Turk J Zool
2011; 35(2): 271-280

doi:10.3906/zoo-0810-6

Research Article

Assessment of heavy metal concentrations in water, plankton, and fish of Lake Manzala, Egypt

Mohamed BAHNASAWY*, Abdel-Aziz KHIDR, Nadia DHEINA

Department of Zoology, Damietta Faculty of Science, Damietta - EGYPT

Received: 07.10.2008

Abstract: The levels of some heavy metals (Cu, Zn, Cd, and Pb) were determined in water, plankton, and fish (*Liza aurata*) collected from 5 sites in Lake Manzala. Metals in the water and fish exhibited a significant seasonal and regional variation, in which all metals attained their maximum value during summer, while the lowest levels were found during winter. The concentration of different metals in water, plankton, and fish tissues followed the same order: Zn > Cu > Pb > Cd. The mean concentrations of metals in the water were as follow: Cu, 0.055; Zn, 0.311; Cd, 0.020; and Pb, 0.022 mg/L. The Cd level in the water was found to be higher than the permissible limit recommended for drinking water. Metals in plankton were much higher than those of water and fish. Gills of the examined fish contained the highest concentration of all of the measured metals, while muscles retained the lowest. In spite of the contamination of Lake Manzala by heavy metals, the level of the metals in fish muscle (the edible part) did not exceed the recommended permissible limit and the fish is considered safe for human consumption.

Key words: Lake Manzala, heavy metals, water, plankton, fish

Introduction

In aquatic systems, heavy metals have received considerable attention due to their toxicity and accumulation in biota (Mason, 1991). Metals generally enter the aquatic environment through atmospheric deposition, erosion of the geological matrix, or due to anthropogenic activities caused by industrial effluents, domestic sewage, and mining wastes (Tarvainen et al., 1997; Stephen et al., 2000). Some of these metals, such as Cd and Pb, are toxic to living organisms even at quite low concentrations, whereas others, such as Zn and Cu, are biologically essential and natural constituents of aquatic ecosystems, and generally only become toxic at very high concentrations. Zn has a multitude of biological functions in the human body. It is an important constituent of over 100 enzymes involved in a variety of fundamental metabolic processes. It is involved in the production and function of several hormones. Excessive intake of Zn causes abdominal pain, violent vomiting, collapse, and degenerative changes in the liver. Cu is probably a functional constituent of all cells. Toxicity can result from excessive intake, which results in gastrointestinal disturbance, headache, cirrhosis, necrosis, and liver failure. Cd is considered the most toxic element to human life. It causes itai-itai, a bone disease similar to rickets, and cardiac enlargement, anemia, gonadal atrophy, kidney failure, and pulmonary emphysema. Pb is toxic and a major hazard to man and animals. Poisoning by lead causes

* E-mail: bahnasawymh@yahoo.com

anemia, encephalopathy, weight and coordination loss, abdominal pain, vomiting, constipation, and insomnia (Khallaf et al., 1998). Being nonbiodegradable like many organic pollutants, metals can be concentrated along the food chain, producing their toxic effects at points often far away from the source of the pollution (Fernandez et al., 2000). Accumulation of heavy metals in the food web can occur either by accumulation from the surrounding medium, such as water or sediment, or by bioaccumulation from the food source (Tulonen et al., 2006). Aquatic organisms have been widely used in biological monitoring and assessment of safe environmental levels of heavy metals.

Lake Manzala, the largest lake in the northern region of Egypt and the most productive for fisheries, is about 52,611 ha in surface area. The lake receives heavy loads of organic and inorganic pollutants via several agricultural drains (Badawy et al., 1995). Due to the toxicity of heavy metals, accurate information about their concentration in aquatic ecosystems is needed (Janssen et al., 2000). Therefore, the objective of this study was to evaluate the pollution level of Lake Manzala by determining the accumulation of Cu, Zn, Cd, and Pb in the water, plankton, and some tissues of the endemic fish *Liza aurata*.

Materials and methods

A map of Lake Manzala showing the sampling sites is presented in the Figure. The lake is bounded by the Mediterranean Sea to the north, the Suez Canal to the east, and the Damietta branch of the Nile to the west. The lake formerly had a brackish environment, which

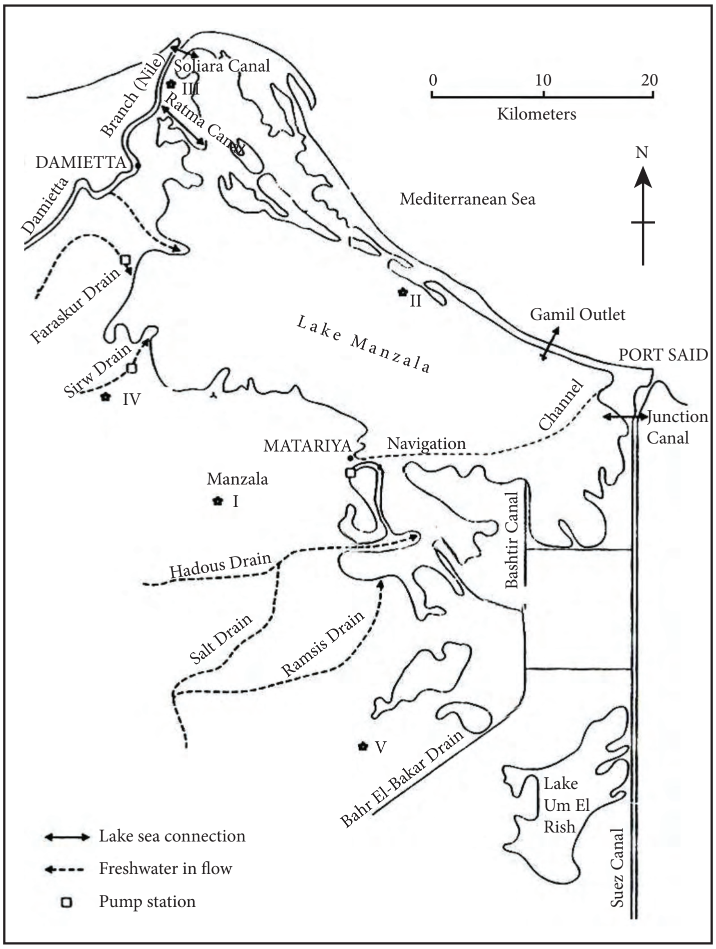

Figure. Location of sampling sites (*) in Lake Manzala: El-Manzala (I), El-Diba (II), El-Ratama (III), El-Sirw (IV), and Bahr El-Bakar (V).

