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Ecotoxicological Studies. 3. Heavy metals contaminating water and fish from Fayoum Governorate, Egypt

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Abstract

The distribution of some heavy metals in water and fish from Fayoum Governorate (Egypt) was studied in samples collected throughout two successive years (1997/1998 and 1998/1999). Water from Lake Qarun, a private fish farm and "Sanhour River" was found to contain heavy metals at concentration levels lower than those found in fish from the first two ecosystems. The heavy metals showed differential bioaccumulation in fish organs (e.g. flesh, head, viscera), and the accumulation pattern (as total heavy metal residues) was seasonally as follows: summer > autumn > winter > spring. Moreover, the relative accumulation of total heavy metals in the studied fish showed the following pattern: "Mousa fish" (*Solea aegyptiaca*) < "Bolti fish" (*Tilapia* sp.) < the shrimp (*Penacus* sp.) < "Bouri fish" (*Mugil* sp.). Among the analyzed metals (e.g. zinc, iron, manganese, copper, cadmium, chromium, nickel, lead, cobalt, tin), lead and cadmium were found in fish at mean concentrations above the permissible limits proposed by FAO.

1. Introduction

The presence of metals in the environment is partially due to natural processes, such as volcanic activity and erosion, but is mostly the result of industrial wastes (PNUE, 1984). Contamination of aquatic ecosystems (e.g. lakes, rivers, streams, etc.) with metals has been receiving increased worldwide attention, and the literature has many publications on this (e.g. Bhattacharya & Sarkar, 1998; Davis & Bastian, 1990; Hakanson, 1984; Harms, 1975; Prat , Toja, Sola, Burgos, Plans, & Rieradevall, 1999; Wiener & Giesy, 1979).

Fish are often at the top of the aquatic food chain and may concentrate large amounts of some metals from the water. Accumulation patterns of contaminants in fish depend both on uptake and elimination rates (Hakanson, 1984). The presence of heavy metals in different foods constitutes serious health hazards, depending on their relative levels. For example, cadmium and mercury injure the kidney and cause symptoms of chronic toxicity, including impaired kidney function, poor reproductive capacity, hypertension, tumors and hepatic dysfunction (Luckey & Venu-gopal, 1977). Lead causes renal failure and liver damage (Emmerson, 1973; Luckey & Venugopal, 1977). Some other metals (e.g. chromium, zinc and copper) cause nephritis, anuria and extensive lesions in the kidney (Luckey & Venugopal, 1977). Therefore, the problem of food, (including fish), contamination by toxic metals is receiving global attention.

Studies in Egypt, conducted on fish samples collected from six Governorates, not including Fayoum, indicate the presence of some metals (e.g. lead, cadmium, chromium, zinc, copper, manganese and iron) in different fish organs (Gomaa, Abou-Arsb, Badawy, & Naguib, 1995). Imported sardine and mackerel fish were found to contain levels of lead and chromium higher than the permissible limits proposed by FAO (1983), whereas concentrations of other metals, such as cadmium, copper, iron, manganese and zinc were found below the permissible limits (Abou-Arab, Ayesh, Amra, & Naguib, 1996).

The Lake Qarun, in addition to a total of 70 private fish farms with a 40-acre surface area for the largest one, is considered as a fishery resource in Fayoum Governorate (Egypt). The lake is used as a general reservoir for agricultural wastewater drainage, as well as for the drainage of the fish farms. Taking into consideration that the lake is a closed basin, the accumulation of chemical pollutants is expected to increase annually in all its components (e.g. water, sediment and fish). Except for a limited study, which dealt with heavy

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metals in fish from the lake (Ibrahim, 1996), no further information is yet available.

Within the framework of a research project, funded by the Academy of Scientific Research and Technology (Egypt), on "Field Studies on Lake Qarun Pollution", the present study was carried out. This part of the study was undertaken to fill some existing gaps, such as: types and quantities of some heavy metals contaminating water and fish from different sources; distribution of heavy metals in different fish tissues; seasonal variation of metals in the fish, and the relative accumulation of metals in various kinds of fish, including shrimp.

