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Heavy Metal Pollution in Coastal Red Sea Waters, Jeddah

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ABSTRACT. The distribution of heavy metals (Mn, Cu, Zn and Cd) in the surface and bottom water layers, as well as their accumulation in the plankton were investigated. Based on the overall mean concentrations, Mn occupied the first order of abundance, followed by Zn, Cu and Cd, giving 6.68, 6.52, 1.69 and 1.05 μgl^{-1} respectively. For plankton, however, the order was Cu > Zn > Mn > Cd, with mean values of 195.92, 179.18, 40.72 and 3.82 μgg^{-1} dry weight, respectively. Comparison of the water and plankton data confirms accumulation of heavy metals in the plankton, representing first trophic level in the marine food chain. The mean concentrations of heavy metals in the study area, especially those for plankton, were considerably higher than the corresponding means obtained from Abhor Creek, located north of Jeddah. This reflects the influence of pollution on the study area.

Introduction

Bankalah Region (21°45′N and 39°04′E, as shown in Fig. 1) is one of the heavily polluted coastal areas of the Red Sea. It extends between the Islamic Harbour south of Jeddah and the desalination plant north of the city (Fig. 2). The length and width of the area are about 10 and 2 km, respectively. Coral reefs exist in the study area and probably cause navigational hazards. The bottom topography is irregular and the water depth increases generally towards the sea, reaching more than 30 m just outside the reef barriers (Behairy and Saad, 1984a).

The considerable increase in population of the city of Jeddah in addition to about two million individuals during the pilgrimage season each year, have polluted its coastal sea waters (El Rayis *et al.*, 1984). The coastal water receives different pollutants from four main sources: untreated domestic sewage wastes, oil pollution from oil refinery of the factory Petromin, fish wastes from the big fish market of Bankalah Region and probably desalination plant effluents. The wastes resulting from several processes related to these sources added a considerable amount of organic and heavy metals load to the study area.

Investigation of trace metals in the Jeddah coast between the Islamic Harbour and Desalination Plant was carried out by El-Rayis *et al.* (1984). The same area was subjected to studies on physicochemical and nutrient parameters (Behairy and Saad 1984a and b). The objective of the present work is to provide an assessment for the state of heavy metal pollution in the water and plankton of Bankalah Region.

Materials and Methods

Eleven sampling stations were selected to represent different regions in the study area (Fig. 2). Water samples were collected in three cruises (October, January and April) and plankton samples in two cruises (October and April). Collection of water samples was carried out from the surface and bottom layers at all stations, except at the shallower station I and II, where only surface water samples were collected.

Water Samples

Surface water samples, about 20 cm below the surface to avoid floating matter, were collected directly in a 5 liter polyethylene Jerrycans previously cleaned with acid (6M HNO_3) and rinsed with deionized water. The bottom water samples were also collected, 50 cm above the bottom, using plastic sampler. The water samples were filtered through 0.45 μm millipore

