Original Research

Concentrations of Some Heavy Metals in Water, Sediment, and Tissues of Pikeperch (*Sander lucioperca*) from Karataş Lake Related to Physico-Chemical Parameters, Fish Size, and Seasons

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Abstract

The aim of the current study is to investigate the relationships between physico-chemical parameters, seasons, and fish size to determine levels of some heavy metals in water, sediment, and gills of *Sander lucioperca* in Karataş Lake, Turkey. Temperature, pH, dissolved oxygen, and EC (electrical conductivity) were measured. DORM 3 and DOLT 4 reference material showed good accuracy. In the water, Fe had the highest level, while Cd had the lowest. Generally, heavy metal levels increased in spring. Both positive and negative correlations were detected between their content in water and physico-chemical parameters. Results of the heavy metal levels were compared with national and international water quality guidelines. In sediment, Fe was the highest too. In fish, high levels of heavy metals were found in liver of pikeperch while low levels in muscle and gill samples depended on metal properties. In season, the metal levels were highest in autumn in muscle, in summer in liver, and in winter in gill. Positive and negative relationships were found between metal levels and fish size. Metal concentrations in the muscle of examined fish were compared with Turkish Food Codex and EC standarts.

Keywords: heavy metal, Turkey, water, sediment, *Sander lucioperca*

Introductıon

Heavy metals are the most common environmental pollutants and a serious threat due to their toxicity, long persistence, biomagnification, and bioaccumulation in the food chain [1]. Heavy metals from natural and anthropogenic sources such as industrial effluents, agricultural runoff, transport, burning of fossil fuels, geochemical structure, and mining activities are continually released into aquatic ecosystems [1-3]. The toxic effects of metals depend on the metal properties. Generally, heavy metals create toxic effects by forming complexes with organic compounds. The concentrations of heavy metal in the water column depend on some physical and chemical factors like temperature, salinity, pH, dissolved oxygen, conductivity, redox potential, and ionic strength [4].

In natural waters, metals can occur in dissolved and particulate forms. Depending on physicochemical conditions, dissolved metal can fall vertically or generate dissolved organic and inorganic complexes [5-7]. Sediments can be a sensitive indicator to the quality of aquatic systems for both spatial and temporal trend monitoring. Moreover, sedi-

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ments may act not only as sinks but also as sources of contamination in aquatic systems [8-10]. Heavy metals can occur in different chemical forms in sediments as metal carbonates oxides, sulfides, and ions in crystal lattices of minerals, which affect their mobilization capacity and bioavailability [11-13].

Fish are generally one of the main protein sources for humans [14] and a useful bioindicator for the determination of heavy metal pollution in aquatic ecosystems [15-17]. To be a good indicator, fish must be long living and inhabit water, making continuous monitoring of the presence of pollutants and sampling easy [18]. Trace metals can be accumulated by fish through the food chain and water [19]. Heavy metals may enter fish bodies in three possible ways (via digestive tract, gills, and body surface) [20, 21]. Concentrations of heavy metal levels in fish depend on different factors such as ecological needs, size, and age of individuals [22], their life cycle and life history, feeding habits [23], season of capture, and physico-chemical parameters of water [24].

Numerous studies have been carried out on metal pollution in water, sediment and different fish species [25-30]. Despite this, there is one study on heavy metal levels in Karataş Lake [31], but no data collected for *Sander lucioperca* that has economic importance.

The pikeperch was referred to several names in different periods by some investigators. Respectively, the pikeperch was referred to as *Perca lucioperca* by *Linnaeus* (1758), *Lucioperca lucioperca* by Berg (1949), *Stizostedion lucioperca* by Colletto and Banarescu (1977) and *Sander lucioperca* by Bogustkaya ve Naseka (1996) [32].

The aim of this study is the following:

(1) To assess relationships between the metal levels in water and physico-chemical parameters
(2) To determine seasonal variations of heavy metal concentrations in water, sediment and gill, muscle and liver of fish
(3) To assess relationships between heavy metal levels in muscle, gill and liver of fish and fish size (total length and weight)
(4) To compare with the acceptable metal levels in water and fish muscle given by different institutions.

Material and Methods

Study Area

Karataş Lake is situated in southwest Turkey south of Burdur city (37º23'N-29º58'E) (Fig. 1). Its area and volume are about 8,100 ha and 420 hm^3, while its depth is approximately 2 m. It is used for irrigation and has great potential for fishery activities. Karataş Lake is an important visiting site for several bird species. There are a lot grain and sugar beet gardens around the lake, which is fed by Bozçay [33, 34]. Six fish species (*Cyprinus carpio*,

Fig. 1. Map of Karataş Lake (Turkey) (from http://www.burdurkulturturizm.gov.tr.) and different locations from which the samples were taken.

Table 1. Size ranges and the relationships between weight and total length of Sander lucioperca from Karataş Lake.

Season	Lenght (cm)	Weight (gr)	Equation[a]	R	P
Summer	28.30-32	174-343	Y=25.569+0.019X	0.736	*
	30.10±1.24	237.7±47.98			
Autumn	39.7-44.5	558-743	Y=26.705+0.024X	0.967	*
	42.5±1.96	636.25±78.39			
Winter	20-42	52-590	Y=22.253+0.034X	0.939	**
	32.51±8.62	300.8±237.78			
Spring	27.60-30.10	240-286	Y=21.141+0.030X	0.566	NS[b]
	29.03±0.85	261.77±15.95			

[a] Y is total fish weight and X is total fish length
[b] NS is not significant, P> 0.05
* Significant is 0.05 level
** Significant is 0.01 level

Scardinius eritrophthalmus, *Sander lucioperca*, *Knidowitschia caucasica*, *Aphanius anatoliae anatoliae*, and *Hseudohhoximus fahirae*) inhabit the lake [35, 36]. Furthermore, *Hseudohhoximus fahirae* is the endemic fish species for the lake [35].

