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Spatial and temporal variability of some physicochemical and Nutrient characteristics of the coastal water of Aqaba Gulf, Egypt during 1998 to 2008

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Abstract

The Gulf of Aqaba is one of two gulfs created by the Sinai Peninsula's bifurcation of the northern Red Sea, The Gulf of Aqaba is about 160 Km length, 24 Km width and its depth may reach 1850m. Environmental Information and Monitoring Program (EIMP) for the Egyptian coastal waters of Aqaba Gulf was established to initiate monitoring and data base system by applying quality control assessments in order to evaluate, protect and sustainable use of the different coastal regions. Within the framework of this program four to six bimonthly field campaigns were carried out annually for eleven years during 1998 – 2008. A total of 11 coastal stations were selected to cover different locations of the Gulf. The surface distribution pattern of hydrographical conditions (water temperature, salinity, dissolved oxygen and pH) and eutrophication parameters (chlorophyll-*a*, total suspended matter, transparency, nitrogen and phosphorus forms as well as reactive silicate) were investigated. The data obtained from the eleven years work deduced that no thermocline or thermal pollution, variations in the pH and salinity values were insignificant and the water was well-oxygenated. The concentrations of nitrogen and phosphorus in the dissolved and total forms as well as reactive silicate were found quite low. The abundance of inorganic nitrogen forms were found in the order NH4-N > NO_3-N≥ NO_2-N reflecting the increasing rate of NH_4-N production than its uptake rate as compared with the other inorganic nitrogen forms. Based on the calculations, nitrogen and phosphorus were found in Aqaba Gulf Coastal waters, principally, in organic forms. The low levels obtained during the present study for each of Chl-*a*, TSM, NH_4-N, NO_3-N, TN, PO_4-P and TP signified that Aqaba Gulf Coastal waters can be classified between oligotrophic to mesotrophic state. Accordingly, it is safe to conclude that the main body of Aqaba Gulf coastal waters is not yet seriously threatened, in spite of the rapid recreational and human developments taken place on its coast during the previous ten years.

Keywords: Aqaba Gulf, Coastal waters, nutrient salts, eutrophication, thermocline,

1. Introduction

The Gulf of Aqaba is one of two gulfs created by the Sinai Peninsula's bifurcation of the northern Red Sea, the Gulf of Suez lies to the west of the Sinai Peninsula and the Gulf of Aqaba to its east. The Gulf of Aqaba is a narrow deep trench extending from Lat. 28° N, Long 24° 23' E, to Lat 29° 33' N, Long 35° 0' E'. It is about 180 Km long and has an average width of 20 Km and mean depth of about 800 m. it is bordered on both sides with a series of high mountains particularly along its western side (Figure 1).

The Gulf of Aqaba, like the coastal waters of the Red Sea, is one of the world's premier sites for diving. The area is especially rich in corals and other marine biodiversity. Due to the importance of the Aqaba Gulf for tourism and the consequent important national income, the Environmental Information and Monitoring Program (EIMP) promoted the initiation of a consistent monitoring aims to the construction of a database system for the water quality, as the basis for the proper management of its coastal region. The EIMP was coordinated by a steering committee with representatives from the Danish International Development Assistance (Danida) and Egyptian Environmental Affair Agency (EEAA). The present study is a part of this program and aims at investigating the spatial and temporal pattern of the water quality along the Egyptian coasts of Aqaba Gulf during the period of eleven years from 1998 to 2008. This work aims to initiate the monitoring program and data base system for the coastal water quality of Aqaba Gulf by using the quality control and quality assurance works in order to evaluate the human impacts by time due to the rapid developments of the recreational and human activities on its coast.

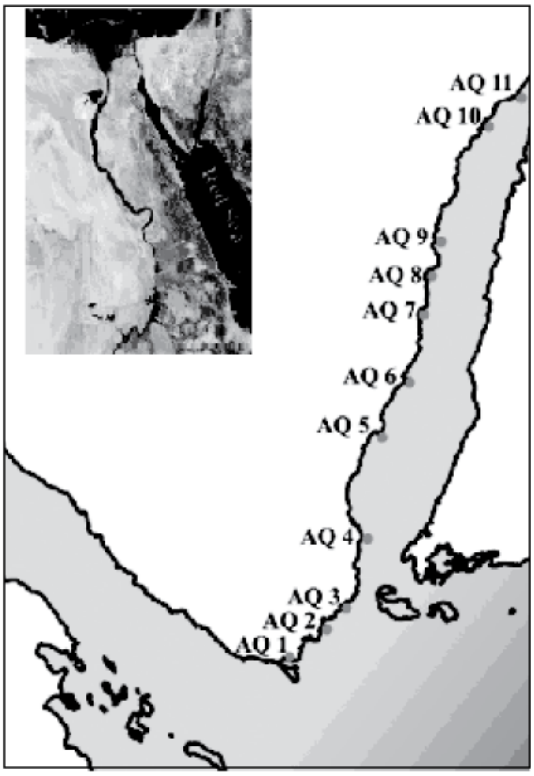

Figure 1. Map showing the locations of sampling sites for the Aqaba Gulf.

