

## Hydrography & Suspended Sediment Load of Oceanic & Estuarine Waters Adjoining Mormugao Harbour during Early Summer

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With the data on some physical parameters collected during March 1972 from a number of stations along 3 sections in and around Mormugao Harbour, a comparative study of the hydrographical conditions and suspended sediment load in the sea adjoining the harbour with those in the harbour bay has been made. The waters in the bay are slightly warmer (30°C) compared to those in the sea around the harbour (28%). While the salinity of waters in the nearby sea is around 34.5‰, no significant reduction in salinity is observed towards the head of the bay due to thorough mixing of waters resulting from intense tidal action and negligible run off. Waters in the sea off Pikene Island appear to be less stable than those off the bay mouth, while in the bay the density of waters decreases gradually from the mouth towards upstream. The sediment load of the waters in the sea adjoining the harbour is less than 15 mg/litre, whereas its value generally varies between 20 and 100 mg/litre in the bay waters. Waters in upper layers of the sea off the harbour are fairly transparent (extinction coeff.,  $k < 0.85$ ) compared to those in the bay, where the turbidity of surface waters increases gradually towards the head (to  $k > 2.8$ ). Surface currents off the Pikene Island are faster compared to those off the bay mouth and further off-shore (beyond 15 fm line) the influence of seasonal southerly current is encountered.

ONE of the best natural harbours on the west coast of India is the Port of Mormugao situated at the southern side of the mouth of Mormugao Bay, into which the river Zuari opens. This port is being developed as a major port in view of its importance in the export of iron ore available locally. In order to understand the processes of siltation in the harbour bay and to obtain the information useful for planning the port development programmes and subsequent maintenance works associated with deepening of the harbour channels, construction of additional breakwater, etc., the Institute has undertaken comprehensive investigations on the hydrography, circulation and sediment load of the waters of Mormugao Bay.

Because of the significant location of this harbour in an area dominated by periodic tidal exchanges of oceanic and estuarine waters, a comparative study of the hydrographical features and suspended sediment load of the sea waters adjoining the harbour with those of the estuarine waters in the harbour bay would be very useful in understanding the physical conditions of the harbour waters and their seasonal variations. Results of the observational programme for such a study carried out during March 1972 are presented in this paper.

### Materials and Methods

March was chosen for these studies because it characterizes the conditions of premonsoon during which the waters in the harbour bay and the adjoining sea are least affected by the river discharge and land drainage. A special cruise was carried out for these studies on board a medium sized vessel *Arjun Prasad* on 10 Mar. 1972 in the sea off Mormugao. During this cruise, two latitudinal sections (one off the harbour bay and

the other at about 4 miles south) each comprising 3 stations and extending up to about 8 miles westward from the 6 fm line (sections I and II; Fig.) were worked out. Two cruises were carried out in the Mormugao Bay on board a mechanized boat, one during ebb (16 Mar. 1972) and the other during flood (21 Mar. 1972), each covering a section of 6 stations located along the axis of the bay from the mouth to the head (section III; Fig. 1). The cruises in the harbour bay were conducted during the period of fairly high tidal ranges (range greater than 1.5 m) in order to obtain extreme conditions in the bay, while the cruise in the adjoining sea was carried out during the period of weak or negligible tidal influence to get a general picture of physical conditions in the sea.

The location of stations along the sections covered in the cruises are shown in Fig. 1. At each of the stations located outside the harbour bay, the boat was anchored and the bathythermograph and the Nansen cast were operated and the currents were measured employing an Ekman current meter. Observations at the stations located in the harbour bay were, however, limited to obtaining temperature and water samples of the surface, middle and bottom waters, in view of the shallow depths encountered in the bay. A bucket thermometer was used to obtain sea surface temperature. Secchi disc was operated at all the stations in order to study transparency of waters concerned.