2. Materials and methods

2.1. Sampling locations

Samples of water were obtained from Lake Qarun (ca. 226 km^2 area); a private fish farm (ca. 40-acre surface area); and "Sanhour River" which is used for irrigating agricultural lands adjacent to the lake. In total, 40 composite samples were seasonally collected from various locations across the lake during the period June 97–May 99, along with 24 from the fish farm. Another 12 composite samples were seasonally collected from the river during the period June 98–May 99.

Throughout the two successive years of study, fish samples were seasonally obtained from the lake and the fish farm (e.g. during July, October, January and April of each year; representing summer, autumn, winter & spring seasons, respectively).

2.2. Sampling procedures

A water sampler of 2 l capacity was used to collect surface water (e.g. 0–15 cm depth) from the concerned ecosystems. At each specified location and date, a number of collections were mixed together in a large vessel, then a representative subsample (ca. 5 l) was transferred into a polypropylene bottle.

Fish samples (e.g. "Bolti": *Tilapia* sp.; " Bouri": *Mugil* sp.; "Mousa": *Solea aegyptiaca*; and "Shrimp": *Penacus* sp.) were obtained from the lake. At the same time, the dominant kinds of fish in the fish farm (e.g. *Tilapia* and *Mugil* sps.) were sampled. At least 2 kg of each fish species were obtained at every sampling time and the samples were placed in ice boxes.

The collected samples were transferred quickly to the laboratory where they were kept at −20°C until analyzed within a few days of sampling.

2.3. Analysis of heavy metals

Stock standard solutions of zinc (Zn), iron (Fe), manganese (Mn), copper (Cu), cadmium (Cd), chromium (Cr), nickel (Ni), lead (Pb), cobalt (Co), and tin (Sn), were obtained from Merck in concentrations of 1000 mg/l (Merck, Darmstadt, Germany).

A Perkin-Elmer (2380) Atomic Absorption Spectrophotometer was employed for the analysis. The maximum absorbance was obtained by adjusting the cathode lamps at specific slits and wavelengths as shown in Table 1.

The samples analyzed were prepared by the method of the Association of Official Analytical Chemists (AOAC, 1995). In fish analyses, different body parts (e.g. flesh, head and viscera) were separated and processed individually. Shrimp was processed as flesh and non-edible part (head + crust).

The heavy metal analyses, either in water or fish, were recorded as means ± standard errors (S.E.) of triplicate measurements.

3. Results and discussion

Table 2 shows that waters of the studied ecosystems had different concentrations of the measured heavy metals. As mean values, such heavy metals were generally found at concentrations not exceeding 0.735 ppm for Cr in lake water; 0.018 ppm for Fe in fish farm water; and 0.520 ppm for Cu in irrigation water (Sanhour River). Irrigation water contained Zn, Fe, Cu, Cd, Pb, and Co of concentrations higher than those detected in water of the two other ecosystems, while the highest concentrations of Mn, Cr, Ni and Sn were recorded for the lake water.

In a 1-year study, Ibrahim (1996) took water samples only during winter and summer seasons from one location in Lake Qarun (e.g. near the outlet of the so called "Bats Drain"), and determined concentrations of heavy metals in these samples. Her results revealed the presence of the following heavy metals: Zn (0.47 ppm); Fe (2.38 ppm); Mn (0.06 ppm); Cu (0.08 ppm); Cd (0.04 ppm); Cr (0.24 ppm); and Pb (0.60 ppm). When comparing such results with

Table 1
Wavelengths and slit widths for determination of heavy metals

Metal	Wavelength (nm)	Slit width (nm)
Zinc (Zn)	319.9	0.7
Ferrous iron (Fe)	248.3	0.2
Manganese (Mn)	279.5	0.2
Copper (Cu)	324.8	0.7
Cadmium (Cd)	228.8	0.7
Chromium (Cr)	425.4	0.2
Nickel (Ni)	232.0	0.2
Lead (Pb)	217.0	0.7
Cobalt (Co)	240.7	0.2
Tin (Sn)	286.3	0.7

our findings, we have to take into consideration that the tabulated data (Table 2) broadly provide results covering the whole lake.

