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Metal pollution loading, Manzalah Lagoon, Nile Delta, Egypt: Implications for aquaculture

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Abstract High cultural enrichment factors are found for Hg (13 ×), Pb (22.1 ×), and other potentially toxic metals (e.g., Sn, Zn, Cu, Ag) in the upper 20 cm of sediment cores from the southeastern Ginka subbasin of Manzalah lagoon, Nile delta, Egypt. Cores from other areas of the lagoon show little metal loading. Metal loading followed the closure of the Aswan High Dam, the availability of abundant cheap electricity, and the development of major power-based industries. Industrial wastes containing potentially toxic metals are dumped into the Nile delta drain system. The load carried by Bahr El-Baqar drain discharges into the Ginka subbasin, which acts as a sink and results in metal loading of the sediment deposited there. Further development of aquaculture in this subbasin, of food-stuff agriculture on recently reclaimed lagoon bottom, or where irrigation waters come from Bahr El-Baqar drain or its discharge should be halted or strictly limited until potentially toxic metals in the drain waters and sediment are removed and polluted input drastically reduced. This environmental assessment of heavy metals in aquaculture or agriculture development should extend to other waterbodies in the northern Nile delta, particularly Idku lagoon and lake Mariut, where industrial metal-bearing wastes discharge into the waterbodies.

Key words Metal pollution — Manzalah Lagoon — Egypt — Aquaculture

Introduction

Manzalah lagoon is located in the northeastern sector of the Nile delta (Fig. 1). It is the largest (≈ 1000 km^2) brackish waterbody and wetlands area in the delta. The lagoon is shallow (< 2 m), with an average depth of ≈ 1.0 m, and is divided into subbasins by natural and artificial barriers. These subbasins are the sites of aquaculture development and open fishing. The Egyptian National Environmental Action Plan, which was adopted by the Council of Ministers early in 1992, identified Manzalah lagoon and Bahr El-Baqar drain as two of the country's "black spots," which are regarded as the most alarming examples of polluted areas from heavy metals and high nutrient supply (Global Environmental Facility 1992). Bahr El-Baqar drain discharges into the Ginka subbasin in the southeast sector of the lagoon. The polluted nature of Manzalah lagoon, entirely or locally by subbasin, and of Bahr El-Baqar drain discharge and aquaculture areas fed by it, raises a question as to the quality of the food fish supply with respect to heavy metals and hence the risk to the health of the consumer. Indeed, many Egyptians are afraid to eat these fish (Global Environmental Facility 1992) and can identify Ginka subbasin fish in the marketplace by the prevalence of gill diseases, internal parasites, and their "unmistakable smell" (Halim and Guerguess 1978). Also in question is the quality of agricultural food crops grown on land reclaimed from lagoon bottom that suffered metal loading after industrial development but before reclamation, or crops grown under irrigation by drainwaters that might carry high contents of heavy metals. These crops include rice, wheat, barley, maize, fruit, and vegetables such as potato, tomato, horsebean, and groundnuts.

This study focuses on the chemistry of the < 2-µm size fraction of sediments in cores from Manzalah lagoon as an indicator of the pollution potential of the ecosystem, especially as regards the Ginka subbasin, which receives discharge from Bahr El-Baqar drain. Metals in suspended and fine-size bottom sediments may access the food web for fish, which can bioaccumulate heavy metals and pass them along the chain to the human consumer. With metal bioaccumulation (e.g., Hg and Pb), the consumer population could be at long-term health risk. The period during which this potentially toxic heavy metal pollution has existed is established by dating where high heavy metal concentra-

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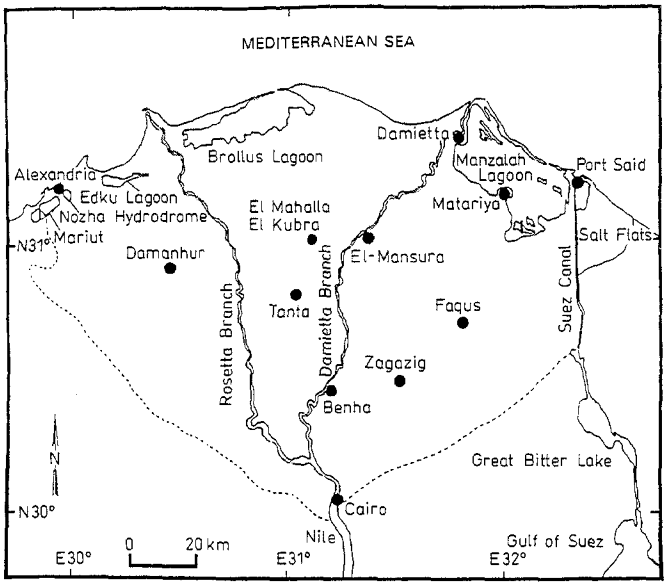

Fig. 1. General location map of the Nile delta showing the position of Manzalah lagoon

tions appear in the cores. In addition, high concentrations of metal assemblages can be useful in identifying potential sources of pollutants (Christianson and Hemond 1991; Farmer 1991).

Before closure of the Aswan High Dam in 1964, commercial fishing was done in Manzalah lagoon but most of the Egyptian catch came from rich fisheries in the Mediterranean Sea (Bishai and Yosef 1977; MacLaren 1981). Discharge from drains carrying municipal sewage, agricultural effluents, and light industry wastes was moved to and through the lagoon into the sea by the annual River Nile flooding. Mediterranean ocean fisheries depended upon the nutrient-rich discharge into the sea from the Damietta and Rosetta branches of the River Nile (Fig. 1) and from flow through the delta lagoons and lakes into the sea.

