

Hydrographic Conditions & Flow Pattern in Cumbarjua Canal, Goa

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Variations in flow pattern and associated changes in temperature, salinity and suspended sediment load of waters at the 2 ends of the Cumbarjua Canal, which links the Mandovi and the Zuari estuaries, were studied in relation to tide for premonsoon, monsoon and postmonsoon seasons. Monthly variations of different hydrographic parameters in the canal were also discussed. While the currents in the southern region of the canal followed the tidal rhythm in all the seasons, flow pattern in the northern region showed marked variation between fair weather periods and monsoon season. Monthly variation in the temperature of waters of the canal showed a double oscillation with maximum values (around 32°C) in May and October and minimum values (around 27°C) in January and August. The waters were highly saline (about 35‰) in May and nearly fresh water conditions (salinity <5‰) prevailed in July and August.

MANDOVI-ZUARI estuarine system of Goa constitutes two tidal estuaries linked by a natural canal, the Cumbarjua canal. Cumbarjua canal is a 17 km long navigable canal following a meandering course. Its northern and southern ends connect the Mandovi and the Zuari estuaries at distances of 14 and 11 km respectively upstream from the mouths of these estuaries (Fig. 1). In its northern part, 2 narrow channels branch out of the canal and merge together before joining the river Mandovi further upstream. The canal is wider (about 210 m) and deeper on the Zuari side compared to the Mandovi side where its width is only about 25 m. It is used by barges carrying iron ore from the upstream region of the Mandovi to the Mormugao harbour during monsoon period when navigation through the mouth of the Mandovi is not possible due to rough conditions in the sea and formation of a sand bar at Aguada near its mouth. Presently bigger barges (more than 500 tonnes) cannot use the canal because of its depth and width limitations. Recognizing the urgency of developing navigation in this canal, which forms an important link in the inland waterways, the Government of Goa, Daman and Diu has undertaken, on top priority, the work of deepening and widening the canal in order to facilitate safe plying of barges up to 1000 tonnes, at all stages of tide and during all seasons. The present study which includes hydrography and currents is important in this context.

Hydrographic conditions and flow pattern in the canal are governed by Zuari and Mandovi estuaries. Influence of Zuari on this canal is expected to be more than that of Mandovi because the Zuari mouth is not only wider than that of Mandovi but also is nearer to the canal. Observations on currents and hydrography at the 2 ends of the canal during post- and pre-monsoon seasons reported earlier by Das *et al.*¹ highlight this feature. Singbal² while

presenting the diurnal variation of some physico-chemical factors in the Zuari estuary has discussed temperature and salinity variations at a station on the southern side of the canal in different seasons. In the present investigation, flow pattern and hydrographic conditions at the 2 ends of the canal over complete tidal cycles during premonsoon, monsoon and postmonsoon seasons and monthly variations of different hydrographic parameters along the length of the canal have been studied in detail, with a view to providing information useful for solving the problems of sedimentation and dispersal of effluents in the canal.

Materials and Methods

Observations were made every month for 1 year (1972). During April, September and January which could be considered as representative months, for premonsoon, monsoon and postmonsoon periods respectively, observations over complete tidal cycles were made at stations A and D located at the

