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The Annual Cycle of Nutrient Salts and Chlorophyll-a in the Coastal Waters of Jeddah, Red Sea

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Abstract. The annual cycle of inorganic nutrients and chlorophyll-a have been examined monthly in the coastal waters of Jeddah at nine stations from June 1993 to May, 1994. The rapid and unprecedented industrial development in the Kingdom of Saudi Arabia especially at Jeddah has resulted in the discharge of partially treated or untreated sewage in the coastal waters. Because of the potential importance of inorganic micro-nutrients as limiting factors affecting the growth of phytoplankton, the levels of nitrate, nitrite, ammonium, phosphate and silicate contents were determined. The sampled area extends from South Corniche in the South of Jeddah to Obhur Creek in the north. Statistical analysis to seek correlations between physio-chemical parameters and chlorophyll-a did not show good correlation which may be due to irregular coastal environment.

Key words: Nutrients salts, Phytoplankton standing crop, Red Sea, Jeddah coastal water.

Introduction

Red Sea has received little attention in determining levels of micro-nutrients (Behairy and Saad, 1984; Dowaidar and Shaikh, 1984). Few scattered sources of informations only deal with short period determinations (Behairy and Saad, 1984; El-Rayis, 1998; El-Rayis *et al.*, 1982; Kandil, 1982; Morcos, 1970; Saad and Fahmy, 1984; Shaikh, 1981). Additionally, some papers have dealt with the measurements of chlorophyll-a (Behairy *et al.*, 1983; Behairy and Saad, 1984; Dowaidar *et al.*, 1978; Dowaidar and Shaikh, 1984; Halim, 1969; Khalil *et al.*, 1984; Shaikh, 1981). This paper deals with the determination of micro-nutrients and chlorophyll-a along the coastal area of Jeddah on an annual basis. Some attempts have been made to alleviate the inter-relations between physical, chemical and biological factors in the Red Sea.

Material and Methods

Three main sites are considered for this study: Petromin, South Cournich and Obhur Creek. They are located within the coastal area of Jeddah Red Sea and have considerable importance due their location (Fig. 1). They lie between latitude 21º22′ and 21º38′N and longitude 39º7′E.

Petromin area was represented by five stations: stations 1 to 3 are located in the southern part of Jeddah Islamic Seaport, facing Jeddah oil refinery unit and are affected by oil shipping. Station 4 has been selected within a small lagoon and was affected by two sources of pollution, in addition to the oil pollution. The refinery cooling system discharge, and the organic materials in the northern part of the lagoon. Station 5 was located beside the desalination station not far from station 4.

South Cournich area was represented by only two stations (6 and 7) due to shallowness. This site is approximately 20 km far from the city center where the industrial and domestic wastes which find their way to the Red Sea.

Obhur Creek area (sharm) was represented also by two stations 8 and 9. It is one of the several creeks spread along the Red Sea coast of Saudi Arabia and is located at 35 km north of Jeddah. Station (8) is located near the mouth of this creek, whereas station (9) is out of the creek and represented a control station.

Sea water samples were collected for different analyses from eight stations, starting from June 1993 to May 1994. The additional station (No. 9) was collected outside the Obhur Creek and commenced from November 1993.

Surface water samples were collected early in the morning at monthly intervals by clean plastic bucket. The water was strained through a 212 nylon (mesh size ≈ 83 μ) to remove zooplankton and other large particulate matter and transferred to 5 liter polythene bottles. Salinity and temperature were measured *in situ*, samples for determination of dissolved oxygen were fixed in the field and for other parameters samples were brought back to the laboratory for immediately determination.

Salinity was determined by measuring the concentration of salt as part per thousand unit (PSU) using a HEDGA refractometer. Temperature was determined using a mercury thermometer ranging from 0ºC to 50ºC in 0.1ºC divisions. Dissolved oxygen was determined according to the Winkler technique, (Strickland and Parsons, 1972). Nitrate, nitrite, ammonium, phosphate, and sili-