The occurrence of heavy metals in the studied ecosystems may be attributed to materials derived from geological sources and airborne deposits (Abernathy, Larson, & Mathews, 1984; Borg, 1987), as well as industrial and domestic wastes (PNUE, 1984). When such heavy metals enter an aquatic ecosystem, they change its water quality, they bind to the sediment and accumulate in the different components, causing adverse effects to the ecosystem and human health depending on

Table 2
Concentration of heavy metals in water samples collected from different ecosystems

Metal	Concentration (ppm)					
	Lake water[a]		Fish farm water[b]		Irrigation water[c]	
	Range	Mean±S.E.	Range	Mean±S.E.	Range	Mean±S.E.
Zn	0.005–0.043	0.027±0.004	0.008–0.185	0.037±0.02	0.03–0.042	0.041±0.002
Fe	0.231–1.24	0.519±0.12	0.066–1.25	0.318±0.14	0.398–0.778	0.602±0.08
Mn	0.042–0.782	0.246±0.11	0.036–0.258	0.101±0.03	0.309–0.324	0.311±0.004
Cu	0.047–0.294	0.152±0.03	0.012–0.320	0.062±0.04	0.451–0.574	0. 520±0.02
Cd	0.0–0.202	0.042±0.02	0.0–0.016	0.006±0.002	0.052–0.068	0.062±0.003
Cr	0.088–3.88	0.735±0.45	0.012–2.00	0.270±0.25	0.170–0.186	0.180±0.003
Ni	0.0–0.355	0.055±0.04	0.0–0.146	0.032±0.02	0.023–0.034	0.031±0.002
Pb	0.0–0.053	0.017±0.007	0.0–0.062	0.012±0.007	0.048–0.088	0.063±0.01
Co	0.0–0.041	0.018±0.007	0.0–0.027	0.003±0.003	0.0–0.046	0.032±0.01
Sn	0.0–0.017	0.002±0.002	0.0–0.008	0.001±0.001	0.0–0.005	0.001±0.001

[a] Total number of samples = 40 (collected during June 97–May 99).
[b] Total number of samples = 24 (collected during June 97–May 99).
[c] Total number of samples = 12 (collected during June 98–May 99).

Table 3
Concentrations of heavy metals in Bolti fish (*Tilapia* sp.) collected from Lake Qarun and fish farm[a]

Metal	Bolti (Lake)				Bolti (Farm)			
	Mean ppm in whole body ±S.E.	Distribution in different parts			Mean ppm in whole body ±S.E.	Distribution in different parts		
		Flesh %	Head %	Viscera %		Flesh %	Head %	Viscera %
Year 1997/1998								
Zn	9.35±4.39	15.2	49.7	35.1	24.6±9.14	33.7	36.8	29.5
Fe	63.9±46.7	15.4	16.5	68.1	258±129	8.3	10.5	81.2
Mn	63.5±59.5	0.6	3.7	95.7	70.2±52.7	2.9	7.0	90.1
Cu	1.72±0.82	16.6	28.7	54.7	3.89±0.51	40.4	20.3	39.3
Cd	0.42±0.37	38.0	20.0	42.0	0.25±0.23	38.4	20.4	41.2
Cr	1.20±0.94	30.8	50.5	18.7	2.62±1.44	25.9	48.8	25.3
Ni	3.12±2.85	11.3	43.6	45.1	3.02±3.00	12.7	42.8	44.5
Pb	7.25±7.08	22.8	58.1	19.1	10.6±6.41	60.2	3.8	36.0
Co	2.75±2.75	10.7	53.3	36.0	2.43±2.42	13.7	52.3	34.0
Sn	0.06±0.06	22.2	44.5	33.3	0.60±0.50	43.4	51.8	4.8
Total	153		376					
Year 1998/1999								
Zn	7.89±0.89	26.0	42.2	31.8	9.31±0.65	30.5	44.2	25.3
Fe	30.4±5.14	32.7	34.5	32.8	32.1±3.50	31.8	36.1	32.1
Mn	3.67±1.00	20.3	33.2	46.5	7.11±0.79	23.4	31.8	44.8
Cu	1.65±0.12	27.6	44.6	27.8	2.00±0.30	32.9	37.8	29.3
Cd	0.239±0.04	32.7	37.4	29.9	0.019±0.01	57.5	42.5	0.0
Cr	0.375±0.11	34.4	44.0	21.6	0.479±0.10	35.0	38.1	26.9
Ni	0.042±0.04	60.9	18.6	20.5	0.003±0.001	100.0	0.0	0.0
Pb	0.163±0.07	36.0	43.1	20.9	0.017±0.01	34.5	65.5	0.0
Co	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sn	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	44.5				51.0			

