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VERTICAL DISTRIBUTION AND INTER-RELATIONS OF OXYGEN AND NUTRIENTS IN THE ARABIAN GULF AND THE GULF OF OMAN IN SUMMER

By

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ABSTRACT

The distribution patterns of oxygen and nutrients (phosphate, nitrate, nitrite and ammonia) were studied along the Arabian shelf of the Arabian Gulf and the Gulf of Oman, including the Strait of Hormuz, during September, 1985 and 1986. Frequency distributions of oxygen and nutrients at different levels indicated the occurrence of a layer of minimum oxygen (< 1.5 ml O_2/1) and maximum nitrate (> 12.0 μg at NO^-_3-N/1) at depths below 50 meters. The co-occurrence of low oxygen, low ammonia and high nitrate shows a probability of nitrification process at that relatively deep water. Means and standard deviations were calculated for the measured parameters. Different linear equations were found betwen some parameters; for which the constants were estimated whenever the total correlation coefficients were significant.

INTRODUCTION

Marine environment of the area investigated comprises two large sea-areas of essentially different oceanographic regimes. One of these sea-areas is the Gulf of Oman which is a deep major arm of the Arabian Sea, and is affected greatly by the monsoon conditions prevailing in the Indian Ocean. The other sea-area is the Arabian Gulf which is a semi-enclosed shallow body of water connected to the Gulf of Oman by the narrow sill-less Strait of Hormuz and having its own pronounced characteristics which are - in many instances - extremes for water freely connected with the world ocean. The area as a whole is located in a highly arid zone. The sum of precipitation and land drainage has no significant effects on its nutrients budget, except at the immediate vicinity of Shatt Al-Arab, as well as the few small rivers fed by precipitation on the Zagros mountains and discharging across the Iranian coast. A total annual discharge of 21.6 cubic kilometers of river-water at Shatt Al-Arab was given by Al-Saadi and Al-Mayah (1983).

As with all semi-enclosed seas, the water exchange between the Arabian Gulf and the Gulf of Oman exerts a determining influence on the nutrients distribution in the area. However, nutrients levels in a water body are intimately related to their immobilization and regeneration, having a type of correlation with the dissolved oxygen (Grasshoff, 1975). Therefore, an understanding of the fundamental relations between nutrient species and oxygen may be essential if the complicated horizontal and, particularly, the vertical pattern of a nutrient distribution are to be appreciated.

The compiled data in literature reveals extraordinary lack of extensive observations on hydrochemical conditions of this region, except the work done by R.V. Meteor in March, 1965 along the Iranian coast of the Arabian Gulf (Grasshoff, 1976), the work conducted on R.V. Atlantis II in February, 1977 (Brewer and Dyrssen, 1985) and the recent work done by R.V. Mukhtabar Al-Bihar during September-October, 1985 and 1986 which is considered as the first large scale contribution to the oceanographic studies ever done in the sea-area of the Gulf Region at its Arabian shelf (El Samra, 1988). Apart from these extensive works, sparse works have been conducted in local limited areas in the Arabian Gulf during the last few years as can be seen from the recent bibliography (Farmer and Docksey, 1983).

The present paper provides a detailed study including the vertical chemical structure, the statistical and simple correlation analyses of chemical data of nutrients and oxygen in the Arabian Gulf and the Gulf of Oman, in order to clarify some fundamental environmental interrelations in an area deserving its oceanographic attention.

MATERIALS AND METHODS

The data presented here are the results of two cruises made by R.V. Mukhtabar Al-Bihar in the Arabian Gulf and Gulf of Oman. First cruise was made in September-October, 1985 to cover the southern part of the Arabian Gulf, and the second one was made in September, 1986 to cover the latter area and extended to cover the strait of Hormuz and an area of the Gulf of Oman to Muscat (Fig. 1).

Seawater samples were collected from different stations at different depths by Nansen bottles. Oxygen, phosphate, nitrate, nitrite and ammonia were determined according to the methods described by Strickland and Parsons (1968). Salinity was obtained with a temperature compensated salinometer model Autolab 601 MK III.

Different methods of statistical analyses were applied for the obtained results:

1 - Mean, standard deviation, minimum and maximum were estimated.

2 - Frequency distributions of categorized values of the different parameters were calculated and plotted.

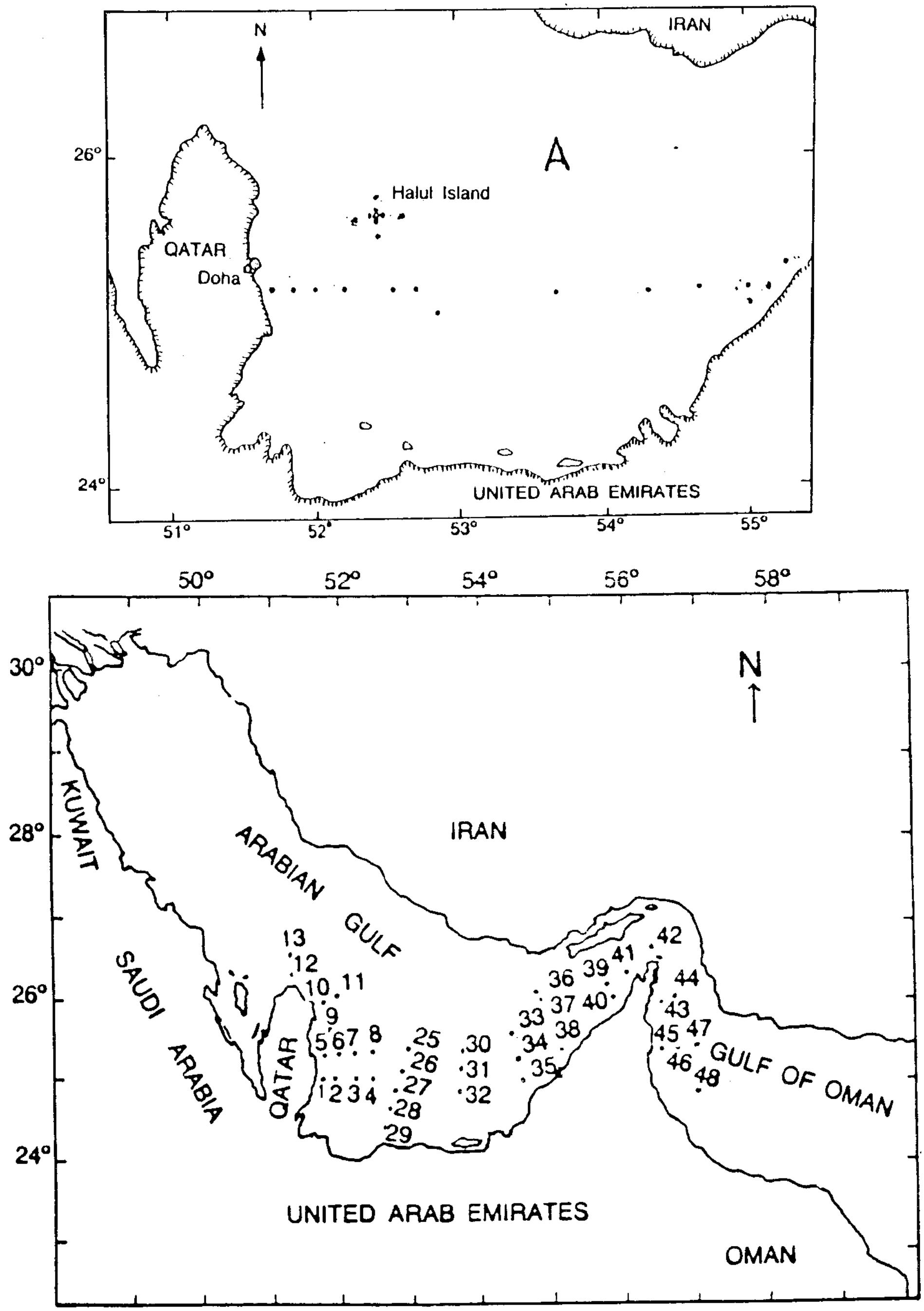

Fig. 1: Sampling locations in the Arabian Gulf and the Gulf of Oman, during September (A) in 1985, (B) in 1986.

