

RESEARCH ARTICLE

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DISSOLVED LABILE AND NON-LABILE TRACE METAL IN EL-MEX BAY WATER, ALEXANDRIA, EGYPT**ABSTRACT:**

El-Mex Bay is a part of Alexandria coast on the Mediterranean Sea. It is subjected to effluents contaminated with several anthropogenic materials including trace metals. One of these effluents is called Umum agricultural drain (rate $8 \times 10^6 \text{ m}^3/\text{d}$). The trace metals (Fe, Mn, Cu, and Cr) in their labile and non-labile forms were determined seasonally in El-Mex Bay surface and bottom water. The determination of the respective labile and non-labile forms was made using chelating cation exchange resin (Chelex-100) and total dissolved metal. Some of hydrographical parameters as (water temperature, salinity, pH, dissolved oxygen (DO) and oxidizable organic matter (OOM) were also studied. The relations between these parameters and the labile and non-labile trace metals were investigated. The results revealed that the order of abundance among the labile forms of the metals was: $\text{Fe} > \text{Cr} > \text{Cu} > \text{Mn}$. Also most of them displayed a negative relationship with salinity, indicating the role of El-Umum Drain as a main contributor of them to the Bay. Moreover, they were at contamination level overcome the background of Oceanic concentration (WQC) but were still lower than the hazardous one. The non-labile dissolved trace metals forms were of concentration values higher than the corresponding labile one and have the same order. Vertically, the high values were found in the bottom more saline water.

KEY WORDS:

labile form, non-labile, trace metals, El-Mex Bay, Alexandria.

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INTRODUCTION:

The elevation in levels of trace metals concentrations in marine environment is a worldwide problem and the discharge of trace metal wastes has many obvious impacts on water, sediments, and biota, led to decrease in productivity, and increase in exposure of humans to harmful substances. The toxicity, bioavailability, bioaccumulation, biodegradability, persistence, mobility, solubility, extractability and many other critical properties is found to depend on the form and nature of the chemical species (Lores and Pennock, 1998). Metals exist in our natural waters in different labile and non-labile forms, but the labile ones are the most important in the environment. They are responsible for bioaccumulation of toxic metals in biota, animals and finally in humans. Therefore, measurement of labile trace metal species in natural waters is essential (Tercier, *et al.*, 1990). According to Lien *et al.* (2007), four categories of dissolved species could be identified (very labile, moderately labile, slowly labile and inert), in addition to particulate species. The labile fraction includes the free metal ion and those less stable metal complexes (which can dissociate immediately) giving the free metal ion and producing an anodic stripping voltametry (ASV) signal. The non-labile fraction includes the more stable metal complexes (and/or fine colloidal) not easily dissociated (Scoullou and Pavlidou, 2000).

In the present work the use of Chelex 100 resin chelating ion exchange resin, was successfully prepared and showed good capabilities for the determination of the labile metals Cr, Cd, Pb and Ni species in both natural river and waste waters, and is currently applied for one of the Alexandria coastal waters at EL-Mex Bay.

El-Mex bay is lying on the Mediterranean Sea and is considered as one of the main fishing grounds. It has surface area of about 19.4 km^2 , and mean depth of about 10 m (Labib, 1997). It receives a heavy load of agricultural, municipal and industrial wastewaters ($7 \times 10^9 \text{ m}^3/\text{year}$) via El-Umum Drain (EL-Rayis and Abdulah, 2006). In addition to direct discharge from five main industries, Chemical, Chloro-

alkali, Tanneries, Cement, and Petroleum, besides additional amount of municipal wastewater from the main sewer of Alexandria (Mikhail *et al.*, 2001). The present work is an attempt to determine each of labile and non-labile forms of the metals (Fe, Mn, Cu, and Cr).

MATERIAL AND METHODS:

Study Area and Sampling Stations

El-Mex Bay (Fig. 1) is elliptical in shape, extends for about 15 Km between El-Agamy headland to the west and the Western Harbor (WH) to the east, and from the shoreline seaward to a depth of 20 m.