changed to a eutrophic freshwater basin due to the increased amounts of agricultural drainage water and sewage discharged into it via 7 major drains (Abdel-Baky et al., 1998). Water, plankton, and mugilid fish (*Liza aurata*, n = 160 fish) samples were collected from 5 different locations of Lake Manzala (Figure) during 4 seasons, from the winter of 2001 to the autumn of 2002. The locations were chosen so as to represent different degrees of pollution. Water samples were collected monthly from a depth of 50 cm in 2 polyethylene bottles, acidified with nitric acid, and kept for analysis. Plankton (zoo- and phytoplankton) samples were collected with the aid of a plankton net (mesh size: 55 µm) through vertical hauls from the upper layer of 10 cm. Filtered plankton samples were acidified with HCl and kept for analysis. Parts of gills, skin, and dorsal muscle were taken from each fish, weighed, put in small Erlenmeyer flasks, dried in an oven at 105 °C for about 24 h, and acid-digested by nitric acid and perchloric acid (2:1) on a hotplate until the solution became clear. Cu, Zn, Cd and Pb concentrations in the water were determined by the extraction method (APHA, 1998) using an atomic absorption spectrophotometer (AAS, Perkin Elmer 2380). Plankton and fish samples were prepared for heavy metal analysis according to the method described by Kalay et al. (1999). Two-way ANOVA was employed to find the significant differences of heavy metal concentrations in water, plankton, and fish organs with regard to sites and seasons (Bailey, 1982). The significance was set at 0.05.

Results and discussion

The mean concentration of Cu, Zn, Cd, and Pb in the water samples collected from Lake Manzala are shown in Table 1. The mean concentration of the

Table 1. Seasonal and sampling site variations of heavy metal concentrations (mg/L) in the water of Lake Manzala (mean ± standard deviation).

Elements	Site	Seasons					ANOVA			
		Winter	Spring	Summer	Autumn	Mean	Factor	df	F-value	Sig.
Cu	I	0.038 ± 0.002	0.051 ± 0.042	0.061 ± 0.02	0.040 ± 0	0.048 ± 0.031				
	II	0.009 ± 0	0.028 ± 0.004	0.031 ± 0.013	0.016 ± 0.029	0.021 ± 0.009	Site	4	16.096	0
	III	0.025 ± 0.003	0.040 ± 0.004	0.055 ± 0.009	0.038 ± 0.007	0.040 ± 0.004	Season	3	14.288	0
	IV	0.032 ± 0.002	0.065 ± 0.002	0.083 ± 0.004	0.049 ± 0.004	0.057 ± 0.004	Site × Season	12	13.479	0
	V	0.053 ± 0.009	0.111 ± 0.002	0.192 ± 0.002	0.088 ± 0.02	0.111 ± 0.007				
	Mean	0.031 ± 0.003	0.059 ± 0.011	0.084 ± 0.010	0.046 ± 0.012	0.055 ± 0.011				
Zn	I	0.177 ± 0.221	0.370 ± 0.136	0.472 ± 0.179	0.246 ± 0.112	0.316 ± 0.154				
	II	0.139 ± 0	0.281 ± 0.058	0.301 ± 0.065	0.198 ± 0.009	0.230 ± 0.031	Site	4	2.421	0.064
	III	0.181 ± 0.013	0.310 ± 0.161	0.372 ± 0.013	0.226 ± 0.114	0.272 ± 0.058	Season	3	3.156	0.035
	IV	0.198 ± 0.047	0.382 ± 0.036	0.493 ± 0.147	0.288 ± 0.042	0.340 ± 0.257	Site × Season	12	2.726	0.009
	V	0.232 ± 0.226	0.470 ± 0.087	0.529 ± 0.183	0.352 ± 0.031	0.396 ± 0.143				
	Mean	0.185 ± 0.101	0.363 ± 0.096	0.433 ± 0.117	0.262 ± 0.062	0.311 ± 0.129				
Cd	I	0.018 ± 0.002	0.021 ± 0.018	0.025 ± 0.002	0.014 ± 0.025	0.020 ± 0.004				
	II	N.D.	0.015 ± 0.031	0.019 ± 0.007	0.011 ± 0.02	0.011 ± 0.007	Site	4	12.854	0
	III	0.009 ± 0.011	0.018 ± 0.002	0.022 ± 0.007	0.014 ± 0.011	0.016 ± 0.011	Season	3	4.607	0.007
	IV	0.016 ± 0.007	0.026 ± 0.002	0.031 ± 0.007	0.021 ± 0.009	0.024 ± 0.004	Site × Season	12	5.614	0
	V	0.021 ± 0.011	0.031 ± 0.009	0.038 ± 0.002	0.027 ± 0.009	0.029 ± 0.009				
	Mean	0.016 ± 0.008	0.022 ± 0.012	0.027 ± 0.005	0.017 ± 0.015	0.020 ± 0.007				
Pb	I	0.006 ± 0.002	0.026 ± 0.011	0.034 ± 0.002	0.011 ± 0.002	0.019 ± 0.007				
	II	N.D.	0.011 ± 0.007	0.017 ± 0.002	0.006 ± 0.002	0.009 ± 0.002	Site	4	11.707	0
	III	N.D.	0.017 ± 0.016	0.029 ± 0.007	0.008 ± 0.002	0.014 ± 0.007	Season	3	4.601	0.007
	IV	0.008 ± 0.004	0.032 ± 0.007	0.054 ± 0.011	0.020 ± 0.007	0.029 ± 0.007	Site × Season	12	10.943	0
	V	0.012 ± 0.007	0.046 ± 0.002	0.074 ± 0.018	0.029 ± 0.002	0.040 ± 0.004				
	Mean	0.009 ± 0.004	0.026 ± 0.009	0.042 ± 0.008	0.015 ± 0.003	0.022 ± 0.005				

