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Heavy Metals and Trace Elements in Whole-Blood Samples of the Fishermen in Turkey: The Fish/Ermen Heavy Metal Study (FHMS)

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Abstract

Selected heavy metal-trace element (Ag, As, Ba, Cd, Cu, Hg, Pb, Sb, Se, Sr, and V) levels were determined by the ICP-MS method in whole-blood samples of fishermen and control group who accommodate in four provinces of the Marmara Sea. Mercury (1.267 ± 1.061 µg/L to 0.796 ± 0.853 µg/L) and lead (17.8 ± 9.0 µg/L to 12.0 ± 6.83 µg/L) levels were higher in the fishermen group than that of control group ($p < 0.001$ for both). There was no difference between the fishermen group and the control group in terms of whole-blood levels of other elements. Total monthly fish consumption was 9340.4 gr in the fishermen group and 326.4 gr in the control group, and the difference between the groups was significant ($p < 0.001$). There was no difference between the groups in terms of having amalgam dental filling ($p > 0.05$). The results suggest that consuming high amounts of sea products caught from the Marmara Sea is a source for some heavy metals such as mercury and lead, which poses a public health risk. Unlike the control group, the positive correlation between arsenic, copper, and strontium levels and age in fishermen can also be evaluated as an indicator of chronic exposure.

Keywords Fishermen · Heavy metals · Trace elements · Whole- blood

Introduction

As a consequence of increased environmental pollution, food is now one of the toxic chemical agents for people (Ikem and Egiebor 2005). Among all foods, fish is of crucial importance for humans as it contains high-quality protein, essential fatty acids (omega-3, omega-6, etc.), vitamins, and essential elements (such as selenium) (Domingo et al. 2007; Guérin et al. 2011). Unfortunately, increasing sea pollution is causing heavy metal and trace element contamination in fish and other sea products (Burger and Gochfeld 2005; Domingo et al. 2007; Naser 2013), which are known to be bioaccumulators and capable of biomagnifying heavy metals at higher trophic levels (Taweel et al. 2013; Ahmed et al. 2015; Islam et al. 2015; Tyokumbur 2016; Saha et al. 2016; Sobihah et al. 2018). This may pose a risk to people who consume seafood frequently (Riisgard and Hansen 1990; Suedel et al. 1994; Güler and Çobanoğlu 1994; Wilhelmsson et al. 2013; Bosch et al. 2016; Keshavarzi et al. 2018; Baki et al. 2018).

Some heavy metals and trace elements are necessary for the continuation of human life and play an important role in various reactions in the human body (such as iron, selenium, copper, and zinc). However, the elements that are considered to be necessary for human metabolism may have a toxic effect if a certain amount is exceeded. On the other hand, some elements (such as arsenic, lead, and mercury) do not have a known role in human physiology and their accumulation in the body may pose a risk to health (Duruibe et al. 2007). Therefore, the concentrations of heavy metals and trace elements taken from various sources must not

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exceed certain limits within the human body (McCally 2002). Whole-blood levels concerning the components of these elements have been used to demonstrate recent exposure (Krachler et al. 1999; Smith et al. 2002; Wilhelm et al. 2004; Pasha et al. 2010).

Toxicities of heavy metals can vary according to various factors such as dose, route of exposure, age, gender, genetics, and nutritional status of the individual. Arsenic, cadmium, lead, and mercury are metals that are important for public health with high toxic properties. Even low-dose exposure to these metals can produce systemic toxic effects. They are also classified as carcinogenic (known or probable) by the US Environmental Protection Agency and the International Agency for Research on Cancer (Tchounwou et al. 2012). In the USA, a Substance Priority List is created by the Agency for Toxic Substances and Disease Registry (ATSDR) and includes the known or suspected toxicities of substances and the potential threats for human exposure. The current list includes 275 items and is reviewed every 2 years (ATSDR 2019).

Turkey is a country surrounded by sea on three sides. Being an inland sea, the Marmara Sea has some distinctive characteristics. It is vulnerable to atmospheric deposition due to its large surface area. The sea is surrounded by the big cities and important industrial zones and since, it has a large volume of water, these characteristics extend the hydraulic retention time and cause pollutants to remain in this environment for long periods (Taşdemir 2002). The Marmara Sea receives heavy inputs of untreated municipal and industrial wastewaters (Bat and Arıcı 2018) and has continuously been polluted by various substances, especially heavy metal-trace elements, for many years as a result of being surrounded by highly populated and heavily industrialized cities, and as a result of the density of sea traffic (Yaşar et al. 2001; Taşdemir 2002; Pekey et al. 2004; Küçüksezgin et al. 2006; Pekey 2006; Artüz 2007; Ministry of Environment and Urbanization 2017; TÜDAV 2019; Tan and Aslan 2020). This has caused a significant loss in both the ecological and economic quality of seawater in Marmara. On the other hand, the Marmara Sea contributes a 7.7% share to the whole Turkish fishing industry (TÜİK 2019). For this reason, determining and monitoring the exposure of various elements across the population consuming sea products from this region is very important for public health. In the study conducted by Bozkurt et al. (2014), the lead level in seawater samples taken from the Marmara Sea was found to be above the allowed limits. As, Cd, Pb, and Zn were detected in high levels in sediments taken from the Marmara Sea, and it has been reported that this is mainly due to road traffic flow, paint industry, and coal burning (Pekey 2006). Similar results were also reported in other studies showing significantly higher cadmium and arsenic levels according to US EPA sediment quality parameters (Otansev et al. 2016; Dökmeci et al. 2019). It has been determined that the Cd level in mussels in the Marmara Sea, the mercury level in some fish species, the Pb, As and Cu levels in rose shrimp species were above the limit allowed in the Turkish Food Codex Regulation (Keskin et al. 2007; Dökmeci et al. 2014). In the study conducted by Aksu et al. (2011), the Pb level in some fish species in the Marmara Sea was found to be above the limit value in both Turkish and European countries. In the study by Kayhan et al. (2017), in the fish samples from the Marmara Sea, the levels of Cd and Pb were found to be much higher than the tolerance limits of the Turkish Food Codex, European Union, and the World Health Organization standards.

In the literature, studies evaluating heavy metal-trace element load in those who regularly consume seafood concentrate on mercury; there are fewer studies related to other heavy metals (Al-Majed and Preston 2000; Frery et al. 2001; Iwasaki et al. 2003; Yokoo et al. 2003; Johnson et al. 2004; Lindberg et al. 2004; Knobeloch et al. 2005; Björnberg et al. 2005; Pinherio et al. 2005; Bates et al. 2007; Elhamri et al. 2007; Kim and Lee 2010; Papu-Zamxaka et al. 2010; Birgisdottir et al. 2013; Ilmiawati et al. 2015; Takeda et al. 2017; Yedomon et al. 2017). However, increasing environmental pollution and pollutant diversity from industry makes it necessary to evaluate of more heavy metals (Rodríguez Martín et al. 2015). Still, the amount of research conducted in Turkey in this field is very limited and is related to mercury (Ünlü 1993; Doğan 1997; Çamur et al. 2016).

