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Recycling study of some heavy metals in the Egyptian aquatic ecosystem

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The effect of season and locality variation on the distribution of heavy metals in ecosystem components (fish, sediment and water) was studied. In fish, the highest mean concentrations of Pb (1·08), Cr (0·62), Cu (1·92), Mn (0·95) and Fe (13·77) were recorded in winter, Zn (8·36) in spring and Cd (1·06) in summer. The lowest concentrations for all metals were in autumn except for Cu and Cr (summer) and Pb (spring). In sediment samples, the highest concentrations (mg/kg wet weight) for Pb (2·7), Cr (0·4), Zn (4·9) and Cu (14) were in winter and autumn and for Cd (1·2), Mn (24·0) and Fe (47·0) in spring. The lowest concentrations for Pb (1·0) and Zn (3·4) were detected in spring, for Cu (0·4) in summer, and for Mn (2·0), Cr (0·0) and Fe (4·0) in autumn. In water the concentrations for Cd and Cu were highest in spring (0·3 and 0·5 mg/kg, respectively) and lowest concentrations were detected in autumn. The maximum concentrations for Zn (0·55) and Fe (0·8) were in autumn and winter and the lowest concentrations in summer. The maximum concentrations for Pb were 0·5 mg/kg in summer and 0·95 mg/kg in autumn. In the Red Sea, fish had the highest concentrations (mg/kg wet weight) of Pb (1·5), Cu (1·8), and Fe (13·8) and the lowest of Zn (1·8). The maximum concentrations of Cr (0·6), Zn (7·0) and Mn (0·5) and the minimum concentrations of Pb (0·4), Cd (0·06) and Fe (6·4) were in Alexandria. Manzala showed the highest concentration of Cd (1·6) and the lowest concentrations of Cr (36·0), Cu (0·80), and Mn (0·02). In sediment, the River Nile showed the maximum concentrations of Cr (0·4), Zn (7·6), Cu (1·0) and Mn (38·6). However, the Red Sea showed the maximum concentrations of Pb (1·9) and Cd (3·2) and the minimum concentrations of Cr (0·15), Zn (1·2), Mn (0·8), and Fe (11·1). The highest concentration of Fe (60) and the lowest concentration of Cu (0·30) were in Manzala. Alexandria showed the minimum concentrations of Pb (0·2) and Cd (0·01). In water, the highest concentrations of Cu (0·5), Mn (1·1), and Fe (0·07) and the lowest concentrations of Cr (0·4) were in the River Nile. The Red Sea showed maximum concentrations of Pb (0·5), Cd (0·3), and Cr (0·7), and the minimum concentration of Zn (0·2). The highest concentration of Zn (0·5) and the lowest concentrations of Pb (0·3), Cd (0·05) and Fe (0·5) were in Alexandria.

INTRODUCTION

Fish, water, and sediments may become contaminated with heavy metals such as mercury, Cd, Pb, Cr, Zn, and Cu. Some of these metals are toxic to virtually every system of the body and may cause serious health hazards to man depending on their levels of contamination (Emmerson, 1973; Luckey & Venugopal, 1977). The tendency of some metals such as Cd to concentrate in sediments may result in a persistent source of the contaminant in the aquatic environment (Fleisher *et al.*, 1974). Studies indicate that fish accumulate Cd from water through the food chain and so both modes of uptake can be toxic (USEPA, 1978).