With the closure of the High Dam, the annual River Nile flooding ceased to occur. Major power-based industries (e.g., chemical, fertilizer, textile, chloroalkane) developed as a result of the availability of abundant cheap electricity. Industrial wastes, including heavy metals and other chemicals, untreated or poorly treated, were distributed into the Nile delta drainage network. The nutrient-rich discharge from the River Nile and the delta lagoons and lakes no longer reached the ocean fisheries in significant quantities and they ceased to be an important source of food fish. The delta waterbodies were no longer thoroughly flushed of the nutrient-rich and other wastes discharged into them and became sinks for potentially toxic wastes such as heavy metals.

To make up for the loss of the ocean fish food supply, intensive aquaculture developed in Manzalah and other lagoons and lakes. The continuous supply of nutrient-rich sewage and agricultural effluent through the drain systems into the lagoon stimulated growth of a food supply for fisheries there. In a short time, the aquaculture sector was thriving, and by the late 1960s and into the 1980s, Manzalah lagoon was supplying about 50 percent of the total Egyptian fish catch. Half of this catch, or 25 percent of the total, came from the Ginka subbasin (Bishai and Yosef 1977; MacLaren 1981; Dowidar and Hamza 1983). This subbasin comprises ≈ 40 km^2 in the southeast corner of the lagoon and receives discharge (municipal sewage, industrial effluents, and agricultural runoff) from Bahr El-Baqar drain and agricultural runoff from the Hadous and Ramsis drains (Fig. 2). Aquaculture development continues in order to help feed a population of 58 million Egyptians (which may grow to 92 million by 2025; World Bank 1993). Lake Mariut and Idku lagoon in the northwestern sector of the Nile delta and "downstream" from Alexandria and its industrial complexes are also important aquacultural sites. Deeper ocean fishing is again contributing to the food supply. Because these sources of food fish have grown and because of a rising level of pollution in Manzalah lagoon, Manzalah's relative contribution has diminished but still represents over 35 percent of the total annual (100,000 tons) Egyptian food fish catch (Global Environmental Facility 1992).

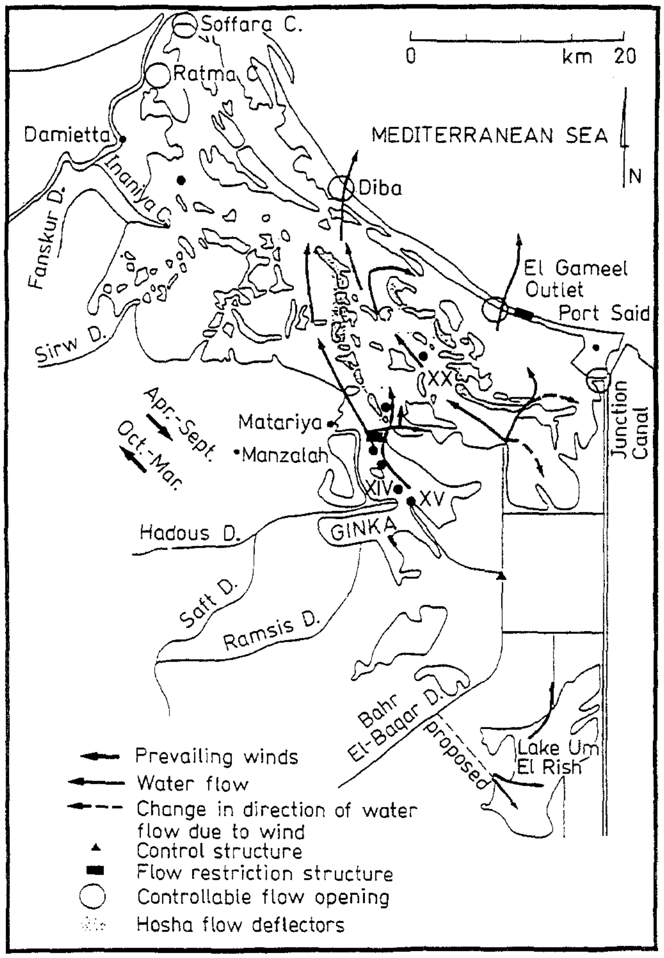

Fig. 2. Map of Manzalah lagoon showing the Ginka subbasin, positions of drains discharging wastes into the lagoon, the principal current flow paths, and positions of cores identified in Fig. 3. Modified from MacLaren (1981) report

Methodology

Sample collection

A suite of 10-cm-diameter cores were collected at 30 locations in Manzalah lagoon during September–October 1990 as part of the Mediterranean Basin Program (sedimentology–geochemistry) at the Smithsonian Institution, Washington, DC (Randazzo 1992). The cores were taken by driving a PVC core liner 30–100 cm into the soft substrate of the shallow lagoon floor. Samples from seven of these cores were selected for the environmental geochemistry study reported on here (Fig. 3). Cores XV, XIV, XIII, and XII present a 5.8-km-long transect from the outfall of Bahr El-Baqar drain, which discharges into the Ginka subbasin. Cores XXIII and XX, from the south-central area, and core II, from the northwestern part of the lagoon, represent only marginally polluted depositional environments.

Age of the sediments

The Smithsonian cores studied range from 75 to 95 cm in length (Randazzo 1992) and were generally sampled at 5-cm intervals. A total of 114 samples were analyzed. Where possible, samples were taken at 2.5-cm intervals to better define the most recent changes in the system. On the basis of radiocarbon dates on long cores, Stanley (1988, 1990) estimated an average long-term sedimentation rate for the Manzalah lagoon region of ≈0.5 cm/yr. Thus, the 5-cm sampling interval in this study may represent a 10-yr period. In Manzalah lagoon, the first appearance of the ^{137}Cs marker isotope (1954–1963) was at a depth of 17–22 cm in core XX (L. K. Benninger 1992, personal communication). In addition, a strong ^{137}Cs signal was found in the 2- to 4-cm-depth interval of the core and probably represents ^{137}Cs from the 1986 Chernobyl Nuclear Power Facility accident. This time bracketing of cored sediment supports the long-term averaged sedimentation rate of 0.5–0.7 cm/yr for Manzalah lagoon. This means that the sedimentary sections in the cores provide about a 150-yr chemical record of values that include preindustrialization (baseline) metal concentrations as well as industry-originated metals.

