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Organic Carbon and Calcium Carbonate Distributions Near Sewage Outfalls in the Jordan Gulf of Aqaba, Red Sea

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ABSTRACT. The organic carbon and calcium carbonate content of sediments at the two sewage outfalls that release effluent into the northeastern tip of the Gulf of Aqaba have been determined and compared twice during 1982 and 1983 with control stations away from sewage pollution. The amounts of organic carbon in sediments at the outfalls and control stations are similar in their particle-size distributions and calcium carbonate content, except the outfall near the phosphate loading port which has less calcium carbonate than its control station. Two additional stations, one on each side of the outfall, were examined. The sediments of these stations constantly have had higher values of organic carbon than the control stations, but lower than that at the outfalls.

A recent review of marine benthic studies has indicated that the most universal of environmental disturbances is that of the organic 'enrichment' of marine environment (Pearson and Rosenberg 1978). One major source influencing the level of organic enrichment is the sewage discharge. The greatest impact of this enrichment in the coastal environment is seen in the excessive algal growth rate and biomass and the reduced diversity of invertebrates (Borowitzka 1972, Fitzgerald 1978). This process of enrichment leading to increased algal growth and increased death rate of colonies of the coral *Stylophora pistillata* is occurring in the Gulf of Aqaba, near Aqaba City, Jordan (Walker and Ormond 1982). There are two sewage outfalls that release effluent from Aqaba City, one is at the northern tip of the Gulf and the other one is south of the phosphate loading port. However, no figures are available for the volume of discharge. One way to assess the extent and impact of sewage pollution in the marine environment is to look for changes in the level of organic carbon (McKee 1967). The present study is a detailed comparison of the organic carbon of the polluted sites with the organic carbon from control sites away from the sewage outfalls.

Material and Methods

Study Area

The Gulf of Aqaba, a slightly hypersaline body of partially enclosed marine water, forms the northern segment of the Red Sea. It is about 170 km long and 5-26 km wide (Friedman 1968). At its northernmost portion, it has a continental shelf 2-3 km wide. The shelf greatly narrows, however, on the eastern side and the depth increases to the south.

There are two sewage outfalls that release effluent into the north-eastern tip of the Gulf of Aqaba (Fig. 1). The first outfall is at the northern tip of the Gulf, referred to here as 'S1', and sporadically releases untreated sewage at about 5-10 m from the shoreline. This site is about 1-1.5 m deep at high tide. A control site, referred to here as 'C1', similar in depth and sediment texture was selected at about 1 km west to S1, away from pollution. The second and the main outfall is near the phosphate loading port, referred to here as 'S2'. This outfall is supposed to release primary treated effluent from the sewage station of Aqaba city. The

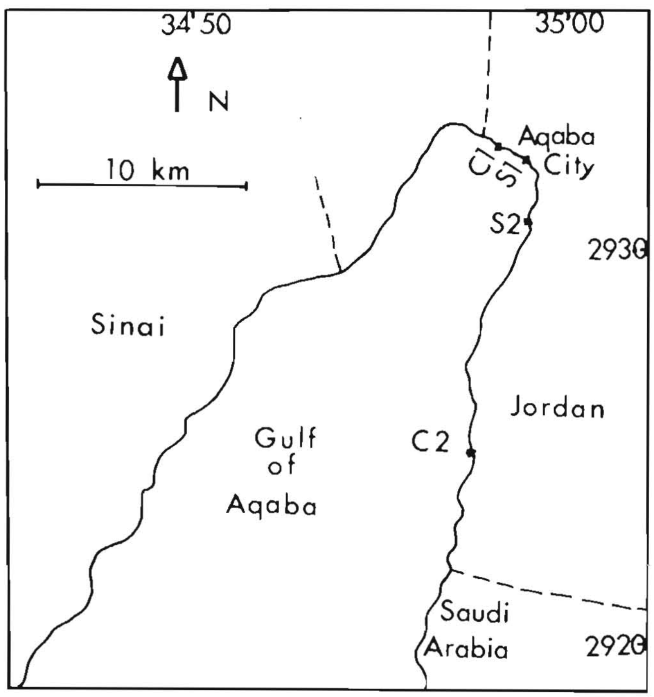

Fig. 1. Location map of the two sewage outfalls in the Jordan Gulf of Aqaba. S1 and C1 are the northern outfall and its control station. S2 and C2 are the outfall near the phosphate loading port and its control station.