Heavy metal pollution of river ecosystems has been reported by several authors (Forstner & Muller, 1974; Schroder & Furbish, 1978; Vinikour *et al.*, 1980; Van Hassel *et al.*, 1980). It has been suggested that certain metals are taken up by benthic organisms and bioconcentrated in the limbic food chain (Patrick & Loutit 1976; Spehar *et al.*, 1978; Chapman *et al.*, 1980). Since fish are often the last link in aquatic food chains, the metal concentrations of many fish species have been analysed in relation to metal contents of water (Yediler, 1978; Wilson & McUohon, 1981; Canton & Stooff, 1982), sediments (Muller & Prosi, 1978; Hakanson, 1984), and prey organisms such as benthic invertebrates (Patrick & Loutit, 1976; Wachs, 1982). It appears in most cases that the bioconcentration factors for heavy metals from water to fish tissues are several times lower than those from water to sediments or to prey organisms (Yediler, 1978; Van Hassel *et al.*, 1980; Wachs, 1982). Nevertheless, the concentration of metals in tissues of commercially used fish often exceed internationally or nationally agreed threshold levels for foodstuffs (Forstner & Muller, 1974).

One problem which often remains unresolved is to know the pathways by which metals are incorporated into the fish. Several authors have demonstrated that gills play an important, perhaps even dominant, role in metal uptake (Hughes & Flos, 1978; Part & Svanberg, 1981; Thomas *et al.*, 1983). This may be primarily true for the water-soluble fractions of metals.

However, in many natural river systems, metal pollution has led to an elevated contamination of particles and organisms on which fish species feed. In consequence it has been assumed that the uptake of heavy metals by the gut of fish may also be of importance (Muller & Prosi, 1978). The validity of this assumption has been proven on the basis of laboratory experiments by several authors (Aoyama *et al.*, 1978*a,b*; Patrick & Loultit, 1976; Knox *et al.*, 1982; Segner & Back, 1985). On the other hand, Dallinger and Kautzky (1985) exemplified model patterns for the transfer of Zn, Cu, Cd and Pb through the food chains of two rivers under study. Low-level, chronic exposure of water causes metal accumulation in sediments. From the sediment the metals may be transferred to water plants or directly to snails. The next step is represented by isopods or snails which feed on water plants or detritus. The transfer to the last link of the food chain is given by rainbow trout feeding on contaminated isopods and snails.

With regard to metal accumulation in marine organisms, Phillips (1980) reported that many factors affect the rate of accumulation, e.g. seasonal variation (temperature). Cd and Zn accumulations were found to be lowest during the warmer seasons (Barak & Mason, 1990). Weakly bound metals in soft organs (liver) may be more easily influenced by seasonal changes than are strongly bound metals in flesh. Various sources of contamination (water, sediments, and fish) are also effected; e.g. sediment may affect fish buried in mud during the winter season (Boyden, 1977).

The distribution of heavy metals among the major components of the aquatic ecosystem may be affected by sampling area (Koli *et al.*, 1978; PNUE, 1984). The Mediterranean is subject to heavy discharges of pollutants from numerous industrial processes, particularly on the Spanish and Italian shores, where there are high concentrations of factories. Among these industries are leather tanning, metallic transformation, oil refineries and petroleum terminals, and organic or inorganic chemical industries which might effect the concentrations of metals in the samples of this area (PNUE, 1984). On other hand, Koli *et al.* (1978) reported that salt water fish have more trace metal concentrations (Fe, Zn, Mn, Cd, and Cu) than freshwater fish.

The objective of this study was to determine the distribution of some heavy metals among the major components of the aquatic ecosystem (fish, water, and sediment) and to explore the effect of season and locality variation on such distribution.

MATERIALS AND METHODS

Sample collection

Fish, water, and sediment samples (142) were collected from four catching areas that represent four different models of the aquatic ecosystem in four different seasons (from summer 1990 to spring 1991). The first location was a selected site on the River Nile at Cairo (El-Malek El-Saleh) which represents an important catching area and a model of running fresh water. The second location was on Manzala lake which is a model of a lake environment surrounded by agricultural fields and drainage water. The third sampling location was Alexandria which represents the Mediterranean ecosystem. The fourth sampling location was Hourghada which represents the Red Sea ecosystem.