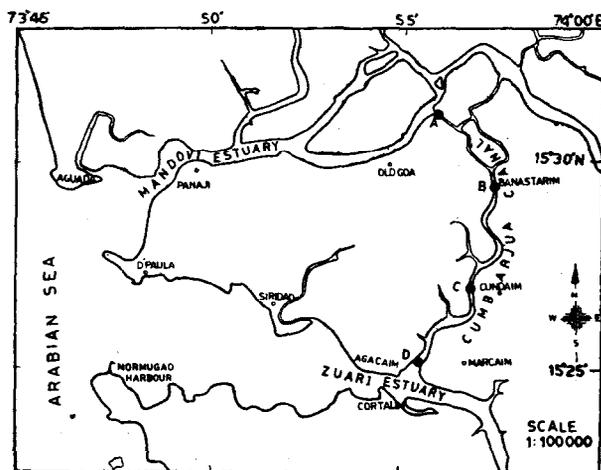


Fig. 1— Location of stations

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two ends of the canal. Tidal cycle observations were carried out either simultaneously or on successive days to study the tidal influence and the associated changes in the hydrographic conditions at the 2 ends of the canal. In the remaining months, 4 stations (A, B, C and D in Fig. 1) along the length of the canal were covered both during the rising tide and the falling tide to study monthly variations of hydrographic conditions in the canal. Stations A, B and C could not be covered in November and December as the canal was closed for navigation during this period. In June, the stations could be covered only during the falling tide. The average depths at stations A, B, C and D are 3.5, 6, 4 and 6 m respectively.

At each station water samples from the surface and subsurface levels were collected. Surface temperature was recorded using a bucket thermometer and subsurface temperatures were measured with reversing thermometers to ensure at least 0.1°C accuracy. Water samples were analysed for salinity employing the titration method (with an anticipated accuracy of 0.05‰). Sediment load was estimated using filtration technique. During the tidal cycle observations the surface currents (0.5 m below the surface) and bottom currents (0.5 m above the bottom) were measured using Ekman type current meters, in addition to the collection of data on temperature, salinity and sediment load, at hourly intervals.

On one of the days of tidal cycle observations (18.1.1973) vertical tide was also recorded at hourly intervals using graduated poles fixed near stations A and D. On comparison with the recorded tide at Mormugao harbour, the high water and low water at station D were found to exhibit a lag of about 30 min from their occurrence at Mormugao harbour. The corresponding lag in respect of high water and low water at station A was about 60 min. No significant difference in the range was noticed.

Results and Discussion

Variations over tidal cycles — Variations in current and hydrographic parameters at stations A and D in relation to tide recorded at Mormugao harbour are shown for premonsoon, monsoon and post-monsoon seasons in Fig. 2.

Premonsoon: At station D, the current was directed into the canal with the starting of rising tide and continued in the same direction for about 7 hr and then reversed (out to Zuari) during falling tide. There was not much difference in the speeds of surface and bottom currents. Flood current attained maximum speed of about 60 cm/sec. At station A, the current was directed into the canal during the initial stages of rising tide but changed its direction out to Mandovi about 2 hr after the starting of rising tide and continued in the same direction for about 6 hr. During the falling tide the flow was into the canal for about 2 hr only and then reversed its direction (out to Mandovi again). This feature appears to be the effect of ebb flow from Mandovi upstream through the narrow side channels which join the canal south of station A. At this station, maximum speed of flow into the canal observed during ebb was only 15

