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DISTRIBUTION PATTERN OF METALS IN THE ENVIRONMENT OF THE LITTLE MOURRAH LAKE

An extensive study was carried out for 16 months to investigate the level of some metals (As, Cd, Cr, Fe, Pb, Mn, Ni, V and Zn) in water and sediment of the Little Mourrah Lake. Accumulation of these metals by phyto- and zooplankton was also investigated. The geographical description and the background history of this lake are included. The concentration factors of the metals in sediment, phyto- and zooplankton were also studied. The level of salinity was determined throughout the period of investigations. The level of the metals in the lake is due to: (a) recreation and beaching activities, (b) disposal of insufficiently treated municipal wastewater, (c) dynamic properties of the Suez Canal induced by shipping activities, (d) high evaporation rate in this lake. The concentration factor of metals in the case of sediments, phyto- and zooplankton was fully discussed and the level of metals in each was arranged in descending order. Correlations between the contents of metals in this lake, some other local and foreign lakes are also presented.

1. INTRODUCTION

Due to increase in the intensity and diversity of industrial pollution as well as the other man's activities, the interaction between heavy metals and the components of aquatic ecosystem is of great importance since these systems produce food [1], [2]. Two important natural processes contributing to the occurrence of heavy metals in natural waters are chemical weathering and soil leaching [3], [4]. In addition, contribution of non-point sources such as rainfall may lead to the increase of heavy metal concentration in the surface water [5].

In natural waters, heavy metals are usually found in low concentrations, but their certain amount present in the sediment and elsewhere is trapped in the water body by non-living particulate, living plants and animals [6], [7].

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Scientists have become interested in examining heavy metals because of their persistence, refractory nature and the ability to be bioaccumulated which makes them pass into the food chain. Therefore, understanding of the interactions between pollutants and the components of the contact systems has been identified as a prerequisite in pollution control. For instance, trace element analyses of lake sediment cores have been used to obtain a historical picture of metal enrichment as a result of natural and artificial phenomena [8], [9].

In Egypt, several workers investigated the distribution pattern of heavy metals in the Nile, El-Temsah Lake, Great Lake and some other local areas [10]–[13]. Accumulation of trace elements by aquatic organisms in marine and fresh water environments represents a fundamental topic in relation to the interaction between these elements and the biosphere [7], [11]–[16]. However, the distribution pattern of heavy metals in the environment of the Little Mourrah Lake has never been studied before. On the other hand, in the vicinity of this lake, the intensification of recreational activity is observed. The use of the beaches is responsible for creation of small communities living there. They produce sewage and municipal wastewaters which are discharged directly into the lake with no treatment [11]–[13], [15].

Our investigations were undertaken in order to establish the level of metals in the water and sediment of the Little Mourrah Lake. Furthermore, the accumulation of these metals by phyto- and zooplankton was also studied extensively.

2. MATERIALS AND METHODS

2.1. GEOGRAPHICAL BACKGROUND

The Little Mourrah Lake is a part of the Mourrah Lakes (figure 1), which are located between the latitudes °30 10 and °30 25 N and the longitudes °30 18 and °32 35 E. The Little Mourrah Lake is located between the latitudes °30 10 and °30 17 N and the longitudes ° 32 30 and °32 35 E. The Mourrah Lakes constitute the central and most important water body of the Suez Canal. They contain about 85% of the canal system waters at a length of 36 km and consist of the northern part (the Great Mourrah Lake) with a maximum width of 13 km and a much narrow southern part (the Little Mourrah Lake). Within the lake system there are artificially dredged canals which enable navigation.

Because nearly 90% of the water in the lakes is contained in the canal, a great majority of the benthic area is available to organisms entering the canal. Most of the bottom of the lake system is natural and has never been dredged out. Therefore, soon after the initial flooding on the opening of the canal, normal sedimentation processes started and an undisturbed build-up of the benthic communities began. The fact that the bottoms of the lakes are almost exclusively sedimentary is of crucial importance for the types of populations which inhabit the canal.