maximum capacity of the station is to treat the sewage of a population of 10,000. With recent development in port activities and industry, the population of Aqaba jumped to 35,000 in 1981. Thus, releasing untreated sewage from this outfall is also expected. The outfall is at about 9-11 m deep, depending on the tide, and 50 to 60 m from the shoreline. A control site, referred to here as 'C2', was selected approximately 12 km from Aqaba City, in the Big Bay, and hence away from any possible sewage pollution.

Sampling

Sediment samples were obtained by a core which collects the sediment from a surface area of 0.01 m^2 to a depth of 15-20 cm. For each outfall, 3 sampling stations (5 × 5 m^2) were selected, one at the outfall, and two, one on each side, 100 m away from the outfall. Triplicate samples were collected from each polluted and control station. All stations were sampled twice. S1 and C1 sites were sampled during September 25-27, 1982 and April 16-18, 1983. While S2 and C2 were sampled during December 28-30, 1982 and April 16-18, 1983. Samples from S2 and C2 were collected by SCUBA diving. All samples were placed immediately in plastic bags and deep-frozen (about −20°C).

Each sample was divided into 3 portions for organic carbon, calcium carbonate, and particle size analyses. The method for determination of organic carbon followed, was that of Walkley and Black (1934) as recommended by Holme and McIntyre (1971). In this method, the organic carbon in the sediment is oxidized with a potassium dichromate-sulphuric acid mixture, and the excess chromate is determined by titration with a standard ferrous salt. For the determination of calcium carbonate content, the method given by Anwar and Mohamed (1970) was used. In this technique, the sediment is soaked in distilled water for 24 hr then dried to a constant weight at 105°C. Following the addition of 50 ml of 1 *N* HCl to 4 g of dried sediment, the excess acid is determined by titration with 0.5 *N* NaOH using phenolphthalin as an indicator.

The particle size distributions of sediment samples were analyzed by a modification of standard methods (ASTM standards 1973). Each sample was well mixed and divided into two weighed portions of more than 100 g each. The percentage of water was estimated by drying one portion to a constant weight at 105°C. The second portion was thoroughly wet sieved through a 63 micron standard sieve to determine the mud fraction. The plus 63 micron fraction was oven dried to a constant weight, then mechanically analyzed by agitation through nested standard sieves for 10 minutes using a sieve shaker. Median diameters (Mo) are derived from the cumulative curves of total particle-size distribution. The degree of sorting (So) is based on the Trask (1932) sorting coefficient (Q_c/Q_f), where Q_c and Q_f are the coarse and fine quartiles of the particle-size distribution.

Results

Particle Size Distribution

Sediments of the northern sewage outfall (S1) and its control site (C1) can be described as sandy on the basis of Folk (1974) classification (Table 1). None of the stations has more than 7% mud (minus 63 μm), except in one sample during April, 1983, where 11.2% of the sediment was mud. Moreover, fine sands (< 500- > 63 μm) make up more than 75% of the sediments in all stations during both sampling periods. Thus, median grain diameters ranged from 122-177 μm during April, 1983. All stations have well sorted sediments.

Near the phosphate loading port, the sediment of the sewage outfall (S2) can also be described as sandy (Table 2). Moreover, fine sands make up more than 79% of the sediment. The sediment of the control site (C2) is similar to S2 in all aspects. However, the sediment 100 m north of S2 is different. The mud and coarse sand (< 2,000-> 500 μm) fractions make up approximately 40% of the sediment. This resulted in poorly sorted sediments (high sorting coefficients). The station 100 m south of S2 has a high coarse sand fraction (29.4-47.1%) during December 1982 collection. However, during May, 1983, sediment samples contained only 13.0-16.6% coarse sand. Mud fraction was low in both collections.