3 - Plotting of the relations between each two parameters was done to find out the type of applicable regression equations, the simple correlation coefficients and the constants of the regression lines at 95 % confidence limit.

RESULTS AND DISCUSSION

Surface distribution of chemical parameters in the area of invistigation were given in detail by El Samra (1988). The exchange of water between the Arabian Gulf and the Gulf of Oman were also described in detail by some authors (Grasshoff, 1978, Brewer & Dyrssen, 1985, Hunter, 1986 and El Samra, 1988).

Vertical distribution patterns of oxygen, phosphate, nitrate and, in particular, salinity (Fig. 2) indicate a Mediterranean type circulation. The surface water (of relatively low salinity and high nutrients) inflows from the Gulf of Oman to the Arabian Gulf. Deep water (of relatively high salinity, >40 %$_o$), on the other hand, tends to outflow in the reverse direction i.e. from the Arabian Gulf to the Gulf of Oman.

Brewer & Dyrssen (1985) stated that the outflowing deep water from the Arabian Gulf to the Gulf of Oman appears to be formed along the coast of UAE (Trucial coast as they mentioned). Hunter (1986) proposed that water of high salinities and densities in the shallower areas of the southwest and south coasts of the Arabian Gulf

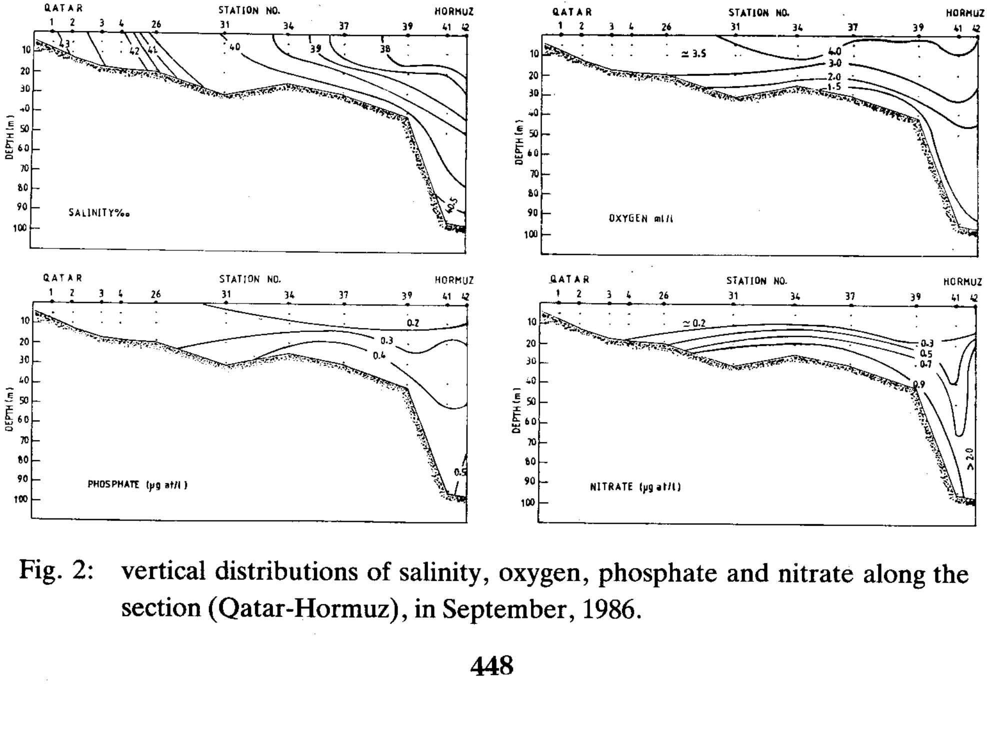

Fig. 2: vertical distributions of salinity, oxygen, phosphate and nitrate along the section (Qatar-Hormuz), in September, 1986.

(the present area of investigation) sinks and is deflected to the right by Coriolis force and passes out of the Gulf through the Strait of Hormuz.

Stations sampled by R.V. Atlantis II (Brewer & Dyrssen, 1985) were too far to the north to sample the core of the outflow, while the present data indicate that the outflow is constrained against the southern side of the Strait of Hormuz. It is also of

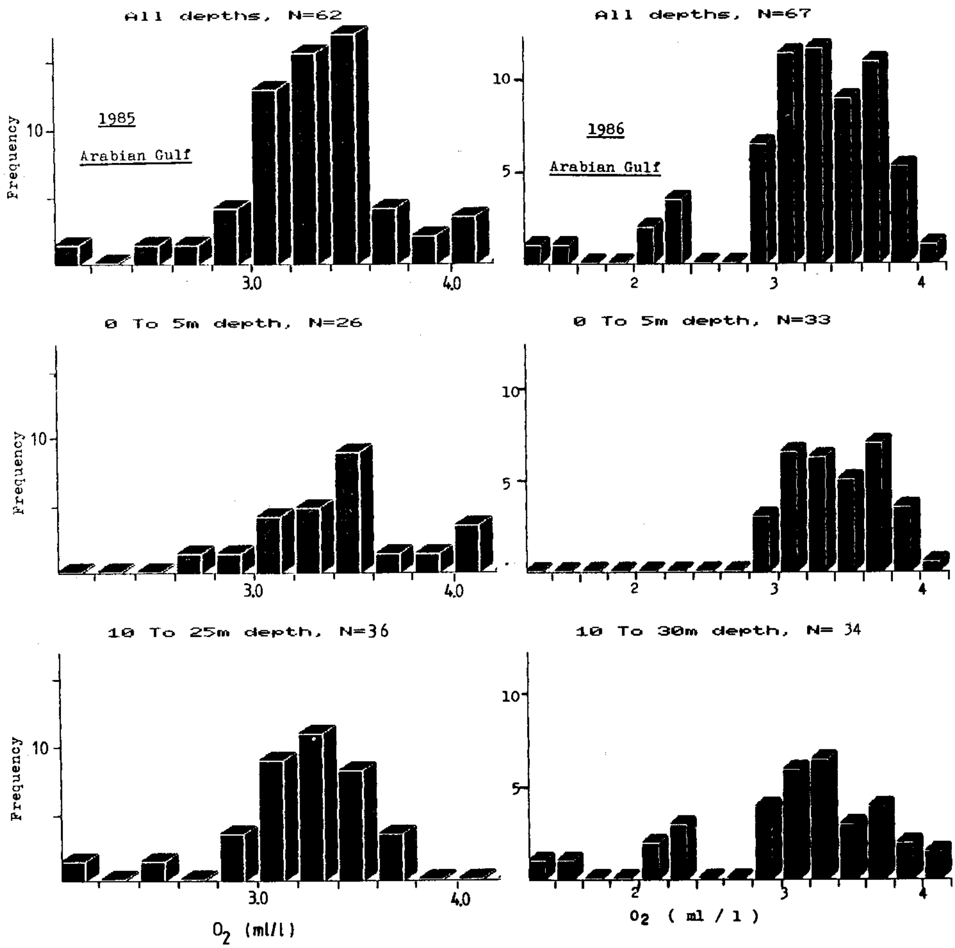

Fig. 3: Frequency distributions of oxygen at different depths in the Arabian Gulf, in September, 1985, and 1986.