Surface and bottom water samples were seasonally collected from six stations in El-Mex Bay area and one sample from the land based source (Umum Drain) during a year 2004 (Fig. 1). The water samples were collected using Niskin's bottle and were kept in acid pre-cleaned polyethylene Jerry can.

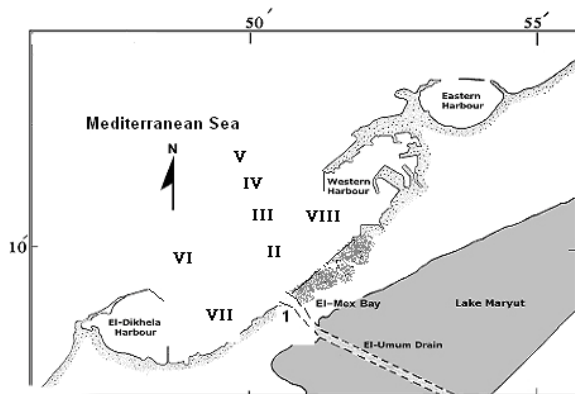


Fig. 1. Map of sampling stations (El-Mex Bay)

In laboratory, the water samples were filtered through 0.45 μ m membrane filters and were stored at 4°C until analysis. The environmental parameters (temperature and the pH values) of the water samples were measured *in situ*. Waters for salinity were also collected and measured in the Lab using bench-Salinometer (Bekman, Model RS-10). Water samples for DO determination was in addition collected and determined according to the classical Winkler method (Strickland and Parsons, 1972). Moreover separate water samples were used for measurement of Oxidizable organic matter (OOM) according to FAO (1976).

Total dissolved Cu, Fe, Cr and Mn were determined in part of the filtered sample after gentle boiling (100 ml) and adding 1 ml of concentrated HNO₃ in Teflon beaker. Then the sample was concentrated by evaporation to near dryness after that 2 ml HCl and 1 ml HNO₃ were added and reevaporate to near dryness again. Redissolution of the residual using 0.1 N HCl was done (Van Loon, 1982).

For labile metals, the other part of filterable sample (2 L) was allowed to pass through a glass column containing the chelating

resin (Chelex-100 in ammonia form) as described by Riley and Taylor (1968). The labile form includes free ionic forms plus any labile complexes whose stability constant less than metal with resin (Abdallah *et al.*, 1976; Förstner and Wittman, 1981). The non-labile metal, strongly bound organic and inorganic calculated by the difference between total filterable metal and labile metal. All trace metal concentrations were determined using flame- Atomic Spectrophotometer (Perkin Elmer. 2380).

Quality control sample

All reagents used were of analytical grade Chelex-100 of 200-400 mesh and concentrated HNO₃ and HClO₄ 70 % were used. To ensure low trace metal blanks, a Milli-Q water purification system was used. All glassware and polyethylene bottles and apparatus were pretreated with 10 % solution of HNO₃ for two days. To minimize the adsorptive losses of trace metals from water samples, all equipments were equilibrated with purified 2 mM CaCl₂ in 2 M tris (hydroxymethyl) amino methane / HCl overnight before use (Figura and McDuffie, 1977). The detection limit (0.2 μ g l⁻¹) was calculated by six determinations (duplicate measurements) in one batch of synthetic seawater. The precision of analytical method was determined by analysis of six replicate samples of stripped seawater and spiked with certain concentrations of different metals (5 μ g l⁻¹), it was expressed as coefficient of variation (C. V.), and the results of the precision was in the range of 10%. The accuracy of the pre-concentrated technique of dissolved metals was performed by spiking 2 liters of seawater, previously stripped of all metals by Chelex-100 resin with different concentration of 1,2,4,6 and 8 μ g l⁻¹, the spiked samples were passed through the resin and the results showed 4% deviation from the certified values.