Sampling and Sample Preparation

This study was carried out in July 2010, October 2010, January 2011, and April 2011 at three sampling stations from Karataş Lake (Fig. 1). The temperature, dissolved oxygen, conductivity (EC), and pH values were measured from three different locations in the lake using YSI multi-parameter equipment. Water, sediment, and fish samples were collected from the same locations. Water samples were taken 50 cm below the water surface in 500 ml bottles, filtered through a Whatman 0.45 µm glassfiber filter, transferred to a 500 ml polypropylene bottle, and acidified with 5 ml of concentrated HNO_3 to pH less than 2.0. Then water samples stored at 4ºC and were analyzed directly.

Sediment samples were taken from the same locations. Sediments were dried in an oven at 50ºC for 48 h, passed through a 2 mm sieve, and homogenized. Fish samples were caught from the same sites. Total length and weight of fish were measured to the nearest millimeter and gram before dissection (Table 1). The lengths and weights varied significantly from season to season (<0.05, <0.01). For analysis, 2.5 g of the epaxial muscle on the dorsal surface, the entire liver, and four gill racers of each sample were dissected, weighed, and dried at 70ºC for 24-48 h until they reached a constant weight. 0.5 g sediment and all other samples were placed in decomposition beakers and 5 ml HNO_3 (65%) added to each, and kept at room temperature for 24 h. Then they were heated at 120 ºC on a hot plate for 2 h, until the solution evaporated slowly to near dryness. After cooling we added 1 ml H_2SO_4 (30%) and diluted to 25 ml with deionized water, then added 1-2 drops HNO_3.

Analytical Procedures

All samples were analyzed three times for Cd, Cr, Cu, Fe, Mn, Mo, Ni, Pb, Se, and Zn using ICP-AES Vista. Two standard materials DORM-3 and DOLT-4, (National Research Council of Canada) were analyzed for all ten elements. The absorption wavelengths were 228.802 nm for Cd, 267.716 nm for Cr, 324.753 nm for Cu, 238.304 nm for Fe, 257.61 nm for Mn, 202.03 nm for Mo, 231.604 nm for Ni, 220.353 nm for Se, 196.026 nm for Pb, and 213.856 nm for Zn. The analysis limits were 0.4 µg/L for Cd, 0.5 µg/L for Cr, 0.3 µg/L for Cu, 0.35 µg/L for Fe, 0.05 µg/L for Mn, 0.8 µg/L for Mo, 1.3 µg/L for Ni, 3 µg/L for Pb, 5 µg/L for Se, and 0.3 µg/L for Zn.

Statistical Procedures

All metal concentrations were determined as milligrams per liter for water and on a dry weight basis as milligrams per gram for sediment and fish tissues. However, we gave the results as milligrams per kilogram. Statistical analysis of data was carried out using SPSS 13 statistical package programs. One-Way ANOVA and Duncan's Multiple Comparison Test were used to compare the data among seasons at the level of 0.05. Pearson rank correlation coefficient was used to test for significant associations between heavy metal levels in water and physico-chemical parameters. Linear regression analyses were applied to the data to compare the relationships between fish size (total length and weight) and heavy metal concentrations.

Results and Discussion

In order to check the validity of the measurements, DORM3 and DOLT4 reference materials were used and certified, and observed values are given in Table 2. The recovery was between 80%-95% for DORM3 and between 86%-98% for DOLT4.

Table 2. Concentrations of metals found in certified reference material DORM-3 and DOLT-4 from the National Research Council of Canada.

Metals	DORM 3 Certified	DORM 3 Observed	Recovery (%)	DOLT 4 Certified	DOLT 4 Observed	Recovery (%)
Cd	0.290±0.020	0.25±0.02	86	24.3±0.8	22.69±0.53	93
Cr	1.89±0.17	1.60±0.77	84	-	-	-
Cu	15.5±0.63	14.72±12.34	95	31.2±1.1	30.37±15.20	97
Fe	347±20	280.6±15.96	80	1833±75	1714.6±34.3	93
Mn	-	-	-	-	-	-
Mo	-	-	-	-	-	-
Ni	1.28±0.24	1.22±0.55	95	0.97±0.11	0.84±0.27	86
Se	-	-	-	8.3±1.3	8.21±0.59	98
Pb	-	-	-	-	-	-
Zn	51.3±3.1	48.41±11.32	94	116±6	101.9±6.74	87

Table 3. Some physical parameters of Karataş Lake water.

