Pakistan J. Zool., vol. 44(5), pp. 1405-1416, 2012.

Relationship of Heavy Metals in Water, Sediment and Tissues with Total Length, Weight and Seasons of *Cyprinus carpio* L., 1758 From Işikli Lake (Turkey)

Selda Tekin-Özan* and Nurşah Aktan
Department of Biology, Faculty of Science and Art, Süleyman Demirel University, Isparta, Turkey

Abstract.- Several heavy metals *vis.,* Ba, As, Co, Cd, Cr, Cu, Fe, Mn, Ni and Zn were estimated in the water, sediment and total of 144 fish samples from Işıklı Lake during March 2009-February 2010. Fe has the highest concentrations in water as well as sediment among the studied metals. The heavy metal levels, except Cr in water were the highest in summer and winter, though lower than WHO standards. Generally higher metal levels were found in liver of *Cyprinus carpio,* while the lowest were determined in muscle tissue. Heavy metal levels in tissues of carp increased in summer and winter, but decreased in autumn and spring. Significant positive and negative relationships were found between heavy metal levels and fish size. Generally some of the results were above the limits for fish proposed by WHO, EC and TSE. This study shows that a potential danger may occur in the future depending on the agricultural development.

Key Words: Heavy metal, metal accumulation, metal uptake, metal toxicity, *Cyprinus carpio*.

INTRODUCTION

Over the last decades the freshwater environment has been polluted by different pollutants and originated by agricultural and industrial activities. Heavy metals are produced from different natural and anthropogenic sources like industrial effluents, agricultural runoffs, transport, burning of fossil fuels, geological structure, mining activities and atmospheric deposition (Adnano, 1986; Dawson and Macklin, 1998; Kalay and Canlı, 2000).

In freshwaters, only a very small percentage of metals are present as dissolved ions, such as copper, cadmium, zinc and lead, most of metals are as complexes, suspended and colloids ions and solid in sediments (Florence *et al*. 1992; Larocque and Rasmussen, 1998). The levels of heavy metals depend on redox potential, ionic strength, pH, temperature, dissolved oxygen and hardness (Barlas, 1999; Larocque and Rasmussen, 1998; Göksu, 2003)

Aquatic sediments can act both as a source and a sink for pollutants, whereby contaminats can lead to sedimental concentrations that can exceed water concentrations (Barron, 1995). Sediment associated metals pose a direct risk to deposit-feeding and detrital benthic organisms and may also represent long-term sources of contamination to higher trophic level (Eimers *et al*., 2001).

Fish are at the higher levels of the food chain and may concentrate large amounts of some heavy metals from the water (Eimers *et al.*, 2001) and also metals can be accumulate in human tissues via food chain. The concentrations of heavy metals in fish depend on body size and age of the individuals, ecological needs, their life cycle and life history, feeding habits, season of capture, some abiotic factors like temperature, dissolved oxygen, pH, conductivity of water (Larkin, 1978; Adams and McLean, 1985) and other factors that influence the metabolic rate of fish (Phillips, 1990; Newman and Doubet, 1989; Canpolat and Çalta, 2003). Abiotic factors change from season to season. And this effects the accumulation of heavy metals in tissues of fish (Canpolat and Çalta, 2003; Eastwood and Couture, 2002; Farkas *et al*., 2002). Essentially, fish assimilate the metals by three possible ways (body surface, gills or digestive tract) (Dallinger *et al*., 1987; Pourang, 1995). The body surface is generally assumed to play a minor role in heavy metal uptake of fish (Dallinger *et al*., 1987; Pourang, 1995; Varanasi and Markey, 1978), whereas gills are regarded to be the important site for direct uptake from the water (Dallinger *et al*., 1987; Hughes and

* Corresponding author: seldaozan@sdu.edu.tr
0030-9923/2012/0005-1405 $ 8.00/0
Copyright 2012 Zoological Society of Pakistan.

Flos, 1978; Thomas *et al.*, 1983).

In this study gill, liver and muscle were chosen as target organs for assessing metal accumulation. Muscles were selected because of its importance for human consumption and as a primary site of metal (Kotze *et al*., 1999). Liver was analyzed because this organ tends to accumulate metals (Tepe *et al*., 2008) and is involved in detoxification (Kotze *et al*., 1999).

Several studies have been conducted on heavy metal contamination in freshwater systems in Turkey (Fidan *et al*., 2008; Demirak *et al*., 2006; Karadede *et al*., 2004; Ebrahimi and Taherianfard, 2010; Erdoğrul and Erbilir, 2007; Tekin-Özan, 2008; Karadede-Akın, 2009; Oymak *et al*., 2009; Ünlü *et al*., 2009). Despite this, there is no study about heavy metal pollution of Işıklı Lake.

The aims of this study were (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 in the fish gills, muscle and liver (3) to assess relationships between heavy metal levels in muscle, gill and liver of fish and fish size (total length and weight) (4) and compare with the acceptable metal levels in water and fish muscle given by different institutions.

MATERIALS AND METHODS

Area description

Işıklı Lake (29º 92´ E, 38º 22´ N), located in the southwest of Turkey (Fig. 1) and used for irrigation. The lake is approximately 7 m depth , its area is 9749 ha and fed by Büyük Menderes Stream, Karanlık Stream and Kuti Stream. There are small rush islands in the lake. There are a lot of apply, cherry and peach gardens, grains fields, restaurants and hotels around it (Aygen and Balık, 2005; Akarsu *et al.,* 2006). The fish species found most commonly in the lake are *Cyprinus carpio*, *Esox lucius, Tinca tinca* and two endemic fish species (*Aphanius anatoliae, Chondrostoma meandrense*) (Akarsu *et al.,* 2006). The lake is polluted by industrial waste from agricultural though rain wash, agricultural runoffs and domestic effluents.

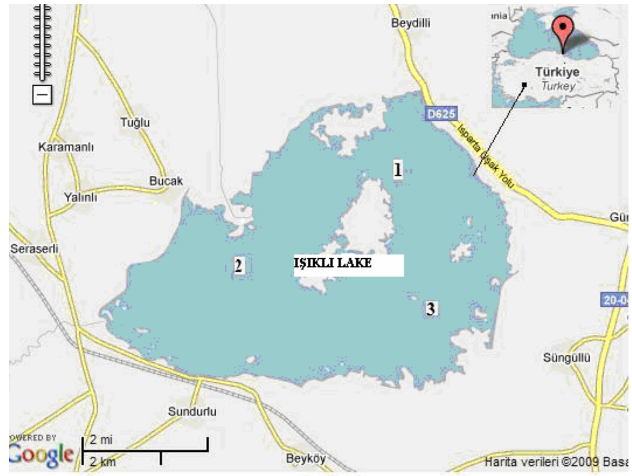

Fig. 1. Map of Işıklı Lake (Turkey) (Taken from maps.google.com) and different localities from where the samples were taken.

Sampling and sample preparation

This study was carried out at twelve months between March 2009 and February 2010. We determined three different site in lake. First site is near to gardens and fields, second site is near to hotels and restaurants and Büyük Menderes Stream flows to lake from the third site. The temperature, dissolved oxygen, conductivity (EC) and pH values were measured from three different localities in the lake by using YSI multiparameter equipment. Water, sediment and fish samples were collected from the same localities. Water samples were taken 50 cm below the water surface in 500 ml bottles, filtered through a Whatman 0.45 µm glassfiber filter, transferred 500 ml polypropylene bottle, 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 localities. Sediments were dried in an oven at 50ºC for 48 h, passed through a 2 mm sieve and homogenized. About 0.2 g. of each sample placed into the digestion bombs, added 3 ml HCI, 2 ml HNO_3, 2 ml HF and digested in a microwave digestion system (Milestone Ethos Plus 2000). After digestion the samples were cooled to room temperature and diluted to 25 ml with high quality deionized water.