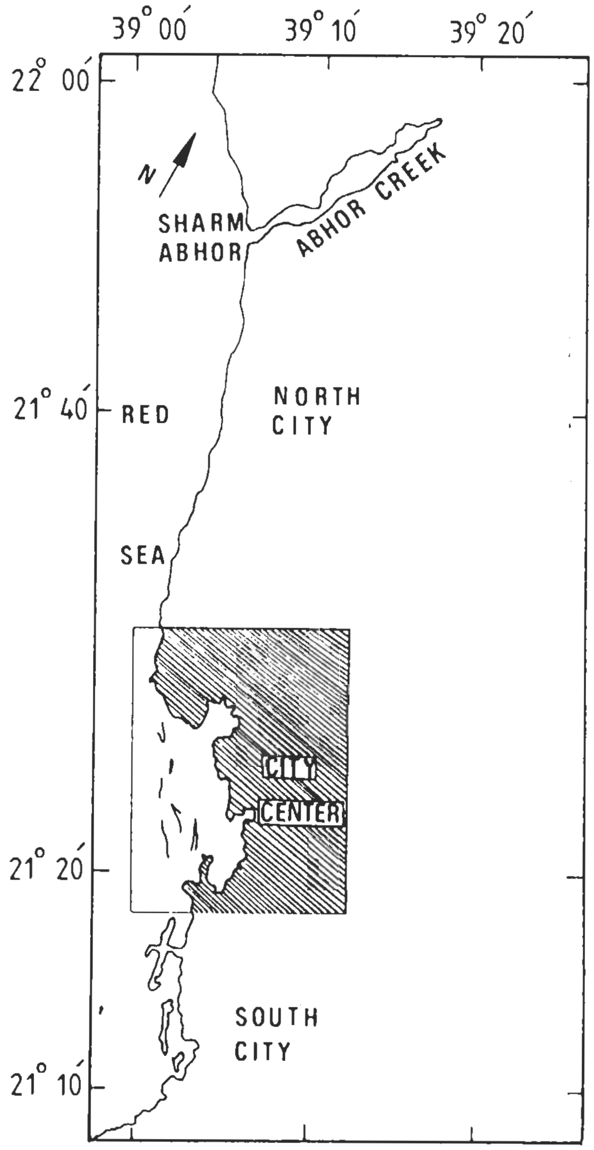

FIG. 1. Map of the Red Sea coast in front of Jeddah.

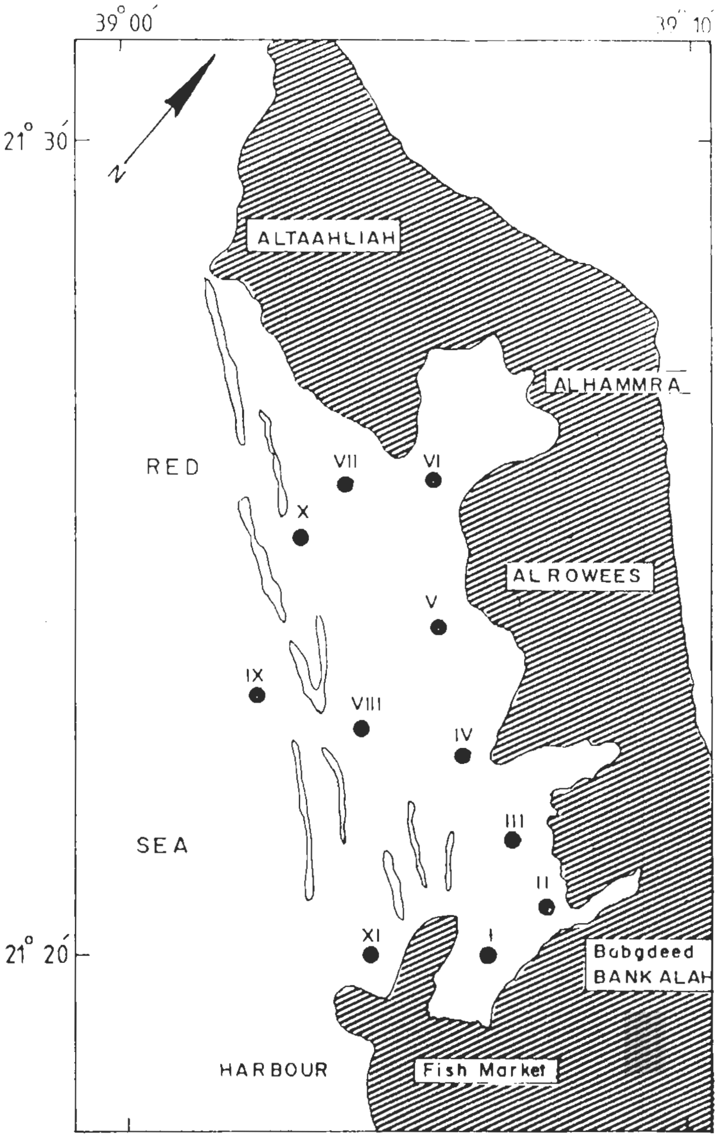

FIG. 2. Study area showing position of sampling stations.

filter which had been previously washed with deionized water. The concentrations of heavy metals in the filterate were determined using Chelex-100 resin preconcentration technique according to the method described by Abdullah and Royle (1974). The blank was determined by passage about 5 l seawater stripped of heavy metals through a Chelex-100 column of ammonium form. The column had been treated in the same way like sample.

