

## **Eutrophication and Chlorophyll-a in a Severely Polluted Coastal Water of Jeddah, Red Sea.**

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*Abstract.* Eutrophication becomes the future hazard as a consequence of irrational development around coastal areas of Jeddah. This area receives variable types of anthropogenic pollutants such as, oil, heavy metals and discharge effluents from the different sources of refinery, manufactures, and various discharge effluents. Micronutrients as a fuel for phytoplankton and hence standing crop were determined in very polluted lakes (Al-Salam and Al-Shabab mostly with sewage) from four stations for 12 months and compared with previous few studies of the Red Sea. High levels of nutrient loadings especially in stations 1 and 4 showed good signs of eutrophication. Salinity and temperature averaged 34.5 and 39.6 PSU and 29 to 30 °C, respectively. Nitrate averaged 1.2 to 14.13 and 1.3 to 3.99  $\mu\text{g at.l}^{-1}$  respectively, for surface and sub-surface layers. Nitrite averaged 0.4 to 4.06  $\mu\text{g at.l}^{-1}$  for surface and 0.34 to 0.64 for sub-surface layers. Ammonia showed averages of 4.14 to 39.52 and 3.93 to 9.35  $\mu\text{g at.l}^{-1}$  for surface and sub-surface water. Surface phosphate averaged 0.86 to 21.93  $\mu\text{g at.l}^{-1}$ , while subsurface averaged 0.45 to 2.19  $\mu\text{g at.l}^{-1}$ . Silicate averaged 4.73 to 27.11 and 6.54 to 10.25  $\mu\text{g at.l}^{-1}$ , in surface and sub-surface layers. Standing crop as Chl-a averaged between 7.24 and 71.64 and 2.78 to 16.38 for surface and sub-surface layers, respectively. Statistical analysis to reveal correlations between physio-bio-chemical parameters did not show good correlation.

### **Introduction**

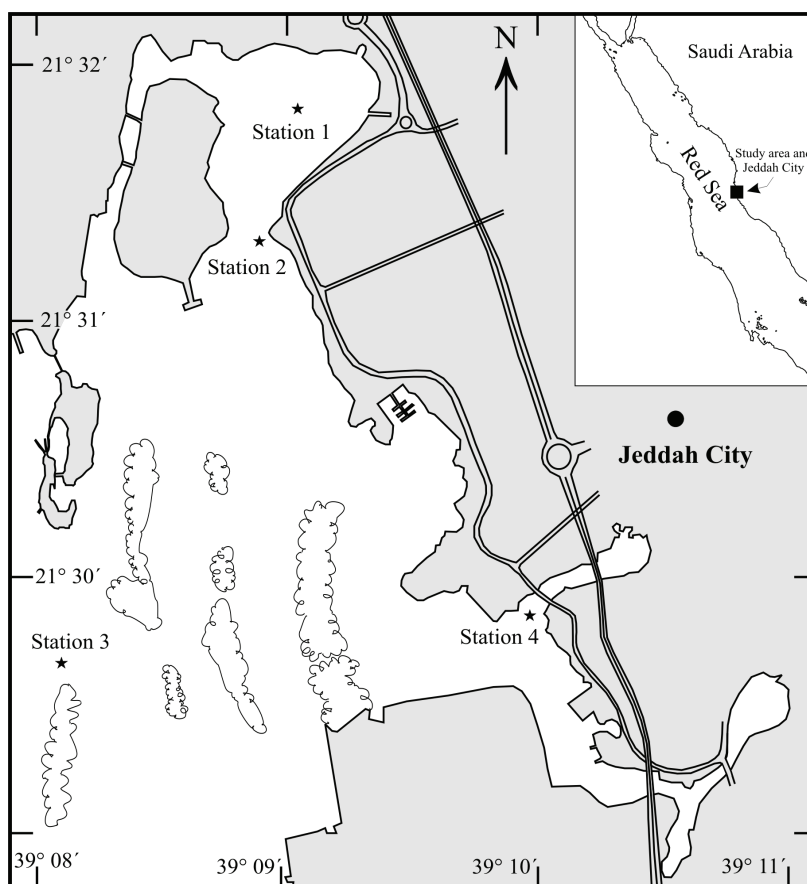
Coastal eutrophication has, since the early 1970s, become the foremost threat to the marine ecosystem such as Archipelago Sea (Bonsdorff *et al.* 1997). The relation between phytoplankton standing crop and physico-chemical factors in Red Sea are rarely studied especially in coastal waters