Season	Temperature (ºC)	pH	Disolved Oxygen (mg/L)	Electrical Conductivity (µg/cm)
Summer	28.99-30.75	9.53-9.70	4.86-5.55	509.0-512.0
	29.98±0.90	9.64±0.95	5.14±0.36	511.0±1.73
Autumn	12.07-16.37	9.07-9.23	5.85-7.32	384.0-455.0
	13.56±2.42	9.14±0.80	6.44±0.77	420.6±35.55
Winter	6.65-7.11	8.16-8.96	8.86-9.52	275.0-314.0
	6.84±0.24	8.65±0.43	9.13±0.34	299.0±21.0
Spring	14.32-17.70	8.73-9.40	4.55-6.31	345.0-451.0
	15.71±1.76	9.12±0.34	5.71±1.00	451.0±54.93

Temperature, pH, dissolved oxygen, and EC of water are given in Table 3. Water temperature ranged between 6.65ºC (in winter) and 30.75ºC (in summer). Mean pH varied between 8.16 (in winter) and 9.70 (in summer). Dissolved oxygen was measured between 4.86 mg/L (in summer) and 9.52 mg/L (in winter). EC values ranged from 275.0 ms/cm (in winter) to 512.0 ms/cm (in summer). Positive relationships were determined among temperature, pH and EC, while a negative relationship was found between temperature and dissolved oxygen (Table 5).

Taş et al. [37] and Tepe [38] measured some physicochemical parameters in Ulugöl Lake and Reyhanlı Yenişehir Lake, and found that pH values increased in summer and decreased in winter. The pH value in lake water has a negative relationship with CO_2 level. The rising pH value in summer may be related to diminishing gase solubility because of high temperature. In summer, CO_2 decreases because of photosynthesis, and pH value increases [39]. Dissolved oxygen was the highest in winter because of decreasing temperature. Warmer water is unable to dissolve as much oxygen [39]. EC reached the maximum level in summer. This might be due to inorganic substances being increased as a result of heavy evaporation in water bodies in warm seasons.

The heavy metal levels in water were given in Table 4. According to the table, Se and Pb were below detection limit (<0.005, <0.003) in all seasons, while Cd (<0.00004) was in only autumn and Cr (<0.0005) in autumn and winter. Fe was the highest metal and Cd was the lowest among the analyzed metals. Similar results were determined in Kızılırmak River Basin [40], Taihu Lake [41], Beyşehir Lake [26], Yeniçağa Lake [30], and Gökçekaya Dam Lake [42]. The highest levels of Cd, Cr, Fe, Mn, Ni, Se, and Zn were determined during the spring, and Mo and Cr were measured in autumn. Mo, Cr, and Cu in summer, Fe and Mn in autumn, and Cd, Ni and Zn in winter were the lowest. There are no significant differences (>0.05) in the levels of metal among seasons.

Heavy metal levels in water depend on the physicochemical parameters of water, such as temperature, pH, salinity, and EC [43]. The solubility of toxic heavy metals increases with the decrease of pH [44]. In this study, the

Table 4. The concentrations (mg·l^{-1}) of some heavy metals in Karataş Lake water.

Season	Cd	Cr	Cu	Fe	Mn	Mo	Ni	Pb	Se	Zn
Summer	0.01-0.23	3.99-5.99	7.25-21.07	1117.6-1888.4	20.38-97.67	7.25-21.07	22.18-35.29	BDL*	BDL	27.06-244.15
	0.12±0.15^{a}**	4.91±0.80^{a}	14.59±6.95^{a}	1402.3±423.003^{a}	47.63±43.38^{a}	14.59±6.95^{a}	28.27±6.6^{a}			116.77±113.3^{a}
Autumn	BDL	BDL	6.47-146.39	243.8-864.8	1.00-12.83	6.47-146.39	11.59-84.98	BDL	BDL	43.27-356.6
			55.33±78.93^{a}	495.9±326.6^{a}	6.43±5.97^{a}	55.33±78.93^{a}	36.6±41.9^{a}			173.5±163.2^{a}
Winter	0.02-0.14	BDL	9.31-26.6	455.7-992.6	3.20-15.84	9.31-26.6	9.23-26.48	BDL	BDL	63.89-65.3
	0.078±0.083^{a}		17.95±12.2^{a}	724.1±379.6^{a}	9.52±8.94^{a}	17.95±12.2^{a}	17.85±12.19^{a}			64.5±1.005^{a}
Spring	0.11-0.32	0.63-20.50	14.48-32.99	699.2-6675.3	66.35-676.9	14.48-32.99	18.78-104.6	BDL	BDL	37.08-494.9
	0.20±0.10^{a}	11.14±.9.98^{a}	20.95±10.42^{a}	3539.5±2998.9^{a}	300.9±328.9^{a}	20.95±10.42^{a}	60.9±42.9^{a}			208.6±249.5^{a}

*Below Detection Limit

**Means with the same superscript in the same row are not significantly different according to Duncan's multiple range test (p<0.05).

levels of some metals were the lowest in summer, when the water is of basic character. In the rainy seasons, metal concentrations increased in water. The water volume of rivers that feed the lake rose due to rain and melting snow. Therefore, these rivers carry more heavy metals to the lake.

The results of heavy metals in water of Karataş Lake were compared with EC [45], WHO [46], TSE-266 [47], and EPA [48] standards. According to these standards, our results were lower than the permissible levels for drinking water.

Pearson's test was used to compare with physico-chemical parameters and heavy metal levels in Karataş Lake water. The results are presented in Table 5. According to the table, there were positive relationships among temperature, pH value, and EC. Temperature had negative relationships with Cu and Se, while positive relationships with other metals. When the pH values increased, only Se and Zn levels decreased. Dissolved oxygen levels had a significant negative relationship with all studied metals except Se. There were positive relationships between EC, Mo, and Zn; the others were negative. There were significant differences between temperature and Ni, EC, Cd, and Cr (<0.05). Tao et al. [41] found negative relationships between pH and some metals like Cu, Cr, and Sb, and between temperature and Cd, Ni, Mn, between dissolved oxygen and Cu, Cr, Ni, Sb, and Zn. It could be concluded that the changes of physico-chemical parameters depend on how seasons affect the levels of some metals.

