

**POLLUTION ASSESSMENT AND FLUSHING CHARACTERISTICS
OF MINDHOLA RIVER ESTUARY**

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Major pollution loads entering the Mindhola River estuary were quantified. Apart from BOD, the other pollutants were within permissible limits. High seawater influx, strong tidal currents and small low tide volume rendered the estuary generally well mixed with good flushing characteristics. After a large number of tidal cycles, the wastewater load retained in the estuary was estimated to be 8 times the load introduced per tidal cycle. The maximum intrusion of seawater was upto 25 km inland during spring tide in April. Although spring tidal range of 1.9 m was observed at 32 km from the estuary mouth, there was no intrusion of salinity at this location. The particulate matter in the estuary which was high and variable, increased as the current speed increased. The trend of decrease of dissolved oxygen as the ebb commenced was probably due to the high BOD released through the Udhna creek. The levels of dissolved Cu, Zn and Pb were relatively high around the confluence point of the Udhna creek and the Mindhola estuary.

Studies of Damanganga (Zingde et al., 1980a), Kolak (Zingde et al., 1980b), Par (Zingde et al., 1979), Ambika (Zingde et al., 1986), Auranga (Zingde et al., 1985), Narmada (Zingde et al., 1981) and Purna (Zingde et al., 1987) River estuaries - all in Gujarat, have revealed considerable deterioration of water quality of the first four estuaries. A comparative study of the estuaries of Gujarat has revealed relatively low mean biomass of zooplankton in the Mindhola River estuary and the chaetognaths which are sensitive

to environmental changes are very poorly represented (Nair et al., 1981). Although this has been attributed to pollution, little is known about the nature of pollutants entering the receiving water and their impact on the water quality. Other studies undertaken in the Mindhola estuary are the behaviour of B, Ca and Mg (Narvekar et al., 1981) and uranium series disequilibrium (Joshi et al., 1983). This paper reports the nature of pollutants entering the water body, their impact on the water quality and the flushing characteristics of the estuary.

MATERIALS AND METHODS

Mindhola River which is narrow and shallow broadens into a wide estuary influenced by the semidiurnal tides. The estuarine region has extensive sand banks and mud flats which get submerged during the high tide. The system is a multifold complex composed of the river, streams, creeks and an extensive area under the tidal influence. The network of tributaries which are periodically filled with tidal water harbour a variety of edible mudskippers, crabs, mullets, prawns etc. The intertidal region which is generally muddy supports a rich growth of *Typha* and other plants (Grasses, solanaceae) except in the mouth region where no vegetation except for the halophytes is seen.

The riverine flow which is high during July-August under the influence of south-west monsoons decreases considerably over the dry period and is minimum during May-June.

Neap and spring tide observations at 14 stations along a 30 km stretch (Fig. 1) of the estuary were undertaken during 1978-80. High and low tide samples were collected from all the stations in the tidal zone. The freshwater was sampled at st 15 which was well beyond the influence of seawater penetration although some tidal fluctuations occurred during springs. The time series studies of some physico-chemical parameters over complete tidal cycles were also undertaken at sts 1, 12 and 14 normally during neaps and springs. As no information on tides was available, the water level changes were also simultaneously measured at these stations. Currents across the cross-section upstream of st 15 were measured over 24 h during neap tides to calculate the river discharge. Currents were also measured at sts 1 and 12.

Pollution assessment of river estuary

A polythene bucket was used for obtaining the surface water samples while. Niskin sampler was employed to collect sub-surface samples. Chlorinity was determined by argentometric titration while DO, BOD, NO_2^- -N, NO_3^- -N, NH_4^+ -N and PO_4^{3-} -P were estimated by standard procedures (Carlberg, 1974, APHA, 1976). Dissolved Cu, Zn and Pb were estimated by AAS (Hilger Watts Atomspek Model H 1550) after pre-concentration.

Major streams bringing wastewater to the estuary were sampled at locations I, II and III marked in Fig. 1 and analysed by standard procedures. For the estimation of Cu, Zn and Pb in wastewater, the sample was preconcentrated by evaporation in presence of concentrated HNO_3 and HCl prior to aspiration in the flame of AAS (FAO, 1975).