Water samples collected during the cruises were analysed in the laboratory for salinity by the titration method and suspended sediment load by the standard filtration method. Temperature data in respect of the cruise in the sea outside the harbour were processed applying necessary thermometer corrections to the readings of reversing thermometers and checking the values against the

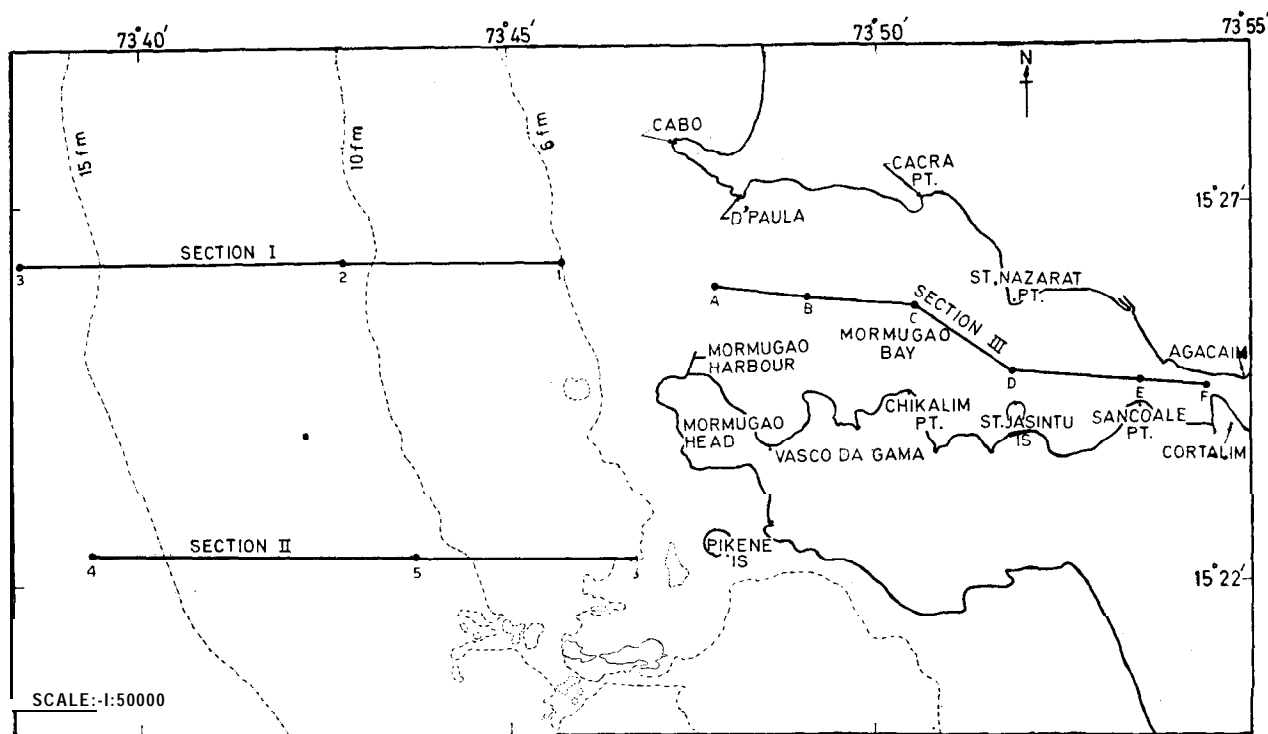


Fig. 1 — Location of stations

records of bathythermograph. From temperature and salinity data, the relevant density ( $\sigma_t$ ) values were computed. Approximate values of extinction coefficient ( $k$ ) were obtained using the relation,  $k = 1.7/D$ , where  $D$  is the Secchi disc reading in metres<sup>1</sup>.

Results and Discussion

Vertical distribution of temperature, salinity, density ( $\sigma_t$ ) and suspended sediment load along sections I to III are presented in Figs. 2 to 5.

**Section I** — Temperature profile indicates the presence of almost isothermal waters off the bay mouth except for the slight decrease in temperature with depth (Fig. 2). Range of variation in temperature in this section is less than 0.8°C. Almost isohaline water (of about 34.7‰ salinity) is present at stations 1 and 2. But at 15 m depth in station 3, a tongue of water with relatively low salinity (< 34.6‰), low density ( $\sigma_t < 22.2$ ) and less amount of suspended load (< 6 mg/litre) is encountered. The density ( $\sigma_t$ ) structure suggests slight upward movement of bottom waters at station 2, while the distribution of sediment load at station 1 indicates waters of low suspended sediment content (< 4 mg/litre) sandwiched between the surface and bottom waters of relatively high sediment load (> 10mg/litre). Values of  $k$  are high at stations 1 and 2 (Table 1) corresponding to the increase in the amount of total suspended load, while the relatively low extinction coefficient value at station 3 located further offshore (near 15 fm line) can be attributed to the low sediment content of the waters in this region.