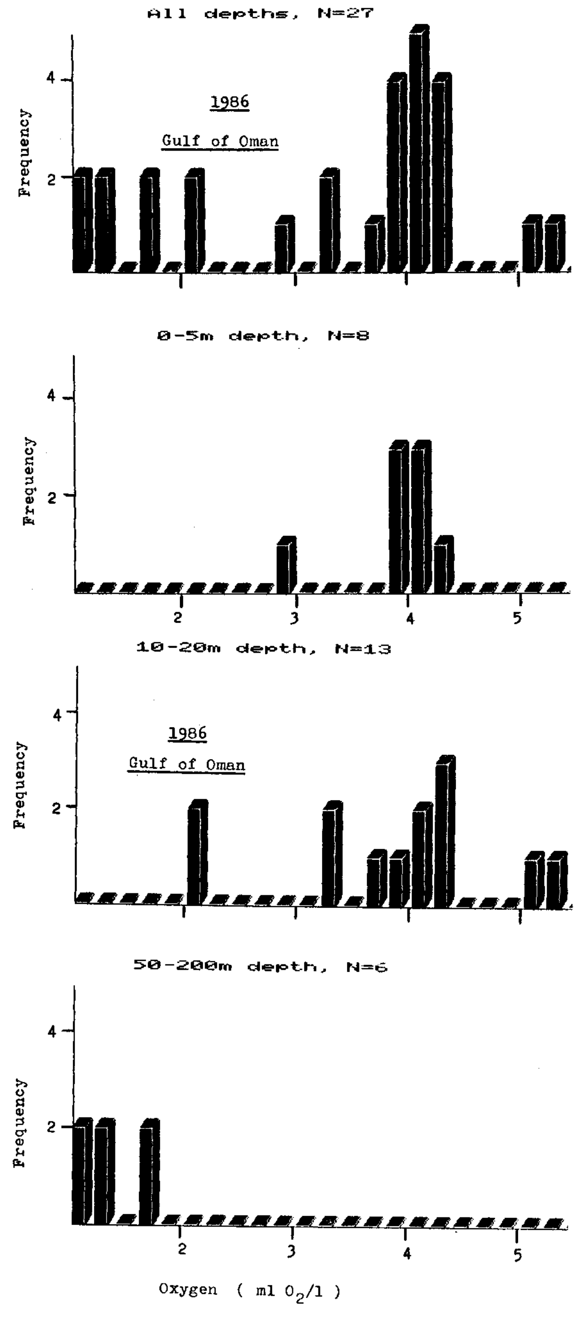

Fig. 4: Frequency distributions of oxygen at different depths in the Gulf of Oman, in September, 1986.

great interest to notice that near Qatar peninsula, the water becomes less stratified and vertically well mixed.

Since the chemical data would help in other studies such as studies dealing with primary productivity or fisheries, it is interesting to find the frequency distributions of different chemical parameters in different water layers, and to calculate the correlations between the different recorded parameters.

Frequency distributions of chemical data at different depths:

The frequency distributions of oxygen in the Arabian Gulf during September, 1985 and 1986 (Fig 3) show that the most frequent oxygen concentrations were between 3 and 4 ml $O_2/1$. However, in 1986, three stations (30, 37 and 39) had low oxygen concentrations (1.2 to 2.0 ml $O_2/1$) near the bottom at a depth of 30 meters. Similarly, in the Gulf of Oman (fig. 4), the most frequent values of oxygen in the surface layer (0 to 20m) lie between 3.0 and 4.4 ml $O_2/1$, while in the relatively deep layer (50-200m) the values were confined below 2.0 ml $O_2/1$.

The most frequent values of nitrates in the Arabian Gulf (Fig. 5) were between 0.1 and 0.35 μg at No_3 -N/1. However, higher values (up to 2.4 μg at No_3 -N/1) were recorded during 1986 at deep layers of stations with depth greater than 20 meters near the Strait of Hormuz. In the Gulf of Oman (Fig. 6), nitrate distribution in the upper 20 meters gives the same pattern as in the Arabian Gulf, while, extreme high concentrations (7.0 - 12.0 μg at No_3 -N/1) were found below 50 meters depth.

The most frequent values of phosphates in the Arabian Gulf (Fig. 7) were between 0.05 and 0.30 μg at PO_4^{3-}-P/1. However, In 1986, lower values (< 0.1 μg at PO_4^{3-}-P/1) were more frequent at depths of zero to 10 meters, where the strong consumption by biological processes is to be expected. Deep layers (50-200m) in the Gulf of Oman (Fig. 6) show high frequency of significantly high phosphate concentrations (up to 1.5 μg at PO_4^{3-}-P/1).

During 1986, the most frequent values of ammonia in the Arabian Gulf (Fig. 8) were less than 0.1 μg at NH_3 -N/1), while higher values (up to O.4 μg at NH_3 -N/1) were frequently recorded in the Arabian Gulf during 1985. Fig. (9) shows that in the upper 20 meters of the Gulf of Oman, the most frequent ammonia values were similar to those of the Arabian Gulf, while in the deeper layers, lower values of ammonia were frequently detected.

Frequency distribution of nitrite in the Arabian Gulf (Fig. 10) shows the same pattern of ammonia distribution. The deep layers (50-200m) of the Gulf of Oman, had no characteristic nitrite concentration.

It seems from the frequency distribution of nutrients and oxygen that the surface