The residue data of the measured metals in sediment have been shown in Table 6. All the analyzed metals were determined in sediment. Cd ranged between 0.11 mg/kg (spring) and 0.25 mg/kg (winter), and the lowest metal among the analyzed metals. Cd had no significant relationships among seasons (> 0.05). Cr values ranged between 13.82 mg/kg (spring) and 53.13 mg/kg (autumn). There were no significant relationships among seasons (>0.05), although Cu value was the highest in autumn (32.27 mg/kg) and the lowest in spring (13.88 mg/kg). Cu levels did not vary significantly among seasons (>0.05). Fe levels vary between 4,244.9 mg/kg (in spring) and 8,116.9 mg/kg (in winter). There were no significant relationships among seasons (>0.05). Mn value ranged between 228.15 mg/kg (spring) and 352.92 mg/kg (autumn). Mn, which was the second highest metal, did not vary significantly among seasons (>0.05). Whereas Mo levels were the highest in summer with 0.68 mg/kg, its levels were the lowest in winter with 0.015 mg/kg. The Mo levels varied significantly in summer from the other seasons (<0.05). Ni levels changed between 47.16 mg/kg (spring) and 203.92 mg/kg (winter). The highest concentration of Pb was in spring (1.13 mg/hg) and lowest in winter (0.54 mg/kg). Zn levels changed between 0.96 mg/kg (in spring) and 55.13 mg/kg (in summer). Zn contents varied significantly from season to season (<0.05).

In this study, heavy metals in sediments taken from Karataş Lake would appear as Fe > Mn > Ni > Zn > Cr > Cu > Se > Pb > Mo > Cd. In comparison, Fe concentrations were the highest and Cd were the lowest in Taihu Lake [41], Beyşehir Lake [26], and Yeniçağa Lake [30].

Table 5. Pearson correlation matrix showing the relationships of metals in water and some physico-chemical parameters in water.

	Temperature (ºC)	pH	Dissolved Oxygen (mg/L)	Conductivity (µg/cm)	Cd	Cr	Cu	Fe	Mn	Mo	Ni	Se	Zn
Temperature (ºC)	1	0.771	- 0.308	0.901	0.070	0.175	-0.124	0.123	0.127	0.102	0.041*	-0.362	0.209
pH		1	0.145	0.660	0.085	0.447	0.121	0.361	0.240	0.122	0.384	-0.117	0.163
Dissolved Oxygen (mg/L)			1	0.064	-0.390	-0.150	-0.188	-0.209	-0.286	-0.141	-0.286	0.256	-0.369
Conductivity (µg/cm)				1	-0.048*	-0.042*	-0.096	-0.061	-0.086	0.176	-0.079	-0.50	0.312
Cd					1	0.672	-0.151	0.711	0.699	-0.207	0.429	-0.267	-0.079
Cr						1	0.058	0.983	0.909	-0.215	0.804	-0.099	-0.261
Cu							1	0.065	0.014	0.214	0.631	0.195	-0.008**
Fe								1	0.962	-0.239	0.806	-0.103	-0.189
Mn									1	-0.295	0.732	-0.151	-0.131
Mo										1	-0.026*	0.481	0.227
Ni											1	0.018*	-0.160
Se												1	-0.154
Zn													1

* and ** indicate the correlation coefficients were significant at 0.05 and 0.01 probability levels, using two-tailed test.

Table 6. The concentrations (mg·kg $^{-1}$) of some heavy metals in Karataş Lake's sediment.

Season	Cd	Cr	Cu	Fe	Mn	Mo	Ni	Pb	Se	Zn
Summer	0.13-0.30	25.57-59.0.	13.98-33.99	6552.2-9401.1	291.9-396.4	0.66-0.72	85.8-161.32	0.45-1.35	0.68-1.76	39.12-55.13
	0.22±0.087^{a}	37.47±18.73^{a}	20.76±10.94^{a}	7500.2±1621.6^{a}	328.02±59.26^{a}	0.68±0.034^{b}	119.65±38.6^{a}	0.86±0.45^{a}	1.21±0.76^{a}	45.004±8.80^{a}
Autumn	0.20-0.31	23.92-101.04	16.91-54.36	7093.01-9024.4	322.87-402.19	0.02-0.014	72.2-261.57	0.18-1.80	2.72-7.16	20.84-45.92
	0.23±0.6^{a}	53.13±41.81^{a}	32.27±19.60^{a}	8012.5±969.04^{a}	352.92±43.008^{a}	0.07±0.059^{a}	156.52±96.36^{a}	0.99±1.14^{a}	4.29±2.48^{a}	30.66±13.39^{a}
Winter	0.16-0.32	12.41-90.58	18.67-24.95	7005.8-8751.6	294.42-338.5	0.01-0.02	65.37-413.93	0.10-1.04	3.13-6.48	19.68-26.34
	0.25±0.084^{a}	45.85±40.28^{a}	20.9±3.51^{a}	8116.9±965.5^{a}	318.5±22.33^{a}	0.015±0.002^{a}	203.92±184.9^{a}	0.54±0.4^{a}	4.38±1.90^{a}	24.08±3.81^{ab}
Spring	0.001-0.19	0.25-32.24	0.34-22.56	117.49-6469.8	6.07-416.8	0.07-0.11	1.78-100.9	0.34-1.93	0.37-2.33	0.96-22.49
	0.11±0.10^{a}	13.82±16.53^{a}	13.88±11.88^{a}	4244.9±3578.08^{a}	228.15±207.42^{a}	0.08±0.025^{a}	47.16±50.12^{a}	1.13±1.12^{a}	1.46±1.001^{a}	12.92±10.96^{b}