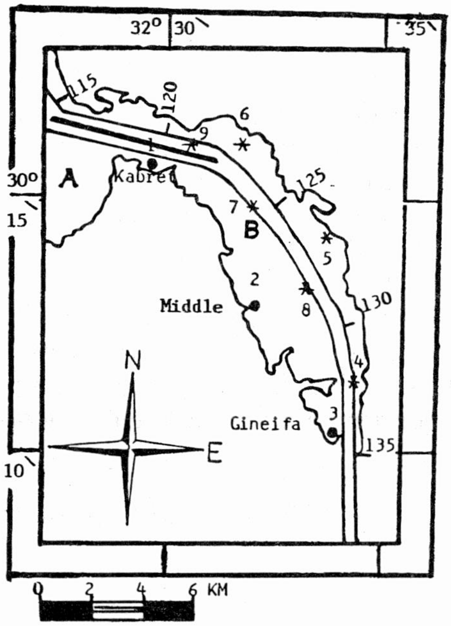

Fig. 1. The Mourrah Lakes and the sampling locations:
A – the Great Mourrah Lake, B – the Little Mourrah Lake

The environment of the Great Mourrah Lake was studied before [12]–[17], but the distribution pattern of metals in the Little Mourrah Lake has been never investigated. Therefore, the present paper deals with the Little Mourrah Lake.

2.2. SAMPLING PROGRAMME

Monthly samples, i.e., 1 dm^3 of water, 1 kg of sediment and 0.3–0.5 g of phyto- and zooplankton, each from the Little Mourrah Lake were collected. This sampling programme was conducted for a period of 16 months in order to study the seasonal variations in metal concentrations. The sampling locations are shown in figure 1.

The water samples were collected using a boat at a depth of 1 m below the water surface and kept in polyethylene bottles. The samples were filtered through 0.45 μm millipore filter and acidified with nitric acid.

Eight Grab samples of the lake sediments were collected monthly. Sediments from submerged sites in the lake were collected by a diver equipped with aqualung.

All sediment samples were drained and transported to the laboratory in heat- and water-resistant sampling bags. These sediment samples were dried for 48 h at 105 °C until a constant weight was obtained, then passed through an 80 mesh (< 210 μm) sieve according to HARDING and WHITTON [9]. About 5 g of the sediment sample was weighed, digested for 30 min in 5 cm^3 of boiling HNO_3

(Analar), followed by H_2O_2, then hydrofluoric acid, made up to the volume with redistilled water and analyzed according to the EPA analytical procedure [18].

Collection and analysis of phyto- and zooplankton were carried out separately using plankton net No. 20 for phytoplankton and mesh No. 8 for zooplankton according to APHA/AWWA [19]. All the samples were collected at a depth ranging from 0.75 to 1.0 m, then transported to the laboratory, where they were subjected to drying in oven at 105 °C for 48 h. Next they were weighed, digested and analyzed according to the EPA Analytical Procedure [18].

Concentrations of metals (As, Cd, Cr, Cu, Fe, Mn, Ni, Pb, V and Zn) were determined by means of instrumentation laboratory atomic absorption spectrometer, model 551. Both flame and graphite furnace techniques were used, depending on the level of metals. The data given in this study are the average values obtained by the statistical evaluation according to RICHARDS and LACAVA [20].

3. RESULTS AND DISCUSSION

3.1. LAKE WATER

The mean values of the metals investigated in the lake water are given in table 1. The levels of the metals in Kabret, Middle and Gineifa are slightly higher than their levels in other locations. This statement is supported by the variation in the mean values of metals in each site within the lake as indicated in figure 2 for iron and zinc as examples. Those slightly higher levels of metals in sites 1 , 2 and 3 (figure 1) are attributed to the recreation and beaching activities as well as to the disposal of insufficiently treated municipal wastewater. The increase in the levels of metals within the lake is mainly due to two factors: (a) the influence of the hydrodynamic properties of the

Table 1

Levels of heavy metals in the water of the Little Mourrah Lake ($\mu g/dm^3$)

Metals	$\bar{X}$	SD
As	2.60	0.92
Cd	0.25	0.08
Cr	0.50	0.06
Cu	3.82	1.07
Fe	29.45	3.97
Pb	3.20	0.97
Mn	3.76	0.85
Ni	1.92	0.67
V	2.13	0.96
Zn	6.10	1.38

$\bar{X}$ – arithmetic means.
SD – standard deviation.