At each sampling month 12 fish (total 144 fish samples) were caught from the same localities. The fish were then transferred to the laboratory. We recorded their age, total body length and total wet weight. The age of *Cyprinus carpio* was determined from scales, which removed from the left side between the posterior end of the pectoral fin and the anterior end of the dorsal fin. Approximately, 2 g of the epaxial muscle on the dorsal surface of the fish, the entire liver and four gill racers each sample were dissected, dried in a freeze-dryer at -80ºC for 6-8 h and then homogenized. About 0.5 g of each sample placed into the digestion bombs, added 5 ml HNO_3 and 1 ml H_2O_2 and digested in a microwave oven (Milestone Ethos Plus 2000). After digestion the samples were cooled to room temperature and diluted to 25 ml with high quality deionized water.

Analytical procedures

All samples were analyzed for three times for Ba, As, Co, Cd, Cr, Cu, Fe, Mn, Ni and Zn by using for ICP-AES Vista. Two standard material DORM-3 and DOLT-4 (National Research Council Canada) were analyzed for each ten elements. The absorption wavelength were 455.403 nm for Ba, 188.979 nm for As, 238.892 nm for Co, 214.438 nm for Cd, 267.716 nm for Cr, 324.753 nm for Cu, 259.94 nm for Fe, 257.61 nm for Mn, 231.604 nm for Ni and 213.856 nm for Zn, respectively. The analysis limits were 0.04 µg/L for Ba, 5 µg/L for As, 0.5 µg/L for Co, 0.4 µg/L for Cd, 0.5 µg/L for Cr, 0.3 µg/L for Cu, 0.4 µg/L for Fe, 0.05 µg/L for Mn, 1.3 µg/L for Ni and 0.3 µg/L for Zn.

Statistical procedures

The results of three months which are belonging to same season metal concentration estimated (March, April and May were averaged for spring; June, July and August for summer; September, October and November for autumn; December, January and February for winter. Statistical analysis of data was carried out using SPSS 15 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. Spearman 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

Table I shows the age, total body length and total wet weight of fish used in this study.

Table I.- **Minumum, maximum and mean lenght, weight and age of the species examined in the present study.**

	Length±SE (cm)	Weight±SE (g)	Age (Year)
Spring	27.70-42.30 (34.36±4.35)	312-1065 (656.11±260.61)	3-8 (5.33±1.51)
Summer	23.22-38.00 (30.48±3.30)	200-802 (433.2±148.07)	3-7 (4.90±1.12)
Autumn	26.80-32.60 (29.73±1.28)	3003-498 (394.53±53.32)	3-5 (4.13±0.68)
Winter	26.50-37.40 (31.06±2.44)	310-851 (476.10±110.42)	3-7 (4.39±1.10)

The certified, observed and recovery rates of DORM 3 and DOLT 4 were given at Table II. Replicate analysis of these reference materials showed good accuracy, with recovery rates for metals between 86% and 98% for DORM 3, 93% and 105% for DOLT 4.

Physico-chemical parameters of the lake

The physico-chemical parameters determined in Işıklı Lake are given in Table III. According to these parameters, the temperature varied between 7.51 and 30.80ºC; the pH between 6.79 and 9.57; the dissolved oxygen between 7.52 and 26.49 m/l and the EC between 182 and 668 during the study period in Işıklı Lake. The maximum temperature and pH values were measured in summer with 28.29ºC and 8.73, and the minimum were in winter with 8.63ºC and 7.78. Significant correlations (<0.05) were found for temperature, pH, dissolved oxygen and EC among the seasons in the lake water. The pH value in water decrease with increasing CO_2. In summer, when CO_2 decrease because of photosynthesis, the pH value increase (Tanyolaç, 1993). Dissolved oxygen was the highest in winter

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

Metals	DORM 3 Certified	DORM 3 Observed	Recovery (%)	DOLT 4 Certified	DOLT 4 Observed	Recovery (%)
Ba	-	-	-	-	-	-
As	6.88±0.30	6.76±0.20	98	9.66±0.62	9.24±0.30	95
Co	-	-	-	-	-	-
Cd	0.29±0.020	0.27±0.002	93	24.3±0.8	22.85±0.22	94
Cr	1.89±0.17	1.69±0.7	89	-	-	-
Cu	15.5±0.63	14.73±1.3	95	31.2±1.1	0.92±1.9	99
Fe	347±20	304.08±12	87	1833±75	1923.38	104
Mn	-	-	-	-	-	-
Ni	1.28±0.24	1.19±0.18	92	0.97±0.11	0.91±0.1	93
Zn	51.3±3.1	44.50±4.2	86	116±6	122.16±8.9	105

because of decreasing temperature since warmer water is unable to dissolve as much oxygen.

Table III.- Some physical parameters of Işıklı Lake's water.

	Temp. (°C)	pH	Dissolved oxygen (mg^{-l})	EC (μs/cm)
Spring	13.21-19.98 (16.00±3.49^{b*})	7.49-8.48 (8.18±0.30)	7.52-10.65 (9.05±1.15^{a})	405-668 (460±83.02^{b})
Summer	25.77-30.80 (28.29±1.89^{c})	8.10-9.57 (8.73±0.42^{c})	10.34-17.34 (13.45±2.45^{b})	246-341 (297.22±37.39^{a})
Autumn	12.55-20.86 (17.29±3.58^{b})	8.46-9.14 (8.78±0.24^{c})	8.17-17.36 (12.32±3.55^{b})	202-344 (273±42.49^{a})
Winter	7.51-10.48 (8.63±0.99^{a})	6.79-8.26 (7.78±0.56)^{a}	14.06-26.49 (21.32±4.19^{c})	182-310 (53.44±40.39^{a})

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

Heavy metal content of lake water

The concentrations of some heavy metals in water of Işıklı Lake is given in Table IV. Fe has the highest concentrations among the studied metals and ranged between 81-8570 ppb, followed by Zn, Mn and As. Generally, the metal levels were the highest in winter and the lowest in spring. The reason of increasing of metal levels in winter can be that the metals are dissolved in acidic environment and decreasing of metal concentrations in maybe caused by heavy rain and melting snow in warm seasons. In water body, some metals increased in summer. This maybe caused by evaporation. Significant correlations were found between heavy metal levels in water except Cr, seasonally (<0.05).

Barlas *et al.* (2005) investigated concentrations of heavy metals in water of Uluabat Lake (Turkey) and found the following concentrations 0.007-3.78 mg/g for Fe, 0.008-0.25 mg/gr for Mn, 0.01 mg/g for Cu, 0.003-0.22 mg/g for Zn, 0.009-0.15 mg/g for Cr and 0.02-0.05 mg/g for Ni. Iron was the most abundant metal likely the present study. Tekin-Özan (2008) investigated concentrations of heavy metals in Beyşehir Lake (Turkey) and found following concentrations (mg/l) as; <BDL-0.10 for Cu, <BDL-2.74 for Fe, <BDL-0.42 for Zn and <BDL-0.52 for Mn. Similar results also have been found in Hazar Lake's water (Karadede-Akın, 2009). They reported that all metals were displayed the highest values during the hot seasons and lowest values during the warm seasons generally. Our results are different from their results. This can be due to different years and lakes.

