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

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ABSTRACT

The levels of some heavy metals (Cu, Zn, Cd, Pb) were determined in water, plankton and fish (*Liza aurata*) collected from five sites in Lake Manzala. Metals in water and fish exhibited a significant seasonal and regional variations in which all metals attained their maximum values during summer, while the lowest level was reported during winter. The accumulation of different metals in water, plankton and fish tissues followed the order Zn> Cu> Pb> Cd. The mean concentrations of the tested metals in water were: Cu (0.055), Zn (0.311), Cd (0.020) and Pb (0.022) mg/l. Cd level in water was found to be higher than the permissible limit recommended for drinking water. Metals in plankton were much higher than those in water and fish. Gills of the examined fish contained the highest concentrations of all the measured metals, while muscles retained the lowest levels. In spite of the contamination of Lake Manzala by such heavy metals, the levels of these metals in the edible fish muscle did not exceed the recommended permissible limits and thus are 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 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 are toxic to living organisms even at quite low concentrations, whereas others are biologically essential as natural constituents of aquatic ecosystem and only become toxic at very high concentrations.

Heavy metals may affect organisms directly by accumulating in the body or indirectly by transferring to the next trophic level of the food chain. Being non-biodegradable like many organic pollutants, they can be concentrated along the food chain, producing their toxic effects at points often far away from the source of 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 is one of the large lakes in northern region of Egypt (about 52611 hectares surface area) and the most productive for fisheries. 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 ecosystem is needed (Janssen *et al.*, 2000). Therefore, the objective of this study was to evaluate the pollution level of Lake Manzala via determining the accumulation of Cu, Zn, Cd and Pb in water, plankton and some tissues of *Liza aurata.*

MATERIALS AND METHODS

Lake Manzala is bounded by the Mediterranean Sea to the north, the Suez canal to the east and Damietta branch of Nile to the west (Fig.1).

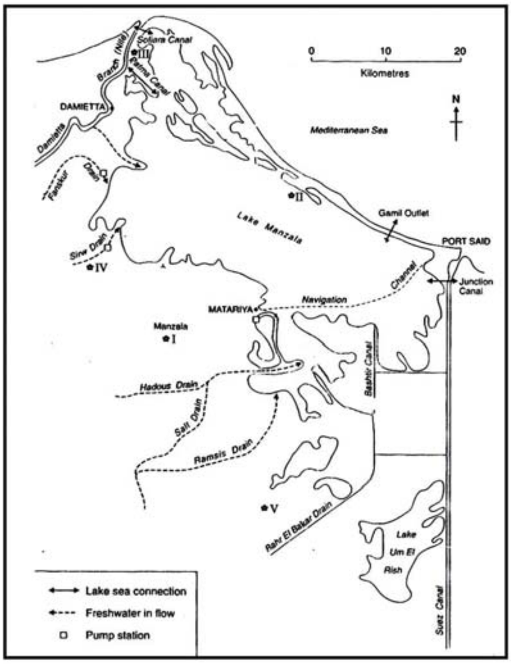

Figure (1): Location of sampling sites (*) in Lake Manzala; El-Manzala (I), El-Diba (II), El-Ratama (III), El-Sirw (IV) and Bahr El-Bakar (V)

The lake has gradually changed from a brackish environment to eutrophic freshwater basin due to the increased amounts of agricultural drainage water and sewage discharge into it via seven major drains (Abdel-Baky *et al.,* 1998). Water, plankton and fish (*Liza aurata*, mugilidae) samples were collected from five different locations in the Lake (Fig.1) during four seasons from winter 2001 to autumn 2002. The locations were chosen to represent different levels of pollution. Water samples were collected monthly from 50 cm depth in two liters polyethylene bottle acidified with nitric acid and kept for analysis. Plankton (zoo and phytoplankton) samples were collected with a plankton net of 55 µm mesh size, through vertical hauls from the upper 10cm layer. 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 ^{o}C for about 24 hours and digested by conc. Nitric acid and perchloric acid on a hotplate until the solution became clear.Cu, Zn, Cd and Pb concentrations in water were determined by extraction method (APHA,1998) using atomic absorption spectrophotometer. Plankton and fish samples were prepared for heavy metals analysis according to the method described by Kalay *et al*.(1999). Two-way ANOVA was employed to find the significant differences of heavy metals concentration in water, plankton and fish organs with regard to sites and seasons (Bailey, 1982).