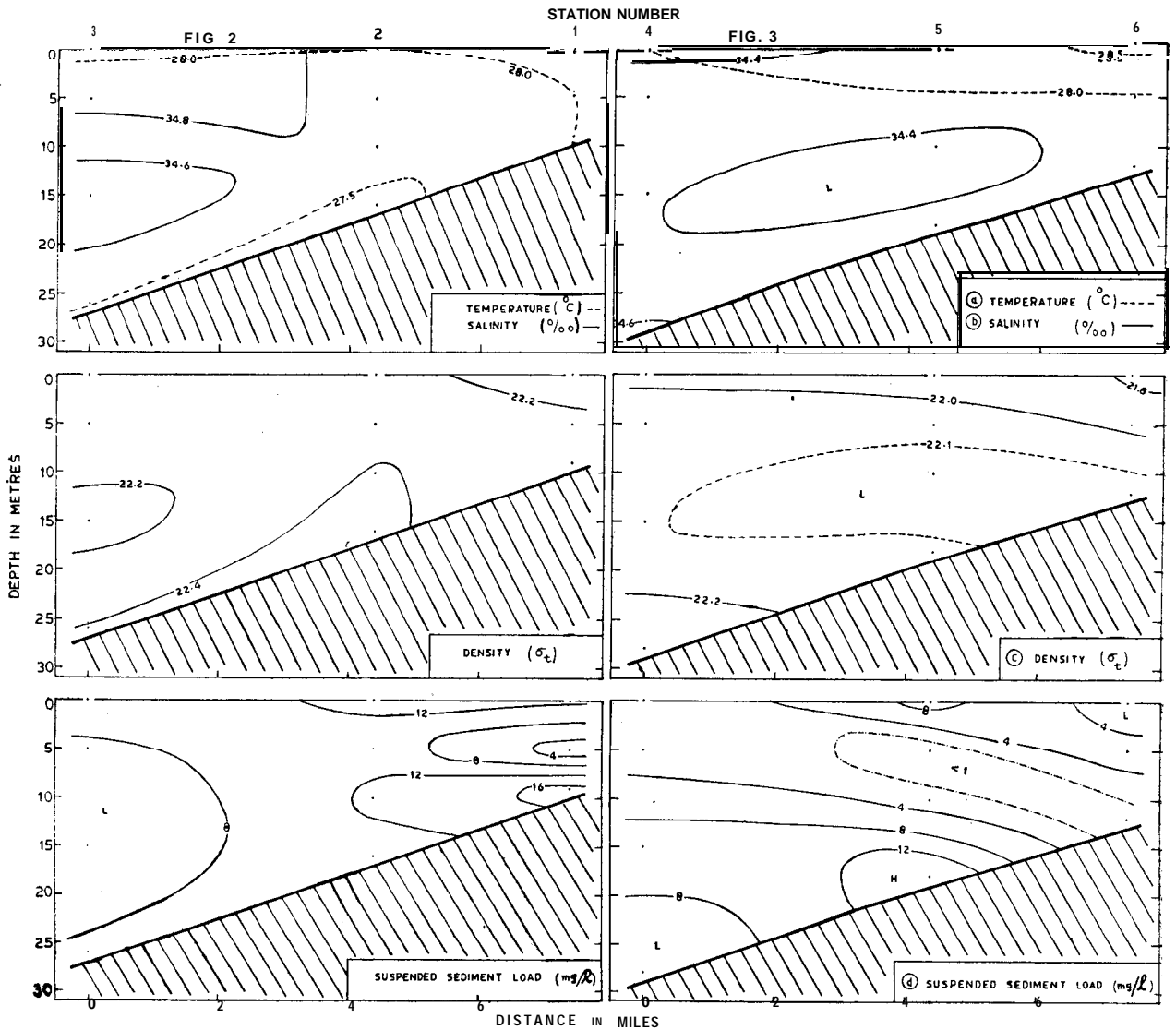
**Section II** — Temperature profile (Fig. 3) of this section (located in the sea off Pikene Island) also indicates nearly isothermal water with a slight but uniform decrease in temperature westward and with depth, the highest value (28.6°C) is encountered