of Saudi Arabia. Sporadic sources within mostly short term determinations of micro-nutrients and Chlorophyll-a as well as qualitative phytoplankton production were reported (Al-Harbi *et al.*, 1998; Behairy *et al.*, 1983; Behairy and Saad, 1984; El-Rayis, 1998; El-Rayis *et al.*, 1982; El-Sayed and Niaz, 1999; Dowaidar *et al.*, 1978; Dowaidar and Shaikh, 1984; Halim, 1969; Hariri *et al.*, 1997; Khalil *et al.*, 1984; Kandil, 1982; Morcos, 1970; Saad and Fahmy, 1984; Shaikh, 1981; and recently Khomayis, 2002). El-Rayis *et al.*, (1982) had reported that the average salinity of sea water of middle Cornish in Jeddah was 37.87%, while average phosphate concentration in the same area was  $13.0 \mu\text{M L}^{-1}$ , but the contents of silicate ranged between  $1.50 \mu\text{M L}^{-1}$  and  $56.10 \mu\text{M L}^{-1}$ . MEPA Series (1987) showed that temperature ranged between  $21^\circ\text{C}$  and  $26^\circ\text{C}$  in the north of Red Sea, and between  $28^\circ\text{C}$  and  $32^\circ\text{C}$  in the south of Red Sea, the low value recorded in winter and the high in summer. Salinity ranged between 37% in the south and 42% in the north of the Red Sea. In the same study the ammonia and phosphate measurements were,  $> 2.0 \mu\text{M L}^{-1}$  and  $3.0 \mu\text{M L}^{-1}$ , respectively. Hariri *et al.* (1997) carried out a study in coastal waters of Jeddah and reported that the temperature average was  $30.45^\circ\text{C}$ , whereas salinity was 38.26%. They found also the range of micronutrients concentrations such as nitrate ( $0.02 - 1.68 \mu\text{M L}^{-1}$ ), nitrite ( $0.15 - 1.15 \mu\text{M L}^{-1}$ ), ammonia ( $0.1 - 2.56 \mu\text{M L}^{-1}$ ) and phosphate ( $0.82 - 6.7 \mu\text{M L}^{-1}$ ). In the area already highly polluted by sewage in the south of Jeddah El-Sayed & Niaz (1999) indicated high values of ammonia ( $130 - 824 \mu\text{M L}^{-1}$ ), phosphate ( $0.5 - 68.4 \mu\text{M L}^{-1}$ ), nitrite ( $0.02 - 1.61 \mu\text{M L}^{-1}$ ) and nitrate ( $0.68 \mu\text{M L}^{-1}$ ). Khomayis (2002) studied the chemical and physical parameters along Jeddah coastal waters. He found temperature ranged between  $23$  and  $31.5^\circ\text{C}$ , salinity between 38.46- 39.22% nitrate between  $0.66 - 3.19 \mu\text{M L}^{-1}$ , nitrite between  $0.30$  and  $1.02 \mu\text{M L}^{-1}$ , ammonia between  $2.11$  and  $9.09 \mu\text{M L}^{-1}$ , phosphate between  $0.16 - 0.74 \mu\text{M L}^{-1}$ , silicate between  $0.3 - 0.85 \mu\text{M L}^{-1}$  and chlorophyll ranged between  $0.31$  and  $2.08 \mu\text{g L}^{-1}$ .

The present study aimed to investigate the chemicals, physical and biological parameters in the polluted sea water ponds of Jeddah coastal waters and make correlations between these parameters and previous studies.

## Materials and Methods

This study was carried out in semi closed sea lagoons (Bohairat Alsalam and Bohairat Alshabab) very heavily polluted by sewage discharges. These lagoons are located at longitudes ( $39^{\circ} 08' - 39^{\circ} 11'$ ) east and latitudes ( $21^{\circ} 29' - 21^{\circ} 33'$ ) north. These lagoons are very shallow with no more than 4 m in depth. Sample stations (Fig. 1) were selected in the middle of Bohairat Alsalam (station 1) and in the mouth of the lagoon (station 2). The fourth station was selected in the mouth of Bohairat Alshabab and affected by the discharge of sewage output. The third station was the control station and located in the open sea.



**Fig. 1.** Map shows the study location and stations.

Sea water samples were collected early morning at monthly intervals (December 2001- November 2002) from the surface water by clean plastic bucket and from the 3m depth by Vandorn bottle. To remove the large particulate matter and zooplankton, the seawater samples were strained through a net of 120 $\mu$  mesh size to 5 liter polythene bottles. The samples were transferred to the laboratory for chlorophyll *a* and micronutrients (phosphate, silicate, nitrate, nitrite, ammonia and silicate) determinations, using the method based on Parsons *et al.* (1984). Salinity and temperature of the seawater were measured *in situ* by a HEDGA refractometer and a mercury thermometer ranging from 0°C -50°C.