Plankton

A phytoplankton net (50 μm mesh size) was used to collect plankton organisms. The plankton samples were filtered using reweighed 0.45 μm millipore membrane filter, the filters were dried at 80°C to constant weight. The dry filters were reweighed, to get the weight of plankton, and subjected to concentrated HNO_3 digestion at 80°C for the determination of heavy metals in the plankton organisms according to the method described by Riley and Segar (1970). The heavy metals (Mn, Cu, Zn and Cd) were determined using flame Atomic Absorption Spectrophotometry (Pye-Unicam Sp 29) and the recommended standard procedure. Precision of metal analysis represented by coefficient of variations (CV) were 8.4, 4.7, 7.6 and 3.0% for Mn, Cu, Zn and Cd, respectively. Recovery from the water using standard addition technique was better than 96% of the standard values of trace metals.

Results and Discussion

The concentrations of dissolved Mn, Cu, Zn and Cd in the surface and bottom water layers, as well as their averages in the Red Sea coastal area of Jeddah are shown in Table 1 and presented graphically in Fig. 3. The levels of these metals accumulated in the plankton collected from the surface water of the study area are presented in Table 2 and Fig. 4.

Dissolved Metals

From the distribution patterns of dissolved heavy metals observed in the study area, considerable high levels of the different metals detected at the surface of stations I and II, selected close to waste discharges, are mainly related to the direct effect of the effluents discharged from the fish market and the domestic sewage. The present data are in good agreement with the nutrient data obtained by Behairy and Saad (1984b), who found high nitrite and less nitrate concentrations at the same two locations and attributed this phenomena to the anoxic conditions prevailing in them and resulting from the severe effect of sewage pollution and the limited water exchange with the open seawater.

The vertical distribution pattern of dissolved metals showed, in general, noticeably elevated concentrations in the surface water compared with those in the bottom water in the area influenced by waste discharges. The opposite trend, however, occurred in the area relatively far away from pollution sources. This reflects the direct effect of pollutants first on the surface water near discharges and the decrease in this effect by increasing the distance from these discharges.

The bottom water at station VIII gave the highest levels of Mn, Cu and Zn in April, as well as of Zn and Cd in October. These high concentrations might be attributed to the location of this station close to coral reefs and their fragments (Behairy and Saad 1984a). The fragments of these reefs play a role in accumulating metals from the surface water and depositing them on the bottom, especially under stagnant conditions observed in April and October. The release of metals from the sediments to the overlying waters occurs under certain conditions. The evidence on the abundance of coral reef fragments at station VIII is supported by the increase in water turbidity due to these fragments and confirmed by the low Secchi value as obtained by Bahairy and Saad (1984a) at this location.

TABLE 1. Seasonal and regional variations of dissolved Mn, Cu, Zn and Cd ($\mu g\ l^{-1}$) in surface and bottom waters of the Red Sea coastal area of Jeddah.