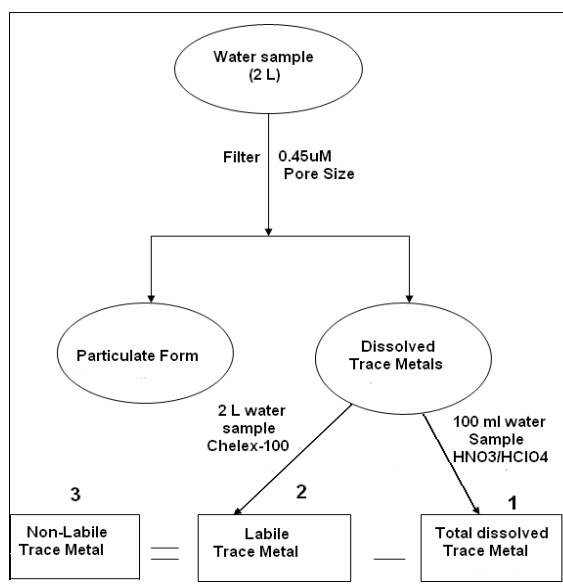


Fig. 2. Flow chart of the trace metals speciation

RESULTS AND DISCUSSION:

1- Physico- Chemical Characteristics of Seawater

Table 1 lists the average annual values of the environmental parameters (pH, salinity; oxidizable organic matter, and dissolved oxygen) in El-Mex Bay.

Table 1. Average values of water quality parameters of El-Mex Bay during a year 2004.

St.	Salinity		Organic matter (mgO ₂ /l)		DO (mg/l)		Range pH Values	
	S	B	S	B	S	B	S	B
I	4.17	18.98	6.38	4.12	1.87	1.27	7.28-7.82	7.85-8.35
II	4.36	25.25	6.12	3.22	1.31	1.55	7.33-7.74	7.95-8.25
III	30.82	38.98	2.70	0.52	6.12	4.59	7.90-8.31	7.95-8.25
IV	24.09	38.06	3.06	0.76	3.94	4.69	7.80-8.45	8.05-8.2
V	17.57	40.00	3.52	0.60	4.64	6.01	7.75-8.43	8.05-8.20
VI	29.65	38.40	2.12	1.08	5.08	4.96	5.05-5.21	8.00-8.10
VII	31.44	39.72	2.44	0.96	5.96	4.14	8.15-8.55	7.95-8.2
VIII	28.16	39.60	1.96	1.08	4.63	2.91	8.15-8.48	7.95-8.25

The average values of water temperature showed fluctuation between 23.65 ± 5.4 to 28.14 ± 5.4 and from 25.62 ± 5.6 to 22.5 ± 4.7 for surface and bottom water, respectively. Slight variations of temperature are strictly related to seasonal conditions. The vertical distribution pattern of water temperature illustrates that surface temperatures were generally higher than those of the bottom water throughout of the year.

The average values of salinity are fluctuated between 4.17 ± 0.43 ‰ at the outlet of Umum Drain (site I) and 31.43 ± 5.65 ‰ at site VII for surface water. Bottom water salinity ranged from 38.98 ± 1.25 ‰ at site IV to 40 ± 2.09 ‰ at site V. Wide variations were observed at different investigated sites according to the distance of the different sites from the effluents. Vertically salinity distribution in the Bay showed a noticeable increase in the bottom waters compared to those of surface water. These results revealed that El-Mex Bay is characterized by the presence of two water layers overlying each other, an upper brackish layer and a lower diluted seawater layer, consistent with similar behavior reported by Mahmoud *et al.* (2005).

The pH values ranged from 8.09 to 8.25 and from 8.05 to 8.11 for surface and bottom water, respectively. The lower pH values were observed at site I (inside El-Umum Drain) and site II (in front of El-Umum Drain). This suggests the effects of different effluents are more significant in the surface water of El-Mex Bay. Moreover, the vertical pH values in the Bay showed relatively high levels in the surface

waters comparing with those recorded in the bottom water. The results revealed that variation of pH values in the Bay was very limited within the stations during the year.

The average DO concentrations varied from 1.31 ± 0.52 mg/l at site II to 6.18 ± 2.44 mg/l at site III and from 2.90 ± 1.61 at site VIII to 4.69 ± 3.06 mg/l at site VI for surface and bottom water, respectively. Relatively low levels of DO were observed at sites I and II which affected by the sewage discharge from El-Umum Drain. High DO content was observed at the northern part of the Bay, where the stations were located further away from the direct effect of sewage discharge. Generally, DO content of the surface water is relatively high when compared with that of bottom measurements. The high values in surface water may be due to the dissolution of O₂ from the air to the surface water. While, the low values in the bottom water may be attributed to respiration at greater rate by marine organisms and biochemical transformation of organic matter.

