

STUDIES ON SOME HYDROGRAPHICAL CHARACTERISTICS OF THE ESTUARINE AND INSHORE WATERS OF GOA DURING THE SOUTH-WEST MONSOON 1972

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ABSTRACT

Various hydrographic parameters, namely, temperature, salinity, dissolved oxygen and inorganic phosphate were studied in the Mandovi and Zuari estuaries and in the inshore waters of Goa during the period July to October, 1972. Cold waters with temperatures as low as 21.1°C and dissolved oxygen content 0.11 ml/l were detected in the inshore region during this period. The presence of this cold and low oxygenated waters is thought to be due to the shoreward transport of the offshore upwelled water, by wind and coastal currents.

INTRODUCTION

The hydrography of the estuarine and inshore waters of Goa have been studied by various workers during different seasons (Dehadrai, 1970; Sankaranarayanan and Jayaraman, 1972; Singbal, 1973; Goswami and Singbal, 1974; Thomas Cherian, Rao and Varma, 1975; Varma, Rao and Thomas Cherian, 1975 and Singbal, 1976). The occurrence of upwelling along the west coast of India has been reported earlier by various workers (Ramasastry and Myrland, 1959; Banse, 1959, 1968 and 1972; Sharma, 1966 and 1968; Reddy and Sankaranarayanan, 1968). Sankaranarayanan and Jayaraman (1972) have reported the intrusion of upwelled water into the estuaries of Goa from the inshore region during the south-west monsoon. Dwivedi, Bhargava, Parulekar, Selvakumar, Singbal and Sankaranarayanan (1973) have reported on the ecology and other environmental data for the monsoon months of 1971. The present study is based on the detailed investigations on the physico-chemical parameters in Mandovi and Zuari estuaries and in the inshore regions of Goa during the south-west monsoon period of 1972 with time and space.

Mandovi and Zuari are the two major river systems opening into the sea along the Goa coast. Both these rivers have permanent connections with the sea and are joined at the upstream by a canal, Cumbarjua canal. The main area of investigation in both the rivers extends upto 10 km upstream from the mouth of the rivers. The station positions are shown in Fig. 1.

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MATERIAL AND METHODS

Detailed investigations on various hydrographical parameters, viz., temperature, salinity, dissolved oxygen and inorganic phosphate were made at 4 different stations in each estuary covering a distance of about 10 km from the mouth of the rivers, at weekly intervals during the period July to October, 1972. The observations were

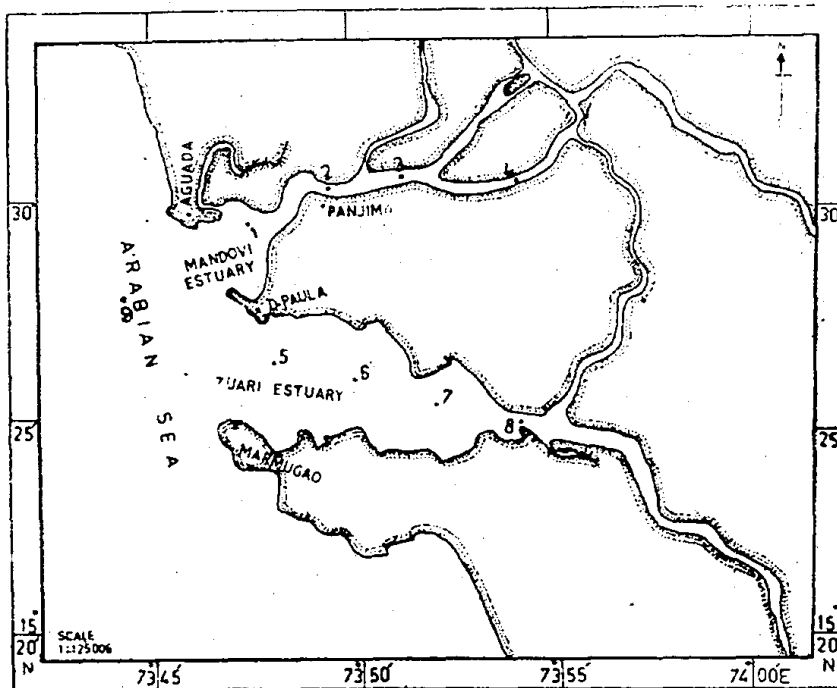


Fig. 1. Map showing station locations.

taken during the flood tide. Changes in various hydrographic parameters over a tidal cycle were also studied on a few occasions at one station (station 1). Due to restriction in movements of small boats the work could not be extended into the sea during the months of July and August. During the months of September and October the study was extended to the coastal waters upto a distance of about 15 km from the coast.

Water samples were collected using Nansen reversing water bottles. For the chemical analyses of the samples the procedure given in Strickland and Parsons (1968) was followed.