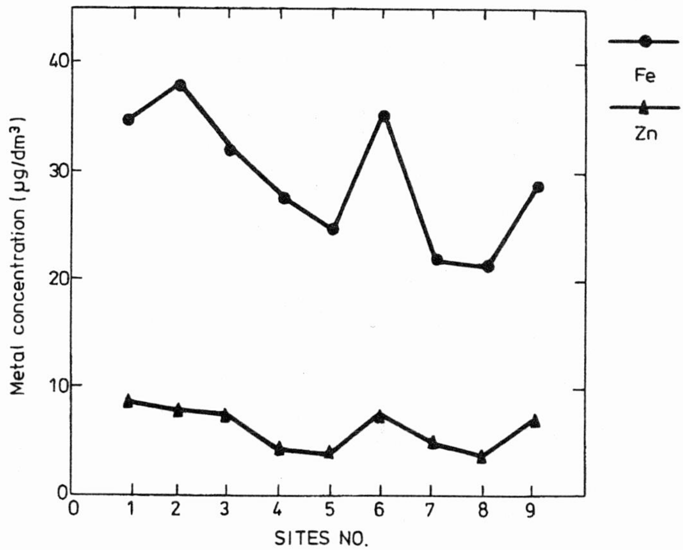

Fig. 2. Variations in mean concentrations of iron and zinc in the lake water at different sites (μg/dm^3)

Suez Canal pathway used for shipping; (b) high evaporation rate in this almost closed inland lake, which also explains the slightly higher levels of metals in the water in comparison with those in the Great Mourrah Lake [12].

Generally, the concentrations of metals in this lake are lower than the concentrations of the same metals in other foreign and local lakes [1], [2], [9], [11], [21]. This may be attributed to the absence of industrial wastewater discharge. The levels of metals in the lake water can be arranged in the following descending order:

$$Fe > Zn > Cu > Mn > Pb > As > V > Ni > Cr > Cd.$$

3.2. LAKE SEDIMENTS

Metal concentrations in the sediment samples are given in table 2. These results prove that these concentrations are comparable with the concentrations stated in other local lake sediments, namely the El-Temsah and Great Lakes [11], [12]. However, these levels are still lower than the levels in other lakes [8], [22], [23]. These concentrations varied according to the site of sampling as shown in figure 3 for copper, lead and zinc. Such a variation indicates that on site (1) the metal concentrations were highest, while on sites 3, 6 and 9 those concentrations were higher than on sites 2, 4 and 5. This may be attributed to the high level of metals in the lake water, particularly in this northern region (sites 1, 3, 6, and 9). Metal concentrations in sediments can be arranged in the following descending order:

$$Fe > Mn > Zn > Pb > Cu > Cr > V > As > Ni > Cd.$$

Table 2

Metal contents in the sediment samples taken from eight different sites along the Little Mourrah Lake (μg/g of dry weight)

Metals	$\bar{X}$	SD	CF (10^3)
As	40.37	16.8	15.5
Cd	4.11	4.2	16.4
Cr	53.10	23.6	106.2
Cu	55.71	14.3	14.6
Fe	4350.10	135.9	147.7
Pb	73.10	14.7	40.7
Mn	593.20	95.8	157.8
Ni	32.60	16.1	17.0
V	44.20	11.6	20.7
Zn	317.90	96.9	52.1

$\bar{X}$ – arithmetic means.
SD – standard deviation.
CF – concentration factor (sediment/water).