RESULTS AND DISCUSSION

Wastewater discharges - Several dyeing and printing, fertilizer, rayon, paper and pulp, pharmaceutical, chemical and textile industries released wastewater generally untreated, into the Bhedwad and Kakra creeks. These two join Udhna creek which carries the load to the Mindhola River estuary near Budia about 10 km upstream from the mouth. The Udhna creek was sampled periodically at location I and results are given in Table 1. The sampling was done to coincide with the neap tide and prior to the commencement of flood in the estuary to minimize the influence of tides. The data obtained during September have not been considered in Table 1 because of some monsoonal freshwater run off. Except for BOD, all other parameters were within the range allowable for release in marine coastal areas (IS: 7968, 1976).

The wastewater ($1.2 \times 10^6 \text{ l day}^{-1}$) from a sugar factory having an average BOD of 130 mg l^{-1} was released through a natural stormwater drain at location II. A group of industries mainly comprising of dyes and pigments, textiles, paper and pulp located at Balesar released the wastewater to a nearby creek which carried the waste to the Mindhola River. This creek was sampled at location III.

Tides and currents - Similar to the other estuaries of Gujarat (Zingde et al., 1977), Mindhola River estuary was under considerable tidal influence with the springs at the mouth (5.5 m) decreasing to 1.9 m at st 14, 32

km inland. The flood period decreased from 4-5 h at the mouth to 2-3 h at st 14 with the ebb extended over a period of 7-10 h (Table 2).

High tidal influence generated strong currents with the maximum current speed exceeding 0.8 m sec^{-1} at st 1 during neaps. The nature of the current profile (Fig. 2) did not vary appreciably at the bottom though the speed was marginally lower particularly during September (Fig. 3). The overall current speed was substantially higher during September and the bimodal pattern (during one tidal cycle) observed during April was absent because of the influence of substantial riverine flow.

Tidal excursion - Tidal excursion was calculated from the plot of the cumulative segment volume against the distance (Fig. 4) by estimating the horizontal distance between low tide and high tide curves (HMS, 1964). The excursion length during springs decreased from 17 km at the mouth to 12 km at Budia where the Udhna creek meets the Mindhola estuary. During neaps the respective distances were 11 and 8 km. Hence, the substantial fraction of pollutants transported through Udhna creek during the ebb tide would be flushed to the sea. However, a portion of the waste water would be carried at least 8 km upstream from the point of release during flood which though would be considerably diluted during its upstream transport, would not be completely flushed out during the following ebb.

The excursion lengths of 3-5 km at st 12 and beyond indicated the possibility of accumulation of wastewater in the inner estuary during periods of weak riverine flow.

Seawater incursion - The intrusion and distribution of seawater in the estuary varied considerably depending on the tidal stage and the period of measurement. The maximum incursion was upto 25 km inland during spring tide in April (lean period of freshwater flow) (Fig. 5) and decreased to 15 km during September (period of appreciable freshwater run off). The estuary was generally well mixed vertically though salinity gradient of 2-4‰ was occasionally observed particularly during neap tides in November-April. Marked salinity gradient however was observed in the mouth region during September specially during flood (Fig. 3). Although spring tidal range of 1.9 m was recorded at st 14 (32 km inland), there was no incursion

Pollution assessment of river estuary

Table 1. Physico-chemical Characteristics (mean) of Effluents.

Parameter (mg l^{-1})	I	II	III
Flow ($\times 10^6 \text{ l day}^{-1}$)	95	1.2	33
Suspended solids	323	280	169
Total dissolved solids	338	0.6	0.06
pH	6.2	6.7	6.0
BOD	136	130	89
COD	273	409	-
Total phosphorus	2.8	0.4	0.12
Total nitrogen	7.2	0.3	0.1
Phenolics	6	0.1	0.1
Oil & grease	781	0.5	0.2
Copper	0.1	0.03	0.04
Zinc	0.3	0.04	0.08
Lead	0.1	-	-

Table 2. Tidal and Current Speed Data for Mindhola River Estuary

Parameter	Station		
	1	12	14
Spring tidal range (m)	5.5	3.0	1.9
Neap tidal range (m)	2.5	1.0	0.5
Average flood period (h)	4 to 5	3 to 4	2 to 3
Average ebb period (h)	7 to 8	8 to 9	9 to 10
High tide time lag* (h)	-	1 to 2	2 to 3
Max. Current Speed (m sec ⁻¹)			
Spring (surface)	1.9	0.6	-
(bottom)	1.7	0.6	-
Neap (surface)	1.0	0.4	-
(bottom)	0.8	0.3	-

