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INTERRELATIONSHIPS AND DISTRIBUTION OF HYDROCHEMICAL PARAMETERS IN COASTAL WATERS OFF VISAKHAPATNAM, EAST COAST OF INDIA

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ABSTRACT

The distribution of hydrochemical parameters in the coastal waters off Visakhapatnam during the July 1979-June 1980 showed distinct changes with time. The observed supersaturation and saturation of oxygen in surface waters was due to favourable plankton growth. The upward tilting of isolines of oxygen saturation indicate the presence of upwelling during premonsoon season. A reasonably good agreement between the calculated vertical diffusion coefficients and the surface-bottom differential in dissolved oxygen concentration (ΔO_2) values was noticed. The distribution of nutrients showed two major peaks. A significant correlation between nitrate and phosphate in surface and bottom waters indicated the prominance and association of these nutrients with planktonic growth. The data on the upward fluxes of N, P, Si, demonstrate that these fluxes are related to productivity occurring during different seasons.

Key-words: Upwelling, vertical diffusion, coefficients, upward fluxes, Visakhapatnam coast.

INTRODUCTION

The present knowledge on the hydrography of the coastal waters off Visakhapatnam is largely due to the cruises conducted by Andhra University during 1952-1958 (LaFond, 1957). Ganapati and Murty (1954) studied the biology and chemistry of sea surface waters off Visakhapatnam while Ganapati and Rama Sarma (1958) carried out a preliminary survey of hydrobiological conditions of the surface waters of Bay of Bengal off Visakhapatnam coast. Studies on the distribution of oxygen and other hydrographical features in the Bay of Bengal are mostly confined to the offshore waters (Naqvi, De Souza, Fondekar and Reddy, 1979; Sankaranarayana and Reddy, 1968). The present study was undertaken to investigate in detail the seasonal variations of dissolved oxygen and related hydrochemical parameters such as phosphate, nitrate and silicate in the coastal waters off Visakhapatnam with special emphasis on their interrelationships with the vertical diffusion coefficients. An attempt has also been made to calculate the upward fluxes of these nutrients.

MATERIAL AND METHODS

Surface and subsurface (10, 20, 40 and 60 m depth) water samples were collected along the transect (up to 60 m depth) from 4 stations (Fig.1) during July 1979 to June 1980 at monthly intervals. Salinity, dissolved oxygen, nitrate, nitrite, phosphate and silicate were determined using standard analytical methods (Anonymous, 1975). Temperature values were obtained using reversing thermometers. Percent oxygen saturation was computed by dividing the observed oxygen concentration with the oxygen solubilities obtained from UNESCO tables (1973) at the given temperature and salinity and then multiplying by 100. The monthly mean wind velocity at Visakhapatnam (from India Meteorological Department), salinity and temperature data were used for calculating the vertical diffusion coefficients (Dz).

$$Dz = \frac{2 \times 10^{-13} W^3}{d \times N^2} \quad cm^2 s^{-1}$$

Where W – mean surface wind velocity, d – depth of water, N – vertical stability parameter = $\left(\frac{g}{\rho} \cdot \frac{d\rho}{dz} \right)^{1/2}$ and ρ – density of water.