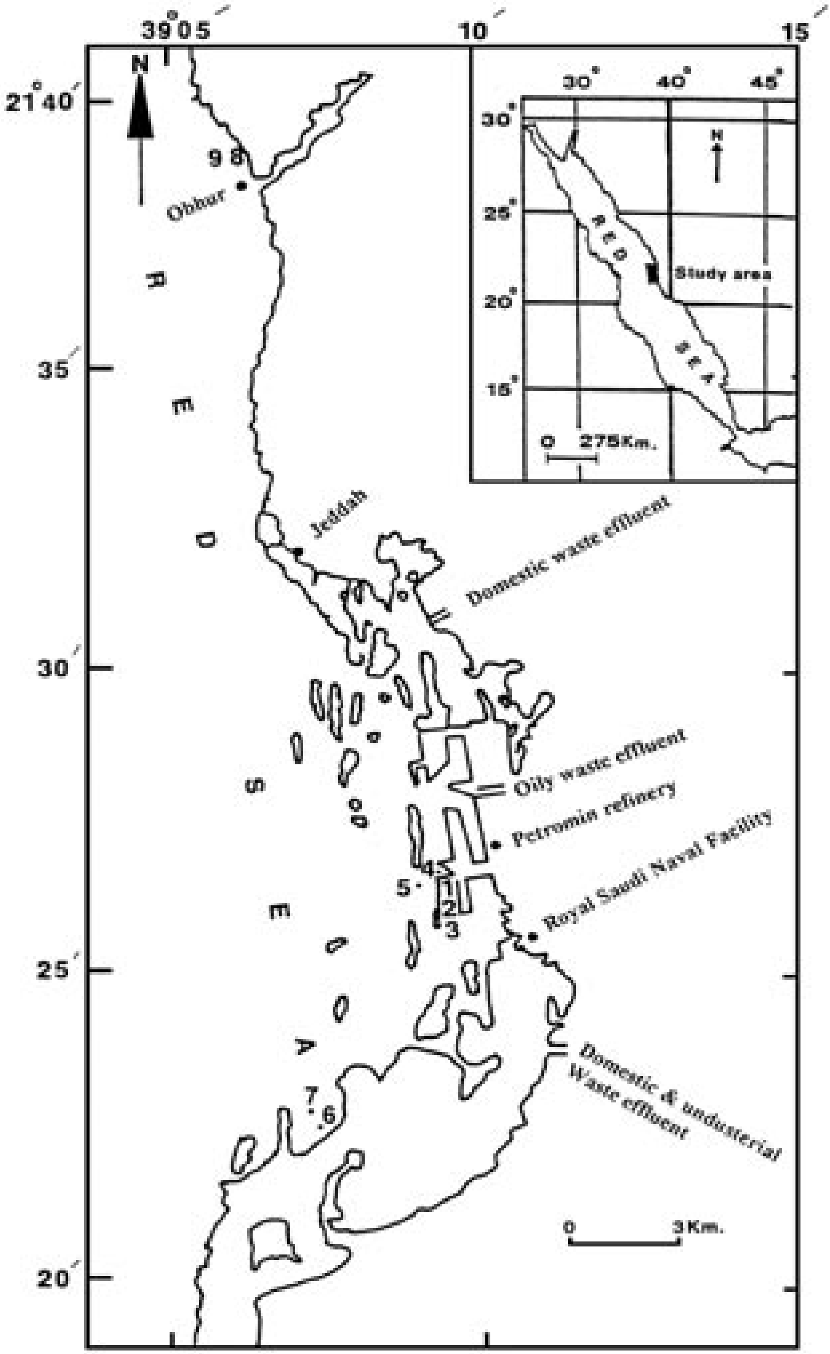

FIG. 1. A map of the study sites.

cate were analysed according to Strickland and Parsons (1972). The phytoplankton standing crop as chlorophyll-a was measured according to the method described by Richards and Thompson (1952) with some modification by Creitz and Richards (1955) and a few minor changes by Strickland and Parsons (1972).

Results

Maximum temperature of 31.5ºC was recorded at station 5 in June 1993; while September 1993 showed thermal homogeny where temperatures were 31ºC at all stations (Table 1). On the other hand lower values ranged between 22-23ºC during January and February 1994. The general pattern of temperature shows that summer time extended from June to October 1993 with a range between 30-31.5ºC. Temperatures decreasing gradually from November 1993 until February 1994 and began to increase again gradually until May 1994.

TABLE 1. Levels of temperature ºC during the study period.

Region	Station	June 93	July 93	Aug. 93	Sep. 93	Oct. 93	Nov. 93	Dec. 93	Jan. 94	Feb. 94	Mar. 94	Apr. 94	May 94
PETROMIN	1	30.00	30.50	30.50	31.00	30.00	26.00	26.00	23.00	22.00	24.00	25.00	25.00
	2	31.00	30.50	30.50	31.00	30.00	26.00	25.00	24.00	23.00	24.00	25.00	25.00
	3	30.00	30.50	30.50	31.00	30.00	26.00	25.00	24.00	23.00	24.00	26.00	25.00
	4	31.00	30.50	30.50	31.00	30.00	26.50	26.00	26.00	23.00	24.00	26.00	25.00
	5	31.50	30.50	30.50	31.00	30.00	27.00	26.00	23.00	23.00	25.00	26.00	26.00
South Cournich	6	30.00	30.50	30.50	31.00	30.00	26.00	26.00	23.00	23.00	23.00	26.00	26.00
	7	30.50	30.50	30.50	31.00	30.00	26.00	26.00	23.00	23.00	24.00	26.00	26.00
Obhur	8	30.00	30.50	30.00	31.00	30.00	26.00	26.00	26.00	23.00	24.00	26.00	26.00
	9						26.00	26.00	26.00	23.00	24.00	26.00	26.00

At the whole area, salinity ranged between 35 and 43 PSU (Table 2). The salinity in Obhur area (35-41; avr. 38.91 PSU) was slightly higher than those observed in Petromin (35.4-43.0; avr. 38.88 PSU) and South Cournich (35.4-41.0; avr. 38.66 PSU). The general trend of salinity showed that the highest values were recorded between September 1993 and April 1994.