2. Materials and methods

Within the frame work of EIMP, four to six field surveys were performed annually during 1998 to 2008. Eleven stations were selected to represent all different environmental conditions in terms of human activities, public resort beaches and some reference sites (Figure 1). The number of field surveys and the stations were reduced to four and 6 stations in the period from 2005 to 2007 then back to the origin in 2008. Water temperature, salinity, dissolved oxygen (DO) and pH were measured in *situ* at each station using a CTD (YSI-600XL). Duplicate water samples for water quality variables were collected at 2-m depth (below surface water), using a PVC Niskin's bottle. Ammonium ion concentrations were determined according to IOC (1983). Nitrite, Nitrate, reactive phosphate and reactive silicate concentrations were determined on pre-filtered seawater samples (Whatman GF/C) following the sepectrophotometric techniques described by IOC (1993) and Strickland and Parsons (1972). Total P and total N were estimated in unfiltered water samples following the procedure described by Valderrama (1981). The concentration of Dissolved Inorganic Nitrogen (DIN as the sum of NH_4-N + NO_2-N + NO_3-N) was calculated. Total suspended matter (TSM) was collected from 3 L seawater samples by filtration through washed, dried and pre-weighed 0.45 µm membrane filter. The filters with the retained particles were washed then air dried in the oven at 60 °C for 24 – 48 hours until constant weight. The difference between the dry weight of membrane filters before and after filtration was expressed in mg/l. For chlorophyll-*a* (Chl-*a*) determination, additional 3l water samples were collected and filtrated on 0.45 µm filters. Chl-*a* was extracted using 90% acetone and measured spectrophotometerically according to Strickland and Parsons (1972). Water transparency was measured using Secchi Disk.

The correlation coefficients between different environmental parameters were calculated ($n = 106$ $p \leq 0.05$) the correlation coefficient is significant at $r \geq 0.195$.

3. Results and discussion

3.1. Hydrographical conditions

Based on the annual averages, the ranges and mean values of water temperature, salinity, pH, dissolved oxygen (expressed in mg/l and % saturation) chlorophyll-*a* and total suspended matter reported in the present study during the period from 1998 to 2008 are shown in Table (1) and represented graphically in Figure 2. The distribution of water temperature was accompanied with their geographic variations i.e. they followed changes in air temperature at different regions of the present study. Stations Aq1, Aq2 and Aq3 represented the highest values of water temperature during the period of study. The annual averages of water temperature varied from 22.65 to 28.36 °C (at stations Aq11 and Aq5 during 2000 and 2007, respectively). A slight increase in water temperature was observed moving southward (from station Aq11 to Aq1). The lowest water temperature values were recorded during 2002, while the highest measurements were observed during 2007. The spatial distribution of salinity displayed a slight increase moving from south to north during the period of study except for 2002 and 2004. The highest mean value of salinity was recorded during 1998 (40.44) at station Aq9, while the lowest one (39.28) was measured at stations Aq5 and Aq9 during 2002 due to the relative increase of human impact in Dahab (Aq5) and Newabaa (Aq9). A significant positive correlation between salinity and water temperature was deduced ($r = 0.22$, $n = 106$, $p \leq 0.05$).

pH and DO did not display clear changes during the period of study. The annual means of pH values were varied from 8.05 at station Aq2 during 2005 and 8.33 at Aq1 during 1999. The revealing distribution pattern of DO indicates high values and well oxygenated waters during the period of study (1998 – 2008). The annual means of DO ranged between 9.07 mg/l (equivalent to 134.67 % DO saturation) calculated at station Aq6 during 2008 and 6.61 mg/l (equivalent to 95.93 % saturation) calculated at station Aq1 during 2005.

Minor changes of studied variables (water temperature, salinity, pH and DO) reveal that the effect of human impact on the distribution pattern of different hydrographical conditions in the Gulf of Aqaba coastal water are still limited. This was expected due to the low population there, the absence of fresh water sources and limitation of land based source (i.e. sewage, agriculture, and / or industrial effluents). Accordingly, these conditions could be principally controlled by the circulation pattern of seawater in the area of study. There was significant positive correlation between salinity and DO ($r = 0.24$, $n = 106$, $p \leq 0.05$) and a moderated negative correlation between water temperature and DO ($r = -0.09$, $n = 106$, $p \leq 0.05$). These conditions confirm the limited effect of human impacts on this region of the Red Sea.

3.2. Trophic State Variables

3.2.1. Chlorophyll-a, Total Suspended Matter and Secchi Disk depth

The ranges and mean values of Chl-*a*, TSM are listed in Tables (1) and represented graphically in Figure 3. Low Chl-*a* and TSM concentrations and high transparency were generally encountered at most stations. This can be highlighted by the distribution of mean values, at which, Chl-*a* ranged from 0.05 µg/l at station Aq10 during 2001 and 0.84 µg/l at station Aq2 during 2005. Total suspended matter ranged from 3.88 mg/l at station Aq3 during 1999 and 22.48 mg/l at station Aq2 during 2008. Finally, Secchi disk transparency ranged from 5.50 m at Aq2 during 2006 and 23.4 m at station Aq10 during 1998. Transparency reached bottom depth at most stations. TSM measurements were negatively correlated with transparency ($r = -0.32$, $n = 106$, $p \leq 0.05$) and positively correlated to DO ($r = 0.32$, $n = 106$, $p \leq 0.05$). Low levels of Chl-*a* and TSM coupled with high values of Secchi disk transparency clearly indicate that the effect of human impact in the investigated Aqaba Gulf coastal waters is still insignificant. Transparency, TSM and Chl-*a* measurements showed a homogeneous distribution at several locations. Their values were significantly correlated with water temperature ($r = -0.65$, 0.37 and 0.33, $n = 106$, $p \leq 0.05$) respectively.