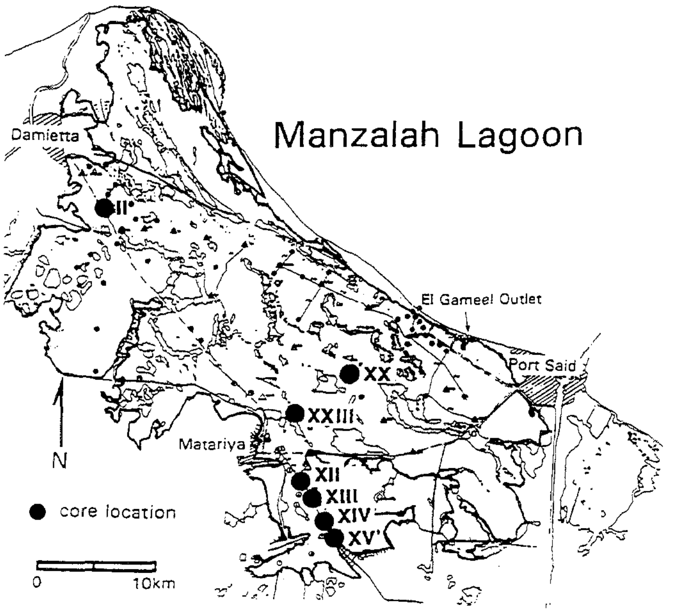

Fig. 3. Detailed map of Manzalah lagoon showing Smithsonian sampling sites and the myriad of natural and man-made barriers to current flow (Randazzo 1992)

Sample preparation and element analysis

The < 2-μm size fraction was separated from the samples by gravity settling. After centrifugation to collect the sediment, the samples were dried at 60°C. At this temperature, the chance of loss of potentially volatile metals (e.g., Hg, As) is minimized.

Mercury was analyzed by cold vapor atomic absorption spectrometry (AAS); Cr and As were determined by instrumental neutron activation analysis (INAA); Cu, Pb, Zn, and Ag were analyzed using inductively coupled plasma atomic emission spectrometry (ICPAES) following digestion with a nitric acid–perchloric acid–hydrofluoric acid mix; and Sn was analyzed by ICPAES after fusion with KI. Replicate analysis on samples containing both low and high concentrations of the elements studied gave precision values of ±5 percent to ±10 percent: Cu, Pb, Zn, Cr, Sn and Hg; > ±10 percent: As and Ag.

Statistical analysis

Means, standard deviations, and ranges were calculated for the analytical data. Pearson product moment correlation coefficients were determined to establish relationships between paired measurements. Concentrations that were below the detection limit (for Ag, As, and Sn) were used at 80 percent of the detection limit for statistical and graphical manipulations. This follows the method of Miesch (1981) and differentiates between low concentrations and samples that were not detectable without skewing the results.

Results

Some heavy metals detected in sediments in Manzalah lagoon (e.g., Hg, Pb, Zn, Cu, and others) are potentially toxic to humans if bioaccumulated through the food web and ingested during an extended period of time. Four cores comprising the Ginka subbasin transect, parallel the current flow from Bahr El-Baqar drain outfall to the subbasin outlet (Fig. 2). Three cores are in the western and south-central parts of the lagoon away from the direct influence of the current exiting the subbasin (Fig. 2). It was postulated that the lower, older parts of cores from the Ginka subbasin should contain natural metal concentrations and indicate, in their younger sections, increased metal loading from the drain discharge of industrial effluents. Moreover, it would be expected that cores outside the Ginka subbasin, with reduced input from Bahr El-Baqar drain, would record more consistent base-to-top metal concentrations, close to background values, throughout the historical record they preserve.

Element concentrations

The means, standard deviations, and ranges of potentially toxic metals analyzed in the cores for this study are listed in Table 1. High values for Hg (822 ppb), Pb (110 ppm), Zn (635 ppm), Cu (325 ppm), and other metals signal metal pollution, probably from industrial sources. The maximum values for other metals that might result from industrial discharge do not indicate pollution (e.g., As at 6 ppm and Cr at 165 ppm).

The sediments from the Ginka subbasin cores have element concentrations that vary with time (from base to top of cores) and in space (along the core sampling transect). Figure 4, for example, shows distributions of Hg, Pb, Zn, and Cu with depth and a time line representing the first appearance of the 1954–1963 ^{137}Cs marker isotope in the cores. These distributions are generally comparable to other heavy metals associated with industrial development (e.g., Ag, Cr, Sn, and As). The four cores all show strong increases in metal concentrations in the upper 20 cm when compared with metal contents in lower parts of cores. This marked time-related change of metal concentrations is not observed in the cores from outside the subbasin (Fig. 5).

If the proposed average sedimentation rate of ≈0.5–0.7 cm/yr for the study area is projected back in time, then core sections below 45 cm represent sediment deposited during the early 1900s and before major industrialization in Egypt. Herein we assume that element concentrations from the deeper core sections indicate preindustrialization baseline values. As shown in Table 2, these values correspond reasonably well with those of 29 Manzalah lagoon surficial sediments collected throughout the lagoon in 1968 (shortly after the Aswan High Dam was emplaced) and analyzed in 1983 (McComas 1983; Saad and others 1985). However, when element concentrations from the top 20 cm of the Ginka subbasin cores are compared with surficial sediment data, the metal loading in the Ginka subbasin is evident (Table 2).