[a] Each value represents an average of four samples collected in July, October, January, and April of each year.

their relative levels (Brenner, Yodder, & Blair, 1995; Luckey & Venugopal, 1977).

Fish are often at the top of the aquatic food chain and may concentrate large amounts of some metals, such as lead, cadmium, chromium, copper, mercury, zinc and iron. These metals accumulate differentially in fish organs and cause serious health hazards to humans. For this reason, the problem of fish contamination by toxic metals has received much attention (e.g. Abou-Arab et al., 1996; Barak & Mason, 1990; Eisenberg & Topping, 1986; Gomaa et al., 1995; Harms, 1975; Hernandez, Medira, Ansuategui, & Lopeg, 1990; Ibrahim, 1996; Lowe, May, Brubangh, 1985; Luckas, 1987; Ramos, Decompose, & Olszyna, 1979; Wiener & Giesy, 1979).

The present study provides data about the contamination potential of fish from Fayoum Governorate (Egypt) by a number of heavy metals.

Table 3 shows concentrations of heavy metals in "Bolti" fish (*Tilapia* sp.) and their distribution in different parts of the fish body (e.g. flesh, head and viscera), either for the fish from Lake Qarun or the fish from the private farm. During the first year of study (1997/1998), all the measured metals, except Cd and Sn, were detected at concentrations higher than 1 ppm (i.e. 1 mg/kg body wt.). The concentrations of a metal, such as Fe, reached 63.9 ppm and 258 ppm, respectively, in lake and farm fish. Concentrations of Zn, Mn, Cu, Cr, Pb, and Sn were also higher in farm fish. The metals were differentially distributed in the different parts of the fish body, but the pattern of distribution of most metals (e.g. Zn, Fe, Mn, Cd, Cr, Ni, Co) was similar for lake and farm fishes. As an exception to such trends, lead (Pb) was mostly accumulated in head of the lake fish (ca. 58%) and in muscle (flesh) of the farm fish (ca. 60%).

As total heavy metal residues, the lake fish contained 153 ppm, corresponding to 376 ppm in the farm fish.

During the second year of study (1998/1999), there was a considerable decline in the concentrations of most heavy metals in *Tilapia* sp. fish (Table 3). As total heavy metal residues, the lake fish contained 44.5 ppm, corresponding to 51.0 ppm in the farm fish.

The "Bouri" fish (*Mugil* sp.), either from the lake or the farm, had higher concentrations of the measured metals (Table 4) compared to the aforementioned species. In this case, concentrations of metals, such as Zn and Fe, in farm fish were higher than those in the lake fish, either during the first or the second years of study. An opposite result was obtained for Pb.

Table 4
Concentrations of heavy metals in Bouri fish (*Mugil* sp.) collected from Lake Qarun and fish farm[a]