TABLE 1 — TRANSPARENCY AND EXTINCTION COEFFICIENT OF WATERS IN THE SEA ADJOINING MORMUGAO HARBOUR

Station NO.	Max. depth of visibility m	Approx. extinction coeff. (k)
1	2.80	0.61
2	2.00	0.85
3	4.00	0.42
4	5.00	0.34
5	3.20	0.53
6	4.00	0.42

with the surface water at station 6 and the lowest (27.5°C) with the bottom water at station 4. Slightly higher values of surface water temperatures at stations 5 and 6 (occupied in the early afternoon) compared to those at stations I and 2 (occupied in the forenoon) may be attributed to the effect of diurnal variation of sea surface temperature.

But an analysis of temperature data of the stations in sections I and II indicates that, apart from this diurnal variation of sea surface temperature, the temperature in general decreases in the seaward direction. from the nearshore area, the waters at stations 1 and 6 being more warm compared to those at stations 3 and 4 respectively. The presence of a cell of low salinity water at about 15 m depth with low  $\sigma_t$  values and relatively high sediment load is encountered at stations 4 and 5. Waters bearing low sediment load (<4 mg/litre) are encountered in the surface at stations 4 and 6, in association with low  $k$  values while waters bearing relatively high sediment load are found in the surface at station 5 in association with comparatively high  $k$  value (Table 1). Low value of sediment load (< 1 mg/litre) encountered with the bottom



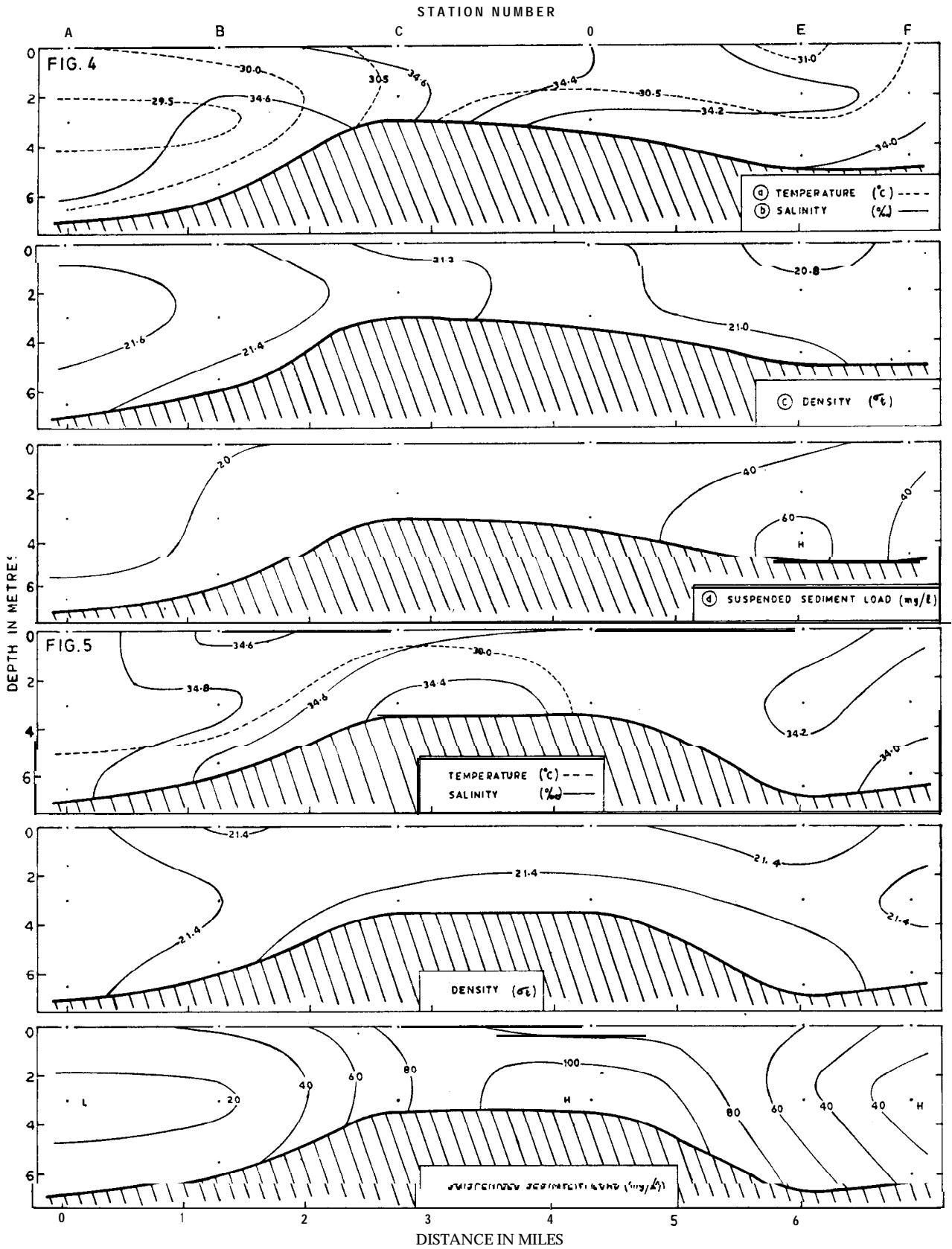
Figs. 2 and 3 — Vertical distribution of temperature, salinity, density ( $\sigma_t$ ) and suspended sediment load along section I (2) and section II (3)