RESULTS

Temperature: The temperature distribution in Mandovi and Zuari estuaries at various stations are given in Fig. 2. The surface temperature variation in Mandovi (Fig. 2A) during the period under observation was between 24.6 and 28.9°C whereas the bottom temperature varied between 24.0 and 27.3°C. Vertical gradient is more in the month of August than in other months. The lowest temperature recorded at the surface as well as at the bottom was in the month of September. The variation in

temperature with depth is more pronounced at stations 1 and 2, which are closer to the river mouth but the general distribution pattern of temperature is more or less similar at all the stations. The surface and bottom temperature variations in the Zuari estuary were 28.0 and 31.0°C and 25.3 and 29.6°C respectively. The minimum temperature recorded was in the month of August. The variations are more pronounced at stations 5 and 6 which are closer to the river mouth. In general, the temperature at the surface as well as at the bottom are higher in Zuari than in Mandovi as reported by Dwivedi, Bhargava, Parulekar, Selvakumar, Singbal and Sankaranarayanan (1973).

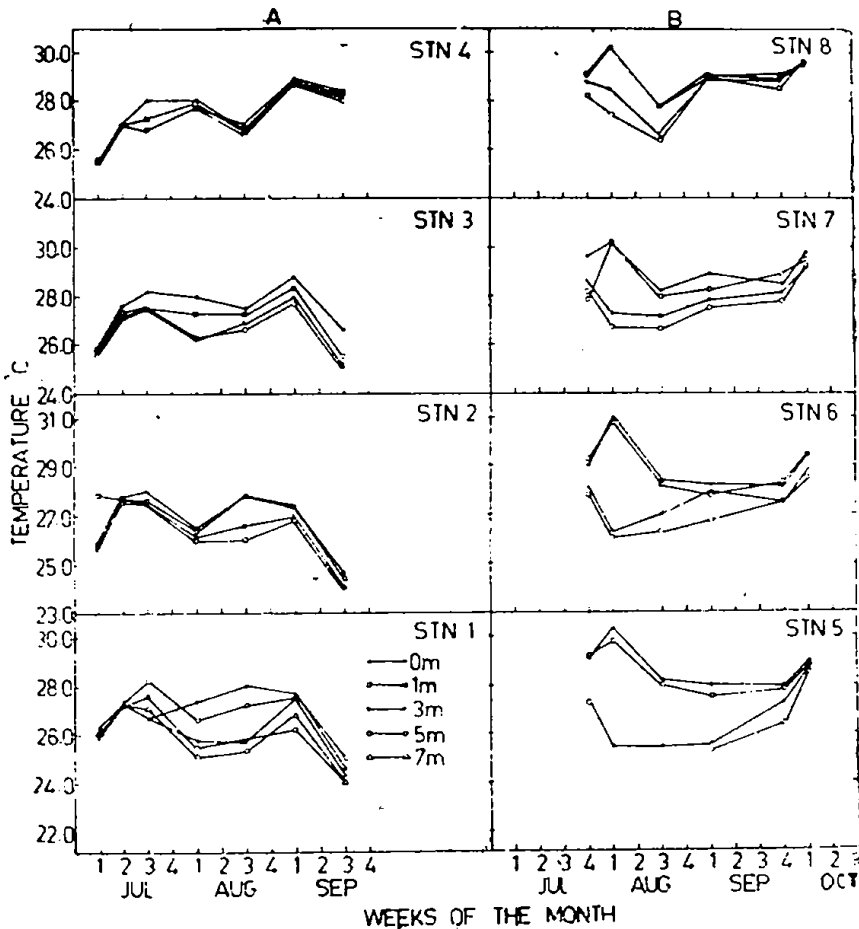


Fig. 2. Distribution of temperature at stations 1 to 8 of Mandovi and Zuari estuaries for the period of July-October.

Salinity: Fig. 3 shows the variation in salinity at different depths of various stations in Mandovi and Zuari. During this period the salinity conditions of the estuaries are subjected to very wide variations due to the fresh water runoff. In Mandovi (Fig. 3A) the surface and bottom values varied between 1.0 and 33.0‰ and 1.0 and 36.8‰ respectively. Generally, salinity values less than 1.0‰ were observed in the month of July. The estuary is highly stratified during this period with freshwater at the top and saline water at the bottom. At station 1, the salinity of the water below 5 m was always more than 30‰ during the months, August and September. At