Metal	Bouri (Lake)				Bouri (Farm)			
	Mean ppm in whole body ±S.E.	Distribution in different parts			Mean ppm in whole body ±S.E.	Distribution in different parts		
		Flesh %	Head %	Viscera %		Flesh %	Head %	Viscera %
Year 1997/1998								
Zn	19.9±4.71	23.0	45.9	31.1	23.83±9.91	17.2	37.6	45.2
Fe	272±148	5.3	24.7	70.0	372±291	4.2	8.1	87.7
Mn	224±208	0.9	5.1	94.0	148±83.1	2.0	5.1	92.9
Cu	6.76±0.71	21.9	27.5	50.6	4.07±0.65	35.4	25.9	38.7
Cd	0.79±0.47	34.9	19.1	46.0	0.62±0.35	38.2	13.8	48.0
Cr	1.50±0.28	35.0	37.4	27.6	3.05±1.42	27.5	34.0	38.5
Ni	3.99±3.95	15.6	31.0	53.4	4.54±4.43	19.8	33.4	46.8
Pb	12.0±1.78	27.7	43.2	29.1	8.00±2.91	22.2	34.5	43.3
Co	1.69±1.47	13.9	20.1	66.0	2.02±1.67	13.6	24.1	62.3
Sn	0.47±0.33	45.4	8.5	46.1	0.21±0.21	47.0	32.0	21.0
Total	543		566					
Year 1998/1999								
Zn	12.0±0.69	32.2	42.2	25.6	13.8±2.00	38.6	39.0	22.4
Fe	37.0±2.00	31.6	39.5	28.9	39.6±2.26	36.1	38.3	25.6
Mn	3.64±0.54	22.6	40.5	36.9	4.25±0.50	21.4	33.0	45.6
Cu	4.71±0.78	44.2	28.0	27.8	5.72±0.82	44.3	30.7	25.0
Cd	0.659±0.05	68.4	30.6	1.0	0.019±0.01	60.6	39.4	0.0
Cr	1.19±0.10	35.3	36.7	28.0	0.602±0.10	39.8	39.2	21.0
Ni	0.011±0.01	100.0	0.0	0.0	0.012±0.01	63.3	21.7	15.0
Pb	1.33±0.27	41.7	41.0	17.3	0.030±0.01	43.1	47.5	9.4
Co	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sn	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	60.6				63.9			

[a] Each value represents an average of four samples collected in July, October, January, and April of each year.

Table 5
Concentrations of heavy metals in Mousa fish (*Solea aegyptiaca*) and shrimp (*Penacus* sp.) collected from Lake Qarun[a]

Metal	Mousa fish				Shrimp		
	Mean ppm in whole body ±S.E.	Distribution in different parts			Mean ppm in whole body ±S.E.	Distribution in different parts	
		Flesh %	Head %	Viscera %		Flesh %	Head and Crust %
Year 1997/1998							
Zn	48.7±22.3	14.8	77.8	7.4	19.9±4.50	60.6	39.4
Fe	27.0±9.15	12.3	81.5	6.2	186±92.7	64.9	35.1
Mn	20.6±4.73	27.7	58.3	14.0	11.0±3.52	52.0	48.0
Cu	0.29±0.15	55.2	13.8	31.0	7.72±2.25	73.6	26.4
Cd	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cr	0.18±0.12	100	0.0	0.0	1.86±0.74	64.5	35.5
Ni	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pb	24.3±8.65	68.2	0.0	31.8	4.98±0.34	100	0.0
Co	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sn	1.94±0.86	100	0.0	0.0	0.0	0.0	0.0
Total	123		232				
Year 1998/1999							
Zn	2.80±0.23	28.0	57.3	14.7	2.37±0.50	69.6	30.4
Fe	2.07±0.40	16.6	76.3	7.1	18.8±2.33	71.0	29.0
Mn	1.93±0.09	28.8	44.2	27.0	1.15±0.02	62.6	37.4
Cu	0.142±0.05	57.6	20.9	21.5	1.00±0.11	68.8	31.2
Cd	0.001±0.001	100	0.0	0.0	0.0	0.0	0.0
Cr	0.048±0.002	43.5	40.8	15.7	0.687±0.06	69.3	30.7
Ni	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pb	0.144±0.04	26.8	48.1	25.1	0.180±0.01	37.4	62.6
Co	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sn	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	7.1				24.2		

[a] Each value represents an average of four samples collected in July, October, January, and April of each year.