waters at station 6 and the high value ( $> 12$  mg/litre) found in the bottom layers at station E may be the result of churning caused by the fast moving waters down the slope of the relatively soft bottom.

Vertical profile of temperature associated with the falling tide (Fig. 5) indicates isothermal water of relatively high temperature ( $> 30^\circ\text{C}$ ) between stations F and D. West of station D also, the waters are nearly isothermal (about  $30^\circ\text{C}$ ) except for slight decrease in temperature with depth. Salinity and suspended sediment load profiles indicate seaward receding of high salinity water ( $> 34.6\text{‰}$ ) bearing low sediment load ( $< 40$  mg/litre) in the mouth of the bay (stations A and B) and intrusion of comparatively low salinity water ( $< 34.0\text{‰}$ ) bearing relatively high sediment load ( $> 40$  mg/litre) downstream into the head of the bay (stations E and F). One conspicuous feature is that the salinity values observed during ebb at the head of the bay (stations E and F) are not much lower than those encountered during flood. The instability indicated in the density structure by movement downstream of denser water ( $\sigma_t > 21.4$ )

Section III — Vertical profiles associated with the rising tide (Fig. 4) clearly indicate intrusion of relatively cold ( $< 30^\circ\text{C}$ ), more saline ( $> 34.6\text{‰}$ ) and denser ( $\sigma_t > 21.4$ ) sea water bearing less sediment load ( $< 20$  mg/litre) into the mouth of the bay (stations A and B). From the mouth to the head of the bay (from stations B to F), a gradual decrease in salinity (from  $34.6$  to  $34.0\text{‰}$ ) and  $\sigma_t$  (from  $21.4$  to  $20.8$ ) and increase in temperature (from  $30$  to  $31^\circ\text{C}$ ) and suspended sediment load (from  $20$  to  $50$  mg/litre) seen in the profiles fairly reflect the characteristic distribution of the parameters associated with a moderately high flood current. Relatively high temperature and low density of waters in the upper layer at station E may be associated with the rush of water into this area from the neighbouring shallow regions. High quantity of suspended sediment load ( $> 60$  mg/

litre) found in the bottom layers at station E may be the result of churning caused by the fast moving waters down the slope of the relatively soft bottom.