The heavy metal levels in water of Işıklı Lake were higher than Atatürk Dam Lake (Karadede and Ünlü, 2000) and lower than the metal levels in Gabbaniya Lake (Al-Saadi *et al.*, 2002). Based on the heavy metals level (Table IV), the water of Lake Işıklı was classified as category I according to the standards of Republic of Turkey Ministry of Environment and Forest (Rebuplic of Turkey Ministry of Environment and Forest, 2004). The concentrations of Fe, As, Zn and Cu in the lake

Table IV.- The concentrations (minimum, maximum, mean and SD values) of some heavy metals in Işıklı Lake's water (ppb).

Metals	Spring (n=9)	Summer (n=9)	Autumn (n=9)	Winter (n=9)
Ba	10-20 (11±0.003) [c*-.]	1-30 (14±0.08) [bc]	8-30 (14±0.008) [ab]	2-20 (12±0.003) [a]
As	200-780 (530±0.2) [a*]	50-730 (340±0.27) [ab]	40-710 (206±0.24) [a]	10-20 (12.5±0.004) [b]
Co	0.4-4.0 (2.4±0.0014) [a]	1.8-3 (2.3±0.08) [a]	0. 1-10 (3.0±0.002) [a]	40-710 (240±0.22) [b]
Cd	0.9-2.15 (1.5±0.004) [b]	1.7-2.6 (2.4±0.0003) [c]	0.1-0.9 (0.3±0.0003) [a]	0.1-3.2 (0.25±0.002) [d]
Cr	2.0-10.0 (4.0±0.001) [a]	1.7-14.0 (7.1±0.06) [a]	0.1-3.2 (0.4±0.001) [a]	1.0-10.0 (5.8±0.002) [a]
Cu	5.0-20.0 (7.5±0.005) [ab]	4.5-100 (23.3±0.002) [b]	1-10 (6.3±0.0033) [a]	10-50 (1.89±0.013) [ab]
Fe	140-820 (360±0.21) [a]	600-8570 (2510±0.291) [b]	200-536 (155±1.56) [ab]	81-739 (246±2.02) [b]
Mn	30-100 (50±0.02) [a]	20-310 (147±0.112) [a]	10-450 (160±0.14) [a]	70-810 (330±0.24) [b]
Ni	0.5-10 (9.2±0.0042) [a]	10-110 (34±0.03) [b]	4-40 (14.4±0.01) [a]	20-70 (34±0.018) [b]
Zn	160-700 (440±0.18)[b]	40-450 (230±0.17) [a]	10-370 (104±0.13) [a]	30-380 (133±0.12) [a]

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

water are lower than WHO standarts (WHO, 1993, 1998), but As (except winter), Fe (except spring), Cu (except autumn) and Zn were found to be above the permissible levels of water according to international criteria (Rebuplic of Turkey Ministry of Agriculture and Rural Areas, 2002).

Relationships of metals in water with physico-chemical parameters were studied using Spearman rank correlation coefficient (Table V). Positive (for Ba, Cu, Ni and Zn) and negative (for As, Co, Cd, Cr, Fe and Mn) correlations were detected between content in the water and temperature (Table V). No significant correlations were found between the metals and water temperature. Negative correlation was found between the concentration of metals (except Ba and Fe) in the water and pH value. Significant correlations were found between Co (<0.01), Cd (<0.01), Cu (<0.05) and pH value. Negative correlations were found only between Ba, Cr, Zn and dissolved oxygen. Significant correlations were found between some metal levels (except Cu, Fe and Mn) and dissolved oxygen. Negative correlations were found between levels of As, Co, Cd, Cu, Mn, Ni and EC. Significant correlations were determined between Ba (<0.01), Co (<0.05), Cr (<0.01), Ni (<0.05), Zn (<0.01) and EC. Hellaweel (1988) determined that heavy metal toxicity is affected by dissolved oxygen, pH and temperature. In present study some metal levels increased with decreasing temperature, dissolved oxygen and EC.

Heavy metal content of lake sediment

The concentrations of heavy metals in sediment are given in Table VI. Fe was the highest in sediment and ranged between 7107.41-25475 mg/kg, followed by Mn (238.4-867.16 mg/kg), Ni (11.23-211.16 mg/kg) and Ba (8.99-245.04 mg/kg). Fe levels were the highest in the Beyşehir Lake (Tekin-Özan, 2008), Uluabat Lake (Barlas *et al.*, 2005), Hazar Lake (Özmen *et al.*, 2004). Iron is generally the most abundant metal in all of the reservoirs because of being one of the most common elements in the earth's crust (Usero *et al.*, 2003). Cd was lowest in the Işıklı Lake's sediment and ranged between 0.19-3.06 mg/kg. Cd level was lowest in sediment in Dipsiz stream, Turkey (Demirak *et al.*, 2006), Habbaniya Lake, Iraq (Al-Saadi *et al.*, 2002), some island waters, Hong Kong (Zhou *et al.*, 1998). This may be because of absence of cadmium is not found in the organic fraction, for low adsorption constant and labile complexation with organic matter (Baron *et al*., 1990).

Ba, Cu, Fe and Zn were highest in summer, while Cr and Ni were highest in spring. The highest mean levels of As and Mn were found in autumn, and that of Co and Cd was recorded in winter. Al-Saadi *et al*. (2002) reported that the Pb, Cu and Cd concentrations were the highest in spring in Habbaniya Lake's sediment. In Beyşehir Lake, the heavy metal concentrations were highest in spring and autumn (Tekin-Özan, 2008). Close correlations (<0.05) were found for Ba, As, Co, Cd and Cr among the seasons in the lake sediment.

Table V.- Spearman correlation coefficient (r) and levels of significance determined for the relationship between the content of heavy metals in water and physical parameters.

x-y	Metals	R	P
Water-temperature (n=36)	Ba	0.328	>0.05
	As	-0.158	>0.05
	Co	-0.302	>0.05
	Cd	-0.217	>0.05
	Cr	-0.163	>0.05
	Cu	0.031	>0.05
	Fe	-0.018	>0.05
	Mn	-0.021	>0.05
	Ni	0.101	>0.05
	Zn	0.019	>0.05
Water-dissolved oxygen (n=36)	Ba	-0.704	<0.01
	As	0.384	<0.05
	Co	0.582	<0.01
	Cd	0.616	<0.01
	Cr	-0.384	<0.05
	Cu	0.326	>0.05
	Fe	0.288	>0.05
	Mn	0.290	>0.05
	Ni	0.491	<0.01
	Zn	-0.452	<0.01
Water-pH (n=36)	Ba	0.313	>0.05
	As	-0.282	>0.05
	Co	-0.520	<.01
	Cd	-0.522	<.01
	Cr	-0.213	>0.05
	Cu	-0.355	<.05
	Fe	0.108	>0.05
	Mn	-0.054	>0.05
	Ni	-0.052	>0.05
	Zn	-0.145	>0.05
Water-EC (n=36)	Ba	0.607	>0.01
	As	-0.317	<0.05
	Co	-0.408	>0.05
	Cd	-0.246	>0.05
	Cr	0.580	>0.05
	Cu	-0.151	>0.05
	Fe	0.169	>0.05
	Mn	-0.146	>0.05
	Ni	-0.355	<0.05
	Zn	0.541	<0.01