The aim of this study is to reveal the effect of seafood consumption on heavy metal-trace element accumulation in the body. For this purpose, 11 heavy metal-trace elements (Ag, As, Ba, Cd, Cu, Hg, Pb, Sb, Se, Sr, and V), which were in the Substance Priority List, were analyzed in the whole-blood samples of fishermen living in four provinces of the Marmara Sea and consuming large proportions of the fish they caught. It was evaluated whether element levels in those fishermen differed from the control group who consumes small amounts of fish in their diet. Thus, this study aimed to understand whether there is an increased heavy metal load in the bloods of individuals who consume more fish from the Marmara Sea, which was proven to be contaminated with heavy metals in different studies, compared to those who consume less fish.

Materials and Methods

Study Design and Participants

This research is part of the “Heavy Metal-Trace Element Load and Risk Mapping in Sea Products and Fishermen”

Fig. 1 The Marmara Sea and the corresponding provinces

project between July 2017 and August 2019. The research was conducted in Istanbul, Kocaeli, Tekirdağ, and Yalova provinces, all of which have a coast to the Marmara Sea that was significantly affected by industrial pollution (Fig. 1). Ethics Committee Permission for the study was obtained from Bulent Ecevit University Clinical Research Ethics Committee (Date: June 6, 2018, No: 2018/12).

As the experimental group, the fishermen who frequently consume the fish they catch from the Marmara Sea were selected. The criteria for inclusion in the study for the fisherman group include: active fishing for at least 5 years, consuming their fish/seafood at least twice a week, being male, and 25 of age or older. A control group was also formed among men who are living in the same city as the fishermen, who are not fishermen, consume sea products less than once in every 15 days, and are 25 ± 2 years of age.

For the calculation of the sample size required for the research, a study conducted by Raposo et al. (2014) in Spain was taken as reference. In that study, heavy metal analysis was performed on the hair in the normal population, and the hair mercury level was reported to be 5.38 mg/kg. It was calculated that the standard deviation (SD) is 20% of this value, and the average hair mercury value is ~10% more than this level in fishermen. With a power of 80% in the Power and Precision Version 3.2.0 program, at least 64 fishermen and 20 controls from each province should be included in the research. To reach the fishermen, the fishermen's cooperatives in Istanbul, Kocaeli, Tekirdağ, and Yalova provinces were visited, and the date and time of field research was determined with negotiations with the fishermen who were registered in the cooperatives. They were interviewed face to face, information was given about the research, and informed consent was obtained from those who agreed to participate. A total of 363 fishermen for the experimental group and 89 non-fishermen for the control group participated in the study.

Sampling and Analytical Methods

In whole-blood samples taken from the fisherman and control groups, antimony (Sb), arsenic (As), barium (Ba), cadmium (Cd), copper (Cu), lead (Pb), mercury (Hg), selenium (Se), silver (Ag), strontium (Sr), vanadium (V) levels were determined. The questionnaire form created by the researchers as a data collection tool was applied using a face to face interview method. Together with the socio-demographic information presented in the survey, questions were asked about the types of fish they consume, their frequencies, and the amounts they consume within a month. Total monthly fish consumption was calculated according to fish type, amount, and frequency. First, studies were carried out with the fishermen in that province, and then a control group was selected from that province in coordination with the ages of the fishermen. After completing the questionnaire, spot blood samples were taken from the participants.

Trace element-free injectors and tubes were used for blood collection. Blood was collected by venipuncture using stainless steel needles in the royal blue EDTA vacutainer tubes for blood (Becton, Dickinson and Co., NJ, USA). The blood aliquots were stored in acid-washed polypropylene vials at −20 °C and transported frozen to the laboratory. Samples were kept at −80 °C until heavy metal-trace element analysis. Laboratory analyses were done in Zonguldak Bülent Ecevit University Science and Technology Application and Research Center. The heavy metal-trace elements in whole-blood samples were measured with ICP-MS (Perkin-Elmer, New York, USA). ICP-MS operating conditions were as follows: RF power 1000 W, nebulizer gas flow rate 0.99 mL/min, auxiliary gas flow rate 1.2 mL/min, lens voltage −9.75 V, and oxide rate 0.021%. For calibration, Perkin-Elmer's (New York, USA) multi-element calibration standard (Ag^{107}, As^{75}, Ba^{138}, Cd^{111}, Cu^{63}, Hg^{202}, Pb^{208}, Sb^{123}, Se^{82}, Sr^{88}, and V^{51}) was used. Pure water and other acid solutions used in all analyses are of ultra-purity. For quality control, the method recommended by Bocca et al. (2005) was used for the preparation of certified whole-blood control samples. The results were reported in μg/L. Five-point calibration curves were used for heavy metal readings. The LOD and LOQ were calculated by using the sigma method (BS EN 15673, 2009). Whole-blood CRM (Seronorm™ Trace Elements Whole Blood L-1) recovery rates LOD and LOQ values are presented in Table 1.

Table 1 Whole-blood CRM recovery rates, LOD and LOQ values

Component	Analytical value of CRM (µg/L)	Recovery rate (%)	LOD[a] (µg/L)	LOQ[a] (µg/L)
Antimony (Sb)	1.91	93.2	0.07	0.21
Arsenic (As)	2.4	95.8	0.02	0.08
Barium (Ba)	346	98.6	0.22	0.62
Cadmium (Cd)	0.36	91.7	0.01	0.04
Copper (Cu)	0.68	89.7	0.11	0.26
Lead (Pb)	10.2	96.9	0.02	0.07
Mercury (Hg)	1.5	90.0	0.033	0.06
Selenium (Se)	59	89.8	0.22	0.56
Silver (Ag)	0.12	91.7	0.004	0.01
Strontium (Sr)	15.3	90.2	0.01	0.03
Vanadium (V)	1.3	92.3	0.006	0.01

[a] *LOD* limit of detection, *LOQ* limit of quantification

Statistical Analysis

Statistical analysis was performed with SPSS 23.0 program. The descriptive statistics included the mean (AM = arithmetic mean), standard deviation (SD), minimum (min), and maximum (max) values for quantitative variables; number (*n*) and percentage (%) for qualitative variables. Kolmogorov–Smirnov test was used to analyze the suitability of the data for normal distribution. To compare the measurement variables between two independent groups, Student's *t*-test was used for the data with normal distribution condition, and Mann–Whitney *U* test was applied to data that were not normally distributed. Chi-square test was applied to analyze qualitative variables in independent groups. The statistical significance level was accepted as $p < 0.05$.

