

## RESIDUAL FLUXES OF SALT & WATER IN THE AZHIKODE ESTUARY, WEST COAST OF INDIA

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### ABSTRACT

Monthly synoptic measurements of current speed, direction, salinity and temperature were made at three Sections in the Azhikode estuary, for a period of one year. The observations were extended over a complete tidal cycle (neap) of 13 hours at all stations and the data were analysed to provide estimates of the residual fluxes of water and salt. The interpolated data for the non-dimensional depth was used for computation of depth, tide and cross sectional averages. A net seaward flow of water was observed, with varying degree of magnitude from season to season. The mechanism which contributed to the residual fluxes of water and salt in the lower reaches of the estuary are quantified here.

### INTRODUCTION

The Azhikode estuarine system formed as a part of Lower Periyar together with the Chalakkudy river joining at the middle, is the second largest backwater system that opens into the Arabian Sea around the middle of Kerala coast. The total fresh water input to the system during the year of observation amounts to 2682

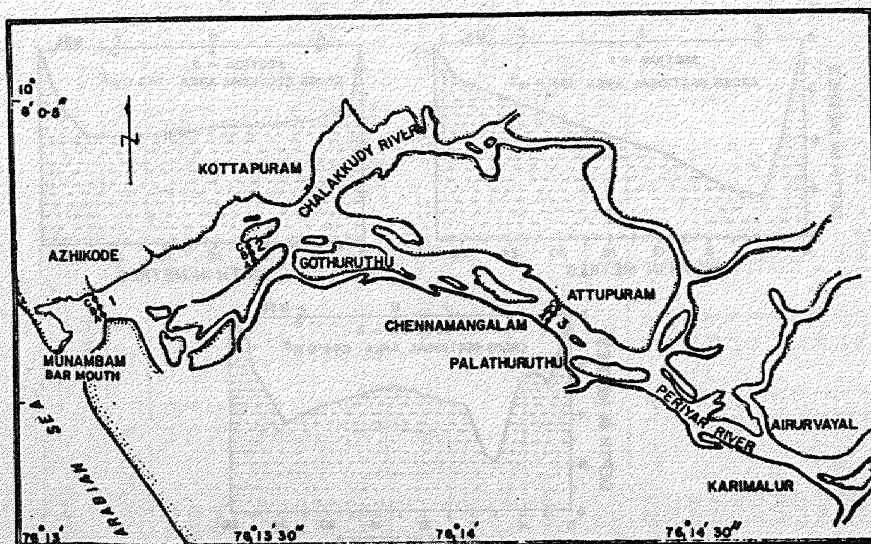


Fig. 1. Station positions.

million  $m^3$ . Approximately 40% of the total fresh water input into the estuary is shared by the Chalakkudy river. The longitudinal extent of the estuarine region under investigation is 16 km from the barmouth and is within the tidal reach of the river.

The purpose of this paper is to characterise, as never has been reported earlier, certain dynamical features and mainly to quantify the mechanisms which contribute to the seasonal residual fluxes of water and salt at different parts of this estuary.

## METHODS

Monthly synoptic measurements of salinity, temperature and currents were made at three sections (1,2 &3), each comprising of 3 stations (A,B, & C) for a period of 1 year (Fig. 1). All the stations were occupied for 13 hours. Hourly measurements were taken at each station from surface to bottom at 1 metre depth interval. Velocity measurements were accomplished by rotor current meters and temperature and salinity by STD meters. River discharge data were collected from the local hydrography department. Hourly measurement of water level at selected and fixed points near each section were made by simple tide staff. Bathymetric survey of the study area was also made (Fig. 2). Cubic splines were used to interpolate data at non-dimensional depth ( $\eta$ ) and to subsequently define these data at the same instances of time. Each parameter was then time averaged and depth averaged for non dimensional depth using the method given by Kjerfve (1975). Ebb flow is taken as +ve and flood as -ve. The tidal average of a variable flow is obtained by averaging over a 12 1/2 hour period to provide good estimate for the residual variables in a