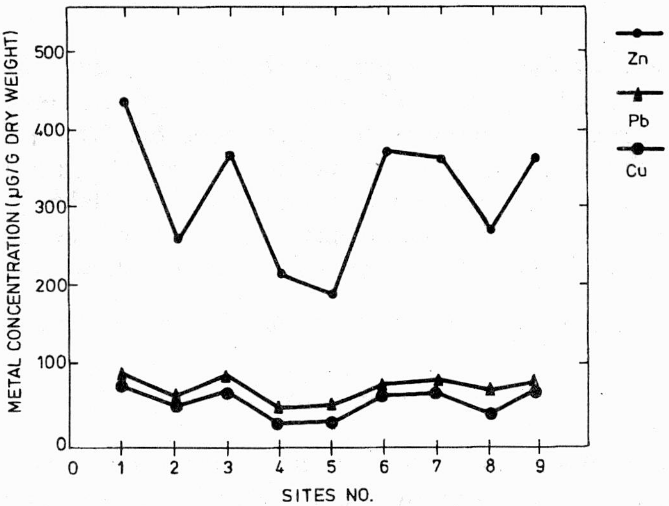

Fig. 3. Mean concentrations of copper, lead and zinc in the lake sediments at different sites (μg/g of dry weight)

Concentration factor (CF), i.e. the ratio of metal content in sediments to metal content in water, is a good indicator of the relation between the content of soluble metals in water and in solid phase, i.e. sediments. The CF shown in table 2 proves that the sedimentation process is intensified due to continuous shipping and rubbish accumulation. Such activities enhance the slow mixing up of sediments with the rubbish that plays an important role in the uptake of metals by the bottom lake sediments. Therefore, the level of metals in sediments may be an indication of the metals presence in water. Thus sediments can be essential in detecting the type of pollution. These findings are in good agreement with those reported by other investigators [3], [12], [13], [23], [24]. It can be seen from the CF (table 2) that the concentrations of iron and manganese in sediments are the highest, i.e. ten times higher than these of the other metals. The concentrations of nickel, cadmium and copper are the lowest. Therefore the respective CFs can be arranged in the following descending order:

$$\mathrm{Mn} > \mathrm{Fe} > \mathrm{Cr} > \mathrm{Zn} > \mathrm{Pb} > \mathrm{V} > \mathrm{Ni} > \mathrm{Cd} > \mathrm{As} > \mathrm{Cu}.$$

3.3. LAKE PHYTO- AND ZOOPLANKTON

Phyto- and zooplankton accumulate the metals investigated (table 3). In general, the results obtained allowed us to state that the level of metals in plankton is reflected by the variation of metal levels in both water and sediments. It was reported by FISHER [25] that the metal concentration factor of phytoplankton is exponentially dependent on the solubility products of metals and their cytotoxicity and linearly dependent on the log of mean oceanic residence times (years) of the metals. He also suggested that the concentration factors and toxicity of metals in marine phytoplankton and oceanic residence times of metals can be predicted within an order of magnitude from the chemical literature. From the results obtained (table 4) it can be seen that certain metals (copper, iron and zinc) which may be considered as nutrient elements to phytoplankton or essential element to zooplankton are concentrated more readily in the plankton. The rate of their accumulation in plankton is the same or even faster than that in the sediments of the lake. On the other hand, certain metals (arsenic, cadmium and lead) that are considered as toxic are less concentrated in the plankton than in the sediments.

Table 3

Metal contents in phyto- and zooplankton samples collected from the Little Mourrah Lake (μg/g of dry weight)

Metals	Phytoplankton		Zooplankton	
	$\bar{X}$	SD	$\bar{X}$	SD
As	3.12	0.12	2.96	0.11
Cd	2.11	0.19	2.98	0.14
Cr	59.34	8.29	117.18	9.13
Cu	98.27	9.71	645.14	21.81
Fe	4.187	78.11	5.975	147.54
Pb	9.08	0.95	17.75	1.93
Mn	431.02	6.56	488.9	8.3
Ni	73.68	8.5	296.8	18.9
V	61.29	9.5	122.7	13.5
Zn	407.6	13.1	2.189	137.8

$\bar{X}$ – arithmetic means.
SD – standard deviation.