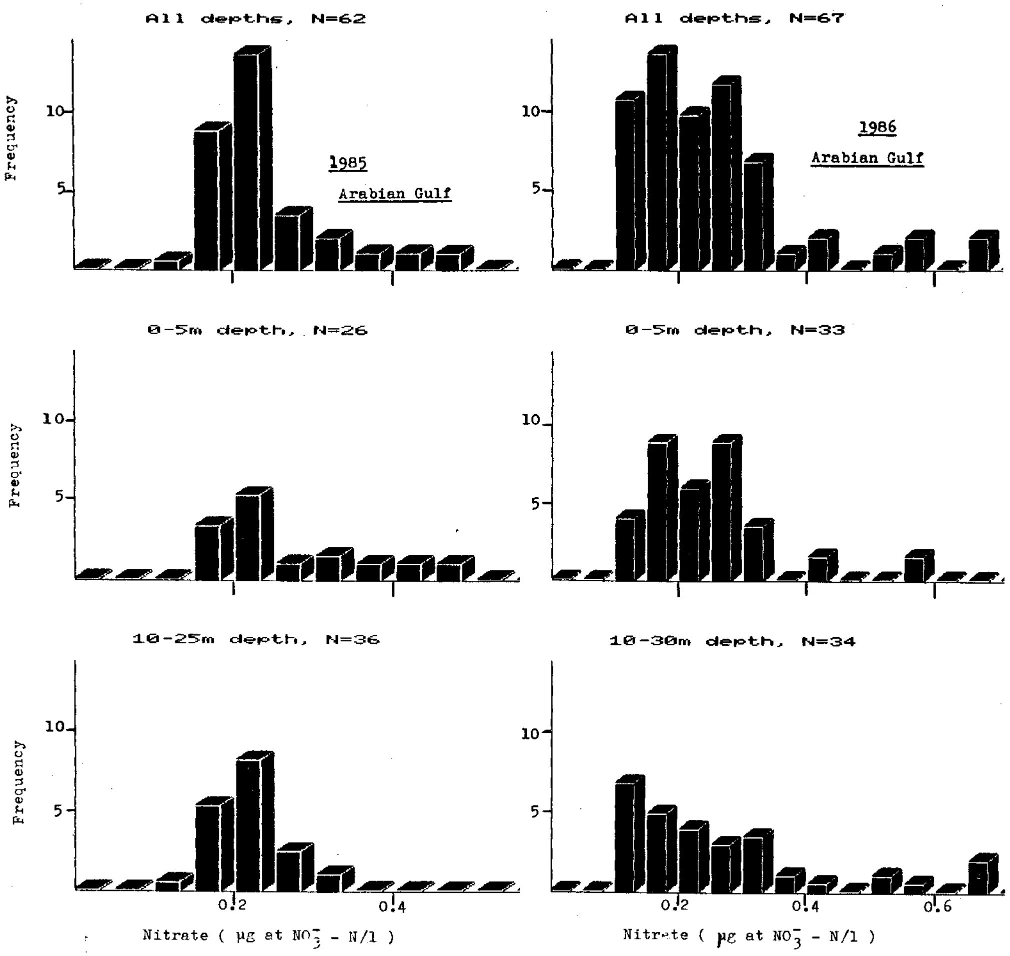

Fig. 5: Frequency distributions of nitrate at different depths in the Arabian Gulf, in September, 1985 and 1986.

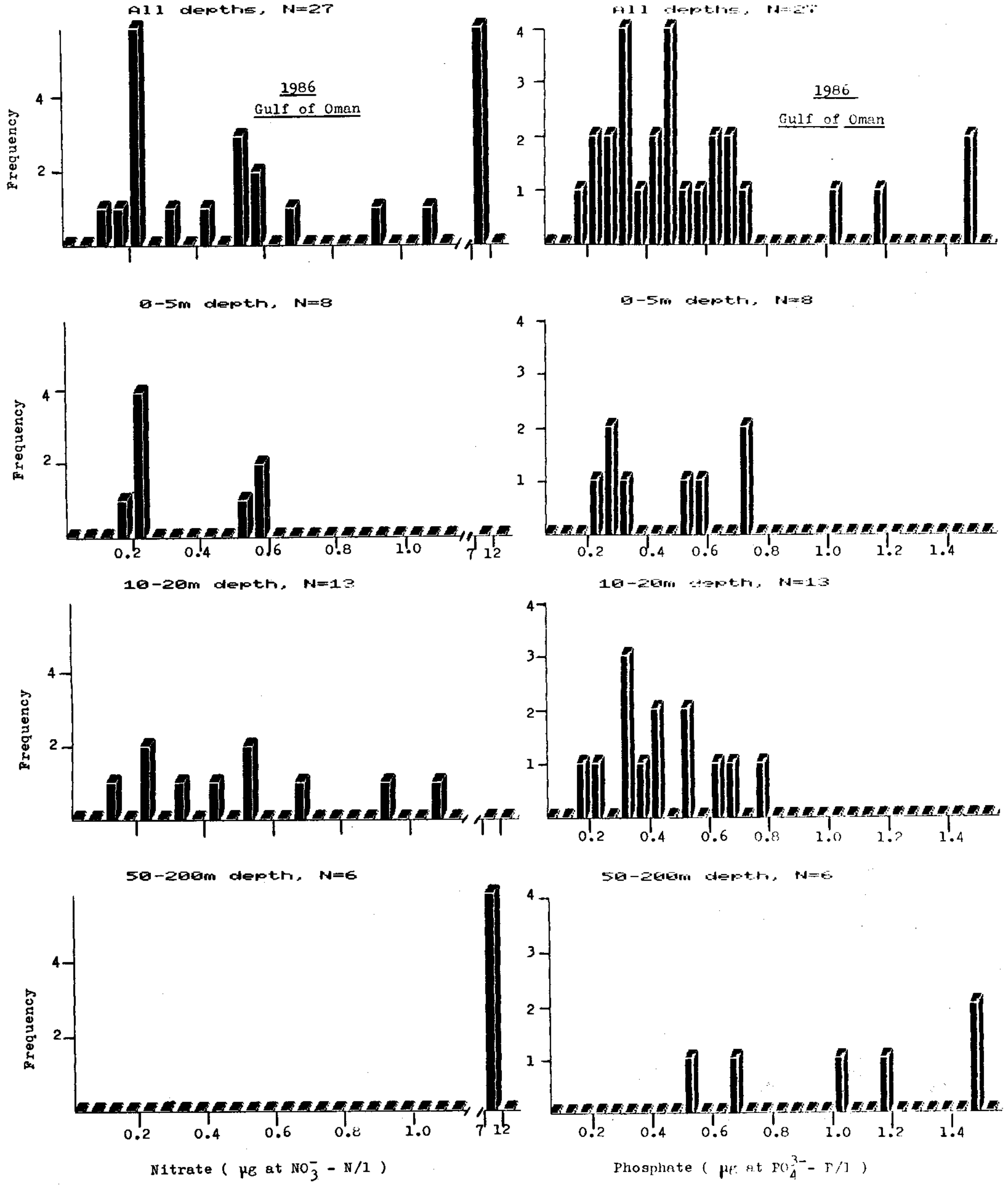

Fig. 6: Frequency distributions of nitrate and phosphate at different depths in the Gulf of Oman, in September, 1986.