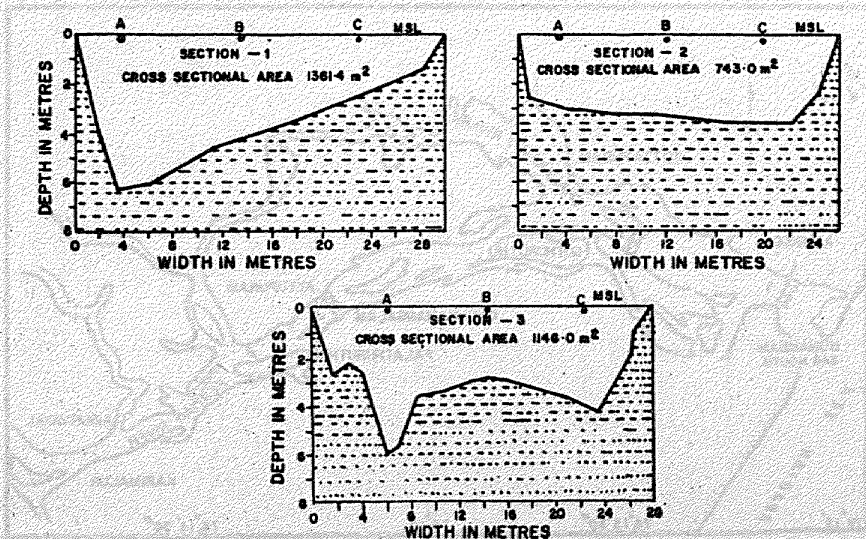


Fig. 2. Cross sectional alignment of the sections studied.

Table 1. SECTION - 1

Month	$V_1 = \langle V \rangle^*$			$\langle S \rangle$			$V_2 = \langle HV \rangle < H \rangle$			$V_{s,1} f$			$V_{s,2} f$			$\langle Q \rangle j$			Fresh water Flux Cusecs
	Stations			Stations			Stations			Stations			Stations			Stations			
	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	
JAN	18.2	25.7	12.4	32.9	32.1	32.0	-0.22	652	-5.75	10257	80								
FEB	05.4	21.6	-2.1	32.5	32.2	30.7	-0.56	317	-61.15	3687	24								
MAR	32.1	15.1	8.6	33.0	32.2	32.1	-0.76	179	-1.13	-711	34								
APR	06.5	05.1	10.4	32.2	32.5	32.9	-0.35	180	0.96	1452	52								
MAY	05.6	06.4	12.0	23.8	21.8	18.1	-0.88	106	-50.45	-406	1596								
JUN	06.4	13.7	15.4	17.9	15.9	13.4	-0.87	198	-193.46	4745	1584								
JUL	35.0	31.4	31.4	13.0	06.6	04.7	1.12	179	-221.46	15872	1368								
AUG	02.8	20.4	12.6	28.4	25.9	24.8	-2.21	78	-135.00	1356	513								
SEP	19.5	25.0	21.2	27.4	23.5	24.6	-2.87	658	-267.90	13661	462								
OCT	29.6	26.9	27.0	25.2	23.3	21.8	-2.92	410	-289.00	12923	266								
NOV	40.1	20.0	38.3	22.4	28.7	16.3	-3.52	497	-113.30	14174	227								
DEC																			

UNITS: \* CM.SEC<sup>-1</sup>, F=10<sup>-3</sup>.sec<sup>-1</sup>, j=10<sup>3</sup>sec<sup>-1</sup>