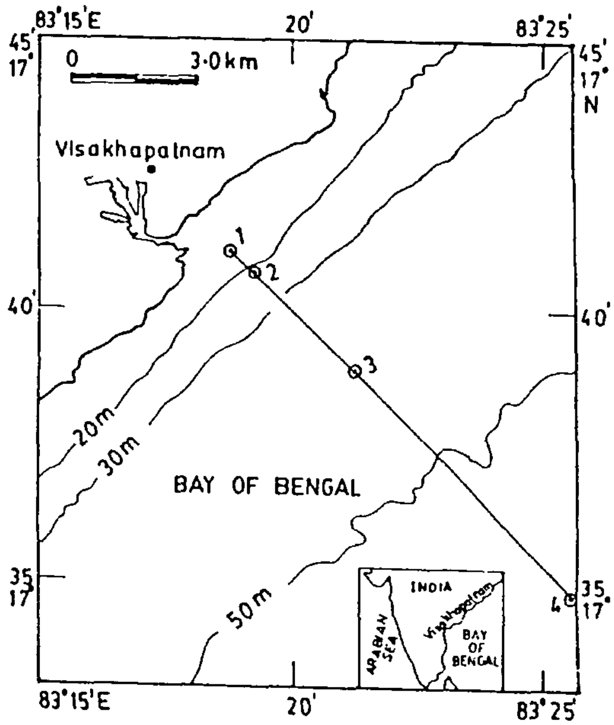

Fig.1. Station location map

RESULTS AND DISCUSSION

Station 3 was selected to represent the seasonal variations because of the fact that stns. 1 and 2 were located near the entrance channel of the Visakhapatnam harbour and subjected to pollution effect and the data for stn.4 in the monsoon season was not available. The monthly variations in different hydrochemical parameters at stn.3 are presented in Fig.2.

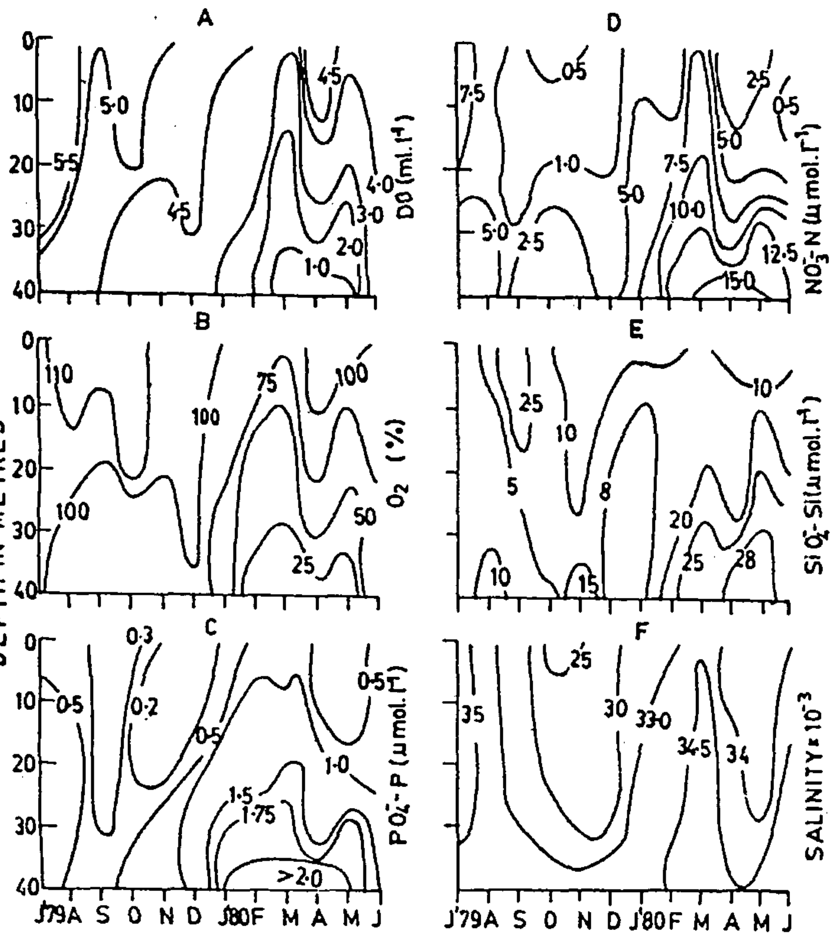

Fig.2. Monthly distribution of chemical parameters (July '79-June '80): (A) Dissolved oxygen, (B) Oxygen saturation, (C) Phosphate-Phosphorus, (D) Nitrate-Nitrogen, (E) Silicate-Silicon, and (F) Salinity.