Results and Discussion

A total of 363 people in the fishermen group and 89 people in the control group participated in the study. The fisherman and control groups were similar in terms of age, presence of chronic diseases, and amalgam tooth fillings, whereas the level of education was found to be higher in the control group and smoking and alcohol consumption higher in the fishermen group. Total monthly fish consumption was 9340.4 ± 6644.5 gr in the fishermen group and 326.4 ± 316.9 gr in the control group revealing a significant difference ($p < 0.001$) (Table 2).

Among 11 heavy metal-trace elements, mercury and lead levels in the whole blood were higher in fishermen than in the control group. Whereas whole-blood mercury levels were 1.27 ± 1.06 (<0.033–5.8) µg/L in fishermen and 0.796 ± 0.853 (0.1–4.5) µg/L in the control group; lead levels were measured as17.8 ± 9.0 (3.5–48.4) µg/L in fishermen and 12.0 ± 6.83 (1.9–31.9) µg/L in the control group ($p < 0.001$ for both) (Table 3 and Fig. 2). There was no difference between the fishermen and the control group in terms of whole-blood levels of heavy metal-trace elements measured, except mercury and lead (Table 3).

Table 2 Some socio-demographic, personal, and health status characteristics of fishermen and control groups

Characteristics	Fishermen (*n* = 263)		Control (*n* = 89)		*p*
	n	%	*n*	%	
Age (mean ± SD)	53.5 ± 13.2		51.9 ± 12.7		0.331
Marital status					0.384
Married	215	81.7	77	86.5	
Single	48	18.3	12	13.5	
Educational status					<0.001
Illiterate/literate	6	2.3	3	3.4	
Primary school	126	47.9	29	32.6	
Elementary school	48	18.3	5	5.6	
High school	63	24.0	16	18.0	
University	20	7.6	36	40.4	
Smoking status					<0.001
Smoker	163	62.0	37	41.6	
Quitter	60	22.8	23	25.8	
Nonsmoker	40	15.2	29	32.6	
Alcohol consumption status					<0.001
User	126	47.9	14	15.7	
Quitter	12	4.6	1	1.1	
Nonuser	125	47.5	74	83.1	
Chronic diseases	137	52.1	47	52.8	0.907
Amalgam tooth filling	52	19.8	20	22.5	0.694
Total fish consumption/month (mean ± SD)	9340.4 ± 6644.5 gr		326.4 ± 316.9 gr		<0.001

Mercury exposure in the general population was mainly due to the consumption of sea products (Jarup 2003). Various studies showed that blood mercury levels were high in individuals with high consumption of sea products. In studies involving 1216 people in the UK, 1749 in Korea, 179 in Norway, 374 in Brazil, and 70 in Germany (Berlin), the mercury levels in the blood were higher in those with higher fish consumption (Bates et al. 2007; Kim and Lee 2010; Birgisdottir et al. 2013; Takeda et al. 2017; Yedomon et al. 2017). In a study conducted among the adolescent age group in Sweden, a positive correlation was found between fish consumption and blood mercury levels (Barany et al. 2003). In a study of fishermen living on different islands in Europe, with frequent consumption of sea products, the level of mercury in their hair was found to be higher than that of other

Table 3 Heavy metal and trace element levels (µg/L) detected in whole-blood samples

Elements	Fishermen ($n = 263$)		Control ($n = 89$)		*p*
	AM[a] (min–max)	SD[a]	AM[a] (min–max)	SD[a]	
Antimony (Sb)	3.68 (0.900–6.30)	1.19	3.89 (1.90–6.00)	0.976	0.227
Arsenic (As)	1.22 (0.300–4.00)	0.609	1.30 (0.400–3.90)	0.758	0.656
Barium (Ba)	2.98 (0.400–9.90)	1.72	3.31 (0.500–10.3)	1.78	0.091
Cadmium (Cd)	1.05 (0.010–4.56)	0.844	1.07 (0.010–5.33)	1.10	0.251
Copper (Cu)	929.1 (309.0–1856.0)	324.7	998.1 (434.0–1802.0)	338.7	0.099
Lead (Pb)	17.8 (3.50–48.4)	9.00	12.0 (1.90–31.9)	6.83	<0.001
Mercury (Hg)	1.27 (<0.033–5.80)	1.06	0.796 (0.100–4.50)	0.853	<0.001
Selenium (Se)	79.3 (28.0–132.0)	22.3	81.9 (21.0–134.0)	22.3	0.383
Silver (Ag)	0.042 (0.010–0.290)	0.042	0.045 (0.010–0.200)	0.037	0.299
Strontium (Sr)	4.64 (0.600–19.6)	2.77	5.60 (0.900–21.6)	4.05	0.099
Vanadium (V)	0.040 (0.010–0.170)	0.026	0.054 (0.010–0.260)	0.050	0.060

[a] *AM* arithmetic mean, *min* minimum value, *max* maximum value, *SD* standard deviation

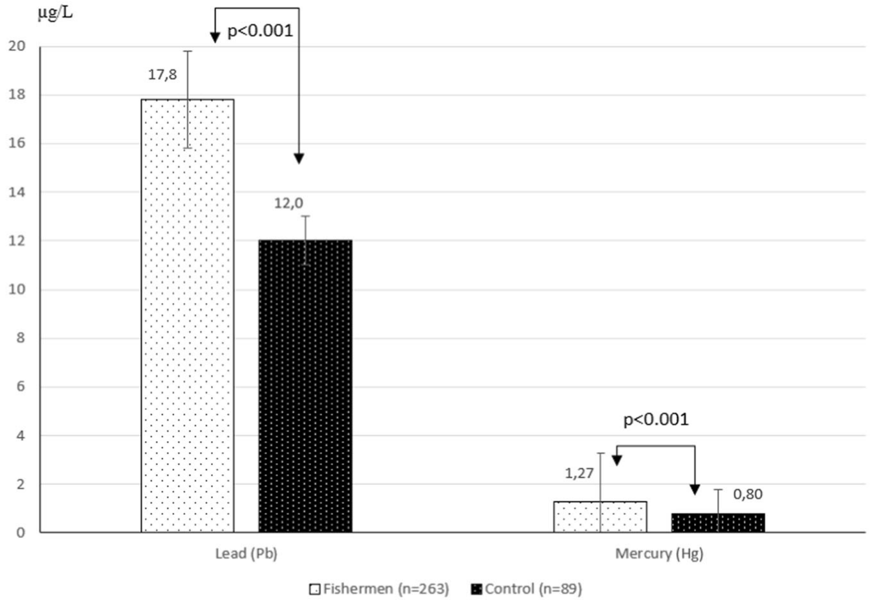

Fig. 2 Whole-blood mercury and lead levels in fisherman and in control groups (µg/L)

village residents (Renzoni 1992). In another study conducted in Sweden, the level of mercury in the blood of fishermen was found to be two times higher than the control group (Svensson et al. 1995). In our study, the level of mercury in the blood of the fishermen was found to be higher than the control group, which was consistent with other findings in the literature. In the studies conducted in the Marmara Sea, the mercury level in some fish species being above the level allowed in the Turkish Food Codex Regulation and the widespread increase of heavy metals in sediments supported the hypothesis that the high blood mercury level in the fishermen's blood samples may be related to the amount of fish consumed (Keskin et al. 2007; Otansev et al. 2016). The fact that fishermen and control groups were similar in terms of having amalgam dental filling eliminated the possibility of difference in mercury levels.