Table 2. SECTION - 3

Month	$V_1 = \langle V \rangle^*$			$\langle S \rangle$			$V_2 = \langle HV \rangle < H \rangle$			$V_{s,1} f$			$V_{s,2} f$			$\langle Q \rangle j$			Fresh water Flux Cusecs
	Stations			Stations			Stations			Stations			Stations			Stations			
	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	
JAN	1.3	1.2	1.8	26.9	23.8	20.6	-0.28	32	3.70	1743	80								
FEB	-0.3	-0.6	0.6	29.0	27.6	26.8	-0.10	11	-1.30	121	23								
MAR	1.1	-0.2	0.8	28.5	27.7	27.6	0.10	35	-0.85	263	34								
APR	-0.5	4.1	0.1	29.3	29.2	28.9	0.08	02	-0.63	344	52								
MAY	23.1	14.9	14.0	00.0	00.0	00.0	-0.16	00	1.60	6135	1596								
JUN	29.7	34.6	30.5	00.0	00.0	00.1	-0.39	00	0.08	12596	1368								
JUL	36.3	34.0	32.4	00.0	00.0	00.0	0.01	01	0.00	13299	513								
AUG	10.3	11.3	10.8	00.0	00.2	00.0	-1.21	01	-0.28	5049	462								
SEP	10.3	10.6	15.9	00.2	00.0	00.0	-0.48	01	-0.62	5049	462								
OCT	17.7	14.0	16.2	01.0	00.1	00.0	-0.49	06	-1.10	4753	266								
NOV	14.9	15.0	18.2	03.3	00.4	00.4	-0.26	21	-2.19	5264	227								
DEC																			

UNITS: \* CM.SEC<sup>-1</sup>, F=10<sup>-3</sup>.sec<sup>-1</sup>, j=10<sup>3</sup>sec<sup>-1</sup>

Table 3.

## SEASONAL CROSS SECTIONAL AVERAGES

Season	$V_1 = \langle \bar{V} \rangle^*$	$\langle S \rangle$	$V_2 = \langle \overline{HV} \rangle$	$\langle H \rangle$	$V_{s,1} f$	$V_{s,2} f$	$\langle \bar{Q} \rangle$	$j$	Fresh water Flux Cusecs
CROSS SECTION 1									
PRE-MONSOON	2.33	32.27	-0.47		412.30	-16.78	3712.90		49.18
MONSOON	14.29	17.86	-0.71		174.60	-140.33	5392.00		1265.00
POST-MONSOON	29.62	22.73	-3.10		677.70	-174.70	13551.80		316.77
CROSS SECTION 3									
PRE-MONSOON	0.78	27.16	0.02		17.53	0.67	617.80		49.18
MONSOON	23.53	0.02	-0.44		0.86	0.35	8609.90		1265.00
POST-MONSOON	14.73	0.60	-0.41		9.16	-1.31	5022.00		316.70

UNITS: \* CM.SEC<sup>-1</sup>, F=10<sup>-3</sup>.sec<sup>-1</sup>, j=10<sup>3</sup>.sec<sup>-1</sup>

predominantly semi-diurnal tidal regime (Hill & Ramster 1972). A condition of zero velocity was applied at the bed over region of extrapolation. Following the method given by Uncles & Jordan (1979), the different parameters such as  $Q$ , the instantaneous rate of transport of water through unit width of water column of depth  $H$ , Non tidal drift (Dyer 1974)  $V_1$ , the residual rate of transport of water resulting from tidal pumping or Stokes drift (Hunter 1972)  $V_2$ , the depth averaged residual fluxes of salt due to the residual transport of water  $V_{s,1}$ , and due to the tidal pumping  $V_{s,2}$ , were computed. Also the seasonal cross sectional averages of these parameters at section I and III were tabulated (Table 3). A detailed account on the analytical methods used here have been reported in earlier publication of the authors (Revichandran *et al.*, 1987, Udaya Varma *et al.*, 1987)).

### RESULTS AND DISCUSSION

This estuarine system is largely influenced by the influx of freshwater which in turn is controlled by the rainy season facilitating the observation periods to be divided into three distinct seasons namely pre-monsoon (Jan-April), Monsoon (June- September) and postmonsoon (October-December). The depth and tidal averaged Eulerian residual current known as the non tidal drift  $V_1 = \langle V \rangle$  and depth and tidal averaged salinity  $\langle S \rangle$  along the different sections, 1, 2 and 3 are compared in Fig. 3. In section 1  $\langle S \rangle$  values remain high from Jan-April and decrease suddenly through the monsoon season; the lowest value being in August. The