A total of 44 fish samples, 33 sediment samples, and 65 water samples were collected during the four different seasons and distributions of these samples were as follows:

Fish:	14 in spring, 7 in summer, 7 in autumn, and 16 in winter
	11 River Nile, 8 Manzala, 9 Alexandria, and 16 Red Sea
Sediment:	13 in spring, 10 in summer, I in autumn, and 9 in winter
	13 River Nile 9 Manzala, 6 Alexandria, and 5 Red Sea
Water:	15 in spring, 29 in summer, 2 in autumn, and 19 in winter
	14 River Nile, 11 Manzala, 25 Alexandria, and 15 Red Sea

Standards of heavy metals

Stock standard solutions of Pb, Cd, Cr, Zn, Cu, Mn, and Fe were obtained from Merck (Darmstadt, Germany) in concentrations of 1000 mg/litre.

Preparation of samples for analysis

Fish samples (flesh) were prepared using the method of AOAC (1980). The samples of water were prepared according to the Fishman and Downs (1966) method. Sediment samples were prepared using the Cottenie *et al.* (1982) method.

Sample determination

All the metals were determined in fish, sediment, and water extracts by using a Perkin-Elmer (2380) atomic absorption spectrophotometer.

Statistical analysis

To test the significance of the differences among the four seasons and the four locations for all the three ecosystem component samples (fish, sediment and water), the data were analysed using a one-way analysis of variance (ANOVA) according to the following model (Winer, 1971):

$$Y_{ij} = \mu + \alpha_i + \epsilon_{ij}$$

where Y_{ij} is the observation on element J under the effect of α_i; μ is the general population mean; α_i is the main effect of season (summer, autumn, winter, and spring), locality (River Nile, Manzala, Alexandria, and Red Sea), or matrix (fish, water, sediment); and ϵ_{ij} is the experimental error associated with measurement on element j. A general linear model of SAS (SAS, 1988) was used to perform the ANOVA. Duncan's multiple range test was used for means separation (Winer, 1971).

RESULTS AND DISCUSSION

Seasonal variation effect on the distribution of heavy metals in ecosystem components

To explore the recycling trend of the heavy metals under study during the four seasons of the year, the concentrations of the heavy metals in the ecosystem components (fish, sediment, and water) were statistically analysed regardless of the type of the ecosystem. Accordingly, significant differences ($P < 0.05$) were detected among seasons for Cu and Fe. No significant differences were observed among other metals. Duncan's test for mean separation indicated that winter samples contained higher concentrations of Cu than summer samples. With regard to Fe, the significantly lowest concentration was found in autumn samples, whereas no significant differences were detected between spring, winter and summer.

The non-significance of the variations among seasons for all metals except for Cu and Fe may be due to the wide variations among the ecosystem components. As a result, the seasonal variation effects were studied for each ecosystem component separately.

Seasonal variation effect on the distribution of heavy metals in fish samples

Mn and Fe (Tables 1 and 2) showed the highest levels (0·95 and 13·8 mg/kg, respectively) in winter, while the lowest levels (0·21 and 2·67 mg/kg, respectively) were detected in autumn. Winter samples showed the highest levels (0·62 and 1·92 mg/kg) for Cr and Cu, respectively, while the lowest levels (0·3 and 0·85 mg/kg, respectively) were observed in summer samples. Cd and Zn showed the minimum levels (0·12 and 3·72 mg/kg, respectively) in autumn, although the maximum level (1·06 mg/kg) for Cd was observed in summer, and the maximum level (8·36 mg/kg) for Zn was detected in spring. Pb showed the highest level (1·08 mg/g) in winter, whereas spring samples showed the lowest level (0·61 mg/kg).