Stations	Depth of stations (m)	Depth of samples (m)	Mn			Cu			Zn			Cd		
			Oct.	Jan.	April	Oct.	Jan.	April	Oct.	Jan.	April	Oct.	Jan.	April
I	1.8	S	528.2	50.60 +	54.20 +	1.11	5.68 +	3.25 +	11.51 +	4.45	7.30	2.45	1.04	1.76 +
II	0.9	S	67.27 +	32.50	43.52	2.51	1.17	1.63	4.41 –	3.06	3.46	1.42	0.77	1.12
III	6.0	S	1.58	7.90	0.73 –	1.60	1.49	0.67	7.63	5.48	4.39	2.39	1.83 +	0.42 –
		B	0.98 –	8.10 +	0.43 –	1.28	4.61 +	1.04	5.66	8.87 +	3.15	1.16	1.54 +	0.77
IV	2.2	S	1.28	2.90	1.84	0.75 –	2.25	3.24	8.18	6.14	11.86 +	1.55	0.60	1.03
		B	1.35	1.74	1.65	0.81 –	1.57	1.25	5.78	5.47	7.50	1.14	0.36	0.72 –
V	11.0	S	1.15	1.80	0.84	1.38	1.00	0.81	4.76	7.26 +	6.40	0.61	0.39 –	0.59
		B	1.41	1.48	1.36	1.41	0.95 –	1.00	8.51	3.81 –	4.14	1.01	0.32 –	0.75
VI	12.0	S	2.08	1.04 –	1.72	2.77 +	0.90 –	1.36	6.52	3.53	5.03	0.49 –	0.48	0.84
		B	1.65	1.23	3.07	2.51	1.62	1.06	5.87	5.07	4.14	0.90	0.73	0.76
VII	14.0	S	1.19	1.59	0.76	2.00	1.12	0.28 –	6.35	2.05 –	2.49 –	0.54	0.90	0.54
		B	1.79	2.70	1.25	1.80	1.49	0.60	9.30	7.80	3.56	0.87	0.71	0.87
VIII	5.5	S	1.65	4.46	0.85	1.38	1.76	0.85	11.23	4.51	3.66	1.48	0.66	0.85
		B	1.74	4.63	4.89 +	2.18	1.17	2.51 +	15.25 +	5.88	10.97 +	3.21 +	0.55	1.34
IX	16.0	S	1.03	1.10	1.05	2.20	1.05	1.61	4.76	5.57	5.23	0.56	0.49	0.51
		B	3.15	2.42	1.33	3.64 +	2.46	0.59 –	12.41	7.80	3.15 –	1.18	1.12	0.99
X	25.0	S	0.19 –	4.01	2.10	1.65	1.32	1.53	6.70	6.71	6.51	2.06	0.63	1.31
		B	1.99	5.52	4.58	1.46	1.48	1.71	4.82 –	7.04	6.41	0.67 –	0.63	1.08
XI	11.0	S	2.99	1.70	2.20	1.52	1.12	1.14	8.00	4.83	6.11	2.48 +	0.53	1.58
		B	4.16 +	0.99 –	2.52	2.57	1.79	2.29	13.01	6.31	9.70	2.00	0.99	1.71 +
Surface averages			12.60	9.96	9.98	1.72	1.72	1.49	7.28	4.87	5.68	1.46	0.76	0.96
Bottom averages			2.02	3.20	2.34	1.96	1.90	1.34	8.96	6.45	5.89	1.35	0.77	1.00
Water column averages			7.31	6.58	6.16	1.84	1.81	1.42	8.12	5.66	5.79	1.41	0.77	0.98
Means				6.68			1.69			6.52			1.05	

S = surface B = bottom

The minimum values are designated by (–) and the maximum by (+).