** Means with the same superscript in the same row are not significant different according to Duncan's multiple range test ($p<0.05$)

Iron is generally the most abundant metal in all of the reservoirs, which is one of the most common elements in the Earth's crust [49]. Pyrite oxidation produced sulphate and the Fe^{2+} ion, which is oxidized to Fe^{3+} by microorganisms such as *Thiobacillus ferrooxidans* [50]. Kerrison et al. [51] reported that Cd accumulates slowly in the sediment. Cadmium is not found in the organic fraction for low adsorption constant and labile complexion with organic matter [52]. Generally, all metal levels increased in autumn and decreased in spring. Tekin-Özan [26] reported that the Cu and Zn levels were the highest in the spring, while Fe and Mn were in autumn in Beyşehir Lake sediments. In Yeniçağa Lake sediment, Mo, Ba, Cr, Mn, Co, and Ni levels were highest in April 2008 [30]. The heavy metal concentrations of Karakaya Dam Lake's sediment were highest in spring and lowest in summer [53]. The higher metal levels are probably because they sink to the bottom with dead plants and animals. While the metal levels could be attributed to the decrease in spring owing to water circulation. This study shows that the sediment from Karataş Lake consists of a very high amount of metals when compared with their levels in water. Due to their strong affinity for particles [54], metals tend to be accumulated by suspended matter or trapped immediately by bottom sediments [55].

Heavy metal levels of muscle, liver and gill of *Sander lucioperca* and its seasonal variations were given in Table 7. Pb was below the detection limit (<0.0003) in all seasons, Cd was below detection limit (<0.0004) in muscle in winter and spring, in liver in winter. Moreover, Cr was below detection limit (<0.0005) in liver in winter, while Se in gill in autumn. Besides, Mn was below detection limit (<0.00005) in liver in spring.

Cd ranged between min. 0.0023 mg/kg (in summer) and max. 0.05 mg/kg (in autumn) in muscle, min. 0.017 mg/kg (in spring) and max. 0.093 mg/kg (in summer) in liver, min. 0.0008 mg/kg (in autumn) and 0.020 mg/kg (in spring) in gill. Cd levels in muscle and liver varied significantly from season to season (<0.05). On the other hand, Cr values ranged between min. 0.02 mg/kg (in spring) and max. 1.07 mg/kg (in winter) in muscle, min. 0.05 mg/kg (in autumn) and max. 55.72 mg/kg (in summer) in liver, min. 0.023 mg/kg (in spring) and 1.43 mg/kg (in winter) in gill. Its concentrations in all tissues varied significantly from season to season (<0.05). Although Cu levels were the lowest in summer (0.40 mg/kg) and the highest in spring (32.24 mg/kg) in muscle, it was the lowest in spring (4.59 mg/kg) and the highest in summer (909.96 mg/kg) in liver. Also, its level was the lowest in summer (0.17 mg/kg) and highest in winter (113.58 mg/kg) in gill. There are no significant relationships among seasons in muscle and gill (>0.05); other relationships are significant (<0.05). Fe values measured between 21.34 mg/kg (in spring) and 49.19 mg/kg (in summer) in muscle, 102.32 mg/kg (in autumn) and 5468.39 mg/kg (in summer) in liver and 4.71 mg/kg (in spring) and 533.88 mg/kg (in winter) in gill. In relation to seasons, Fe levels varied significantly (<0.05) in muscle, liver, and gill. Mn levels were the lowest in spring (0.09 mg/kg) and the highest in summer (14.10 mg/kg) in muscle, the lowest in winter (2.77 mg/kg) and the highest in summer (75.36 mg/kg) in liver, the lowest in summer (0.01 mg/kg) and the highest in winter (11.54 mg/kg) in gill. Mn concentrations varied significantly in all tissues among the seasons (< 0.05). Mo values ranged between 0.001 mg/kg (in spring) and 0.55 mg/kg (in autumn) in muscle, 0.0001 mg/kg (in spring), and 71.61 mg/kg (in summer) in liver, 0.0001 mg/kg (in spring) and 3.49 mg/kg (in summer) in gill. There were significant relationships among the seasons in all tissues (< 0.05). Ni was measured between 0.21 mg/kg (in summer) and 2.55 mg/kg (in winter) in muscle, 2.77 mg/kg (in summer), and 75.36 mg/kg (in winter) in liver, 0.03 mg/kg (in spring) and 60.54 mg/kg (in winter) in liver. Its concentrations in liver varied significantly from season to season (< 0.05). Se ranged between 0.13 mg/kg (in spring) and 3.04 mg/kg (in winter) in muscle, 1.66 mg/kg (in spring), and 517.12 mg/kg (in summer) in liver, 0.06 mg/kg (in spring) and 3.40 mg/kg (in winter) in gill. Selenium levels were found to be significant in tissues among seasons (< 0.05). Zn was the lowest in spring (7.39 mg/kg) and highest in autumn (37.47 mg/kg) in muscle, lowest in spring (27.25 mg/kg) and the highest (2996.03 mg/kg) in liver, the lowest in summer (7.09 mg/kg) the highest in spring (53.13 mg/kg) in gill. Significant relationships were found in tissues from season to season (< 0.05) (Table 7).