3.2.2. Nutrient salts

The mean values of different nutrients of Aqaba Gulf coastal water are listed in Table (2) and represented graphically in Figures 4, 5. The data indicated that, dissolved inorganic nitrogen concentrations during the eleven years of study are quite low. This is evidence from the mean values of NH_4-N, which varied from 0.32 µM at station Aq11 during 2001 to 1.98 µM at station Aq3 during 2006. Nitrite concentrations were always lesser than 0.1 µM NO_2-N at all stations during the study period from 1998 to 2004 and less of exceeding of this level during the recently years (from 2005 to 2008). The maximum annual average (0.53µM) was recorded at station Aq5 during 2008. Nitrate concentrations ranged from 0.08 to 2.19 µM NO_3-N measured during 1999 at station Aq2 and Aq11, respectively. Based on the mean values, the concentrations of dissolved inorganic nitrogen forms followed the order $NH_4 > NO_3 > NO_2$ in all stations except for station Aq11which represents in a reverse order $NO_3 > NH_4 > NO_2$ as shown in the following table:

Table 1. the percentage of ammonia, nitrite and nitrate to total inorganic nitrogen forms calculated at Aqaba Gulf coastal water during 1998 to 2008.

Station	Ammonia %	Nitrite %	Nitrate %
Aq1	60.88	7.96	31.16
Aq2	66.97	8.07	24.97
Aq3	61.51	8.82	29.67
Aq4	60.31	7.71	31.98
Aq5	56.93	10.25	32.83
Aq6	50.26	7.21	42.53
Aq7	52.36	8.36	39.28
Aq8	55.24	11.04	33.73
Aq9	49.02	10.40	40.59
Aq10	52.10	11.64	36.26
Aq11	42.36	9.91	47.73

Table 2. The ranges and mean values (± standard deviation) of the nutrient salts of Aqaba Gulf surface coastal water during 1998 – 2008

St. No.	NH_4-N	NO_2 -N	NO_3 - N	TN	PO_4-P	TP	SiO_4 - Si
Aq 1	0.39 - 1.68 (0.93 ± 0.38)	0.02 - 0.44 (0.12 ± 0.12)	0.18 - 0.87 (0.48 ± 0.20)	12.86 - 76.22 (28.74 ± 19.51)	0.01 -0.08 (0.03 ± 0.02)	0.41 - 1.82 (0.90 ± 0.50)	0.71 - 2.63 (1.16 ± 0.57)
Aq 2	0.43 - 1.78 (1.06 ± 0.43)	0.02 - 0.40 (0.13 ± 0.11)	0.08 - 0.60 (0.39 ± 0.13)	17.63 - 68.34 (34.15 ± 17.59)	0.01 - 0.05 (0.03 ± 0.01)	0.54 - 6.92 (1.48 ± 1.81)	0.72 - 3.02 (1.41 ± 0.72)
Aq 3	0.41 - 1.89 (0.90 ± 0.45)	0.02 - 0.45 (0.13 ± 0.12)	0.19 - 0.76 (0.43 ± 0.16)	15.67 - 66.72 (31.83 ± 16.04)	0.01 - 0.08 (0.04 ± 0.02)	0.44 - 2.19 (1.03 ± 0.54)	0.75 - 3.41 (1.31 ± 0.74)
Aq 4	0.53 - 1.40 (0.85 ± 0.39)	0.02 - 0.40 (0.11 ± 0.17)	0.34 - 0.69 (0.45 ± 0.13)	19.47 - 79.05 (32.65 ± 28.84)	0.01 - 0.07 (0.03 ± 0.02)	0.56 - 1.84 (0.89 ± 0.42)	0.57 - 2.30 (1.25 ± 0.49)
Aq 5	0.44 - 1.28 (0.80 ± 0.28)	0.02 - 0.57 (0.14 ± 0.15)	0.23 - 0.78 (0.46 ± 0.15)	16.01 - 66.97 (31.45 ± 15.19)	ND - 0.12 (0.04 ± 0.03)	0.55 - 1.72 (0.94 ± 0.36)	0.54 - 9.21 (2.2 ± 2.85)
Aq 6	0.39 - 1.23 (0.74 ± 0.31)	ND - 0.33 (0.11 ± 0.11)	0.25 - 1.11 (0.62 ± 0.30)	15.71 - 63.73 (32.00 ± 16.72)	0.02 - 0.27 (0.07 ± 0.09)	0.51 - 2.21 (1.16 ± 0.50)	0.75 - 6.29 (1.76 ± 1.85)
Aq 7	0.43 - 1.31 (0.73 ± 0.33)	0.01 - 0.30 (0.12 ± 0.09)	0.36 - 1.15 (0.54 ± 0.28)	13.62 - 67.30 (32.48 ± 18.27)	0.01 - 0.13 (0.06 ± 0.05)	0.53 - 2.45 (1.11 ± 0.69)	0.56 - 1.99 (1.16 ± 0.42)
Aq 8	0.33 - 1.39 (0.69 ± 0.35)	0.01 - 0.46 (0.14 ± 0.13)	0.16 - 0.55 (0.42 ± 0.12)	14.34 - 53.93 (32.85 ± 14.44)	0.01 - 0.42 (0.08 ± 0.13)	0.61 - 4.85 (1.49 ± 1.31)	0.57 - 3.62 (1.31 ± 0.84)
Aq 9	0.34 - 1.16 (0.65 ± 0.28)	0.01 - 0.52 (0.14 ± 0.17)	0.15 -0.81 (0.54 ± 0.20)	21.64 - 55.41 (32.95 ± 15.35)	0.03 - 0.08 (0.04 ± 0.02)	0.45 - 1.85 (0.93 ± 0.44)	0.57 - 1.53 (0.99 ± 0.35)
Aq 10	0.37 - 0.96 (0.63 ± 0.20)	0.04 - 0.42 (0.14 ± 0.13)	0.18 - 0.57 (0.44 ± 0.11)	15.68 - 46.09 (26.71 ± 10.41)	0.02 - 0.07 (0.04 ± 0.02)	0.49 - 2.37 (0.95 ± 0.61)	0.49 - 1.17 (0.91 ± 0.27)
Aq 11	0.32 - 1.12 (0.66 ± 0.23)	0.05 - 0.40 (0.15 ± 0.10)	0.33 - 2.19 (0.75 ± 0.62)	18.33 - 67.00 (35.31 ± 16.53)	0.02 - 0.23 (0.07 ± 0.07)	0.64 - 2.51 (1.22 ± 0.57)	0.60 - 3.09 (1.32 ± 0.89)
Average	(0.78 ± 0.14)	0.13 ± 0.02)	(0.50 ± 0.10)	(31.88 ± 2.45)	(0.05 ± 0.02)	(1.10 ± 0.22)	(1.37 ± 0.44)