The dissolved oxygen of the whole area varied between 1.8 and 10.65 mg O_2 l^{-1} (Table 3). Dissolved oxygen in Petromin area (2.0-10.65; avr. 6.61 mg O_2 l^{-1}) was slightly higher than those observed in South Cournich (2.8-10.65 avr. 6.51 mg O_2 l^{-1}) and Obhur area (1.8-10.24; avr. 6.4 mg O_2 l^{-1}). Station 5 showed pronounced decrease than the other stations. Lowest values were recorded during June to August, while the highest were from December 1993 to May 1994.

TABLE 2. Levels of salinity as part per thousand (psu) during the study period.

Region	Station	June 93	July 93	Aug. 93	Sep. 93	Oct. 93	Nov. 93	Dec. 93	Jan. 94	Feb. 94	Mar. 94	Apr. 94	May 94	A. Average
PETROMIN	1	35.40	35.20	35.40	38.00	39.00	40.00	41.00	40.00	42.00	40.00	39.00	39.00	38.66
	2	35.40	35.40	35.50	39.00	40.00	39.00	40.00	40.00	42.00	39.00	39.00	39.00	38.61
	3	35.60	35.50	35.50	40.00	40.00	40.00	41.00	41.00	42.00	40.00	40.00	38.00	39.05
	4	35.80	35.60	35.50	40.00	40.00	38.00	40.00	40.00	43.00	40.00	40.00	39.00	38.91
	5	35.40	35.30	35.50	40.50	41.00	41.00	41.00	40.00	42.00	41.00	39.00	39.00	39.22
South Cournich	6	35.60	35.40	35.40	40.00	41.00	41.00	40.00	40.00	41.00	39.00	40.00	38.00	38.86
	7	35.70	35.40	35.40	40.00	40.00	41.00	40.00	40.00	40.00	35.00	40.00	39.00	38.46
Obhur	8	35.00	35.40	35.50	41.00	40.00	41.00	40.00	40.00	40.00	40.00	40.00	39.00	38.91
	9						41.00	40.00	40.00	40.00	40.00	40.00	39.00	

TABLE 3. Levels of dissolved oxygen (mg O_2. l^{-1}) during the study period.

Region	Station	June 93	July 93	Aug. 93	Sep. 93	Oct. 93	Nov. 93	Dec. 93	Jan. 94	Feb. 94	Mar. 94	Apr. 94	May 94	A. Average
PETROMIN	1	2.50	3.60	3.00	6.97	6.00	6.72	8.91	9.43	6.26	7.32	9.10	6.58	6.37
	2	2.80	4.00	2.80	8.59	5.91	7.29	8.59	9.02	6.50	7.64	9.59	8.45	6.77
	3	3.00	3.80	3.00	10.45	5.33	7.45	8.26	9.18	7.32	8.70	8.86	8.86	7.02
	4	3.60	4.80	4.00	6.56	5.51	7.29	8.91	9.10	8.13	7.32	7.40	10.65	6.94
	5	2.00	3.60	3.20	6.16	5.27	6.89	8.26	8.78	7.07	5.28	8.21	6.75	5.95
South Cournich	6	3.50	3.50	3.00	8.26	5.67	7.53	9.07	9.27	6.26	6.66	7.72	7.97	6.53
	7	2.80	3.40	3.00	6.08	4.86	7.13	8.91	8.86	6.83	6.42	8.80	10.65	6.48
Obhur	8	1.80	3.80	3.10	10.04	5.43	7.29	8.10	8.70	6.01	6.66	7.97	7.88	6.40
	9						7.29	8.74	8.37	6.50	6.58	10.24	9.67	

Nitrate concentrations showed wide range of variations particularly in Petromin area (0.19-10.04; avr. 2.31 µg at. N. l^{-1}). Stations 1 and 5 sustained high nitrate concentrations with mean values of 3.04 and 3.19 µg at. N. l^{-1}, respectively (Table 4). South Cournich area showed low values (0.07-4.88; avr. 1.22 l^{-1} g at. N. l^{-1}), while Obhur area was of the lowest nitrate content. Temporal variation of nitrate concentrations show high values between October 1993 and March 1994 with maximum concentration in November.