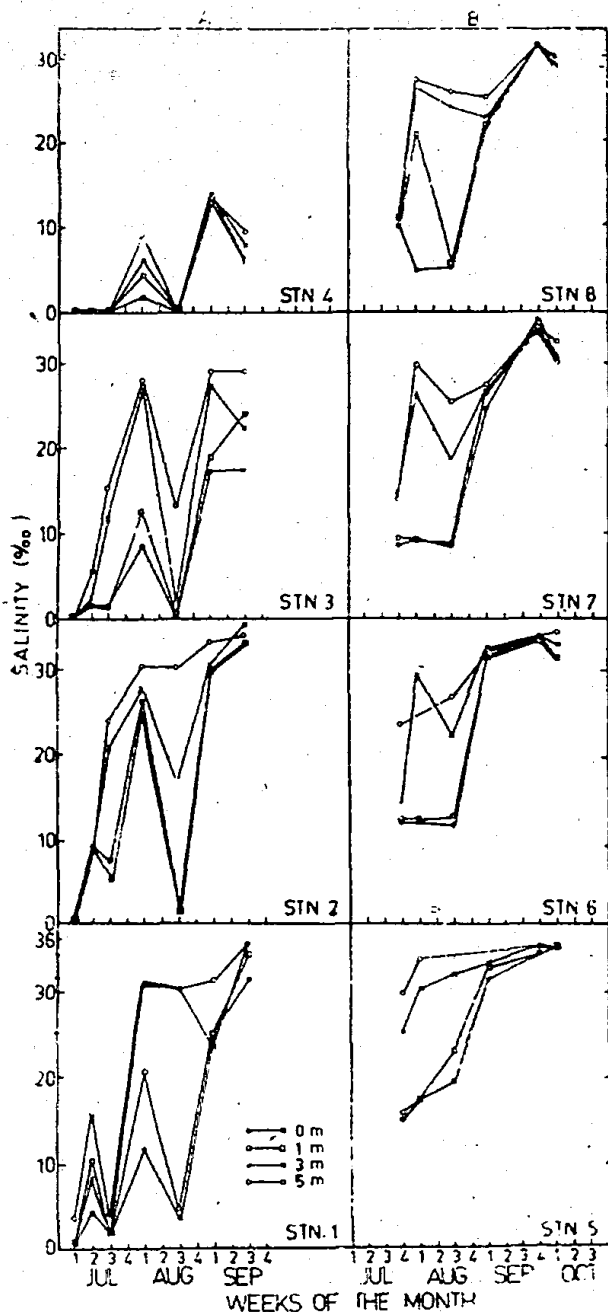


Fig. 3. Distribution of salinity at stations 1 to 8 of Mandovi and Zuari estuaries for the period of July-October.

Phosphate: The inorganic phosphate concentration at the surface layers do not show any definite pattern (Fig. 5) but at the subsurface-layers, the concentration levels show an increase from the middle of July and remains high till October in Mandovi (Fig. 5A). The surface and bottom values of phosphate varied between 0.1 and 1.9 $\mu\text{g-at/l}$ respectively. The subsurface phosphate concentrations remained high at all

other stations also, the fresh water influence is felt only in the surface layers, except in the month of July when the monsoon is very active and the river discharge is more or less similar to that of Mandovi but the vertical gradient is less during the months of September and October. In general, higher salinity values are encountered in Zuari than in Mandovi as reported by Dwivedi, Bhargava, Parulekar, Selvakumar, Singbal and Sankaranarayanan (1973).

Oxygen: Dissolved oxygen distribution in the Mandovi and Zuari is shown in Fig. 4. During the last week of July there is a drop in the oxygen values at the subsurface depths. Thereafter, the values show an upward trend till early September and fall during the last week (Fig. 4B) and these low oxygen values, especially at the subsurface depths persist till October. The surface and bottom oxygen concentrations in Mandovi (Fig. 4A) varied between 2.24 and 5.82 ml/l and 0.45 and 5.40 ml/l respectively. Low values were observed in the months of August and September. The low oxygen content is more pronounced at station 1, than at other stations. (In Zuari (Fig. 4B) the surface values varied between 1.75 and 5.30 ml/l whereas the bottom values varied from 1.30 to 5.0 ml/l.) The variations are more pronounced at station 5, which is closed to the mouth of the estuary.