The regional average concentrations of OOM ranged from 1.96 to 6.38 and from 0.52 to 4.12 for surface and bottom water, respectively. High values of oxidizable organic matter in surface water of El-Mex Bay indicating water pollution, which is linked to sewage effluents discharged to the area (6 million m³/day), industry and agriculture practice. Vertical distribution showed decrease with depth at most stations, while seasonal variation presented abrupt fluctuations during the year due to external manipulation of the Bay.

2- Dissolved trace metals

The regional and seasonal variation of the average values of trace metals species (Cr, Cu, Fe, and Mn) are shown in figure 3 and table 2.

2.1. Labile trace metals

Seasonal variation of labile metals concentration (Cr, Cu, and Mn) in the investigated area showed high levels during the summer period, while the labile Fe concentration was decreased (Fig. 3).

The data of the present study indicated that the regional mean values of labile form of dissolved metals in surface water ranged from 2.65 ± 0.94 to 11.65 ± 12.33 µg/l for Cr, 1.84 ± 1.68 to 12.64 ± 2.20 µg/l for Cu, 6.07 ± 4.07 to 32.53 ± 21.99 µg/l for Fe and 2.16 ± 0.14 to 4.68 ± 0.87 µg/l for Mn. In the same respect, these values for bottom water were in the following: 2.01 ± 1.15 to 4.19 ± 3.23 µg/l for Cr, 1.13 ± 1.93 to 13.39 ± 3.35 µg/l for Cu, 6.73 ± 8.24 to 26.31 ± 15.20 µg/l for Fe and from 3.03 ± 0.69 to 8.50 ± 0.19 µg/l for Mn (Table 2). It is clear that the high values for all metals were recorded at the surface water except for station I which showed reverse trend. The order of metals in labile form was as the following: Fe > Cr > Cu > Mn. In general the values of Cr and Cu in labile form were relatively homogeneously

distributed and maximum values were recorded at stations I and II. Table 3 reveals a significant correlation between Cr and Cu with $r = 0.74$ ($n = 32$, $p = 0.05$). However, distribution of Fe showed fluctuated among different stations for surface and bottom water. This may be related to the physical mixing of brackish and marine waters, which leads to a continuous decrease in trace metal content of seawater in El-Mex Bay with

increasing salinity (Emara and Sheriadah, 1991). Zeri and Voutsinou-Taliadouri (2003) should that the distribution and behaviour of trace metals in seawater is affected by various processes, such as: mixing of water bodies; particle-water interaction, either through biological uptake or through adsorption-desorption mechanisms; and diffusion from bottom sediments.