In previous research involving 207 people in the USA and 179 people in Norway, it was found that those who consumed high amounts of sea products had higher blood lead levels (Hovinga et al. 1993; Birgisdottir et al. 2013). Similarly, in a study conducted in Brazil, it was found that the blood lead level was higher in groups with a high frequency of shellfish consumption (Takeda et al. 2017). In our study, the blood lead level in the fisherman group was found to be higher compared to the control group. According to this result, it can be said that frequent consumption of fish and sea products increases lead exposure. In the studies conducted in the Marmara Sea, the fact that the lead level in seawater samples, some fish species and shrimp species was above the allowed limits and the fact that the enrichment of lead and other heavy metals in sediments was common suggested that the high blood lead

Table 4 Whole-blood heavy metal and trace element levels according to some characteristics of fishermen and control group (μg/L)

Elements	AM[a]	SD[a]	AM[a]	SD[a]	*p*
Fishermen ($n = 263$)					
	Alcohol nonusers/quitters ($n = 137$)		Alcohol users ($n = 126$)		
Cadmium (Cd)	0.946	0.886	1.16	0.782	0.001
Mercury (Hg)	1.14	1.00	1.40	1.10	0.028
	Nonsmokers/quitters ($n = 100$)		Smokers ($n = 163$)		
Antimony (Sb)	3.91	1.18	3.53	1.17	0.008
Arsenic (As)	1.32	0.641	1.15	0.580	0.036
Cadmium (Cd)	0.577	0.636	1.34	0.826	<0.001
Copper (Cu)	998.9	329.5	886.3	315.2	0.005
Mercury (Hg)	1.06	0.950	1.40	1.11	0.008
	Without chronic diseases ($n = 126$)		With chronic diseases ($n = 137$)		
Barium (Ba)	3.06	1.47	2.89	1.93	0.044
Strontium (Sr)	4.06	1.88	5.17	3.30	0.007
Control ($n = 89$)					
	Without chronic diseases ($n = 42$)		With chronic diseases ($n = 47$)		
Antimony (Sb)	3.65	0.997	4.10	0.913	0.027
Arsenic (As)	1.08	0.603	1.50	0.829	0.005
Vanadium (V)	0.041	0.040	0.066	0.055	0.006

[a] *AM* arithmetic mean, *SD* standard deviation

level may be due to the excess consumption of fish caught here (Bozkurt et al. 2014; Aksu et al. 2011; Kayhan et al.2017; Pekey 2006; Otansev et al. 2016; Dökmeci et al. 2014, 2019). The fact that lead, which can have harmful effects even at low concentrations, was detected at a significantly higher level in fishermen who consumed sea products frequently suggested that some health risks may arise for individuals who consume fish products caught in the region.

The most important source of cadmium exposure for the nonsmoking general population is food. Those who consume sea products also face an increased risk of cadmium exposure (Jarup 2003; ATSDR 2012). Studies reported different results with regular consumption of sea products and cadmium levels. While in the studies conducted by Birgisdottir et al. (2013) in Norway and Ilmiawati et al. (2015) in Japan, a positive relationship was detected between these two parameters, whereas no relation was found between regular consumption of sea products and blood cadmium level in the studies conducted by Guan et al. (2015) in the USA and Takeda et al. (2017) in Brazil. In our study, no difference was found between the fisherman group and the control group in terms of blood cadmium levels. It is known that smoking has a significant contribution to cadmium exposure (ATSDR 2012). The fisherman group consumed more fish and smoked more than the control group. Despite the coexistence of these two conditions, there was no difference between the groups in terms of blood cadmium level. This was in line with the studies showing that regular consumption of seafood did not create a significant risk increase in terms of cadmium exposure in individuals. However, in the fishermen who still smoke, the blood cadmium level was found to be significantly higher than the fishermen who did not use/quit. This finding was consistent with other studies in the literature where blood cadmium, lead, and mercury levels were found to be statistically significantly higher in smokers compared to nonsmokers (Mortada et al. 2004; Erzen and Lijana 2006; Alrobaian and Arida 2019; Repić et al. 2020).

Sea products can be an important source of barium exposure for humans (WHO 2016; ATSDR 2007). In the literature, the number of studies examining the amount of the consumption of sea products and the level of barium in humans is limited. In a study conducted with 452 women in China, it was found that there was no correlation between hair barium concentration and fish consumption (Li et al. 2017). In our study, no difference was found between the fisherman group and the control group in terms of blood barium levels.

People may be exposed to strontium by inhaling aerosols, or through food (vegetables or fish) and drinking water (ATSDR 2004). In the literature, different results were obtained in studies in which the effects of the consumption of sea products on strontium levels in humans were examined. In a study conducted in Italy, while the amount of fish consumption did not differ significantly between serum strontium levels of different groups, in the study conducted in Australia, the blood strontium level of the group with less fish consumption was higher than those with higher fish consumption (Buscemi et al. 2014; Hinwood et al. 2015). In another study conducted in Spain, a positive correlation was found between Sr plasma level and age (Henriquez-Hernandez et al. 2020). In our study, no difference was found between the fisherman group and the control group in terms of blood strontium levels.

The consumption of sea products is one of the main sources of arsenic exposure for humans. The arsenic accumulation in the human body can vary according to the differences in arsenic metabolism (Mitra et al. 2004). There are studies in the literature that report a positive relationship between fish consumption and blood arsenic levels (Miklavcic et al. 2013; Meltzer et al. 2002; Birgisdottir et al.

2013). In the study conducted in Brazil, such a relationship was not detected (Takeda et al. 2017). In our study, no difference in terms of blood arsenic levels was found between the fisherman group consuming regular sea products and the control group. The short half-life of ace in the blood may also be effective in this (Heitland and Köster 2006).

In a limited number of studies examining the effect of regular consumption of sea products on antimony exposure, no relation was found between blood antimony levels and the consumption of sea products (Yedomon et al. 2017). In our study, no difference was found between the fisherman group and the control group in terms of blood antimony levels.