Table 1. Effect of seasonal variation on the distribution of lead, cadmium, chromium, zinc, copper, manganese and iron in ecosystem components (fish, sediment and water)

Metal	Summer		Autumn		Winter		Spring	
	Range	Mean±SE	Range	Mean±SE	Range	Mean±SE	Range	Mean±SE
Fish (concentration in (mg/kg)								
Lead	0·49–1·16	0·70±0·09	0·26–2·70	1·04±0·32	0·06–4·65	1·08±0·36	0·21–1·55	0·61±0·08
Cadmium	0·05–6·04	1·06±0·84	0·03–0·30	0·12±0·04	0·01–1·88	0·25±0·12	0·03–6·04	0·55±0·42
Chromium	ND–0·58	0·30±0·08	0·17–0·68	0·35±0·06	0·12–1·29	0·62±0·09	ND–1·22	0·41±0·09
Zinc	0·29–9·13	6·59±0·89	2·58–4·71	3·72±0·32	1·64–20·9	7·43±1·42	ND–15·7	8·36±1·12
Copper	0·66–1·01	0·85±0·05	0·52–1·77	0·92±0·18	0·18–6·41	1·92±0·48	0·09–7·08	1·62±0·48
Manganese	0·17–0·69	0·43±0·08	0·11–0·28	0·21±0·02	0·09–2·24	0·95±0·16	0·08–1·04	0·35±0·08
Iron	3·98–33·3	13·2±3·83	0·12–4·78	2·67±0·61	2·16–47·0	13·8±3·98	1·08–17·83	8·61±1·21
Sediment (concentration in (mg/kg)								
Lead	0·6–4	1·40±0·3	2·70	2·70	0·10–10·0	1·50±1·1	ND–2	1·0±0·2
Cadmium	0·1–1	0·30±0·1	0·05	0·05	ND–0·10	0·02±0·01	ND–14	1·2±1·1
Chromium	ND–1	0·30±0·1	ND	ND	ND–1·00	0·40±0·1	0·1–1	0·3±0·1
Zinc	0·5–12	4·30±1·7	4	4	0·40–16·0	4·90±1·6	0·1–11	3·4±1·2
Copper	0·1–1	0·40±0·1	3	3	0·10–3·00	1·40±0·3	0·1–1	0·5±0·1
Manganese	0·4–0·41	20·4±5·0	2	2	0·30–49·0	21·10±6·0	0·1–78	24±5·8
Iron	5–57	39·8±6·1	4	4	4–44	30·40±4·3	12·0–89	47±7·5
Water (concentration in (mg/litre)								
Lead	ND–3	0·5±0·10	ND–0·1	0·05±0·01	ND–1·00	0·30±0·10	ND–1·00	0·2±0·1
Cadmium	ND–0·7	0·1±0·10	ND	ND	ND–0·10	0·10±0·10	ND–3·20	0·3±0·2
Chromium	ND–1	0·4±0·10	0·9–1	0·95±0·20	ND–1·00	0·60±0·10	ND–2·00	0·5±0·2
Zinc	ND–1	0·2±0·01	0·1–1	0·55±0·20	ND–3·00	0·50±0·20	ND–3·00	0·5±0·2
Copper	ND–1	0·2±0·03	0·1–0·1	0·10±0·02	0·10–1·00	0·20±0·02	ND–4·00	0·5±0·3
Manganese	ND–1	0·2±0·03	0·35–0·4	0·35±0·03	0·10–0·40	0·20±0·03	ND–13·00	1·1±0·8
Iron	ND–1	0·5±0·10	0·2–1	0·60±0·04	0·40–4·00	0·80±0·20	ND–1·00	0·6±0·1

Table 2· Maximum and minimum mean concentrations of tested metals in ecosystem components (fish, sediment, and water) during different seasons