Dissolved oxygen and oxygen saturation: Industrial and domestic wastes containing nutrients (phosphate and nitrate) entering through the channels of Visakhapatnam harbour into the nearshore waters (Sarma, Raju and Bose Babu, 1982) enhanced the phytoplankton production and thus the supersaturation of oxygen at station 1 (110%) and 2 (105%) was noticed. Fig.2 (A & B) show the monthly variations in the distribution of oxygen and oxygen saturation respectively at stn. 3 during the year. A reasonably good agreement between the calculated vertical diffusion coefficients (Dz, Table I) and the surface-bottom differential in dissolved oxygen concentration (ΔO_2) values was found. The water column is mixed (Dz = 0.05 cm^2s^{-1}) in the southwest monsoon season (June-Sept) and the ΔO_2 values varied between 0.18 and 1.24 $ml.l^{-1}$. Murty and Varadachari (1968) reported that the current and wind were favourable for upwelling along the coast. The study conducted by Naqvi, De Souza, Fondekar and Reddy (1979) also revealed the presence of upwelling beyond the continental shelf off Visakhapatnam where oxygen concentration was found to be about 15% less than the saturation level. However, in the present investigation the surface oxygen concentration ranged from 4.5 to 6.0 $ml.l^{-1}$ (100 to 110% saturation values) during Jul-Aug indicating that upwelling was nearly absent in the nearshore waters. In a recent study (Narasimha Rao, Rao, Rao and Rama Raju, 1986), it was reported that the upwelling centre (cooler water) appeared first close to the coast during March and then moved offshore with the progress of time. During October and November the vertical and horizontal displacement of isolines of oxygen (Fig.3c) indicated vertical circulation directed downward in the shelf and onshore at the surface, characteristic of sinking along this coast during these months. The vertical diffusion coefficient values were observed to be lowest during Oct-Nov (Dz = 0.003-0.008 cm^2s^{-1}) and the ΔO_2 values were low and uniform (1.26 $ml.l^{-1}$) probably due to sinking phenomenon favoured by a reversal in the wind and the current direction in this season bringing northern diluted waters along the coast towards the south. During the NE monsoon season (Dec-Feb) the surface waters appeared to be more or less saturated with oxygen. The low vertical diffusion coefficient (0.006 to 0.01 cm^2s^{-1}) and the comparatively high ΔO_2 (2.67 $ml.l^{-1}$) may have resulted in the undersaturation of oxygen in bottom waters due to the lack of mixing during this season. The low concentration of oxygen in the bottom waters was apparently due to the biochemical oxidation of organic matter and its limited renewal.

In the premonsoon season, during March the water column was found to be deficient in oxygen with a saturation of 50-80% (3-4.0 $ml.l^{-1}$) at the surface. The upward tilting of isolines of oxygen saturation supported by the high ΔO_2 (3.64 $ml.l^{-1}$) values indicated the presence of upwelling. It has been reported earlier (Bhavanarayana and LaFond, 1957) that the upwelling and subsurface water occurred along this coast due to favourable winds in the premonsoon season with maximum intensity during March. Murty and Varadachari (1967) reported that during premonsoon, waters from a depth of 60 m reached the surface while during monsoon period, waters from a depth of 100 m or more reached the surface. The effect of upwelling was evident even at shallow station 2 (Fig.3a). The surface water oxygen saturation (Fig.2A & B) in April may possibly be due to phytoplankton blooms which occur in April as reported by Ganapati and Murty (1956). However, the gradual increase in dissolved oxygen through May-June indicates the gradual disappearance of upwelling towards the end of May. This is substantiated from the high vertical diffusion coefficient (Dz = 0.21 cm^2s^{-1}) in May and low ΔO_2 (0.64 $ml.l^{-1}$) in the present investigation.

Table I — Diffusion coefficient (Dz), Stratification (N^2), Wind (W), (ΔO_2) Oxygen differential, and vertical fluxes of nitrate, phosphate and silicate for station 3 (40 m).