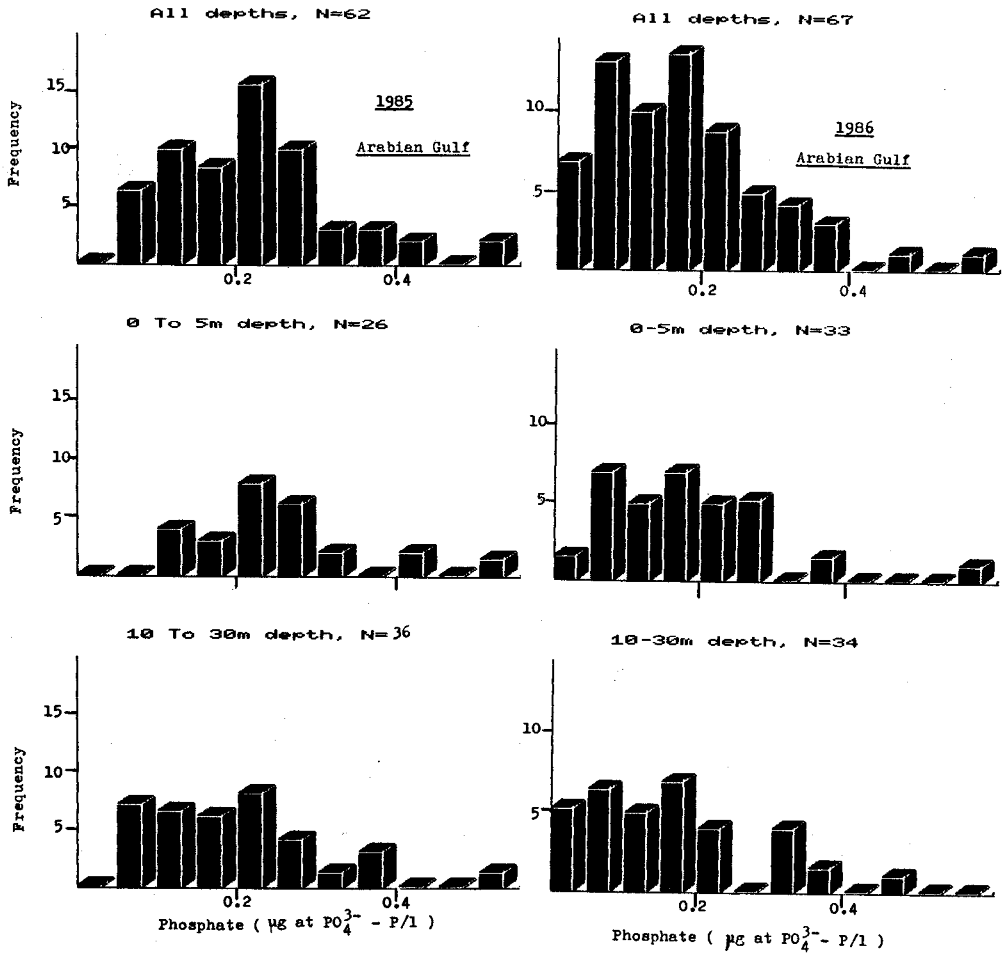

Fig. 7: Frequency distributions of phosphate at different depths in the Arabian Gulf, in September, 1985 and 1986.

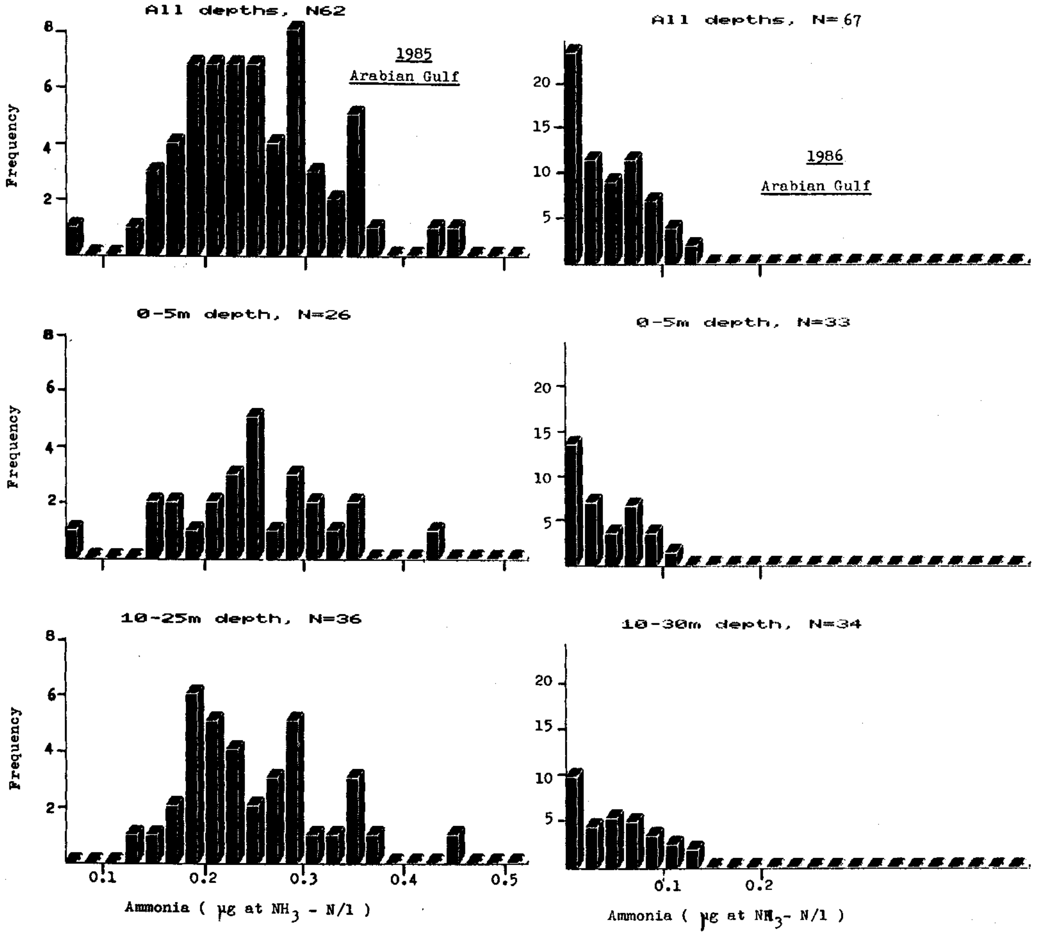

Fig. 8: Frequency distributions of amonia at different depths in the Arabian Gulf, in September, 1985 and 1986.