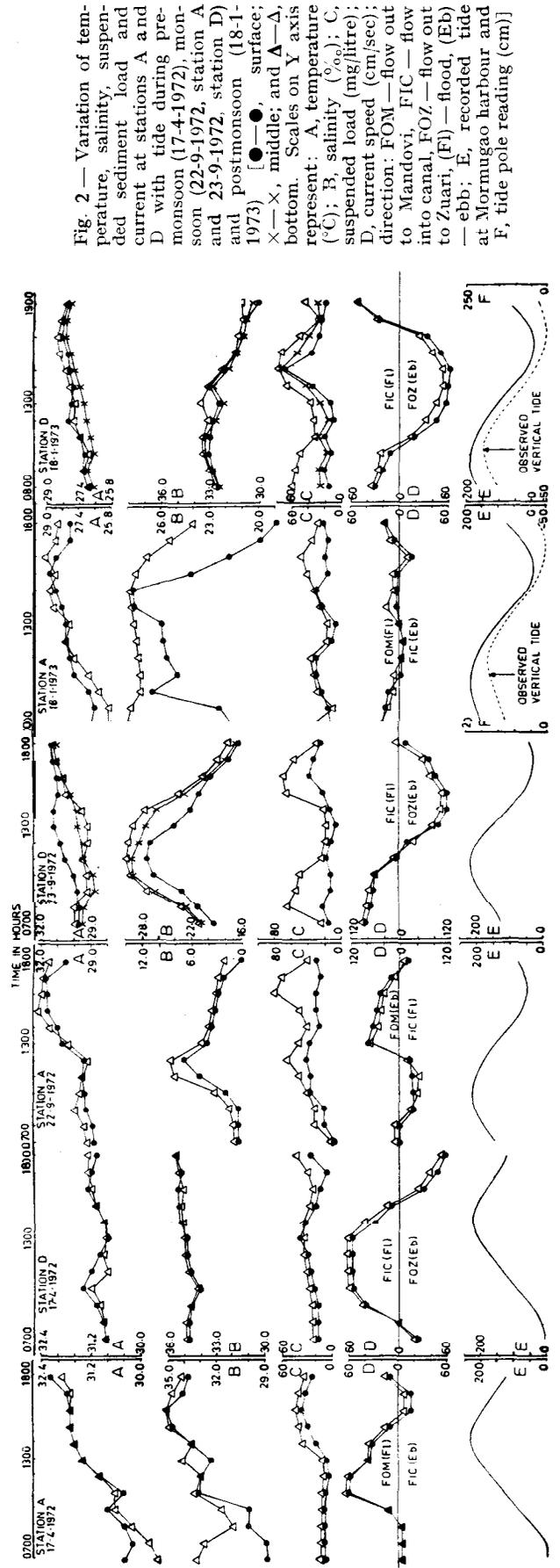


Fig. 2 — Variation of temperature, salinity, suspended sediment load and current at stations A and D with tide during premonsoon (17-4-1972), monsoon (22-9-1972, station D) and 23-9-1972, station D) and postmonsoon (18-1-1973) [●—●, surface; x—x, middle; and Δ—Δ, bottom. Scales on Y axis represent: A, temperature (°C); B, salinity (‰); C, suspended load (mg/litre); D, current speed (cm/sec); direction: FOM—flow out to Mandovi, FIC—flow into canal, FIC(FI)—flow out to Zuari, (FI)—flood, (Eb)—ebb; E, recorded tide at Mormugao harbour and F, tide pole reading (cm)]

cm/sec, while maximum speed encountered during flood was 60 cm/sec.

At station D, the temperature and salinity of the waters varied between 30.8° and 31.4°C and 34.0 and 35.4‰ respectively. In the first few hours of rising tide (up to about 10 a.m.), the temperature increased while the salinity decreased indicating the influx of waters brought in from Zuari upstream during falling tide. But as the flood attained maximum speed around noon, the temperature decreased while the salinity increased showing the influx of waters into the canal from the Zuari mouth. Vertical gradients in salinity were negligible, reflecting well mixed condition of the waters in the estuarine system. Simultaneous observations at station A showed comparatively more variations in the temperature and the salinity of the waters over tidal cycle, the respective ranges being 29.6-32.2°C and 29-35‰. Steep increase (~ 2°C) in the temperature of the waters from morning through evening may be attributed to the combined effect of tide and insolation. Low values of salinity encountered with the surface waters in the early hours of rising tide may be explained as the effect of flood from Mandovi side before the flood advancing from Zuari side dominates this area.

At both the stations, suspended sediment load varied between 5 and 45 mg/litre, and its value was more for bottom waters than for surface waters, in general. At station D, sediment load increased with the current speed. At station A, sediment load increased during the latter part of flood and attained maximum values in association with the flow into the canal during ebb which lasted only about 2 hr in this region.