Metal	Maximum Mean±SE	Season	Minimum Mean±SE	Season
Fish (concentration in mg/kg)				
Lead	1·08±0·36	Winter	0·61±0·08	Spring
Cadmium	1·06±0·84	Summer	0·12±0·04	Autumn
Chromium	0·62±0·09	Winter	0·30±0·08	Summer
Zinc	8·36±1·12	Spring	3·72±0·32	Autumn
Copper	1·92±0·48	Winter	0·85±0·05	Summer
Manganese	0·95±0·16	Winter	0·21±0·02	Autumn
Iron	13·8±3·98	Winter	2·67±0·61	Autumn
Sediment (concentration in mg/kg)				
Lead	2·70±1·10	Autumn	1·00±0·20	Spring
Cadmium	1·20±1·10	Spring	0·02±0·01	Winter
Chromium	0·40±0·10	Winter	0·00	Autumn
Zinc	4·90±1·60	Winter	3·40±1·20	Spring
Copper	3·00±0·30	Autumn	0·40±0·10	Summer
Manganese	24·0±5·80	Spring	2·00±0·15	Autumn
Iron	47·6±7·50	Spring	4·00±0·43	Autumn
Water (concentration in mg/litre)				
Lead	0·50±0·10	Summer	0·05±0·01	Autumn
Cadmium	0·30±0·20	Spring	ND	Autumn
Chromium	0·95±0·20	Autumn	0·40±0·10	Summer
Zinc	0·55±0·20	Autumn	0·20±0·01	Summer
Copper	0·50±0·30	Spring	0·10±0·02	Autumn
Manganese	1·10±0·80	Spring	0·20±0·03	Summer and Winter
Iron	0·80±0·20	Winter	0·50±0·10	Summer

Fish samples collected during the different seasons showed all metals at lowest concentration in autumn; the lowest concentrations of Cu and Cr were in summer, and of Pb were in spring. All metals were at highest concentration in winter except for Zn (spring), and Cd (summer). Similar trends were found by Barak and Mason (1990), who reported that accumulation was lowest during the warmer seasons, when Pb accumulation was fastest.

Seasonal variation effect on the distribution of heavy metals in sediment

Table 1 and 2 illustrate the concentrations of different heavy metals during the seasons of the year. However, it should be noted that, in autumn, only one sediment sample could be obtained; therefore, general inferences could not be made.

The maximum concentrations of Cd, Pb, Cu, Mn, and Fe were found in spring (1·2, 1·5, 0·5, 24·0, and 47·0 mg/kg, respectively), while Cr (0·4) and Zn (4·9 mg/kg) showed maximum concentrations in winter.

The minimum concentrations of Pb (1·0) and Zn (3·4 mg/kg) were detected in spring, of Cu (0·4) and Mn (20·4 mg/kg) in summer, of Cr (0·3 mg/kg) in spring and summer, and of Fe (30·4 mg/kg) in winter.

Seasonal variation effect on the distribution of heavy metals in water

Tables 1 and 2 show that Cd (0·3 mg/kg) and Cu (0·5 mg/kg) were detected at their highest concentrations in spring, whereas the lowest concentrations (ND and 0·1 mg/kg, respectively) were found in autumn. However, Zn (0·55 mg/kg) and Fe (0·8 mg/kg) showed their highest concentrations in autumn and winter and their minimum concentrations (0·2 and 0·5 mg/kg, respectively) were detected summer. Summer samples showed the highest concentration of Pb (0·5 mg/kg) but the lowest concentration of Cr (0·4 mg/kg). The maximum concentration of Cr (0·95 mg/kg) and minimum concentration of Pb (0·05 mg/kg) were detected in autumn. The maximum concentration of Mn (1·1 mg/kg) was recorded in spring while the minimum was in summer and winter (0·2 mg/kg).

Locality variation effect on the distribution of heavy metals in fish samples

Tables 3 and 4 show that Pb, Cu, and Fe are found at maximum levels in the Red Sea, which recorded 1·5, 1·8, and 13·3 mg/kg, respectively. This locality was found to have the maximum levels of Zn (1·8 mg/kg). However, Alexandria showed the maximum levels of Cr (0·6 mg/Kg), Zn (7·0 mg/kg) and Mn (0·5 mg/kg), whereas it showed the minimum levels of Pb (0·4), Cd (0·08) and Fe (6·4 mg/kg). On the other hand, Cd was found at the maximum level in Manzala, and this locality showed the lowest levels of Cr (0·36), Cu (0·8) and Mn (0·2 mg/kg).