N.D.: not detected (<0.001)

measured metals in water was found to be in the following order, in mg/L: Cd (0.020) < Pb (0.022) < Cu (0.055) < Zn (0.311). This order of occurrence agrees with the previous studies performed on Lake Manzala (Abdel-Baky et al., 1998; Ibrahim et al., 1999a). Generally, all of the metals had a higher concentration at site V. This region receives huge quantities of sewage and industrial wastes, as well as agricultural drainage water via the Bahr Al-Bakar drain. Badawy and Wahaab (1997) reported that water in the Bahr Al-Bakar region is not suitable for human use. It was found that this site is rich in organic carbon (Dheina, 2007), and many authors found a correlation between the concentration of heavy metals in the water and the abundance of organic matter (Radwan et al., 1990a; Abdel-Baky et al., 1998). Site II appeared to be the cleanest region of the lake, as it contained the lowest levels of the investigated metals. This site probably did not receive many pollutants from agricultural, industrial, and sewage drains. The level of metals exhibited seasonal fluctuations. The highest levels in the water were found during summer, while the lowest values occurred during winter. These seasonal variations may be due to the fluctuation of the amount of agricultural drainage water, sewage effluents, and industrial wastes discharged into the lake (Zyadah, 1995). Ali and Abdel-Satar (2005) attributed the increase of metal concentrations in the water during hot seasons (spring and summer) to the release of heavy metals from the sediment to the overlying water under the effect of both high temperature and a fermentation process resulting from the decomposition of organic matter. The seasonal variations of metals in water have been reported by different authors for different bodies of water: El-Safy and Al-Ghannam (1996), Abdel-Baky et al. (1998), and Ibrahim et al.(1999a) for Lake Manzala, and Hamed (1998) for the Nile River. Comparing the previous studies of Lake Manzala, Abdel-Hamid and El-Zareef (1996) found lower Cu concentrations (0.01-0.02 mg/L); El-Safy and Al-Ghannam (1996) obtained lower Cd levels but higher Pb levels; Abdel-Baky et al. (1998) recorded higher values of Cu, Zn, Cd, and Pb (0.08, 7.94, 0.11, and 0.64 mg/L, respectively); and Ibrahim et al. (1999a) found a higher value of Pb (0.09 mg/L) but lower levels of Cu, Zn, and Cd (0.03, 0.23, and 0.005 mg/L, respectively) than in the present study. Compared with other lakes, the Cu, Zn, Cd, and Pb levels of Lake Manzala are higher than those of Lake Piaseczno in Poland (0.015, 0.058, 0.001, and 0.018 mg/L, respectively) (Radwan et al., 1990a), while Lake Lapland in Finland had higher Zn levels (1.84 mg/L) (Mannio et al., 1995) and Lake Dominic in Poland had higher Cu levels (3.93 mg/L) (Szymanowska et al., 1999). Also, higher concentrations of Cd (0.11 mg/L) and Pb (0.086 mg/L) were found in Lake Beyşehir in Turkey (Altındağ and Yiğit, 2005), and higher Cu, Cd, and Pb levels (0.14, 0.04, 0.03 mg/L, respectively) were found in Lake Uluabat in Turkey (Elmaci et al., 2007).

According to the US EPA (1986), Cu, Zn, and Pb levels in Lake Manzala are within the permissible limit recommended for drinking and irrigation purposes, while Cd was found in higher concentrations than those recommended.

Assessment of heavy metal concentrations in plankton is very important because plankton is often the main diet for many predators and may remarkably contribute to the transfer of heavy metals to higher trophic levels. The mean concentrations of heavy metals in plankton are shown in Table 2. The results indicated that Cu, Zn, Cd, and Pb concentrations of plankton were much higher than those of water. This may be related to the large surface of plankton organisms (phyto- and zooplankton) in relation to their mass unit, and their active metabolism leading to rapid adsorption of various pollutants (Ravera, 2001). Ravera (2001) added that some algal species protect themselves by trapping and accumulating pollutants (e.g. metals) in their polysaccharide walls. The order of abundance of metals in plankton was Zn > Cu > Pb > Cd. This corresponds to the same order of abundance of these metals in water, which supports the hypothesis that water is an important source of plankton contamination. Elmaci et al. (2007) reported that the quantity of heavy metals in plankton depends on their concentration in water and partially on sediment. Plankton metal contamination did not show differences between sites, except for Pb, which attained a higher concentration at site V. The water of that site also had the highest concentration of this metal. The concentration of heavy metals in plankton has been reported to depend upon several factors, such as the productivity of the body of water, the physicochemical properties of the water, quantitative and qualitative

Table 2. Seasonal and sampling site variations of heavy metal concentrations (µg/g dry weight) in plankton from Lake Manzala (mean ± standard deviation).