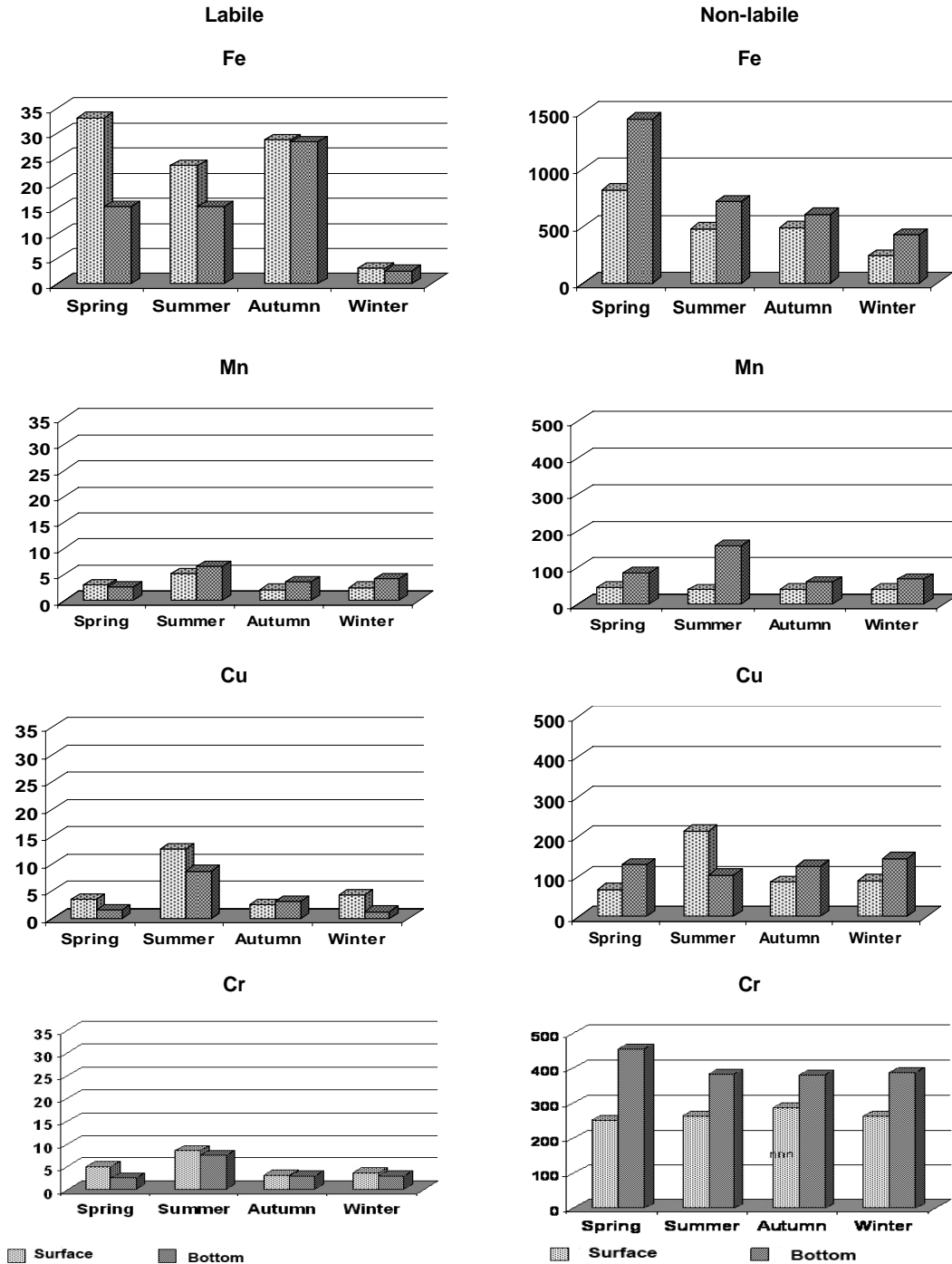


Fig. 3. Seasonal variations of the average values of different metal species (µg/l) in El-Mex Bay water

Table 2. Regional variations of the average values of different metal species ($\mu\text{g/l}$) in El-Mex Bay water