Table 4

Concentration factors of metals from the Little Mourrah Lake

Metals	Phytoplankton $10^3 \times CF$	Zooplankton $10^3 \times CF$
Arsenic	1.2	1.1
Cadmium	8.4	11.9
Chromium	118.7	234.4
Copper	25.7	168.9
Iron	142.2	202.9
Lead	6.0	14.9
Manganese	114.6	130.0
Nickel	38.4	151.5
Vanadium	28.8	57.6
Zinc	66.8	358.9

CF – concentration factor.

Metal concentrations in phytoplankton can be arranged in the following descending order:

$$Fe > Mn > Zn > Cu > Ni > V > Cr > Pb > As > Cd.$$

The concentration of metals in zooplankton can be arranged in the following descending order:

$$Fe > Zn > Cu > Mn > Ni > V > Cr > Pb > Cd > As.$$

Concentration factors of the metals in the lake sediment and bioaccumulation factors for both phyto- and zooplankton are shown in figure 4. A comparison of the CFs proves that zooplankton accumulates metals more efficiently than phytoplankton. These higher accumulation factors are mostly typical of chromium, copper, iron, lead, nickel, vanadium and zinc. A comparison between the CFs of plankton and sediments showed that the latter accumulate arsenic, cadmium, lead and manganese more efficiently than the former. The mechanism of the metal uptake from water by sediments may be explained either by adsorption, complexation or by both processes [8], [23], [26].

Based on all results obtained it can be stated that the levels of metals in water, sediments, phyto- and zooplankton in this lake are within the range or even lower than the levels of metals in some other lakes [1], [8], [9], [11]–[13], [23]–[26]. Taking account of the salinity (figure 5), it is evident that this lake is characterized by high salinity. The salinity is considered as a seasonal phenomenon with a maximum of 48‰ in summer and a minimum of 43‰ in winter (see figure 5). The seasonal fluctuation in the salinity is 5‰. Therefore, it is evident that in the future the salinity of this lake may follow the behaviour pattern typical of the one of the Latiral lagoons of the Red Sea with salinity fluctuating seasonally around the value of 45‰.

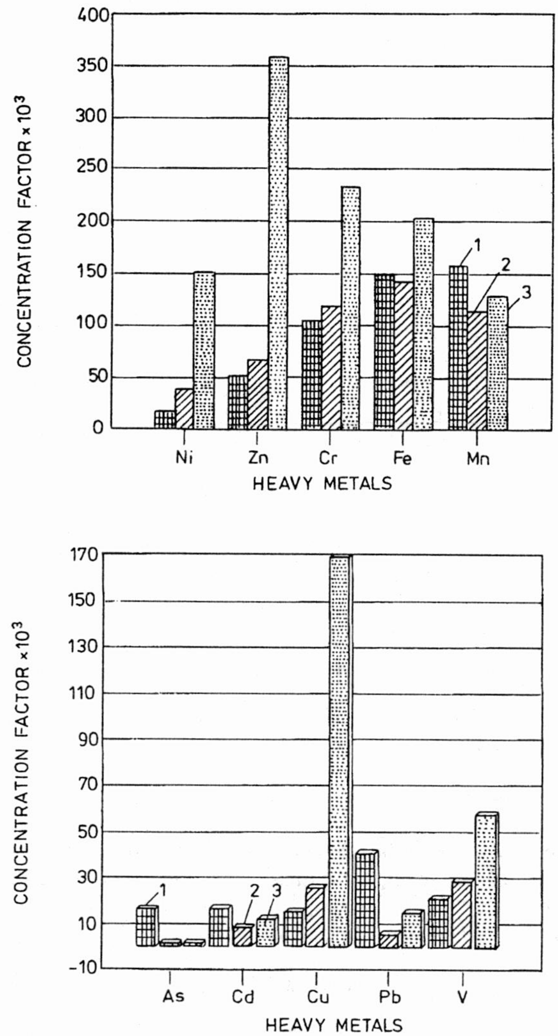

Fig. 4. Concentration factor of metals in sediments (1), phyto- (2) and zooplankton (3) in the Little Mourrah Lake