Elements	Site	Seasons					ANOVA			
		Winter	Spring	Summer	Autumn	Mean	Factor	df	F-value	Sig.
Cu	I	88.430 ± 13.830	111.430 ± 25.160	118.860 ± 23.050	96.340 ± 15.370	103.760 ± 18.180				
	II	48.570 ± 21.230	69.440 ± 8.780	75.480 ± 31.840	59.910 ± 20.670	63.350 ± 25.360	Site	4	2.315	0.74
	III	71.890 ± 8.100	84.860 ± 23.050	93.830 ± 23.500	78.000 ± 15.370	82.140 ± 20.050	Season	3	1.142	0.344
	IV	90.570 ± 23.060	115.750 ± 20.490	135.720 ± 30.460	104.000 ± 30.740	111.510 ± 17.200	Site × Season	12	2.166	0.034
	V	108.760 ± 34.890	136.620 ± 39.110	154.430 ± 41.510	126.000 ± 32.120	131.450 ± 49.640				
	Mean	81.644 ± 20.222	103.620 ± 23.318	115.664 ± 30.072	92.850 ± 22.854	98.442 ± 26.086				
Zn	I	406.420 ± 140.220	537.720 ± 71.710	549.090 ± 97.020	462.180 ± 89.950	488.850 ± 168.740				
	II	248.540 ± 126.800	358.040 ± 64.740	380.150 ± 92.860	267.190 ± 185.200	313.480 ± 115.400	Site	4	1.557	0.204
	III	251.640 ± 104.860	428.960 ± 177.860	460.650 ± 125.260	390.410 ± 52.360	382.910 ± 124.150	Season	3	2.386	0.083
	IV	430.670 ± 74.050	610.280 ± 174.540	695.730 ± 216.230	520.140 ± 110.890	564.210 ± 77.180	Site × Season	12	2.048	0.045
	V	490.850 ± 66.650	620.280 ± 144.180	737.650 ± 91.970	560.460 ± 48.940	602.310 ± 91.080				
	Mean	365.624 ± 102.516	511.056 ± 126.606	564.654 ± 124.668	440.076 ± 97.468	470.352 ± 115.310				
Cd	I	20.170 ± 1.620	27.000 ± 6.450	32.000 ± 8.940	25.670 ± 8.600	26.210 ± 9.400				
	II	14.290 ± 7.750	21.280 ± 2.450	25.340 ± 7.750	17.760 ± 3.270	19.670 ± 9.970	Site	4	2.065	0.104
	III	18.610 ± 5.090	26.000 ± 6.450	30.430 ± 6.580	22.670 ± 9.660	24.430 ± 9.540	Season	3	2.350	0.087
	IV	24.820 ± 12.910	33.220 ± 2.860	36.670 ± 8.600	29.470 ± 8.940	31.040 ± 11.220	Site × Season	12	2.947	0.005
	V	27.380 ± 7.920	39.970 ± 6.000	46.000 ± 12.910	31.270 ± 8.600	36.150 ± 9.800				
	Mean	21.054 ± 7.058	29.494 ± 4.842	34.088 ± 8.956	25.368 ± 7.814	27.500 ± 9.986				
Pb	I	56.750 ± 13.450	79.130 ± 33.620	91.130 ± 33.620	69.530 ± 22.410	74.130 ± 16.630				
	II	44.750 ± 13.450	61.210 ± 28.870	72.050 ± 15.930	55.310 ± 18.280	58.330 ± 47.010	Site	4	3.644	0.013
	III	51.300 ± 2.040	74.780 ± 27.500	83.720 ± 22.460	67.450 ± 24.820	69.310 ± 24.510	Season	3	0.961	0.421
	IV	77.130 ± 33.620	109.300 ± 34.350	118.450 ± 51.640	91.170 ± 44.830	99.010 ± 27.270	Site × Season	12	0.628	0.806
	V	95.690 ± 25.180	132.830 ± 43.050	149.130 ± 33.620	118.530 ± 53.930	124.040 ± 31.460				
	Mean	65.124 ± 17.548	91.450 ± 33.478	102.896 ± 31.454	80.398 ± 32.854	84.964 ± 29.376				

species composition of zoo- and phytoplankton, the capacity of heavy metal absorbance, and the season (Kerrison et al., 1998; Radwan et al., 1990b; Elmaci et al., 2007). Compared with results of other studies, small plankton and macrozooplankton from American lakes accumulated lower levels of Cu, Zn, Cd, and Pb (Chen et al., 2000). Plankton from lakes in southern Finland showed higher levels of Cu but lower levels of Cd, Zn, and Pb (Tulonen et al., 2006). Compared with this study, Elmaci et al. (2007) recorded enormously higher concentrations of Cu, Zn, Cd, and Pb (6820.0, 20,290.0, 1450.0, and 580.0 µg/g dry weight, respectively).

Heavy metal concentrations in the muscle, skin, and gills of *Liza aurata* are shown in Tables 3-6. The order of metal concentration in the fish organs was Zn > Cu > Pb > Cd. The higher levels of Zn and Cu can be attributed to their biological role in normal metabolism and the growth of plankton and fish, which cause them to have an active uptake and storage. There were significant differences between sites, seasons, and fish organs. The highest concentrations of Cu, Zn, Cd, and Pb were found in tissues of fish from site V. The water of this site contained the highest levels of the measured metals. This is in agreement with the findings of Shakweer (1998), who concluded that the concentration of trace metals in various organs of fish reflects the degree of water pollution in the aquatic environments in which such fish are living. Ravera (2001) reported that if an environment receives foreign pollutants (e.g. metals), the organisms living in it could take up the pollutants from the water or/and food and concentrate it in their bodies. The order of metal contamination in the fish organs was as follow: gills > skin > muscles. Gills accumulated the highest level of Zn (47.41-136.17), followed by Cu (10.51-16.52), Pb (6.44-10.94), and Cd (2.33-6.06), all measured in µg/g dry weight. The high content of metals in gill tissues can be attributed to the fact that fish gills play a distinct

Table 3. Seasonal and sampling site variations of copper concentrations (μg/g dry weight) in different organs of *Liza aurata* from Lake Manzala (mean ± standard deviation).