Heavy metal uptake by the fish

The seasonal variations of concentrations of the metals expressed in mg/kg dry weight, in muscle, liver and gill of *Cyprinus carpio* from Işıklı Lake is summarized in Table VII. Ba and Mn concentrations in different tissues ranged from 0.84-23.75 mg/kg and 0.81-22.68 mg/kg and bioaccumulation order was gill>liver>muscle. As, Cd, Cu and Fe concentrations among different tissues ranged from 0.53-2.66 mg/kg, 0.05-1.16 mg/kg, 1.03-3.22 mg/kg and 13.77-840.94 mg/kg and the order of bioaccumulation was liver>gill> muscle. Co, Cr and Ni were higher in liver, lower in gills, with the order of liver > muscle>gill. Zn concentration among different tissues ranged from 20.06-823.22 mg/kg and the order of bioaccumulation was liver=gill>muscle. Generally higher metal levels were found in liver, while the lowest were found in muscle tissue. These results are in aggrement with some other studies about heavy metal accumulation in fish (Canlı and Atli, 2003; Canpolat and Çalta, 2003; Karadede *et al.*, 2004; Tekin-Özan, 2008; Canlı *et al.*, 1998). Liver is the major organ involved in xenobiotic metabolism in fish (Romeo *et al.*, 1994). It is well known that high induction levels of metallothionein occur in liver tissue of fishes (Heath, 1987). The lowest levels were detected in muscle because muscle is not an active tissue in accumulation of heavy metals (Alam *et al.*, 2002; Amundsen *et al.*, 1997).

In this study, we also aimed at determining the seasonal variation of heavy metals in liver, gill and muscle of *Cyprinus carpio*. In muscle, maximum metal level was 1.10 mg/kg for Ba, 6.46 mg/kg for Cr, 0.95 mg/kg for Ni in spring, 85.99 mg/kg for Fe, 47.41 mg/kg for Zn in summer, 1.11 mg/kg for As in autumn and 0.94 mg/kg for Co, 0.50 mg/kg for Cd, 2.27 mg/kg for Cu, 2.11 mg/kg for Mn in winter. As (<0.05), Co (<0.01), Cd (<0.01), Cr (<0.05), Cu (<0.05), Fe (<0.01), Mn (<0.05) and Zn (<0.01) levels were found significant from season to season.

In liver, maximum metal level was 77.22 mg/kg for Cr in spring, 2.12 mg/kg for Ba, 1.72 mg/kg for As, 3.22 mg/kg for Cu, 85.99 mg/kg for Fe, 5.73 mg/kg for Mn , 4.72 mg/kg for Ni and 823.22 mg/kg for Zn in summer, 2.07 mg/kg for Co, 1.16 mg/kg for Cd in winter. Ba (<0.05), As (<0.01), Co (<0.05), Cd (<0.01), Mn (<0.01) and Zn (<0.05) concentrations in livers varied significantly from season to season.

In gills, the maximum metal levels was 23.75 mg/kg for Ba, 28.68 mg/kg for Cr and 2.09 mg/kg

Table VI.- The concentrations (minimum, maximum, mean and SD values) of some heavy metals in Işıklı Lake's sediment (mg/kg).

Metals	Spring (n=9)	Summer (n=9)	Autumn (n=9)	Winter (n=9)
Ba	25.98-245.04 (94.43±8.53) [a*]	46.18-188.42 (103.85±4.35) [b]	8.99-217.54 (93.94±6.27) [b]	10.82-165.13 (50.70±4.97) [b]
As	6.06-13.08 (10.00±2.48) [a]	3.42-11.99 (8.72±0.34) [a]	7.03-16.33 (12.54±0.31) [a]	1.14-11.37 (5.66±0.32) [b]
Co	0.63-2.99 (2.28±1.11) [a]	0.01-3.53 (2.22±0.12) [ab]	0.91-6.84 (2.69±0.01) [bc]	1.04-7.67 (4.15±0.18) [c]
Cd	0.47-1.09 (0.81±0.18) [b]	0.19-0.61 (0.40±0.01) [a]	0.09-0.68 (0.46±0.016) [a]	1.69-3.06 (2.22±0.045) [c]
Cr	11.60-269.55 (138.21±8.22) [b]	55.45-190.50 (114.40±4.90) [a]	24.63-161.71 (68.05±4.28) [a]	27.96-137.76 (57.92±3.18) [c]
Cu	2.68-38.24 (24.19±0.97) [a]	15.38-34.57 (24.22±0.61) [a]	11.40-34.67 (21.86±0.82) [a]	10.33-38.84 (20.53±0.87) [a]
Fe	17.22-25475 (16679.42± 948.82) [a]	11237.86-25217.14 (19215.78± 54.87) [a]	6443.83-24125.99 (16644.30± 68.12) [a]	7107.41-23975.21 (14692± 58.33) [a]
Mn	238.4-867.16 (502.26±18.6) [a]	282.02-683.62 (468.29±1.38) [a]	247.86-842.15 (532.69±2.10) [a]	282.54-843.45 (520.76±1.96) [a]
Ni	11.23-211.16 (107.34±6.487) [a]	40.58-210.83 (110.39±6.20) [a]	29.70-111.98 (66.55±3.08) [a]	33.39-122.01 (61.98±0.27) [a]
Zn	16.34-76.94 (60.36±1.81) [a]	50.33-143.35 (82.16±2.68) [a]	45.67-159.56 (80.30±3.30) [a]	41.64-84.74 (60.72±1.40) [a]

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

for Ni in spring, 2.66 mg/kg for As in summer, 281.69 mg/kg for Fe and 22.68 mg/kg for Mn in autumn, 0.90 mg/kg for Co, 0.51 mg/kg for Cd and 2.30 mg/kg for Cu in winter. In relation to season, Ba (<0.05), As (<0.01), Co (<0.05), Cd (<0.01), Cu (<0.05), Fe (<0.01), Mn (<0.05), Ni (<0.01) and Zn (<0.05) were significant in gill. The maximum concentrations of metals were reached in summer and winter, while the lowest were in spring and autumn. The levels of heavy metals in summer and winter were also found in *Tinca tinca* in Beyşehir Lake (Tekin-Özan, 2008), *Capoeta capoeta umbla* in Hazar Lake (Karadede-Akın, 2009), *Tilapia zillii* in Manzalah Lake (Zyadah, 1999). The increase of heavy metal levels in summer could be because of the increased physiological activity of fish during summer primarily induced by the increasing water temperature (Canpolat and Çalta, 2003). Zyadah (1999) recorded that higher values of heavy metals in winter and spring was because of their decrease in wastewater from agricultural fields.

