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Distribution of Some Heavy Metals in Sediments, Water and Different Trophic Levels from Jeddah Coast, Red Sea

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ABSTRACT. Amounts of some heavy metals (Cu, Zn, Cd, Fe and Mn) in sediments at surface, suspended matter, water, planktons, and some macro-algae and fishes from Jeddah coastal zone were studied. Aluminium, Mg, Ca and P were also measured in the sediments. Distributions of the heavy metals (salinity and dissolved oxygen or hydrogen sulphide) in the water and bulk sediments, suggest that the coastal area can be divided into two zones; the Bankalah Zone, adjacent to sewage outfalls from Jeddah City center, is anoxic and contains high values of the heavy metals, and the other (representing the rest of Jeddah coastal area between the Islamic Harbour and Attahlia) is oxic and far from this effect. The metal contents of its different environmental compartments including the studied biota are comparable to those in their counterparts in less polluted areas of the Red Sea as well as of the world.

Study of the sediments' interrelationships between those heavy metals and P and Al suggests that the concentrations of Cu, Zn and Al can distinguish Bankalah sediments from the others of Jeddah coast, and shows that partial mobilization of Mn from the Bankalah sediments to the host euxinic water has occurred.

Introduction

Because of potential health hazards, there is a great concern about setting up a base-line levels for many elements in Saudi coastal areas of the Red Sea and the Arabian Gulf. The objective of the present work is to evaluate the impact of an abrupt increase in modernization, urbanization and industrialization that are occurring on the coast of Jeddah City.

Trace metals investigation in the Jeddah coast, between the Islamic Harbour and Attahlia, started in 1981, when only Cu, Cd and Mn were determined in the water (El-Rayis *et al.* 1984). There is no information about the level of the metals in the other parts of the ecosystem of this coastal area. The present work was carried out to investigate the occurrence and distribution of those three metals as well as Zn and Fe not only in water column, but also in sediments, planktons, algae (2 species) and fishes (3 species). Aluminium, Mg, Ca and P were also measured in the sediments.

Material and Methods

The area under investigation is shown in Fig. 1. It is bordered from north, east and west by the city of Jeddah. On its southern side, there are some patches of submerged barrier reef shoals. The coast is indented with embayments, such as Al Arbaeen lagoon, that is included in Bankalah zone, Reayat Al-Shabab lagoon and Al-Nafura embayment (close to Al-Hamra District). The sea bottom topography of the area is irregular, but there is a general increase in the depth westward. The depth between the coast and the reefs varies between 1 and 20 m, and beyond the reefs it exceeds 30 m (El-Rayis *et al.* 1982).

Water Samples

Sixteen sampling locations, shown in Figure 1 were chosen to represent different parts of the Jeddah coast. Surface water samples from all the stations were collected (about 10 cm below the surface to avoid floating materials) directly in 5 liter polyethylene Jerry cans, an acid cleaned (6 N HNO_3) and deionized

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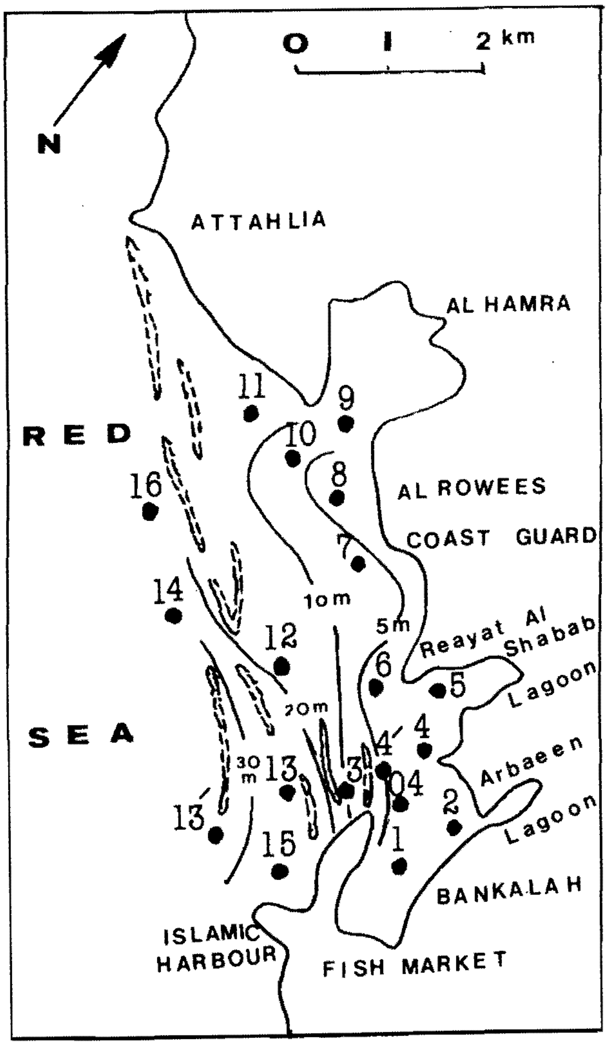

FIG. 1. Locations of sampling stations along Jeddah coast between Islamic Harbour and Attahlia.

water rinsed. Subsurface water samples (about 5 l) were also collected by a plastic sampler from only four stations (2, 5, 12 and 14; Fig. 1), extending from Bankalah coast towards the sea. The samples were filtered through 0.45 μm pore size Millipore filters which had been prewashed with deionized water, dried and weighed. The filtered water was allowed to pass through a glass column containing the ammonium form of Chelex-100 resin to preconcentrate the dissolved metals (Abdullah and Royle 1974). The metals on the resin were elluted with silica distilled 2 *M* HNO_3 and evaporated to near dryness. One ml 6 *M* HNO_3 was added to dissolve the metals in the residue and made up the solution to 25 ml using deionized water.

The filter (with particulate materials) was washed, dried and reweighed for determination of total suspended matter (TSM). The trace metals were then extracted from the particulates using 2 *M* HNO_3 as described by Smith *et al.* (1981).

Sediments

The sediments were collected at sixteen stations shown in Fig. 1, using a stainless steel Ekman's grab. The sample was well mixed, after being freed from coarse shell fragments and visible sea grass leaves when present, 200 g of it was transferred to a self-sealing plastic bag. About 20 g of the sample was dried at 80°C in a silica basin, and then ground in an agate mortar. One gram of the dry sediment was digested with 25 ml of 2 *M* HNO_3 (Smith *et al.* 1981) on a hot plate for four hours. The content was evaporated to near dryness. One ml 6 *M* HNO_3 was added to dissolve the metals in the residue and made up the solution to 25 ml using deionized water. The extraction of the metals from the bulk sediments were made here, in order to be able to compare their levels with those found by other investigators (mentioned in Table 4) in the other coastal shelf sediments in the region.