Organ	**Site**	**Seasons**					**ANOVA**			
		Winter	Spring	Summer	Autumn	Mean	Factor	df	F-value	Sig.
Gills	I	11.520 ± 0.610	12.340 ± 0.770	13.850 ± 1.250	13.620 ± 0.280	12.830 ± 1.230	Site	4	80.467	0
	II	10.510 ± 1.010	11.660 ± 1.180	12.770 ± 0.800	12.580 ± 0.540	11.880 ± 1.240	Season	3	48.159	0
	III	11.820 ± 0.580	12.820 ± 1.030	13.250 ± 0.700	12.660 ± 0.840	12.640 ± 0.910	Organ	2	3565.515	0
	IV	11.830 ± 0.810	14.370 ± 1.810	14.420 ± 2.890	13.220 ± 0.670	13.460 ± 1.970	Site × Season	12	1.325	0.204
	V	14.220 ± 0.830	16.510 ± 1.290	16.520 ± 2.320	14.680 ± 1.440	15.480 ± 1.790	Site × Organ	8	7.986	0
Skin	I	7.780 ± 0.080	7.870 ± 0.150	8.940 ± 0.310	8.870 ± 0.190	8.370 ± 0.590	Season × Organ	6	4.024	0.001
	II	6.730 ± 0.080	6.820 ± 0.200	7.930 ± 0.420	7.340 ± 0.120	7.200 ± 0.540				
	III	6.740 ± 0.570	7.860 ± 0.230	8.920 ± 0.530	7.840 ± 0.540	7.840 ± 0.910	Site			
	IV	7.830 ± 0.150	8.920 ± 0.200	8.960 ± 0.290	8.860 ± 0.070	8.640 ± 0.510	×			
	V	8.960 ± 0.210	9.210 ± 0.280	9.710 ± 0.490	9.590 ± 0.450	9.370 ± 0.460	Season			
Muscles	I	3.430 ± 0.250	3.960 ± 0.240	4.700 ± 0.230	3.880 ± 0.220	3.990 ± 0.510	×			
	II	3.610 ± 0.480	3.810 ± 0.110	4.030 ± 0.260	3.550 ± 0.140	3.750 ± 0.330	Organ	24	1.555	0.052
	III	3.460 ± 0.210	3.990 ± 0.340	4.150 ± 0.190	4.110 ± 0.210	3.930 ± 0.360				
	IV	3.990 ± 0.300	4.570 ± 0.120	4.740 ± 0.410	4.520 ± 0.180	4.460 ± 0.380				
	V	4.000 ± 0.270	4.930 ± 0.320	5.490 ± 0.150	5.430 ± 0.280	4.960 ± 0.660				

Table 4. Seasonal and sampling site variations of zinc concentrations (μg/g dry weight) in different organs of *Liza aurata* from Lake Manzala (mean ± standard deviation).

Organ	**Site**	**Seasons**					**ANOVA**			
		Winter	Spring	Summer	Autumn	Mean	Factor	df	F-value	Sig.
Gills	I	52.720 ± 5.620	75.360 ± 2.970	86.250 ± 2.980	68.460 ± 4.100	70.700 ± 13.030	Site	4	748.475	0
	II	47.410 ± 2.910	66.740 ± 3.490	74.660 ± 2.710	59.260 ± 3.170	62.020 ± 10.680	Season	3	1091.732	0
	III	52.640 ± 3.110	74.450 ± 2.940	81.730 ± 3.200	67.290 ± 4.460	69.030 ± 11.480	Organ	2	9358.979	0
	IV	64.350 ± 3.530	91.580 ± 2.410	103.470 ± 2.470	79.630 ± 2.370	84.760 ± 15.070	Site × Season	12	21.840	0
	V	67.210 ± 3.630	101.360 ± 3.810	136.170 ± 4.260	94.460 ± 3.010	99.800 ± 25.440	Site × Organ	8	53.910	0
Skin	I	35.310 ± 3.820	54.350 ± 2.490	60.280 ± 2.510	46.980 ± 1.030	49.230 ± 9.860	Season × Organ	6	132.850	0
	II	30.630 ± 3.700	42.700 ± 2.430	51.340 ± 2.590	39.370 ± 2.460	41.010 ± 8.040				
	III	33.720 ± 2.250	54.660 ± 2.920	65.630 ± 3.230	41.460 ± 2.780	48.870 ± 12.820	Site			
	IV	41.420 ± 2.690	62.560 ± 2.430	78.240 ± 3.490	52.260 ± 2.730	58.620 ± 14.140	×			
	V	47.520 ± 2.530	72.460 ± 2.810	85.380 ± 3.170	61.360 ± 3.620	66.680 ± 14.590	Season			
Muscles	I	15.500 ± 1.520	19.660 ± 2.020	24.060 ± 1.870	18.340 ± 2.860	19.390 ± 3.720	×			
	II	12.460 ± 1.610	18.070 ± 1.480	17.460 ± 1.490	14.270 ± 1.860	15.570 ± 2.790	Organ	24	9.000	0
	III	12.980 ± 2.360	19.680 ± 2.250	21.290 ± 2.540	16.760 ± 2.080	17.680 ± 3.880				
	IV	19.410 ± 2.470	27.760 ± 2.420	29.780 ± 2.320	22.440 ± 2.270	24.850 ± 4.760				
	V	25.380 ± 3.190	30.240 ± 1.850	35.450 ± 3.340	27.640 ± 2.300	29.680 ± 4.600				

Table 5. Seasonal and sampling site variations of cadmium concentrations (µg/g dry weight) in different organs of *Liza aurata* from Lake Manzala (mean ± standard deviation).

Organ	Site	Seasons					ANOVA			
		Winter	Spring	Summer	Autumn	Mean	Factor	df	F-value	Sig.
Gills	I	3.350 ± 0.590	3.620 ± 0.820	4.190 ± 0.470	2.920 ± 0.700	3.520 ± 0.770	Site	4	67.547	0
	II	2.630 ± 0.520	3.360 ± 0.550	3.400 ± 0.310	2.330 ± 1.170	2.930 ± 0.810	Season	3	34.024	0
	III	3.170 ± 0.370	3.970 ± 0.450	4.170 ± 0.400	3.290 ± 0.260	3.650 ± 0.560	Organ	2	1152.758	0
	IV	4.180 ± 0.720	5.090 ± 0.830	5.420 ± 0.840	4.380 ± 0.330	4.770 ± 0.830	Site × Season	12	0.691	0.759
	V	4.570 ± 0.740	5.280 ± 0.620	6.060 ± 1.160	4.850 ± 1.230	5.190 ± 1.060	Site × Organ	8	19.836	0
Skin	I	1.620 ± 0.120	2.140 ± 0.090	2.210 ± 0.110	1.770 ± 0.160	1.940 ± 0.280	Season × Organ	6	7.364	0
	II	1.590 ± 0.070	1.730 ± 0.090	1.720 ± 0.090	1.640 ± 0.200	1.670 ± 0.130				
	III	1.520 ± 0.070	2.170 ± 0.090	1.870 ± 0.150	1.680 ± 0.140	1.810 ± 0.270	Site			
	IV	1.670 ± 0.090	2.280 ± 0.320	2.340 ± 0.090	1.970 ± 0.130	2.070 ± 0.320	×			
	V	2.070 ± 0.410	2.560 ± 0.270	2.760 ± 0.130	2.520 ± 0.270	2.480 ± 0.370	Season			
Muscles	I	0.970 ± 0.370	1.060 ± 0.210	1.390 ± 0.150	1.110 ± 0.070	1.130 ± 0.270	×			
	II	0.810 ± 0.120	0.970 ± 0.060	1.140 ± 0.080	1.070 ± 0.100	1.000 ± 0.150	Organ	24	0.411	0.994
	III	0.960 ± 0.120	1.130 ± 0.060	1.230 ± 0.070	1.110 ± 0.070	1.110 ± 0.130				
	IV	1.190 ± 0.150	1.260 ± 0.060	1.420 ± 0.090	1.170 ± 0.100	1.260 ± 0.140				
	V	1.270 ± 0.090	1.340 ± 0.060	1.610 ± 0.160	1.230 ± 0.090	1.370 ± 0.180				

