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FLUSHING TIME AND PRELIMINARY MASS BALANGE ESTIMATES OF SOME TRACE METALS IN MEX BAY, WEST OF ALEXANDRIA

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ABSTRACT

Mex Bay has a flushing time ranging from 1.1 day in winter and 2.8 day in summer. Mass balance estimates of some trace metals (Pb, Cd and Hg) in the Bay revealed that the net seaward fluxes of Pb and Cd are considerably higher than the metals inputs from Umum and chloralkali effluents. For Hg the net seaward flux is comparatively smaller than that supplied by the effluents. This suggests the importance of other sources and sinks in the mass balance formulations of these metals. The mean concentrations of the total Pb, Cd and Hg in the Bay waters do not seem, until now, to reach the levels that threaten the living organisms existing in this area.

INTRODUCTION

Mex Bay is one of the main fishing grounds in the west of Alexandria, Egypt. It has an area of about 30 km^2 (including the Western Harbour) and an average depth of about 9 m. The Bay is affected by pollutants of different kinds from several sources ; mixed agricultural runoff from Umum drain, industrial wastes from a chlor-alkali plant and sanitary effluents, mostly from the main sewer of Alexandria at Kayet Bey (Figure 1). In addition, the Bay receives airborne particles from the fumes of an adjacent oil refinery and a cement factory.

Waste disposal into Mex Bay is known to increase the concentration of some heavy metals such as Hg, Cd and Pb, especially in the vicinity of industrial and drain outfalls (Aboul Dahab et al., 1984; El-Rayis et al., 1984 and Aboul Dahab,1985). In the last few years attention has been given to trace metals in the aquatic environment off Alexandria, including Mex Bay (El-Nady, 1981 and Halim, 1983). Investigations of total Hg in recent sediments on the inner shelf (El-Sayed and Halim, 1979) and its level in biota (El-Sokkary 1980, Aboul Dahab 1985, Halim et al. 1984) have revealed the existence of a mercury problem west of Alexandria (Mex Bay). The environmental conditions in Mex Bay, and in particular the level and fate of heavy metals, have been intensively investigated by the Aquatic Environmental Pollution Project of Alexandria University (Aboul Dahab et al., 1984, El-Rayis et al.,1984). El-Gindy

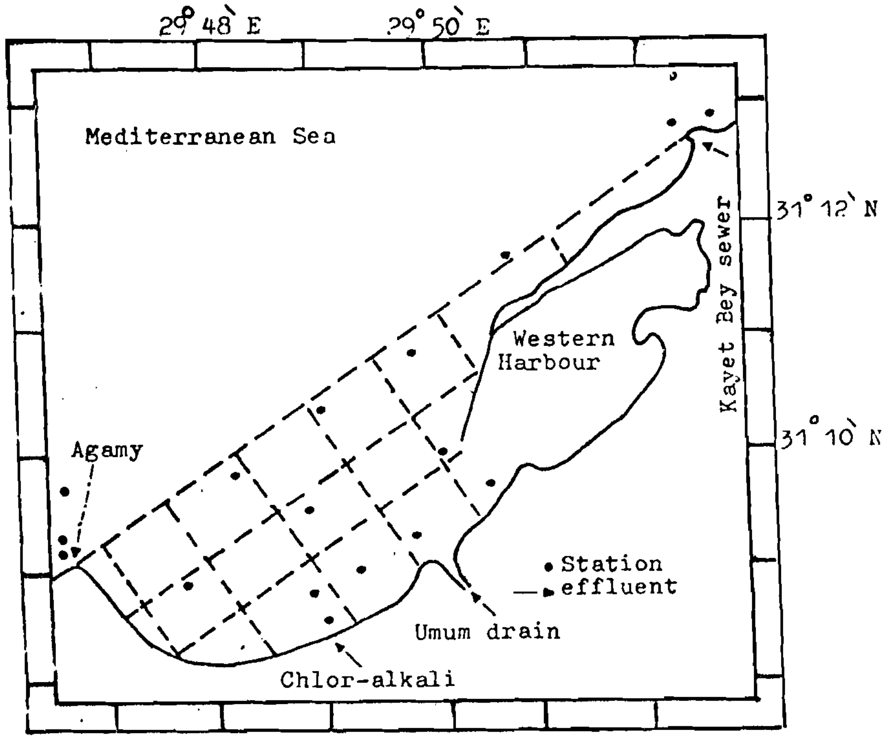

FIG. 1.
Map of Mex Bay, showing locations of stations, main effluents, and grid used.