Even though it is not statistically significant, elevations in arsenic, barium, cadmium, copper, antimony, strontium, vanadium levels in the control group suggested that there may be ways of interaction such as air, water, workplace environment factors other than frequent consumption of sea products in the industry-dense working area.

According to some characteristics of fishermen and control groups, the whole-blood levels of heavy metal-trace elements were evaluated and the statistically significant differences are given in Table 4. The mercury level was 1.40 ± 1.10 µg/L for fishermen who consume alcohol and 1.14 ± 1.00 µg/L for fishermen who never consumed/quit consuming alcohol ($p = 0.028$). Cadmium levels were 1.16 ± 0.782 µg/L for fishermen who still consume alcohol and 0.946 ± 0.886 µg/L for fishermen who never consumed/quit consuming alcohol ($p = 0.001$). The mercury levels were 1.40 ± 1.11 µg/L for fishermen who are smokers and 1.06 ± 0.950 µg/L for fishermen who never consumed/quit smoking ($p = 0.008$). Cadmium level was 1.34 ± 0.826 µg/L for fishermen who are smokers and 0.577 ± 0.636 µg/L in fishermen who never consumed/quit smoking ($p < 0.001$). Compared to the control group, mercury and cadmium were higher for those using cigarette or/and alcohol in the fishing group; strontium was higher in for those who is a patient with chronic disease. These results suggested that lead was high in fishermen independently, and the high consumption of cigarettes and alcohol in fishermen compared to the control group affects mercury and cadmium levels.

Antimony, arsenic, and copper levels were higher in nonsmokers/quitters than that of smokers ($p = 0.008$, $p = 0.036$, $p = 0.005$, respectively). Barium level was higher in ones without chronic diseases than the ones with chronic diseases (respectively, $p = 0.044$, $p = 0.007$) (Table 4). There was no difference in the level of full blood mercury in those with or without amalgam tooth filling in both fishermen and the control group (respectively, $p = 0.752$, $p = 0.847$). In the control group, no difference was found between whole-blood element levels according to alcohol use and smoking status ($p > 0.05$). Antimony, arsenic, and vanadium levels were found to be higher in those with chronic diseases compared to those without chronic diseases ($p = 0.027$, $p = 0.005$, $p = 0.006$, respectively) (Table 4).

Table 5 Correlation between age and element levels in the fisherman and in the control groups

Elements	Fishermen ($n = 263$)		Control ($n = 89$)	
	r	*p*	*r*	*p*
Antimony (Sb)	0.260	<0.001	0.377	<0.001
Arsenic (As)	0.232	<0.001		
Copper (Cu)	0.276	<0.001		
Strontium (Sr)	0.358	<0.001		
Vanadium (V)	0.348	<0.001	0.329	0.002

Correlation between age and whole-blood heavy metal-trace element levels was examined in the fisherman and the control group, and the elements with correlation were presented in Table 5. A positive correlation was found between age and whole-blood antimony, arsenic, copper, strontium, and vanadium levels in the fishermen group. In the control group, a positive correlation was found between age and whole-blood antimony and vanadium levels (Table 5). Unlike the control group, the positive correlation between arsenic, copper, and strontium levels and age in fishermen can also be evaluated as an indicator of chronic exposure. The effect of age on arsenic and antimony bioaccumulation was demonstrated in other studies (Rahman et al. 2016; Liu et al. 2011). The combined effect of arsenic and antimony reported in previous studies is also important (Liu et al. 2011; Henriquez-Hernandez et al. 2020).

Conclusion

The results suggest that consuming high amounts of sea products caught from the Marmara Sea is a source for some heavy metals such as mercury and lead. Because the fish consumed are caught from the Marmara Sea, this points to the pollutants in the sea. Excessive consumption of fish caught from the Marmara Sea may cause health risks related to these elements. However, to reveal the relationship between blood element levels and fish/seafood consumption, further studies are required to evaluate the fish consumption characteristics in detail such as the type, amount of the consumed seafood, and the of heavy metal-trace elements contents.

Biomonitoring studies in humans are important in the management of chemical risks. Biomonitoring studies generally focus on a few elements whose toxicity is well known. However, the number and quantity of chemicals released to the environment increases day by day. For this reason, biomonitoring studies with a large list of elements will be a warning about new pollutants. It is important that ten elements other than mercury were evaluated in this study. In addition, a systematic monitoring system can be established for heavy metal-trace element levels in seawater and sea products, and individuals who regularly consume them for early notification of the problem to take necessary precautions. The levels of heavy metals and trace elements and detected in whole blood may be affected acutely and chronically by many factors such as air, drinking water, food, drug use. More comprehensive follow-up studies are needed, in which all factors can be examined together.

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Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

Ethics Approval This study was performed in line with the principles of the Declaration of Helsinki. Approval was granted by the Clinical Research Ethics Committee of Zonguldak Bülent Ecevit University (Date: June 6, 2018/No: 2018/12).

References

Ahmed MK, Shaheen N, Islam MS, Habibullah-al-Mamun M, Islam S, Mohiduzzaman M, Bhattacharjee L (2015) Dietary intake of trace elements from highly consumed cultured fish (*Labeo rohita*, *Pangasius pangasius* and *Oreochromis mossambicus*) and human health risk implications in Bangladesh. Chemosphere 128:284–292

Aksu A, Balkıs N, Taşkın ÖS, Erşan MS (2011) Toxic metal (Pb, Cd, As and Hg) and organochlorine residue levels in hake (*Merluccius merluccius*) from the Marmara Sea, Turkey. Environ Monit Assess 182:509–521. https://doi.org/10.1007/s10661-011-1893-1

Al-Majed NB, Preston MR (2000) Factors influencing the total mercury and methylmercury in the hair of the fishermen of Kuwait. Environ Pollut 109:239–250

Alrobaian M, Arida H (2019) Assessment of heavy and toxic metals in the blood and hair of Saudi Arabia smokers using modern analytical techniques. Int J Anal Chem. https://doi.org/10.1155/2019/7125210

Artüz ML (2007) Bilimsel Açıdan Marmara Denizi (Scientific Perspective of Marmara Sea) (in Turkish). Turkey Bar Association Publications, Ankara

ATSDR (2004) Toxicological profile for Strontium. Department of Health and Human Services, Agency for Toxic Substances and Disease Registry, Atlanta. https://www.atsdr.cdc.gov/toxprofiles/tp159.pdf. Accessed 18 Apr 2018

ATSDR (2007) Toxicological profile for Barium and Barium Compounds. Department of Health and Human Services,Agency for Toxic Substances and Disease Registry, Atlanta. https://www.atsdr.cdc.gov/ToxProfiles/tp24.pdf. Accessed 20 May 2018