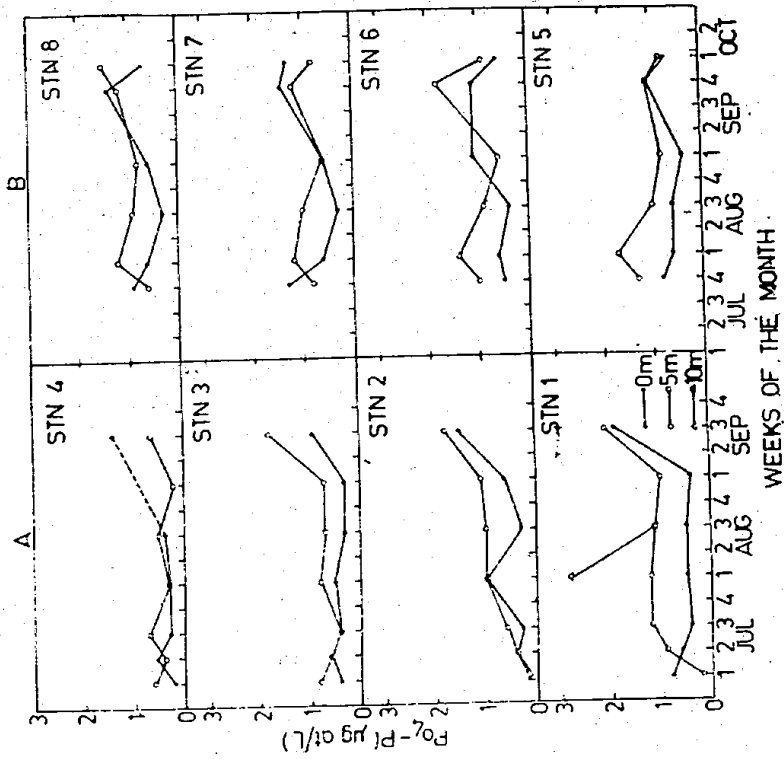


Fig. 5. Distribution of inorganic phosphate at stations 1 to 8 of Mandovi and Zuari estuaries for the period of July-October.

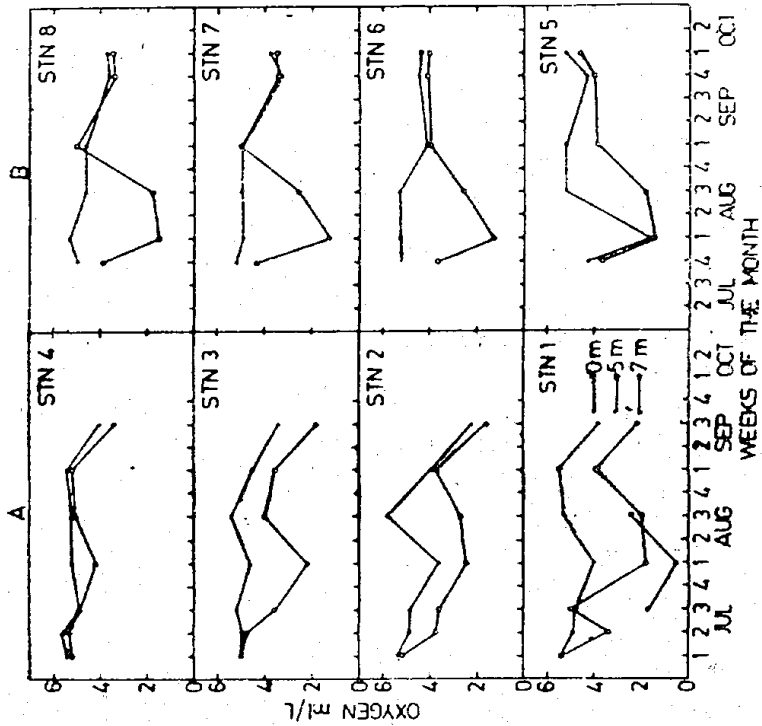


Fig. 4. Distribution of dissolved oxygen at stations 1 to 8 of Mandovi and Zuari estuaries for the period of July-October.

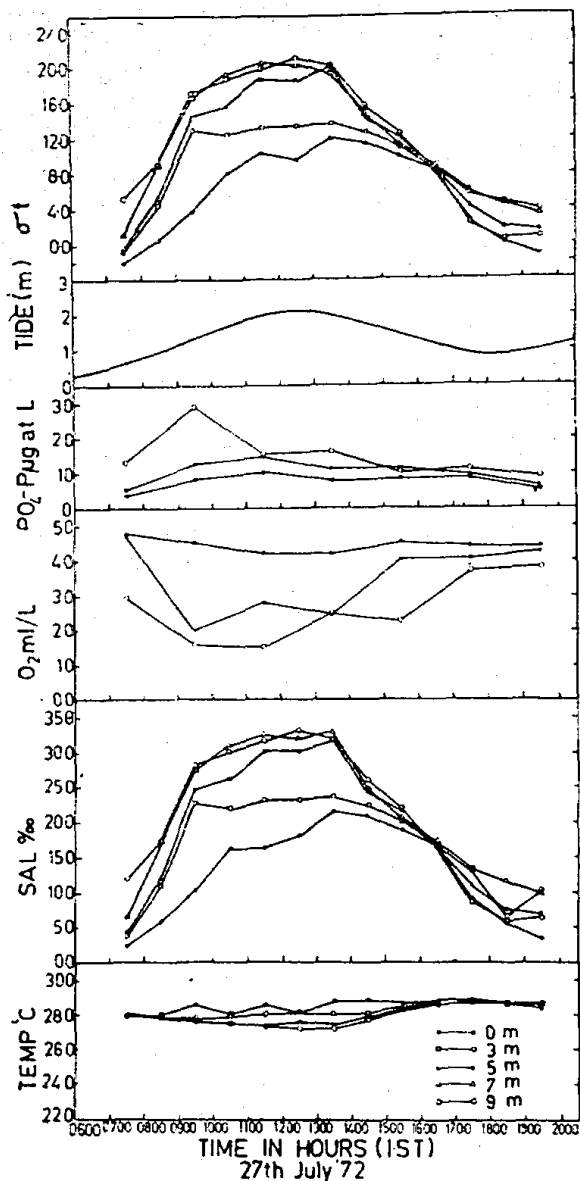


Fig. 6. Distribution of various parameters in relation to tide on 27th July 1972.