Planktons

A phytoplankton net (53 μm mesh size) was used to collect planktonic organisms from the coastal area, outside the Bankalah zone. The plankton samples were filtered through the (washed and weighed) membrane filters. Then dried at 60°C to constant weight. The filters with their contents were hot digested with concentrated HNO_3 for extraction of the metals from the plankton organisms (Riley and Segar 1970).

Algae

Brown algae, *Sargassum vulgare* and *Cystoseira barbata* were collected from the Jeddah coast, near the Coast-guard station, and south of Attahlia (Fig. 1). They were cleaned from foreign materials, washed with running water and also with deionized water, dried at 40°C, and then powdered in an agate mortar. Part of it was used for determination of ash content (at 700°C). The other part was used for extraction of metals using the method of Riley and Segar (1970).

Fish

Three teleosti fish *Pagurus haffara, Gerres oyena* and *Mugil.crenilabis,* were caught by a professional fisherman from the coastal area, west of the Islamic Harbour. The fish samples were subjected to biometric study, then dissected to subsamples, the dorsal and peduncle muscles, liver, and viscera or gut. The water content for each type of the subsamples, collected from more than one specimen of the same species, was determined. The dried sample was powdered and mixed, then subjected to the concentrated HNO_3 hot digestion method (Riley and Segar 1970).

The metals, Cu, Zn, Fe, Mn and Cd, were measured in the acid extracts using flame atomic absorption spectrophotometry (Model-IL-970). The efficiency of the Chelex-100 technique for preconcentration of the metals, Cu, Zn and Cd, from sea water was tested using water spiked with these metals. The recovery was in the range 99 ± 5% for all metals. Standard addition technique and replicate analysis were used with the sediments, fish muscles and algae. The factors obtained from the standard addition technique for sediments and algae were used for calculation of the concentrations of metals in uspended matters and planktons, respectively. The coefficients of variation are 8.5, 1.9 and 3.8% for Cu, Zn and Cd, respectively, in the water. The coefficients of variation of Cu, Zn, Cd, Fe and Mn are 1.0, 1.5, 3.3, 1.0, and 3.0% for sediments; 4.5, 8.0, 3.5, 5.5 and 6.0% for algae; and 4.9, 8.9, 3.2, 8.0 and 6.5% for fishes, respectively. The recovery of the spikes was better than 95% of the standard values of heavy metals.

Aluminium and P were measured in the sediment extract using the colorimetric methods (pyrocatechol violet and molybdenum blue complex, respectively). The Ca and Mg contents were measured using EDTA-titrimetric method, and dissolved oxygen and hydrogen sulphide in the water were measured titrimetrically (Grasshoff 1984).

Salinity was measured in the samples using an inductive salinometer (Beckman, Bench type).

Results and Discussion

All the analytical results for the water, sediments, planktons, algae and fishes are shown in Tables 1, 2 and 3, respectively.

Water

Dissolved Metals

In the surface water, copper concentrations ranged

TABLE 1. Analytical results for water of the Red Sea coast off Jeddah, between the Islamic Harbour and Attahlia.

Station No.	Depth (m)	Cu		Zn		Cd		Fe		Mn		TSM mg/l	O_2/(H_2S) ml/l	Salinity ‰
				µg/l										
		Diss.	Part.	Diss.	Part.	Diss.	Part.	Diss.	Part.	Diss.	Part.			
Bankalah Zone :														
1	0	4.00	3.8*	5.9	8.4*	1.71*	0.25	8.4*	7.7*	41.90*	4.0*	67.5	(16.2)	10.50
2	0	6.31*	3.5	6.7*	8.2	0.82	0.94*	5.2	6.9	33.30	17.0	124.1*	(6.8)	28.42
	0.5	1.11	1.7	6.5	4.0	1.25	0.09	5.4	3.1	12.10	22.0	63.1	(7.0)	31.58
	1	0.71	1.5	4.4	3.3	1.09	0.06	5.2	3.8	20.20	56.0	72.9	(3.2)	36.43
4	0	0.35	0.6	3.3	1.5*	0.81	0.07	2.8	4.7	1.34	25.0*	21.7	2.7	39.58*
5	0	0.92	0.7	3.5	1.8	0.65*	0.06*	2.1	2.4	1.03	13.0	18.7*	2.9*	39.48
	1	0.49	0.8	3.4	1.3	0.21	–	2.8	3.4	1.37	8.0	7.1	3.2	39.48
	3	1.11	0.5	7.2	2.1	0.80	ND	2.8	1.5	1.27	9.0	11.8	3.7	39.44
Surface $\bar{X}$	0	2.90	2.15	5.80	5.00	0.998	0.33	4.63	5.43	19.39	14.75	58.0	2.8	29.50
SD		(2.78)	(1.74)	(1.69)	(3.82)	(0.48)	(0.42)	(2.84)	(2.38)	(21.32)	(8.73)	(9.40)	(11.5)	(13.70)
3	0	0.78	0.80	5.0	3.0	0.61	0.06	3.2	1.7*	1.80	8.0*	77.8*	0.6	36.91
6	0	1.25	1.40	4.6	1.8	1.24*	ND	3.1	0.8	2.30	2.0	4.9	4.2	39.56*
7	0	1.18	0.80	5.3	1.0	0.83	0.06	2.5	1.3	1.75	0.8	4.8	4.4	39.44
8	0	1.70	4.60*	9.2*	3.7*	0.37	ND	3.4*	1.1	1.85	1.1	4.3	4.7	39.44
9	0	2.15*	0.44	6.5	0.7	0.50	ND	3.2	1.1	1.39	0.9	4.6	4.4	39.51
10	0	1.57	0.26*	3.5	0.2	0.42	0.06	2.5	0.4	1.37	0.5	6.1	4.6	39.26
11	0	1.12	0.28	6.5	1.5	0.72	0.03	2.8	0.2	1.28	0.4	3.7	5.4*	39.29
12	0	–	–	6.8	–	0.62	ND	3.4	0.3	1.20	0.5	6.0	4.1	39.48
	1	1.51	1.50	4.9	1.0	1.07	0.37	2.2	0.6	1.17	0.5	4.1	4.2	39.51
	3	0.88	0.40	5.7	0.9	0.69	0.09	3.5	0.8	2.89	0.7	5.7	4.7	39.50
	5	0.80	0.20	4.9	0.4	1.07	0.19	3.3	0.8	2.66	1.0	5.9	4.2	39.54
13	0	0.56	0.40	3.3	0.3	0.60	0.10	2.6	0.4	1.20	0.6	4.0	4.1	39.32
14	0	0.67	0.30	3.7	2.8	0.89	0.15*	2.1	0.3	3.02*	0.3	4.6	4.4	39.31