*Compared with st 1

Pollution assessment of river estuary

Table 3 - Flushing Time of Mindhola River Estuary Calculated from Salinity Distribution

Segment	Tide	Salinity ($\times 10^{-3}$)		Salinity downstream ($\times 10^{-3}$)	Volume ($\times 10^6 \text{ m}^3$)	Volume down- stream ($\times 10^6 \text{ m}^3$)	Volume of freshwater ($\times 10^6 \text{ m}^3$)		Flushing time (tidal cycles)		
		Nov	Apr				Nov	Apr	Nov	Apr	
C ₀ - C ₁	High	28.5	29.3	28.5	29.3	17.858	17.858	1.70	1.62	0.7	1.5
C ₁ - C ₂	High	25.2	25.6	27.92	28.65	21.650	21.650	2.46	2.39	1.1	2.2
C ₂ - C ₃	High	10.3	11.4	24.41	25.22	27.034	27.034	6.09	5.86	2.6	5.3
C ₃ - C ₄	High	0.13	0.4	22.04	24.21	29.957	29.957	9.08	7.44	3.9	6.7
C ₄ - C ₅	High	0.04	0.04	-	23.14	31.264	31.264	-	8.80	-	8.0
C ₀ - C ₁	Low	6.4	9.2	6.4	9.2	3.198	3.198	2.55	2.29	1.3	2.1
C ₁ - C ₂	Low	2.2	4.3	5.8	8.76	3.722	3.722	3.04	2.71	1.6	2.5
C ₂ - C ₃	Low	0.8	2.3	4.4	6.53	5.684	5.684	4.55	4.53	2.6	4.1
C ₃ - C ₄	Low	0.04	0.15	3.4	5.15	7.256	7.256	6.13	6.09	3.4	5.5
C ₄ - C ₅	Low	-	0.04	-	4.66	8.012	8.012	-	6.86	-	6.2

Riverine freshwater flow per tide cycle was: $\bullet 1.9 \times 10^6 \text{ m}^3$ and $\blacktriangledown 1.1 \times 10^6 \text{ m}^3$.

Zingde et al.

Table 4. Dissolved Trace Metals ($\mu\text{g l}^{-1}$) in Mindhola River Estuary.

Station	Salinity (o/oo)	Cu	Zn	Pb
1	33.8	7.8	13	ND*
	17.3	5.2	10	3.5
	6.3	7.5	12	3.2
6	15.6	5.9	16	6.6
	9.2	12.2	28	6.8
	0.3	15.9	48	4.7
12	6.1	6.8	9	ND
	0.8	9.4	7	ND
	0.1	6.9	12	5.7
14	0.06	4.9	6	ND
15	0.05	3.1	10	2.7

* Not detectable.

Pollution assessment of river estuary

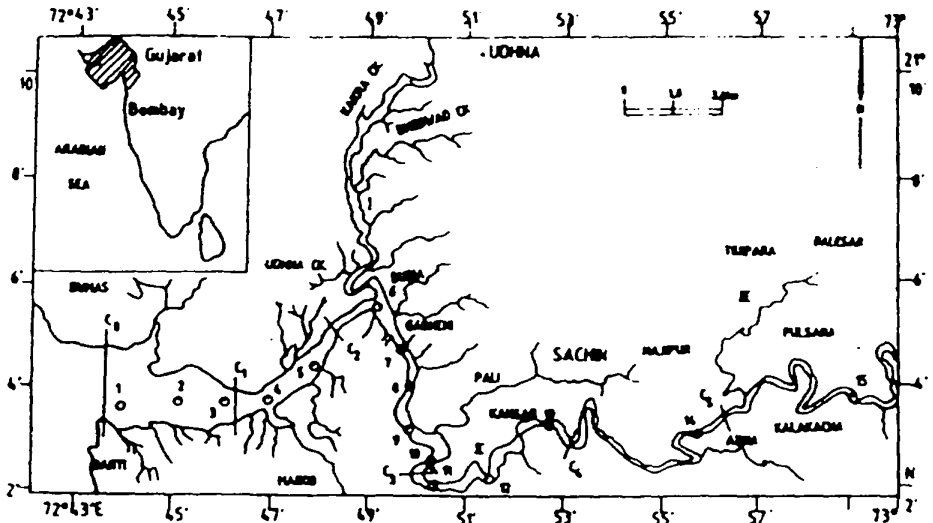


Fig. 1 Sampling locations in Mindhola River estuary.