Rao and Thomas Cherian (1975) have also observed at the station near the mouth of the estuary larger tidal variations, with low temperature at the bottom during high tide, in the month of September.

The salinity variations at the surface and subsurface levels with tide were remarkably high during the months July and August, obviously due to the fresh water influx. The variation of salinity during the months July and August in relation to tidal currents were reported earlier by Antony, Rao and Sankaranarayanan (1974). But during the month of September, the variation is considerably less (15 and 35 ‰).

stations during the months of August and September. The phosphate content at the surface and the bottom showed a definite increase towards the mouth of the river. The distribution of phosphate in the Zuari river (Fig. 5B) also showed more or less the same trend. The maximum and minimum values at the surface were 1.4 and 0.3 $\mu\text{g-at/l}$ and at the bottom, 1.8 and 0.6 $\mu\text{g-at/l}$.

Distribution of parameters during tidal cycles

Variations of different physico-chemical parameters have been studied during different tidal cycles at station 1 during the months of July, August and September and are shown in Figs. 6, 7 and 8.

Observations taken during the tidal cycle on the 27th of July, 1972 (Fig. 6) do not indicate much variations in water temperature with tide. This may be due to the heavy fresh water discharge by the rivers, precipitation and overcast sky, whereas observations taken during the months of August and September (Figs. 7 and 8) showed wide temperature variations with change in tide. The surface and subsurface temperature showed lower values during the flood and higher values during the ebb. The minimum temperature is recorded one hour after the predicted flood maximum. Varma,

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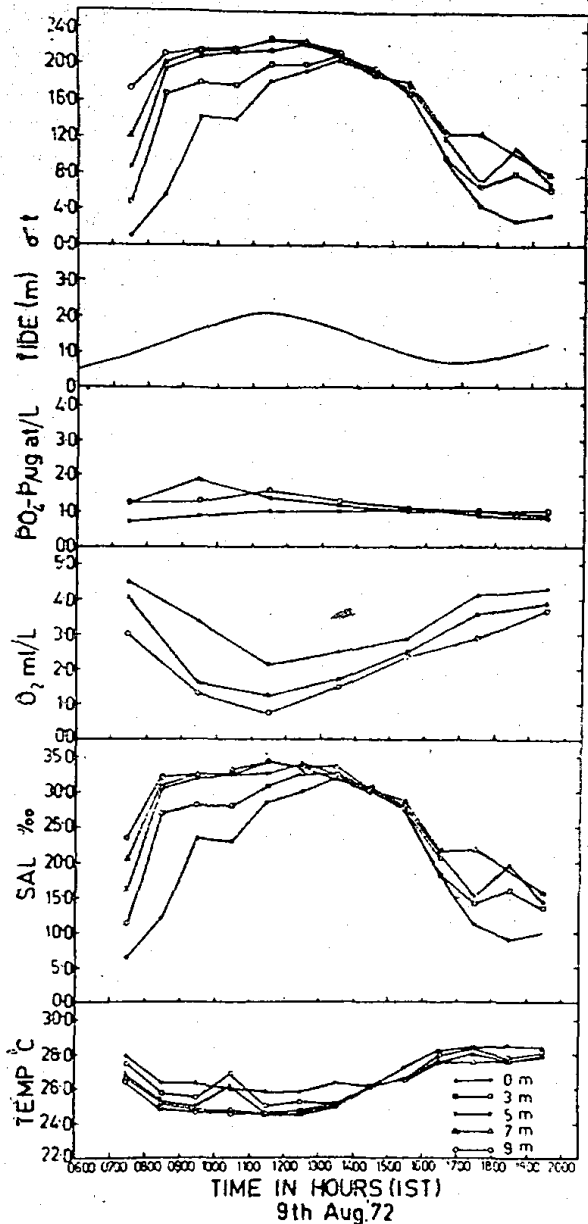


Fig. 7. Distribution of various parameters in relation to tide on 9th August, 1972.