We believe that timing of metal loading in the Ginka subbasin corresponds with the closure of the Aswan High Dam in 1964. This is based on the first appearance of the ^{137}Cs marker isotope (1954–1963) at 17–22 cm, the strong Chernobyl ^{137}Cs marker (1986) at 2–4 cm depth in cores (sampled during October–November 1990), and an assumed average rate of sedimentation of ≈0.5–0.7 cm/yr for the Manzalah region. Inexpensive electricity from the High Dam enhanced the development of power-based in-

Table 1. Means, standard deviations, and ranges of selected metals analyzed in Manzalah lagoon cores for this report[a]

	Core XV (*n* = 16)			Core XIV (*n* = 18)			Core XIII (*n* = 16)			Core XII (*n* = 17)			Core XXIII (*n* = 15)			Core XX (*n* = 18)			Core II (*n* = 14)		
Metal	Mean	SD	Range	Mean	SD	Range	Mean	SD	Range	Mean	SD	Range	Mean	SD	Range	Mean	SD	Range	Mean	SD	Range
Hg ppb	190	263	18–822	114	134	5–355	70	62	15–195	35	4	5–90	49	28	25–135	47	41	15–175	43	11	20–60
Pb ppm	24	38	2–110	25	28	4–80	14	6	6–28	19	11	4–47	12	26	2–107	9	8	2–36	7	4	2–15
Zn ppm	210	184	89–635	222	154	102–476	122	2	97–177	107	10	92–168	157	23	134–199	171	43	123–282	164	31	137–233
Cu ppm	109	70	52–275	102	36	69–166	79	8	67–93	81	23	52–138	68	7	52–79	63	15	47–105	81	9	69–108
Ag ppm	0.9	1.5	0.2–4.7	0.5	0.5	0.2–1.7	0.4	0.3	0.2–1	0.4	0.2	0.2–.9	0.2	0.2	0.2–0.9	0.3	0.1	0.2–.5	0.1	0.04	0.1–0.2
Sn ppm	5.8	5.5	1–14	6.4	5.3	0.8–14	1.8	1.2	1–4	1.1	0.8	0.8–3	BDL	—	BDL–2	BDL	—	BDL	BDL	—	BDL
Cr ppm	159	28	138–215	153	21	134–187	143	4	138–148	146	9	133–160	152	13	117–165	143	18	120–180	148	10	135–168
As ppm	2.9	1.5	1–7	2.6	0.9	2–4	2.3	1	0.8–4	2.9	0.6	2–4	3.4		1–8	3		1–5	3.7		3–8

[a] BDL is below detection limit.

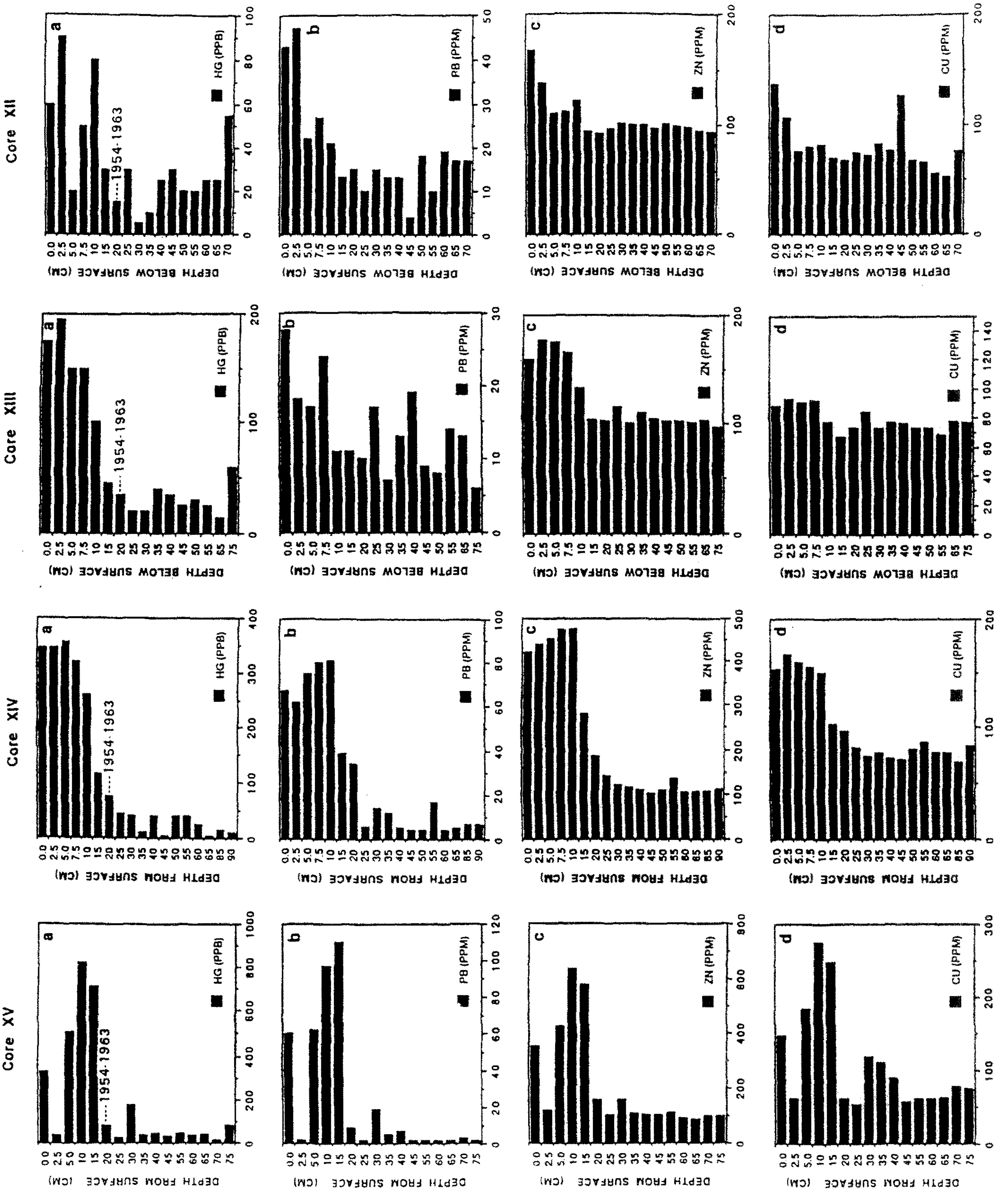

Fig. 4. Downcore distribution of Hg, Pb, Zn, and Cu in the core transect in the Ginka subbasin, from the outfall of Bahr El-Baqar drain (core XV) to the subbasin outlet (core XII). The first appearance of the 1954–1963 ^{137}Cs marker isotope is indicated. Note that the element concentration scales of the bar graphs differ