## Results

Temperature ranged between 25.5-33.5 °C. Maximum value was recorded at station 4 (August 2002), and the minimum was in January 2002 at station 1 (Table 1). The general pattern of temperature shows that summer extended from June to November 2002 with an average 29-30 °C. In general, temperatures showed lower levels during January 2002 at all stations.

**Table 1. Average surface temperature (°C) at all stations during the study period.**

Stations Months	Station 1	Station 2	Station 3	Station 4
Dec2001	26	28.5	28.5	28
Jan 2002	25.5	26.5	27	26
Feb	28.5	27	28	28.5
Mar	29	27	28	28
Apr	27	27	27.5	28.5
May	27	28	28	29
Jun	29	29	30	31
Jul	30.5	30.5	31.5	32.5
Aug	32	32	32.5	33.5
Sep	31	32	32	32
Oct	33	31.5	32	32.5
Nov	29	29	29	30
<b>Average</b>	<b>29.0</b>	<b>29.0</b>	<b>29.5</b>	<b>30.0</b>

Salinity ranged between 25.5 and 40.5 PSU (Table 2). Station 4 experienced lower levels of salinity than the other stations, except of 31 PSU recorded in August at station 1. It ranged at station 4 between 25.5

PSU in April and 40 PSU in May with an average of 34.5 PSU. Salinity at station 3 ranged between 36 and 40.5; avr. 36.9 PSU., while salinity at station 2 ranged between 37 and 40; avr. 39.5 PSU., and station 1 ranged between 31 and 40; avr.37.5 PSU.

**Table 2. Levels of salinity as (psu) along the study area during the study period.**

Months	Station 1	Station 2	Station 3	Station 4
Dec. 2001	40	40	40	39
Jan. 2002	37.5	40	39.5	32.5
Feb	31	40	36	30
Mar	40	40	40	40
Apr	39.5	37	40.5	25.5
May	40	40	40.5	40
Jun	36.5	37.5	40	35
Jul	39	40	40	36
Aug	31	39	39	34
Sep	38	40	40	32
Oct	38.5	40	40	34.5
Nov	39	40	40	36
<b>Average</b>	<b>37.5</b>	<b>39.5</b>	<b>39.6</b>	<b>34.5</b>

Nitrate concentrations in surface and sub-surface layer are shown in Table 3. Surface water showed high level of nitrate and wide range of variations particularly in station 1 and 4 (0.08-62.31, avr.12.60  $\mu\text{g at.l}^{-1}$ ; and 2.1-39.51, avr. 14.13  $\mu\text{g at.l}^{-1}$  respectively. Stations 2 and 3 showed less variations (UDL-5.52, avr. 2.27  $\mu\text{g at.l}^{-1}$ ; and UDL-2.76; avr. 1.12  $\mu\text{g at.l}^{-1}$  respectively. Temporal changes in nitrate showed high levels from July until September with the highest value of 62.31  $\mu\text{g at.l}^{-1}$  recorded in August at the surface water of station1. Station 2 showed high level in June. Temporal variation in station 4 showed high levels during most of the study period with high peaks during April and September. Surface nitrate readings were usually higher than sub-surface ones. Temporal variations in Sub-surface waters showed high nitrate levels during December 2001 at station 2, 3 and 4; and the highest level occurred during August at station 1.

**Table 3. Concentrations of nitrate (NO<sub>3</sub>) as µg at  $I^l$  during the study period.**

Stations Months	Station 1		Station 2		Station 3		Station 4	
	Surface	Sub-surface	Surface	Sub-surface	Surface	Sub-surface	Surface	Sub-surface
Dec-01	4.75	1.9	3.67	7.75	2.76	7.51	6.6	5.44
Jan-02	5.46	5.7	1.6	0.82	1.01	0.53	27	2.56
Feb	0.08	UDL	3.67	0.37	0.45	0.58	4.55	2.79
Mar	5.05	1.45	1.39	0.45	1.26	0.63	2.1	1.08
Apr	1.22	0.72	1.81	4.52	1.6	0.53	39.51	4.71
May	5.78	1.13	0.23	1.55	0.75	0.29	2.23	0.91
Jun	4.39	0.67	5.52	0.33	0.34	0.12	12.42	2.89
Jul	22.78	2.88	UDL	0.43	1.39	0.21	1.58	2.74
Aug	62.31	16.8	0.27	0.28	UDL	UDL	14.06	1.98
Sep	14.39	3.95	UDL	1.21	UDL	UDL	31.23	3.66
Oct	UDL	UDL	UDL	UDL	UDL	UDL	UDL	UDL
Nov	UDL	UDL	UDL	UDL	UDL	UDL	UDL	UDL
<b>Average</b>	<b>12.62</b>	<b>3.91</b>	<b>2.27</b>	<b>1.77</b>	<b>1.2</b>	<b>1.3</b>	<b>14.13</b>	<b>2.88</b>