TABLE 1: *Cont.*

Station No.	Depth (m)	Cu		Zn		Cd		Fe		Mn		TSM mg/l	O_2/ (H_2S) ml/l	Salinity ‰
				μg/l										
		Diss.	Part.	Diss.	Part.	Diss.	Part.	Diss.	Part.	Diss.	Part.			
	1	1.34	0.30	4.6	0.8	0.89	0.03	2.4	0.9	1.66	0.4	4.2	4.7	39.21
	3	1.00	0.20	3.5	0.6	0.85	0.44	2.7	0.6 '	1.49	0.6	4.6	5.5	39.30
	5	1.08	0.20	7.2	0.4	1.17	0.07	2.8	1.0	2.14	0.4	5.1	4.9	39.31
	10	0.81	0.20	9.6	0.8	0.79	0.08	3.3	0.8	2.52	0.4	8.6	5.5	39.31
	15	1.35	0.30	6.2	0.9	0.88	0.39	3.3	0.3	1.97	0.3	4.9	4.5	39.32
Surface $\bar{X}$	0	1.22	1.03	5.27	1.67	0.68	0.048	2.88	0.76	1.72	1.51	12.08	4.09	39.15
SD		(0.52)	(1.39)	(1.96)	(1.26)	(0.26)	(0.052)	(0.44)	(0.52)	(0.58)	(2.33)	(23.10)	(1.28)	(0.74)
General mean		1.74	1.37	5.27	2.68	0.77	0.13	3.38	2.09	6.77	5.29	25.20	3.88	36.39
SD		(1.66)	(1.53)	(1.76)	(2.70)	(0.35)	(0.24)	(1.64)	(2.50)	(13.18)	(7.73)	(37.37)	(1.27)	(8.02)

' & ¯ = Maximum and minimum value, respectively. ND = Not detected. $\bar{X}$ = Mean
SD = Standard deviation. TSM = Total suspended matter.

TABLE 2. Analytical results for sediments from the Red Sea coast off Jeddah, between the Islamic Harbour and Attahlia.

Station No.		PO$_4$-P	Al	Ca	Mg	Cu	Zn	Cd	Fe	Mn
		μg/g		μg/g		μg/g				
Bankalah zone										
1		1352'	1923'	55	25¯	91	185'	3.6	1064'	132
2		871	777	95¯	28	45	84	3.0¯	564	107
04		640	600	125	63	25	46	3.9	411	65
4		462¯	595	129	66	16	23	4.1	399	61
4¯		634	692	178'	91'	14	20¯	7.2'	325¯	50
	$\bar{X}$	791.8	917.4	116.4	54.6	38.2	71.6	4.36	552.6	83.0
	SD	(345.3)	(567.4)	(45.4)	(27.9)	(32.0)	(68.4)	(1.64)	(298.8)	(34.9)
Rest of Jeddah coast										
3		316	488	152	92	10	9	5.6	192	18
6		254	480	169	76	11	9	6.2	248	20
7		330	492	150	94	11	9	6.0	236	31
9		199	460	129	109	11	7	6.0	224	20
10		245	489	197	50	10	7	5.9	234	40
11		404	612'	156	103	13	9	5.7	283	42
13		259	127¯	199	114'	9¯	5¯	5.9	88¯	13
13'		384	482	145	73	11	14	5.8	241	23
14		174	256	219'	44	9	6	5.9	139	12
15		452'	559	86¯	47¯	20'	40'	2.8	436'	220'
16		512	391	172	112	12	13	5.3	329	43
	$\bar{X}$	320.8	439.6	161.3	83.1	11.6	11.6	5.55	240.9	43.8
	SD	(107.3)	(137.5)	(36.6)	(26.7)	(3.1)	(9.8)	(0.94)	(91.7)	(59.5)
General Average		468.0	588.9	147.3	74.2	19.9	30.4	5.18	338.3	56.1
SD		(300.5)	(388.2)	(43.7)	(29.5)	(21.0)	(46.2)	(1.28)	(227.3)	(55.1)
Concentration factor (X 1000)						11.4	5.76	6.72	100.10	8.29

$\bar{X}$ = Mean.
SD = Standard Deviation.
' & ¯ = Maximum and minimum value, respectively.

between 0.35 and 6.31 μg/l with an average of 1.74 μg/l. The values of Cd concentrations varied between 0.37 and 1.71 and Mn between 1.03 and 41.9 μg/l, with respective averages of 0.77 and 1.71 μg/l. These values are very close to those observed before in the area by El-Rayis *et al.* (1984).

The concentrations of Zn and Fe ranged between 3.3 and 9.2; and 2.1 and 8.4 μg/l, with respective averages of 2.68 and 3.38 μg/l. These values are close to those recorded in other coastal areas between Sharm Obhur and Yanbo, north of Attahlia (Table 4). In general, the highest concentrations of the studied metals, especially Mn, were recorded from the Bankalah zone, which receives the effluents discharged from a fish market (Fig. 1) and from a primary treatment plant for the domestic sewage of the center of Jeddah City. (The first source has now stopped completely due to the transfer of the fish market to another place away from this zone). Due to the septic sewage loaded with organic matter, the water of the Bankalah zone was not well ventilated, especially at its surface, where lower values of dissolved oxygen or higher content of hydrogen sulphide (H_2S) than in the subsurface waters were observed. This H_2S rich surface water was also low in its salinity value (< 10.5%, Table 1). The ventilated water off the Jeddah coast, in general, contains lower concentrations of trace metals and the variation in the concentration was narrower relative to those in the Bankalah area (Table 1).

Particulate metals

In the surface water, the suspended metals (μg/l) showed patterns of distribution similar to those of their dissolved counterparts. The highest contents of

TABLE 3. Analytical results from the biological materials of different trophic levels (and their concentration factors) from the Red Sea coast off Jeddah.