Monsoon: During monsoon, at station D, the directions of flow were same as those in premonsoon. Maximum speed recorded during flood was about 90 cmjsec while that observed during ebb was about 110 cm/sec. At station A, during flood, except in the early stages, the flow was directed into the canal and during ebb the flow was directed out to Mandovi. Maximum speeds observed during ebb and flood were about 75 and 50 cm/sec respectively. Compared to premonsoon, the ebb (flow out to Mandovi) is strengthened during this season as it is aided by the large influx of water from Mandovi upstream into the canal through narrow side channels. This change in the flow pattern from premonsoon to monsoon is mainly caused by the large amount of freshet during monsoon. Monsoon run-off influences the flow pattern considerably at station A, so that even during early stages of the rising tide, fresh water was encountered at the station and the flow was directed out to Mandovi. Relatively longer duration of flow into the canal (for about 4 hr) at station A compared to premonsoon and postmonsoon periods may be attributed to decrease in the magnitude of tidal energy available at the Zuari side during monsoon.

Variation in water temperature is slightly more (28.8-32.2°C) at station A compared to that (28.7-31.4°C) at station D. At both the stations, the temperature showed variation with tide coupled with

diurnal heating. At station A, the bottom water temperature, in general, was more than that of surface water. A rather steep rise (about 2°C) in the temperature of the entire water column with the commencement of ebb is an interesting feature observed at this station.

Variation in salinity was 0 to 8.5‰ at station A and 16 to 29.6‰ at station D. Thus the salinity of waters in general and its range over tidal cycle in particular, is much more at station D compared to those at station A. This feature indicates clearly the greater marine influence on the Zuari side of the canal compared to the Mandovi side. Salinity gradient in the vertical was observed at station D throughout the period of observation, reflecting the stratified conditions prevailing in the estuarine system during this season. Previous studies by the authors^{3,4} indicated similar features in the middle regions of Mandovi and Zuari estuaries during the same season. At station A, fresh water was encountered during first half of rising tide and thereafter the salinity of the water and its vertical gradient increased gradually, until the flow reversed indicating that this station falls in the upstream region of the estuarine system during this period.

Sediment load in the waters in general, its range (5-80 mg/litre) as well as its depth wise increase, are more at both the stations during this period due to high run-off. At station D, the sediment load showed a semitidal fluctuation, the feature being prominent in respect of waters near the bottom.

Postmonsoon: During postmonsoon, at station D, the flow pattern was same as that during the other 2 seasons. Maximum speed attained by the current during ebb was about 60 cmjsec. Surface and bottom currents reversed almost at the same time after the slack periods. At station A, premonsoon flow pattern was restored during this season because of the diminishing effect of freshet. With the starting of the rising tide, the flow was directed into the canal for about 1 hr and then reversed out to Mandovi following the domination of flood advancing from Zuari side. During falling tide, the flow was directed into the canal (~ 2½ hr) till the ebb flow from Mandovi upstream through the side channels dominated and reversed its direction out to Mandovi.

At station D, the temperature varied between 26.7° and 28.4°C, the waters at mid-depth being slightly cooler than the surface and bottom waters. The temperature range is comparatively more (25.8-29.0°C) at station A. At both the stations, relatively warm waters were encountered with the falling tide and the temperature variation showed the influence of both tide and insolation.

Salinity varied between 30.0 and 33.7‰ and did not show much vertical gradient at station D. Comparatively, salinity variation was more (19-25‰) at station A, where a distinct depthwise increase in salinity was observed.

Suspended sediment load varied between 7 and 50 mg/litre at station A and between 10 and 80 mg/litre at station D. At both the stations the

suspended load generally increased with depth and showed fluctuation with tide. Sediment load in bottom water was relatively higher when bottom current was stronger, the relation being prominent in the case of station D.

Flow pattern in the canal during flood and ebb phases of tide in different seasons, as deduced from the preceding discussion, is shown schematically in Fig. 3. Flow pattern in the southern region of the canal followed the tidal rhythm in all the seasons. But in the northern region, the flow pattern showed significant change between the fair weather periods and the monsoon season. During fair weather seasons, the flow was directed out to Mandovi estuary except in the early stages of flood and ebb. In this region, during rising tide, the predominant flow was directed out to the Mandovi due to the dominance of tidal energy from the Zuari side. During falling tide also the predominant flow was directed out to the Mandovi due to the effect of side channels which bring in ebb waters from the Mandovi upstream. In monsoon, due to the large amount of freshet, the tidal energy reaching this region from the Zuari side is considerably reduced and the flow is mainly controlled by the tide from the Mandovi mouth, its direction being into the canal during flood and out to the Mandovi during ebb.