Locality variation effect on the distribution of heavy metals in sediment samples

Concentrations of the tested metals among localities are given in Tables 3 and 4. The River Nile showed

Table 3. Effect of locality variation on the distribution of lead, cadmium, chromium, zinc, copper, manganese and iron in ecosystem components (fish, sediment and water)

Metal	Alexandria		Manzala		River Nile		Red Sea	
	Range	Mean±SE	Range	Mean±SE	Range	Mean±SE	Range	Mean±SE
Fish (concentration in mg/kg)								
Lead	0·06–1·00	0·40±0·10	0·30–0·60	0·50±0·04	0·06–1·16	0·50±0·10	0·50–4·70	1·50±0·30
Cadmium	0·01–0·45	0·08±0·04	0·03–6·04	1·60±0·90	0·02–1·00	0·20±0·10	0·05–1·90	0·30±0·10
Chromium	ND–1·30	0·61±0·20	0·17–0·44	0·36±0·03	ND–0·07	0·40±0·10	ND–1·22	0·50±0·10
Zinc	3·30–13·0	7·00±1·20	2·60–9·10	6·70±0·80	1·60–9·20	5·50±0·80	0·10–6·40	1·80±0·50
Copper	0·34–2·40	1·20±0·30	0·70–1·10	0·80±0·10	0·20–7·10	1·70±0·60	0·10–6·40	1·80±0·50
Manganese	0·90–1·00	0·50±0·10	0·10–0·30	0·20±0·03	0·03–0·70	0·40±0·10	0·01–2·20	0·50±0·20
Iron	1·10–15·40	6·40±1·80	1·50–17·80	9·00±2·40	2·80–33·3	10·8±2·60	2·00–47·0	13·3±4·00
Sediment (concentration in mg/kg)								
Lead	0·04–0·60	0·20±0·10	0·90–2·00	1·30±0·10	0·05–10·30	1·60±0·70	0·09–3·60	1·90±0·60
Cadmium	0·01–0·02	0·01±0·003	0·10–1·20	0·20±0·10	0·01–0·20	0·10±0·02	0·01–14·00	3·20±2·70
Chromium	0·05–0·44	0·17±0·06	0·21–0·67	0·39±0·05	0·03–1·10	0·40±0·08	ND–0·40	0·15±0·10
Zinc	0·10–6·20	1·40±0·90	0·70–11·00	2·40±1·10	0·65–15·50	7·6±1·40	0·40–4·00	1·20±0·70
Copper	0·70–1·70	0·90±0·20	0·10–0·60	0·30±0·10	1·00–2·90	1·00±0·20	0·07–3·10	0·90±0·60
Manganese	0·30–15·0	9·80±2·60	10·1–21·3	16·0±1·30	9·00–78·0	38·6±4·50	0·10–2·30	0·80±0·40
Iron	4·10 24·1	14·5±2·80	42·3 88·8	60·0±4·80	28·6–73·1	46·8±3·50	3·50–20·4	11·1±3·80
Water (concentration in mg/litre)								
Lead	ND–2·60	0·30±0·10	0·03–0·40	0·30±0·04	ND–1·10	0·40±0·10	0·04–1·10	0·50±0·10
Cadmium	ND–0·01	0·05±0·05	0·02–0·40	0·06±0·03	ND–0·08	0·10±0·06	ND–3·20	0·30±0·20
Chromium	ND–1·04	0·60±0·05	ND–1·20	0·40±0·10	ND–0·70	0·40±0·05	ND–1·80	0·70±0·20
Zinc	ND–3·00	0·50±0·20	0·08–0·50	0·30±0·04	0·03–1·30	0·30±0·10	ND–0·90	0·20±0·06
Copper	0·03–0·50	0·20±0·02	ND–0·20	0·08±0·02	0·06–4·40	0·50±0·30	0·04–1·90	0·50±0·10
Manganese	ND–1·00	0·20±0·05	0·03–0·50	0 20±0·05	0·03–12·50	1·10±0·90	0·01–0·60	0·20±0·05
Iron	ND–1·40	0·50±0·07	0·30–1·00	0·60±0·06	0·04–3·90	0·70±0·20	0·30–1·10	0·60±0·10