Metal	Station	Labile				Non-Labile			
		Surface		Bottom		Surface		Bottom	
		Ave \pm SD		Ave \pm SD		Ave \pm SD		Ave \pm SD	
Cr	I	4.70	1.93	2.01	1.15	109.87	107.11	142.36	100.34
	II	11.65	12.33	3.02	1.49	113.08	105.28	180.07	95.01
	III	5.24	2.26	4.19	3.23	353.67	95.63	470.31	60.15
	IV	3.29	1.08	2.64	1.50	273.91	141.75	425.76	76.10
	V	4.43	0.78	2.71	0.30	261.74	81.12	399.30	52.20
	VI	5.55	2.31	2.78	0.47	324.03	130.13	403.87	91.13
	VII	3.71	0.35	4.12	1.83	345.94	31.41	456.64	113.41
	VIII	2.65	0.94	2.99	1.09	356.45	100.97	432.81	115.56
Cu	I	12.64	21.20	13.39	23.35	46.30	23.87	62.83	43.16
	II	11.71	16.68	3.13	1.93	42.11	26.06	66.02	39.94
	III	6.87	5.29	1.31	1.07	93.84	37.26	127.10	66.81
	IV	3.34	2.32	2.76	2.94	78.56	44.17	118.27	11.35
	V	3.66	2.02	1.78	2.04	70.36	13.17	139.45	15.95
	VI	2.70	2.03	1.93	0.59	384.75	541.36	123.02	14.07
	VII	3.44	0.50	3.37	3.12	101.30	12.06	193.50	84.55
	VIII	1.84	1.68	1.63	0.82	101.06	41.81	180.45	58.63
Fe	I	25.06	20.06	23.40	15.61	386.04	290.98	649.48	566.84
	II	25.00	21.21	16.40	15.47	476.47	315.86	681.99	574.13
	III	32.53	21.99	23.98	15.16	484.06	166.02	1215.66	1035.91
	IV	21.21	15.71	26.31	19.77	409.14	259.31	560.49	402.95
	V	16.40	11.20	6.73	8.24	298.11	209.77	805.86	272.83
	VI	27.72	18.45	10.17	0.66	631.81	137.10	327.77	237.65
	VII	22.72	20.09	12.56	18.88	459.10	259.48	1532.39	2034.74
	VIII	6.07	4.07	13.01	14.74	896.95	934.17	593.33	195.73
Mn	I	3.60	1.58	8.50	9.19	30.32	18.93	113.03	115.91
	II	3.87	3.40	3.90	1.57	21.42	15.87	113.03	133.84
	III	3.44	1.86	3.63	1.81	50.28	18.37	143.69	113.45
	IV	2.16	0.14	3.38	0.80	39.10	27.86	61.61	11.81
	V	2.50	0.57	3.03	0.69	27.80	25.59	75.41	15.38
	VI	4.68	4.87	4.71	3.75	59.51	21.88	59.63	5.56
	VII	3.26	1.65	3.45	0.24	55.77	11.60	106.68	67.73
	VIII	2.24	1.41	3.26	0.58	48.36	11.42	74.88	16.49

Table 3. Comparison of level of dissolved labile trace metals concentrations ($\mu\text{g/l}$) with those in other studies in the region.

	Fe	Cu	Cr	Mn	Reference
El Mex-Bay Range	3.36-31.72	1.84-11.71	2.65-9.68	Nd-4.23	Present study
Gulf of Suez Range	4.92-15.3	1.64-3.72	0.04-0.13	0.92-2.5	Hamed, 1996
El Mex-Bay Range	5.14-16.89	1.91-3.35	-	-	Okbah, 1999
El Mex-Bay Range	17.14	0.71	0.11	0.16	El-Moselhy and
Egyptian Sea west area	9.02	14.60	-	2.55	Shakweer <i>et al.</i> , 2006
Egyptian Sea east area	10.80	5.96	-	5.05	Shakweer <i>et al.</i> , 2006
El-Mex-Bay Range	27.21-70.91	3.69-4.90	1.48-7.06	2.7-31.28	Maha, 2008
El-Mex Bay	22.7	-	-	1.73	Emara and Shereadah, 1991
Oceanic water	3.00	3.00	0.60	2.00	WQC, 1972
Minimal risk conc.	50	10	-	20	WQC, 1972
Hazardous conc.	300	50	-	100	WQC, 1972

Figure 3 shows the seasonal variation of trace metals in the study area. It is clear from the figure that maximum values of Cr, Cu, and Mn were recorded during summer, while maximum values of Fe were recorded during autumn for surface and bottom waters and in spring for only surface water. This may be attributed to the influence of drainage wastewater from the surrounding area. The results showed remarkable decreasing in the concentrations of different labile metals towards the sea water (St V) and around the eastern region of the Bay due to the dilution with large amount of wastewater from the Western Harbour.

In comparison with other published data in different coastal seawater (Table 3), the concentration of Fe is similar to those reported by Okbah and Nasr (2006) along the Mediterranean Sea in front of Nile Delta region of Egypt. On the other hand, the Mn concentration in the present study decreased three folds than the coastal zone of Nile Delta region and similar to the mixed zone. Also, the concentration of Cu was approximately six folds higher than those reported by Okbah and Nasr (2006). Generally, concentration of surface dissolved metals in El-Mex Bay showed consistently higher concentrations for all studied metals than the background of oceanic concentrations. On the other hand, all metals were lower than the hazardous concentrations recorded by WQC (1972).