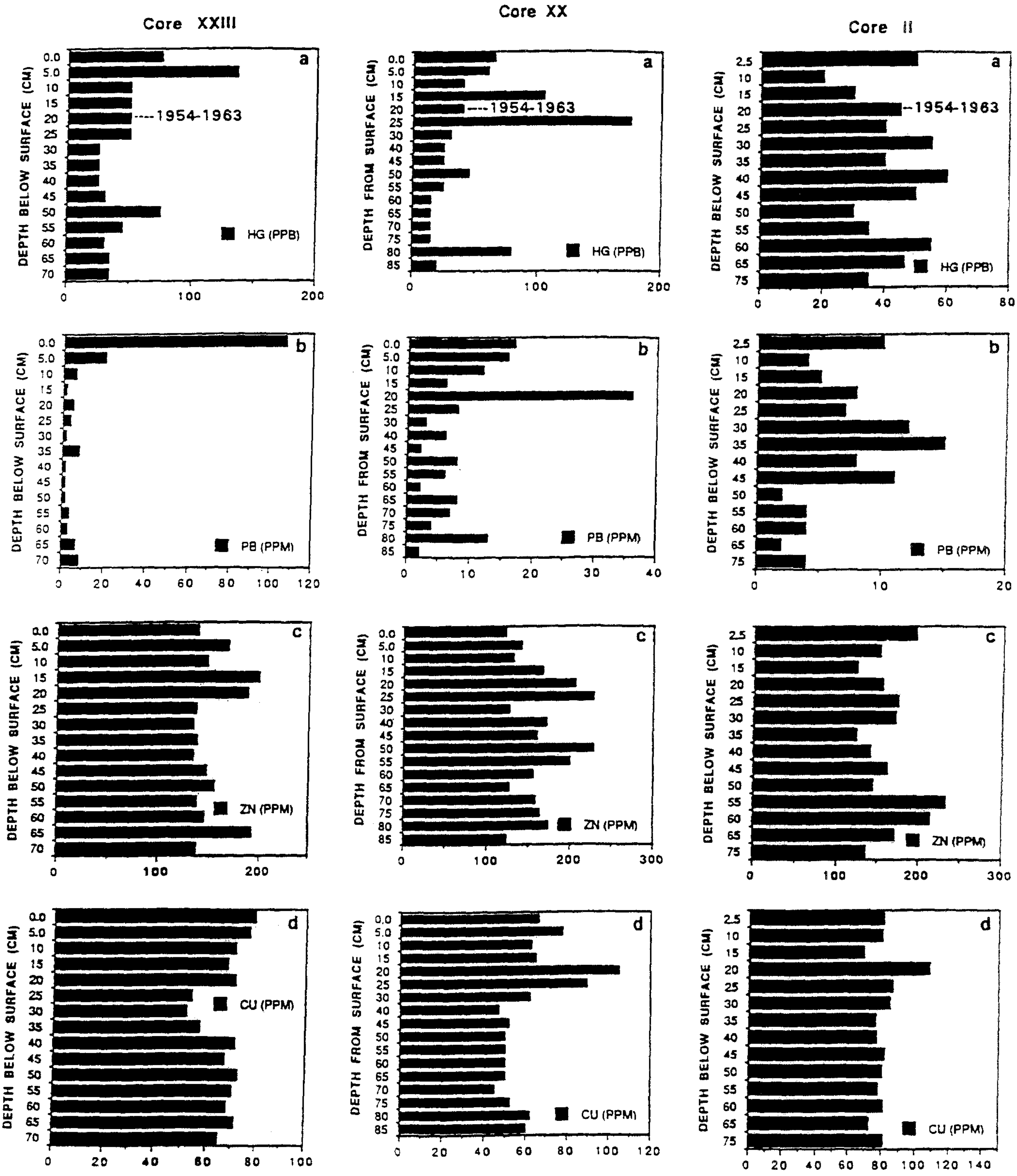

Fig. 5. Downcore distribution of Hg, Pb, Zn, and Cu in three cores from outside the Ginka subbasin. The first appearance of the 1954–1963 ^{137}Cs marker isotope is indicated. Note that the element concentration scales of the bar graphs differ

dustries. These industries have discharged untreated or poorly treated metal-bearing wastes into the River Nile distributary and drain system where, with municipal sewage and agricultural pollutants, they then become part of the total waste stream in the Nile delta.

Analyses indicate a clear decrease in potentially toxic heavy metal concentrations in the upper 20 cm of sediment from cores XV to XIV to XIII to XII (Fig. 4) along the Ginka subbasin sampling transect. This decrease parallels the flow path of currents carrying the waste discharge from the drain (Fig. 2). These decreasing heavy metal contents

Table 2. A Comparison of element mean concentrations of 26 surficial sediments collected from Manzalah lagoon in 1968 (McComas 1983; Saad and others 1985), with baseline concentrations in 4 cores from Ginka subbasin and with element mean concentrations in upper 20 cm of the same cores[a]

		Core sediments (collected 1990)	
Element	Surficial sediments (1968)	Baseline	Polluted
Hg ppb	ND	29	242
Pb ppm	10	9	42
Zn ppm	119	104	245
Cu ppm	207	73	128
Cr ppm	80	143	164
Cd ppm	0.2	0.4	0.5
Ni ppm	63	118	112
Mn ppm	776	794	933
Ag ppm	ND	0.3	0.6
As ppm	ND	2.4	3.3
Sn ppm	ND	1.0	6.8

[a] ND = not determined

are found for most comparative sampling levels within the cores as well as for the entire upper 20-cm sections (Fig. 4).