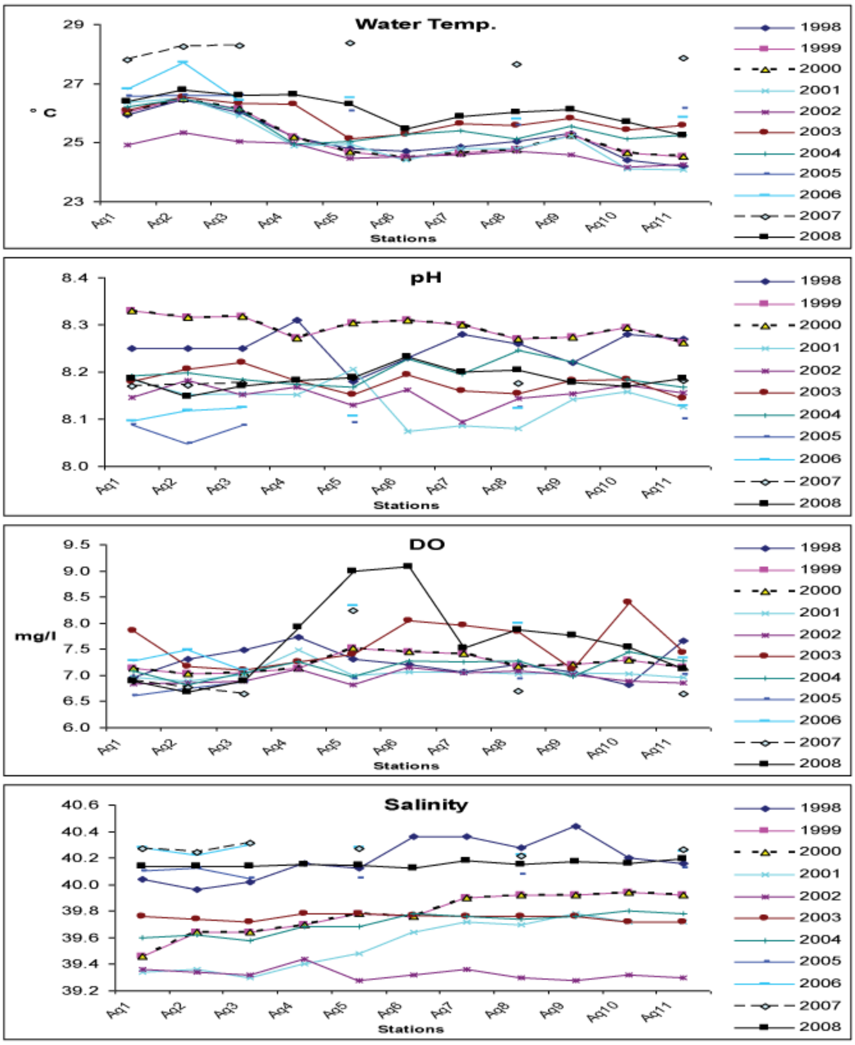

Figure 2. Variations in the annual mean values of some studied physicochemical characteristics of Aqaba Gulf Coastal Water during 1998 – 2008.