Table 6. Seasonal and sampling site variations of lead concentrations (µg/g dry weight) in different organs of *Liza aurata* from Lake Manzala (mean ± standard deviation).

Organ	Site	Seasons					ANOVA			
		Winter	Spring	Summer	Autumn	Mean	Factor	df	F-value	Sig.
Gills	I	7.140 ± 0.760	8.720 ± 0.420	9.320 ± 0.680	8.480 ± 0.590	8.420 ± 1.000	Site	4	104.379	0
	II	6.440 ± 0.670	7.020 ± 0.490	7.660 ± 0.560	6.480 ± 0.570	6.900 ± 0.730	Season	3	40.010	0
	III	6.940 ± 0.470	7.880 ± 0.540	8.320 ± 0.740	7.360 ± 0.630	7.630 ± 0.770	Organ	2	5872.010	0
	IV	8.120 ± 0.700	9.460 ± 0.650	9.840 ± 0.670	9.080 ± 0.740	9.130 ± 0.910	Site × Season	12	0.504	0.911
	V	9.460 ± 0.680	10.280 ± 0.350	10.940 ± 0.670	10.380 ± 0.580	10.270 ± 0.760	Site × Organ	8	34.132	0
Skin	I	2.440 ± 0.310	2.780 ± 0.380	2.950 ± 0.310	2.620 ± 0.620	2.700 ± 0.440	Season × Organ	6	9.482	0
	II	2.340 ± 0.240	2.490 ± 0.530	2.630 ± 0.370	2.410 ± 0.380	2.470 ± 0.370				
	III	2.420 ± 0.340	2.610 ± 0.360	2.860 ± 0.320	2.530 ± 0.350	2.610 ± 0.350	Site			
	IV	2.620 ± 0.360	2.860 ± 0.350	3.070 ± 0.310	2.720 ± 0.430	2.820 ± 0.380	×			
	V	2.750 ± 0.310	3.070 ± 0.430	3.270 ± 0.380	2.810 ± 0.370	2.980 ± 0.410	Season			
Muscles	I	1.720 ± 0.370	1.900 ± 0.390	2.110 ± 0.300	1.920 ± 0.220	1.910 ± 0.330	×			
	II	1.410 ± 0.200	1.620 ± 0.520	1.750 ± 0.180	1.540 ± 0.190	1.580 ± 0.310	Organ	24	0.464	0.986
	III	1.540 ± 0.300	1.820 ± 0.400	1.940 ± 0.350	1.750 ± 0.280	1.760 ± 0.340				
	IV	1.970 ± 0.480	2.160 ± 0.360	2.370 ± 0.370	2.130 ± 0.320	2.160 ± 0.380				
	V	2.190 ± 0.460	2.470 ± 0.230	2.660 ± 0.360	2.420 ± 0.430	2.440 ± 0.390				

role in metal uptake from the environment. Due to their respiratory function, gills are in direct contact with the contaminated medium (water), and have the thinnest epithelium of all of the organs (Kotze et al., 1999).

These results are in agreement with the many authors who have reported that gills have a high tendency to accumulate heavy metals (Ünlü et al., 1996; Kotze et al., 1999; Wong et al., 2001; Coetzee et al., 2002; Altındağ and Yiğit, 2005). Gills in the present study showed higher concentrations of Cu, Zn, Cd, and Pb than those of *Mugil cephalus* from the northeastern Mediterranean Sea (Canlı and Atlı, 2003). Following the gills, the skin accumulated lower concentrations of the metals. The skin tissues, together with the gill tissues, are characterized by a mucus layer on the outer surface. The presence of this mucus influences the diffusion of water pollutants across the fish epidermis, acting as an effective barrier (Varanasi and Markey, 1978; Yılmaz, 2003). There are few studies about the metal content of fish skin, although it could be a consumed part of the fish. Compared with this study, skin of *Mugil cephalus* from İskenderun Bay (Turkey) accumulated higher levels of Pb and Zn (Yılmaz, 2005). Muscles retained the lowest concentration of the measured metals. This finding was in agreement with the observations of many authors who have shown that fish muscles have a low tendency to accumulate the heavy metals to which they are exposed (Blasco et al., 1998; Canlı et al., 1998; Ibrahim et al., 1999a; Canlı and Atlı, 2003; Karadede et al., 2004; Yılmaz, 2005). According to the National Health Medical Research Council (NHMRC) (cited by Ibrahim et al., 1999b), in light of the recommended permissible limits of heavy metals in fish tissue for human consumption, it would be declared that the muscle of *Liza aurata* in the present study is considered safe for human consumption. Metal concentrations in fish organs exhibited seasonal variations in which all of the detected metals attained their highest levels during summer, while the lowest values were found during winter. These seasonal variations were more or less similar to the fluctuation in the surrounding environment as a result of the increase or decrease of drainage water discharged into the lake (Abdel-Baky et al., 1998). Compared with other studies, *Liza aurata* from the middle eastern coast of Tunisia accumulated higher levels of Cu (4.78 µg/g dry weight) and Zn (45.0 µg/g dry weight) but lower levels of Cd (0.07 µg/g dry weight) in its muscles (Hamza-Chaffai et al., 1996). Enormously higher concentrations of Cu and Zn (23.16 and 27.26 µg/g wet weight, respectively) were found in the muscle of *Liza abu* from the Tigris River in Turkey (Ünlü et al., 1996), as compared with this study. Blasco et al. (1998) also measured a remarkably high concentration of Cu and Zn in the muscle of *Liza aurata* from Cadiz Bay, Spain. Higher levels of Cu, Zn, Cd, and Pb were also detected in the muscle of *Liza ramada* from Lake Manzala (Ibrahim et al., 1999a) and from the Damietta Nile estuary (Ibrahim et al., 1999b). Higher concentrations of Zn (37.39 µg/g dry weight), Pb (5.32 µg/g dry weight), and Cu (4.41 µg/g dry weight), but lower concentrations of Cd (0.66 µg/g dry weight) were recorded in the muscle of *Mugil cephalus* from the northeastern Mediterranean Sea (Canlı and Atlı, 2003) than in *Liza aurata* from this study.