Linear regression analysis and significant associations between the metal levels of tissues and the size (total length and weight) are shown in Tables VIII and IX. Significant negative relationships were found between fish length and As (<0.05), Co, Cd, Fe, Mn (<0.01) in the muscle, Ba, As (<0.01), Co, Cd, Cu (<0.01), Fe (<0.01), Mn (<0.01), Zn (<0.01) in liver and Ba, As (<0.01), Co, Cd, Cu (<0.01), Fe (<0.01), Mn (<0.01) in gill. All the other significant relationships were positive (Table VIII). The tissues of *Cyprinus carpio* showed significant negative relationships between weight and As (<0.05), Fe in muscle, Ba, As, Cr, Cu, Mn, Zn in liver and Ba (<0.05), As (<0.01), Co, Cd, Cu (<0.01), Fe (<0.01), Mn (<0.01) in gill. The other significant relationships are positive (Table IX). The positive and negative relationship between heavy metal levels in the tissues and fish size (total length and weight) has generally been supported in the literature. Nussey *et al.* (2000) found that levels of metals increased with the decrease in the length of *Labeo umbratus*. In an other study, it was found that the concentration of Cu, Fe, Mn and Zn in some tissues of *Capoeta capoeta umbla* increased with the increase in length. The metabolic activity is the most important factor that play a significant role in heavy metal accumulation (Douben, 1989; Elder and Collins, 1991). Canlı and Atli (2003) reported negative correlation between metal levels and size, which may be because of the difference in metabolic activity between younger and older fish. Heath (1987) found that the presence of heavy metals in water affect the fish development and juveniles are sensitive in the early life stages like larval development and juvenile growth. Canpolat and Çalta (2003) expressed that smaller fish are more active and need more oxygen to supply more energy.

The results of this study were compared with permissible levels of heavy metal in fish tissues reported in the literature. Cd concentration was higher than the acceptable limits for fish tissues in spring (EC, 2006). WHO limits the levels for Zn at 30 mg/kg, for Cr at 1.0 mg/kg, for Fe at 2.0 mg/kg and for Mn at 1.0 mg/kg (UNESCO/WHO/UNEP,

Table VII.- Heavy metal concentrations (minimum, maximum, mean and SD values) in different organs of *Cyprinus carpio* from the Işıklı Lake (mg/kg).

Season	Metals	Muscle	Liver	Gill
Spring	Ba	0.22-4.20 (1.10±0.074) [a*]	0.1-2.18 (0.84±0.057) [a]	14.08-35.18 (23.75±0.59) [ab]
	As	0.15-1.01 (0.55±0.023) [a]	0.10-2.17 (1.05±0.065) [a]	0.16-1.43 (0.75±0.035) [a]
	Co	0.03-0.29 (0.11±0.05) [a]	0.01-1.02 (0.15±0.021) [a]	0.01-0.16 (0.05±0.003) [ab]
	Cd	0.03-0.10 (0.06±0.02) [a]	0.03-0.34 (0.14±0.008) [b]	0.03-0.16 (0.07±0.002) [b]
	Cr	0.26-49.39 (6.46±1.026) [b]	0.02-1110.95 (77.22±2.28) [a]	0.45-307.99 (28.68±0.87) [a]
	Cu	0.29-5.55 (1.03±0.05) [a]	0.72-4.63 (2.18±0.083) [a]	0.55-3.58 (1.97±0.06) [ab]
	Fe	6.12-31.37 (13.77±0.42) [a]	48.86-2692.5 (700.66±51.21) [a]	112.31-349.9 (180.56±4.76) [a]
	Mn	0.27-1.80 (0.81±0.033) [a]	0.59-5.70 (1.80±0.097) [a]	0.90-22.45 (11.86±0.45) [a]
	Ni	0.21-2.53 (0.95±0.058) [a]	0.32-55.63 (3.19±0.94) [a]	0.38-22.45 (2.09±0.38) [b]
	Zn	1.19-50.21 (20.06±0.86) [a]	89.02-2292.2 (648.06±6.50) [ab]	293.61-779.8 (525.54±12.95) [ab]
Summer	Ba	0.19-15.26 (2.12±0.322) [a]	0.24-27.33 (4.11±0.68) [b]	0.60-41.20 (21.53±11.17) [a]
	As	0.03-2.12 (0.63±0.055) [a]	0.05-6.49 (1.72±0.19) [a]	0.15-20.90 (2.66±0.49) [b]
	Co	0.01-0.92 (0.12±0.018) [a]	0.0005-0.59 (0.13±0.018) [a]	0.0001-0.16 (0.03±0.004) [a]
	Cd	0.0007-0.55 (0.05±0.0013) [a]	0.0005-0.75 (0.08±0.014) [a]	0.001-0.27 (0.04±0.006) [a]
	Cr	0.02-27.10 (4.19±0.71) [a]	0.08-55.78 (8.08±1.48) [a]	0.05-15.60 (2.22±0.35) [a]
	Cu	0.14-8.61 (1.36±0.15) [a]	0.98-10.25 (3.22±0.19) [a]	0.51-3.20 (1.81±0.088) [a]
	Fe	5.52-115.4 (85.99±2.645) [b]	263.8-3768.3 (840.94±5.97) [a]	22.01-843.68 (270.63±19.66) [b]
	Mn	0.25-9.98 (1.32±0.18) [a]	0.41-26.50 (5.73±0.64) [b]	0.30-36.79 (15.98±1.29) [b]
	Ni	0.08-6.52 (1.25±0.15) [a]	0.10-35.65 (4.27±0.76) [a]	0.21-1.42 (0.76±0.300) [a]
	Zn	9.21-390.17 (47.41±7.01) [b]	201.7-3268.9 (823.22±7.04) [b]	32.59-751.87 (459.25±22.89) [a]
Autumn	Ba	0.36-3.22 (1.01±0.058) [a]	0.29-4.11 (1.34±0.16) [a]	17.89-40.30 (16.70±0.56) [b]
	As	0.11-2.01 (1.11±0.051) [b]	0.004-5.28 (1.71±0.14) [a]	0.41-3.11 (1.65±0.077) [ab]
	Co	0.04-0.25 (0.12±0.005) [a]	0.01-0.22 (0.09±0.006) [a]	0.0002-0.31 (0.09±0.007) [b]
	Cd	0.0072-0.03 (0.01±0.009) [a]	0.003-0.16 (0.04±0.005) [a]	0.0007-0.06 (0.01±0.001) [a]
	Cr	0.0011-94.32 (7.23±1.98) [a]	0.06-113.44 (14.22±0.28) [a]	0.15-527.06 (20.23±0.95) [a]
	Cu	0.56-2.57 (1.35±0.19) [a]	0.99-4.81 (2.19±0.08) [a]	1.24-5.35 (2.21±0.078) [b]
	Fe	2.22-63.22 (24.36±0.12) [ab]	227-1875.3 (636.67±2.87) [a]	138.39-603.2 (281.69±11.62) [b]
	Mn	0.31-3.09 (0.83±0.051) [a]	0.08-3.90 (0.95±0.081) [a]	12.07-35.41 (22.68±0.61) [c]
	Ni	0.04-7.26 (1.15±0.14) [a]	0.26-4.27 (1.30±0.096) [a]	0.16-3.06 (0.82±0.057) [a]
	Zn	19.43-81.89 (38.97±1.43) [b]	102.8-2341.9 (517.20±5.40) [ab]	273.44-850 (572.04±1.17) [b]
Winter	Ba	0.32-1.80 (0.91±0.039) [a]	0.25-2.92 (1.04±0.079) [a]	13.74-33.16 (21.81±0.57) [a]
	As	0.04-1.51 (0.53±0.034) [b]	0.09-3.41 (1.28±0.095) [b]	0.03-1.17 (0.56±0.031) [c]
	Co	0.59-1.26 (0.94±0.016) [b]	0.81-5.90 (2.07±0.16) [b]	0.67-1.19 (0.90±0.013) [c]
	Cd	0.31-0.78 (0.50±0.009) [b]	0.51-3.24 (1.16±0.057) [b]	0.34-0.69 (0.51±0.007) [c]
	Cr	0.36-5.60 (1.43±0.015) [a]	0.50-32.27 (4.10±0.65) [a]	0.63-21.00 (2.81±0.04) [a]
	Cu	1.02-4.28 (2.27±0.089) [b]	1.70-4.79 (2.56±0.066) [a]	1.37-4.41 (2.30±0.006) [b]
	Fe	28.11-79.07 (43.61±11.99) [ab]	343.1-1209.4 (721.14±21.25) [a]	142.19-340.7 (223.94±5.023) [ab]
	Mn	1.49-2.88 (2.11±0.032) [b]	1.91-9.58 (4.79±0.22) [a]	10.22-31.39 (18.31±0.53) [ab]
	Ni	0.49-6.59 (1.32±0.14) [a]	0.73-12.73 (2.97±0.25) [a]	0.53-7.26 (1.32±0.02) [ab]
	Zn	23.15-80.82 (46.37±1.54) [b]	82.37-1937.8 (431.56±4.94) [a]	233.33-902.1 (557.63±16.52) [b]