Although the distribution patterns of Cd and Mo in tissues of *Sander lucioperca* in Karataş Lake follows the order liver> muscle> gill, Cr levels follow the order: liver=muscle> gill. In addition, Cu, Fe, Mn, Ni, and Zn levels follow the order: liver> muscle=gill, and Se level liver> muscle> gill. In this study, the results showed that the highest of heavy metals were found in the liver while the lowest concentrations were found in muscle and gill. This finding is in agreement with those of other studies regarding fish tissues [26, 29, 31, 56-60]. Liver is a vital organ in vertebrata and has a major role in metabolism [57]. The accumulation of metals in liver could be due to the greater tendency of the elements to react with the oxygen carboxylate, amino group, nitrogen, and/or sulphur of the mercapto group in the metallothionein protein, whose level is highest in the liver [61]. Metal levels in the gills could be due to the element complexing with the mucus, which is impossible to remove completely from between the lamellae before tissue is prepared for analysis [62]. In addition, muscle tended to accumulate low metals because of inactive tissue accumulating heavy metals [63].

Fe was the highest metal in tissues. Its distribution in tissues was the same as in water and sediment. Iron is an integral part of many proteins and enzymes that maintain good health. In humans, iron is an essential component of proteins involved in oxygen transport [64, 65]. It is also essential for the regulation of cell growth and differentiation. In addition, iron in the body is found in hemoglobin [66]. The second highest metal was zinc (after iron). Similar results have been found by some researchers [26, 67, 68]. This can be due to the fact that Zn is an essential metal [69]. More than one hundred specific enzymes require zinc for their catalytic function [70]. The lowest metal was Cd in tissues of fish. Cd also was lowest in water

Table 7. Heavy metal concentrations (mg·kg^{-1}) in different organs of *Sander lucioperca* from Karataş Lake.

Season	Tissue	Cd	Cr	Cu	Fe	Mn	Mo	Ni	Pb	Se	Zn
Summer	Muscle	0.0023-0.013 0.0045 ± 0.005^{a}	0.17-0.38 0.26 ± 0.066^{ab}	0.40-1.62 0.78 ± 0.40^{a}	21.34-66.89 34.58 ± 14.64^{b}	1.21-14.10 3.61 ± 3.975^{ab}	0.15-3.38 0.78 ± 1.069^{b}	0.21-2.24 0.88 ± 0.62^{a}	BDL*	0.13-1.33 0.65 ± 0.46^{a}	11.89-31.57 23.18 ± 6.33^{b}
	Liver	0.15-0.93 0.44 ± 0.29^{b}	5.05-55.72 19.99 ± 15.22^{b}	15.92-114.4 64.17 ± 38.23^{a}	316.36-5468.39 1795.08 ± 1740.74^{b}	8.30-75.36 37.34 ± 24.88^{b}	20.96-71.61 38.32 ± 20.87^{b}	3.64-57.62 16.72 ± 19.48^{ab}	BDL	81.55-517.12 248.32 ± 156.06^{b}	708.93-2996.03 1508.3 ± 776.6^{b}
	Gill	0.009-0.014 0.012 ± 0.0023^{a}	0.10-0.12 0.10 ± 0.15^{a}	0.17-1.09 0.39 ± 0.30^{a}	9.40-75.73 27.08 ± 22.57^{a}	0.01-0.05 0.028 ± 0.032^{a}	1.30-3.49 1.69 ± 0.68^{b}	0.01-0.03 0.02 ± 0.01^{a}	BDL	0.18-1.25 0.62 ± 0.50^{ab}	7.09-24.08 11.63 ± 6.17^{a}
Autumn	Muscle	0.003-0.10 0.05 ± 0.03^{bc}	0.14-0.44 0.34 ± 0.14^{a}	0.46-3.93 1.98 ± 1.505^{a}	14.75-49.83 37.98 ± 15.75^{b}	1.48-7.84 6.08 ± 3.07^{b}	0.01-0.01 0.102 ± 0.005^{a}	0.30-2.16 0.90 ± 0.55^{a}	BDL	0.65-0.81 0.72 ± 0.075^{ab}	14.47-37.47 27.65 ± 9.85^{b}
	Liver	0.035-0.036 0.356 ± 0.0008^{a}	04.17-21.64 8.99 ± 8.44^{a}	76.27-345.35 195.12 ± 122.68^{ab}	102.32-229.02 170.71 ± 52.92^{a}	6.29-10.90 7.60 ± 2.20^{a}	1.02-6.17 3.47 ± 2.58^{a}	2.35-10.95 4.57 ± 4.24^{a}	BDL	33.04-47.93 40.01 ± 7.25^{a}	280.72-481.81 401.13 ± 87.03^{a}
	Gill	0.0008-0.0043 0.0021 ± 0.0019^{a}	0.0023-0.03 0.016 ± 0.02^{a}	0.54-5.29 2.10 ± 2.22^{a}	18.55-29.42 24.36 ± 4.57^{a}	0.03-0.07 0.049 ± 0.024^{a}	0.0001-0.38 0.27 ± 0.18^{a}	0.04-1.44 0.42 ± 0.68^{a}	BDL	BDL	3.91-21.33 13.16 ± 7.82^{a}
Winter	Muscle	BDL	0.16-1.07 0.589 ± 0.38^{c}	0.87-26.98 7.21 ± 8.73^{a}	8.57-63.06 32.38 ± 15.37^{b}	0.55-6.93 2.13 ± 2.36^{a}	0.01-0.55 0.13 ± 0.18^{ab}	0.27-2.53 1.15 ± 0.63^{a}	BDL	0.12-3.04 1.267 ± 0.92^{b}	8.30-50.54 19.81 ± 12.42^{ab}
	Liver	BDL	BDL	27.49-909.96 269.02 ± 274.40^{b}	132.79-4470.65 1544.78 ± 1656.17^{ab}	2.77-46.30 14.38 ± 15.74^{a}	0.0001-6.17 2.05 ± 2.29^{a}	4.18-146.74 46.65 ± 47.97^{b}	BDL	17.47-110.01 48.81 ± 37.18^{a}	128.90-429.85 295.10 ± 87.91^{a}
	Gill	0.0053-0.009 0.0075 ± 0.0020^{a}	0.03-1.43 0.97 ± 0.49^{b}	0.23-113.58 16.65 ± 36.63^{a}	9.47-533.88 144.41 ± 160.51^{b}	0.09-11.54 7.11 ± 4.12^{b}	0.0001-0.84 0.32 ± 0.33^{a}	0.44-60.54 9.78 ± 19.17^{a}	BDL	0.19-3.40 2.039 ± 1.52^{b}	5.47-89.70 34.99 ± 27.39^{b}
Spring	Muscle	BDL	0.02-0.28 0.11 ± 0.10^{a}	0.50-32.24 5.033 ± 10.23^{a}	3.15-49.19 15.71 ± 13.81^{a}	0.09-3.10 0.58 ± 0.96^{a}	0.001-0.04 0.02 ± 0.029^{a}	0.27-2.51 1.14 ± 0.63^{a}	BDL	0.13-0.36 0.28 ± 0.10^{a}	7.39-18.34 10.88 ± 3.45^{a}
	Liver	0.017-0.023 0.021 ± 0.0033^{a}	0.027-0.41 0.021 ± 0.003^{a}	4.59-243.89 71.03 ± 89.42^{a}	178.54-555.74 375.64 ± 126.62^{a}b	BDL	0.0001-0.47 0.17 ± 0.19^{a}	1.43-23.28 7.34 ± 7.28^{a}	BDL	1.66-4.56 2.78 ± 1.55^{a}	27.25-75.34 45.28 ± 14.69^{a}
	Gill	0.01-0.02 0.015 ± 0.006^{a}	0.05-0.34 0.16 ± 0.091^{a}	0.95-6.09 3.17 ± 1.60^{a}	4.71-92.49 47.57 ± 22.92^{ab}	7.46-20.38 11.7 ± 4.05^{c}	0.0001-0.12 0.03 ± 0.04^{a}	0.02-3.83 1.37 ± 1.17^{a}	BDL	0.06-0.27 0.16 ± 0.096^{a}	12.91-53.13 37.81 ± 11.54^{b}