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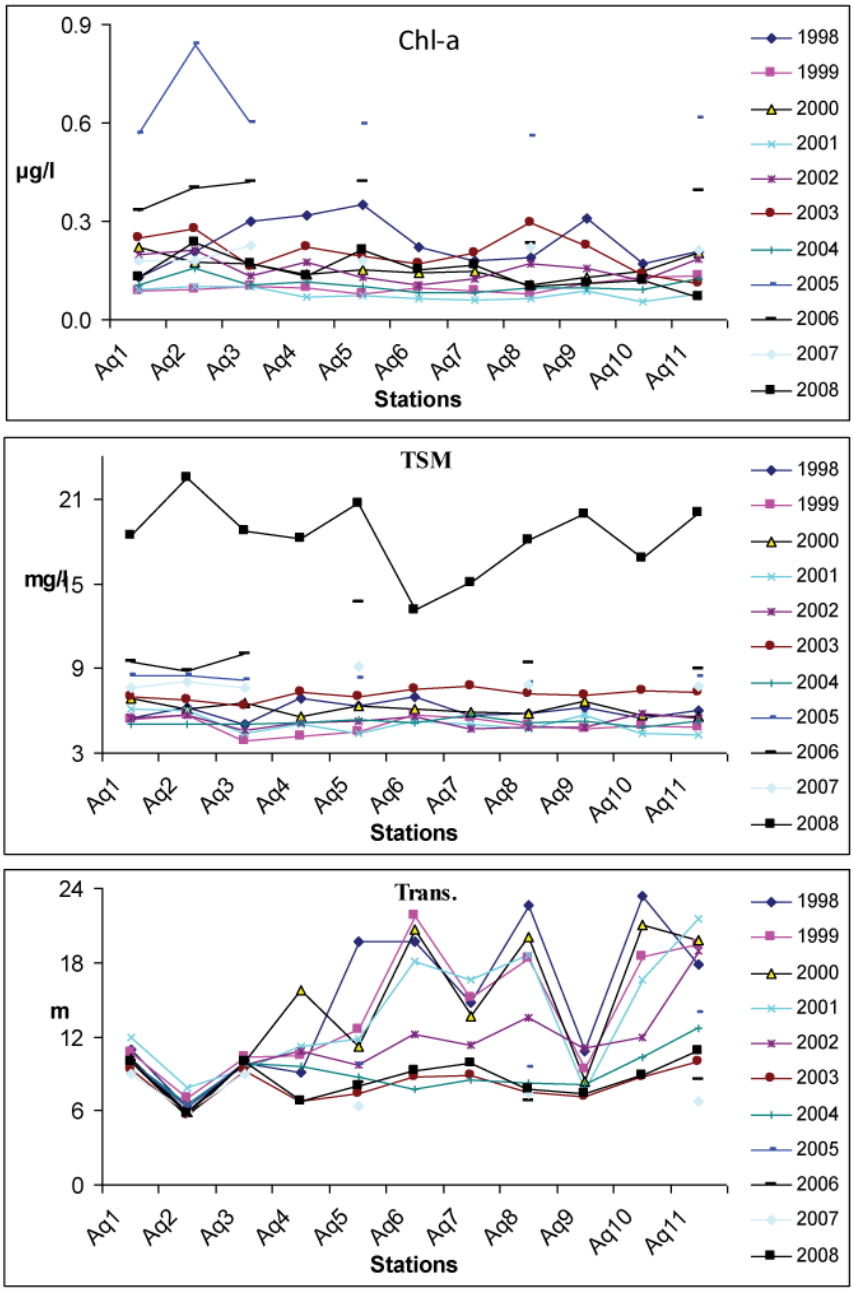

Figure (3): Variations in the annual mean values of some studied hydro -chemical characteristics of Aqaba Gulf Coastal Water during 1998 – 2008.

