

Some aspects of circulation and mixing in lower reaches of Periyar estuary, west coast of India

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Monthly synoptic field observations of vertical profiles of velocity and salinity were made at 9 stations along 3 sections in the estuary from January-December 1985. Value of dimensionless stratification and circulation parameters were worked out from the observed salinity and velocity. Residual salinity structure showed that the estuary can be classified as salt wedge and density gradient depending on the longitudinal distance from the estuary and the river discharge. There was a net seaward flow of water with varying degree of magnitude from season to season. Stratification was confined only to the lower region of the estuary during monsoon, while the upper reaches were well mixed, during postmonsoon (October-December) and premonsoon (January-April) seasons, however, stratification to a lesser degree was observed throughout the estuary.

In an estuary, different characteristics depend on longitudinal distance, seasons of the year or phase of the tide¹⁻⁵. The characteristics can be due to many factors such as coupling of strong tidal oscillations with residual water circulation generated by non-linear interaction between tidal flow and estuarine topography, density gradient, mass input due to freshwater discharge and meteorological forcings. This paper discusses results of investigations on salinity, flow pattern, circulation and mixing processes of the lower reaches of Periyar.

Materials and Methods

The lower reaches of Periyar is defined as the region extending from the mouth of the river at Azhikode upstream up to 16.9 km (Fig. 1). The annual input of freshwater into this estuarine system is about $2700 \times 10^6 \text{ m}^3 \cdot \text{y}^{-1}$, of which 60% is contributed by Periyar river and the rest by Chalakudy river. Sedimentation, particularly at the barmouth region (section 1) has become a major hindrance to navigation. The presence of many small islands, with alterations made on the periphery by way of encroachment, new constructions, reclamations, etc. makes the circulation in this estuarine system very complex.

Monthly synoptic field observations of vertical profiles of velocity, temperature and salinity were made at 9 stations along 3 cross sections 1, 2 and 3 of the estuary (Fig. 1) from January-December 1985. Each station A, B and C was occupied for 13 h so as to cover one complete semidiurnal tidal cycle during

neap tide. Measurements of current speed and direction were made by rotor current meters (accuracy for velocity $\pm 1 \text{ cm} \cdot \text{sec}^{-1}$ and direction $\pm 2.68^\circ$; designed by NIO, Goa, India) and salinity and temperature were measured by indigenously developed STD meters (accuracy of $\pm 0.01 \times 10^{-3}$). The data collected were interpolated for non-dimensional depths, $\eta = 0.0 (0.1) 0.9$ by applying cubic spline interpolation technique^{6,7}. Mean value of parameters of 3 stations A, B and C for each depth was taken to represent the corresponding value at a section and used for further computations. Ebb directed flow was denoted by a +ve sign and flood currents by -ve sign. Tidal average of variable flow was obtained by averaging over a $12\frac{1}{2}$ h period to provide good estimate for residual variables in a predominantly semi-diurnal tidal regime. The values of dimensionless stratificati-

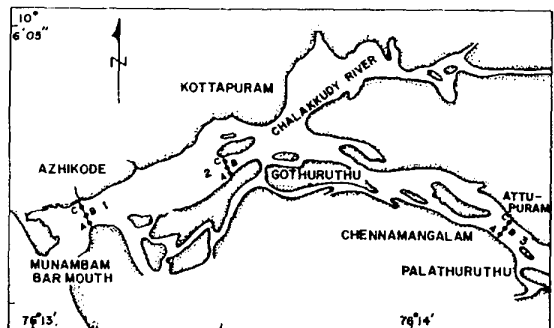


Fig. 1—Station locations

on and circulation parameters were worked out from the observed salinity and velocity values³. Hourly water level variations were also obtained using simple tide staffs installed at 3 fixed points, along the estuary at or near the observation stations.