Table 4. Maximum and minimum mean concentration of tested metals in ecosystem components (fish, sediment, and water) collected from different Egyptian localities

Metal	Maximum Mean±SE	Locality	Minimum Mean±SE	Locality
Fish (concentration in mg/kg)				
Lead	1·50±0·30	Red Sea	0·40±0·10	Alexandria
Cadmium	1·60±0·90	Manzala	0·08±0·04	Alexandria
Chromium	0·60±0·20	Alexandria	0·36±0·03	Manzala
Zinc	7·00±1·20	Alexandria	1·80±0·50	Red Sea
Copper	1·80±0·50	Red Sea	0·80±0·10	Manzala
Manganese	0·50±0·10	Alexandria	0·20±0·30	Manzala
Iron	13·3±4·00	Red Sea	6·40±1·80	Alexandria
Sediment (concentration in mg/kg)				
Lead	1·90±0·60	Red Sea	0·20±0·10	Alexandria
Cadmium	3·20±2·70	Red Sea	0·01±0·003	Alexandria
Chromium	0·40±0·08	River Nile	0·15±0·10	Red Sea
Zinc	7·60±1·40	River Nile	1·20±0·70	Red Sea
Copper	1·00±0·20	River Nile	0·30±0·10	Manzala
Manganese	38·6±4·50	River Nile	0·80±0·40	Red Sea
Iron	60·0±4·80	Manzala	11·1±3·80	Red Sea
Water (concentration in mg/litre)				
Lead	0·50±0·10	Red Sea	0·30±0·10	Alexandria and Manzala
Cadmium	0·30±0·20	Red Sea	0·05±0·05	Alexandria
Chromium	0·70±0·20	Red Sea	0·40±0·10	River Nile and Manzala
Zinc	0·50±0·20	Alexandria	0·20±0·06	Red Sea
Copper	0·50±0·30	River Nile	0·08±0·02	Manzala
Manganese	1·10±0·90	River Nile	0·15±0·05	Alexandria, Manzala and Red Sea
Iron	0·70±0·20	River Nile	0·50±0·07	Alexandria

maximum levels (mg/kg) of Cr (0·4), Zn (7·6), Cu (1·0), and Mn, whereas the Red Sea showed maximum levels of Pb (1·9) and Cd (3·2). On the other hand, the Red Sea showed the lowest levels of Cr (0·15), Zn (1·2), Mn (0·8) and Fe (11·1). Manzala showed the maximum level of Fe (60 mg/kg) and the minimum level of Cu (0·3 mg/kg). Alexandria showed the minimum levels of Pb (0·2) and Cd (0·01 mg/kg).

Locality variation effect on the distribution of heavy metals in water samples

Tables 3 and 4 indicate that the River Nile shows the maximum mean levels of Cu (0·5), Mn (1·1) and Fe (0·7 mg/litre) but the minimum level of Cr (0·4 mg/litre). On the other hand, Pb (0·5), Cd (0·3), and Sr (0·7 mg/litre) were detected at the maximum levels in the Red Sea; however, this locality showed the minimum level of Zn (0·2 mg/litre). Alexandria samples contained the maximum level of Zn (0·5 mg/litre) but the lowest levels of Pb (0·3 mg/litre), Cd (0·05) and Fe (0·5).

Pattern distribution of tested heavy metals among the main component of the ecosystem

To detect the level of the tested heavy metals in the main components of the ecosystem, the data from fish, water, and sediment were analysed collectively regardless of the season and locality where these samples were collected (Tables 5 and 6).