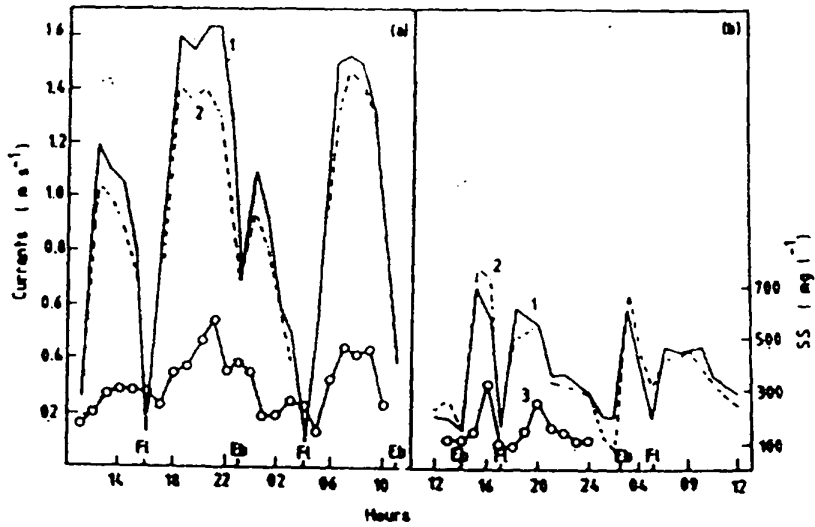


Fig.2. Variation of suspended solids(3) and current speed at the surface (1) and at the bottom (2) with time on 13-14 April 1979 at (a) st 1, and (b) st 12.

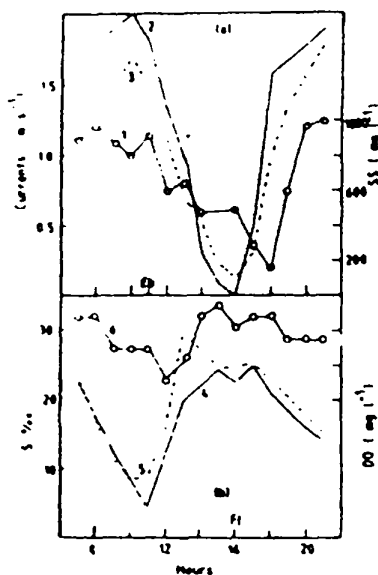


Fig.3. Temporal changes of some physico-chemical parameters at st 1 on 23 September 1979; (a) current speed : surface (2) and bottom (3) and suspended solids (1); (b) salinity: surface (4) and bottom (5) and DO (6).

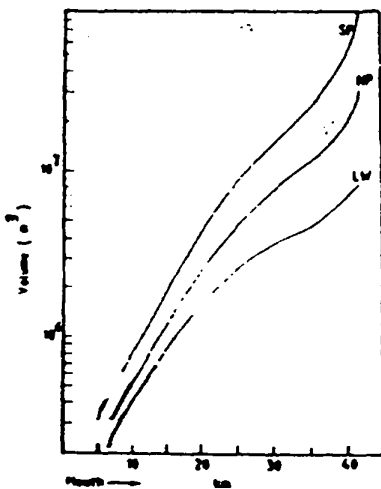


Fig.4. Volume of water in the estuary under different tidal conditions. LW - low water; NP - neap flood; SP - spring flood.