UDL= under detection limit

Nitrite concentrations in surface and sub-surface layers are shown in Table 4. Surface water showed wide range of variations particularly in station 4, (0.07-13.98 avr.4.06 µg at  $I^l$ ). Stations 1, 2, and 3 showed low nitrite levels (0.2-2.16, avr.0.97; 0.03-1.78, avr.0.5; and 0.1-1.28, avr.0.4 µg at  $I^l$ ), respectively. January 2002, April seems to experience slight higher levels in all the three stations and higher levels at station 1 appeared during August.

**Table 4. Concentrations of nitrite (NO<sub>2</sub>) as µg at  $I^l$  during the study period.**

Stations Months	Station 1		Station 2		Station 3		Station 4	
	Surface	Sub-surface	Surface	Sub-surface	Surface	Sub-surface	Surface	Sub-surface
Dec-01	1.47	1.51	1.13	1.09	0.97	0.99	1.43	1.37
Jan-02	1.76	1.57	1.47	1.39	1.28	1.36	9.91	1.52
Feb	0.2	0.1	0.51	0.46	0.33	0.33	1.37	0.51
Mar	0.25	0.15	0.15	0.13	0.25	0.1	0.79	0.15
Apr	2.13	0.9	1.78	0.19	0.25	0.11	11.65	0.36
May	0.92	0.31	0.19	1.28	0.41	0.09	0.23	0.38
Jun	0.22	0.43	0.18	2.15	0.28	0.23	3.99	0.46
Jul	0.82	0.21	0.03	0.09	0.19	0.09	0.07	0.33
Aug	2.16	0.17	0.07	0.1	0.15	0.1	3.48	0.13
Sep	0.2	0.13	0.1	0.33	0.33	0.13	13.98	0.36
Oct	1.23	0.42	0.3	0.23	0.2	0.36	1.54	0.2
Nov	0.28	0.33	0.13	0.22	0.1	0.13	0.24	0.13
<b>Average</b>	<b>0.97</b>	<b>0.52</b>	<b>0.50</b>	<b>0.64</b>	<b>0.40</b>	<b>0.34</b>	<b>4.06</b>	<b>0.49</b>

Subsurface water showed similar trend of low nitrite concentrations as surface water except station 2 where levels of nitrite were slightly higher than surface during May- September and November.

Ammonia concentrations in surface and sub-surface water are shown in Table 5. Surface water showed wide range of variations at all stations. Surface water at station 4 showed higher level during the study period (3.83-82.37; avr. 39.52  $\mu\text{g at.l}^{-1}$ ), although the highest ammonia level of 103.98  $\mu\text{g at.l}^{-1}$  occurred at station 1 during January. Lowest values occurred in the surface and sub-surface layer of station 1, 2, and 3 in December, in the surface and the sub-surface layers at station 4 during January and October, respectively. High values of ammonia occurred in the sub-surface layer during April (St. 1-3) and January (St. 4).

**Table 5. Concentrations of Ammonia ( $\text{NH}_4$ ) as  $\mu\text{g at.l}^{-1}$  during the study period.**

Stations Months	Station 1		Station 2		Station 3		Station 4	
	Surface	Sub-surface	Surface	Sub-surface	Surface	Sub-surface	Surface	Sub-surface
Dec2001	0.38	0.64	0.38	0.06	0.77	0.32	9.64	9.70
Jan 2002	103.98	5.88	5.30	9.48	4.09	10.28	3.83	20.05
Feb	4.62	4.8	15.74	3.05	2.5	3.92	49.47	8.83
Mar	8.21	5.03	3.69	3.05	15	3.78	54.78	10.71
Apr	2.40	51.76	39.76	19.48	3.02	17.22	62.17	4.73
May	3.83	4.48	1.83	18.76	8.03	0.67	7.50	5.70
Jun	4.47	1.61	11.17	1.98	3.35	1.78	42.28	12.18
Jul	1.92	1.39	1.20	1.20	2.33	1.55	14.82	12.23
Aug	2.18	2.60	1.75	1.68	2.51	1.48	52.63	3.83
Sep	4.43	2.35	2.58	6.51	2.68	2.82	40.24	5.40
Oct	2.40	1.03	1.29	1.66	1.19	1.24	82.37	3.37
Nov	1.48	3.11	2.16	2.42	4.21	2.16	54.58	15.47
<b>Average</b>	<b>11.69</b>	<b>7.05</b>	<b>7.24</b>	<b>5.78</b>	<b>4.14</b>	<b>3.93</b>	<b>39.52</b>	<b>9.35</b>