(1986) made a preliminary estimate of the mass balance of some trace metals in this Bay. He did not take into consideration, however, the seasonal fluctuations of fresh water and trace metal fluxes into the Bay and did not include the Western Harbour in his calculation of fresh water standing stock in Mex Bay.

The aim of the present work is to calculate the flushing time of the Bay and to estimate the mass balance of the three metals: Hg, Cd, and Pb, taking into account their physical forms and their seasonal fluctuations. The concentration levels of the metals in relation to some proposed water quality standards are also considered.

MATERIAL AND METHODS

The data used in the present work were collected in the framework of the Aquatic Environmental Pollution Project of Alexandria University (Aboul Dahab et al., 1984 and El-rayis et al., 1984). Four seasonal cruises have been carried out between August 1983 and August 1984. A relatively large data base has been generated on the water quality of the effluents, the hydrochemical conditions of the Bay, the cycle of trace metals, particularly mercury, and on nutrient dynamics. Data on salinity and on discharge rates of fresh water into the Bay were used to calculate the flushing time of the Bay in both winter and summer, and to estimate the rate of exchange of salt water between the Bay and open sea. In these estimates a two layer model of circulation was applied (Bowden, 1967; Officer, 1976). Data on metal concentrations in the effluents and in the Bay water together with the calculated salt water fluxes at the open boundary of the Bay were used to estimate input and output rates of metals and their standing amounts in the Bay.

Flushing Time and Water Budget:

The flushing time t is defined as the time required to replace the existing fresh water in an estuary at a rate equal to the effluent discharge. The period that a pollutant material will spend in the estuary before being swept out to the sea depends on the flushing time. The greater the flushing time, the longer the pollutants will remain in the estuary and the greater will be the resulting steady state of their concentration (Bishop,1983).

The flushing time of Mex Bay was calculated as follows:

1- The vertical average salinity $\bar{S}$ at each hydrographic station (Fig. 1) is given by

$$\bar{S} = \frac{1}{h} \int_{0}^{h} \bar{s}\, dz \qquad (1)$$

where h is the total depth and s is the average salinity in the layer dz in thickness.

2- The Bay was divided into 18 boxes (Fig. 1) and the volume of each box V_i ($10^6 m^3$) calculated using the bathymetric chart of the Bay.

3- Salinity value at the center of each box, S_i, was interpolated from the values of s.

4- The fraction of fresh water F_i within each box i is given by

$$F_i = (\sigma - S_i) / \sigma \qquad (2)$$

where o is the normal salinity of the offshore water. Present observations showed that o equals 39.40 ‰ in winter (February 1984) and 39.10 ‰ in summer (August 1984).

5- The volume of fresh water in the Western Harbour was estimated from the mean salinity at the stations nearer to the Harbour outlet and at some stations inside the Harbour (Farag, 1982).

6- The volume of fresh water in Mex Bay is given by

$$V_f = \sum V_i F_i \qquad (3)$$

and the flushing time (Dowden, 1967 and Officer, 1976) by

$$t = V_f / R \qquad (4)$$

where R is the rate of discharge of fresh water into the Bay from both Chlor-alkali and Kayet Bey outfalls and from Umum Drain.

Although the rate of fresh water discharge into the Bay is higher in winter, the volume of fresh water existing in the Bay in this season is smaller than that observed during Summer (Table 1). The average vertical distribution of salinity in Mex Bay (Figure 2) also shows that the Bay water is more saline in winter and less saline in summer. The flushing time of Mex Bay was found to range from 1.1 day to

TABLE 1

Flushing time and water budget in Mex Bay.