Specimen	Moisture %	Ash %	Length cm	Weight g	Cu	Zn	Cd	Fe	Mn
					µg/g dry weight				
1. *Algae :*									
C. barbata									
Near Attahlia	15.9	33.0			3.4	16	1.39	187	21
Near Coastguard	15.7	33.2			2.4	8	1.39	102	5
Mean	15.8	33.1			2.9	12	1.39	144.5	13
Concentration factor (X 1000)					2.3	2.28	9.04	50.2	7.6
S. vulgare									
Near Attahlia	15.3	19.2			9.6	24	3.33	911	60
	15.5	19.5			6.3	16	2.78	465	65
Near Coastguard	15.2	19.3			21.2	47	2.22	1335	182
	15.2	19.4			7.7	29	2.50	789	93
Mean	15.3	19.4			11.2	29	2.71	649.6	137.5
Concentration factor (X 1000)					9.18	5.5	3.99	225.6	58.2
2. *Plankton :*									
Near shore					176	–	19.3	1452	69
Intermediate					94	–	3.2	1242	65
Offshore					17	53	5.9	126	12
Mean					95.7	53	6.13	940	48.7
Concentration factor (X 1000)					78.4	10.1	9.0	326.4	28.3
3. *Fish :*									
Mugilidae :									
Mugil crenilabis, 5*			16-19 17.5**	96-144 118.8**					
Dorsal	72				1.1	31	0.36	18	2.2
Peduncle	71				1.0	43	0.72	24	4.6
Flesh mean					1.05	37	0.54	21	3.40
Liver	70				2.8	40	0.96	328	1.2
Gut	63				4.9	52	0.25	99	3.6
Flesh concentration factor (X 1000)					0.86	7.0	0.79	7.3	1.98
Gerreidae :									
Gerres oyena, 5*			17.6-21.0 19.4**	137-205 168.6**					
Dorsal	75				1.3	62	0.29	46	1.1
Peduncle	72				1.5	105	0.94	51	3.2
Flesh mean					1.4	83.5	0.62	48.5	2.15
Liver	74				17.7	158	9.50	578	6.3
Gut	71				71.1	93	6.11	358	12.7
Flesh concentration factor (X 1000)					1.15	15.8	0.91	16.8	1.25
Sparidea :									
Pagurus haffara, 2*			18.5-19.5 19.0**	162-197 179.5**					
Dorsal	75				0.6	65	0.5	15	1.4
Peduncle	72				1.3	60	0.9	32	3.8
Flesh mean					0.95	62.5	0.70	23.5	2.6
Liver	73				276	957	1.3	1179	–
Gut	65				7.7	141	3.8	221	8.6
Flsh concentration factor (X 1000)					0.78	11.9	1.03	8.2	1.51

* = Number of specimens ** = Average

most of the suspended metals (µg/l) and TSM were recorded in the water of Bankalah zone (Table 1). This suggests that waters with high TSM content are also rich in suspended metals. The interrelationships between each of these metals and the TSM in the oxygenated surface water, except for those at stations 1 and 2, are shown in Table 5. This shows that TSM is correlated well with both Fe and Mn ($r > 0.9$), and associations are also found between Fe-Mn and Cu-Zn. The association of Fe or Mn with TSM, in oxic surface waters, refers to their lithogenic or detrial origin, and the association of Cu and Zn with each other and not with

TABLE 4. Comparison of the concentration of the elements studied in water, sediments and organisms of different trophic levels from the Red Sea coast off Jeddah with those in other areas in the region and in the world.

Sample Region	Cu	Zn	Cd	Fe	Mn	Al	Ca	Mg	P	Reference
	μg/g on dry weight basis (except water in μg/l)									
Water										
Jeddah coast :										
Bankalah zone	2.90	5.80	0.998	4.63	19.4					Present work
Rest of the coast	1.22	5.27	0.68	2.88	1.7					Present work
Sharm Obhur, Jeddah	1.17	2.23	0.68	3.5	0.8					Behairy *et al.* (1983)
Saudi coast between										
Jeddah and Yanbu	0.8	9.5	0.41	1.7	0.3					El-Rayis (unpublished data)
Liverpool Bay, U.K.	1.5	13.8	0.88	2.0	1.7					El-Rayis (1977)
Oceanic water	1.5	4.9	0.1	2.0	0.1					Brewer and Spencer (1975)
Plankton										
Jeddah coast	95.7	53	6.13	940	48.7					Present work
Sharm Obhur	106	92	2.03	1116	17.3					Behairy *et al.* (1983)
Oceanic	11.3	87	2.0	650	9.0					Turekian (1976)
Phytoplankton	7.0	38	2.0	430	9.0					Johnston (1976)
Zooplankton	10.0	113	4.0	197	4.0					Johnston (1976)
Phytoplankton	1-15	10-100	1-5	200-1500	5-15					Brewer & Spencer (1975)
Zooplankton	6.1-210	96-1030	0-7.2	85-4600	5.1-170					Falandysz (1984)
Algae										
Cystoseira barbata	2.9	12	1.39	144.5	13					Present work
Saragassum vulgare	11.2	29.0	2.71	649.6	137.5					Present work
Sea weed (all types)	15	9.0	0.5	300	50					Johnston (1976)
Cystoseira trinodis	2.5	5.5	0.58	–	–					Denton & Burdon-Jones (1986a)
Saragassum crassifolium	1.4	1.7	0.37	–	–					" " "
Saragassum confusum	7	14	1.6	–	–					Pak *et al.* (1977)
Fish										
Mugil crenilabis	1.05	37.0	0.54	21	3.4					Present work
Gerres oyena	1.4	83.5	0.62	48.5	2.2					Present work
Pagurus haffara	0.95	62.5	0.70	23.5	2.6					Present work
Salt bream,										
Muscle	1.5	13.6	–	–	–					Denton & Burdon-Jones
Liver	37.9	128.0	–	–	–					(1986b)
Sparus aurata										
Muscle	4-10	18-37	0.14-0.54	19-62	2-4					Ezzat *et al.* (1985)
Liver	23-31	94-105	0.58-1.04	287-495	8-16					
Mugil capito										
Dorsal	5.0	35	0.10							El-Rayis *et al.* (1985)
Peduncle	5.0	35	0.30							
Liver			0.33							
Gut			0.51							
Sediments										
Jeddah coast :										
Bankalah	38.2	71.6	4.36	552.2	83.0	917	116	55	792	Present work
Rest of the coast	11.6	11.6	5.55	240.9	43.8	440	161	83	321	Present work
Saudi coast between										
Jeddah and Yanbu	13	19	10	785	51	–	254	44	350	FMS, Report (1984)
Al-Ghardaqa	22	40	–	1049	150	1849	142	18	–	El-Sayed (1984)
Sharm Obhur, Inside	8.9	11.7	8.9	2224	38	–	–	–	–	Behairy *et al.* (1983)
Outside	6.2	4.8	6.2	244	19	–	–	–	–	
Jordan Gulf	3-	14-	1.2-	550-	16-					
of Aqaba	19	199	9.0	16000	244		–	–	–	Abu Hilal (1987)
Arabian Gulf	21	45	1.5	15000	409	–	–	–	–	Samhan *et al.* (1979)
Arabian Gulf	25	33	0.2	5868	1158	–	–	–	–	Abaychi & Douabul (1986)