1992). Heavy metal levels in *Cyprinus carpio* from Işıklı Lake are above these limits. Institute of Turkish Standarts and Ministry of Agricultural and Rural Areas standards limit the levels for As at 1 mg/kg, for Cd at 0.1 mg/kg, for Zn at 50 mg/kg and for Cu at 20 mg/kg (Republic of Turkey Ministry of Agricultural and Rural Areas, 2002; TSE, 1997). Our results show that As and Zn exceed these limits in all tissues (except muscle), only in winter for Cd, but do not exceed for Cu.

Table VIII.- The relationships between total lenght and heavy metal concentrations of the *Cyprinus carpio* caught from the Işıklı Lake[a].

Tissue		Ba	As	Co	Cd	Cr	Cu	Fe	Mn	Ni	Zn
Muscle	Equation[a]	*Y*=-10.84+ 0.418*X* 3.241*X*	*Y*=1.67+	*Y*=0.952+ (-0.0313)*X*	*Y*=0.237+ (-0.0181)*X*	*Y*=-112.96+ (-0.0311)*X*	*Y*=-13.14+ 4.192X	*Y*=110.36+ 0.494*X*	*Y*=4.056+ (-1.596)*X*	*Y*=-10.041+ (-0.0892)*X*	*Y*=-53.93+ 0.376X
	R value	0.173		-0.218	-0.068	-0.053	0.223	0.315	-0.048	-0.295	0.3870.218
	P value	*[c]	*	NS[b]	NS	*	**[d]	NS	**	**	**
Liver	Equation	*Y*=0.641+ (-0.248)*X*	*Y*=2.854+ (-0.0576)*X*	*Y*=1.527+ (-0.0312)*X*	*Y*=0.988+ (-0.0209)*X*	*Y*=98.274+ (-2.24)X	*Y*=5.057+ (-0.08)*X*	*Y*=692.40+ 0.998*X*	*Y*=13.091+ 0.313*X*	*Y*=-3.258+ 0.192X	*Y*=637.35+ (-0.879)*X*
	R value	-0.245		-0.182	-0.115	-0.141	-0.065	-0.236	-0.008	-0.290	0.111-0.005
	P value	**	*	NS	NS	NS	**	NS	**	NS	NS
Gill	Equation	*Y*=33.34+ (-0.076)*X*	*Y*=32.78+ (-1.34)*X*	*Y*=31.80+ (-0.956)*X*	*Y*=31.68+ (-0.783)*X*	*Y*=31.45+ (-0.081)X	*Y*=34.01+ (-1.184)*X*	*Y*=33.37+ 0.076*X*	*Y*=34.67+ (-0.182)*X*	*Y*=31.07+ 0.385X	*Y*=31.23+ 0.064*X*
	R value	-0.162		-0.297	-0.097	-0.044	0.146	-0.245	-0.259	-0.394	0.2350.030
	P value	NS	**	NS	NS	NS	**	**	**	**	NS

[a] Y is metal concentartions (mg/kg) *X* is total fish lenght (mm).
[b] NS. Not significant at the $p<0.05$ level.
[c] Significant at the level $p<0.05$ level
[d] Significant at the level $p<0.05$ level

Table IX.- The relationships between weight and heavy metal concentrations of the *Cyprinus carpio* caught from the Işıklı Lake.

Tissue		Ba	As	Co	Cd	Cr	Cu	Fe	Mn	Ni	Zn
Muscle	Equation[a]	*Y*=0.393+ 0.054*X*	*Y*=0.920+ (-0.0457)*X*	*Y*=0.574+ (-0.0379)*X*	*Y*=0126+ 0.025*X*	*Y*=-10.49+ 0.0591X	*Y*=-2.19+ 0.091*X*	*Y*=50.83+ (-0.017)*X*	*Y*=1.71+ (-0.093)*X*	*Y*=-1.97+ 0.075X	*Y*=9.53+ 0.076*X*
	R value	0.124		-0.174	-0.079	0.024	0.173	0.320	-0.003	-0.171	0.4240.284
	P value	NS	*[c]	NS[b]	NS	*	**[d]	NS	*	**	**
Liver	Equation	*Y*=3.36+ (-0.030)*X*	*Y*=1.44+ (-0.08)*X*	*Y*=0.471+ 0.013*X*	*Y*=0.309+ 0.035*X*	*Y*=52.93+ 0.050X	*Y*=2.85+ 0.064*X*	*Y*=705.55+ 0.036*X*	*Y*=4.07+ (-0.016)*X*	*Y*=0.225+ 0.05X	*Y*=673.79+ (-0.127)*X*
	R value	-0.166	-0.140		0.028	0.013	-0.080	-0.105	0.016	-0.086	0.161-0.041
	P value	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Gill	Equation	*Y*=607.46+ (-4.64)*X*	*Y*=557.86+ (-64.74)*X*	*Y*=510.76+ (-49.18)*X*	*Y*=503.21+ (-31.77)*X*	*Y*=491.59+ 0.490X	*Y*=640.61+ (-68.75)*X*	*Y*=594.76+ (-0.406)*X*	*Y*=658.58+ (-9.40)*X*	*Y*=473.11+ 19.81X	*Y*=488.19+ 0.02*X*
	R value	-0.182		-0.263	-0.092	-0.033	0.163	-0.261	-0.254	-0.373	0.2220.017
	P value	*	*	NS	NS	NS	*	**	**	*	NS

For details of symbols see Table VIII.

CONCLUSIONS

The water and the sediment of lake had highest concentration of Fe. In lake Isikhi, the concentration of metals were the highest in summer and winter. The levels of Fe, As, Zn and Cu in the lake water were lower than the WHO standards. The concentration of some metals, however, increased with decreasing temperature, dissolved oxygen and EC.

Four of the ten elements reached the maximum level in sediment during summer. Close correlations (<0.05) were found for Ba, As, Co, Cd and Cr in the sediment among seasons. Sediment are important hosts for pollutant heavy metals, therefore they have been used to monitor the pollution in aquatic environment.