ATSDR (2012) Toxicological profile for cadmium. Department of Health and Human Services, Agency for Toxic Substances and Disease Registry, Atlanta. https://www.atsdr.cdc.gov/toxprofiles/tp5.pdf. Accessed 10 May 2018

ATSDR (2019) ATSDR's substance priority list. Agency for Toxic Substances and Disease Registry. https://www.atsdr.cdc.gov/spl/#2019spl. Accessed 10 May 2018

Baki MA, Hossain MM, Akter J, Quraishi SB, Haque Shojib MF, Atique Ullah AKM, Khan MF (2018) Concentration of heavy metals in seafood (fishes, shrimp, lobster and crabs) and human health assessment in Saint Martin Island, Bangladesh. Ecotoxicol Environ Saf 159:153–163. https://doi.org/10.1016/j.ecoenv.2018.04.035

Barany E, Bergdahl IA, Bratteby L, Lundh T, Samuelson G, Skerfving S, Oskarsson A (2003) Mercury and selenium in whole blood and serum in relation to fish consumption and amalgam fillings in adolescents. J Trace Elem Med Biol 17(3):165–170

Bat L, Arıcı E (2018) Heavy metal levels in fish, molluscs, and crustacea from Turkish seas and potential risk of human health. In: Holban AM, Grumezescu AM (eds) Food quality: balancing health and disease. Handbook of food bioengineering, vol 13. Academic Press, pp. 159–196

Bates CJ, Prentice A, Birch MC, Delves HT (2007) Dependence of blood indices of selenium and mercury on estimated fish intake in a national survey of British adults. Public Health Nutr 10(5):508–517. https://doi.org/10.1017/S1368980007246683

Birgisdottir BE, Knutsen HK, Haugen M, Gjelstad IM, Jenssen MTS, Ellingsen DG, Thomassen Y, Alexander J, Meltzer HM, Brantsaeter AL (2013) Essential and toxic element concentrations in blood and urine and their associations with diet: results from a Norwegian population study including high-consumers of seafood and game. Sci Total Environ 463–464:836–844

Björnberg KA, Vahter M, Grawe KP, Berglund M (2005) Methyl mercury exposure in Swedish women with high fish consumption. Sci Total Environ 341:45–52

Bocca B, Forte G, Petrucci F, Senofonte O, Violante N, Alimonti A (2005) Development of methods for the quantification of essential and toxic elements in human biomonitoring. Ann Ist Super Sanita 41(2):165–170

Bosch AC, O'Neill B, Sigge GO, Kerwath SE, Hoffman LC (2016) Heavy metals in marine fish meat and consumer health: a review. J Sci Food Agric 96(1):32–48. https://doi.org/10.1002/jsfa.7360

Bozkurt E, Eliri Ö, Kesiktaş M (2014) Analysis of heavy metals in seawater samples collected from beaches of Asian side of Istanbul. J Recreat Tour Res 1(1):39–47

Burger J, Gochfeld M (2005) Heavy metals in commercial fish in New Jersey. Environ Res 99:403–412

Buscemi S, Vasto S, Di Gaudio F, Grosso G, Bergante S, Galvano F et al. (2014) Endothelial function and serum concentration of toxic metals in frequent consumers of fish. PLoS ONE 9(11):1–8

Çamur D, Güler Ç, Vaizoğlu SA, Özdilek B (2016) Determining mercury levels in anchovy and in individuals with different fish consumption habits, together with their neurological effects. Toxicol Ind Health 32(7):1215–1223

Doğan N (1997) Determination of levels of mercury in fish in Mersin and in the hair of humans living in the region. Postgraduate Thesis, Mersin University Faculty of Science, Department of Environmental Engineering, Mersin (in Turkish)

Dökmeci AH, Yıldız T, Ongen A, Sivri N (2014) Heavy metal concentration in deepwater rose shrimp species (Parapenaeus longirostris, Lucas, 1846) collected from the Marmara Sea coast in Tekirdağ. Environ Monit Assess 186:2449–2454. https://doi.org/10.1007/s10661-013-3551-2

Dökmeci AH, Sabudak T, Dalmış V (2019) Accumulation of essential and toxic metals in sediment from the Marmara Sea along

Tekirdağ coast: risk assessment for ecological health. Desalination Water Treat 169:166–172. https://doi.org/10.5004/dwt.2019.24671

Domingo L, Bocio A, Falc G, Llobet JM (2007) Benefits and risks of fish consumption part I. A quantitative analysis of the ıntake of omega-3 fatty acids and chemical contaminants. Toxicology 230:219–226

Duruibe JO, Ogwuegbu MOC, Egwurugwu J (2007) Heavy metal pollution and human biotoxic effects. Int J Phys Sci 2(5):112–118

Elhamri H, Idrissi L, Coquery M, Azemard S, El Abidi A, Benlemlih M et al. (2007) Hair mercury levels in relation to fish consumption in a community of the Moroccan Mediterranean Coast. Food Addit Contam 24(11):1236–1246

Erzen I, Lijana ZK (2006) Cadmium concentrations in blood related to smoking habits in a group of males aged between 18 and 26 years. Trace Elem Electrolytes 23(1):60–65

Frery N, Maury-Brachet R, Maillot E, Deheeger M, de Merona B, Boudouet A (2001) Gold-mining activities and mercury contamination of native Amerindian communities in French Guiana: key role of fish in dietary uptake. Environ Health Perspect 109 (5):449–456

Guan S, Palermo T, Meliker J (2015) Seafood intake and blood cadmium in a cohort of adult avid seafood consumers. Int J Hyg Environ Health 218(1):147–152

Guérin T, Chekri R, Vastel C, Sirot V, Volatier JL, Leblanc JC, Noel L (2011) Determination of 20 trace elements in fish and other seafood from the French market'. Food Chem 127:934–942

Güler Ç, Çobanoğlu Z (1994) Bireyin iş ve çevresel zararlara cevabını değiştiren durumlar (Situations that change the individual's response to work and environmental losses). Ministry of health environmental health basic resource series No:4. Ministry of Health Press, Ankara (in Turkish)

Heitland P, Köster HD (2006) Biomonitoring of 37 trace elements in blood samples from inhabitants of northern Germany by ICP–MS. J Trace Elem Med Biol 20:253–262

Henriquez-Hernandez LA, Romero D, Gonzalez-Antuna A, Gonzalez-Alzaga B, Zumbado M, Boada LD et al. (2020) Biomonitoring of 45 inorganic elements measured in plasma from Spanish subjects: a cross-sectional study in Andalusian population. Sci Total Environ 706:135750