Organic Carbon and Calcium Carbonate Distributions

Sediments of S1, C1, and the two stations on both sides of S1 have similar low calcium carbonate content; 5.2-6.1% (Table 3). However, sediments of these stations contain different amounts of organic carbon. During September 1982, the organic carbon in S1 was significantly higher than the organic carbon in C1 and the two stations on both sides ($P < 0.5\%$, Student's t-test). Although the amount of organic carbon in S1 decreased during April 1983, it was still significantly ($P <$ 2-5%) higher than organic carbon in C1. No significant differences, however, were found between the organic carbon content of S1 and the two stations on both sides.

Table 4 shows the organic carbon and calcium carbonate content in sediments of C2, S2, and the two stations 100 m north and south of S2. The calcium carbonate increases from the north station (10.0% during December 1982 and May 1983) southward to C2 (25.2 and 21.2% during December 1982 and May 1983, respectively). The concentration of organic carbon was significantly higher in S2 than the concentration in C2 ($P < 1\%$) during both collections. The concentrations of organic carbon in the north and south stations were lower than that of S2, but higher than C2.

Table 1. Particle size distribution of sediments from the northern sewage outfalls (S1) and its control site (C1) in the Gulf of Aqaba. Values of the sorting coefficient are dimensionless.

Date of Collection / Station	Sept. 25-27, 1982					April 16-18, 1983				
	Coarse* sand % wt.	Fine** sand % wt.	Mud+ % wt.	Median diameter (µm)	Sorting coefficient	Coarse* sand % wt.	Fine** sand % wt.	Mud+ % wt.	Median diameter (µm)	Sorting coefficient
Control	13.4	79.8	6.6	153	1.3	9.4	88.4	0.1	156	1.2
	12.4	87.5	0.3	150	1.3	10.5	88.4	1.2	177	1.2
	16.6	75.8	7.1	163	1.3	12.0	78.8	5.5	170	1.3
Sewage outfall	6.0	93.6	0.4	154	1.2	8.9	87.5	2.1	174	1.2
	5.4	88.2	6.9	127	1.4	5.0	92.5	2.3	148	1.2
	5.0	92.2	2.9	142	1.3	2.3	85.1	11.2	140	1.4
100 m east	5.3	90.8	4.3	122	1.4	10.0	86.9	2.1	153	1.2
	10.0	89.6	0.1	142	1.3	14.0	83.9	0.6	160	1.3
	5.0	92.8	0.1	130	1.2	6.9	90.3	2.1	164	1.3
100 m west	3.2	96.1	0.3	141	1.3	3.4	94.7	1.9	124	1.4
	5.4	94.0	0.4	142	1.3	4.0	93.7	1.8	121	1.4
	5.3	88.2	6.2	142	1.3	4.7	90.7	2.1	130	1.4

* < 2,000 - > 500 µm

** < 500 - > 63 µm

\+ < 63 µm

Table 2. Particle size distribution of sediments from the sewage outfall (S2) near the phosphate loading port and its control site (C2) in the big bay of the Gulf of Aqaba. Values of the sorting coefficient are dimensionless.

Date of Collection / Station	December 28-30, 1982					May 15-17, 1983				
	Coarse* sand % wt.	**Fine** sand % wt.**	**Mud+ % wt.**	**Median diameter (μm)**	**Sorting coefficient**	**Coarse* sand % wt.**	**Fine** sand % wt.**	**Mud+ % wt.**	**Median diameter (μm)**	**Sorting coefficient**
Control	9.0	89.4	1.3	107	1.4	9.1	86.7	3.3	100	1.4
	12.0	81.0	4.6	113	1.4	7.8	88.0	3.3	100	1.4
	7.3	91.4	0.8	116	1.5	5.9	85.5	7.6	102.5	1.4
Sewage outfall	8.6	84.8	5.5	75	1.4	8.9	90.0	1.8	96	1.5
	8.2	89.4	0.9	92	1.5	8.3	90.4	1.6	95	1.5
	7.5	79.2	11.74	86.5	1.4	16.0	83.25	0.7	115	1.6
100 m north	14.25	65.0	17.4	62.5	2.8	24.7	54.8	4.3	192	2.2
	29.2	61.9	7.2	155	2.1	23.8	52.9	5.3	200	2.4
	10.3	61.5	25.5	72	1.8	16.1	62.4	11.0	113	2.1
100 m south	46.9	43.3	5.1	257	1.9	16.6	81.6	1.9	127	1.7
	29.4	64.7	4.9	167.5	1.8	13.0	84.4	2.5	112	1.5
	47.1	51.6	0.35	240	1.7	15.4	82.0	2.5	122	1.6