Season	R ($10^6 m^3 day^{-1}$)	V_f ($10^6 m^3$)	t (day)	T_i ($10^6 m^3 day^{-1}$)	T_o ($10^6 m^3 day^{-1}$)
Winter	8	8.9	1.1	257	265
Summer	5	14.2	2.8	125	130
Average	6.5	11.6	2.0	191	198

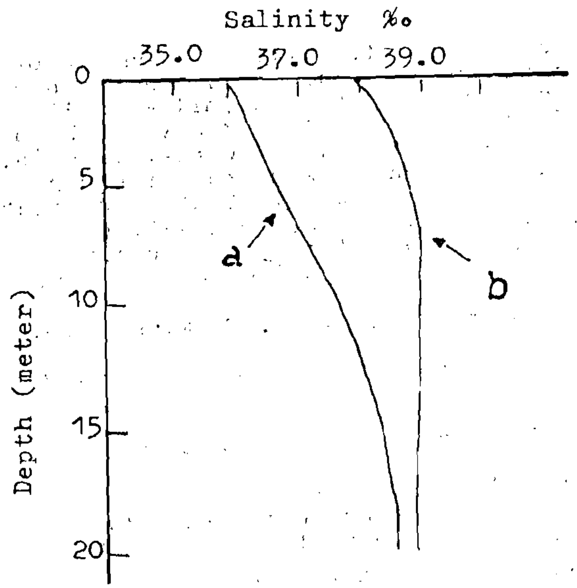

FIG. 2.
Vertical distribution of average salinity in Mex Bay, a- in Summer, b- in Winter.

2.8 day in summer. Pollutants discharged into the Bay during summer, therefore, will remain longer and consequently their steady state concentration will be greater in this season.

In the two-layer model adopted (Bowden, 1967 and Officer, 1976) it is assumed that the exchange of water between the Bay and the sea takes place entirely by advection; horizontal diffusion being negligible. The rate of flow can be calculated, therefore, from a knowledge of the mean salinity of the inflowing and outflowing layers and the fresh water influx (Bowden, 1967 and Officer, 1976). Let T_o be the volume transport and S_o the salinity in the outflowing water, T_i, S_i the corresponding quantities for the inflowing water. Assuming stationary conditions in both winter and summer, continuity of water and salt gives

$$T_o = R\,S_i / (S_i - S_o)\ ,\ T_i = R\,S_o / (S_i - S_o)$$

For the winter season, the data indicate that S_i = 39.10 ‰. and S_o = 37.92 ‰., while for the summer season S_i = 38.90 ‰. and S_o = 37.40 ‰. .

Table 1 shows that the rate of exchange of water between the Bay and the sea in winter is much higher than that observed in summer. The average inflow is 191 x 10^6 m^3 day^{-1} and the outflow is 198 x 10^6 m^3 day^{-1}. The observed higher rate of water exchange during winter is mainly due to the larger fresh water input and the frequent occurrence of strong wind (about 22 knot) that accelerates horizontal circulation and increases the intensity of vertical mixing within the Bay. This results in the observed higher salinity and shorter flushing time during that season.

Mass Balance Estimates of lead, Cadmium and Mercury:

The different sources and sinks of trace metals in Mex Bay are:

- Effluents discharge, coastal erosion and leaching from ships.
- Exchange with the open sea.
- Volatilization and atmospheric fallout.
- Sedimentation and release from sediment.
- Exchange with biota and fishing activity.

Coastal erosion, leaching from ships, fishing activity, exchange with atmosphere, sediment and biota are disregarded at this stage, due to the lack of data required for their estimation. Other parameters in the balance are estimated as follow:

- The input of metals into the Bay was estimated from their concentrations in the chlor-alkali and Umum effluents (Aboul Dahab, 1985) and the discharge rates of these two effluents.

- Metals input and output due to the exchange with the open sea were estimated from the rate of exchange of Bay water with the sea and the mean concentrations of the metals in the upper and lower layer of the Bay at its open boundary.

The inputs of the three metals (Pb, Cd and Hg) from the main effluents (Umum and chlor-alkali) to the Bay are larger in winter than in summer. Pb was mostly in the particulate form, while Cd was mainly in the dissolved form. In case of Hg, both particulate and dissolved forms have, approximately, the same contributions to the total Hg input to Mex Bay (Table 2).

Although the rates of discharge of trace metals into Mex Bay are higher in winter, the amountes of trace metals existing in the Bay are relatively smaller in this season than in summer. From Table 2, it is clear that most of Pb and Hg within the Bay are in the particulate form while Cd remains mainly in a dissolved form.