Table 6
An example demonstrating heavy metal concentrations[a] in fish[b] samples collected in different seasons during the year 1997/1998

Metal	Concentration (ppm)							
	Bolti fish (*Tilapia* sp.)				Bouri fish (*Mugil* sp.)			
	Summer 1997	Autumn 1997	Winter 1998	Spring 1998	Summer 1997	Autumn 1997	Winter 1998	Spring 1998
Zn	25.1	50.2	13.4	9.74	25.0	51.16	13.1	6.11
Fe	616	272	87.9	55.4	1243	135	82.5	26.7
Mn	228	17	22.8	12.8	359	202	25.7	4.26
Cu	4.09	5.2	3.06	3.16	4.58	2.92	5.65	3.11
Cd	0.97	0.0	0.024	0.024	1.17	0.0	1.28	0.035
Cr	6.13	3.82	0.318	0.228	6.55	4.08	1.32	0.243
Ni	12.1	0.0	0.0	0.0	17.8	0.0	0.188	0.126
Pb	16.4	26.0	0.14	0.0	8.35	14.2	9.23	0.196
Co	9.70	0.0	0.0	0.0	6.96	0.0	1.12	0.0
Sn	0.310	2.08	0.0	0.0	0.853	0.0	0.0	0.0

[a] Concentrations are expressed on whole fish body basis.
[b] The example is given on farm fish.

As total heavy metal residues, the lake fish contained 543 ppm, corresponding to 566 ppm in the farm fish, during the first year. These values declined to 60.6 and 63.9 ppm, respectively, during the second year.

Table 5 shows the results of heavy metal analyses for "Mousa" fish (*Solea aegyptiaca*) and the shrimp, *Penacus* sp. collected from Lake Qarun throughout the two successive years of study. These species are not cultured in the private fish farms. They seemed to be less contaminated by most of the measured metals than the above-mentioned fish. As total heavy metal residues, the *Solea* sp. fish contained 123 ppm during the first year, corresponding to 7.1 ppm during the second year of study. For the shrimp, *Penacus* sp., these values were 232 and 24.2 ppm, respectively. Furthermore, both organisms were highly polluted with lead (Pb), especially during the first year of study.

Generally, the results of heavy metal analyses in fish indicate that *Mugil* sp., either from the lake or the farm, had the tendency to accumulate higher levels of metals than *Tilapia* sp. The lowest levels of heavy metal contaminants were in *Solea* sp. On the other hand, the contamination levels declined in all kinds of fish collected in the second year of study (1998/1999). Studies indicate that fish accumulate metals from the water, and the accumulation pattern depends both on uptake and elimination rates (Hakanson, 1984). In their studies on cadmium, lead and copper levels in freshwater fish collected from rivers in the USA between 1979 and 1981, Lowe et al. (1985) reported changes in the concentrations of these metals from one year to another, which supports our findings.

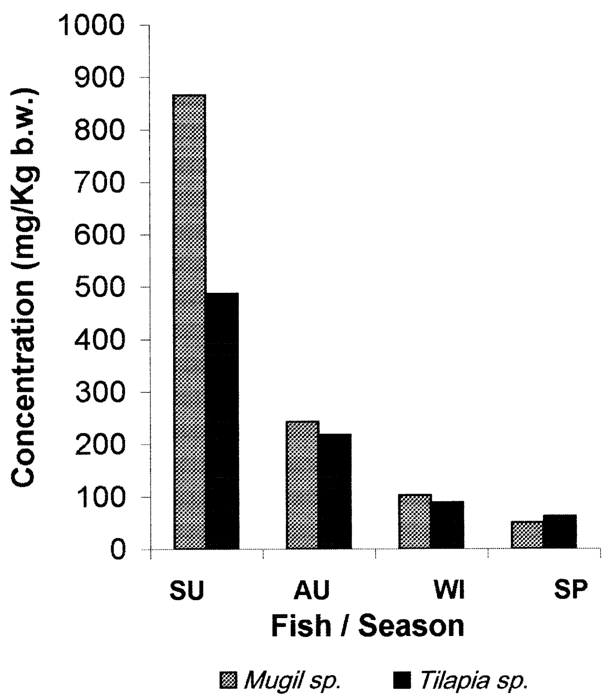

Fig. 1. Seasonal variation of total heavy metal concentrations in the farm fish. The values express general means for the results of 2 successive years. Seasons: SU, Summer; AU, Autumn; WI, Winter; SP, Spring.