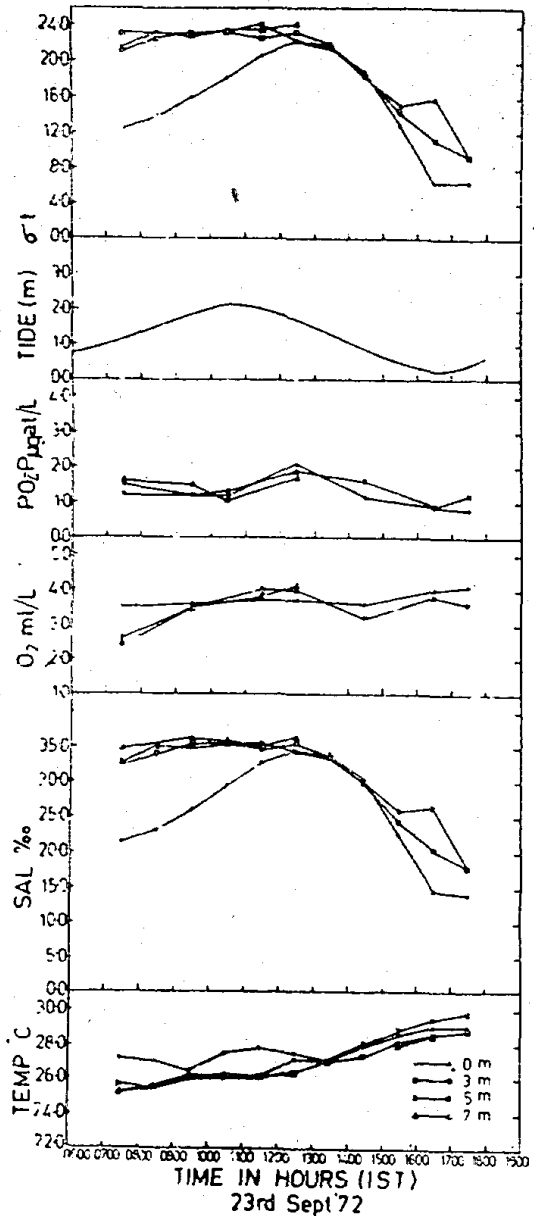


Fig. 8. Distribution of various parameters in relation to tide on 23rd September, 1972

The total rainfall for the month of September was 73 mm. Varma, Rao, Thomas Cheria (1975) observed a salinity variation between 10 and 35‰ at the mouth of the estuary in the month of September. The differences in the salinity variations could be attributed to the variation in the freshwater discharge. The estuary is well stratified during the flood tide and well mixed during ebb. The mixing is prominent when the ebb velocity is maximum.

In general, there is a reduction in the dissolved oxygen content at the surface and subsurface levels during the high water in all the three months, but with varying degrees. The oxygen values start increasing as the ebb flow begins.

Table I. Data on observations taken in the nearshore waters of Goa (station 9).

Date	Depths (m)	Temp. (°C)	Salinity (‰)	σ_t	Oxygen (ml/l)	PO ₄ -P ($\mu\text{g at/l}$)
21-9-1972	0	26.6	31.64	20.34	3.80	1.28
	3	24.3	35.78	24.23	3.36	—
	5	23.5	35.81	24.33	2.24	2.05
	10	22.6	36.06	24.88	0.50	1.90
26-9-1972	0	29.5	32.88	20.33	4.82	0.88
	3	27.7	33.24	22.20	5.04	—
	6	26.6	34.83	22.74	4.87	1.30
	9	25.8	35.00	23.25	3.55	—
	12	25.2	35.17	23.30	1.96	1.16
30-9-1972	0	28.8	31.11	19.24	5.32	0.56
	3	27.7	33.95	21.72	—	—
	5	25.7	33.95	22.36	5.04	0.67
	7	24.1	35.35	23.91	2.02	—
	11	23.0	35.35	24.22	0.89	1.19
30-9-1972	0	28.0	33.77	21.49	5.60	0.49
	3	25.8	33.40	21.91	4.82	—
	5	24.2	35.17	23.71	2.69	0.94
	10	23.6	35.17	23.90	3.14	0.98
	15	23.5	35.35	24.34	0.67	1.79
	17	22.6	35.35	24.36	0.11	1.82
5-10-1972	0	29.8	28.44	16.91	5.38	0.62
	3	28.2	32.70	20.88	4.42	—
	5	27.4	34.47	21.94	4.39	1.10
	7	26.6	34.47	22.61	4.48	—
	9	26.2	35.17	23.00	4.14	2.10

The inorganic phosphate concentrations also show a general increase at the surface and subsurface levels during the high tide. The values start increasing as the flood tide sets in and the values drop during the ebb flow. The vertical gradient diminishes due to mixing. High phosphate values generally coincided with the low oxygen values.

Some of the hydrographical observations made in the nearshore waters in the months of September and October are given in Table I. It is clear from the data that the inshore waters are comparatively cooler, poorly oxygenated and rich in inorganic phosphates with high density. Temperature at 10 m (bottom) during the last week of September was 22.58°C with salinity 36.06‰, σ_t 24.88 and oxygen 0.5 ml/l. By the first week of October this water starts losing its characteristics as could be seen from the table.