The relationships between different labile metals and salinity are displayed in tables 4 and 5. Concentrations of all labile dissolved metals tend to decrease with salinity, consistent with similar behaviour reported in El-Mex Bay (Abdallah, 2008) and in Conwy estuary in England (Zhou *et al.*, 2003). In contrast, Scoullos and Pavlido (2000) reported a strong correlation between salinity and labile species of cadmium and leads, whereas zinc showed a weaker positive correlation with salinity. As shown in tables 4 and 5, negative correlation between salinity values and labile metals concentration were recorded ($r = -0.75, -0.58, -0.84, -0.48$ for Cr, Cu, Fe,

and Mn, respectively). This can be explained by the fact that the labile metals comes from the human activity and anthropogenic sources.

Table 4. Correlation Matrix in Surface Water of El-Mex Bay using a year 2004

	S‰	OM	pH	DO	Cr	Cu	Fe	Mn	Cr	Cu	Fe	Mn
	Labile								Non-Labile			
S‰	1.00											
OM	-0.63	1.00										
pH	0.97	-0.46	1.00									
DO	0.79	-0.26	0.80	1.00								
Cr Labile	-0.75	0.19	-0.83	-0.42	1.00							
Cu	-0.58	-0.15	0.26	0.72	0.23	1.00						
Fe	-0.84	0.67	-0.77	-0.51	0.63	0.07	1.00					
Mn	-0.48	0.43	-0.36	0.12	0.64	0.54	0.47	1.00				
Cr Non-Labile	0.93	-0.60	0.88	0.65	-0.76	0.13	-0.89	-0.45	1.00			
Cu	0.79	-0.50	0.83	0.52	0.74	-0.03	-0.69	-0.47	0.62	1.00		
Fe	0.88	-0.23	0.07	-0.13	-0.24	-0.36	-0.47	-0.36	0.51	-0.18	1.00	
Mn	0.81	-0.13	0.91	0.71	-0.89	0.14	-0.57	-0.38	0.69	0.77	-0.09	1.00

Table 5. Correlation Matrix in Bottom Water of El-Mex Bay using a year 2004

	S‰	OM	pH	DO	Cr	Cu	Fe	Mn	Cr	Cu	Fe	Mn
	Labile								Non-Labile			
S‰	1.00											
OM	0.14	1.00										
pH	0.41	0.02	1.00									
DO	-0.11	-0.62	-0.09	1.00								
Cr Labile	0.26	0.12	0.11	-0.25	1.00							
Cu	-0.11	-0.14	0.09	0.41	0.24	1.00						
Fe	-0.16	0.03	0.42	0.05	-0.82	-0.09	1.00					
Mn	-0.02	0.01	-0.38	-0.44	0.54	-0.48	-0.73	1.00				
Cr Non-Labile	0.72	-0.52	0.04	-0.37	0.38	-0.37	-0.38	0.26	1.00			
Cu	0.73	-0.62	0.05	-0.29	0.34	-0.44	-0.37	0.28	0.99	1.00		
Fe	0.97	0.15	0.46	-0.23	0.43	-0.12	-0.28	0.16	0.68	0.68	1.00	
Mn	0.66	0.19	0.07	-0.39	0.35	-0.53	-0.35	0.36	0.97	0.98	0.64	1.00

2.2. Non-labile trace metals

Figure 3 shows the regional distribution of non labile trace metals in El-Mex Bay water. The metals concentration in non labile form is much higher than the labile one. The regional mean values of non labile form of dissolved metals in surface water were scattered in the following ranges: Cr (from 109.87 ± 17.11 to 356.45 ± 10.97 $\mu\text{g/l}$), Cu (from 42.11 ± 26.06 to 384.75 ± 41.36 $\mu\text{g/l}$), Fe (from 298.11 ± 29.77 to 896.95 ± 93.17 $\mu\text{g/l}$) and Mn (from 21.42 ± 15.9 to 59.51 ± 21.90 $\mu\text{g/l}$). On the other hand, the distributions for bottom water were in the following ranges: from 142.36 ± 34.00 to 470.31 ± 60.15 $\mu\text{g/l}$ for Cr, from 62.83 ± 34.00 to 193.50 ± 84.55 $\mu\text{g/l}$ for Cu, from 327.80 ± 37.70 to 1532.39 ± 203.74 $\mu\text{g/l}$ for Fe and from 59.63 ± 5.56 to 144.69 ± 13.50 $\mu\text{g/l}$ for Mn.