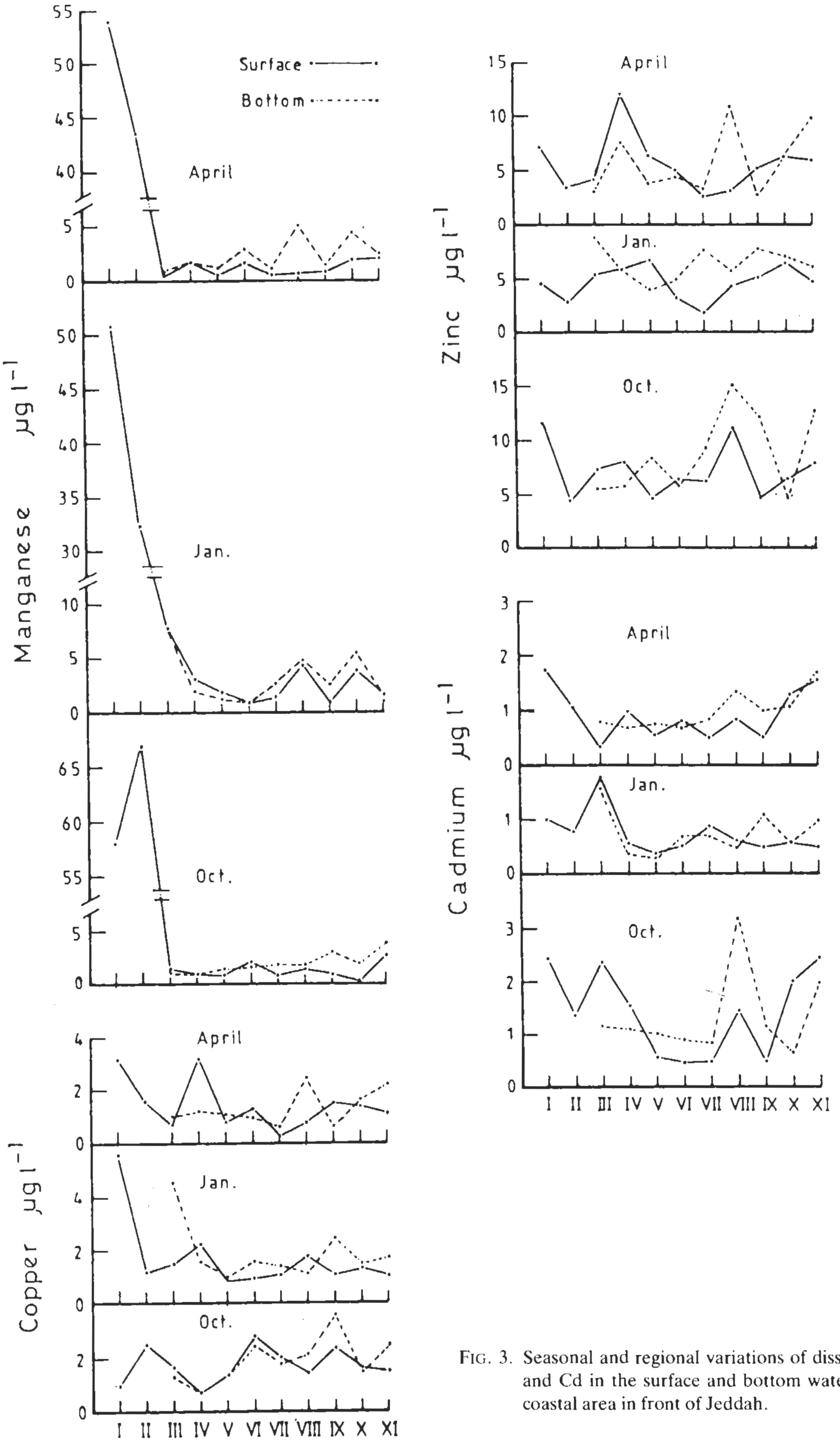

FIG. 3. Seasonal and regional variations of dissolved Mn, Cu, Zn and Cd in the surface and bottom waters of the Red Sea coastal area in front of Jeddah.

TABLE 2. Levels of Mn, Cu, Zn and Cd ($\mu g\ g^{-1}$ dry weight) in plankton from the surface water of the Red Sea coastal area of Jeddah during October and April.

Stations	Mn		Cu		Zn		Cd	
	Oct.	April	Oct.	April	Oct.	April	Oct.	April
I	100.20 +	112.25 +	68.80	125.34	109.28	317.15	6.12 +	7.42
II	70.51	78.63	38.71	84.21	91.32	198.41	4.25	6.02
III	14.39	15.37	8.95 –	43.39	30.21 –	81.53	0.88	1.57
IV	14.28 –	30.85	13.18	85.06	80.03	214.07	0.62	4.77
V	20.31	25.17	23.18	115.28	60.83	181.17	0.54 –	1.07 –
VI	40.17	27.78	35.59	164.10	97.02	295.88	0.78	4.83
VII	66.16	52.60	118.85	640.93	210.14 +	537.98	ND	8.72
VIII	18.24	12.77 –	33.51	236.47	40.60	173.69	3.93	4.63
IX	34.31	35.40	197.82	1656.24 +	118.92	608.52 +	0.64	3.73
X	45.87	22.03	301.28 +	27.89	208.66	57.71	1.75	11.87 +
XI	41.21	17.28	270.11	21.25 –	178.91	49.75 –	0.99	8.90
averages	42.33	39.10	100.91	290.92	111.45	246.90	1.86	5.78
means	40.72		195.92		179.18		3.82	

ND = Not detected.
The minimum values are designated by (–) and the maximum values by (+).