Pollution assessment of river estuary

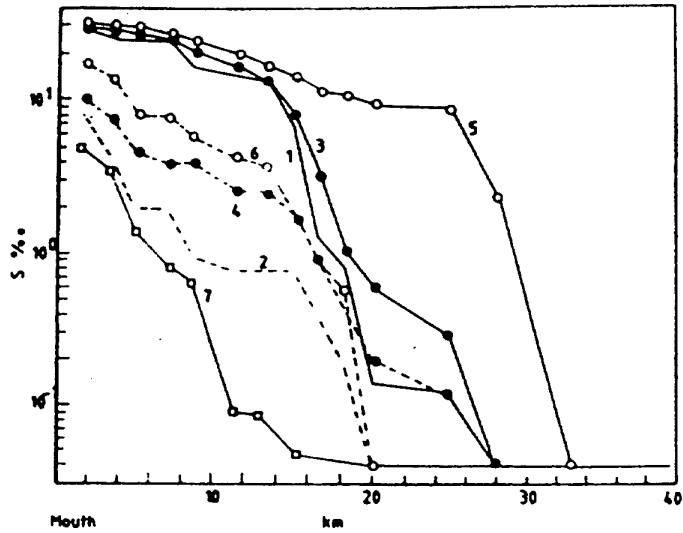


Fig. 5. Salinity during high tide (1) and low tide (2) on 21-22 November 1978; high tide (3) and low tide (4) on 5-6 April 1979; high tide (5) and low tide (6) on 13-14 April 1979; low tide (7) on 25 September 1979.

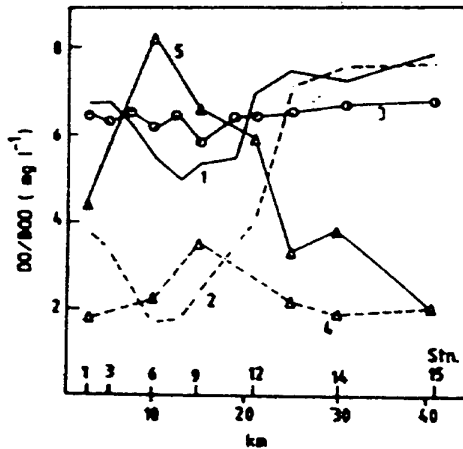


Fig. 6. DO during high tide (1) and low tide (2) in April and during high tide (3) in September and BOD during high tide (4) and low tide (5) in April.

Zingde et al.

of seawater at this location (Fig. 5) and the rise in water level was due to the piling of freshwater as the tidal front advanced through the estuary. This has been observed in many estuaries of Gujarat. Even at st 12 (20 km inland), the seawater content was less than 3% during neap flood and increased to 30% during spring flood in April. The seawater component was less than 10% during spring flood at this location in November.

Flushing characteristics - The tidal prism for the Mindhola River estuary was estimated at $23.2 \times 10^6 \text{ m}^3$ and $83.9 \times 10^6 \text{ m}^3$ during neap and spring respectively with the average low tide volume of $8.0 \times 10^6 \text{ m}^3$. The application of tidal prism method (Dyer, 1973) gave a flushing time of just about one tidal cycle. The fraction of well mixed water removed from the estuary was then calculated to be 74 and 90% during neap and spring respectively. After an infinite number of tidal cycles under a continuous flow of pollutants in the estuary, the load fraction L calculated by using the relation.

$$L = \frac{y}{1-y}$$

worked out to be only 0.35 and 0.1 during neap and spring respectively (y being the fraction remaining after one tidal cycle).

The flushing time was also calculated by using the fraction of freshwater method. The freshwater fraction f at any point in the estuary can be calculated from the relation

$$f = \frac{S_0 - S}{S_0}$$

where S_0 is the salinity of water outside the estuary and S is the salinity at a given point in the estuary. The total volume of freshwater F accumulated in the estuary is

$$F = f \int d(\text{volume})$$

integrated over the total volume. If steady state is assumed then

$$t = \frac{F}{R}$$

where t is the flushing time and R is the river discharge per tidal cycle.

Pollution assessment of river estuary

The results summarized in Table 3 were obtained during neap tide and close enough to the time of either high or low water so that no substantial volume error was introduced in the calculations. Comparison of the value obtained by the tidal prism method with Table 3 showed that the assumption of complete mixing made in the former led to the flushing time which was lower than obtained from the observed distribution of salinity.

$$\text{Since } r = \frac{1}{T} \text{ and } L = \left(\frac{1}{T}\right) - 1$$

where r is the exchange ratio, the load retained after a large number of tidal cycles under a continuous flow of pollutants would be 2.2 to 7.3 times the load introduced per tide cycle.

Suspended solids - The suspended load entering the estuarine complex through river discharge at st 15 was below 160 mg l^{-1} . There was marked increase in the estuarine zone and the concentration was widely variable. The tidal dependance of particulate matter with increase with the current speed is evident from Figs. 2 and 3. This is typical of the estuaries of Gujarat region which are shallow with the bottom material generally composed of clay and fine sand.