TABLE 4.Concentrations of nitrate (No_3) µg at. l^{-1} during the study period.

Region	Station	June 93	July 93	Aug. 93	Sep. 93	Oct. 93	Nov. 93	Dec. 93	Jan. 94	Feb. 94	Mar. 94	Apr. 94	May 94	A. Average
PETROMIN	1	0.62	0.24	0.42	1.84	6.96	4.79	1.86	3.17	10.04	2.54	3.65	0.40	3.04
	2	0.77	0.32	0.31	0.77	1.96	6.82	2.80	1.38	1.35	0.80	1.04	0.44	1.56
	3	0.77	0.72	0.22	0.46	3.02	6.07	2.06	0.99	0.34	5.85	0.19	0.33	1.75
	4	0.29	0.72	0.26	0.94	1.64	5.17	1.79	1.38	3.17	3.89	3.65	1.20	2.01
	5	0.78	1.94	0.27	3.07	3.53	8.87	8.08	6.60	0.7	3.36	0.41	0.65	3.19
South Cournich	6	0.27	1.20	0.12	0.94	1.57	4.88	1.84	1.04	1.23	1.35	0.92	0.07	1.28
	7	0.72	0.82	0.28	2.20	2.18	3.82	0.77	0.36	0.70	0.65	0.90	0.50	1.16
Obhur	8	0.28	0.34	0.08	0.48	0.70	3.80	0.10	0.41	0.19	0.51	0.22	0.84	0.66
	9						0.82	1.69	0.36	0.05	0.32	0.10	1.23	

As nitrate concentrations, nitrite showed a similar trend but with minor concentrations (Table 5). Petromin area showed slightly higher values (0.04-3.44; avr. 0.50 µg at. N. l^{-1}) than the other areas. High values of 2.78 and 3.44 µg at. N. l^{-1} occurred at station 5 in July and August, respectively with a mean of 1.02 µg at. N. l^{-1}. The general trend of temporal distribution showed a slightly high values during July and August.

TABLE 5. Concentrations of nitrite (No_2) µg at. l^{-1} during the study period.

Region	Station	June 93	July 93	Aug. 93	Sep. 93	Oct. 93	Nov. 93	Dec. 93	Jan. 94	Feb. 94	Mar. 94	Apr. 94	May 94	A. Average
PETROMIN	1	0.69	1.04	0.92	0.19	0.09	0.21	0.26	0.09	0.34	0.13	0.36	0.40	0.39
	2	0.69	0.69	0.69	0.11	0.09	0.26	0.36	0.06	0.36	0.17	0.34	0.53	0.36
	3	1.04	0.69	0.35	0.11	0.09	0.19	0.28	0.09	0.38	0.66	0.34	0.04	0.36
	4	0.69	0.69	0.69	0.11	0.15	0.21	0.21	0.09	0.32	0.70	0.36	0.04	0.36
	5	0.59	2.78	3.44	0.36	0.57	0.91	1.36	0.72	0.34	0.34	0.43	0.40	1.02
South Cournich	6	0.35	1.04	1.24	0.15	0.13	0.23	0.17	0.09	0.40	0.26	0.43	0.38	0.41
	7	0.35	0.69	0.69	0.36	0.10	0.19	0.13	0.06	0.38	0.23	0.40	0.04	0.30
Obhur	8	0.69	0.69	0.40	0.13	0.15	0.13	0.26	0.17	0.40	0.19	0.43	0.17	0.32
	9						0.06	0.32	0.06	0.32	1.02	0.38	0.11	

Ammonia concentrations showed irregular fluctuations from undetectable levels in September (stations 1, 2 and 3) to 36 µg at. N. l^{-1} in October (St. 4) (Table 6). Petromin area showed higher values (0.00-36.0; avr. 4.54 µg at. N.

l^{-1}) than the other areas. Stations 4 and 5 usually sustained higher concentrations with averages of 4.64 and 9.09 µg at. N. l^{-1}, respectively. Obhur area showed lower values with a range of 0.09 to 13.13 µg at. N. l^{-1}.

TABLE 6. Concentrations of Ammonia (NH_4) µg at. l^{-1} during the study period.