each of the other metals, has been deduced to their biogenic origin, (El-Rayis *et al.* 1984). Cd is the only metal which shows no significant relation with any of the other metals. El-Rayis *et al.* (1984) related this to its tendency for more soluble chlorocomplex compounds and to associate with the carbonate phase of deposited particles (as will be seen hereafter).

TABLE 5. Interrelationships between suspended heavy metals and total suspended matter studied in the surface oxic water of Jeddah coast, between Islamic Harbour and Attahlia, on the Red Sea.

TSM	1					
Mn	0.96	1				
Fe	0.90	0.96	1			
Cd	0.23	0.17	0.08	1		
Zn	0.38	0.09	0.10	−0.03	1	
Cu	−0.08	−0.11	0.08	−0.48	0.80	1
	TSM	Mn	Fe	Cd	Zn	Cu

n = 12. Value of significance at the 1% level is > 0.66.

Vertical distribution

The bottom water in the Bankalah zone seems not to be restricted from exchange with the outside water. (See, for example, the vertical distribution of dissolved oxygen or H_2S, salinity and Mn along the water column of station 2, in Bankalah area, Fig. 2 and Table 1). Where the amounts of H_2S and dissolved Mn in the bottom water were lower, they are almost halves of those in the surface water (Fig. 2). This means that there was an intrusion of outside coastal oxic water as a subsurface layer towards this zone (similar to the two layer-estuarine system). During its movement towards the Bankalah area, its oxygen content will decrease and eventually be exhausted due to mixing with the subsurface water bearing high content of H_2S, (*e.g.* station 2) and consequently leading to a decrease in the H_2S values of the subsurface water. This process has also been reflected on the occurrence and distribution of the Mn forms (dissolved and particulate) down through that water column. Figure 2 shows that the percentage of dissolved fraction over the total Mn decreases from 66.2% at the surface to 26.6% in the bottom waters. On the contrary, the % particulate Mn increases in the same direction. If this distribution is compared with that in another oxic water column (*e.g.* the one at station 5), it will be noted that the percentage of dissolved Mn to the total along the whole water column was only in the range between 7.3 and 12.4%, *i.e.* most of the Mn was present in the particulate form. This means that the more soluble Mn (II) was dominant in the deoxygenated or reducing water (of station 2), whereas in the oxygenated or oxidizing water Mn was present mainly in the particulate form (Mn III or IV oxides). This is in agreement with the findings of

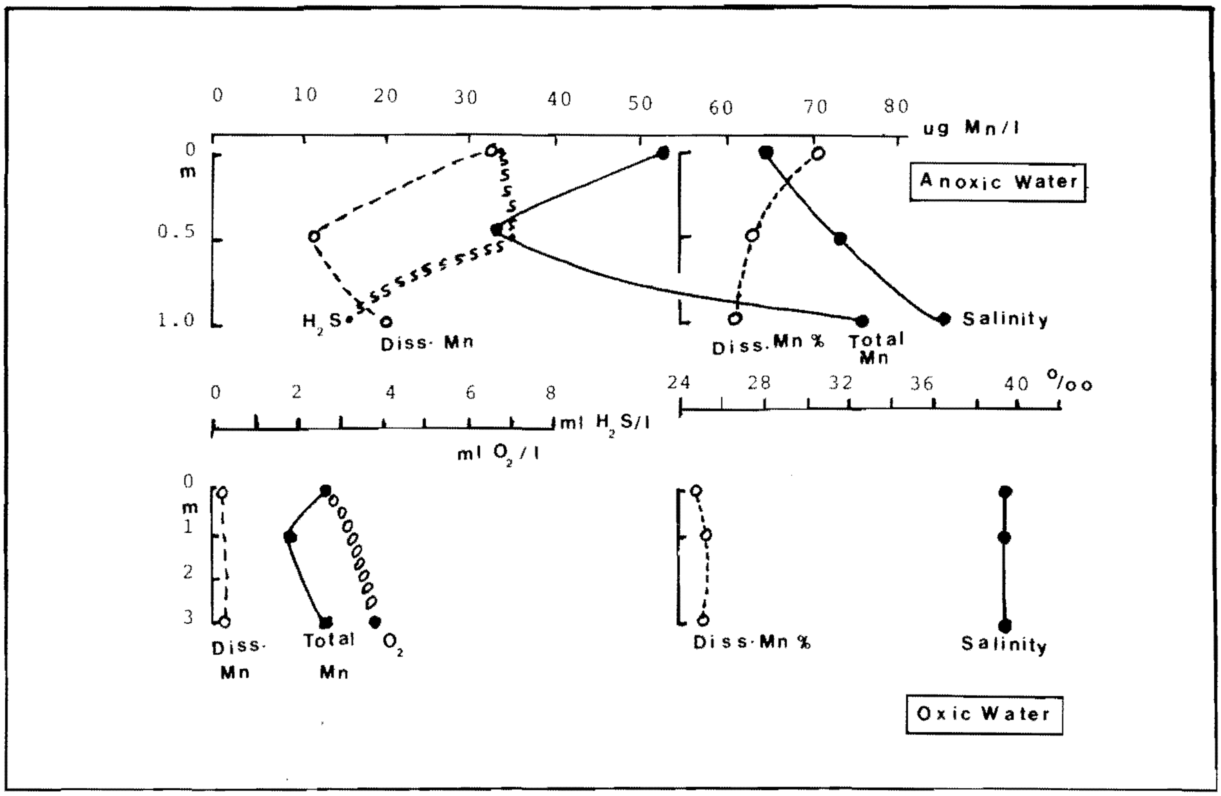

FIG. 2. Distributions of oxygen, hydrogen sulphide, salinity and manganese against depth at stations 2 and 5, Jeddah coast.

other studies such as those by El-Rayis *et al.* (1984) for the same area, El-Rayis (1977) for Oslofjord, and Kremling (1983) for the Baltic Sea.