Phosphate concentrations in surface and sub-surface water are shown in Table 6. Phosphate content showed wide range of variations at all stations from undetectable level to 58.31  $\mu\text{g at.l}^{-1}$ . Station 4 sustained the highest levels in surface and sub-surface layers during all the study period with averages of 39.52 and 9.35  $\mu\text{g at.l}^{-1}$ , respectively.

**Table 6. Concentration of phosphate (PO<sub>4</sub>) as µg at *I*<sup>1</sup> during the study period.**

Stations Months	Station 1		Station 2		Station 3		Station 4	
	Surface	Sub-surface	Surface	Sub-surface	Surface	Surface	Sub-surface	Surface
Dec2001	0.40	0.30	UDL	0.85	UDL	2.35	3.05	0.60
Jan 2002	0.83	1.25	1.15	0.80	1.28	1.15	32.93	2.90
Feb	0.45	0.65	5.55	0.45	0.40	0.45	32.93	2.85
Mar	2.95	0.75	0.70	UDL	1.85	UDL	8.70	0.90
Apr	15.48	2.58	11.08	UDL	UDL	5.78	25.13	UDL
May	15.47	UDL	11.08	UDL	UDL	UDL	58.31	UDL
Jun	1.78	0.05	10.73	0.18	0.43	0.13	22.75	2.60
Jul	1.13	UDL	UDL	UDL	0.73	UDL	0.70	7.40
Aug	3.08	0.22	0.15	0.23	1.47	0.02	27.47	0.77
Sep	UDL	UDL	UDL	UDL	UDL	UDL	22.15	0.95
Oct	UDL	UDL	0.02	UDL	0.43	0.14	26.15	1.24
Nov	0.05	0.39	0.24	0.19	0.34	0.39	2.95	1.74
<b>Average</b>	<b>4.16</b>	<b>0.77</b>	<b>4.52</b>	<b>0.45</b>	<b>0.86</b>	<b>1.30</b>	<b>21.93</b>	<b>2.19</b>

Silicate concentrations in surface and sub-surface layers are shown in Table 7. Silicate concentrations showed wide range of variations from UDL (August and September) to 68.84 µg at *I*<sup>1</sup> (January) at station 4. High levels of silicate appeared during December 2001 and January 2002 at all stations. The levels dropped in February and March. It is noticeable occasionally in stations 2, 3 and 4, the sub-surface water sustained higher levels than surface ones.

**Table 7. Concentration of silicate (SiO<sub>3</sub>) as µg at *I*<sup>1</sup> during the study period.**

Stations Months	Station 1		Station 2		Station 3		Station 4	
	Surface	Sub-surface	Surface	Sub-surface	Surface	Sub-surface	Surface	Sub-surface
Dec2001	20.08	9.54	16.10	31.21	12.72	30.32	26.94	22.66
Jan 2002	14.76	14.66	15.21	13.77	25.10	18.39	68.84	34.79
Feb	4.57	3.89	6.86	4.69	0.91	1.49	26.17	5.49
Mar	8.00	5.60	1.49	4.23	2.74	UDL	11.89	5.26
Apr	12.00	9.37	10.51	6.74	4.69	3.09	54.74	8.69
May	7.09	5.43	1.37	2.11	0.51	UDL	1.60	2.11
Jun	6.06	3.66	13.43	2.51	0.80	1.77	53.83	5.66
Jul	14.00	4.86	5.77	3.43	1.77	3.37	6.11	5.20
Aug	58.44	2.93	0.65	1.71	UDL	UDL	13.68	0.42
Sep	8.69	1.83	1.77	1.03	0.34	UDL	20.57	23.32
Oct	40.80	7.20	1.77	2.46	0.34	0.23	20.57	4.74
Nov	31.98	12.19	6.42	4.60	2.14	3.42	20.43	4.71
<b>Average</b>	<b>18.87</b>	<b>6.76</b>	<b>6.78</b>	<b>6.54</b>	<b>4.73</b>	<b>7.76</b>	<b>27.11</b>	<b>10.25</b>



Station 4 sustained higher levels in surface and sub-surface water (1.6-68.84, avr. 27.11 and 0.42-34.79, avr. 10.25  $\mu\text{g at. l}^{-1}$  respectively. Station 1 sustained concentrations of 4.57-58.44, avr. 18.87  $\mu\text{g at. l}^{-1}$ ; and 1.83-14.66, avr. 6.76  $\mu\text{g at. l}^{-1}$  in surface and sub-surface respectively. Stations 2 and 3 showed averages surface concentrations of 6.78 and 6.54 and sub-surface concentrations of 6.54 and 7.76  $\mu\text{g at. l}^{-1}$ , respectively.