Moreover, Table 6 demonstrates the seasonal variation of heavy metals in *Tilapia* and *Mugil* sps. fish from the farm, during the year 1997/1998. The maximum concentrations of metals such as Fe, Mn, Cr, Ni, and Co were reached in summer samples of both fish species, while the maximum concentrations of metals such as Zn and Pb were reached in autumn samples. The lowest concentrations of Zn, Fe, Mn, Cr, and Pb were with samples of the spring season.

The seasonal variation of heavy metals (as total values), based on the data of two successive years, revealed the following result: summer > autumn > winter > spring; fish samples collected from the fish farm (Fig. 1).

Tables 3–5 provide information about the distribution of heavy metals among different parts of the fish body (e.g. flesh, head and viscera). The present findings agree with previous investigators (e.g. Barak & Mason, 1990; Eisenberg & Topping, 1986; Gomaa et al., 1995; Halocombe, Benoit, Leanard, & McKinn, 1976; Hernandez et al., 1990; Ibrahim, 1996; Wiener & Giesy, 1979), who concluded that heavy metals accumulate differentially in fish organs.

In Egypt, as in other parts of the world, fish are liable to be contaminated by pollutants such as pesticides and heavy metals. Contamination levels can be compared to the permissible limits recommended by Food and Agriculture Organization (FAO). Accordingly, Table 7 shows the mean concentrations of some heavy metals in the different kinds of fish compared to the permissible limits of FAO (1983). All types of fish and shrimp were found to contain zinc, copper and tin below the recommended limits, which are 150 ppm for Zn, 10.0 ppm for Cu and 50.0 ppm for Sn. However, all of them contained lead at mean concentrations above the permissible limit (1.5 ppm; FAO, 1983). *Tilapia* sp. from Lake Qarun, *Mugil* sp. from the lake and the fish farm, respectively,

Table 7
Concentrations (ppm) of some heavy metals in the fish samples, collected from Fayoum Governorate, compared to the permissible limits[a]

Metal	*Tilapia* sp.		*Mugil* sp.		*Solea* sp.	*Penacus* sp.	Permissible limits (ppm)
	(L)	(F)	(L)	(F)	(L)	(L)	FAO (1983)
Zn	8.6	17.0	16.0	18.8	25.7	11.2	150
Cu	1.7	3.0	5.7	4.9	0.22	4.4	10.0
Cd	0.33*	0.13	0.73*	0.32*	0.001	0.0	0.2
Pb	3.7*	5.3*	6.6*	4.0*	12.2*	2.6*	1.5
Sn	0.03	0.30	0.24	0.11	1.0	0.0	50.0

[a] Each value is a general mean for the concentration level of the corresponding metal, based on results of 2 successive years. L, Lake fish; F, Farm fish. Values designated by asterisks are above the permissible limits.

contained 0.33, 0.73 and 0.32 ppm of cadmium, while *Tilapia* sp. from the fish farm, *Solea* sp. and *Penacus* sp. contained 0.13, 0.001 and 0.0 ppm, respectively. The permissible limit for cadmium is 0.20 ppm (FAO, 1983). Our results agree with Ibrahim (1996) who found that "Mousa" (*Solea* sp.) from Lake Qarun had cadmium levels below the permissible limits. The author mentioned that lead in this fish, as well as, cadmium and lead in "Bolti" (*Tilapia* sp.) and "Bouri" (*Mugil* sp.) from the lake, were detected at concentrations below the permissible limits, results which conflict with the findings of the present study. Ibrahim (1996) based her results on two composed samples (winter and summer), collected from Lake Qarun during a 1-year of study, whereas the results here were based on eight composite samples, representing different seasons, over two successive years.

In their studies on heavy metals in fish imported to Egypt, Abou-Arab et al. (1996) found that sardine and mackerel had higher levels of lead and chromium than the permissible limits proposed by FAO. However, other metals (e.g. cadmium, copper, iron, manganese and zinc) were found at levels lower than the proposed permissible limits.