Monthly variations — Distribution of temperature and salinity along the canal during ebb and flood

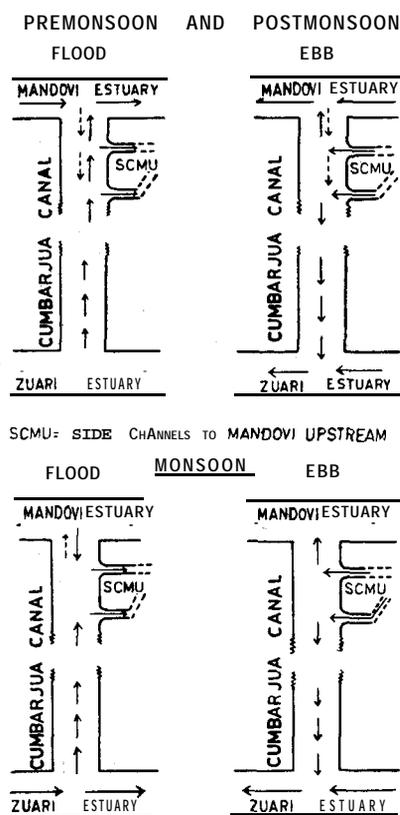


Fig. 3 — Flow pattern (schematic) in Cumbarjua Canal during different seasons [—→, predominant flow; and - - - -> flow restricted to initial stage of tide]

phases of the tide for different months are shown in Fig. 4.

Temperature: Temperature of the waters in the canal, in general, increased gradually from about 27°C in January to about 32°C in May reflecting the influence of heating during spring and summer. Subsequently with the onset of monsoon, temperature of waters decreased gradually to about 27°C in August. With the retreat of monsoon, temperature of waters increased rather quickly to about 32°C in October, probably due to maximum insolation resulting from the clear skies prevailing during this period. Again from November onwards gradual decrease in temperature was observed due to winter cooling.

During March-May, temperature of waters in the southern region of the canal, in general, was slightly lower than that of waters in the northern region, suggesting a greater influence of marine waters on the Zuari side. However, during June-August, temperature of waters in the northern region was slightly lower than that of waters in the southern region presumably due to the influence of monsoon run-off. It is interesting to note the significant vertical temperature gradients, observed in October, during rising tide.

Salinity: Salinity of the waters in the canal was maximum in May, when it ranged between 34.0 and 35.7‰. With the onset of monsoon, considerable reduction in salinity was noticed in June and the waters were generally free of salt during July-August. However, waters with slight salinity (up to 5‰) were encountered at the southern end of the canal (station D) during flood phase of the tide in these months. From October onwards, a gradual increase in salinity was observed. Generally, salinity of waters in the canal decreased northward from the Zuari side. This decrease was maximum in October and minimum in May. Salinity gradients, in the vertical were also maximum in October and minimum in May.

Suspended load: Values of suspended sediment load encountered during ebb and flood phases of the tide in different months are shown in Table 1. In general, the flood waters were found to bear more sediment load than ebb waters during premonsoon period. In monsoon and postmonsoon months higher sediment load was encountered with

TABLE 1 — SUSPENDED SEDIMENT LOAD OF WATERS IN CUMBARJUA CANAL IN DIFFERENT MONTHS

Month	Suspended sediment load (mg/litre)	
	During ebb	During flood
January	10-50	10-40
February	10-50	20-70
March	20-80	20-100
May	20-100	40-120
June	30-65	—
July	50-80	20-60
August	70-120	60-90
October	10-60	10-50