RESULTS AND DISCUSSION

The mean concentrations of Cu, Zn, Cd, Pb in water samples collected from Lake Manzala are shown in Table 1. The mean concentrations of the tested metals in water were found in the following order: Cd (0.020)< Pb (0.022)< Cu(0.055)<Zn (0.311) mg/l. This order of occurrence agrees with the previous studies performed on Lake Manzala (Abdel-Baky *et al*., 1998; Ibrahim *et al.,* 1999). All the metals attained their maximum values at site V which receives huge quantities of sewage and industrial wastes, beside agricultural drainage water via Bahr Al-Bakar drain. Badaway and Wahaab (1997) reported that water in Bahr Al-Bakar region is not suitable for human use. It was found that this site is rich in organic carbon (Dheina, 2007) and some authors found a correlation between the concentration of heavy metals in water and the abundance of organic matter (Radwan *et al*.1990a; Abdel-Baky *et al*., 1998).Site II appeared to be the least polluted region of the lake as it contained the lowest levels of the investigated metals. Since it did not receive much of agricultural, industrial and sewage drains. The levels of metals exhibited seasonal fluctuations, where Cu, Cd, Pb showed significant differences between seasons. Their highest levels were found during summer, while their 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 (Zyada, 1995). Ali and Abdel-Satar (2005) attributed the increase of metals concentration in water during hot seasons (spring and summer) to the release of heavy metals from sediment to the overlying water under the effect of both high temperature and fermentation process due to decomposition of organic matter. The seasonal variations of metals in water were reported by different authors in different water dodies: El-Safy and Al-Ghannam (1996), Abdel-Baky *et al*.(1998), Ibrahim *et al*. (1999) in Lake Manzala, Hamed(1998) in River Nile. Compared with the previous studies of Lake Manzala, Abdel-Hamid and El-Zareef (1996) found lower values of Cu (0.01-0.02)mg/l, El-Safy and

Al-Ghannam (1996) obtained lower Cd but higher Pb, Abdel-Baky *et al.*(1998) recorded higher values of Cu (0.08), Zn (7.94), Cd (0.11), Pb (0.64) mg/l, Ibrahim *et al.*(1999) reported higher value of pb (0.09) but lower levels of Cu (0.03), Zn (0.23) and Cd (0.005) mg/l. Compared with other lakes, Cu, Zn, Cd, Pb in Lake Manzala are higher than those of Piaseczno Lake (Poland) (0.015, 0.058, 0.001, 0.018 mg/l respectively) (Radwan *et al*,1990a), Lapland Lake (Finland) had higher Zn (1.84 mg/l) (Mannio *et al*.,1995), Dominic Lake had higher Cu (3.93mg/l) (Szymanowska *et al*.,1999). Higher concentrations of Cd (0.11) and Pb (0.086) mg/l were found in Beysehir Lake, Turkey (Altindag and Yigit,2005). Uluabat Lake (Turkey) contained higher Cu (0.14), Cd (0.04), Pb (0.03) mg/l (Elmaci *et al*.,2007).

According to USEPA (1986) Cu, Zn, Pb levels in Lake Manzala were within the permissible limit recommended for drinking and irrigation purposes, while that of Cd was found higher than those recommended.

Studying of heavy metals 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 results (Table2) indicate that Cu, Zn, Cd, Pb concentrations in plankton were much higher than those of water. This may be related to the large surface of plankton organisms (phyto + zooplankton) in relation to their mass unit, and their active metabolism leading to rapid adsorption of various pollutants (Ravera, 2001). The latter author added that some algal species protect themselves by trapping and accumulating pollutants (e.g metals) in their polysaccharides wall. 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 support 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. All the metals in plankton attained their maximum values at site V, where its water had the highest concentrations of these metals. The accumulation of heavy metals in plankton has been reported to depend upon several factors, such as the productivity of water body, the physico-chemical properties of the water, quantitative and qualitative species composition of zoo and phytoplankton, capacity of heavy metals absorbance and season (Radwan *et al*., 1990b; Kerrison *et al*., 1998; Elmaci *et al*., 2007). There were no significant differences in metals in plankton between sites and seasons. Compared with other studies, small plankton and macro zooplankton from American lakes accumulated lower levels of Cu, Zn, Cd, Pb (Chen *et al*., 2000). Plankton from lakes in southern Finland showed higher level of Cu but lower levels of Cd, Zn, Pb (Tulonen *et al*., 2006). Elmaci *et al*. (2007) recorded enormously higher concentrations of Cu (6820.0), Zn (20290.0), Cd (1450.0), Pb (580.0) µg/g dry weight.