Phytoplankton biomass results as chlorophyll-a (Chl-a) in surface and subsurface water are shown in Table 8. Levels of Chl-a showed wide range of variations at all stations. Chl-a was higher in surface water than subsurface ones except in some occasions at stations 1 and 2 where sub-surface Chl-a were higher than surface ones. Station 4 still expressed the highest, even in Chl-a values in the surface and sub-surface layers during the study period, ranged between 27.17-242.2, avr. 71.64 mg Chl-a  $\text{l}^{-1}$  for the surface and between 5.63-46.55, avr. 16.38 mg Chl-a  $\text{l}^{-1}$  in the sub-surface water. Station 1 showed high level in August 32.54 mg Chl-a  $\text{l}^{-1}$  and low level occurred in May 4.25 mg Chl-a  $\text{l}^{-1}$ , and few peaks occurred in February and April. Station 2 showed the highest in April 14.71 and the lowest in March 3.58 mg Chl-a  $\text{l}^{-1}$  which was followed by peaks with the same timing of station 1. Station 3 sustained high level in July and the highest occurred in August (22.38 mg Chl-a  $\text{l}^{-1}$ ) while the lowest occurred in March (1.84 mg Chl-a  $\text{l}^{-1}$ ).

**Table 8. Levels of Chlorophyll-a (mg Chl-a  $\text{l}^{-1}$ ) during the study period.**

Stations Months	Station 1		Station 2		Station 3		Station 4	
	Surface	Sub-surface	Surface	Sub-surface	Surface	Sub-Surface	Surface	Sub-surface
Dec2001	BD	BD	BD	BD	BD	BD	BD	BD
Jan 2002	8.8	7.98	5.82	3.57	3.85	1.82	55.96	9.98
Feb	29.07	26.35	14.71	19.52	2.44	1.55	47.09	11.1
Mar	9.49	3.76	3.58	3.9	1.84	1.37	27.17	5.89
Apr	13.14	9.38	14.02	4.69	5.47	1.77	96.29	9.92
May	4.25	3.99	5.6	2.38	2.79	1.31	40.99	13.66
Jun	28.76	7.19	12.34	4.88	6.9	4.00	33.68	5.63
Jul	6.43	6.58	5.89	5.47	9.11	2.18	28.68	13.69
Aug	32.54	12.49	12.48	33.55	22.38	4.31	68.94	13.14
Sep	7.81	7.69	7	3.65	9.07	4.31	242.21	14.28
Oct	6.59	7.53	7.67	8.33	4.66	2.79	42.04	36.31
Nov	10.87	3.38	9.61	9.45	11.09	5.19	104.96	46.55
<b>Average</b>	<b>14.34</b>	<b>8.76</b>	<b>8.97</b>	<b>9.04</b>	<b>7.24</b>	<b>2.78</b>	<b>71.64</b>	<b>16.38</b>

## Discussion & Conclusion

The results showed the differences in chemical and biological parameters than previous studies in polluted areas of the Red sea. Surface water temperature reported in this study appeared within the level suggested by MEPA (1987) that temperature within the average of 28-32°C in the southern Red Sea. In this study temperature appeared between 26-33.5°C and increment noticed from June to October 2001. Salinity reached its maximum in August at all stations except station 1 (October). The annual amplitude was 8°C and supported with Khomayis (2002). The general trend showed increasing temperature from station 1 to station 4.

Salinity showed that station 4 experienced the lowest average of 34.5% while high average appeared at station 3 and 2 with values of 39.5 and 39.6% respectively. El-Rayis *et al.* (1982) recorded an average of 37.87% at the surface water of the middle Red Sea. Khomayis (2002) showed similar levels of salinities (38.46-39.22%) in Petromin and south Cournich areas.