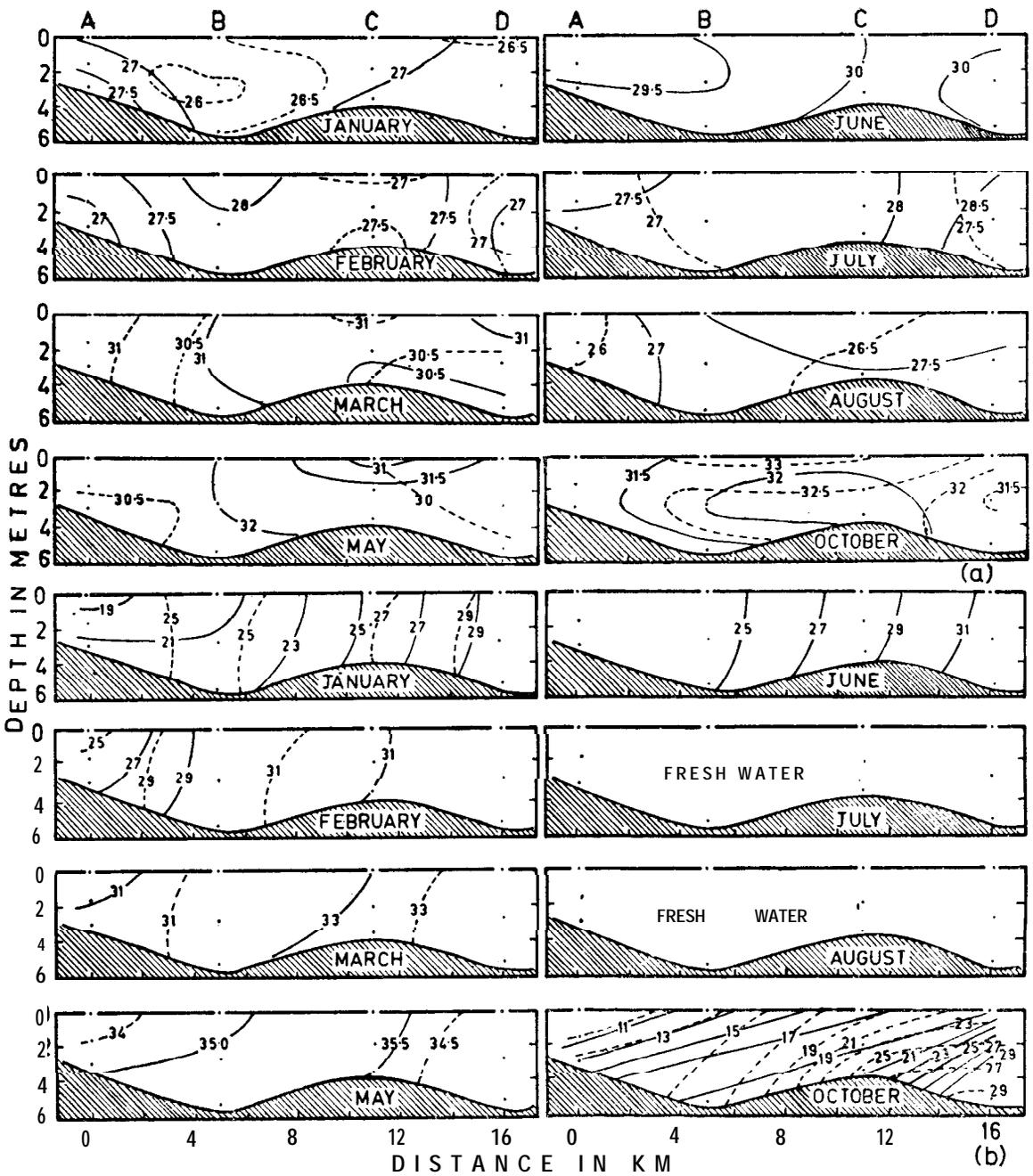


Fig. 4 -Vertical distribution of (a) temperature ($^{\circ}\text{C}$) and (b) salinity (‰) along Cumarjua Canal in different months [Distance indicated is from station A located on Mandovi side. --, ebb and - - -, flood]

ebb waters. Sediment load of the waters, in general, was higher (60-120 mg/litre) in August.

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