The marked increases in metal concentrations found in samples from the upper 20 cm of cores from the Ginka subbasin are not recorded in the three cores (XX, XXIII, and II) from other areas (south-central and western) of Manzalah lagoon (Fig. 5). However, there is one high Hg and one high Pb value in cores XXIII and XX (Fig. 5) relative to contents in their lower sections (at depths of 45–75 cm). No high metal values are recorded in core II.

Cultural enrichment factor

The degree of metal loading in sediment from Manzalah lagoon is determined by dividing the average metal contents in the upper 20 cm of a sediment core by its baseline (natural) values. In this study, the baseline concentrations are established from samples deeper than 45 cm (preindustrialization sediment deposits). In the study of pollution from anthrogenic activity, this is the cultural enrichment factor (CEF) (Fergusson 1990). The CEFs for the potentially toxic metals analyzed are given for each core in Table 3 and are displayed graphically in Fig. 6. Spatially, there is a progressive decrease in CEF values from core XV along the Ginka subbasin core transect from the Bahr El-Baqar outfall (Table 3; Fig. 6). This corresponds with the previously described decreases in metal concentrations in the

Table 3. Cultural enrichment factors for selected metals in cores from Ginka subbasin (XV, XIV, XIII, XII) and from other areas in Manzalah lagoon (XX, XXIII, II)

	Metal							
	Hg	Pb	Zn	Cu	Cr	Ag	Sn	As
CEF core XV	13.0	22.1	4.2	2.7	1.4	15.4	7.0	1.5
CEF core XIV	11.2	8.3	3.8	1.9	1.3	4.5	10.8	1.8
CEF core XIII	5.2	1.4	1.5	1.2	0.9	1.1	1.3	1.0
CEF core XII	2.1	2.3	1.3	1.3	1.3	2.2	0.9	1.3
CEF core XX	2.8	2.3	0.8	1.3	0.8	1.1	1.0	1.4
CEF core XXIII	1.9	8.1	1.1	1.1	0.9	0.9	1.0	1.1
CEF core II	1.1	1.5	0.9	1.1	0.9	0.9	1.1	1.4

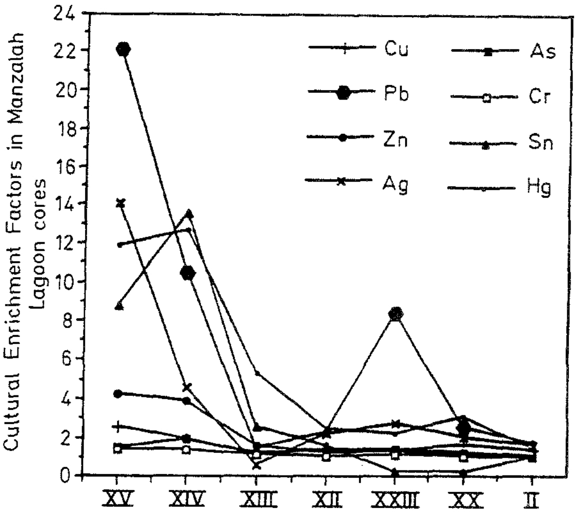

Fig. 6. Graphic representation of the cultural enrichment factors (CEFs) of the potentially toxic metals in the cores

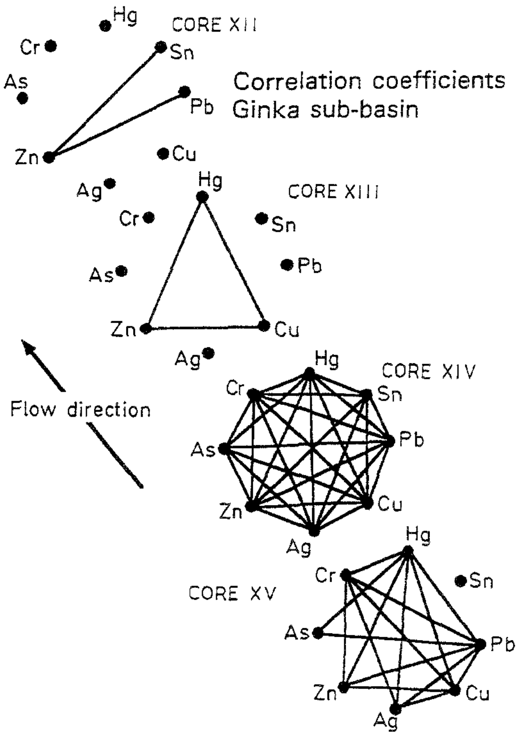

Fig. 7. Correlation coefficient nets showing the significant correlations among the eight potentially toxic metals evaluated in the cores studied. Only the cores in the Ginka subbasin had significant correlations. Core XV is close to the outfall of Bahr El-Baqar drain. A line between elements indicates a positive correlation at the 99.9 percent confidence level

upper 20 cm of Ginka subbasin cores with distance from the drain outfall (Fig. 4). The CEF values for cores outside the subbasin show little anthropogenic influence on metal contents (Table 3). Only Pb in core XXIII shows a high CEF, and this is from one high value for Pb in the sample from the core top (Fig. 5).