Generally speaking, the concentrations of the elements studied in the oxygenated water columns at stations 5, 12 and 14 (Table 1) differ very little relative to that of station 2 in the Bankalah area.

Sediments

The concentrations of metals in the bulk sediments of Jeddah coast range as 9-91, 55-185, 2.8-7.2, 88-1064, 12-220, 127-1923, 55-219, and 25-114 μg/g (on dry weight basis, DW) for Cu, Zn, Cd, Fe, Mn, Al, Ca, and Mg, respectively. The respective averages are 20, 30, 5, 338, 56, 589, 147 and 74 μg/g DW. Phosphorus concentrations range between 1352 and 174 μg P/g DW, with the average 468.0 μg/g DW. These values are similar to those of the sediments of other Saudi Red Sea coastal areas between Sharm Obhur and Yanbo, the Jordanian Gulf of Aqaba, and also those in the Arabian Gulf (Table 4).

Al, Ca and Mg were used to provide a means of measuring both the carbonate and non-carbonate phases of the sediments. The carbonate phase was calculated here as CaCO equivalent to the sum of Ca and Mg. On average, it represents 55.4% of the total weight of the sediment in the area.

Table 6 shows the correlation coefficients between the elements studied in the sediments of the Jeddah coast. Iron correlated with Al better than Mn, *i.e.* Fe in this case can be used in place of Al, representing the non-carbonate sediments as well. The Cu, Zn and P contents seem to be associated more with the detrital sediments, as they show a very good correlation coefficients (r) with Fe ($r > 0.95$) and Al ($r > 0.90$). Their association with Mn was relatively small ($r < 0.60$, $n = 16$), because of the inclusion of the values of sediments of stations 1 and 15 (Fig. 3) during the calculation of r. If these two stations are excluded, the values of r would become > 0.91 (Table 6). The relationships between Mn and each of P, Cu, Zn and Fe are shown in Figure 3a, b, c and d, respectively. The sediment at station 1 has a low Mn concentration relative to the corresponding values of the Cu, Zn or P, whereas at station 15, the Mn concentration is higher.

The sediment of station 1 is lying beneath an anoxic water, therefore, it is sapropelic in character. Also the overlying water is rich in dissolved Mn (II) and depleted in particulate or sedimentary Mn (Table 1). This implies partial mobilization of Mn from the sedimentary particles (at station 1) into the water, as soluble Mn (II). The observed low concentration of the Mn in the sediment at this station is interpreted to correspond to P, Cu or Zn (Fig. 3).

At station 15, the increase in the concentration of Mn relative to that for each of the other metals reflects the occurrence of a sedimentation or accumulation process for sedimentary particles enriched with Mn which could be from anthrogenic source due to activities in the harbour and/or the Bankalah area.

TABLE 6. Correlation coefficients between each two variable elements studied in the sediments of Jeddah coast, between Islamic Harbour and Attahlia, on the Red Sea.
$n = 16$. Value of significance at the 1% level is > 0.57 or < -0.57.

	P	Al	Ca	Mg	Cu	Zn	Cd	Fe	Mn
P	1								
Al	0.90	1							
Ca	-0.73	-0.73	1						
Mg	-0.53	-0.54	0.85	1					
Cu	0.93	0.94	-0.75	-0.63	1				
Zn	0.94	0.94	-0.77	-0.65	0.997	1			
Cd	-0.58	-0.45	0.79	0.64	-0.60	-0.63	1		
Fe	0.95	0.95	-0.82	-0.62	0.97	0.97	-0.66	1	
Mn	0.57	0.51	-0.75	-0.58	0.55	0.60	-0.81	0.66	1
Mn	0.95	0.78	–	–	0.91	0.91	–	0.96	1

$n = 14$. Values of stations 1 and 15 were not included.

When examining the fate of the excess water from the Bankalah zone, it is noted that its direction is southwards towards the harbour, or toward station 15. The Bankalah water, as has been seen, is enriched with dissolved Mn (II) which will be reprecipitated as particulate Mn (III or IV) oxides as soon as the surplus water meets the well oxygenated water during its way-out towards the harbour.

Ca, Mg and Cd show direct relationships with each other ($r > 0.64$), and inverse relations with the other elements studied, (Table 6). The association of Cd with Mg and Ca (the main constituents of the carbonate sediments) relates to the occurrence of the process of substitution of Cd for Ca and Mg in such sediments, (Goldschmedit, 1954), the ionic radii of these three elements being almost identical. Similar findings have also been reported for other coastal areas, for example, Liverpool Bay (El-Rayis 1977).

Biological Materials

Brown Algae

The concentration ranges of the metals in the brown algae, *C. barbata*, are: 2.4-3.4, 8-16, 1.39, 102-187; and 5-21 μg/g DW for Cu, Zn, Cd, Fe and Mn, respectively. In *S. vulgare*, they are 6.3-21.2, 16-47, 2.22-

n	14	16
r	0.95	0.57

n	14	16
r	0.91	0.55

(c)

n	14	16
r	0.91	0.66

(d)