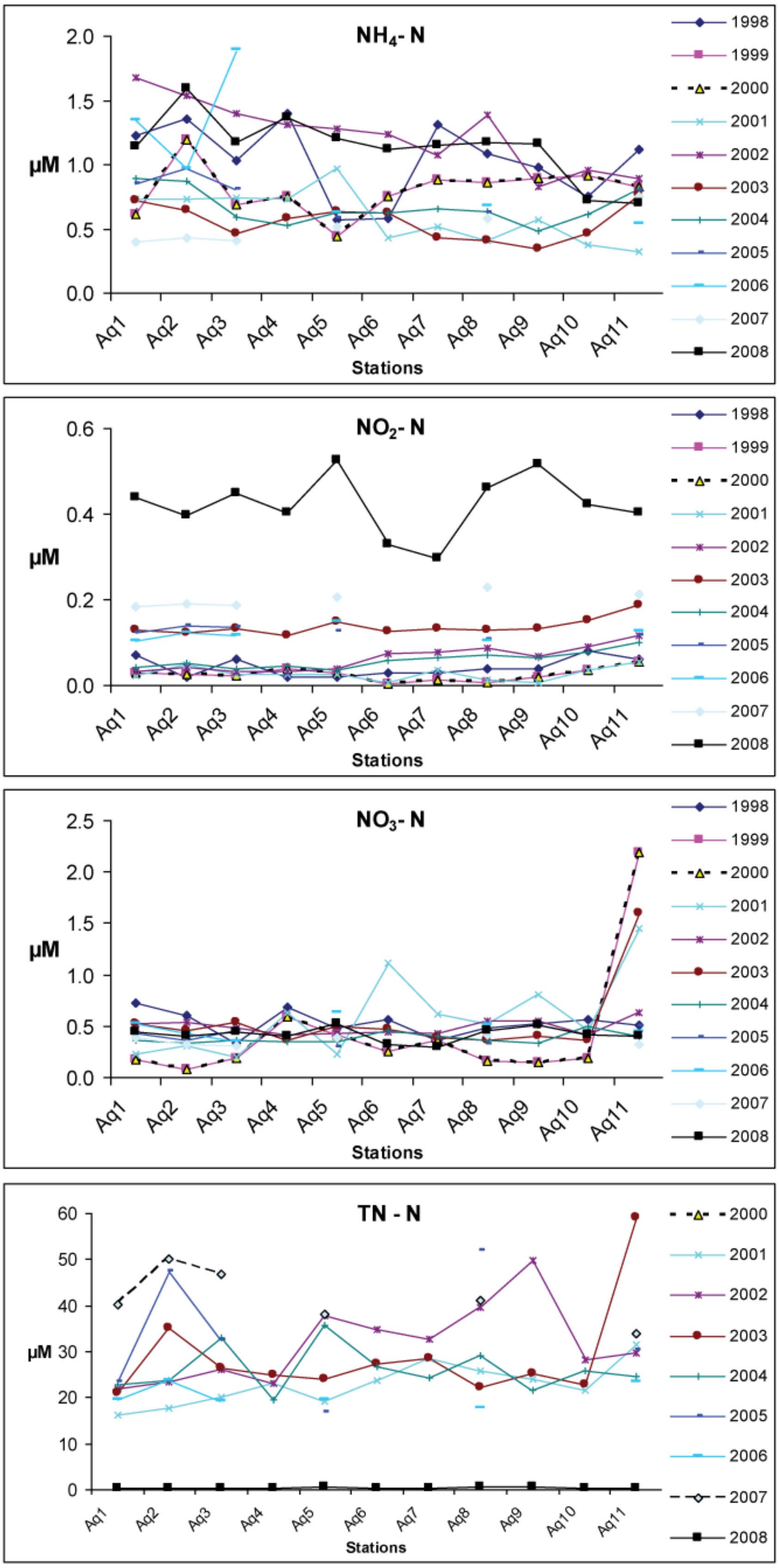

Figure 4. Variations in the annual mean values of nitrogen forms of Aqaba Gulf Coastal Water during 1998 – 2008.

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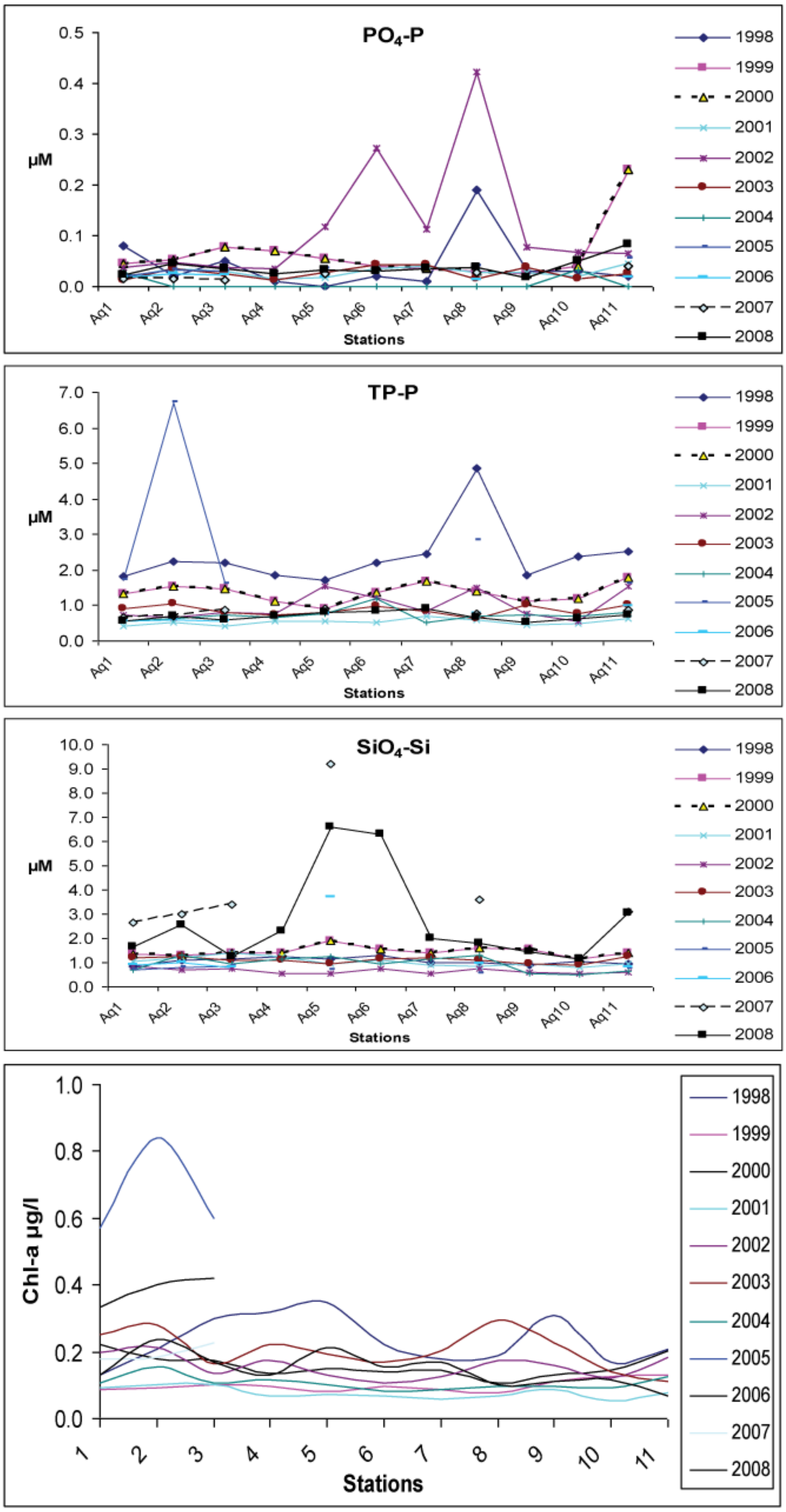

Figure 5. Variations in the annual mean values of phosphate and reactive silicate of Aqaba Gulf Coastal Water during 1998 – 2008.