As previously mentioned, the fish from the private farm seemed to have higher heavy metal contents than the fish from Lake Qarun. In an attempt to interpret such a difference, the fish feed commonly used in the private fish farms was analyzed. As shown in Table 8, the analyzed sample contained undetectable concentrations of tin, but high concentrations of the other tested metals. Therefore, the fish of such farms, unlike those of the lake, are being exposed to further (and direct) contaminating sources. On the other side, the fish farms in Fayoum Governorate are draining into the lake, which is a closed ecosystem. This in turn may be considered as one of the factors contributing to contamination in Lake Qarun, besides contamination from agricultural drainage water.

As shown in Table 9, the results of the present study are used to elucidate the accumulation patterns of heavy metals for the lake fish. In this respect, we used the *Solea* sp. fish as a reference to determine the "relative accumulation indices (R.A.I.)". Accordingly, a metal such as zinc had an index of 0.33, 0.62 and 0.43, respectively for *Tilapia* sp., *Mugil* sp., and *Penacus* sp. compared to *Solea* sp. which has an index of 1.0. A similar trend was obtained for the metal (lead) which appeared to be more accumulated in *Solea* sp. than in the other organisms. Other metals, such as iron, copper and chromium showed an opposite trend, whereas they have accumulation indices more than 1. For example, copper accumulated in *Tilapia* sp., *Mugil* sp., and *Penacus* sp., respectively, 7.68, 26.1, and 19.8 times more than in *Solea* sp. With respect to total heavy metal

Table 8
Concentrations of heavy metals in fish feed

Metal	Concentration (mg/kg; ppm)
Zinc	42.0
Iron	149
Manganese	37.7
Copper	22.5
Chromium	12.7
Cadmium	6.20
Nickel	10.6
Lead	7.15
Cobalt	6.85
Tin	ND

The analysis is conducted on a sample of fish feed commonly used in the private farms (composed of 30% dried fish powder + 70% bran). ND, Not detectable.

Table 9
Relative accumulation of heavy metals in Lake Qarun fishes (including the shrimp, *Penacus* sp.)

Metal	*Solea* sp.		*Tilapia* sp.		*Mugil* sp.		*Penacus* sp.	
	Concn.[a] (ppm)	R.A.I.[b] (× times)	Concn.[a] (ppm)	R.A.I.[b] (× times)	Concn.[a] (ppm)	R.A.I.[b] (× times)	Concn.[a] (ppm)	R.A.I.[b] (× times)
Zn	25.7	1.00	8.62	0.33	15.9	0.62	11.2	0.43
Fe	14.5	1.00	47.1	3.25	155	10.6	103	7.06
Mn	11.3	1.00	33.6	2.98	114	10.1	6.06	0.54
Cu	0.22	1.00	1.69	7.68	5.74	26.1	4.36	19.8
Cd	0.001	1.00	0.33	330	0.73	730	nd	nc
Cr	0.11	1.00	0.79	7.18	1.35	12.3	1.27	11.6
Ni	nd	nc	1.58	nc	2.00	nc	nd	nc
Pb	12.2	1.00	3.71	0.30	6.64	0.54	2.58	0.21
Co	nd	nc	1.38	nc	0.85	nc	nd	nc
Sn	0.97	1.00	0.03	0.03	0.24	0.25	nd	nc
Total	65.0	(1.0)	98.9	(1.5)	302	(4.6)	128	(2.0)

[a] Each value is a general mean for the concentration level of the corresponding metal, based on results of 2 successive years.
[b] Relative accumulation indices (R.A.I.) are results from dividing the other concentration values by the corresponding values of *Solea* sp. fish. nd, Not detectable; nc, Not calculated.

residues, the tested organisms showed the following accumulation indices: *Solea* sp. (1.0); *Tilapia* sp. (1.5); *Penacus* sp. (2.0); and *Mugil* sp. (4.6). This result may reflect the general capacity of these organisms to accumulate metals in their tissues.

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