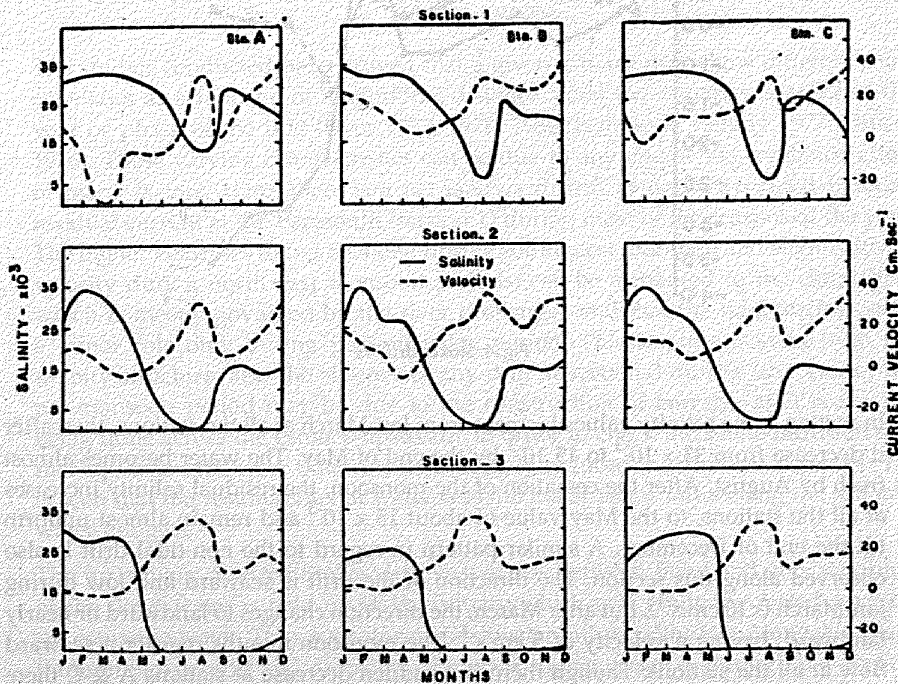


Fig. 3. Residual salinity and non-tidal drift along stns. 1, 2 and 3 during January-December, 1985.

lowest value at station A is  $12 \times 10^{-3}$ , while at B & C it nearly touches  $5 \times 10^{-3}$ . After a sudden increase in September ( $29.0 \times 10^{-3}$ ) at stations A and  $25 \times 10^{-3}$  at B & C, there is a decrease in salinity structure at all stations, ( $22 \times 10^{-3}$ ) at stations A & C and  $15.0 \times 10^{-3}$  at station C, through October to December.

The non tidal drift along the section also shows a more or less uniform trend from month to month though with variations in magnitude. At station A, the flow is landward during March to June. But during monsoon the flow is directed seaward, reaching a maximum of  $36 \text{ cm.s}^{-1}$  at all stations in August. However, by September there is a lowering of the drift values to  $2 \text{ cm.s}^{-1}$  to  $12 \text{ cm.s}^{-1}$  at stations A & C; while it remains high at stations B as before. The maximum value is attained in December ( $40 \text{ cm.s}^{-1}$ ), after it gains speed from September.