Region	Station	June 93	July 93	Aug. 93	Sep. 93	Oct. 93	Nov. 93	Dec. 93	Jan. 94	Feb. 94	Mar. 94	Apr. 94	May 94	A. Average
PETROMIN	1	0.72	0.98	1.20	0.00	15.28	6.00	3.94	4.41	2.44	1.13	2.44	2.53	3.42
	2	0.50	0.80	1.00	0.00	10.31	5.81	0.75	1.22	1.03	0.56	0.75	3.75	2.21
	3	2.00	0.80	0.80	0.00	21.84	7.78	0.47	0.84	0.38	2.81	0.56	1.59	3.32
	4	0.42	0.77	0.40	1.39	36.00	6.00	1.31	5.06	1.03	0.84	0.90	1.50	4.64
	5	0.96	0.96	0.72	1.41	16.69	20.25	11.72	6.84	1.50	23.16	2.81	22.03	9.09
South Cournich	6	0.82	0.82	0.92	2.00	18.28	4.88	1.22	4.50	0.28	3.28	0.38	5.06	3.54
	7	0.77	0.32	0.80	2.06	13.59	4.13	0.75	2.10	0.56	0.09	0.66	5.06	2.57
Obhur	8	0.24	0.24	0.20	0.40	13.13	3.00	0.50	1.20	0.56	1.03	0.28	4.5	2.11
	9						3.00	1.50	1.00	0.09	1.69	1.50	1.88	

The phosphate content varied from undetectable level observed at all stations during July and August to 2.72 µg at. P. l^{-1} in October, station 4 (Table 7). As usual Petromin area sustained higher phosphate concentrations in comparison with the other area with an average of 0.42 µg at. P. l^{-1}. The highest concentrations were recorded at station 4 with a mean of 0.74 µg at. P. l^{-1}, while the lowest concentrations were reported at station 8. The general temporal trend showed depletion during July and August and the highest in February and March.

TABLE 7. Concentrations of phosphate (PO_4) µg at. l^{-1} during the study period.

Region	Station	June 93	July 93	Aug. 93	Sep. 93	Oct. 93	Nov. 93	Dec. 93	Jan. 94	Feb. 94	Mar. 94	Apr. 94	May 94	A. Average
PETROMIN	1	0.00	0.00	0.00	0.05	0.70	0.19	0.09	0.19	1.88	0.66	0.00	0.28	0.34
	2	0.10	0.00	0.00	0.05	0.70	0.1	0.66	0.19	0.98	0.33	0.05	0.23	0.29
	3	0.04	0.00	0.00	0.23	0.66	0.14	0.14	0.14	0.84	1.22	0.90	0.23	0.38
	4	0.00	0.00	0.00	0.05	2.72	0.19	0.42	0.19	0.94	0.89	2.58	0.84	0.74
	5	0.05	0.00	0.00	0.23	0.42	0.19	0.94	0.28	0.75	1.08	0.28	0.09	0.36
South Cournich	6	0.01	0.00	0.00	0.23	0.23	0.19	0.23	0.14	0.19	0.28	0.23	0.23	0.16
	7	0.00	0.00	0.00	1.03	0.42	0.19	0.09	0.1	0.28	0.47	0.38	0.38	0.28
Obhur	8	0.01	0.01	0.01	0.09	0.19	0.19	0.05	0.14	0.47	0.47	0.70	0.19	0.21
	9						0.14	0.05	0.14	0.09	1.41	1.03	0.23	

Silicate content showed a complete depletion from September to December at all stations (Table 8). The silica levels increased in January to reach maximum concentrations of 6.32 and 5.39 µg at. Si. l^{-1} in May at station 1 and 9, respectively. The South Cournich area showed lower values than the other areas.

TABLE 8. Concentrations of silicate (SIO_3) µg at. l^{-1} during the study period.

Region	Station	June 93	July 93	Aug. 93	Sep. 93	Oct. 93	Nov. 93	Dec. 94	Jan. 94	Feb. 94	Mar. 94	Apr. 94	May 94	A. Average
PETROMIN	1	0.02	0.02	0.02	0.00	0.00	0.00	0.00	1.00	0.84	0.37	1.60	6.32	0.85
	2	0.02	0.01	0.01	0.00	0.00	0.00	0.00	0.85	1.39	0.19	0.37	1.58	0.37
	3	0.02	0.02	0.03	0.00	0.00	0.00	0.00	1.30	3.35	0.65	1.58	0.74	0.64
	4	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.90	0.74	0.65	1.30	1.39	0.42
	5	0.02	0.0	0.00	0.00	0.00	0.00	0.00	0.65	2.32	2.23	1.20	1.86	0.69
South Cournich	6	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.80	0.56	0.65	0.56	1.02	0.30
	7	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.37	2.42	1.21	0.56	1.30	0.4
Obhur	8	0.02	0.00	0.01	0.00	0.00	0.00	0.00	0.74	0.93	1.10	1.21	0.56	0.38
	9						0.00	0.00	0.19	1.21	0.56	2.51	5.39	

Phytoplankton biomass as chlorophyll-a (Chl-a) was measured in mg. m^{-3} (Table 9). Minimal concentrations have generally been reported during early summer and did not exceed 0.69 mg. m^{-3}. The amount of Chl-a increased markedly to reach 7.14 and 9.81 mg. m^{-3} in September at stations 4 and 7, respectively and 10.16 mg. m^{-3} in October at station 4. The values of Chl-a fluctuated in a narrow range from November 1993 to April 1994 and formed another increases in May at stations 5, 6 and 7. The South Cournich area showed a slightly higher concentration than the other areas.