Conclusion

Lake Manzala is a very important lake in Egypt due to its dimensions and economic activity. The results of the present study clearly demonstrate that Lake Manzala is highly contaminated with Cu, Zn, Cd, and Pb due to the continuous discharge of different pollutants into it. Metal contamination in water, plankton, and fish organs followed the order of Zn > Cu > Pb > Cd. The Cd in the water was found in higher concentrations than the reference values for drinking and irrigation purposes. Furthermore, metal concentrations in plankton were much higher than those in water. The order of metal contamination in fish organs was as follow: gills > skin > muscles. The highest metal concentrations were found in fish tissues from the most contaminated site, showing that metal accumulation in *Liza aurata* reflects the degree of water pollution. The results of this study supplied valuable information on the level of metal contamination in Lake Manzala. Great efforts and cooperation between different authorities are needed to protect the lake from pollution and reduce environmental risk. This can be achieved by treatment of the agricultural, industrial, and sewage discharge. Regular evaluation of pollutants in the lake is also very important.

References

Abdel-Baky, T.E., Hagras, A.E., Hassan, S.H. and Zyadah, M.A. 1998. Environmental impact assessment of pollution in Lake Manzalah, 1-Distribution of some heavy metals in water and sediment. J. Egypt. Ger. Soc. Zool. 26: 25-38.

Abdelhamid, A.M. and El-Zareef, A.A.M. 1996. Further studies of the pollution status on the southern region of El-Manzalah Lake. In: Proceedings of the Conference on Food Borne Contamination and Egyptian's Health, Mansoura, November 26-27, pp. 141-150.

Ali, M.H. and Abdel-Satar, A.M. 2005. Studies of some heavy metals in water, sediment, fish and fish diets in some fish farms in El-Fayoum province, Egypt. J. Aquat. Res. 31: 261-273.

Altındağ, A. and Yiğit, S. 2005. Assessment of heavy metal concentrations in the food web of lake Beyşehir, Turkey. Chemosphere 60: 552-556.

APHA. 1998. Standard methods for the examination of water and wastewater, 20th edition. American Public Health Association, Baltimore.

Badawy, M.I. and Wahaab, R.A. 1997. Environmental impact of some chemical pollutants on Lake Manzala. International Journal of Environmental Health Research 7: 161-170.

Badawy, M.I., Wahaab, R.A. and Abou Waly, H.F. 1995. Petroleum and chlorinated hydrocarbons in water from Lake Manzala and associated canals. Bull. Environ. Contam. Toxicol. 55: 258-263.

Bailey, N. 1982. Statistical methods in biology, 2nd ed. John Wiley, New York.

Blasco, J., Rubio, J.A., Forja, J., Gomezparra, A. and Establier, R. 1998. Heavy metals in some fishes of the Mugilidae family from salt ponds of Cadiz Bay, Spain. Ecotoxicology and Environmental Restoration 1: 71-77.

Canlı, M. and Atlı, G. 2003. The relationships between heavy metal (Cd, Cr, Cu, Fe, Pb, and Zn) levels and the size of six Mediterranean fish species. Environmental Pollution 121: 129-136.

Canlı, M., Ay, Ö. and Kalay, M. 1998. Levels of heavy metals (Cd, Pb, Cu, Cr and Ni) in tissues of *Cyprinus carpio*, *Barbus capito* and *Chondrostoma regium* from the Seyhan River, Turkey. Turk. J. Zool. 22: 149-157.

Chen, C.Y., Stemberger, R.S., Klaue, B., Blum, J.D., Pickhardt, P.C. and Folt, C.L. 2000. Accumulation of heavy metals in food web components across a gradient of lakes. Limnol. Oceanogr. 45: 1525-1536.

Coetzee, L., du Preez, H.H. and van Vuren, J.H. 2002. Metal concentrations in *Clarias gariepinus* and *Labeo umbratus* from the Olifant and Klein Olifants River, Mpumalanga, South Africa: Zinc, copper, manganese, lead, chromium, nickel, aluminium and iron. Water SA 28: 433-448.

Dheina, N.A. 2007. Biological and ecological studies on some species of family Mugilidae from different habitats in relation to their parasitic fauna. Ph.D. Dissertation. Damietta Faculty of Science, Mansoura University, Egypt.

Elmacı, A., Teksoy, A., Olcay Topaç, F., Özengin, N., Kurtoğlu, S. and Savaş Başkaya, H. 2007. Assessment of heavy metals in Lake Uluabat, Turkey. Afr. J. Biotech. 6: 2236-2244.

El-Safy, M.K. and Al-Ghannam, M.L. 1996. Studies on some heavy metal pollutants in fish of El-Manzala Lake. In: Proceedings of the Conference on Food Borne Contamination and Egyptian s Health, Mansoura November 26-27, pp. 151-180.