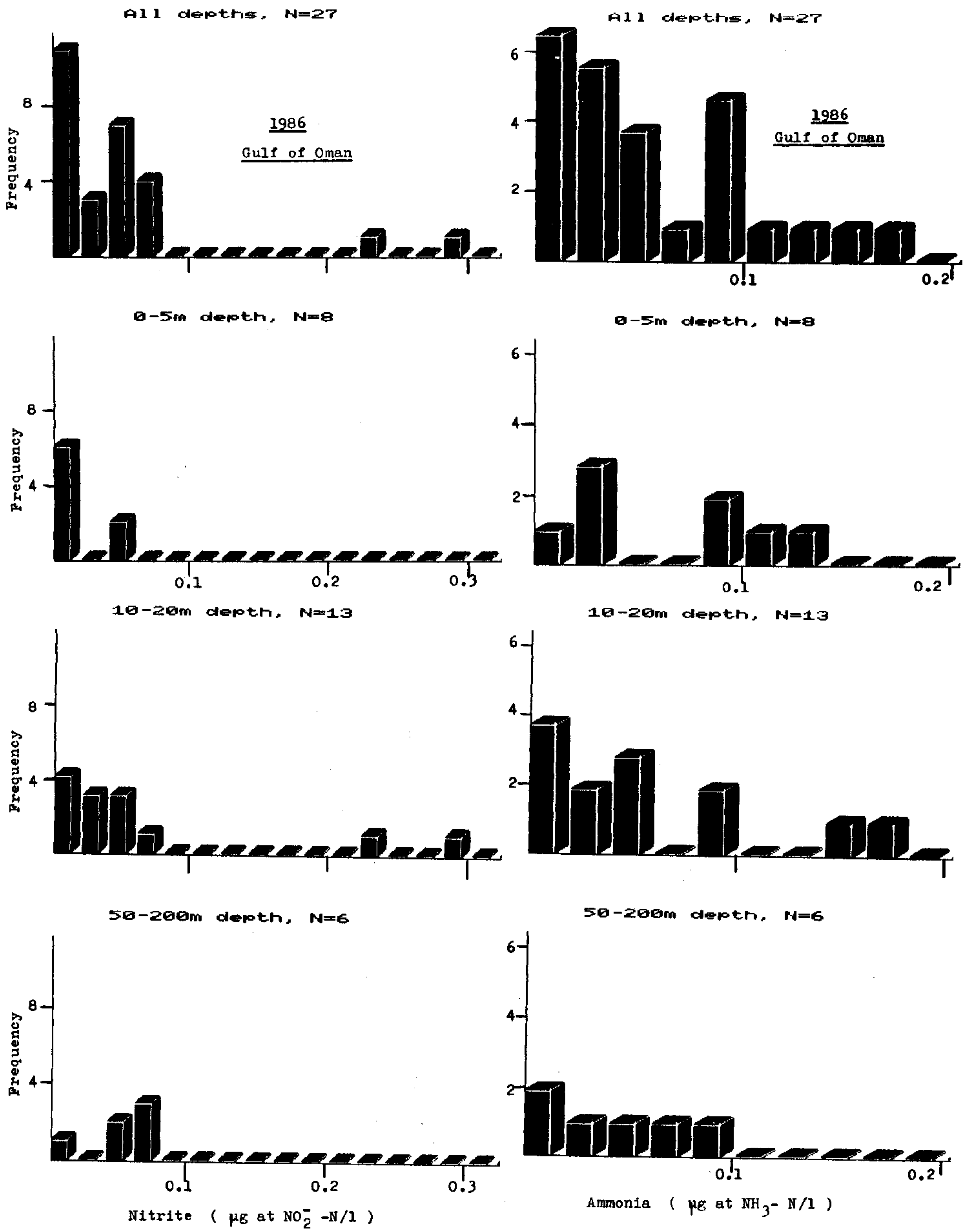

Fig. 9: Frequency distributions of nitrite and amonia at different depths in the Gulf of Oman, in September, 1986.

layer of the two Gulfs (0-10m) in the area of investigation, has more or less the same properties. This indicates a type of mixing due to the inflowing of surface water from the Gulf of Oman into the Arabian Gulf. El Samra (1988) defined an area of mixed water between the two Gulfs which is the present area of investigation. It is also noticed that the deep layer in the Gulf of Oman has probably originated from the outflow of relatively deep water of the Arabian Gulf, thus supporting the idea of Brewer & Dyrssen (1985), that the present area is the core of the water outflow from the Arabian Gulf. Salinity values in this layer could not have originated in the Indian Ocean proper.

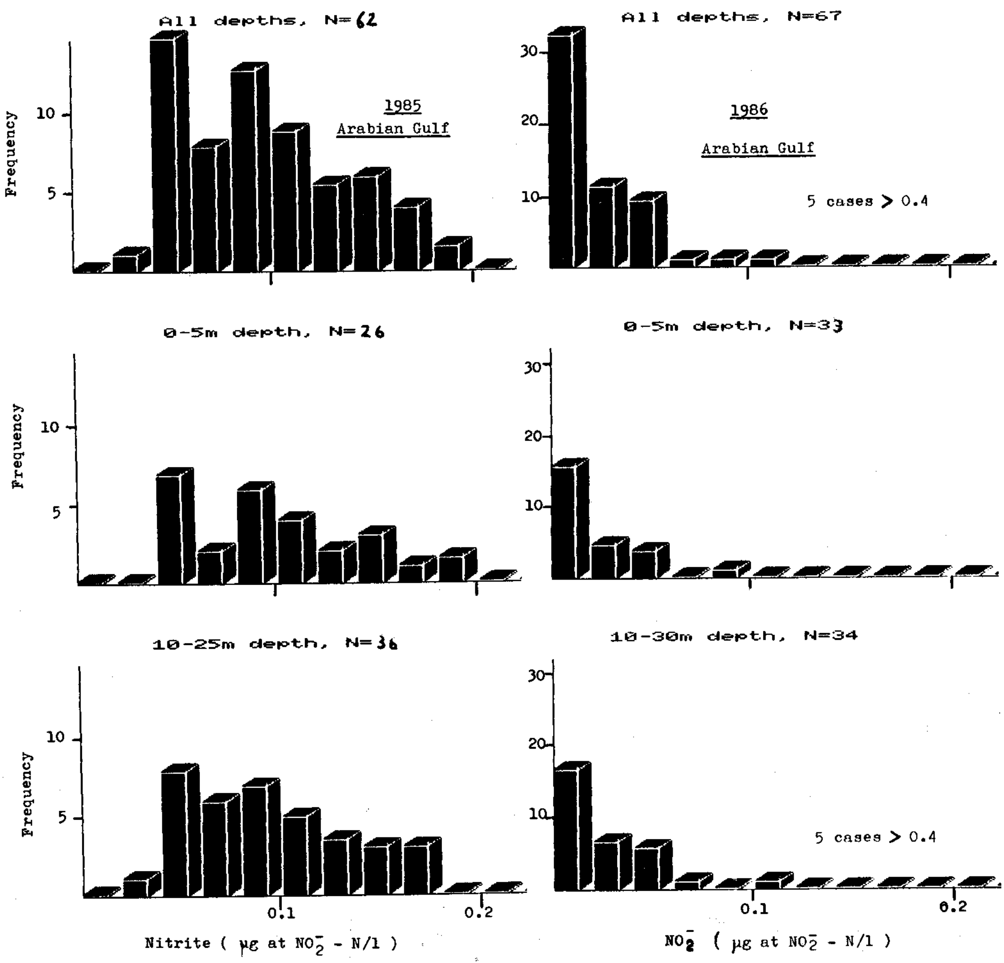

Fig. 10: Frequency distributions of nitrite at different depths in the Arabian Gulf. in 1985 and 1986.

Statistical measures of chemical data:

The mean values, standard deviations, minima and maxima of data recorded in the Arabian Gulf (Table 1) show that the means of oxygen in 1985 and 1986 had the same values within the standard deviation of estimates. The mean values of phosphate and