Figs. 4 and 5 -- Vertical distribution of temperature, salinity, density ( $\sigma_t$ ) and suspended sediment load along section III during flood (4) and ebb (5)

over the water with relatively low density ( $\sigma_t < 21.4$ ) at station F may be only apparent because the actual density of these bottom waters may be quite higher than that indicated by  $\sigma_t$  value as they bear large quantity of sediment load (Fig. 5). The presence of very high amount of suspended load in the waters between stations C and E may presumably be due to the peculiar configuration of the bottom topography and comparatively fine nature of the bottom sediments<sup>2</sup> while gradual increase in the sediment load of the waters with depth may be associated with significant reduction in the speed of ebb current in this area. The extinction coefficient of surface waters increases gradually from the mouth of the bay upstream (Table 2). The probable reason for this may be that the sediment load brought in by the waters from the upstream gets deposited in the neighbourhood of the mouth of the bay where the currents undergo considerable reduction in speed. Relatively high range of variation in the values of extinction coefficient observed during flood shows the influence of intrusion of sea water into the bay.

**Surface currents** -The speeds of the surface currents (Fig. 6) at stations 1, 2 and 3 in section I are 9.3, 7.8 and 9.3 cm/sec respectively while at stations 4, 5 and 6 in section II relatively strong currents with speeds 11.1, 12.5 and 23.3 cm/sec res-

pectively are encountered. Although the observations are made around the slack period and when the tidal ranges are small in order to avoid the effect of tide as far as possible, the currents observed at rearshore stations, those at 6 fm line and 11 fm line, are not free from the influence of tide. The surface currents beyond 15 fm line show a southerly or south-westerly flow, probably due to the influence of a southerly surface current prevailing during the premonsoon season<sup>3</sup>.

TABLE 2 — TRANSPARENCY AND EXTINCTION COEFFICIENT OF WATERS IN MORMUGAO BAY

Station No.	During rising tide		During falling tide	
	Max. depth of visibility In	Approx. extinction coeff. k	Max. depth of visibility In	Approx. extinction coeff. k
A	—	—	—	—
C	0.00	1.70	0.90	1.89
D	0.90	0.45	1.89	0.80
E	—	—	—	—
F	0.45	0.40	4.25	3.78