TABLE 9. Levels of chlorophyll-a mg chl-a. m^{-3} during the study period.

Region	Station	June 93	July 93	Aug. 93	Sep. 93	Oct. 93	Nov. 93	Dec. 93	Jan. 94	Feb. 94	Mar. 94	Apr. 94	May 94	A. Average
PETROMIN	1	0.13	0.11	0.19	1.41	1.16	0.80	0.89	1.14	0.74	0.95	1.02	0.57	0.76
	2	0.10	0.08	0.16	1.72	0.96	0.80	1.23	1.15	0.72	0.37	1.08	1.17	0.80
	3	0.03	0.14	0.25	3.52	0.58	0.74	1.07	0.97	1.11	0.23	0.99	1.48	0.93
	4	0.28	0.12	0.69	7.14	10.16	0.71	0.59	1.31	1.11	0.42	1.40	1.04	2.08
	5	0.12	0.11	0.46	1.18	1.29	0.60	0.70	1.19	0.61	1.12	0.74	4.36	1.04
South Cournich	6	0.09	0.07	0.48	1.43	0.35	0.41	0.38	0.52	0.39	2.49	1.74	5.19	1.13
	7	0.30	0.09	0.18	9.81	0.70	0.66	0.46	0.39	0.55	0.36	1.20	7.18	1.82
Obhur	8	0.10	0.02	0.04	0.87	0.47	0.33	0.25	0.17	0.77	0.39	0.09	0.22	0.31
	9						0.44	0.26	0.25	1.30	0.23	0.95	0.70	

Discussion

The Red Sea is a semi-enclosed system in which evaporation is one of the most important factors affecting salinity (Behairy *et al.*, 1981). The evaporation in the Red Sea reaches its minimal in September to October and maximum in May Meshal *et al.* (1983), but did not affect the trend of salinity in this study.

Water temperature increased from March to September and reached its maximum value of 31.0ºC in September. The same observation was recorded by Behairy *et al*. (1981) but the maximum temperature was 34.8ºC. The annual amplitude was 9ºC and supported by Behairy *et al*. (1981), in comparison with 6.9ºC recorded in the same latitude by Morcos (1970). This difference reflects the continental influence on surface temperature of coastal water which undergoes larger daily and seasonal fluctuations than those of the open sea at the same latitude (Behairy *et al*., 1981, Meshal *et al*., 1983). Surface water temperature shows increasing trend from south to north and from January to May. This is supported by the finding of Meshal *et al*. (1983).

Dissolved Oxygen was very low during warm seasons. Oxygen solubility decreases with increasing temperature and salinity (Johannas and Betzer, 1975). However, in the Red Sea, dissolved Oxygen is affected mostly with temperature.

Although nitrate is considered as the most stable inorganic nitrogen compound in seawater (Kandil, 1982) the assimilation of nitrogen by phytoplankton needs a set of transformation to form amino acids in which the substrate for these reaction is always ammonium ion (Owens and Esaias, 1976). In the process of nitrification in the sea, nitrate is the end product (Riley and Chester, 1971). Depletion of nitrate observed during different times may be due to increase in the rate of nitrate assimilation (Park *et al*., 1970; Nicholls and MacCrimmon, 1975) and the possible reduction of nitrate.

The nitrate levels in the study area varied from a low of 0.1 µg at.N. l^{-1} at station 8 in December 1993 and station 9 in April 1994 to a maximum of 8.87 µg at. N. l^{-1} at station 5 in November 1993.

Behairy and Saad (1984) have reported a large variation in the levels of nitrate concentration in coastal waters of Jeddah. Their averages at different stations, on the basis of data collected during 1982-83, ranged from 0.02 to 56.37 µg at. N. l^{-1}. However their study area was in front of a sewage discharge from a waste treatment plant. The high concentration of nitrate at times coincided with the discharge of effluents from the plant which may have not been treated properly. The sewage effluents usually increase the levels of nutrient salts.