It is clear from figure 3 that the high concentrations were recorded in the bottom water i.e. in the direction of increasing of both

by Abdel-Moati (1990) showed that 20% of dissolved Copper was removed during the mixing process. Copper is characterized by a deep demineralization cycle, but it is scavenged also by particles in deep waters. Manganese is influenced strongly by redox processes. It is a highly particle reactive element, with increased concentrations in surface waters; these fall rapidly to very low values, with depth, as a result of oxidative scavenging onto particles. Due to several biogeochemical and sedimentological processes that occur there, the coastal zone may act as a source or sink of trace metals (Martin and Windom, 1991).

salinity and pH. This result suggests an existence of inorganic ligands forming strong complexes in saline water. Copper is characterized by a deep demineralization cycle, but it is scavenged also by particles in deep waters. The high rate of organic matter decomposition in the summer season is the main reason for the increasing dissolved trace metals concentration in this period (Okbah and Nasr, 2006).

A good positive significant correlation was found between salinity and trace metals concentrations in the non-labile form (Cr, Cu, Fe and Mn) which $r = 0.93, 0.79, 0.88,$ and 0.81 ($n=32$ $p = 0.05$), respectively for the surface water, while the bottom water were $r = 0.72, 0.73, 0.97,$ and 0.66 , respectively. On the other hand, an inverse relationship was found between trace metals and both salinity and organic matter (Tables 4&5). The flocculation process with humic substances could be playing an important role in the removal of trace metals, the results reported

In general, it was found that their relative contribution and patterns are determined by three main factors: salinity, pH, and the presence of dissolved organic carbon. Increasing salinity stimulates formation of very labile chloro-complexes, while increasing pH stimulates the formation of inert species and particulates. A considerable part of slowly labile species seems to be metal complexes with organic ligands. The distributions of Cr, Cu, Fe, and Mn in El Mex Bay water are described in term of salinity distributions. These metal-salinity relationships are useful both for the assessment of the quality of trace metal data and for the identification of geochemical interesting features in the distributions.

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العناصر الشحيحة الذائبة الحرة والمرتبطة فى مياه خليج المكس-الأسكندرية-مصر

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مصرف العموم هو المصدر الرئيسى لهذه العناصر. كما أظهرت النتائج أن تركيزات هذه العناصر أكبر من مثيلتها الرجعية المحيطية (WOC) ولكن أقل من التركيزات التى تمثل خطورة. أيضا أوضحت النتائج بأن تركيزات هذه العناصر فى الصورة المرتبطة أكبر من تلك فى الصورة الحرة. أيضا إتضح أن التركيزات فى المياه القاعية أكبر منها فى المياه السطحية. أى فى إنتاجه زيادة الملوحة.

يعتبر خليج المكس من المصادر الرئيسية لصيد الأسماك على ساحل البحر المتوسط بالأسكندرية بمصر. ويتعرض هذا الخليج للتلوث من عدة مصادر أرضية تحتوى على العناصر الشحيحة ومخلفات أخرى. ولقد تم دراسة توزيع بعض العناصر الشحيحة الذائبة (الحديد والمنجنيز والنحاس والكروم) موسميا فى المياه السطحية والقاعية لخليج المكس فى الصور الحرة والمرتبطة. كما درست العلاقة بين الخواص الطبيعية (درجة الحرارة والملوحة والرقم الهيدروجينى والأكسجين الذائب والمواد العضوية المؤكسدة) وهذه العناصر فى الصور الحرة والمرتبطة. وأشارت النتائج إلى أن تركيز هذه العناصر فى الصورة الحرة كانت على النحو التالى : $Fe > Cr > Cu > Mn$ ، ولقد أعطوا جميعا علاقة عكسية مع الملوحة مما يشير إلى أن

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