DISCUSSION

From the foregoing account, it is clear that the Mandovi and Zuari estuaries are subjected to wide range of variations, in physico-chemical conditions during

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Table II. Data on observations taken in the nearshore waters of Goa at different stations.

Date	Depths (m)	Temp. (°C)	Salinity (‰)	$\sigma-t$	Oxygen (ml/l)	PO ₄ -P (μ g at/l)
20-9-1973	0	23.0	35.26	24.25	4.59	3.22
1.6 km from the coast	3	22.3	35.44	24.49	1.57	5.22
	7	22.1	35.44	24.54	1.01	5.89
	0	23.8	35.62	24.19	3.58	2.56
5 km from the coast	2	23.7	35.44	24.08	3.02	2.82
	5	22.0	35.44	24.57	1.01	3.96
	10	21.6	35.44	24.68	0.67	3.42
	0	24.0	33.13	22.23	3.02	2.62
8 km from the coast	5	22.0	35.97	24.97	1.23	2.36
	10	21.5	36.15	25.25	0.67	2.64
	15	21.4	36.19	25.38	0.56	3.72
	0	28.5	33.66	21.20	4.73	0.77
29-9-1973	5	23.2	35.26	24.09	2.02	1.36
	10	22.2	35.26	24.38	1.01	—
	16	22.2	35.67	24.69	0.34	2.35
	0	28.0	29.74	18.74	4.09	0.32
8 km from the coast	5	24.2	34.96	23.57	2.35	1.24
	10	22.0	35.93	24.94	0.67	1.64
	19	21.7	35.93	25.03	0.11	2.60
	0	28.0	32.68	20.67	4.70	0.97
16 km from the coast	5	23.7	34.99	23.74	1.79	1.31
	10	21.6	35.73	24.90	0.67	1.34
	15	21.1	35.84	25.12	0.45	1.24
	23	21.1	35.84	25.12	0.22	1.41

the months of July to October. During the months of July to September, the freshwater flow through these rivers is maximum. The total rainfall for each month, June, July, August and September was 811, 598, 300 and 73 mm respectively. The current velocities are maximum during this period both at the surface and bottom and are of the order of 212 cm/sec and 160 cm/sec respectively during the ebb flow (Antony, Rao and Sankaranarayanan, 1974). This may be due to the larger fresh water flow. At the same time, the salinity variation at the bottom during the tidal cycle is significant (6.9-33.0‰) thereby indicating considerable influx of inshore waters into the estuary. The water temperature is low in July, August and September. The low surface temperature observed during this period may be due to less incident radiation by overcast sky and large amounts of fresh water discharge and also due to precipitation. The average rate of runoff from the Zuari for the period June to October was calculated as 9 km³ (Das, Murty and Varadachari, 1972). Lower temperature of the estuarine water observed during the flood tide during the months of August, September and October may be due to

the incursion of cold water from the sea. Varma, Rao and Thomas Cherian (1975) also observed lower temperature of the water with high tide. The high salinity, low oxygen and high phosphate values were observed in the estuary from the first week of August till the last week of September. The hydrographical data collected from the inshore regions (Tables I & II) during the months September and October also show low temperature, low oxygenated and high density water with the high phosphate content. Rama Sastry and Myrland (1959) have discussed upwelling off Cochin and farther south extending up to a distance of 100 km from the coast and water reaching the surface coming from depths of 50 and 75 m. Banse (1968) has described the presence of cool subsurface water on the shelf between Cochin and Karachi during the southwest monsoon and the regular upwelling to the surface up to 15°N more. Later Banse (1972) reported the upslope of isotherms and isopycnals off Goa coast before June. The data collected from the coastal region during the months of September and October clearly indicate the characteristics of upwelled water. The results from the estuarine region also indicate the presence of low temperature, low oxygenated water, especially during high tide from the first week of August. In the month of October, the cool, high density water is present below 10 m depth in the coastal regions, but is not detectable in the estuaries.

Though low temperatures were observed during early July, the data on salinity, oxygen and phosphate do not show the characteristics of the upwelled water. But the data collected in the months of August, September and October clearly show the presence of this water. According to Sharma (1968), the upwelling commences at deeper depths in the month of February and the upwelled water gradually reaches the surface layer by May and the cessation takes place by the end of July/August. But, from the present study in this region, the high density and low oxygen water is detectable by first week of August and continues to persist till early October.