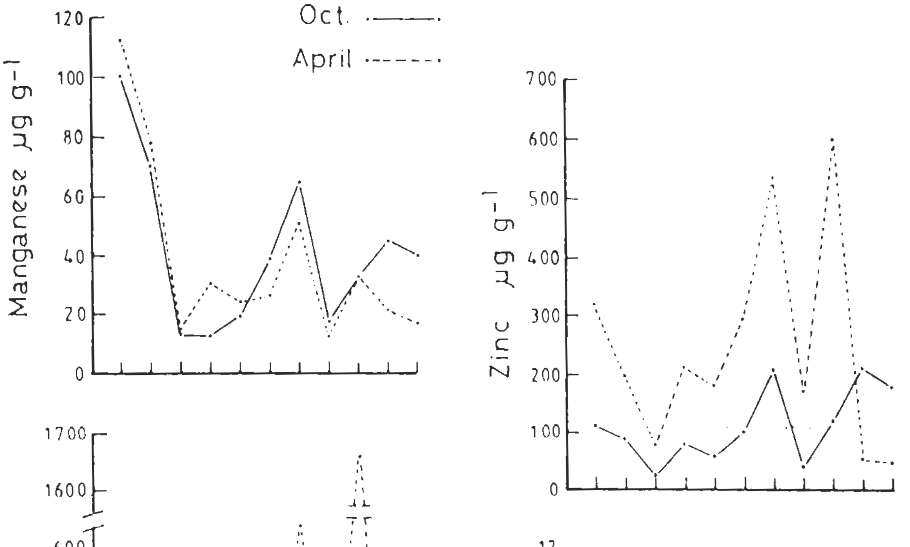

FIG. 4. Levels of Mn, Cu, Zn and Cd in plankton collected from surface coastal water of the Red Sea of Jeddah during October and April.

In January, however, the maximum concentrations of all metals in the bottom water at station III reflect the direct effect of waste disposal on this location. On the contrary, the minima of all metals (except Mn) in the bottom water were found at station V selected relatively far away from direct pollution sources.

At the heavily polluted area (stations I and II), the surface Mn concentrations were considerably higher than those for the other heavy metals (Table 1 and Fig. 3). This is in agreement with the findings of El-Rayis *et al.* (1984) on the same investigated area and Kremling (1983) in the anoxic Baltic Sea area.

Correlation coefficients between dissolved Mn and the environmental characteristics, as well as nutrient salts (unpublished correlations) showed significant negative relationships with transparency ($r = -0.42475$), pH ($r = -0.44247$) and dissolved oxygen ($r = -0.94925$). However, this relationship was positive with nitrite ($r = 0.51700$), reactive phosphate ($r = 0.96678$) and silicate ($r = 0.87887$). Based on the above relationships, the presence of high levels of dissolved Mn can be considered as a good indicator for the environmental pollution. Stumm and Morgan (1981) stated that low redox potential conditions usually favour a considerable amount of the available Mn in the medium to be in the more soluble Mn (II) form rather than in the suspended Mn (III and IV) forms.

Based on the overall mean concentrations of dissolved heavy metals in the study area, Mn occupied the first order of abundance followed by Zn, Cu and Cd (Mn > Zn > Cu > Cd) giving 6.68, 6.52, 1.69 and 1.05 μgl^{-1} respectively. This may confirm the role of Mn as a good indicator for pollution relative to the other metals. El Rayis and Saad (1992) found the same order of abundance in lagoon Mariut subjected also to the influence of untreated sewage and industrial wastes.

Metals in the Plankton

The levels of different heavy metals in the plankton (Table 2) showed that the highest contents of Mn in October and April and Cd in October were obtained in the plankton collected at station I, selected very close to waste discharges. This undoubtedly reflects the direct pollution effect on this location. However, the maximum values of Cu and Zn obtained at a location far away from pollution sources (station IX) in April coincided possibly with the active role of plankton abundance in April (spring) in accumulating the biological important metals.

Based on the overall means of metals accumulated in the plankton, copper gave the highest mean level followed by Zn, Mn and Cd (Cu > Zn > Mn > Cd) giving 195.92, 179.18, 40.72 and 3.82 μgg^{-1} dry weight respectively. This reflects the biological importance of Cu and Zn for the plankton in seawater. This evidence is supported by the strong positive association ($r = 0.84116$) between PCu and PZn (Table 3).

The interrelationships between dissolved metals (D) and their levels in the plankton (P) (Table 3) showed that PMn was correlated positively with DMn ($r = 0.81821$) and DCu ($r = 0.41127$). This reveals that under stress conditions plankton can accumulate Mn from seawater. PCd is the only metal which showed no significant association with any of the other metals. El Rayis *et al.* (1984) found the same observation with Cd and attributed this to its tendency for more soluble chloro-complex compounds.

Comparison between the data of the present study with other data (Table 4) illustrates higher mean values of dissolved heavy metals in the present study compared with the corresponding means in the comparatively unpolluted Obhur Creek, north of study area and in the oceanic water. The increase in Mn was remarkable and for the other metals was noticeable. Variations in the mean values of metals in the study area compared with those found by El Rayis *et al.* (1984) for the same area reflect differences in amounts of discharged wastes. Furthermore, the considerable

TABLE 3. Correlation coefficient matrix between dissolved heavy metals (D) and their levels in the plankton (P) in surface water of the Red Sea coastal area of Jeddah.