n	14	16
r	0.96	0.66

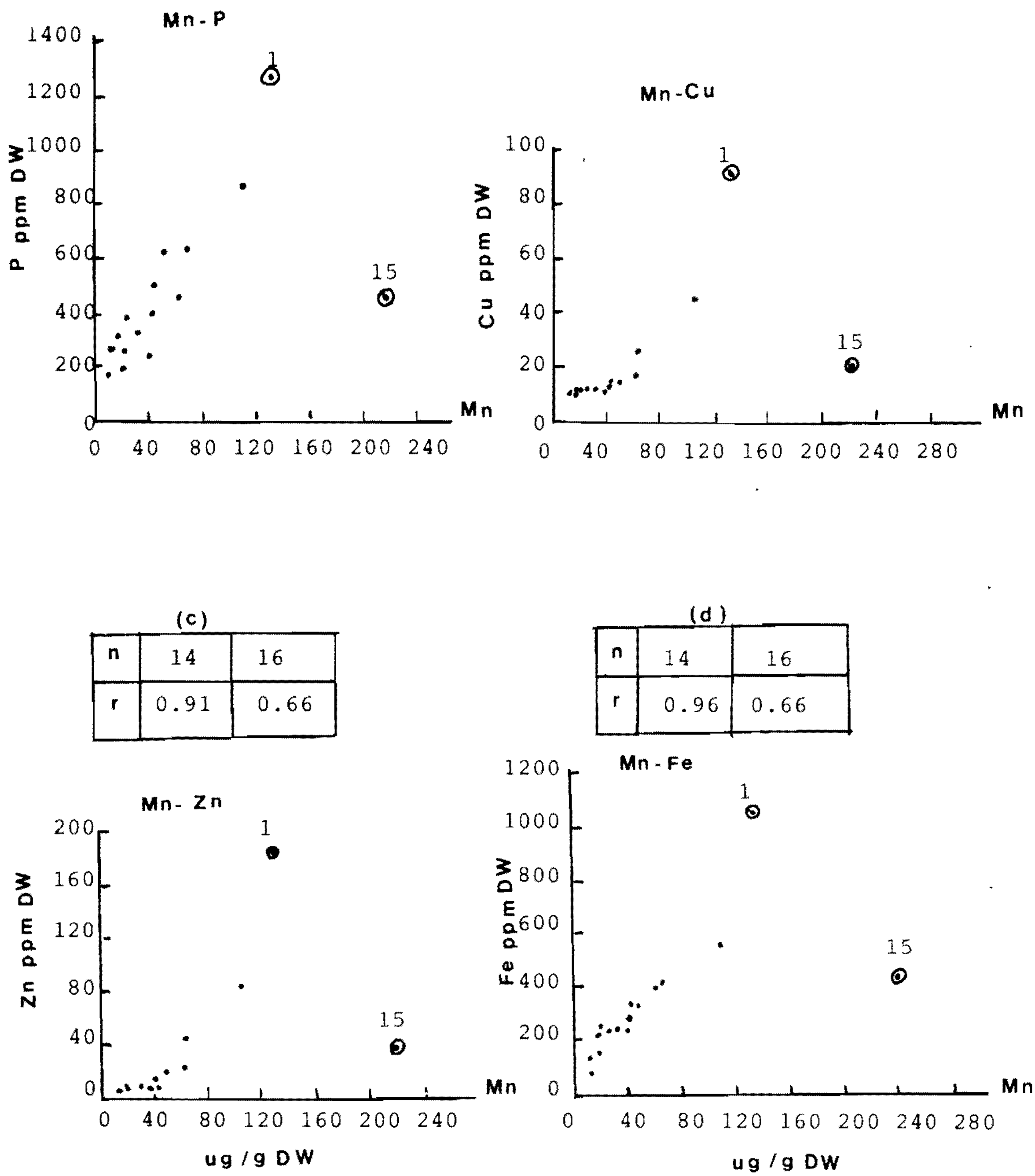

FIG. 3. Graphic relationships between Mn and each of P, Cu, Zn and Fe in sediments of Jeddah coast.

3.33, 465-1335 and 55-182 μg/g DW, respectively, with respective averages of 11.2, 29.0, 2.71, 649.6 and 100 μg/g DW.

The level of the metal concentration in the last brown algae was higher than in the *Cystoseira* species. This seems to be caused by the ability of the *Sargassum* to concentrate more metals from the surrounding water than the other one. The concentration factors of the metals for each algae are shown in Table 3.

Planktons

Analyses of planktons' samples collected from the near, intermediate and offshore waters are shown in Table 3. The metal concentration in the planktons decreases roughly in the seawards direction. However, it is difficult here to assess, if this is due to contamination in the near coastal zone. The plankton sample is a composite sample of different photo- and zooplankton organisms, which differ in their metal contents. However, the concentrations in the plankton range between 17-176, 10.1-53, 3.2-9.3, 126-1452, and 12-69 μg/g DW for Cu, Zn, Cd, Fe and Mn, respectively, with respective means 96, 53, 6.1, 940 and 49 μg/g D.W. Comparison of the concentration factors of metals by the planktons (Table 3) with those of the two brown algae (shown in the same table) indicates that planktons are more efficient at concentrating the metals Cu, Zn, Cd and Fe than algae. In general, the concentrations of the metals in the plankton in the present area are similar to those in other areas in the region (Table 4).

Fish

The results of the biometric study (length and weight) of the three types of the fish are shown in Table 3 which also contains data on the metal concentrations in the different tissues and organs for each fish species. Generally, the concentrations of Cd, Fe and Mn are higher in the peduncle than in the dorsal muscles. It seems likely that the former is not only a place for the accumulation of fats (Ezzat *et al.* 1985), but also for metals too. Another striking feature is the presence of much higher concentrations of Cu, Zn, Cd and Fe (especially Fe) in the liver than in the fish flesh; Fe concentrations in the liver of *Mugil* and *Pagurus* species may be more than an order of magnitude higher. Liver is an organ which contains haemoglobin, of which Fe is an essential component.

The gut also contained higher concentrations of most of the metals than does fish flesh. All these observations, however, are similar to those found for pelagic fish (*Sparus auratus* and *Mugil capito*, Table 4) from the Mediterranean Sea, off Alexandria (El-Rayis *et al.* 1985 and Ezzat *et al.* 1985). The high metal contents of the liver and gut of the fish lead us to recommend that these parts of the fish should not be eaten or fed to poultry as direct or indirect food, before examining their metal contents. This is particularly true for those of toxic ones, such as mercury and Cd. This will eliminate the possibility of biomagnification of these metals becoming a source for health hazards for human.

Differentiation of the Polluted Bankalah Zone from the Rest of Jeddah Coast

On the basis of distribution of the concentrations of the metals in the water and suspended matter, the coast off Jeddah can be divided into two zones. In the Bankalah zone, which is close to the outfalls for domestic effluents, the water has relatively high concentrations of metals and is poorly ventilated. The other zone includes the rest of Jeddah coast between the Islamic Harbour and Attahlia, in which the water is well aerated and contains only low level of trace metals.