Combined solids released through the wastewater amounted to about $36,000 \text{ kg day}^{-1}$ out of which $31,000 \text{ kg day}^{-1}$ is contributed by Udhna creek. Though the load is high it is not likely to influence the background levels appreciably.

DO and BOD - The Mindhola estuary was subjected to substantial pollution due to the high organic load associated with the wastewater discharges. Out of the total BOD of $16,000 \text{ kg day}^{-1}$, nearly $13,000 \text{ kg day}^{-1}$ was transported through Udhna creek. The organic load influenced the oxygen balance in the estuary. There was a general tendency for DO to decrease with the ebb even during September (Fig. 3) and values around 2 mg l^{-1} were observed during April between sts 6 and 9 (Fig. 6). The BOD during low tide revealed marked increase throughout the estuary with high values between sts 6 and 9 (Fig. 6).

Zingde et al.

Inorganic nutrients and trace metals - Diurnal measurements of nutrients undertaken at sts 1, 12, 14 and 15 did not reveal any systematic variations. The mean monthly concentrations varied in the following ranges : $\text{PO}_4^{3-}\text{-P}$ (1.1-3.7 $\mu\text{g-at l}^{-1}$), $\text{NO}_3^- \text{-N}$ (7.9-19.9 $\mu\text{g-at l}^{-1}$), $\text{NO}_2^- \text{-N}$ (0.5-10.0 $\mu\text{g-at l}^{-1}$) and $\text{NH}_4^+ \text{-N}$ (0.4-12.0 $\mu\text{g-at l}^{-1}$). Except for $\text{NH}_4^+ \text{-N}$ which was often high and varied widely in the estuary, the concentrations of others were within the range observed for unpolluted estuaries of the region (Zingde et al., 1981 and Zingde et al., 1987). From the levels of $\text{NO}_3^- \text{-N}$ and $\text{PO}_4^{3-}\text{-P}$, it appeared that $\text{NO}_3^- \text{-N}$ was the growth limiting factor in the estuary.

Dissolved Cu and Zn revealed increase in concentration with decrease in salinity (Table 4) because of the greater impact of wastewater during low tides when the estuary volume decreased at least by 75% of the high tide value.

REFERENCES

- Carlberg, R. 1972 : New Baltic Manual, Cooperative Research Report Series A, No. 29 (International Council for the Exploration of the sea, Denmark), pp. 144.
- Dyer, K.R. 1973 : Estuaries : a physical introduction, (John Wiley, London), pp. 140.
- Effects of pollution discharges on the Thames estuary, 1964: (Her Majesty's Stationary Office, London), 4.
- Joshi, L.U., Zingde, M.D. and Desai, B.N. 1983 : J. Radional Chem., 76, 99.
- Manual of methods in aquatic environment research, Part I, 1975 : Methods of detection, measurement and monitoring of water pollution, (FAO, Rome), 212.
- Nair, V.R., Gajbhiye, S.N., Jiyalal Ram and Desai, B.N. 1981 : Indian J. Mar. Sci., 10, 90.
- Narvekar, P.V., Zingde, M.D. and Kamat Dalal, V.N. 1981: Indian J. Mar Sci., 10, 90.

Pollution assessment of river estuary

- Standard methods for the examination of water and waste-water. (APHA, Washington, DC), 1976: pp. 1193.
- Zingde, M.D., Narvekar, P.V., Sarma, R.V. and Desai, B.N. 1980 : Indian J. Mar. Sci., 9, 94.
- Zingde, M.D., Sabnis, M.M., Mandalia, A.V. and Desai, B.N. 1980 : Mahasagar - Bull. Natn. Inst. Oceanogr., 13, 99.
- Zingde, M.D., Sarma, R.V. and Desai, B.N. 1979 : Indian J. Mar. Sci., 8, 266.
- Zingde, M.D., Narvekar, P.V. Sarma, R.V. and Sabnis, M.M. 1986 : Mar. Pollut. Bull., 17, 267.
- Zingde, M.D., Sharma, P. and Sabnis, M.M. 1985 : Mahasagar-Bull. Natn. Inst. Oceanogr., 18, 307.
- Zingde, M.D., Chander, S. and Desai, B.N. 1981 : Indian J. Mar. Sci., 16, 161.
- Zingde, M.D., Mandalia, A.V. and Rokade, M.A. 1987 : Indian J. Mar. Sci., 16, 94.