Results and Discussion

There is a decrease throughout the year of tidal range up the estuary from the barmouth (Table 1). These variations are due to funneling effect, slowing down of tidal wave and frictional dissipation of energy due to a decrease in depth towards the head of the estuary. The increased water level range and also distorted tidal profile at the barmouth region during monsoon and postmonsoon months can be attributed to heavy influx of freshwater. During November and December, the tides are of a nearly mixed type and for the rest of the period, they are semidiurnal. The elevations of the tide observed for different seasons are in close concurrence with those at Cochin Backwaters⁸. A lowering of water level during monsoon in the estuary, agrees well with the predicted tide also.

Seasonal vertical mean of salinity and Eulerian residual flows are depicted in Fig. 2 along sections 1, 2 and 3. During the premonsoon (January-April) vertical salinity gradient remains low (1 to 2×10^{-3}) at sections 1 and 2 and high (17.5×10^{-3}) at section 3

which shows that stratification is more towards the head of the estuary compared to barmouth. At all these sections comparatively higher gradient occurs between 0 and 0.6 η depth.

During monsoon, stratification is more towards the barmouth of the estuary, with zero salinity from top to bottom at section 3 and salinity gradients 5×10^{-3} at section 2 and 9.5×10^{-3} at section 1. Thus it can be seen that the density gradient circulation is limited to barmouth region during monsoon. During postmonsoon (October-December) season while the surface water from 0-0.4 η depth has no salinity, a small gradient of 2×10^{-3} is observed from 0.4 η to bottom. But at section 2, the salinity gradient is as high as 8×10^{-3} in the entire vertical column. At the barmouth section the gradient is only at the top layers up to 0.7 η depth showing that the density gradient circulation is confined to upper sections only. Thus the different sections of the estuary experience different modes of circulation with changing seasons.

Table 1—Tidal values and average depth in different sections

Month	Maximum predicted tide at Cochin* (cm)	Tide (cm)		
		Section 1	Section 2	Section 3
Jan.	94	80	35	25
Feb.	73	55	48	45
March	54	50	47	33
April	57	55	59	50
June	87	60	53	45
July	90	85	59	65
Aug.	59	60	38	70
Sept.	73	75	43	75
Oct.	95	85	42	50
Nov.	108	85	41	40
Dec.	101	65	54	55

	Depth (m)		
	St A	St B	St C
Section 1	7.70	3.44	1.55
Section 2	2.20	2.75	2.30
Section 3	4.25	2.99	2.75

*Seasonal tidal range (m): monsoon, 48.5; premonsoon, 60.67; and postmonsoon, 57.43.

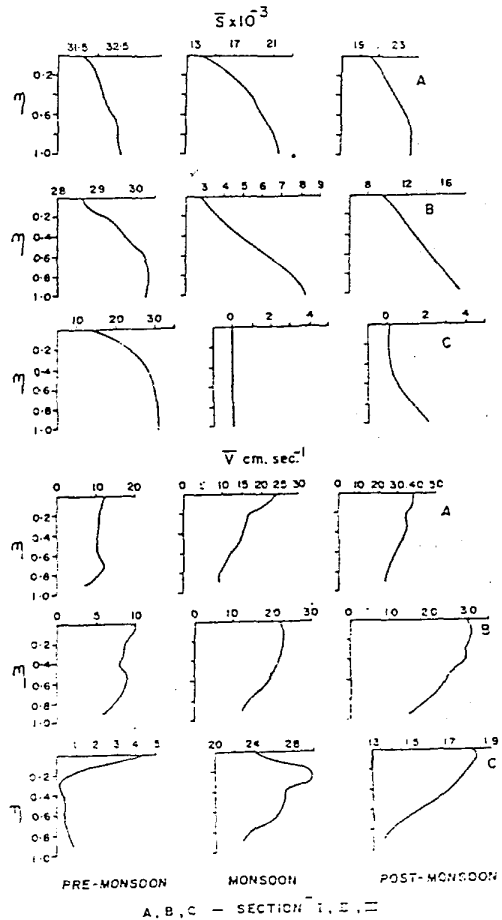


Fig. 2—Seasonal mean values of salinity and velocity at different sections [A = section 1, B = section 2, C = section 3]