This probably suggests that the process of upwelling starts in the southern regions earlier in the northern parts because of the early onset of the monsoonal winds in the southern regions. Therefore, the detection of upwelled water off Goa coast during August-October suggests the delay in the onset of the upwelling phenomenon in this area. The density of this water varies between 23.0 and 25.0 σ_t . This high density and poor oxygenated water indicates that this water comes from well below 100 m. The data collected from the Arabian Sea during *Darshak* cruise (1974) around 17°30'N, 71°30' E long during the month of May, indicates that 25.0 σ_t level is present at depths between 90 and 100 m. The presence of this water in the estuaries especially at the bottom is clearly felt during high water at Stations 1 and 2 in Mandovi and 5 and 6 in Zuari estuaries. This cold, low oxygenated high density water with high phosphate content loses its characteristics towards upstream and during ebb flow.

The large variations in temperature, salinity and oxygen observed during this period is expected to influence profoundly the flora and fauna of the estuaries, especially, the bottom communities. Oxygen levels less than 0.5 ml/l are encountered in the estuary on certain occasions.

The contribution of phosphorus through the river water is low as could be seen from the low surface values, especially, when fresh water discharge is at

maximum and also from the decreasing trend in the phosphorous levels upstream. The major source appears through local replenishment from the bottom mud and from the sea.

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REFERENCES

- Antony, M. K., D. P. Rao and V. N. Sankaranarayanan, 1974. Studies on the monsoonal flow of the Mandovi estuary. *Mahasagar - Bulletin of the National Institute of Oceanography*, 7(1&2): 69-72.
- Banse, K., 1959. On upwelling and bottom trawling off the south-west coast of India. *Journal of the Marine Biological Association of India*, 1(1): 33-49.
- Banse, K., 1968. Hydrography of the Arabian Sea shelf of India and Pakistan and effects on demersal fishes. *Deep Sea Research*, 15: 45-79
- Banse, K., 1972. Upsloping of isotherms on the continental shelf of Goa and Bombay in June 1972. *Journal of the Marine Biological Association of India*, 14(1):344-356.
- Das, P. K., C. S. Murty and V. V. R. Varadachari, 1972. Flow characteristics of Comburjua canal connecting Mandovi and Zuari estuaries. *Indian Journal of Marine Sciences*, 1(2): 95.
- Dehadrai, P. V., 1970. Changes in the environmental features of the Mandovi and Zuari estuaries in relation to tides. *Proceedings of the Indian Academy of Sciences*, 72(B): 68-80.
- Dwivedi, S.N., R. M. S, Bhargava, A.H. Parulekar, R. A. Selvakumar, S. Y. S. Singbal and V.N. Sankaranarayanan. 1973. Ecology and environmental monitoring of Mandovi, Zuari and Comburjua canal complex during monsoon months. *Journal of Indian Fisheries Association*, 3: 113-130.
- Goswami, S. C. and S. Y. S. Singbal, 1974. Ecology of Mandovi and Zuari : Plankton community in relation to hydrographic conditions during monsoon months, 1972. *Indian Journal of Fisheries*, 3: 51-57.
- Rama Sastry, A. A. and P. Myrland, 1959. Distribution of temperature, salinity and density in the Arabian Sea along south Malabar coast (south India) during the post-monsoon season. *Indian Journal of Fisheries*, 6(2): 233-255.
- Reddy, C. V. G. and V. N. Sankaranarayanan 1968. Distribution of nutrients in the shelf waters of Arabian Sea along the west coast of India. *Bulletin of the National Institute of Sciences of India*, 38(II): 206-220.
- Sankaranarayanan, V. N. and R. Jayaraman, 1972. Intrusion of upwelled water in Mandovi and Zuari estuaries. *Current Science*, 41(6): 204-206.
- Sharma, G. S., 1966. Thermocline as an indicator of upwelling. *Journal of the Marine Biological Association of India*, 8: 8-19.
- Sharma, G. S., 1968. Seasonal variation of some hydrographic properties of the shelf waters off the west coast of India. *Bulletin of the National Institute of Sciences of India*, 38(1): 263-276.

- Singbal, S. Y. S., 1973. Diurnal variation of some physico-chemical factors in the Zuari estuary of Goa. *Indian Journal of Marine Sciences*, 2: 90-93.
- Singbal, S. Y. S., 1976. Diurnal variation of some physico-chemical factors in the Mandovi estuary of Goa. *Bulletin of the National Institute of Oceanography*, 9(1 & 2): 27-34.
- Strickland, J. D. H. and T. R. Parsons, 1968. A manual of sea water analysis. *Bulletin of the Fisheries Research Board of Canada*, 167, 311 pp.
- Thomas Cherian, L. V. Gangadhara Rao and K. K. Varma, 1975. Variations in physical characteristics of the waters of Zuari estuary. *Indian Journal of Marine Sciences*, 4 : 8-10.
- Varma, K. K., L. V. Gangadhara Rao and Thomas Cherian, 1975. Temporal variations in hydrographic conditions of Mandovi estuary. *Indian Journal of Marine Sciences*, 4: 11-17.