Nitrate concentrations showed higher values at stations 1 and 4 than the control station 3, which might explain the effect of domestic discharge. Station 1 is located in the center of Al-Salam Lake where domestic waste is discharged and high nitrate levels occurred from July-September and with maximum value of 62.31  $\mu\text{g at.N.l}^{-1}$  in August. Station 4, which is located also at a very sever domestic discharge, affect the monthly fluctuations from April-September with the highest of 39.51  $\mu\text{g at.N.l}^{-1}$  in April. Behairy and Saad (1984) have reported a large variation 0.02-56.37  $\mu\text{g at.N.l}^{-1}$  in the same area of the coastal water of Jeddah. Khomayis (2002) also reported high levels of nitrate reached 10.04 and 8.87  $\mu\text{g at.l}^{-1}$  during February 1994 and November 1993 around the Petromin area affected by organic discharges. Hariri *et al.* (1997) reported nitrate ranged between 0.02 and 1.68  $\mu\text{g at.l}^{-1}$  in the coastal area of Jeddah. El-Sayed and Niaz (1999) found that the concentration of nitrate never exceed 0.68  $\mu\text{g at.l}^{-1}$  in the Southern Cournich of Jeddah. The previous results in (Hariri *et al.*, 1997 and El-Sayed and Niaz, 1999) are in agreement with this study that nitrate at high effluent discharges experience high levels of nitrate and vice versa.

Levels of nitrite showed low levels at all stations except surface water of station 4. Average levels of stations 1-3 were between 0.4-0.97

$\mu\text{g at.l}^{-1}$  while average increased to  $4.06 \mu\text{g at.N.l}^{-1}$  at station 4. The most interesting point that levels of nitrite goes parallel to levels of nitrate. Three peaks of nitrite and nitrate occurred in January, June and September. This might be explained by the reduction of nitrate to nitrite and the oxidation of ammonia to nitrite (Grasshof, 1969).

Ammonia levels in the surface and subsurface water showed high values during all the study period. Station 1 and 4 experienced higher levels and reached  $103$  and  $82.37 \mu\text{g at.N.l}^{-1}$ , respectively due to the effect of domestic waste effluents. In comparison to previous studies, Hariri *et al.* (1997) reported ammonia ranged between  $0.1$  and  $2.56 \mu\text{g at.l}^{-1}$  in the coastal water of Jeddah. Khomayis (2002) found ammonia ranged between  $2.11$  and  $9.09 \mu\text{g at.l}^{-1}$ , and high level of  $36 \mu\text{g at.l}^{-1}$  recorded in October in a location close to oily and domestic waste effluent. El-Sayed and Niaz (1999) reported higher levels of ammonia at the domestic effluents of south Jeddah when level reached  $824 \mu\text{g at.N.l}^{-1}$ .

Although it is reported that phosphate levels are very low in the Red Sea; El-Rayis *et al.* (1982) reported levels between  $0.5$ - $68 \mu\text{g at.l}^{-1}$  in the surface water of middle cournich of Jeddah. In May, phosphate experience high levels at station 1, 2 and 4 with values of  $15.47$ ,  $11.08$  and  $58.31 \mu\text{g at.l}^{-1}$  respectively. These high levels might be caused by the effect of domestic effluents. This suggestion might be supported by the results found by El-Sayed and Niaz (1999) where a value reached  $170 \mu\text{g at.l}^{-1}$  in the domestic effluent of Jeddah. Khomayis (2002) reported levels between depletion and  $2.72 \mu\text{g at.l}^{-1}$  in the coastal water of Jeddah.

Although the Red Sea is known for its poor silicate levels, and no rivers are connecting to it, silicate concentrations showed high levels. In this study, silicate experienced the highest level of  $68.84 \mu\text{g at.l}^{-1}$  during January at station 4. Additionally, high levels occurred at all stations with maximum concentration of  $54.44 \mu\text{g at.l}^{-1}$  at station 1. Not only the surface water, but also the subsurface ones recorded high values of  $34.79 \mu\text{g at.l}^{-1}$  (station 4) and  $30.32 \mu\text{g at.l}^{-1}$  (station 3). The average of silicate during this study reached  $4.73$ - $27.11 \mu\text{g at.l}^{-1}$  for surface water and ranged of  $4.73$ - $10.25 \mu\text{g at.l}^{-1}$  for subsurface water, although Khomayis (2002) reported average of  $0.3$  to  $0.85 \mu\text{g at.l}^{-1}$  at different stations of the coastal water of the Red Sea. This finding of high value might be the consequence of variable effluent discharges in the study area.

Standing crop as Chl-a was rarely investigated in the Saudi coastal water. The previous study (Khomayis, 2002) reported average amount of Chl-a of 0.02 and 10.16  $\mu\text{g} \cdot \text{L}^{-1}$ , in Obhur and Petromin areas, respectively. The high values occurred at station 4, during Sep. and Oct. 1993, which was affected with two sources of pollutions, refinery cooling system discharge and organic material in addition to Jeddah oil refinery.