The sediments of the Bankalah area (stations 1, 2, 04 and 4) are enriched in Cu and Zn with respect to the other metals and other sediments of Jeddah coast. This is clearly shown in Fig. 4, which shows, for example, the relationship between Cu or Zn with each of Fe and Al. This suggests that Cu and Zn may be useful for characterizing the polluted area of Jeddah coast. The sources of both of these elements are probably mainly biogenic. During leaching these sediments with a mild leaching agent (Chester and Hughes 1967), the author noted that the leachable Cu represents only about 34% of the total Cu content of the sediment, which may confirm its boundness organically. Cu and Zn in the sediments have been used as other indicators in eutrophic areas in the world (e.g. Oslofjord, David Doff, personal comm.) as discriminators to distinguish oxic and anoxic sediments.

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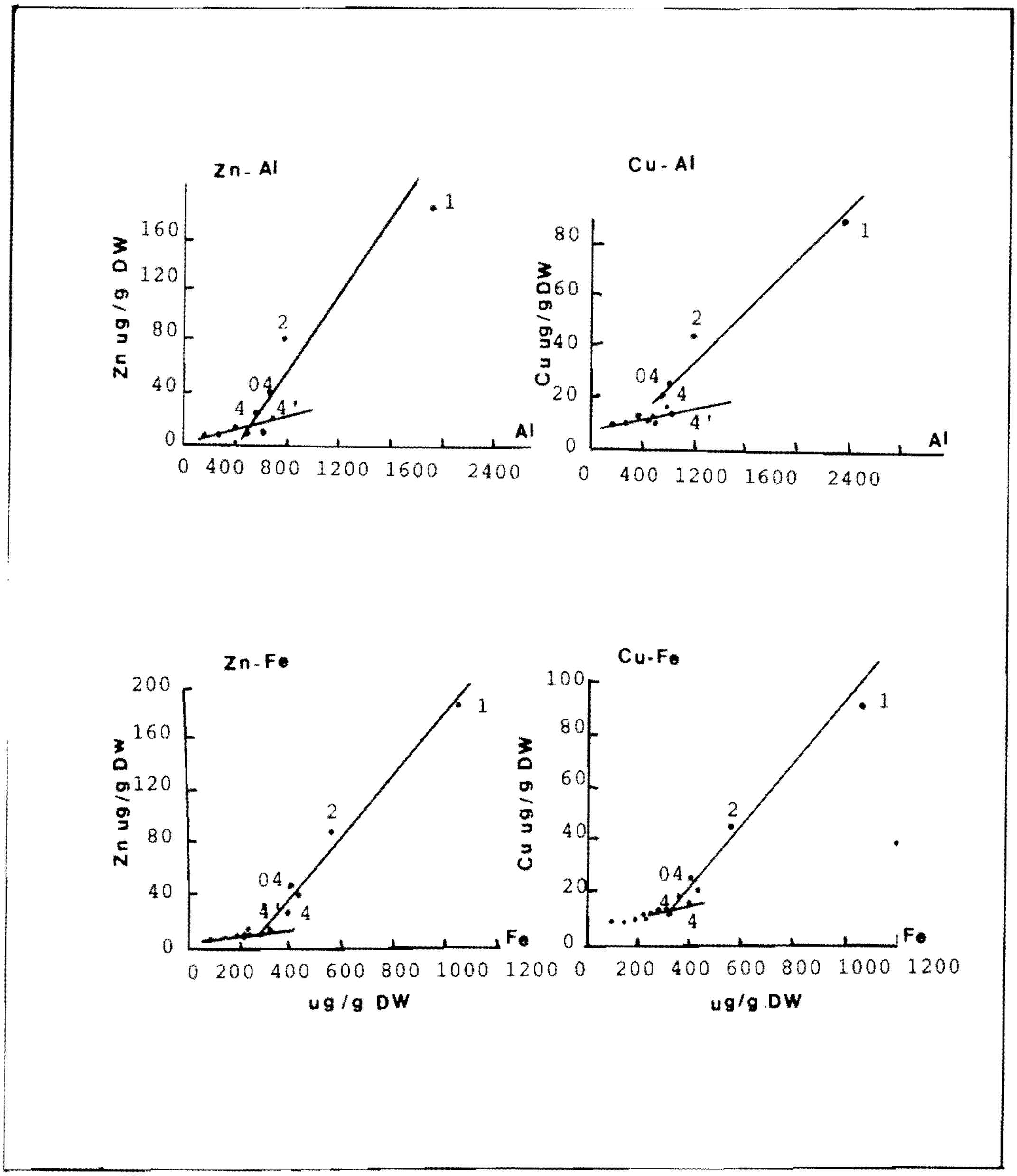

FIG. 4. Graphic relationships among Al, Fe, Cu, and Zn in sediments of Jeddah coast.

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توزيـع بعض الفلزات الثـقيلة في الرسوبيات والمـياه وفي المستويات البيئيـــة الأخرى لشاطىء جـــدة - البحر الأحمر

عثمان عبد المطلب الرَّيِّس

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المستخلص . تمت دراسـة مستويات بعض الفلزات الثقيلة (النحاس والزنك والكاديوم والحديد والمنجنيز) في الرواسب السطحية والمواد المعلقة والعوالق وبعض الطحالب الكبيرة والأسماك من منطقة شاطىء جدة . وتم قياس الألومنيوم والمغنسيوم والكالسيوم والفوسفور في الرواسب . من توزيع الفلزات الثقيلة (وأيضا من توزيع الملوحة والأكسجين أو كبريتيد الهيدروجين الذائب) في المياه والرسوبيات ، أمكن تقسيم الشاطىء إلى جزأين ، أحدهما منطقة البنقلة وهي في حالة آسنة ، وتحتوي على تركيزات عالية من الفلزات وتكون قريبة من صرف مياه المجاري من مركز مدينة جدة . والأخرى (شاملة باقي المنطقة الشاطئية بين الميناء الإسلامي والتحلية) مياهها مؤكسجة وبعيدة عن أثر هذا الصرف ومستويات الفلزات بها وفي عينات الأحياء التي جمعت منها تكون مناظرة لمثيلاتها في مناطق أخرى غير ملوثة بالبحر الأحمر والعالم .

من دراسة العلاقات بين الفلزات الثقيلة والفوسفور مع بعضها البعض ومع الألومنيوم اتضح أنه من بحث علاقة الزنك والنحاس مع الألومنيوم يمكن التمييز بين رسوبيات منطقة البنقلة عن باقي الرسوبيات بالشاطىء وأن هناك تحررًا جزئيًا للمنجنيز من رواسب البنقلة نحو المياه الآسنة التي فوقها .