Heavy metals concentration in muscle, skin and gills of *Liza aurata* are shown in Tables (3-6). There were significant differences between sites, seasons and fish organs. The highest concentrations of Cu, Zn, Cd, Pb were found in tissues of fish from site V, where its water contained the highest levels of the measured metals. This agrees with Shakweer (1998) who concluded that the level of bioaccumulation of trace metals in various organs of fish reflects the degree of water pollution in aquatic environment in which such fish are living. Ravera (2001) reported that if an environment receives foreign pollutants the organism living in it will take up the pollutants from the water or/and food, and concentrate it in its body. The order of detection of metals in the fish organs was as follow: gills>skin>muscles. Gills accumulated the highest level of Zn (62.018-99.80), Cu (11.88-15.48), Pb (6.9-10.26) Cd (2.93-5.19), µg/g dry weight. The high content of metals in gill tissues can be attributed to the fact that fish gills play a distinct role in metal uptake from the environment. Due to its respiratory function, gills are in direct contact with the contaminated water and have the thinnest epithelium of all organs (Kotze *et al*., 1999). This result agrees with many authors who reported that gills have a high tendency to accumulate heavy metals (Unlu *et al*., 1996; Kotze *et al*., 1999; Wong *et al*., 2001; Coetzee *et al*., 2002; Altindag and Yigit, 2005). Compared with other studies, gills in the present study showed higher concentrations of Cu, Zn, Cd, Pb than those reported in *Mugil cephalus* from northeast Mediterranean Sea (Canli and Atli, 2003). Following the gills, the skin accumulated lesser concentrations of the metals. The skin tissue together with the gill tissues are characterized by a mucus layer on the outer surface. This can indicate them as excretion routes involving the slaughing off mucus from their surface (Varanci and Markey, 1978, Yilmaz 2003). Skin of *Mugil cephalus* from Iskenderun Bay (Turkey) accumulated higher levels of Pb and Zn (Yilmaz, 2005). Muscles retained the lowest concentrations of the measured metals. This finding confirms the observations of many authors who showed that fish muscles have low tendency to accumulate heavy metals to which they are exposed (Blasco *et al*., 1998, Canli *et al*., 1998, Ibrahim *et al*.,1999, Canli and Atli, 2003, Karaded *et al*.,2004, Yilmaz, 2005). In light of the recommended permissible limits of heavy metals in fish tissue for human consumption according to the National Health Medical Research Council (NHMRC) (cited from Ibrahim *et al*.,1999b), it can be declared that the muscles of *Liza aurata*, in the present study, are considered safe for human consumption. Metals concentrations in fish organs exhibited seasonal variations in which all the detected metals attained their highest levels during summer, while their lowest values were found during winter. These seasonal variations can be attributed to 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 in their muscle higher levels of Cu (4.78), Zn (45.0) but lower level of Cd (0.07) µg/g dry weight (Hamza-Chaffai *et al.,*1996). Enormously higher concentrations of Cu (23.16) and Zn (27.26) µg/g wet weight were found in muscle of *Liza abu* from Tigris River (Turkey) (Unlu *et al*., 1996). Blasco *et al*.(1998) measured a remarkably high concentration of Cu and Zn in muscle of *Liza aurata* from Cadiz Bay (Spain). Higher levels of Cu, Zn, Cd, Pb were detected also in muscles of *Liza ramada* from Lake Manzala and from Damietta Nile Estuary (Ibrahim *et al*., 1999a&b). Higher concentrations of Zn (37.39), Pb (5.32), Cu (4.41) but lower Cd (0.66) µg/g dry weight were recorded in muscle of *Mugil cephalus* from the north east Mediterranean Sea (Canli and Atli, 2003).

CONCLUSION

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. Great efforts and co-operation 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 discharges. Regular evaluation of pollutants in the lake is also very important.

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Table 1: Seasonal variations of heavy metals concentrations (mg/l) in water of Lake Manzala.

Elements	Site	Seasons					ANOVA			
		Winter	Spring	Summer	Autumn	Total	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 x 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				
	Total	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 x 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				
	Total	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 x 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				
	Total	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 x 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				
	Total	0.009 ± 0.004	0.026 ± 0.009	0.042 ± 0.008	0.015 ± 0.003	0.022 ± 0.005				

N.D. : not detected

Table 2: Seasonal variations of heavy metals concentrations (µg/g dry weight) in plankton from Lake Manzala.

Elements	Site	Seasons					ANOVA			
		Winter	Spring	Summer	Autumn	Total	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 x 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				
	Total	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 x 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				
	Total	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 x 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				
	Total	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 x 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				
	Total	65.124 ± 17.548	91.450 ± 33.478	102.896 ± 31.454	80.398 ± 32.854	84.964 ± 29.376				

Table.3: Seasonal variations of copper concentration ((µg/g dry weight) in different organs of Liza aurata from Lake Manzala.

Organ	Site	Seasons					ANOVA			
		Winter	Spring	Summer	Autumn	Total	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 x 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 x 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 x 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	x			
	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	x			
	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 variations of Zinc concentration (µg/g dry weight) in different organs of *Liza aurata* from Lake Manzala.

Organ	**Site**	**Seasons**					**ANOVA**			
		Winter	Spring	Summer	Autumn	Total	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 x 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 x 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 x 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	x			
	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	x			
	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 variations of cadmium concentration (μg/g dry weight) in different organs of *Liza aurata* from Lake Manzala.

Organ	Site	Seasons					ANOVA			
		Winter	Spring	Summer	Autumn	Total	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 x 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 x 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 x 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	x			
	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	x			
	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 variations of lead concentration (µg/g dry weight) in different organs of *Liza aurata* from Lake Manzala.

Organ	**Site**	**Seasons**					**ANOVA**			
		Winter	Spring	Summer	Autumn	Total	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 x 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 x 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 x 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	x			
	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	x			
	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				