The statistical analysis (one-way ANOVA) showed that there were highly significant differences ($P<0{\cdot}01$) for Cu concentration. The flesh showed the significantly highest mean value (1·5 mg/kg) followed by sediment (0·8 mg/kg), whereas the water showed the significantly lowest mean value (0·3 mg/litre). The same trend was observed with Zn, where highly significant differences ($P>0{\cdot}01$) among the studied ecosystem components were detected. Flesh showed the highest mean value (7.0 mg/kg). The lowest mean value (0·3 mg/litre) was recorded in water. Sediment showed an intermediate value (4·1 mg/kg).

Different trends were noticed for Mn, Pb, and Fe. The values detected in the tested samples indicated highly significant differences ($P>0{\cdot}01$). Sediment showed the highest mean level (Mn 21·5, Pb 1·3 and Fe 39·0 mg/kg), where as the lowest concentration were found in water (Mn 0·4, Pb 0·35, and Fe 0·6 mg/litre). Intermediate concentrations were found in flesh (Mn 0·43, Pb, 0·87 and Fe 10·4 mg/kg) (Tables 5 and 6). Although Cd showed the same trend as the previous three metals, no significant differences were detected.

Cr showed another trend in its distribution in the ecosystem component where the significantly highest mean concentration was detected in water (0·5 mg/litre) but the significantly lowest mean concentration (0·33 mg/kg) was found in sediment. However, no significant differences were detected, either between water and flesh or between flesh and sediment.

Table 5. The distribution (mg/kg) of lead, cadmium, chromium, zinc, copper, manganese and iron among the main ecosystem components (fish, sediment and water)

Metal	Fish		Sediment		Water	
	Range	Mean±SE	Range	Mean±SE	Range	Mean±SE
Lead	0·06–4·70	7·08±0·14	0·04–10·30	1·30±0·30	ND–2·60	0·35±0·05
Cadmium	0·01–6·0	0·45±0·19	0·01–13·90	0·56±0·40	ND–3·20	0·12±0·05
Chromium	ND–1·30	0·46±0·05	ND–1·10	0·33±0·04	ND–1·80	0·50±0·05
Zinc	ND–20·90	7·00±0·70	0·10–15·50	4·10±0·80	ND–4·40	0·30±0·07
Copper	0·09–7·10	1·50±0·20	0·07–3·10	0·80±0·10	ND–4·40	0·30±0·10
Manganese	0·08–2·20	0·43±0·10	0·13–78·2	21·5±3·20	ND–12·50	0·40±0·20
Iron	1·10–47·0	10·4±1·70	3·50–88·8	39·0±3·90	ND–3·90	0·60±0·10

Table 6. Pattern of heavy metals distribution (mg/kg) among the main ecosystem components (fish, sediment, and water)[a]

Metal[b]	Minimum		Intermediate		Maximum	
	Mean±SE	Ecosystem component[c]	Mean±SE	Ecosystem component[c]	Mean±SE	Ecosystem component[c]
Copper**	0·30±0·10	W(c)	0·80±0·10	S(b)	1·50±0·20	F(a)
Zinc**	0·30±0·07	W(c)	4·10±0·80	S(b)	7·00±0·70	F(a)
Manganese**	0·40±0·20	W(b)	0·43±0·10	F(b)	21·0±3·20	S(a)
Lead**	0·35±0·05	W(c)	0·87±0·14	F(b)	1·30±0·30	S(a)
Cadmium**	0·12±0·05	W(a)	0·45±0·19	F(a)	0·56±0·40	S(a)
Iron**	0·60±3·10	W(c)	10·4±1·70	F(b)	39·0±3·90	S(a)
Chromium**	0·33±0·04	S(b)	0·46±0·05	F(ab)	0·50±0·05	W(a)

[a] Means that share a following letter are not significantly different.
[b] **Highly significant, $P<0{\cdot}01$. * Significant, $P<0{\cdot}05$.
[c] F, fish flesh; S, sediment; W, water.

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