During this study and at all stations general trend of high of Chl-a levels were recorded and particularly at station 1 and 4. As these two stations received high quantity of effluents, which resulted in increasing levels of nutrients, eutrophication, were suitable for increasing phytoplankton standing crop, and hence occurrence of high Chl-a concentrations.

**Table 9. Correlation coefficient values between bio-physico-chemical parameters and Chl-a values.**

Chl-a	SiO <sub>3</sub>	PO <sub>4</sub>	NH <sub>4</sub>	NO <sub>2</sub>	NO <sub>3</sub>	S‰	T°C	
								T°C
							0.0178	S‰
						0.5824	0.0061	NO <sub>3</sub>
					0.1341	0.4335	0.1072	NO <sub>2</sub>
				0.1247	0.0589	0.2344	0.0002	NH <sub>4</sub>
			0.0204	0.0829	0.0148	0.1115	0.026	PO <sub>4</sub>
		0.0861	0.0646	0.4235	0.0137	0.4644	0.235	SiO <sub>3</sub>
	0.0004	0.0055	0.0092	0.4988	0.4300	0.1332	0.0407	Chl-a

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## الإثراء الغذائي والمحصول القائم (اليخضور - أ) في منطقة ساحلية ملوثة لمحافظة جدة - البحر الأحمر

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المستخلص. الإثراء الغذائي، الخطر القادم نتيجة التطور الغير منظم للمناطق الساحلية لمدينة جدة والتي تستقبل ملوثات خارجية عن البحر مثل البترول، العناصر الثقيلة، ومصبات الصرف الصحي. تم قياس الأملاح المغذية، والوقود الحياتي للهائمات النباتية والذي يحسن من قيم المحصول القائم لهذه الهائمات، والمحصول القائم على مدى سنة في أربعة محطات ملوثة غالباً بالصرف الصحي تقع ضمن (بحيرتي السلام والشباب)، ومن ثم مقارنة النتائج مع الدراسات السابقة والشحيحة. التركيزات العالية من المغذيات وخاصة في المحطتين ١، و ٤ دللت على وجود مؤشرات للإثراء الغذائي. متوسطات درجات الحرارة والملوحة بلغت من ٢٩ وحتى ٣٠ درجة مئوية، بينما الملوحة بلغت ٣٤,٥ وحتى ٣٩,٦ جزء في الألف. متوسط النترات كان ١,٢ إلى ١٤,١٣  $\mu\text{g at.l}^{-1}$  في المياه السطحية، ١,٣ إلى ٣,٩٩  $\mu\text{g at.l}^{-1}$  في المياه التحت سطحية. بلغت متوسطات النيتريت من ٠,٤ إلى ٤,٠٦  $\mu\text{g at.l}^{-1}$  في السطح، أما المتوسطات في المياه التحت سطحية فبلغت ٠,٣٤ وحتى ٠,٦٤  $\mu\text{g at.l}^{-1}$ . متوسطات الأمونيا في السطح كانت من ٤,١٤ وحتى ٣٩,٥٢  $\mu\text{g at.l}^{-1}$  أما في المياه التحت سطحية فبلغت ٣,٩٣ إلى ٩,٣٥  $\mu\text{g at.l}^{-1}$ . متوسط تركيز الفوسفات في المياه السطحية بلغ من ٠,٨٦ إلى

٢١,٩٣ وفى التحت سطحية من ٠,٤٥ إلى ٢,١٩  $\mu\text{g at.l}^{-1}$ .  
متوسطات السليكات كانت في السطح من ٤,٧٣ وحتى ٢٧,١١  $\mu\text{g at.l}^{-1}$   
بينما ٦,٥٤ وحتى ١٠,٢٥  $\mu\text{g at.l}^{-1}$  كانت من نصيب المناطق  
التحت سطحية. متوسطات المحصول القائم ممثلاً في اليخضور - أ  
كانت ٧,١٤ إلى ٧١,٦٤ في السطح، ٢,٧٨ إلى ١٦,٣٨  $\mu\text{g at.l}^{-1}$   
في المناطق التحت سطحية. التحليلات الإحصائية ممثلة في  
معاملات الارتباط لم تظهر علاقات صريحة، واقعية، وقوية بين  
اليخضور - أ والعوامل الفيزيوكيميائية الأخرى، وقد يرجع السبب لوجود  
عوامل أخرى مؤثرة بجانب الإثراء الغذائي مثل المعادن الثقيلة والمواد  
البتروولية.