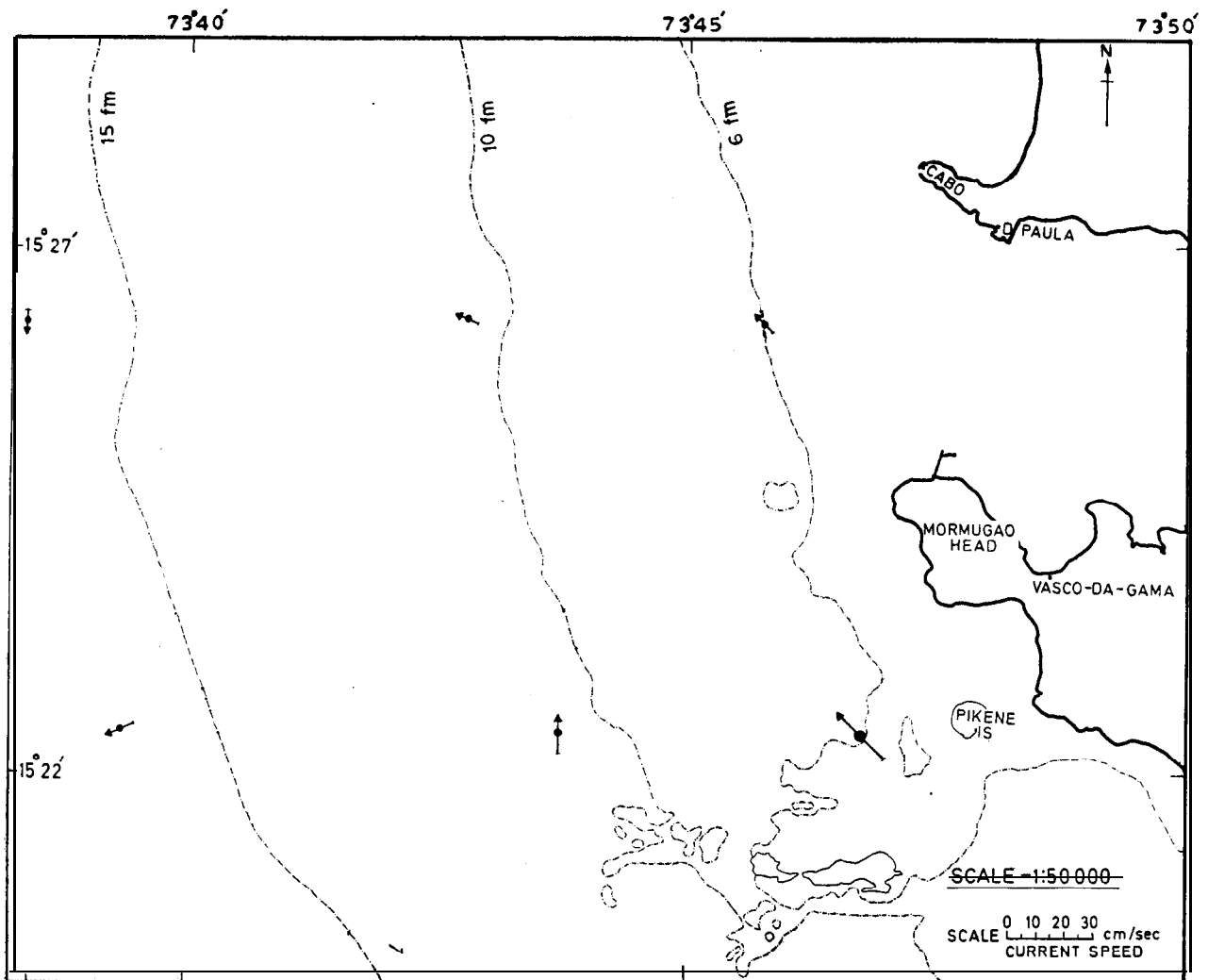


Fig. 6 — Surface currents in the sea adjoining Mormugao Harbour

In general, waters in the sea off Mormugao Harbour are mostly isothermal with a slight decrease in temperature with depth (28.0-27.5°C) while south of the harbour, off the Pikene Island, the temperature decreases gradually in the seaward direction also (28.5-27.5°C). During the flood, the temperature of the waters is low (< 30°C) in the mouth of the bay compared to that of waters (>30°C) in the head of the bay. During the ebb, almost isothermal waters prevail in the bay.

In the sea adjoining Mormugao Harbour the salinity varies generally between 34.3 and 34.8‰. The salinity distribution in the Mormugao Bay reflects thorough mixing of waters during both flood and ebb, the average range of variation being of the order of 0.6‰ only, between the mouth and head of the bay.

Vertical density structure in the sea off Mormugao Harbour reveals that the waters off the bay mouth are more stable compared to those south of the harbour, off the Pikene Island. However, further seaward, beyond 15 fm line, the conditions appear to reverse. In the bay, the density of waters decreases gradually from the mouth towards upstream during both the phases of tide, the variation being more conspicuous during flood than during ebb.

Suspended load of waters in the sea adjoining the harbour is less than 15 mg/litre. In the bay waters, the amount of suspended sediments generally varies between 20 and 100 mg/litre, the values encountered with the ebb waters being significantly higher than those of flood waters. One conspicuous feature is the seaward migration of the zone of high

suspended load from the head of the bay during ebb (Figs. 4 and 5).

Waters in the upper layers of the sea off the Mormugao Harbour are fairly transparent (depth of disappearance of Secchi disc >2 m and the approximate extinction coefficient (< 0.85) compared to those in the bay, where the Secchi depth is generally less than 1 m, the approximate extinction coefficient being greater than 1.7. The turbidity of surface waters in the bay increases gradually from the mouth towards the head of the bay, where the extinction coefficient of the waters is generally very high (>2.8).

In the sea adjoining Mormugao Harbour, the surface currents are faster off the Pikene Island compared to those off the bay mouth. However, further offshore (beyond 15 fm line), southerly to south-westerly surface currents with speeds of the order of 10 cm/sec prevail.

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