The exchange rates of trace metals between the Bay and the open sea are, generally, higher in winter. There is a net seaward flux of trace metals (Pb, Cd and Hg) from the Bay, mainly in the particulate form for Pb and Hg and in the

TABLE 2

Mass balances, proposed marine water-quality standards and weighted average concentration of some trace metals in Mex Bay.

Pb			Cd			Hg		
D	P	T	D	P	T	D	P	T
Average input from effluents ($kg\ day^{-1}$)								
10.9	29.5	40.4	1.7	0.6	2.3	3.4	3.0	6.4
Average standing amount of metal (kg)								
64.0	128.0	192.0	41.1	7.8	48.9	3.0	12.2	15.2
Average outflow to the sea ($kg\ day^{-1}$)								
29.5	76.5	106.0	19.0	5.0	24.0	1.5	5.8	7.3
Average inflow to the Bay ($kg\ day^{-1}$)								
6.5	12.0	18.5	9.8	2.3	12.1	1.0	2.5	3.5
Net seaward flow ($kg\ day^{-1}$)								
23.0	64.5	87.5	9.2	2.7	11.9	0.5	3.3	3.8
Weighted average concentration ($u\ gl^{-1}$)								
		0.7			0.2			0.06
Proposed standard ($u\ gl^{-1}$)								
		8.0			3.0			0.14

(D=dissolved, P=particulate, T=total)

dissolved form for Cd (Table 2). The net seaward fluxes of Pb and Cd are considerably higher than the rates of discharge of these metals into the Bay from both Umum and chlor-alkali effluents. The net seaward flux of Hg is comparatively smaller than that supplied by the effluents. Thus, for Pb and Cd the other sources (e. g. atmospheric fallout, leaching from ships, etc.) have a considerable contribution to their mass balances, while for Hg the sinks (e. g. sedimentation, biological activity, etc.) contribute considerably to its mass balance in Mex Bay.

Water Quality:

Mex Bay is contaminnated with Pb, Cd and Hg in the vicinity of both the industrial and drain outfalls (Aboul Dahab et al., 1984, El-Rayis et al., 1984). According to the standards of marine water proposed by the State of California (Klapow and Lewis, 1979; in Bishop, 1983) the weighted average concentrations of Pb, Cd and Hg in Mex Bay are generally lower than the proposed standards for marine water (Table 2). Pb and Cd concentrations obtained fall within the ranges found by Nurnberg et al. (1977) for the Ligurian and Tyrrhenian coastal waters. The mean total concentration of Hg is comparable to that on the Istrian coast and in the Adriatic (Anon., 1983).

SUMMARY AND CONCLUSIONS

The data collected during the activity of the Aquatic Environmental Pollution Project of Alexandria University (Aboul Dahab et al., 1984 and El- Rayis et al., 1984) were used in the present work to calculate the flushing time of Mex Bay, to estimate the mass balances of three toxic metals (Hg, Cd and Pb) and to evaluate the concentration levels of these metals in relation to some proposed water quality standards for trace metals.

Although the rates of discharge of fresh water and trace metals (Pb, Cd and Hg) into the Bay are higher in winter, the amounts of fresh water and trace metals existing in the Bay are relatively smaller than in the summer season.

The flushing time was found to range from 1.1 day in winter and 2.8 day in summer. Thus the trace metals discharged into the Bay during summer will remain longer and consequently their steady state concentrations of exchange of water and trace metals between the Bay and the sea during winter season are, generally, higher than in summer. This is mainly due to the larger fresh water input and to the frequent occurrence of relatively strong wind during winter enhancing mixing inside the Bay and accelerating the exchange of water and any other material between the Bay and the sea. The net seaward fluxes of Pb and Cd are considerably higher than the rates of discharge of these metals into the Bay from Umum and chlor-alkali effluents, while for Hg it is comparatively smaller than that supplied by these two effluents. This suggests the importance of the other sources and sinks in the mass balances formulations of these trace metals.

The weighted average concentrations of Pb, Cd and Hg in Mex Bay are, generally, lower than the proposed standards for marine water. Metal pollution in this Bay dose not seem, until now, to reach the levels that threaten the living organisms existing in that area.

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