The relative increase of NH_4 concentration which is the preferred N form for phytoplankton uptake is unclear. An insignificant positive correlation between NH_4-N and Chl-*a* was found during the study period (r = 0.19). Variation of water temperature affecting the distribution of nitrogen forms in the coastal seawater of Aqaba Gulf. Water temperature was positively correlated with nitrite (r = 0.43, n = 106, $p \leq 0.05$) while it was negatively correlated with both of nitrate and TN (r = - 0.34 and – 0.26, respectively. n = 106, $p \leq 0.05$). These concentrations of nitrogen forms, based on the classification reported by Skrivanic and Strin (1982) and Franco (1983), allow classifying the Aqaba Gulf coastal waters as oligotrophic to mesotrophic. These authors indicated that oligtrophic, seawater displaying concentration of 0.5 µM for each NH_4 and NO_3 whereas, in eutrophic water the concentration of these nutrients are usually in the order of 2.0 µM for NH_4 and 4 µM for NO_3.

The levels of total nitrogen (TN) displayed remarkable variations (from 2000 to 2008) and ranged from 12.86 to 79.05 µM measured at station Aq1during 2000 and at station Aq4 during 2008, respectively. Based on the mean values, DIN accounted about 4.5 % of TN (3.8 -5.4%). The large difference between TN and DIN concentrations suggest that nitrogen is found in the Aqaba Gulf coastal waters mostly in organic forms. This result is in agreement with the general view of microbial food web and phytoplankton dynamics, in which NH_4, NO_2 and NO_3 are rapidly processed by phytoplankton and other microbial components. Meanwhile, the organic nitrogen is assimilating by aquatic organisms in a much slower rate (Riley and Chester 1971). Faganeli (1983) pointed out that, in the eutrophic Bay of Koper (North Adriatic), the relative composition of total nitrogen are 11.3 % for particulate, 68.8 % for dissolved organic and 20 % for the inorganic forms. DIN levels obtained during the present investigation are remarkably lower than those mentioned above coincided with the limited effect of land based source on the Aqaba Gulf coastal waters. A n insignificant correlation between DIN and DO was deduced (r= 0.08, n = 106, $p \leq 0.05$), while a significant correlation between nitrite and DO was deduced (r= 0.30, n = 106, $p \leq 0.05$).

A remarkable increase in the mean values of phosphate concentrations was observed at stations Aq8 (0.19, 0.42 µM) during 1998 and 2002, respectively, Aq11 (0.23 µM) during 1999 and Aq7, Aq11 (0.13 and 0.09 µM, respectively) during 2000 and Aq5, Aq6, Aq7 and Aq8 (0.12, 0.27, 0.11 and 0.42 µM) during 2002. These stations are located in the area of Newabaa Port and Taba City which affected directly with the relative increase in human activities. At the other locations, PO_4 were very low, consequently the N:P ratios were very high reaching 78 : 1 and suggesting that, phosphate could be the limiting nutrient for phytoplankton growth. A strong positive correlation between phosphate and DIN, was calculated (r = 0.32, n = 106, $p \leq 0.05$), while a strong negative correlation between phosphate and each of water temperature and salinity were deduced (r = - 0.26 and – 0.26 respectively, n = 106, $p \leq 0.05$). The variation in PO_4 concentrations was associated with the level of impact on the Newabaa Port area of Aqaba Gulf coastal waters. Low PO_4 contents could be related mostly to their sorption and deposition on iron born dust conveyed to the basin from the surrounding mountains and deserts. Suzumura *et al*. (2000) reported the effect of composition and physicochemical characteristics of natural particles on phosphate adsorption-desorption processes under various aquatic environment. Marchetti (1984) pointed out that, generally the concentration of PO_4 in the surface waters are extremely low (expressed as values for ortho-phosphate 0.03 µM or less), whereas typical concentrations for eutrophic coastal waters are above 0.15 µM and highly eutrophic system will be beyond 0.3 µM. Okbah *et al*. (1999) reported that inorganic phosphorus concentrations in Aqaba Gulf are very low particularly in the euphotic zone (~ 200 m). In contrast, the Northern Red Sea has higher values ranged between not detected – 0.34 µM. The geographic and temporal distribution pattern of TP displayed a large variability during the investigation period TP ranged from 0.41 to 6.72 µM at station Aq1 and Aq2 during 2001 and 2005, respectively. The highest TP values were measured during 1998 (except for Aq2 during 2005 Figure 5). Based on the mean values, phosphate constituted about 9.07 % of TP, implying that phosphate is mostly accounted by particulate and organic forms. These data also suggested that the coastal water of Aqaba Gulf is unpolluted. Such conclusion is consistent with indications provided by Nalewajko and Lean (1980) who pointed out that in moderated polluted coastal waters, the relative composition of phosphorus forms are: 28.5 98% for particulate, 1.2 – 4% for colloidal, 0.1 – 22 % for reactive phosphate and 0.1 – 6 % for dissolved organic P. Giovanardi and Tromellini (1992) stated that the levels of TP and TN in oligotrophic waters are 0.27 and 47.2 µM respectively, whereas in mesotrophic waters reach 0.89 and 53.8 µM and in eutrophic seawaters 2.81 and 133.9 µM, these levels when compared with those reported in the present study indicate that the Aqaba Gulf coastal waters in front of Egypt are "located" within the oligo to meso-trophic conditions.