* < 2,000 - > 500 μm
** < 500 - > 63 μm
\+ < 63 μm

Table 3. Organic carbon and calcium carbonate in sediments from the northern sewage outfall (S1) and its control site (C1) in the Gulf of Aqaba. Each percentage is the average value of three samples given in brackets.

Station \ Date of collection	Sept. 25-27, 1982		April 16-18, 1983	
	Organic carbon %	$CaCO_3$ %	Organic carbon %	$CaCO_3$ %
Control	0.042 [0.054, 0.025, 0.046]	5.3 [5.2, 5.6, 5.2]	0.037 [0.041, 0.041, 0.030]	5.4 [5.9, 4.9, 5.5]
Sewage outfall	0.138 [0.126, 0.129, 0.159]	5.4 [5.0, 5.4, 5.8]	0.058 [0.066, 0.049, 0.059]	5.4 [5.5, 5.4, 5.3]
100 m east	0.060 [0.060, 0.060, 0.059]	5.5 [6.0, 5.8, 4.8]	0.060 [0.060, 0.053, 0.067]	6.1 [5.6, 6.9, 5.9]
100 m west	0.071 [0.066, 0.069, 0.077]	5.8 [6.2, 5.8, 5.3]	0.048 [0.045, 0.045, 0.055]	5.2 [5.5, 5.5, 4.5]

Table 4. Organic carbon and calcium carbonate in sediments from the sewage outfall near the phosphate loading port (S2) and its control site (C2) in the big bay of the Gulf of Aqaba. Each percentage is the average value of three samples given in brackets.

Date of collection / Station	December 28-30, 1982		May 15-17, 1983	
	Organic carbon %	**$CaCO_3$ %**	**Organic carbon %**	**$CaCO_3$ %**
Control	0.105 [0.10, 0.104, 0.109]	25.2 [25.5, 24.8, 25.3]	0.082 [0.075, 0.100, 0.072]	21.2 [21.9, 17.3, 24.3]
Sewage outfall	0.286 [0.345, 0.238, 0.275]	14.5 [14.6, 15.8, 13.2]	0.267 [0.260, 0.240, 0.300]	10.9 [12.4, 10.6, 9.8]
100 m south	0.171 [0.191, 0.138, 0.183]	24.7 [23.7, 25.7, 24.6]	0.164 [0.202, 0.161, 0.130]	22.0 [22.6, 21.1, 22.2]
100 m north	0.218 [0.219, 0.323, 0.112]	10.0 [11.6, 7.5, 10.8]	0.196 [0.168, 0.159, 0.261]	10.0 [8.8, 9.1, 11.9]

Discussion

It is apparent that sewage dumping into the Gulf of Aqaba has significantly increased the amount of organic carbon at the sewage outfalls. The greatest impact of organic matter additions to the coastal environment is seen in the excessive growth of non-endemic plants, the reduction in the species diversity which in turn tends to change the food-chain components for indigenous organisms, often increasing biological oxygen demand, and lowering water transparency (Ketchum 1972). Walker and Ormond (1982) have documented the excessive algal growth in the 'sewage area' near the phosphate loading port in Aqaba. They also observed a corresponding increase in the population density of sea urchins, *Diadema setosum* and the sea-hare, *Aplysia*. However, they found that the death rate of coral colonies of *Stylophora pistillata* was 4-5 times as great in the 'sewage area' as in a control area. Moreover, Walker and Ormond did not observe any regrowth of coral tissue over damaged areas of *S. pistillata* colonized by algae. Thus, sewage dumping will eventually eliminate all coral colonies of *S. pistillata* in the 'sewage area'. Sewage dumping may also affect other components of the marine biotope. Assessing such effects on benthic invertebrates in the Gulf of Aqaba is now in progress by the present authors. Other studies, however, are certainly needed to evaluate the effects of sewage dumping on pelagic life as well as to monitor for heavy metals and toxic substances in seawater.