Higher metal levels were found in liver, lower were in muscle. Generally, higher levels of metals were found in the summer and winter. Both negative and positive relationships were found between metal levels and fish size (total length and weight). Generally some of the results were above the limits for fish proposed by WHO, EC and TSE. This study shows that a potential danger may occur in the future depending on the agricultural development.

ACKNOWLEDGEMENTS

This work supported by TÜBİTAK, ÇAYDAG with 108Y334 project no. I would like to thank The Scientific and Technological Research Council of Turkey for its financial support.

REFERENCES

ADAMS, M.S. AND MCLEAN, R.B., 1985. Estimation of largemouth bass, *Micropterus salmoides* Lacepedei growth using the liver somatic index and physiological variables. *J. Fish Biol.,* **26:**111-126.

ADNANO, D.C., 1986. *Trace metals in the terrestrial environment.* Springer Verlag, New York.

AKARSU, F., BAYILI, B. AND EROĞLU, V., 2006. Işıklı Gölü, *Türkiye'nin Önemli Doğa Alanları,* Doğa Derneği, Türkiye, Cilt 1.

ALAM, M.G.M., TANAKA, A., ALLINSON, G., LAURENSON, L.J.B. AND STAGNITTI, F., 2002. A Comparison of trace element concentrations in cultured and wild carp (*Cyprinus carpio*) of Lake Kasumigaura, Japan. *Ecotoxicol. environ. Safety,* **53:** 348-354.

AL-SAADİ, H.A., AL-LAMİ, A.A., HASSAN, F.A. AND AL-DULYMİ, A.A., 2002. Heavy metals in water, suspended particles, sediments and aquatic plants of Habbaniya Lake, Iraq. *Int. J. environ. Stud.,* **59:** 589-598.

AMUNDSEN, P., STALDVİK, F.J., LUKİN, A.A., KASHULİN, N.A., POPOVA, O.A. AND RESHETNİKOV, Y.S., 1997. Heavy metal contamination in freshwater fish from the Border Region Between Norway and Russia. *Sci. Total Environ.,* **201:** 211-224.

AYGEN, C. AND BALIK, S., 2005. Işıklı Gölü ve kaynaklarının (Çivril- Denizli) Crustacea Faunası. *E.Ü. Su Ürünleri Dergisi.,* **22:** 371-375.

BARLAS, N., 1999. A pilot study of heavy metal concentration in various environments and fishes in the Upper Sakarya River Basin. *Environ. Toxicol.*, **14:** 367-373.

BARLAS, N., AKBULUT, N. AND AYDOĞAN, M., 2005. Assessment of heavy metal residues in the sediment and water samples of Uluabat Lake, Turkey. *B. Environ. Contam. Toxicol.,* **74:** 286-293.

BARON, J., LEGRET, M. AND ASTRUC, M., 1990. Study of interactions between heavy metals and sewage sludge: Determination of stability constants and complexation capacities of complexes formed with Cu and Cd. *Environ. Technol.,* **11:** 151-162.

BARRON, M.G., 1995. Bioaccumulation and biconcentration in aquatic organisms. In: *Handbook of ecotoxicology* (eds. D.F. Hoffmann, B.A. Rattner, G.A. Burton, and J. Cairns), Lewis. Boca Raton, FL, pp. 652.

CANLI, M. AND ATLI, G., 2003. The relationships between heavy metal (Cd, Cr, Cu, Fe, Pb, Zn) levels and the size of six Mediterranean fish species. *Environ. Pollut.,* **121:** 129-136

CANLI, M., AY, Ö. AND KALAY, M., 1998. Levels of heavy metals (Cd, Pb, Cu, Cr and Ni) in tissue of *Cyprinus carpio*, *Barbus capito, Chondrostoma regium* from the Seyhan River, Turkey. *Tr. J. Zool.,* **22:** 149-157.

CANPOLAT, Ö. AND ÇALTA, M., 2003. Heavy metals in some tissues and organs of *Capoeta capoeta umbla* (Heckel, 1843) fish species in relation to body size, age, sex and seasons. *Fresenius environ. Bull.,* **12:** 961-966.

DALLINGER, R., PROSI, F., SENGER, H. AND BACK, H., 1987. Contaminated food and uptake of heavy metals by fish (a review and proposal for further research). *Oecologia Berlin,* **73:** 91-98

DAWSON, E.J. AND MACKLIN, M.G., 1998. Speciation of heavy metals in floodplain and flood sediments: a reconnaissance survey of the Aire Valley, West Yorkshire, Great Britain. *Environ. Geochem. Hlth.,* **20:** 67-76.

DEMIRAK, A., YILMAZ, F., TUNA, A.L. AND ÖZDEMIR, N., 2006. Heavy metals in water, sediment and tissues of *Leuciscus cephalus* from a stream in southwestern Turkey. *Chemosphere*, **63:** 1451-1458.

DOUBEN, P.E., 1989. Lead and cadmium in stone loach (*Noemacheilus barbatulus* L.) from three rivers in Derbyshire. *Ecotoxicol. environ. Safe.*, **18:** 35-58.

EASTWOOD, S. AND COUTURE, P., 2002. Seasonal variations in condition and liver metal concentrations of yellow perch (*Perca flavescens*) from a metal-contaminated environment. *Aquat. Toxicol.*, **58:** 43-56.

EBRAHIMI, M. AND TAHERIANFARD, M., 2010. Concentration of four heavy metals (cadmium, lead, mercury, and arsenic) in organs of two fish (*Cyprinus carpio* and *Capoeta sp.*) from the Kor River, Iran. *Environ. Monit. Assess.*, **168:** 575-585.

EC, 2006. Commission Regulation Maximum levels for certain contaminants in foodstuffs. 2006 EC. No: 1881/2006.

EIMERS, R.D., EVANS, R.D. AND WELBOURN, P.M., 2001. Cadmium accumulation in the freshwater isopod *Asellus racovitzai:* the relative importance of solute and particulate sources at trace concentrations. *Environ. Pollut.*, **111:** 247-258.

ELDER, J.F. AND COLLINS, J.J., 1991. Freshwater molluscs as indicators of bioavailability and toxicity of metals in surface systems. *Rev. environ. Contam. Toxicol.*, **122:** 37-79.

ERDOĞRUL, Ö. AND ERBILIR, F., 2007. Heavy metal and trace elements in various fish samples from Sir Dam Lake, Kahramanmaraş. Turkey. *Environ. Monit. Assess.*, **130:** 373-379.

FARKAS, A., SALÁNKİ, J. AND SPECZİÁR, A., 2002. Relation between growth and the heavy metal concentrations in organs of bream *Abramis brama* L. populating Lake Balaton. *Arch. environ. Contam. Toxicol.*, **43:** 236-243.

FİDAN, A.F., CİĞERCİ, İ.H., KONUK, M., KÜÇÜKKURT, İ., ASLAN, R. AND DÜNDAR, Y., 2008. Determination of some heavy metal levels and oxidative status in *Carassius carassius* L., 1758 from Eber Lake. *Environ. Monit. Assess.*, **147:** 35-41.

FLORENCE, T.M., MORRISON, G.M. AND STAUBER, J.L., 1992. Determination of trace element speciation and the role of speciation in aquatic toxicity. *Sci. Total Environ.*, **125:** 1-13.

GÖKSU, M.Z.L., 2003. *Su Kirliliği.* Çukurova Üniversitesi, Su Ürünleri Fakültesi Yayınları, No:7, Adana.