Month	Dz ($cm^2 s^{-1}$) $.10^{-3}$	N^2 (s^{-2}) $.10^{-4}$	W ($m\ s^{-1}$)	ΔO_2 ($ml.l^{-1}$)	Vertical flux (μ mol m^{-2} day^{-1})		
					Nitrate (N)	Phosphate (P)	Silicate (Si)
Jul '79	62.0	2.40	3.1	0.82	33.5	-	-
Aug '79	39.9	5.37	3.5	1.24	45.9	57.5	45.9
Sep '79	7.1	4.80	1.9	0.18	3.5	0.02	1.7
Oct '79	3.1	14.94	2.1	1.37	3.5	0.04	5.2
Nov '79	8.2	6.51	2.2	1.16	0.9	0.06	4.3
Dec '79	13.6	5.76	2.5	0.13	1.2	0.4	6.1
Jan '80	5.5	3.70	1.6	2.28	8.6	1.4	2.6
Feb '80	10.3	4.50	2.1	2.95	24.2	3.0	32.0
Mar '80	18.2	6.70	2.9	2.85	41.5	2.7	57.0
Apr '80	78.6	4.07	4.0	4.24	241.9	9.5	354.2
May '80	207.0	1.92	4.3	3.85	613.4	52.7	734.4
Jun '80	45.6	3.59	3.2		112.3	9.9	86.4

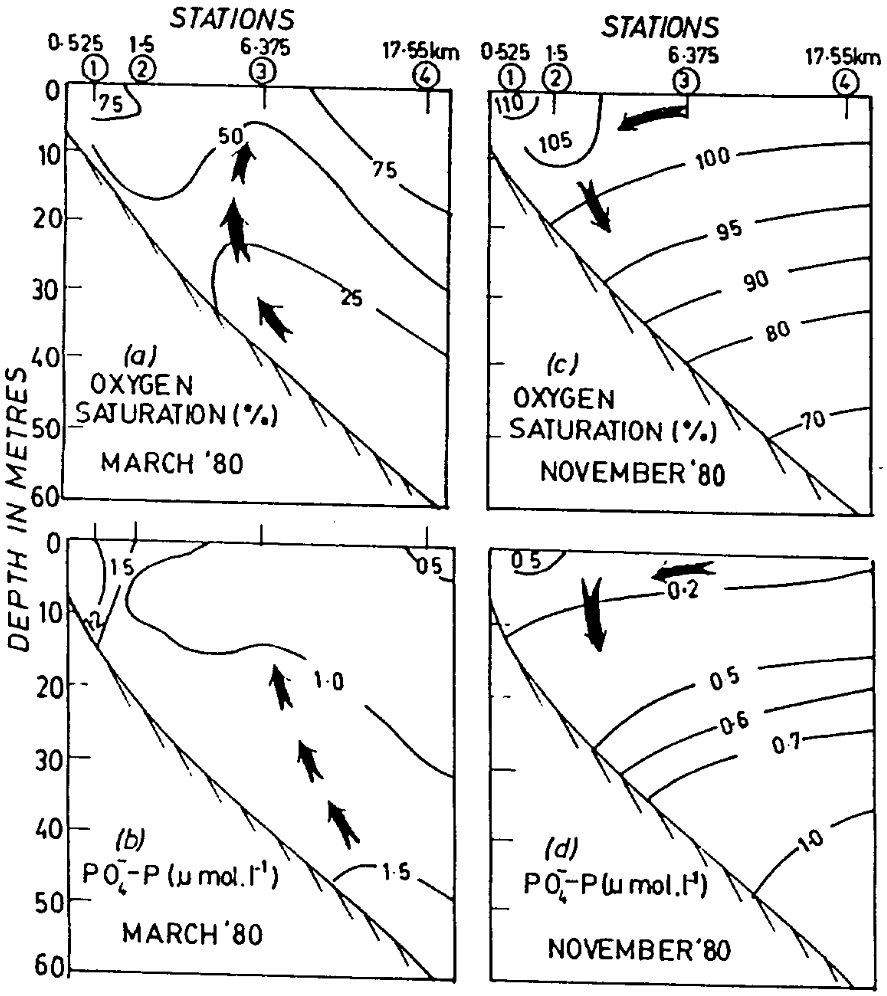

Fig.3. Distribution of oxygen saturation (%) (a & c) and Phosphate-Phosphorus (b & d) during March and November, 1980.