* Means with the same superscript in the same row are not significantly different according to Duncan's multiple range test ($p<0.05$)
** Below Detection Limit

Table 8. The relationships between total length and heavy metal concentrations of the *Sander lucioperca* caught from Karataş Lake.

Tissue		Cd	Cr	Cu	Fe	Mn	Mo	Ni	Pb	Se	Zn
Muscle	Equation	[a]y=-0.062+0.003X	y=0.498±0.005X	y=14.256±0.322X	y=29.806+0.454X	y=-29.806+0.164X	y=0.710±0.01X	y=1.836±0.037X	[e]BDL	y=2.411±0.049X	y=15.997+0.101X
	R Value	0.636	-0.12	-0.291	-0.012	0.348	-0.105	-0.267	BDL	-0.524	0.068
	P Value	[b]NS	NS	NS	Ns	NS	NS	NS	BDL	**	NS
Liver	Equation	y=1.126±0.027X	y=26.609±0.434X	y=337.118±6.134X	y=3547.21±77.12X	y=90.33±1.99X	y=18.958±0.122X	y=98.58±2.42X	BDL	y=379.393±7.456X	y=796.62±6.56X
	R Value	-0.409	0.254	-0.229	-0.366	-0.558	-0.033	-0.511	BDL	-0.319	-0.06
	P Value	NS	NS	NS	*	[d]**	NS	**	BDL	NS	NS
Gill	Equation	y=0.02+0.0001X	y=1.702±0.044X	y=33.32±0.857X	y=73.54±0.21X	y=20.51±0.431X	y=2.18±0.40X	y=-7.201+0.348X	BDL	y=2.96±0.065X	y=63.852±1.186X
	R Value	-0.379	-0.573	-0.287	-0.015	-0.504	-0.297	0.216	BDL	-0.332	-0.40
	P Value	NS	[c]*	NS	NS	*	NS	NS	BDL	NS	*

[a] y is metal concentrations (mg/kg) X is total fish length (g). [b] NS – Not significant at the p<0.05 level. [c] Significant at the level p<0.01 level. [d] Significant at the level p<0.05 level. [e] Below Detection Limit.

Table 9. The relationships between weight and heavy metal concentrations of the *Sander lucioperca* caught from Karataş Lake.