The distribution pattern of SiO_4 concentration displays small spatial annual variation. The mean values ranged from 0.49 to 9.21 at Aq10 during 2004 and Aq5 during 2007, respectively (Figure 5). Generally, the highest values were determined during 2007 and 2008, the lowest ones during 2002. Okbah *et al.* (1999) pointed out those surface values of silicate in the Aqaba Gulf are lower than those of the Northern Red Sea water. Beltagi (1984) pointed out that, primary producers of northern Red Sea are mainly composed of blue green algae to a lesser extent by diatoms, the main consumer of silicate. This means that, diatoms constitute a minor component in the Aqaba Gulf and Northern Red Sea. According to Fahmy (2003) the main factors controlling SiO_4 distribution in the Egyptian Red Sea coastal waters, are:

(i) the supply of SiO_4 which flows in the Red Sea through the straight of Bab El-Mandab
(ii) biological composition
(iii) organic matter decomposition and
(iv) the partial dissolution of quartz and clay particles transported to the sea from the surrounding deserts during sand storms.

Silicate was positively correlated with each of water temperature, salinity, TSM, DO, nitrite and TN (r = 0.43, 0.35, 0.43, 0.46, 0.48 and 0.43 respectively, n = 106, $p \leq 0.05$), and negatively correlated with transparency (r = - 0.22, n = 106, $p \leq 0.05$).

Generally, salinity may affect the distribution of different parameters. Significant positive correlations were signified between salinity and each of TSM, Chl-*a*, nitrite, and TN (r = 0.47, 0.39, 0.39 and 0.29 respectively, n = 106, $p \leq 0.05$).

4. Conclusion

The data obtained during the present study signified that, monitoring and data base system constructed for Aqaba Gulf Coastal waters in front of Egypt during seven years (1998 – 2008) revealed insignificant variations for each of salinity and pH values, well oxygenated seawater, low levels for each of Chl-*a*, TSM, nitrogen, phosphorus and reactive silicate, accordingly, it can be classified between oligotrophic to mesotrophic state. Therefore, it is safe to conclude that the main body of Aqaba Gulf coastal regions in front of Egypt is not yet seriously threatened in spite of the rapid recreational and human developments taken place on its coast during the previous ten years.

Acknowledgements

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References

Beltagi, A.I.: 1984, Oceanographic and Fisheries Investigations in the Egyptian Red Sea. Special publication, Academy of Scientific Research and Technology, NIOF, Egypt, pp 98.

Faganeli, J.: 1983, Organic nitrogen and phosphorus in Gulf of Trieste (N. Adriatic) *Archives Oceanography and Limnology*, 20: 153-117.

Fahmy, M. A.: 2003, Water quality in the Red Sea coastal waters (Egypt): Analysis of spatial and temporal variability. *Chemistry and Ecology*, 19(1): 67-77.

Franco, P.: 1983, Fattori influenti sulla produttivita primaria dell'Adriatico settentrionale. Proceeding International Conference: Problems of Adriatic Sea Trieste, Vol. 155, p A4.

Giovanardi and Tromellini, E.: 1992, Statistical assessment of tropic conditions. Marine Eutrophication Proceedings of an International Conference Bologna, Italy, 21-24 March 1990, pp 211-233.

International Oceanographic Commission: 1983, Chemical methods for use in marine environmental monitoring. Manuals and Guides. UNESCO, p 53.

International Oceanographic Commission: 1993, Nutrient analysis in tropic marine waters. Manuals and Guides. Vol. 28 UNESCO, pp. 1-24.

Marchetti, R.: 1984, Quadro analitico complessivo del risultati delle indagini condotte negli anni 1977-1980. II. Problema dell'eutrofizzazione nelle acque costiere dell'Emilia- Romagna: Situazione ipotesi di intervento, Bologna, Regione Emilia Romagna, p 308.

Nalewajko, C. and Lean, D.R.: 1980, Phosphorus. In: Morris(Ed), *The physiological Ecology of Phytoplankton*, Blackwell Science Publisher, Oxford, pp 235 – 258.

Okbah, M.A.; Mahmoud, Th.H. and El-Deek, M.S.: 1999, Nutrient salts concentrations in the Gulf of Aqaba and Northern Red Sea. *Bulletin of National Institute Of Oceanography and Fisheries,*. 25: 103-116.

Riley, J.P. and Chester, R.: 1971, *Introduction to marine chemistry*, Academic Press, p 757.

Skrivanic, V.A. and Strin, J.: 1982, Basic Physical Chemical and Biological Data Reports R. V. A Mohorov ICIC Adriatic Cruises 1974-76. Hydrographic Institute of Yugoslav Navy split, p. 175.

Strickland, J.D.H. and Parsons, T.R.: 1972, *A Practical Hand Book of Sea Water Analysis*. Fisheries Research Board of Canada Bulletin 167, 2nd ed., p. 310.

Suzumura, M., Ueda, S. and Suni, E.: 2000, Control of phosphate concentration through adsorption and desorption process in ground water and sea water mixing at sand beaches in Tokyo Bay, Japan. *Journal of Oceanographic Society of Japan*, 56: 667- 673.

Valderrama J.C.: 1981, The simultaneous analysis of total nitrogen and total phosphorus in natural waters. *Marine Chemistry,* 10: 109 – 122.