Seasonal variations in dissolved oxygen in bottom water at station 3 showed the lowest values (0.99 $ml.l^{-1}$) in April and highest in September (5.41 $ml.l^{-1}$). Lowest values occurred during April and is in agreement with observed large surface to bottom differential in temperature, salinity and also density (Narasimha Rao, Rao, Rao and Rama Raju, 1986).

Nutrients: The seasonal variation in nutrients of the inshore waters can be satisfactorily explained in terms of difference in the effects of horizontal advection and vertical mixing combined with effects of biological uptake, regeneration and transport.

Phosphate: The usual pattern of annual variation in the concentration of inorganic phosphate at the shallow stations 1 and 2 was masked by surface run off through the entrance channel of Visakhapatnam harbour.

The seasonal variation in inorganic phosphate at station 3 (40 m depth) is shown in Fig.2C. Although previous studies (Ganapati and Rama Sarma, 1958) carried out on the surface waters off Visakhapatnam coast indicated no peak in phosphate during the southwest monsoon season, high values of inorganic phosphate observed during Jul-Aug in the present study showed impact of subsequent organic pollution (Ganapati and Raman, 1973; 1976; 1979) caused by the discharge of domestic sewage and industrial effluents into the Visakhapatnam harbour affecting the coastal waters. Further, the phosphate peak in the southwest monsoon season supports our earlier conclusion (Rama Raju, Sarma, Narasimha Rao and Vijaya Kumar, 1987) that the flushing of effluents introduced into the inner harbour region can be expected to be faster during monsoon period than in the other seasons. Previous investigations on the distribution of phytoplankton (Ganapati and Murthy, 1953) off this coast indicated two maxima, an 'autumn' peak in November and 'spring' peak in April. But there was a tendency for a shift of these maxima in the inshore water and thus the high surface concentrations of phosphate during January might be due to phytoplankton blooms. The high concentrations of phosphate at bottom waters during the post monsoon season was apparently due to the regeneration from water column and sediments, owing to the steady, calm conditions of the sea during this period. The upward tilting of isolines in the distribution of phosphate during March (Fig.3b) also showed that the nutrient rich deeper waters reached the surface, and thus enriched the waters for phytoplankton growth. The present observations confirm the earlier report (Ganapati and Subba Rao, 1957) that upwelling affects the nearshore waters also on this coast.

Nitrate: The pattern of distribution of nitrate (Fig.2D) during the present investigation was more or less similar to that of phosphate although variations in magnitude occurred from season to season. The high concentration of nitrate observed during the southwest monsoon season (Jul-Aug) may be due to the flushing of pollutants from the harbour waters to nearshore waters. The increase in nitrate concentration in bottom waters during post monsoon season may be the result of intense regeneration processes. It is interesting to note that the ratio of N/P in these coastal waters was found to be less than 16 throughout the year. The low N/P ratio cannot be due to excess phosphate since the concentration of phosphate itself was low in these coastal waters. Riley (1967) suggested that the low ratio of N/P in coastal waters and estuaries may be due to slow rate of regeneration of nitrate compared to phosphate. N/P ratios between 5:1 and 8:1 are common in inshore waters (Steffansson and Richards, 1963; Pratt, 1965, Naqvi, De Souza and Reddy, 1978; DeSouza, Naqvi and Reddy, 1981) and the deficiency in the ratio of nitrogen to phosphate in many inshore areas indicates that nitrogen is the limiting nutrient for photosynthesis.