Correlation coefficients

The metals that are enriched in the Ginka subbasin cores show strong multielement intercorrelations significant at the 99.9 percent confidence level in cores XV and XIV. The element enrichments over background contents are the highest in these two cores. There are fewer significant correlations in cores XIII and XII along current flow in a direction away from Bahr El-Baqar drain outfall toward the subbasin outlet (Fig. 7). There are no significant correlations between these metals in cores outside the subbasin.

Discussion and conclusions

The highest concentrations for metal pollutants in Manzalah lagoon are in the Ginka subbasin cores and are in the upper 20 cm of the sediment sequence. Samples from core XV, closest to the outfall from Bahr El-Baqar drain, have the highest concentrations of heavy metals. Metal contents in the other cores along the sampling transect decrease with distance from the drain outfall. This decrease is seen for the entire upper 20-cm core sections and, in most cases, for corresponding sampling intervals. Bahr El-Baqar drain carries the waste stream from Cairo, 140 km to the southwest, which is added to by communities and industries along the reach of the drain for discharge into the Ginka subbasin. Metals in the drain and after discharge into the subbasin react according to the physical–chemical conditions and are dispersed following the flow path of water moving to the subbasin outlet.

Bahr El-Baqar drainwater is anoxic, perhaps azoic (Bishai and Yosef 1977; MacLaren 1981; Halim and Guerguess 1982; Toews 1986) and contains 8.5–17.8 ml/l dissolved H_2S (Dowidar and Abdel-Moati 1983). Similarly, water near the drain outfall contains 8.1–20.6 ml/l (mean of 15.3 ml/l) dissolved H_2S (Dowidar and others 1984). The lagoon water is anoxic to at least 0.25 km from the drain outfall (Bishai and Yosef 1977; Halim and Guerguess 1982; Toews 1986). Metals wastes discharged into the drain as soluble cations may adsorb onto suspended clay minerals or other active surface substrates that are discharged at the outfall. Metals may also react with the HS^- ion derived from H_2S at the pH (7.8) measured in the drainwaters and near the outfall (MacLaren 1981) to form colloidal sulfide minerals. The highest concentrations of metals mobilized in this manner might be expected to be in sediments close to the outfall. As particulates enter the hydrological flow, metal concentrations in the sediments should decrease as distance from the outfall increases. This is what is observed for the Ginka subbasin cores and for almost all equivalent sampling levels in the upper 20 cm. In the cores evaluated, significant metal pollution loading is seen for Hg, Pb, Zn, Ag, Cu, and Sn. The Cr loading is not strong, and As concentrations do not signal pollution. These metals, including the essential micronutrients Zn and Cu, can be harmful to different degrees, including causing death, for humans and other life forms in the ecosystem if they are ingested and bioaccumulate with time (Manahan 1991).

In humans, bioaccumulation from Manzalah lagoon could be through food fish captured in the Ginka subbasin within about 1.6 km of Bahr El-Baqar drain outfall where metal loading is highest in the sediment. A fillet sample of *Tilapia* sp., the most common food fish taken in Manzalah lagoon, obtained northeast of the Bahr El-Baqar outfall and outside the Ginka subbasin contained 0.29 ppm Hg and 0.71 ppm Pb (Lane 1992). These values are within World Health Organization maximum permissible concentrations (e.g., 0.5 ppm Hg) for fish, but this does not address bioaccumulation values that can develop. No fish samples have been analyzed from waters along the flow path of waters discharged from Bahr El-Baqar drain where heavy metal contents of sediments are the highest in the lagoon. Much of the food fish is consumed locally but much is also sold in Cairene markets.

Another pathway to human consumers for metal pollutants in the food web is via food crops grown by contaminated irrigation waters carried by Bahr El-Baqar drain or on reclaimed lagoon bottom that suffered metal loading previous to reclamation.

In Manzalah lagoon, metal pollution loading correlates temporally with industrial development that followed closure of the Aswan High Dam in 1964. Our data show that the Ginka subbasin in the southeast lagoon sector serves as a sink for industrial metal wastes carried to it by Bahr El-Baqar drain. Metal concentrations in cores XX, XXIII, and II indicate that the areas they represent, e.g., the northwest and south-central parts of the lagoon, are not significantly affected by metal pollution. The metal contamination reflected by the sediment chemistry does not seem to exit the subbasin in substantial amounts. The CEFs for Ginka subbasin cores and the other cores studied show this (Table 3).

Perspectives

The Global Environmental Facility Chairman's Report, presented in October 1992, states that the Manzalah ecosystem is in danger from three environmental risk factors: (1) long-term metal pollution loading, (2) inflow of agriculture-originated organic biocide compounds, and (3) eutrophication resulting from high nutrient input of municipal sewage and agricultural runoff (fertilizer and waste products) coupled with high photosynthetic activity.

If the chemical load carried by Bahr El-Baqar drain can be treated before discharge, metal pollutant loading can be reduced to levels acceptable by the World Health Organization. The quality of food fish as well as food crops grown with drain waters can be secured against long-term health risks from the bioaccumulation of toxic metals. Failure to do this could result in a situation such as experienced at Minimata Bay, Japan, where industrial discharge of a slug of Hg into the bay waters in 1953 resulted in its concentration along the food chain and bioaccumulation of the element in fish. The fish are important to the diet of the local inhabitants. In 1960, 43 people died of Hg poisoning, which progressively attacked their nervous systems, 116 more were permanently disabled, and thousands more are at risk for major health problems. The situation in Manzalah lagoon is less threatening than that which affected Minimata Bay, but over a longer period of time, without eliminating the existing problem, it could affect the Nile delta population.