The present results are in a good agreement with those reported by other investigators [17], [27]. The lake investigated has only a minor source of particulate, suspended matter or metal addition, including shipping, beaching and recreation activities. Additional pollution is due to the discharge of domestic wastewater produced by relatively small communities living in Kabret and Geneifa. The slightly higher concentrations of certain metals such as zinc, iron, lead and copper may be attributed to some sort of the influence from the Northern Red Sea in which the concentrations of these elements are high [28]. This explanation is

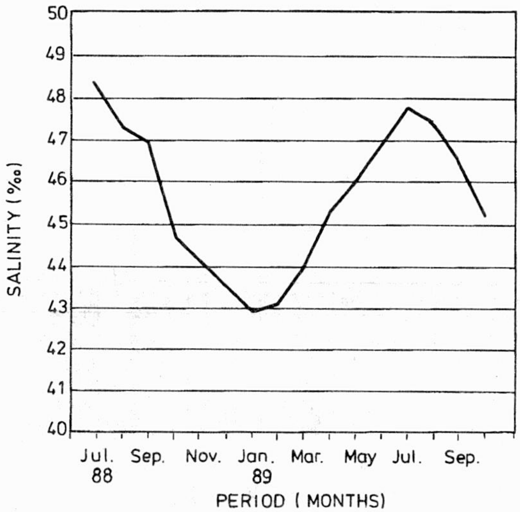

Fig. 5. Variation in salinity of the Little Mourrah Lake during a period of sixteen months

confirmed by other scientists [27], [29]. In addition, the Abou-Sultan power plant at the Great Mourrah Lake causes local thermal pollution, which may affect flora and fauna of the Little Mourrah Lake in the future.

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ROZKŁAD METALI W ŚRODOWISKU MAŁEGO JEZIORA MOURRAH

Przez 16 miesięcy badano stężenia niektórych metali (As, Cd, Cr, Fe, Pb, Mn, Ni, i Zn) w wodzie i osadzie Małego Jeziora Mourrah. Prześledzono także akumulację tych metali przez fito- i zooplankton. Przedstawiono opis geograficzny i historię jeziora, a także współczynniki zatężenia metali w osadzie, fito- i zooplanktonie. W czasie badań określono zasolenie jeziora. Na stężenie metali w jeziorze wpływają: a) działalność związana z wypoczynkiem, b) zrzut niedostatecznie oczyszczonych ścieków komunalnych, c) żegluga na Kanale Sueskim, d) szybkie odparowywanie wody. Omówiono wyczerpująco współczynnik zatężenia metali w osadach, fito- i zooplanktonie. Stężenia badanych metali w osadzie i planktonie przedstawiono w porządku malejącym. Przedstawiono także korelacje między zawartością metali w badanym jeziorze, jeziorach lokalnych i tych położonych poza granicami Egiptu.

РАСПРЕДЕЛЕНИЕ МЕТАЛЛОВ В СРЕДЕ МАЛОГО ОЗЕРА МОУРРАХ

В течение 16 месяцев исследованы концентрации некоторых металлов (As, Cd, Cr, Fe, Pb, Mn, Ni и Zn) в воде и отложениях Малого Озера Моуррах. Наблюдали также аккумуляцию этих металлов фито- и зоопланктоном. Представили географическое описание и историю озера, а также коэффициенты концентрации металлов в отложениях, фито- и зоопланктоне. Во время исследований была определена засоленность озера. На концентрацию металлов в озере влияют: а) деятельность, связанная с отдыхом, б) отвод недостаточно очищенных коммунальных сточных вод, в) плавание по Суэзском канале, г) быстрое испаривание воды. Обсужден коэффициент концентрации металлов в отложениях, фито- и зоопланктоне. Концентрации исследуемых металлов в отложениях и планктоне представлены в понижающейся очередности. Представлены также корреляции между содержанием металлов в исследуемом озере, локальных озерах и озерах, расположенных за границами Египета.