In another study Saad and Fahmy (1984) have described the physico-chemical characteristics of coastal waters to the north of Jeddah. Their dissolved nitrate concentrations varied from 0.1-7.42 µg at. N. l^{-1} in March and 2.62-13.92 µg at. N. l^{-1} in April for the coastal waters whereas the open sea values reported by the authors at a nearby stations ranged from 0.46-3.24 µg at. N. l^{-1} in March and 4.63-6.42 µg at. N. l^{-1} in April. They also studied the distribution of nutrient salts in the coastal waters of the Red Sea between Jeddah and Yanbu based on the data collected during 1981-82. The nitrate concentration ranged from 0.03 to 4.37 µg at. N. l^{-1} in May and 0.07-3.46 µg at. N. l^{-1} in November. The present observations are in agreement with the previous studies where the concentrations are high, close to a polluted area and low in areas away from it. The high nitrate concentration could be due to the decrease in uptake and the possible decomposition of organic matter as well as the oxidation of nitrite to nitrate.

The nitrite concentration varied from a minimum of 0.06 µg at. N. l^{-1} at station 9 during November 1993 and January 1994 to a maximum of 3.44 µg at. N. l^{-1} at station 5 in August 1993. Behairy and Saad (1984) also found that the values of nitrites varied from 0.06 µg at. l^{-1} in April to 1.46 µg at. l^{-1} in January based on the data for the years 1982-83 in the coastal waters of Jeddah.

Saad and Fahmy (1984) recorded that the dissolved nitrite concentration for the open seawater was from 0.02 to 0.13 µg at. l^{-1} in the north of Jeddah. Shaikh (1981) observed that total depletion of nitrite in Obhur Creek means that the water was well oxygenated and did not receive sewage waste. In a similar study by Saad and Fahmy (1984) relating to the distribution of nutrient salts in coastal waters of the Red Sea between Jeddah and Yanbu the nitrite concentration ranged from 0.01 to 0.31 µg at. l^{-1} in May. Average nitrite values found by Kandil (1982) in the coastal waters of the Red Sea in front of Hurgada ranged from 0.02 to 0.08 µg at. l^{-1}.

Depletion of nitrite and its low values might be attributed to the increase in nitrite oxidation to nitrate and probably its reduction to ammonia as well as nitrite uptake by phytoplankton (Kandil, 1982). The high nitrite concentrations are due possibly to the reduction of nitrate to nitrite and the oxidation of ammonia to nitrite (Grasshof, 1969). The concentration of nitrite in the sea water is useful due to its intermediate position between ammonia and nitrate.

The major sources of ammonium input in marine environment are believed to be land runoff, zooplankton excretion, remineralization of organic matter and sewage discharges and decomposition of animal and plant matter (Ketchum, 1962; Verlencar, 1987). Ammonium is preferred by phytoplankton as a source of nitrogen (Eppley *et al*., 1979; McCarthy *et al*., 1977). In the present study the concentration of ammonia varied from a high of 36.00 µg at. l^{-1} at station 4 in October 1993 to a low of 0.20 µg at. N. l^{-1} in July 1993 at station 8. Normally lower ammonia values should occur with lower nitrite content and vice versa. The available ammonia may be due to the decomposition product of organic material.

The phosphorus concentrations in the searched area ranged between depletion and maximum recorded of 1.9 µg at. l^{-1} at stations 4 and 9. This could be attributed to the discharges from the heavily polluted area. El-Rayis *et al.* (1982) found that the concentration of phosphorus ranged between 0.5-68.4 µg at. l^{-1} in the coastal water in front of the Jeddah city center area. Station 9 at the Obhur area showed also high values and this could be attributed to the high discharges of pollutant from the recently developed recreational centers at the Obhur area. During this study, values in the Obhur area ranged between 0.01 and 1.41 µg at. l^{-1}. El-Rayis *et al.* (1982) reported average values of 0.3 µg at. l^{-1} for the open seawater. Saad and Fahmy (1984) alsso recorded similar values in the coastal water.

In general, phosphorus showed two peaks, one during warm season in October and the other between January-March. Published literature reveals that the annual cycle of phosphorous consist of maximum concentrations in the summer season (Smayda, 1957; Jefferies, 1962; Hobbie *et al*., 1975).

The growth of diatoms in natural waters is regulated by the availability of silica in the dissolved form (Paasche, 1973). Silica ranged between undetectable level and 6.32 µg at. Si. l^{-1}. The average value of Obhur Creek was similar to that of El-Rayis *et al*. (1982). During summer season June-December, silica could not be detected, most probably due to the subsequent presence of a strong thermocline layer. The irregular spatial pattern occurred from January-May could be attributed to the growth and the uptake of silica by diatoms (Ewins and Spencer, 1967).

Chlorophyll-a concentration in terms of phytoplankton biomass generally fluctuates from time to time particularly in coastal waters. Welch and Issac (1967) showed that chlorophyll-a values may vary upto 800% in an estuary over 24 hours. A marked variability, in space and time, in phytoplankton standing crop was observed in the study area. The major factors affecting photosynthesis rates are degree of irradiance, spectral composition of light, water temperature and concentration of nutrient salts (Boney, 1975). The variation in phytoplankton growth is complicated due to the interaction between ecological factors and rates of regeneration of nutrients. Table (10) shows that there exists either none or little correlation between Chl-a and the different environmental parameters.