Hinwood AL, Stasinska A, Callan AC, Heyworth J, Ramalingam M, Boyce M et al. (2015) Maternal exposure to alkali, alkali earth, transition and other metals: concentrations and predictors of exposure. Environ Pollut 204:256–263

Hovinga ME, Sowers M, Humphrey HEB (1993) environmental exposure and lifestyle predictors of lead, cadmium, PCB and DDT levels in Great Lakes fish eaters. Arch Environ Health 48 (2):98–104

Ikem A, Egiebor NO (2005) Assessment of trace elements in canned fishes (Mackerel, Tuna, Salmon, Sardines and Herrings) marketed in Georgia and Alabama (United States of America). J Food Compos Anal 18:771–787

Ilmiawati C, Yoshida T, Itoh T, Nakagi Y, Saijo Y, Sugioka Y, Sakamoto M, Ikegami A, Ogawa M, Kayama F (2015) Biomonitoring of mercury, cadmium, and lead exposure in Japanese children: a cross-sectional study. Environ Health Prev Med 20 (1):18–27

Islam MS, Ahmed MK, Raknuzzaman M, Habibullah-Al-Mamun M, Masunaga S (2015) Metal speciation in sediment and their bioaccumulation in fish species of three urban rivers in Bangladesh. Arch Environ Contam Toxicol 68(1):92–106

Iwasaki Y, Sakamoto M, Nakai K, Oka T, Dakeishi M, Iwata T et al. (2003) Estimation of daily mercury intake from seafood in Japanese women: Akita cross-sectional study. Tohoku J Exp Med 200:67–73

Jarup L (2003) Hazards of heavy metal contamination. Br Med Bull 68 (1):167–182

Johnson C, Sallsten G, Schütz A, Sjörs A, Barregard L (2004) Hair mercury levels versus freshwater fish consumption inhousehold members of Swedish Angling Societies. Environ Res 96 (3):257–263

Kayhan F, Büyükurgancı N, Kaymak G (2017) Accumulation of cadmium and lead in commercially important fish species in the Gulf of Gemlik, Marmara Sea, Turkey. Aquat Sci Eng 32 (4):178–183. https://doi.org/10.18864/TJAS201716

Keshavarzi B, Hassanaghaei M, Moore F, Rastegari Mehr M, Soltanian S, Lahijanzadeh AR, Sorooshian A (2018) Heavy metal contamination and health risk assessment in three commercial fish species in the Persian Gulf. Mar Pollut Bull 129(1):245–252. https://doi.org/10.1016/j.marpolbul.2018.02.032

Keskin Y, Başkaya R, Özyaral O, Yurdun T, Lüleci NE, Hayran O (2007) Cadmium, lead, mercury and copper in fish from the Marmara Sea, Turkey. Bull Environ Contam Toxicol 78:258–261. https://doi.org/10.1007/s00128-007-9123-9

Kim N, Lee B (2010) Blood total mercury and fish consumption in the Korean general population in KNHANES III, 2005. Sci Total Environ 408:4841–4847

Knobeloch L, Anderson HA, Imm P, Peters D, Smith A (2005) Fish consumption, advisory awareness and hair mercury levels among women of childbearing age. Environ Res 97(2):220–227

Krachler M, Rossipal E, Micetic-Turk D (1999) Concentrations of trace elements in sera of newborns, young infants and adults. Biol Trace Elem Res 68:121–135

Küçüksezgin F, Kontas A, Altay O, Uluturhan E, Darılmaz E (2006) Assessment of marine pollution in Izmir Bay: Nutrient, heavy metal and total hydrocarbon concentrations. Environ Int 32 (1):41–51

Li Z, Wang B, Huo W, Liu Y, Zhu Y, Xie J, Li Z, Ren A (2017) Are concentrations of alkaline earth elements in maternal hair associated with risk of neural tube defects? Sci Total Environ 609:694–700

Lindberg A, Björnberg KA, Vahter M, Berglund M (2004) Exposure to methylmercury in non-fish-eating people in Sweden. Environ Res 96:28–33

Liu B, Wu F, Li X, Fu Z, Deng Q, Mo C (2011) Arsenic, antimony and bismuth in human hair from potentially exposed individuals in the vicinity of antimony mines in Southwest China. Microchem J 97(1):20–24

McCally M (2002) Life support: the environment and human health. MIT Press, London

Meltzer HM, Maage A, Ydersbond TA, Haug E, Glattre E, Holm H (2002) Fish arsenic may influence human blood arsenic, selenium, and T4:T3 ratio. Biol Trace Elem Res 90(1):83–98

Miklavcic A, Casetta A, Tratnik JS, Mazej D, Krsnik M, Mariuz M, Sofianou K, Spiric Z, Barbone F, Horvat M (2013) Mercury, arsenic and selenium exposure levels in relation to fish consumption in the Mediterranean area. Environ Res 120:7–17

Ministry of Environment and Urbanization (2017) Denizlerde Bütünleşik Kirlilik İzleme İşi 2014-2016 Marmara Denizi Özet Raporu (Integrated marine pollution monitoring work 2014-2016 Marmara Sea summary report). Ministry of Environment and Urbanization, Ankara (in Turkish)

Mitra SR, Mazumder DN, Basu A, Block G, Haque R, Samanta S, Ghosh N, Smith MM, von Ehrenstein OS, Smith AH (2004) Nutritional factors and susceptibility to arsenic-caused skin lesions in West Bengal, India. Environ Health Perspect 112 (10):1104–1109

Mortada WI, Sobh MA, El-Defrawy MM (2004) The exposure to cadmium, lead and mercury from smoking and its impact on renal integrity. Med Sci Monit 10(3):CR112–CR116

Naser HA (2013) Assessment and management of heavy metal pollution in the marine environment of the Arabian Gulf: a review. Mar Pollut Bull 72:6–13

Otansev P, Taşkın H, Başsarı A, Varinlioğlu A (2016) Distribution and environmental impacts of heavy metals and radioactivity in sediment and seawater samples of the Marmara Sea. Chemosphere 154:266–275. https://doi.org/10.1016/j.chemosphere.2016.03.122

Pasha Q, Malik SA, Shaheen N, Shah MH (2010) Investigation of trace metals in the blood plasma and scalp hair of gastrointestinal cancer patients in comparison with controls. Clin Chim Acta 411 (7-8):531–539

Papu-Zamxaka V, Mathee A, Harpham T, Barnes BR (2010) Elevated mercury exposure in communities living alongside the Inanda Dam, South Africa. J Environ Monit 12(2):472–477

Pekey H (2006) Heavy metal pollution assessment in sediments of the Izmit Bay, Turkey. Environ Monit Assess 123(1):219–231

Pekey H, Karakaş D, Ayberk S, Tolun L, Bakoğlu M (2004) Ecological risk assessment using trace elements from surface sediments of İzmit Bay (Northeastern Marmara Sea) Turkey. Mar Pollut Bull 48(9):946–953