	DMn	DCu	DZn	DCd	PMn	PCu	PZn	PCd
DMn	1.00000							
DCu	.33301	1.00000						
DZn	.07167	.28711	1.00000					
DCd	.35546	.05486	.54054	1.00000				
PMn	.81821	.41127	.07649	.24999	1.00000			
PCu	.08482	.14830	–.18603	–.12653	.31417	1.00000		
PZn	–.02706	–.02698	–.31956	–.34023	.28480	.84116	1.00000	
PCd	.29837	–.03882	–.05461	–.11025	.22465	.17582	.21582	1.00000

The significant values are > 0.36049 or < – 0.36049

n = 22.

TABLE 4. Comparison between the average concentrations of dissolved heavy metals in water ($\mu g\ l^{-1}$) and plankton ($\mu g\ g^{-1}$ dry weight) of the Red Sea coastal area of Jeddah with other data.

	Mn	Cu	Zn	Cd	References
Water					
Bankalah region	6.68	1.69	6.52	1.05	Present study
Bankalah region	14.60	1.52	–	0.79	El-Rayis *et al.* (1984)
Obhur Creek	1.93	1.64	5.36	0.85	Fahmy and Saad (in press)
Obhur Creek	0.78	1.17	2.23	0.68	Behairy *et al.* (1983)
Oceanic water	0.10	1.50	4.90	0.10	Brewer and Spencer (1975)
Plankton					
Bankalah region	41.00	196.00	179.00	3.80	Present study
Obhur Creek	20.10	12.20	35.70	0.70	Fahmy and Saad (1996)
Obhur Creek	17.30	106.00	92.00	2.00	Behairy *et al.* (1983)
Average composition of plankton	9.00	11.30	87.00	2.00	Turekian (1976)

high levels of all metals found in the plankton of study area relative to the corresponding levels in Obhur Creek, as well as the average plankton composition, reflects the role of plankton in accumulating metals from the highly polluted study area.

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التلوث بالمعادن الثقيلة
فى مياه البحر الأحمر الساحلية أمام جدة

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المستخلص: تتعرض المياه الساحلية للبحر الأحمر أمام مدينة جدة بالمملكة العربية السعودية لضغط نتيجة صرف مخلفات المجارى من هذه المدينة ، حيث يزداد هذا الصرف زيادة ملحوظة خلال موسم الحج مما يؤدى إلى زيادة مستويات التلوث . كما يحد حاجز الجزر المرجانية نصف المغمورة بالجانب الغربى لمنطقة الدراسة من تبادل مياه هذه المنطقة مع مياه البحر المفتوح مما يزيد من مشكلة التلوث . تمت دراسة توزيع المعادن الثقيلة (منجنيز ، نحاس ، زنك ، كادميوم) فى طبقات المياه السطحية والقاعية بالإضافة إلى تراكمهم فى البلانكتون بمنطقة الدراسة . اعتمادا على المتوسط العام لتركيزات المعادن الثقيلة الذائبة بمنطقة الدراسة وجد أن المنجنيز احتل المرتبة الأولى من حيث الوفرة وتلاه الزنك ثم النحاس ثم الكادميوم حيث سجلت هذه المعادن ٦ر٦٨ ، ٦ر٥٢ ، ١ر٦٩ ، ١ر٠٥ ميكروجرام/ لتر على التوالى . وبالنسبة للبلانكتون ، فكان الترتيب هو نحاس > زنك > منجنيز > كادميوم حيث سجلت قيم متوسطاتهم ١٩٥ر٩٢ ، ١٧٩ر١٨ ، ٤٠ر٧٢ ، ٣ر٨٢ ميكروجرام/ جرام من الوزن الجاف على التوالي . تؤكد مقارنة النتائج والبلانكتون تراكم المعادن الثقيلة فى البلانكتون والذى يمثل أولى الحلقات فى السلسلة الغذائية البحرية . وجد أن متوسطات تركيزات المعادن الثقيلة فى منطقة الدراسة خاصة بالنسبة للبلانكتون كانت أعلى كثيرا عن مثيلاتها من المتوسطات التى تم الحصول عليها من منطقة شرم أبحر والتى تقع شمال جدة وهذا يعكس تأثير التلوث عل منطقة الدراسة .