Tissue		Cd	Cr	Cu	Fe	Mn	Mo	Ni	Pb	Se	Zn
Muscle	Equation	[a]y=0.021+ 0.001X	y=7.539±0.011X	y=14.256±0.322X	y=27.608+0.004X	y=0.608+0.006X	y=0.633±0.001X	y=0.991±0.001X	[e]BDL	y=1.302±0.001X	y=17.318+0.006X
	R Value	0.728	-0.126	-0.270	0.017	0.365	-0.213	-0.211	BDL	-0.413	0.109
	P Value	[c]*	NS	NS	Ns	*	NS	*	BDL	*	NS
Liver	Equation	y=22.854±0.028X	y=243.67±0.319X	y=141.837+0.002X	y=2331.82±3.915X	y=45.055±0.064X	y=22.854±0.028X	y=49.792±0.092X	BDL	y=243.673±0.319X	y=784.38±0.623X
	R Value	-0.186	-0.412	0.002	-0.499	-0.569	-0.186	-0.518	BDL	-0.412	-0.154
	P Value	[b]S	NS	NS	[d]**	**	NS	**	BDL	NS	NS
Gill	Equation	y=1.44±0.002X	y=2.048±0.004X	y=16.166±0.032X	y=62.273±0.014X	y=0.608+0.006X	y=1.44±0.002X	y=0.991±0.001X	BDL	y=2.048±0.004X	y=17.318+0.006X
	R Value	-0.363	-0.551	-0.286	0.026	0.365	-0.363	-0.211	BDL	-0.551	0.109
	P Value	*	*	NS	NS	*	*	NS	BDL	*	NS

[a] y is metal concentrations (mg/kg) X is total fish length (g). [b] NS – Not significant at the p<0.05 level. [c] Significant at the level p<0.01 level. [d] Significant at the level p<0.05 level. [e] Below Detection Limit.

and sediment. The absorption of metals is to a large extent a function of their chemical forms and properties [71].

The level of metals shows differences among seasons. In general, the metal levels were highest in autumn in muscle, in summer in liver and in winter in gill. Karadede-Akın [59] found the highest Cd, Mn, Ni, Zn, and Fe levels in liver of *Capoeta capoeta umbla* in winter, Cu levels in summer. Tekin-Özan [26] reported that Fe levels in muscle of Tinca tinca from Beyşehir Lake had increased in spring. Canpolat and Çatla [23] determined the highest heavy metal level in some tissue and organs of *Capoeta capoeta umbla* in spring and summer. Seasonal changes of metal concentrations in fish depend on physical and chemical parameters of water, feeding age [4], growth, and reproductive cycle of fish [72].

The relationships between fish size (weight and total length) was shown in Tables 8 and 9. Significant relationships were found between fish weight and Ni (<0.05) and Se (<0.05) levels in the muscle, Fe (<0.01), Mn (<0.01) and Ni (<0.01) levels in the liver, Cd (<0.05), Cr (<0.05), Mo (<0.05), and Se (<0.05) levels in the gill. There were significant positive relationships between fish weight and Cd (<0.05), and Mn (<0.05) levels in the muscle Mn (<0.05) level in the gill. Other relationships were insignificantly positive and negative.

Significant negative relationships were determined between fish total length and Se levels (<0.01) in the muscle, Fe (<0.05), Mn (<0.01), and Ni (<0.01) in the liver, and Cr (<0.05), Mn (<0.05), and Zn (<0.05) in the gill. All the other insignificant relationships were positive and negative. So that generally higher concentrations of heavy metals were observed in the small fish. In other research, no significant relationships between the heavy metal levels and fish length [18, 73] showed that accumulation of metals (Cd, Cu, Zn, and Pb) in muscle, liver, and gill decrease with an increase in the length of *Abramis brama*.

Canpolat and Çatla [23] investigated the relationships between metal (Cu, Fe, Mn, and Zn) levels and fish (*Capoeta capoeta umbla*) size, and found that there was a significant relationship between fish weight and Fe levels in liver and gill, Mn level in liver, gill, and skin, fish length and Fe levels in liver and gill, and Mn levels in liver and gill. The metal levels and fish size correlations depend on several factors. Heath [62] showed that the presence of heavy metals in water affect fish development, larval development, and juvenile growth, as they are more sensitive than the mature stages. Canlı and Atlı [74] indicated that the negative relationships between fish size and metal levels could be due to differences in metabolic activity between younger and older fish. Smaller fish are more active and need more oxygen to supply more energy [23].

In conclusion, Karataş Lake is one of the most important water sources of the region because of its use for irrigation and having great potential fisheries activity. Fish generally accumulate contaminants from aquatic environments, and have been largely used in food safety studies. Permissible levels are for Zn:30 mg/kg, Cr:10 mg/kg, Fe:2.0 mg/kg, and Mn:1.0 mg/kg. Permissible levels proposed by the Turkish Food Codex and the EC have set the following maximum levels for the metals studies, above which consumption is not permitted: 0.5 mg/kg and 0.05 mg/kg for Cd, 20 mg/kg for Cu, and 50 mg/kg for Fe [75, 76]. The concentrations of these metals in muscle of pikeperch studies were in all cases lower than the maximum levels, except Mn in summer and autumn. Therefore, muscle is suitable for human consumption in Turkey. Although levels of heavy metals are not high, this study shows that precautions need to be taken in order to prevent future heavy metal pollution.

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