Fernandez, M., Cuesta, S., Jimene, O., Garcia, M.A., Hernandez, L.M., Marina, M.L. and Gonzalez, M.J. 2000. Organochlorine and heavy metal residues in the water/sediment system of the Southeast Regional Park in Madrid, Spain. Chemosphere 41: 801-812.

Hamed, M.A. 1998. Distribution of trace metals in the River Nile ecosystem, Damietta branch between Mansoura city and Damietta province. J. Egypt. Ger. Soc. Zool. 27: 399-415.

Hamza-Chaffai, A., Romeo, M. and El-Abed, A. 1996. Heavy metals in different fishes from the middle eastern coast of Tunisia. Bull. Environ. Contam. Toxicol. 56: 766-773.

Ibrahim, A.M., Bahnasawy, M.H., Mansy, S.E. and El-Fayomy, R.I. 1999a. Heavy metal accumulation in water, sediment and some fishes in Lake Manzala, Egypt. J. Egypt. Ger. Soc. Zool. 29: 43-58.

Ibrahim, A.M., Bahnasawy, M.H., Mansy S.E. and El-Fayomy, R.I. 1999b. Distribution of heavy metals in the Damietta Nile Estuary ecosystem. Egypt. J. Aquat. Biol. & Fish. 3: 369-397.

Janssen, C.R., De Schamphelaere, K., Heijerick, D., Muyssen, B., Lock, K., Bossuyt, B., Vangheluwe, M. and Van Sprang, P. 2000. Uncertainties in the environmental risk assessment of metals. Hum. Ecol. Risk. Assess. 6: 1003-1018.

Kalay, M., Ay, Ö. and Canlı, M. 1999. Heavy metal concentrations in fish tissues from the northeast Mediterranean Sea. Bull. Environ. Contam. Toxicol. 63: 673-681.

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. Environment International 30: 183-188.

Kerrison, P.H., Annonsi, D., Zerini, S., Ravera, O. and Moss, B. 1998. Effects of low concentrations of heavy metals on plankton community dynamics in a small, shallow, fertile lake. J. Plankton Res. 10: 779-812.

Khallaf, E.A., Galal, M. and Authman, M. 1998. Assessment of heavy metals pollution and their effects on *Oreochromis niloticus* in aquatic drainage canals. J. Egypt. Ger. Soc. Zool. 26: 39-74.

Kotze, P., du Preez, H.H. and van Vuren, J.H. 1999. Bioaccumulation of copper and zinc in *Oreochromis mossambicus* and *Clarias gariepinus*, from the Olifants River, Mpumalanga, South Africa. Water SA 25: 99-110

Mannio, J., Jarvien, O., Tuominen, R. and Verta, M. 1995. Survey of trace elements in lake waters of Finnish Lapland using the ICP-MS technique. Sci. Total Environ. 160-161: 433-439.

Mason, C. 1991. Biology of freshwater pollution. Longman Scientific and Technical, Harlow, England.

Radwan, S., Kowalik, W. and Kornijow, R. 1990a. Accumulation of heavy metals in a lake ecosystem. The Science of the Total Environment 96: 121-129.

Radwan, S., Kowalik, W. and Kowalczyk, C. 1990b. Occurrence of heavy metals in water, phytoplankton and zooplankton of mesotrophic lake in eastern Poland. The Science of the Total Environment 96: 115-120.

Ravera, O. 2001. Monitoring of the aquatic environment by species accumulator of pollutants: a review. J. Limnol. 60: 63-78.

Shakweer, L.M. 1998. Concentration levels of some trace metals in *Oreochromis niloticus* at highly and less polluted areas of Mariut Lake. J. Egypt. Ger. Soc. Zool. 25: 125-144.

Stephen, C., Jewett, A. and Sathy Naidu, A. 2000. Assessment of heavy metals in red king crabs following offshore placer gold mining. Mar. Pollut. Bull. 40: 478-490.

Szymanowska, A., Samecka-Symerman, A. and Kampers, A.J.1999. Heavy metals in three lakes in west Poland. Ecotoxicol. Environ. Safety 43: 21-29.

Tarvainen,T., Lahermo, P. and Mannio, J.1997. Source of trace metals in streams and headwater lakes in Finland. Water, Air, Soil Pollut. 94: 1-32.

Tulonen, T., Pihlstrom, M., Arvola, L. and Rask, M. 2006. Concentrations of heavy metals in food web components of small, boreal lakes. Boreal Environ. Res. 11: 185-194.

US EPA.1986. United States Environmental Protection Agency. Quality criteria for water. EPA 440 15-86-001. May 1986.

Ünlü, E., Akba, O., Sevim, S. and Gümgüm, B. 1996. Heavy metal levels in mullet, *Liza abu* (Heckel, 1843) (Mugilidae) from the Tigris River, Turkey. Fresenius Environ. Bull. 5: 107-112.

Varanasi, U. and Markey, Y.D. 1978. Uptake and release of lead and cadmium in skin and mucus of coho salmon (*Oncorhynchus kisutch*). Comp. Biochem. Physiol. 60: 187-191.

Wong, C.K., Wong, P.P.K. and Chu, L.M. 2001. Heavy metal concentrations in marine fishes collected from fish culture sites in Hong Kong. Arch. Environ. Contam. Toxicol. 40: 60-69.

Yılmaz, A.B. 2003. Levels of heavy metals (Fe, Cu, Ni, Cr, Pb and Zn) in tissue of *Mugil cephalus* and *Trachurus mediterraneus* from Iskenderun Bay, Turkey. Environ. Res. 92: 277-281.

Yılmaz, A.B. 2005. Comparison of heavy metal levels of grey mullet (*Mugil cephalus*) and sea bream (*Sparus aurata*) caught in İskenderun Bay (Turkey). Turk. J. Vet. Anim. Sci. 29: 257-262.

Zyadah, M. 1995. Environmental impact assessment of pollution in Lake Manzalah and its effect on fishes. Ph.D. Dissertation, Zoology Department, Faculty of Science, Mansoura University, Egypt, 127 pp.