TABLE 10. Correlations coefficieny values between physico-chemical parameters and Chl-a values.

		S% 0	Toc	D.O2	No2	No3	NH3	PO4	SiO3	Chl-a
		1	2	3	4	5	6	7	8	9
S% 0	1									
Toc	2	–0.668								
D.O2	3	0.309	–0.688							
No2	4	–0.141	0.283	–0.485						
No3	5	0.384	–0.242	0.169	–0.015					
NH3	6	0.268	0.022	–0.032	–0.113	0.374				
PO4	7	0.436	–0.314	0.202	–0.116	0.327	0.352			
SiO3	8	0.239	–0.411	0.310	–0.141	–0.133	–0.038	0.211		
Chl-a	9	0.202	0.004	0.200	–0.190	–0.015	0.355	0.355	0.026	

The chlorophyll-a concentrations as reached in this study ranged between 0.02 and 10.16 mg. m^{-3} with an average of 1.11 mg. m^{-3} in the coastal waters of Jeddah, as compared to values of 1.18 ± 0.7 mg. m^{-3} in the Arabian Gulf and 0.55 ± 0.12 mg. m^{-3} in the Gulf of Oman (El-Gindy and Dorgham, 1992). This indicates that the production potential of the Red Sea is low. The development of a thermocline or halocline prevents the recycling of nutrients from deeper waters to the euphotic zone (Armstrong and Lafond, 1966). There is little nutrient input to the pelagic system from land run-off to compensate for the steady loss of nutrients by sinkage out of the euphotic zone.

Conclusion

Chlorophyll-a concentration in terms of phytoplankton biomass fluctuates considerably with time and place. Chlorophyll-a concentrations were generally higher in September-October 1993 and May 1994 in the study area. The Petromin and South Cournich areas showed a pronounced increase in Chl-a concentration (averages of 1.12 and 1.48 mg. m^{-3} respectively) than the Obhur (Avg. 0.31 mg. m^{-3}) which may be due to the higher level of pollution in the first two areas which cause increase of production, additionally, the total nitrogen and phosphate ratios in the first two areas showed values of 5.83 and 7.04:1 respectively. Obhur area showed a value of 4.9:1 whereas the control station showed the lowest value of about 2.04:1. The seasonal and regional variations of phytoplankton growth are complicated due to interaction between ecological factors and levels of nutrients and their return to water column by physical and chemical processes and the rates of their consumption in the primary production process. Statistical applications could not show good correlations between parameters and Chl-a, which might be due to the irregular coastal environment. Clear contradiction between the phytoplankton biomass and the nutrient contents was sometimes observed in the study area. During certain periods and at some stations, the high nutrient content was accompanied by low biomass. However in general the higher nutrient contents were accompanied by increased chlorophyll-a concentration.

The spatial and temporal distribution of non-conservative oceanographic properties *e.g.* concentration of phytoplankton are difficult to study by collecting samples by ships. In contrast, satellites can provide wide-ranging repeated coverage for some properties like the chlorophyll content of the upper part of the photic zone.

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الدورة السنوية للأملاح المغذية واليخضور- أ في المياه الساحلية لمحافظة جـدة ، البحر الأحمر

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المستخلص. تمت دراسة الدورة السنوية لبعض الأملاح غير العضوية واليخضور-أ على شاطيء محافظة جدة. حيث إن التطورات الصناعية السريعة والمفاجئة في المملكة العربية السعودية عامة وفي محافظة جدة خاصة تسببت نسبياً في إلقاء بعض مواد الصرف غير المعالجة أو المعالجة جزئياً إلى الشواطيء. نظراً لأهمية بعض هذه المواد ، (غير العضوية) باعتبارها عوامل محددة لنمو الهائمات النباتية، فقد تم قياس تركيزات النترات، النيتريت، الأمونيا، الفوسفات والسليكات في عينات مائية شهرية من تسعة محطات ممتدة من الكورنيش الجنوبي وحتى منطقة خليج أبحر خلال الفترة من شهر يونيو ١٩٩٣ وحتى شهر مايو ١٩٩٤, المحاولات الإحصائية لإيجاد علاقات بين العوامل الفيزيو-كيميائيه واليخضور-أ لم تعطي نتائج جيدة ربما للتأثر بالعوامل البيئية الشاطئية المتغيرة.

الكلمات المفتاحية: الأملاح المغذية، المحصول الثابت، اليخضور- أ ، البحر الأحمر، المياه الشاطئية