Silicate: The seasonal variation of silicate (Fig.2E) in these coastal waters was also somewhat similar with that of the other nutrients. The annual range of silicate was 2.5-30 $\mu mol.l^{-1}$. Ganapati and Murty (1953) found that the surface silicate concentration varied between 4.9 and 9.4 $\mu mol.l^{-1}$ and a general increase at all the depths with a maximum of

Table II – Correlation coefficients for various parameters

Interrelationship	South-West Monsoon season (June-Sept.)		Transition period (Oct.-Nov.)		North-East Monsoon season (Dec.-Feb.)		Premonsoon season (Mar.-May)	
	Surface water (upto 10m)	Bottom water	Surface water	Bottom water	Surface water	Bottom water	Surface water	Bottom water
PO_4-P-NO_3-N	0.3678^{x}	0.8995*	0.3936^{x}	0.9094^{+}	0.5011^{+}	0.7101*	$0.4822^{@}$	0.9275*
PO_4-P-SiO_4-Si	0.2817	0.5346^{x}	-0.0295	0.4143	0.1997	0.8066*	0.1596	0.5354^{+}
DO-Salinity	0.5108^{+}	0.2448	0.1754	-0.8920*	-0.6584*	-0.6723*	$-0.4238^{@}$	$-0.4753^{@}$
SiO_4-Si-Salinity	0.0402	0.5552^{x}	-0.0530	-0.2764	0.3679^{x}	0.5389^{+}	0.0538	-0.1715

Level of Significance: * 99.9%, + 99%, @ 95%, x 90%. All other values are not significant.

27.5 μ mol.l^{-1} at 60 m. Our present investigations revealed that the low concentrations of silicate (2.5-5.0 μ mol.l^{-1}) were present during Jul-Aug which agrees with the observations made by Rajendran, Rajagopal, and Reddy (1980). However, during the transition period from SW to NE monsoon high concentrations of silicate (10-15 μ mol.l^{-1}) were probably due to the transportation of silicate through northern diluted waters flowing towards south during this time. The more or less similar distribution in the surface concentrations of silicate during Sept-Jan indicate that it is not consistent with the peak observed during post monsoon season in the case of other nutrients. The maximum in the silicate concentration appearing during Mar-Apr was due to the upwelling of nutrient laden deeper waters.

Interrelationships: An attempt has been made to understand the relationship between the hydrochemical parameters both in the surface and bottom waters during different seasons. Correlation coefficients and level of significance are given in Table II. The results show that a significant correlation (90% level in surface waters and 99% level in bottom waters) existed between nitrate and phosphate both in surface and bottom waters. The correlation between phosphate and silicate at 99% significant level in bottom waters in pre- and post-monsoon seasons indicate the association of silicates with other nutrients in physical and biological processes occurring in these nearshore waters. Inverse correlation between dissolved oxygen and salinity was noticed during most of the year while the relationship between silicate and salinity was not at all significant.

Upward fluxes: As the flux and concentrations of plant nutrients are important factors in controlling the productivity of marine waters, calculations have been made for the upward fluxes of these nutrients viz., phosphate, nitrate and silicate.

Utilizing the vertical diffusion coefficients (Dz, Table I) and the observed gradients in the nutrient concentrations, the upward fluxes of all these nutrients in different months was calculated from the formula $J = Dz \cdot dc/dz$. During upwelling, the vertical mass transfer due to diffusion and convective processes was estimated by using the relation $J = Dz \cdot dc/dz + wc$ where w represents the rate of upwelling. The reported values (Narasimha Rao, Rao, Rao and Rama Raju, 1986) of upwelling speed (9.60×10^{-4} cm s^{-1}) during March and April and sinking speed (5.77×10^{-4} cm s^{-1}) for October and November were utilised in the flux calculations (Table I). The maximum fluxes of N, P, Si (613.4, 52.7, 734.4 μ mol. N/P/Si m^{-2}day^{-1} respectively) in the pre monsoon season indicated high productivity in these coastal waters as also evidenced from phytoplankton peak (Ganapati and Murty, 1953) and low fluxes (0.9; 0.06; 4.3 μ mol. N/P/Si m^{-2}day^{-1} respectively) during October and November indicate low productivity in the sinking period.

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