The Eulerian residual current registers a net seaward flow throughout the year (Fig. 2). The velocity gradient is very negligible from surface to bottom during premonsoon at sections 1 and 2. However, the velocity is high from 0 to 0.3η at section 3. This shows that the circulation near the barmouth (down stream) is mostly tide dominated during premonsoon and in the upper region of the estuary, it is due to density gradient. During monsoon (June-September), even though the residual flow is directed seaward at all sections and having higher velocities as compared to premonsoon season, a large velocity gradient is found near the barmouth. This is indicative of the density gradient circulation restricting between sections 1 and 2 and a freshwater dominated circulation in section 3. In postmonsoon, a gradual reversal to the premonsoon condition is noticed. However, residual velocities which are directed seaward, remain very high in the lower region and reasonably high in the upper region. This also shows that the circulation between sections 1 and 2 is mostly governed by the density gradient.

Distribution of saline water into the estuarine region is shown in Fig. 3. Major incursion of saline water occurs at all depths from January to April, when the salinity is $> 30 \times 10^{-3}$. Even at a distance of 16.5 km from the barmouth, high saline water can be traced at mid and bottom layers. But, this is restricted to 6 km in the case of surface. With the onset of monsoon, freshwater ($< 0.5 \times 10^{-3}$) is traceable to a distance of 3 km at surface, 5 km at mid and bottom, from the barmouth. At section 3 salinity is almost zero at all levels during June-December. After the cessation of monsoon, salinity increases from 1 to 20×10^{-3} at surface and in the case of mid and bottom depths, from 10 to 25×10^{-3} and 15 to 25×10^{-3} respectively.

The amount of freshwater (f) in terms of salinity (S) at different segments along the estuary is calculated for 3 seasons of the year using the formula⁵

$$f = (S_0 - S_n) / S_0$$

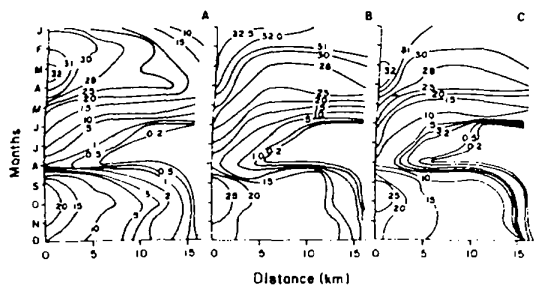


Fig. 3—Monthly variation of isohalines at different depths [A, 0 η; B, 0.9 η and C, 0.5 η]

where S_0 is salinity of undiluted coastal seawater and S_n is the mean salinity in a given segment of the estuary. During monsoon f value (Fig. 4) is large (0.45) even at barmouth (section 1) and the freshwater fraction steadily increases towards the head of the estuary reaching unity at a distance of 16.5 km upstream (section 3). During postmonsoon also, the same increasing trend of freshwater fraction is evident. However, low f values all along the estuary during premonsoon are indicative of low river discharge. The increased river flow causes both a downstream movement of the salinity intrusion and a more rapid circulation of water. Thus increased river discharge is accompanied by a more rapid exchange of freshwater with the sea, the volume of freshwater accumulated in the estuary increasing to a lesser extent than does the discharge.

Circulation and mixing processes—Based on residual salinity structure, the circulation in this region can be classified as salt wedge and density gradient, depending on the longitudinal distance and river discharge. From barmouth (section 1) and extending up to 5.5 km (section 2), high stratification is observed in monsoon, giving rise to a salt wedge circulation. There is no saline discontinuity layer anywhere in the region. Evidently, there is enough friction between different stratified layers to bring forth a uniform salinity gradient from surface to bottom due to entrainment processes. During other seasons, a tide dominated mixed circulation is noticed. The upper reaches of the estuary experience a freshwater dominated seaward directed circulation during monsoon and salt wedge circulation, during the other seasons. Stratification is confined to the lower region of the estuary only during monsoon, while the upper reaches are well mixed. Stratification to a lesser degree is found during other seasons, throughout the estuary. The shallow regions show mostly freshwater mode of circulation. Generally, there is a net seaward flow of water with varying degree of magnitude from season to season.