HEATH, A.G., 1987. *Water pollution and fish physiology.* CRP Press Inc. Florida, USA, 245 pp.

HELLAWELL, M.J., 1988 Toxic substances in rivers and streams. *Environ. Pollut.*, **50:** 61-85.

HOLCOMBE, G.W., BENOIT, D.A., LEONARD, E.N. AND MCKIM, J.M., 1976. Longterm effects of lead exposure on three generations of brook trout, *Salvelinus fontinalis. J. Fish. Res. Bd. Canada,* **33:** 1731-1741.

HUGHES, G.M. AND FLOS, R., 1978. Zinc content of the gills of rainbow trout (*S. gairdneri*) after treatment with zinc solutions under marmoxic and hypoxic conditions. *J. Fish Biol.*, **13:** 717-728.

KALAY, M. AND CANLI, M., 2000. Elimination of essential (Cu, Zn) and non- essential (Cd, Pb) metals from tissues of a freshwater fish *Tilapia zillii* following an uptake protocol. *Tr. J. Zool.*, **24:** 429-436.

KARADEDE, H. AND ÜNLÜ, E., 2000. Concentrations of some heavy metals in water, sediment and fish species from the Atatürk Dam Lake (Euphrates), Turkey. *Chemosphere,* **41:** 1371-1376.

KARADEDE, H., OYMAK, S.A. AND ÜNLÜ, E., 2004. Heavy metals in mullet, *Liza abu*, and catfish, *Silurus triostegus*, from the Atatürk Dam Lake (Euphrates), Turkey. *Environ. Int.*, **30**: 183-188.

KARADEDE-AKIN, H., 2009. Seasonal variations of heavy metals in water, sediments, pondweed (*P. pectinatus* L.) and freshwater fish (*C.c. umbla*) of Lake Hazar. Elazığ-Turkey. *Fresenius environ. Bull.*, **18:** 511-518.

KOTZE, P., PREEZ, H.H. AND VAN VUREN, J.H.J., 1999. Bioaccumulation of copper and zinc *Oreochromis mossambicus* and *Clarias gariepinus* form the Olifants river, Mpumalanga, South Africa. *Water SA.*, **25:** 99-100.

LARKIN, P.A., 1978. Fisheries management: an assay for ecologists. *Annu. Ecol. Syst.*, **9:** 57-73.

LAROCQUE, A.C.L. AND RASMUSSEN, P.E., 1998. An overview of trace metals in the environment form mobilization to remediation. *Environ. Geol.*, **33:** 85-100.

NEWMAN, M.C. AND DOUBET, D.K., 1989. Size-dependence of mercury (II) accumulation kinetics in the mosquitofish, *Gambusia affinis* (Baird and Girard). *Arch. environ. Contam. Toxicol.*, **18**: 819-825.

NUSSEY, G., VAN VUREN, J.H.J. AND DU PREEZ, H.H., 2000. Bioaccumulation of chromium, manganese, nickel and lead in the tissues of the moggel, *Labeo umbratus* (Cyprinidae), from Witbank Dam, Mpumalanga. *Water SA.,* **26:** 269-284.

OYMAK, S.A., KARADEDE-AKIN, H. AND DOĞAN, N., 2009. Heavy metal in tissues of *Tor grypus* from Atatürk Dam Lake, Euphrates River-Turkey. *Biologia,* **64:** 151-155.

ÖZMEN, H., KÜLAHÇI, F., ÇUKUROVALI, A. AND DOĞRU, M., 2004. Concentrations of heavy metal and radioactivity in surface water and sediment of Hazar Lake. Elazığ, Turkey. *Chemosphere,* **55:** 401-408.

PHILLIPS, D.J.H., 1990. Arsenic in aquatic organisms: A review, emphasisisng chemical speciation. *Aquat. Toxicol.*, **16:** 151-186.

POURANG, N., 1995. Heavy metal bioaccumulation in different tissues of two fish species with regard to their feeding habits and trophic levels. *Environ. Monit. Assess.*, **35:** 207-219.

REPUBLIC OF TURKEY MINISTRY OF AGRICULTURAL

AND RURAL AREAS, 2002. *Su ürünleri kanunu ve su ürünleri yönetmeliği*. Ankara. 63-78 pp.

REPUBLİC OF TURKEY MİNİSTRY OF ENVİRONMENT AND FOREST, 2004. Su kirliliği kontrolü yönetmeliği, Resmi gazete, 31.12.2004, No: 25687.

ROMEO, M., MATHIEU, A., GNASSIA-BARELLI, M., ROMANA, A. AND LAFAURIE, M., 1994. Heavy metal content and biotransformation enzymes in two fish species from NW Mediterranean. *Mar. Ecol. Prog. Ser.*, **107:** 15-22.

TANYOLAÇ, J., 1993. *Limnoloji*. Hatipoğlu Yayınevi., Ankara, 263 pp.

TEKIN-ÖZAN, S., 2008. Determination of heavy metals in water, sediment and tissues of tench (*Tinca tinca* L., 1758) from Beyşehir Lake (Turkey). *Environ. Monit. Assess.*, **145:** 295-302.

TEPE, Y., TÜRKMEN, M. AND TÜRKMEN, A., 2008. Assessment of heavy metals in two commercial fish species of four Turkish seas. *Environ. Monit. Assess.*, **146:** 277-284.

THOMAS, D.G., CRYER, A., SOLBE, J., DE, L.G. AND KAY, J.A., 1983. Comparison and protein binding of environmental cadmium in the gills, kidney and liver of rainbow trout (*Salmo gairdneri* Richardson). *Comp. Biochem. Physiol*,. **76:** 241-246.

TSE, 1997. Institution of Turkish Standards. Annual Progress Report.

UNESCO/WHO/UNEP. 1992. *Water quality assessments*, pp. 10-13. Chapman and Hall Ltd., London.

ÜNLÜ, E., KARADEDE-AKIN, H., AKTÜRK, M.N. AND YANAR, M., 2009. Bioaccumulation of cadmium by nile tilapia *Oreochromis niloticus* (L.) in the presence of green algae *Cladophora glomerata* (L.) Kutz. *Fresenius environ. Bull.*, **18:** 2055-2059.

USERO, J., IZQUIERDO, C., MORILLO, J. AND GRACIA, I., 2003. Heavy metals in fish (*Solea vulgaris, Anguilla anguilla* and *Liza aurata*) from Salt Marshes on the Southern Atlantic Coast of Spain. *Environ. Int.*, **1069:** 1-8.

VARANASI, U. AND MARKEY, D., 1978. Uptake and release of lead and cadmium in skin and mucus of coho salmon (*Oncorynchus kisutch*). *Comp. Biochem. Physiol.*, **60:** 187-191.

WHO, 1993. *41st report of the joint expert committee on food addivities* (JEFCA).

WHO, 1998. *Guidelines for drinking-water quality*. Second edition, volume 1 Geneva.

ZHOU, H.Y., CHEUNG, R.Y.H., CHAN, K.M. AND WONG, M.H., 1998. Metal concentrations in sediments and *Tilapia* collected from inland waters of Hong Kong. *Water Res.*, **11:** 3331-3340.

ZYADAH, M.A., 1999. Accumulation of some heavy metals in *Tilapia zillii* organs from Lake Manzalah, Egypt. *Tr. J. Zool.*, **23:** 365-372.

(Received 4 April 2012, revised 7 August 2012)