The suggestion that a properly engineered and managed wetland (Manzalah lagoon) can resolve some of the environmental problems in the lagoon and posed by the lagoon for the Mediterranean Sea (Global Environmental Facility 1992) is excellent. This is especially true given the lack of economic resources to invest in and operate conventional treatment systems at or near the source discharges into the drain network. However, bioremediation that must be part of a managed, engineered wetland system, and the subsequent use of the biomass, could cause problems as threatening as those it could solve. If, for example, the biomass is used to produce animal feed and fuel pellets, its metal pollutants such as Hg and Pb and others must first be extracted. Any metal pollutants in animal feed risk bioaccumulation by the animal and transfer to human consumers for continued bioaccumulation. Some metal pollutants in fuel pellets (e.g., Hg and/or Pb) can result in long-term health risks from domestic or industrial emissions. Thus, in a plan for a managed wetland, in this case Manzalah lagoon, bioengineering must be exemplary in both concept and application. Stringent monitoring systems and schedules for metals in food fish, food crops, and waters and sediments in the lagoon and the drains are absolutely essential.

Although it is not the topic of this report, it should be noted that eutrophication of the lagoon is possible when the nutrient-rich load and high photosynthetic activity in the lagoon overcome the biological oxygen demand so that an anaerobic hypolimnion layer develops. However, at present, high primary productivity and wind mixing rejuvenate lagoon water and prevent eutrophication (Wahby and others 1972; Bishai and Yosef 1977; Halim and Guerguess 1982; Toews 1986). In the future, bioremediation may be useful in controlling eutrophic conditions in a managed Manzalah wetlands by balancing the amount of nutrient delivered to the amount of photosynthetic activity required in order to maintain an environment capable of sustainable aquaculture.

There is grave concern that the industrial-originated metals, the organic biocide compounds, and the nutrients that stimulate the eutrophication process, discharged into Manzalah lagoon, will seriously impact on the chemistry of coastal Mediterranean Sea waters and sediments. This concern is real and will be heightened in the near future as a serious and intensifying cumulative pollution threat because of the effect of several Factors that individually, or together, will increase the flow and interaction of lagoon water and seawater, which will harm both the Manzalah wetlands and the fragile Mediterranean environment. These include rising sea level and neotectonic subsidence in the Manzalah lagoon region (Stanley and Warne 1993), increased population and sewage discharge, increased agriculture and irrigation wastewater runoff, and increased industrial output and waste effluent discharge.

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References

Bishai HM and Yosef SF (1977) Some aspects of the hydrography, physico-chemical characteristics and fisheries of Lake Manzalah. UAR Bull Inst Oceanogr Fish 7:1–30

Christianson SR and Hemond HF (1991) Unmixing of Cs-137, Pb, Zn and Cd records in lake sediments. Environ Sci Technol 25: 1627–1643

Dowidar NM and Abdel-Moati AR (1983) Distribution of nutrient salts in Lake Manzalah (Egypt). Rapp P-V Reun CIESM 28:185–188

Dowidar NM and Hamza RW (1983) Primary productivity and biomass of Lake Manzalah, Egypt. Rapp P-V Reun CIESM 28: 182–192

Dowidar NM, Irgolic KJ, and Abdel-Moati AR (1984) Trace metals in Lake Manzalah, Egypt. Workshop, Pollution in the Mediterranean. Lucerne: CIESM, pp 331–337

Farmer JF (1991) The perturbation of historical pollution records in aquatic systems. Environ Geochem Health 13:67–73

Fergusson JE (1990) The heavy elements: Chemistry, environmental impact and health effects. New York: Pergamon Press, 412 pp

Global Environmental Facility Chairman's Report (1992) Part Two. Washington, DC: pp 182–199, UNDP/UNEP/World Bank

Halim Y and Guerguess SK (1978) Eutrophication in a brackish delta lake. J Etud Pollut Attaya, Monaco CIESM 4:435–438

Halim Y and Guerguess SK (1982) Oxygen distribution in Lake Manzalah. Oceanol Acta 5:309–312

Lane P & Associates (1992) Global Environmental Facility: Egyptian engineered wetlands—environmental impact assessment. E-388, New York: United Nation Development Programme 2 vol

MacLaren Engineers, Planners and Scientists Inc. (1981) Lake Manzalah study: Report to Arab Repub. Egypt and UNDP. EGY/76/001/07, Cairo: Ministry of Development and New Communities 12 vol

Manahan SE (1991) Environmental chemistry. Chelsea, Michigan: Lewis Publ., 583 pp

McComas SR (1983) Metal and chlorinated hydrocarbon status of surficial sediments from three Nile Delta lakes, Egypt. MS thesis. University of Minnesota, Minneapolis, Minnesota 240 pp

Randazzo G (1992) Evoluzione del Delta del Nilo: Confronto tra i sedimenti attuali e recenti della laguna Manzala e gli ambienti e recenti olocenici della piana deltizia. Unpublished doctoral thesis. University of Messina, 95 pp

Saad MAH, McComas SR, and Eisenreich SJ (1985) Metals and chlorinated hydrocarbons in surficial sediments of three Nile Delta lakes, Egypt. Water, Air and Soil Pollut 24:27–39

Stanley DJ (1988) Subsidence in the northeastern Nile Delta: Rapid rates, possible causes, and consequences. Science 240:495–500

Stanley DJ (1990) Recent subsidence and northeast tilting of the Nile delta, Egypt. Marine Geol 94:147–154

Stanley DJ and Warne AG (1993) Nile delta: Recent geological evolution and human impact. Science 260:628–634

Toews DR (1986) Fisheries transformation on Lake Manzalah, Egypt during the period 1920–1980: Toxic contamination in large lakes. In: Schmidtke NW (ed), Proceedings from 1986 World Conference on Large Lakes. Chelsea, Michigan: Lewis Publishers, pp 25–51

Wahby SD, Yosef SF, and Bishara NF (1972) Further studies in the hydrography and chemistry of Lake Manzalah. UAR Bull Inst Oceanogr Fish Egypt 2:401–422

World Bank (1993) World Development report 1993: Investing in health. New York: Oxford University Press, 329 pp