Table 1

Results of statistical analyses of chemical data in the Arabian Gulf

Variable	Depth (m)	No. of points	Mean	Stand. deviat.	Min.	Max.
September, 1985						
Oxygen	0-5	26	3.454	0.349	2.73	4.06
ml O_2/1	10-25	36	3.237	0.317	2.10	3.71
Phosphate	0-5	26	0.244	0.092	0.11	0.52
μg at. PO_4^{3-}-P/1	10-25	36	0.195	0.108	0.05	0.54
Ammonia	0-5	26	0.245	0.076	0.07	0.43
μg at. NH_3 -N/1	10-25	36	0.244	0.071	0.12	0.45
Nitrite	0-5	26	0.094	0.042	0.04	0.19
μg at. NO_2^- -N/1	10-25	36	0.089	0.038	0.03	0.16
Nitrate	0-5	26	0.250	0.087	0.16	0.48
μg at. NO_3^- -N/1	10-25	36	0.218	0.042	0.13	0.32
September, 1986:						
Oxygen	0-5	33	3.480	0.380	2.90	4.37
ml O_2/1	10-3O	34	3.069	0.660	1.37	4.12
Phosphate	0-5	33	0.171	0.107	0.00	0.56
μg at. PO_4^{3-} -P/1	10-30	34	0.170	0.118	0.02	0.47
Ammonia	0-5	33	0.033	0.032	0.00	0.10
μg at. NH_3 -P/1	10-30	34	0.048	0.040	0.00	0.13
Nitrite	0-5	33	0.020	0.024	0.00	0.10
μg at. NO_2 -N/1	10-30	34	0.166	0.319	0.00	1.13
Nitrite	0-5	33	0.232	0.090	0.12	0.59
μg at. NO_3 -N/1	10-30	34	0.388	0.326	0.10	1.25

ammonia in the Arabian Gulf were higher in 1985 than in 1986, while nitrite and nitrate showed extreme high mean values at depth 10-30 meters in 1986 leading to higher mean values in 1986 than in 1985. The results in the Gulf of Oman (Table 2) show that inspite of the different standard deviations, the means of oxygen in the upper 20 meters were nearly the same (3.8-3.9 ml O_2/1) as in the Arabian Gulf. However, it is significant to identify a layer of low oxygen (1.32 ml O_2/1) below 50 meters depth. Ammonia showed the same trend as oxygen with lower means in the deep layer than those in the upper one. Phosphate, nitrite and particularly, nitrate in the Gulf of Oman showed the trend of increasing mean values with increasing depth, with significantly high characteristic values in deep waters.

Table 2

Results of statistical analyses ofchemical data in the Gulf of Oman, September, 1986.

Variable	Depth (m)	No. of points	Mean	Stand. deviat.	Min.	Max.
Oxygen	0-5	8	3.900	0.390	2.98	4.29
ml O_2/1	10-20	13	3.803	0.940	2.14	5.33
	50-200	6	1.320	0.270	1.03	1.65
	all	27	3.280	1.260	1.03	5.33
Phosphate	0-5	8	0.406	0.209	0.19	0.67
μg at.	10-20	13	0.381	0.172	0.12	0.71
PO_4^{3-}-P/1	50-200	6	1.028	0.425	0.47	1.47
	all	27	0.533	0.365	0.12	1.47
Ammonia	0-5	8	0.061	0.046	0.01	0.13
μg at.	10-20	13	0.053	0.056	0.00	0.17
NH_3-N/1	50-200	6	0.037	0.034	0.00	0.08
	all	27	0.052	0.048	0.00	0.17
Nitrite	0-5	8	0.015	0.022	0.00	0.05
μg at.	10-20	13	0.064	0.095	0.00	0.31
NO_2-N/1	50-200	6	0.048	0.021	0.01	0.07
	all	27	0.046	0.70	0.00	0.31
Nitrite	0-5	8	0.341	0.184	0.15	0.58
μg at.	10-20	13	0.915	0.826	0.11	2.35
NO_3^--N/1	50-200	6	8.722	1.828	7.03	12.13
	all	27	2.480	3.548	6.11	12.13

Results of regression analyses:

Plotting of the relations between each two chemical parameters in the Arabian Gulf indicates that the conditions in September, 1985 and 1986 were significantly different. In 1985; most of the correlation coefficients were not significant at 95 confidence limit, except the relation between phosphate and nitrite in the layer 10-30 meters depth (Table 3). In 1986, on the other hand, seven relations were found to be significant (Table 3). To explain these annual variations, the meteorological

Table 3

Results of regression analysis in the Arabian Gulf, (critical r at 0.05 limit = 0.29, N = 34).

Depth (m)	x	y	corr coeff. r	Y = a + bx		Standard dev. of estimates
				a	b	
September, 1985:						
10-25	NO_2^-	PO_4^{3-}	0.56	0.051	1.625±0.407	0.091
September, 1986:						
10-30	O_2	NO_2^-	-0.69	1.195	-0.335±0.062	0.234
	O_2	NO_3^-	-0.77	1.559	-0.382±0.056	0.211
	O_2	PO_4^{3-}	-0.69	0.551	-0.124±0.023	0.087
	PO_4^{3-}	NO_2^-	0.61	-0.116	1.661±0.377	0.256
	PO_4^{3-}	NO_3^-	0.61	0.103	1.679±0.388	0.263
	NO_2^-	NO_3^-	0.87	0.241	0.888±0.090	0.164
	NO_2^-	PO_4^{3-}	0.61	0.132	0.227±0.052	0.095

conditions at Doha Airport, in 1985 and 1986 (Annual Climatological reports, State of Qatar) have been compared. The main difference between the conditions in the two years, during August and September, was found in the dominant wind direction; in 1985, the dominant direction was on average a N-NE wind, while in 1986, the dominant direction was 50-130° (on average, an Eastern wind). The upwelling on the southern Arabian side in the study area, Fig. (1), could be more efficiently generated by the eastern winds than by the NE winds. The eastern wind is expected to be associated with high nutrients concentration and propable more significant correlations between the different nutrient components, which is the case of September, 1986. Hence, the significant linear equations obtained in September, 1986, could be applied when the winds are blowing dominantly from the east.

It would be of great interest to compare the regression equations between nitrite and phosphate in 1985 and 1986, in the layer 10-30 meters depth (Fig. 11). The data points of each of the two years are represented in different symbols. It is shown, from the figure, that the nitrite concentrations in 1985 were limited at values less than 0.2 μg at NO_2 -N/1, while, in 1986 the concentrations reached 1.2 μg at NO_2 -N/1. The equation which represents 1985 data could be reasonably applied, within the standard deviation estimates, to the low nitrite values (< 0.2 μg at NO_2 -N/1) of 1986 data. The estimation of phosphate from nitrite concentrations higher than 0.2 could be obtained using the equation of 1986, Fig. (11).

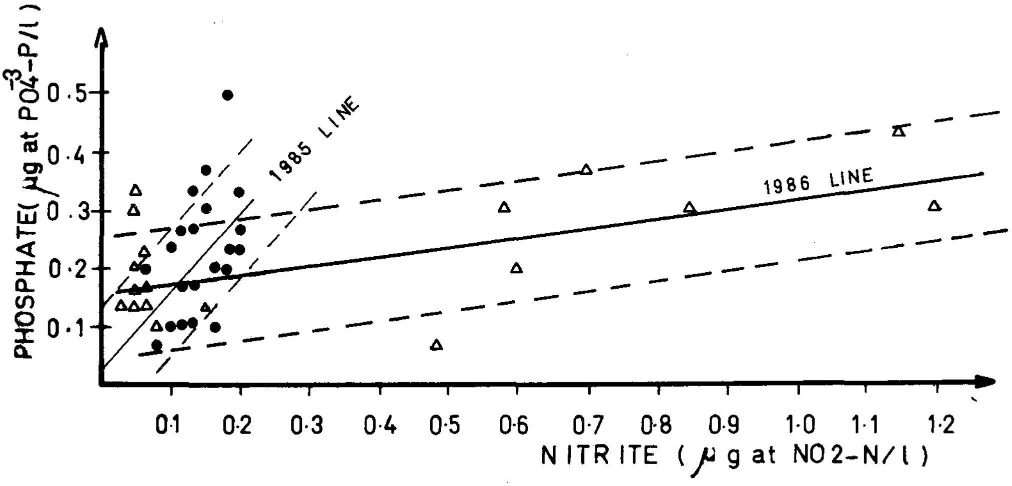

Fig. 11: Linear relations between phosphate and nitrite during September, 1985 and 1986.