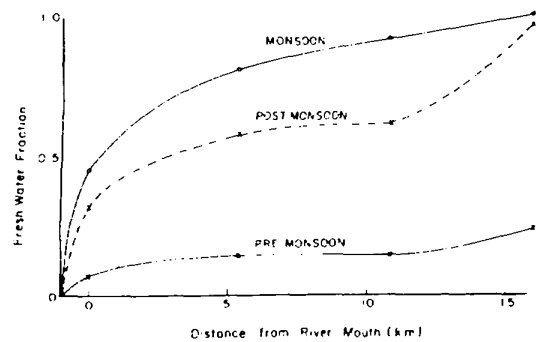


Fig. 4—Distribution of freshwater fraction during different seasons

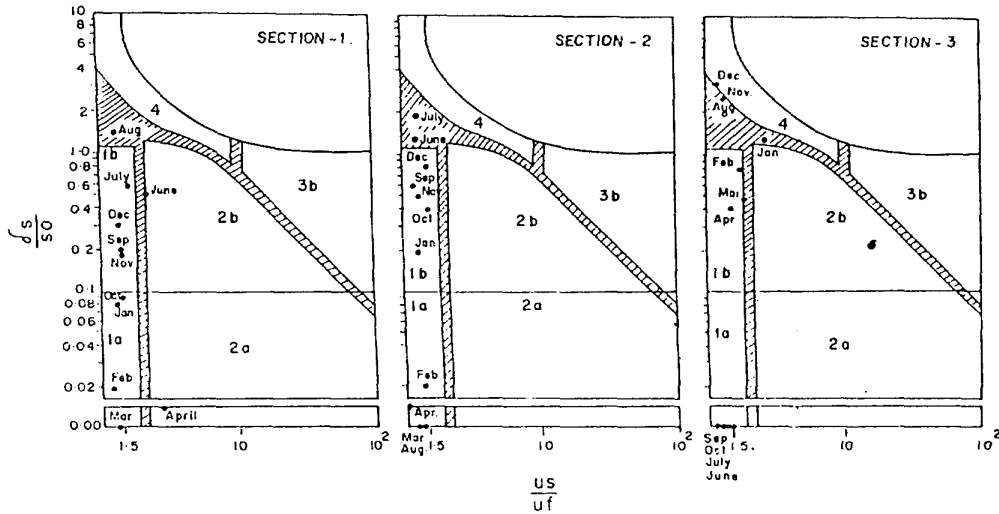


Fig. 5—Stratification-circulation diagram showing classification of estuary

Classification of estuary—Quantitative means of classifying and comparing estuaries, which requires measurements of salinity and velocity only, has been developed³. The classification is depicted in stratification-circulation diagrams (Fig. 5). The value of stratification parameter, $\delta s/S_0$ (ratio of the surface to bottom difference in salinity, δs divided by the mean cross sectional salinity, S_0) is very low during post and pre-monsoon seasons along sections 1 and 2; whereas in section 3 higher values are found. The circulation parameter, U_s/U_f (the ratio of the net surface current to the mean cross sectional velocity) shows a high value in April and January at section 1 and section 3 respectively. For the remaining period the value is uniformly high. These diagrams show that the different regions of the estuary come under varying classifications. At barmouth and the adjoining area extending to 5 km along the estuary, there exists well mixed condition during postmonsoon months with a seaward flow, signifying the upstream salt transfer mainly by advection and partly through diffusion. After the onset of monsoon, this region becomes stratified showing that the salt transfer is through diffusion and shearing

stress. The state of stratification continues even beyond the monsoon season, but to a lesser degree. However, in the upstream part of the estuary the condition is quite different and there is no saline intrusion during monsoon.

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