The percentage of organic matter has been shown to be inversely related to sediment texture (Bader 1954, Newell 1965, Phillips 1972, Ismail 1980), but directly related to percentage of calcium carbonate (Sverdrup *et al.* 1942, Hulings and Ismail 1978). Since the sediment texture and the calcium carbonate content of S1, C1, and the two stations on both sides of S1 are similar, the increase in organic carbon in S1 is due to sewage pollution. Similarly, the release of sewage effluent near the phosphate port resulted in a significant increase in the amount of organic carbon, although C2 has a similar sediment texture and higher calcium carbonate content. In addition, it has been observed that sediment samples from S2 had a lot of undecomposed trash, *e.g.* plant seeds and cigarette remains.

The increase in the amount of organic carbon near sewage outfalls in the Gulf of Aqaba, however, is not 'extreme'. Similar values of organic carbon have been reported from non-polluted productive areas in the Gulf. Hulings and Ismail (1978) reported a mean value of 0.22% organic carbon for sediments from seagrass beds. Wahbeh (1976) found the organic carbon of a beach on the north coast of Aqaba to average 0.23%.

Elevated organic carbon values in polluted areas have been reported by many workers (Aston and Hewitt 1977, Nichols 1977, Botton 1979, Grizzle 1979, Romano 1979, Dauer and Connor 1980). For example, in the New York Bight, Botton (1979) found that the organic carbon was higher in the sewage sludge dumping station (mean 1.95%) than the control station (mean 1.29%). Aston and

Hewitt (1977) reported a mean value of 1.12% organic carbon in the polluted Walton Backwaters, England.

It is noteworthy to indicate that the organic carbon in sediments from the station 100 m north of S2 was higher than that in the station 100 m south of S2 in both collections. This is probably due to the fact that the north station is closer to the phosphate loading port. The pollution by the mineral phosphate dust results usually in an intense process of eutrophication which in turn gives rise also to increased algal growth and biomass (Fishelson 1973). Another possible reason for this difference is the counter-clockwise pattern of circulation in the northern Gulf of Aqaba (Mergner and Schumacher 1974), which probably carries the sewage effluent more to the north. However, Hulings (1979), based on direct measurements of the currents, proposed a clockwise pattern of circulation in the northern Gulf of Aqaba.

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توزيـــع الكــربــون العضــوي وكــربــونـات الكالسيوم بالقرب من مصبات المياه العادمة في خليج العقبة الأردني - البحر الأحمر

نعيم إسماعيل وجمال عوض

دائرة العلوم الحياتية - جامعة اليرموك - إربد - المملكة الأردنية الهاشمية

تم تعيين كمية الكـربون العضوي وكربونات الكالسيوم في الترسبات عند مصبين للمياه العادمة والتي تتسرب في الشمال الشرقي لخليج العقبـة. وللمقـارنـه تم تعيين هذه المعـايير كذلك في محطتين تبعدان عن الأماكن الملوثه في عامي **١٩٨٢** و **١٩٨٣**.

تبـين من هذه الـدراسة أن كمية الكربون العضوي بالقـرب من مصبي المياه العادمة كانت أعلى منها في محطتي المقـارنـة بالـرغم من التشـابه في كمية كربونات الكالسيوم والتوزيع الحجمي للترسبات.

إلا أن كمية كربونات الكالسيوم بالقرب من مصب المياه العادمة في منطقة تحميل الفوسفات كانت أقل منها في محطة المقارنة.

بالإضافة لذلك فقد تم تعيين كمية الكربون العضوي وكربونات الكالسيوم في محطتين على جانبي كل مصب وقد وجـد أيضا أن كمية الكربون العضوي كانت أعلى منها في محطتي المقارنه إلا أنها أقل من تلك بالقرب من مصبي المياه العادمة.