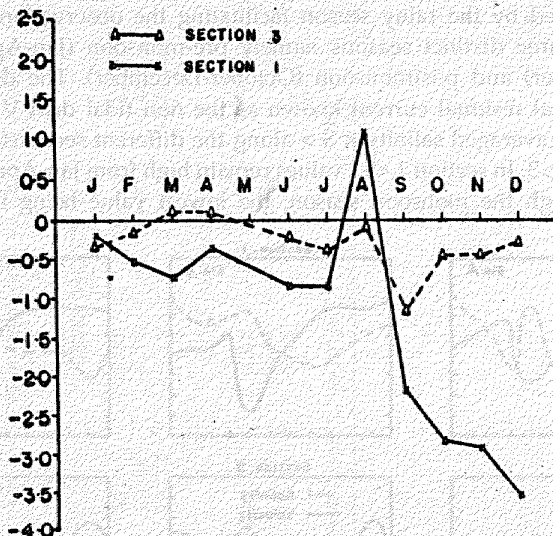


Fig. 4. Stokes drift  $V_2$

In section 2, the salinity values increase from Jan-March at all the stations, thereafter it decrease from  $33 \times 10^{-3}$  to  $15 \times 10^{-3}$  by the end of May. The water becomes almost fresh by August. After the cessation of the monsoon, the residual salinity increases at all the stations, to the May value of about  $15 \times 10^{-3}$  and remain almost uniform till the end of December. A similar pattern in regard to the non-tidal drift is also observed along this section. The direction of the drift is seaward and low during Jan-March ( $<10 \text{ cm.s}^{-1}$ ), but after March, the direction changes to landward or nearly landward; having a velocity of  $5 \text{ cm.s}^{-1}$ . The monsoon months register a seaward flow at all the stations. Though there is a sudden decrease at stations A & C there is an increase in the velocity structure at all the stations from September to Decem-

ber. In this section it is seen that the residual flux of water is the major factor influencing the salt and water budget. Contrary to the findings in Sections 1 and 2, the residual salinity in section 3, either remains constant or even registers a slight increase from Jan to April, and drops to zero by June and remains negligibly low up to December, at all the stations. The residual velocity gradually increases from 0 in January to  $30 \text{ cm.s}^{-1}$  in July, and reaches a maximum of  $40 \text{ cm.s}^{-1}$  in August. In September and October it is again low ( $10 \text{ cm.s}^{-1}$ ) and afterwards increases by November to December, reaching a value of about  $20 \text{ cm.s}^{-1}$ .

The residual rate of transport of water resulting from tidal pumping worked out along section 1 and 3 is profiled in figure 4. At section 1 it is directed landward during the entire period except in August. At section 3, except during March, the Stokes drifts are directed landward.

Salt transport due to the residual fluxes of water,  $V_{s,1}$  and due to the tidal pumping  $V_{s,2}$  for different months at each station along Section 1 and section 3 (Tables 1&2) illustrate that the net residual flux of salt due to residual flux of water is directed down the estuary, while that due to the tidal pumping is directed up the estuary across section 1. However, during monsoon and postmonsoon higher values are attained. In the case of section 3 they are directed down the estuary with values of 0.86 and 17.53, during monsoon and pre-monsoon periods. But in post-monsoon season the mode of transport changes to upstream direction with low values.

## CONCLUSION

The studies conducted have proved that a given estuary may show different characteristics as a function of longitudinal distance along the estuaries, seasons of the year or phase of the tide (Dyer 1973, 1978, 1980; Hansen & Rattray 1977; Officer 1976). These varying characteristics can be due to any one or the combined effect of many factors. Here, there is a net landward drift of depth averaged Eulerian residual current at the Barmouth (section 1) during most of the seasons of the year. The higher velocities found all along during south west monsoon and slightly lower velocity during north east monsoon periods; can be attributed to the circulation, which is mostly governed by the river discharges and that the tidal forcings play a minor role only during post-monsoon period. This is quite evident from the salinity structure; also the absence of any drift at section 3 during later half of the pre-monsoon period may be due to the construction of barrage, as it is usually being done across the estuary upstream, in order to check the saline intrusion further up, when the river output is considerably reduced in summer. In section 1 it is seen that the residual flux of water was the major factor influencing the salt and water budgets.

The up estuary directed Stokes drift shows that between flood and ebb, a portion of the flood water is held up in the estuary which gets gradually mixed up with the estuarine water. Thus even during freshwater influx, saline intrusion takes place through Stokes drift and diffusion. The main source of salt is through the vertical shear in the tidal and residual currents and also due to the residual flux through

tidal pumping. During the lean months of freshwater flow, the high residual flux of salt, directed up the estuary, is mainly contributed through advection when the residual Eulerian currents are directed by tidal flow. Near the barmouth the higher values of the residual fluxes of salt correlate with the amplitude of the tidal wave. The magnitude of the residual fluxes of salt is indicative of the importance of the advective processes in the salt balance in this part of the estuary.

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