Pinherio MCN, Müler RCS, Sarkis JE, Vieira JLF, Oikawa T, Gomes MSV et al. (2005) Mercury and selenium concentration in hair samples of women in fertile age from Amazon riverside communities. Sci Total Environ 349:284–288

Rahman M, Vahter M, Sohel N, Yunus M, Wahed MA, Streatfield PK et al. (2016) Arsenic exposure and age- and sex-specific risk for skin lesions: a population-based case–referent study in Bangladesh. Environ Health Perspect 114(12):1847–1852

Raposo JC, Navarro P, Sarmiento A, Arribas E, Irazola M, Alonso RM (2014) Analytical proposal for trace element determination in human hair. Application to the Biscay province population, northern Spain. Microchem J 116:125–234

Renzoni A (1992) Comparative observations on levels of mercury in scalp hair of humans from different Islands. Environ Manag 16 (5):597–602

Repić A, Bulat P, Antonijević B, Antunović M, Džudović J, Buha A, Bulat Z (2020) The influence of smoking habits on cadmium and lead blood levels in the Serbian adult people. Environ Sci Pollut Res 27:751–760. https://doi.org/10.1007/s11356-019-06840-1

Riisgard HU, Hansen S (1990) Biomagnification of mercury in a marine grazing food-chain: Algal cells *Phaeodactylum tricornutum*, mussels *Mytilus edulis* and flounders *Platichthys flesus* studied by means of a stepwise-reduction-CVAA method. Mar Ecol Prog 62(3):259–270

Rodríguez Martín JA, De Arana C, Ramos-Miras JJ, Gil C, Boluda R (2015) Impact of 70 years urban growth associated with heavy metal pollution. Environ Pollut 196:156–163

Saha N, Mollah MZI, Alam MF, Rahman MS (2016) Seasonal investigation of heavy metals in marine fishes captured from the Bay of Bengal and the implications for human health risk assessment. Food Control 70:110–118

Smith D, Hernandez-Avila M, Tellez-Rojo MM, Mercado A, Hu H (2002) The relationship between lead in plasma, and whole blood in woman. Environ Health Perspect 110:263–268

Sobihah NN, Zaharin AA, Nizam MK, Juen LL, Kyoung-Woong K (2018) Bioaccumulation of heavy metals in maricultured fish, *Lates calcarifer* (Barramudi), *Lutjanus campechanus* (red snapper) and *Lutjanus griseus* (grey snapper). Chemosphere 197:318–324. https://doi.org/10.1016/j.chemosphere.2017.12.187

Suedel B, Boraczek J, Peddicord R, Clifford P, Dillon T (1994) Trophic transfer and biomagnification potential of contaminants in aquatic ecosystems. Rev Environ Contam Toxicol 136:21–89

Svensson BG, Nilsson A, Jonsson E, Schütz A, Akesson B, Hagmar L (1995) Fish consumption and exposure to persistent organochlorine compounds, mercury, selenium and methylamines among Swedish fishermen. Scand J Work Environ Health 21:96–105

Takeda SHK, Kuno R, Barbosa Jr F, Gouveia N (2017) Trace element levels in blood and associated factors in adults living in the metropolitan area of Sao Paulo, Brazil. J Trace Elem Med Biol 44:307–314

Tan İ, Aslan E (2020) Metal pollution status and ecological risk assessment in marine sediments of the inner Izmit Bay. Reg Stud Mar Sci. https://doi.org/10.1016/j.rsma.2019.100850

Taşdemir Y (2002) The Marmara Sea: pollutants and environment related precautions (in Turkish). J Fac Eng 7(1):39–45

Taweel A, Shuhaimi-Othman M, Ahmad AK (2013) Assessment of heavy metals in tilapiafish (*Oreochromis niloticus*) from the Langat River and Engineering Lake in Bangi, Malaysia, and evaluation of the health risk from tilapia consumption. Ecotoxicol Environ Saf 93:45–51. https://doi.org/10.1016/j.ecoenv.2013.03.031

Tchounwou PB, Yedjou CG, Patlolla AK, Sutton DJ (2012) Heavy metal toxicity and the environment. In: Luch A (ed.) Molecular, clinical and environmental toxicology. Experientia supplementum, vol 101. Springer, Basel

TÜDAV (2019) Marmara Sea action plan (in Turkish). Turkish Marine Research Foundation. http://tudav.org/calismalar/deniz-alanlari/marmara-denizi/marmara-denizi-eylem-plani/. Accessed 11 June 2019

TÜİK (2019) Su Ürünleri İstatistikleri (Fisheries statistics). Turkish Statistical Institute. http://tuik.gov.tr/PreTablo.do?alt_id=1005. Accessed 18 Apr 2019

Tyokumbur ET (2016) Bioaccumulation of heavy metals in the fish species *Sarotherodon melanotheron* from Alaro Stream Ecosystem in Ibadan. N Y Sci J 9(2):83–87. https://doi.org/10.7537/marsnys09021614

Ünlü H (1993) Determination of correlation between fish consumption and methylmercury accumulating in the hair. Phd Thesis, Faculty of Health Sciences, Department of Pharmaceutical Toxicology, Ankara University, Ankara (in Turkish)

WHO (2016) Barium in Drinking-water. World Health Organization Press, Geneva. https://www.who.int/water_sanitation_health/water-quality/guidelines/chemicals/barium-background-jan17.pdf?ua=1. Accessed 20 May 2019

Wilhelm M, Ewers U, Schulz C (2004) Revised and new reference values for some trace elements in blood and urine for human biomonitoring in environmental medicine. Int J Hyg Environ Health 207:69–73

Wilhelmsson D, Thompson RC, Holmström K, Linden O, Eriksson-Hagg H (2013) Marine pollution. In: Noone K, Sumaila UR, Diaz R (eds) Managing ocean environments in a changing climate, 1st ed. Elsevier, USA, p 127–169

Yaşar D, Aksu AE, Uslu O (2001) Anthropogenic pollution in İzmit Bay: heavy metal concentrations in surface sediments. Turkish J Eng Environ Sci 25:299–313

Yedomon B, Menudier A, Etangs FLD, Anani L, Fayomi B, Druet-Cabanac M, Moesch C (2017) Biomonitoring of 29 trace elements in whole blood from inhabitants of Cotonou (Benin) by ICP-MS. J Trace Elem Med Biol 43:38–45. https://doi.org/10.1016/j.jtemb.2016.11.004

Yokoo EM, Valente JG, Grattan L, Schmidt SL, Platt I, Silbergeld EK (2003) Low level methylmercury exposure affects neuropsychological function in adults. Environ Health 2:8