The relations between the significantly correlated variables in the different layers of the Gulf of Oman are shown by table (4). Unfortunately, there are no other available data in the same season in other years and the same region to validate these relations. The plotting of the data on scatter diagrams did not indicate non-linear relations and the vertical distributions of oxygen, phosphate and nitrate followed straight lines with highly significant correlation coefficients between each variable and the depth for the whole water column. However, better accuracy in the estimations is obtained for the high concentrations in the deep layers.

In conclusion, the present treatment of chemical data in the Gulf sea-area indicates that, at least, two distinct layers could be detected in the mixed area of the two Gulfs. The upper layer (0-50 meters depth), in one hand, has its own chemical characteristics which is similar to surface water of the Gulf of Oman tending to change gradually as its water enters the Arabian Gulf. The deeper layer (below 50 meters depth) in the Gulf of Oman, on the other hand, has outstanding characteristics; it is rich in nutrients and poor in oxygen.

It is also of great importance to notice that bottom water of the relatively deep locations in the Arabian Gulf shows a strong decrease of oxygen content to reach values less than 2.5 ml $O_2/1$. The co-occurrence of nitrate maxima with the oxygen and ammonia minima at the deep stations in the Gulf of Oman indicates the effect of nitrification process by which ammonia is oxidized to nitrate consuming the oxygen present in the waters. Therefore, these deep features could be due to chemical processes which usually occur in the deep layer.

Table 4

Results of regression analysis in the Gulf of Oman. (r = correlation coeff)

Depth (m)	x	y	n	r	critic. r at 0.05	Y = a + bx		Standard deviation
						a	b	
0-5	PO_4^{3-}	NO_3^-	8	-0.66	0.63	0.577	-0.580±0.270	0.150
	NH_3	NO_3^-		-0.81		0.539	-3.225±0.957	0.118
10-20	O_2	NO_3^-	13	-0.64	0.48	3.045	-0.560±0.210	0.660
	PO_4^{3-}	NH_3		-0.57		0.123	-0.184±0.080	0.050
	PO_4^{3-}	NH_2^-		-0.57		0.123	0.355±0.128	0.080
	NO_2^-	NO_3^-		0.72		0.517	6.238±1.821	0.600
50-200	O_2	PO_4^{3-}	6	-0.98	0.74	3.061	-0.538±0.150	0.093
	O_2	NH_3		-0.77		0.169	-0.096±0.040	0.024
	O_2	NO_2^-		-0.84		0.136	-0.067±0.021	0.013
	O_2	NO_3^-		-0.78		15.716	-5.292±2.090	1.267
	PO_4^{3-}	NO_2^-		0.91		0.002	0.046±0.010	0.010
	PO_4^{3-}	NO_3^-		0.80		5.186	3.438±1.292	1.230
0-200	depth	O_2	27	-0.74	0.32	3.892	-0.021±0.004	0.869
	depth	PO_4^{3-}		0.74		0.357	0.006±0.001	0.252
	depth	NO_3^-		0.91		0.363	0.072±0.006	1.486

REFERENCES

Al Saadi, H.A. and A.A. Al-Mayah, 1983. Aquatic plants of Iraq. Centre for Arab Gulf Publications, University of Basrah. 52: 192 pp.

Anon., 1986. Annual climatological report. State of Qatar, Ministry of Communication & Transport, Dept of Meteorology.

Brewer, P.G. and D. Dyrssen, 1985. Chemical oceanography of the Persian Gulf. Prog. Oceanog. 14: 41-55.

El Samra, M.I., 1988. Chemical observations in the Arabian Gulf and the Gulf of Oman. Arab Gulf J. Scient. Res., Math. Phys. Sci., A6 (2), 205-215.

Farmer, A.S.D and J.E. Docksey, 1983. A bibliography of the marine and maritime environment of the Arabian Gulf and Gulf of Oman. Kuwait Bull. Mar. Res. 4: 121 pp.

Grasshoff, K., 1975. The hydrochemistry of landlocked basins and fjords. In, Chemical Oceanography, ed. J.P. Riley & G. Skirrow, Academic Press, Vol. 2: 456-593.

Grasshoff, K., 1976. Review of hydrographical and productivity conditions in the Gulf Region. UNESCO Technical Papers in Marine Science, 26: 39-62.

Hunter, J.R., 1986. The physical oceanography of the Arabian Gulf: a review and theoretical interpretation of previous observations. In, Marine Environment and Pollution, ed. R. Halwagy, D. Clayton and M. Behbehani, Kuwait University, 1-25.

Strickland, J.D.H. and T.R. Parson, 1986. A practical handbook of seawater analysis, Fish. Res. Bd. Can. Bull. 167: 311 pp.

التـوزيـع الرأسي والعـلاقـات البينيـة للأكسجين والأملاح المغذية في الخليج العربي وخليج عمان في فصل الصيف

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يختص البحث بدراسة شاملة للأكسجين والأملاح المغذية في مياه المنطقة البحرية على الجانب العربي من الخليج العربي وخليج عمان . وقد تمت هذه الدراسة بواسطة سفينة مختبر البحار في (سبتمبر ـ أكتوبر) لعامي ١٩٨٥ ، ١٩٨٦ . ويقدم البحث التوزيع الرأسي للملوحـة والأكسجـين والأمـلاح المغـذيـة (الفـوسفات ، النيترات ، النيتريت والأمونيا) مع مناقشة تفصيلية لمستويات تلك الخواص بالأعماق المختلفة . وقد تبين من البحث أن الطبقة السطحية لكل من الخليج العربي وخليج عمان تحتوي على تركيزات من الأكسجين تتراوح بين ٣ ، ٤ مل/ لتر بينما ينخفض التركيز إلى ١,٢ مل/لتر في مياه القاع بالخليج العربي ويصل إلى حده الأدنى في خليج عمان عند العمق بين ٥٠ ، ٢٠٠ متـر . أمـا في حالات النيتـرات ـ على وجه الخصوص ـ والفوسفات فنجد أنه يحدث العكس . فتقـل تركيزاتها بالمياه السطحية بينما تزيد كثيراً بالمياه القاعية . ويدل تغير الأكسجـين والنيتـرات والأمـونيـا مع الأعماق على حدوث عملية النترتة التي تتأكسد بموجبها الأمونيا إلى نترات ويستهلك تبعاً لذلك الأكسجين الذائب بمياه القاع . وقد تم حساب المتوسطات والانحراف المعياري لكل منها للمتغيرات التي درست وذلك في كل عمق على حدة . وقد تم أيضاً مناقشة الحسابات التي تمت لايجاد العلاقات الرياضية بين كل متغيرين على حدة . وقد تميزت نتائج عام ١٩٨٦ بوجود علاقات خطية واضحة وذات دلالة ريـاضيـة بين معظم الخواص التي درست وخاصة بين الأكسجين وكل من الفوسفات والنيترات مما يجعل دراسة تلك العلاقات بين الخواص الكيميائية من الأهمية من حيث إمكانية استخدامها في دراسات أخرى مثل دراسة انتاجية أو مصايد الخليج العربي وخليج عمان .