

Water & Salt Budget in the Azikode Estuary during Postmonsoon Season

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Computed values of flux showed that seaward Eulerian residual flow of water was the major factor influencing the salt and water budget in the Azikode estuary. Depth integrated residual flow was seaward at all depths. Upstream transport of salt was mainly due to diffusion. Salt transport due to vertical current shear increased in the upstream direction. The magnitude of Stokes drift was greater near the barmouth where tidal action was high. At section 1, near the barmouth, the effective eddy diffusivity K_e increased from surface to mid-depth and then decreased. However at section 2, K_e showed two maxima at non-dimensional depths $\eta = 0.3$ and $\eta = 0.8$. Due to increasing stratification and less tidal action values of effective eddy diffusivity were less in section 2.

Azikode estuary is formed by the major arm of the Periyar river opening out at the Azikode barmouth. Now this is being developed as a fishing harbour. The sedimentation in the estuarine region as well as at the barmouth is a major hindrance to the safe traffic of the fishing boats. The circulation in the estuarine region is very complex due to the presence of small islands. An attempt has been made in this study to compute fluxes of salt and water due to Eulerian residual flow of water, Stokes drift and vertical shear in order to assess their relative importance in the transport processes in the estuary.

Materials and Methods

The study area (Fig. 1) with an average depth of 4 m comprised 2 sections, one near the barmouth (section 1) with 2 stations (A and B) and the other (section 2) with 3 stations (C, D and E) at a distance of 5 km upstream. Synoptic field observations of current and salinity were made at the 2 cross sections. Since the tides in this region being semidiurnal the observations were extended to over 13 h to cover one complete tidal cycle. Hourly observations of salinity and currents were taken for each station from surface to bottom at 1 m depth interval. Current speed and direction measurements were made using indigenous rotor current meter (accuracy for velocity $1 \text{ cm} \cdot \text{sec}^{-1}$ and direction $\pm 2.68^\circ$; designed by NIO, Goa, India). For salinity measurements, indigenously developed STD meter (accuracy of 0.01×10^{-3}) was used. Tide measurements were made using simple tide staff.

The data collected were interpolated for non-dimensional depths $\eta = 0, 0.1, 0.2, \dots, 0.9$ using cubic spline interpolation technique¹. Velocity and salinity

values for every η value were plotted against time and the smoothed values were used for further computations. Seaward flow was taken as positive. Depth and tide averages were computed using the method given in Kjerfve².

Symbols and formulae used for computations are given below³.

Setting \bar{X} as depth average,

$\langle X \rangle$ as tidal average and

$\langle \bar{X} \rangle$ as depth average of tide average.

Where X is any variable such as observed salinity S, velocity V, depth H and $Q = H\bar{V}$ the instantaneous rate of transport of water through a unit width of water column of depth H.

$$\bar{V} = \bar{V} - \langle \bar{V} \rangle$$

$$\bar{S} = \bar{S} - \langle \bar{S} \rangle$$

$$\bar{H} = H - \langle H \rangle$$

$$V' = V - \bar{V}$$

$$S' = S - \bar{S}$$

$$\bar{Q} = Q - \langle Q \rangle$$

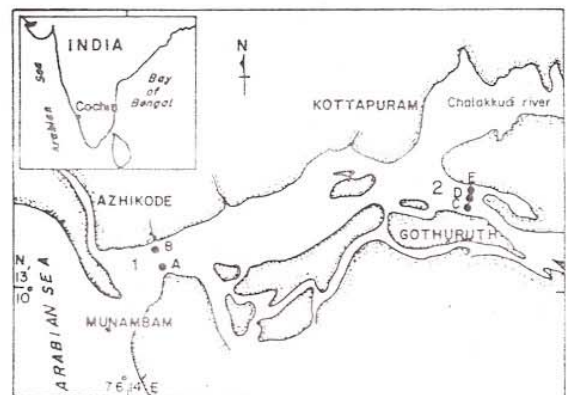


Fig. 1—Study area with location of stations

Eulerian residual flow of water $V_1 = \langle \bar{V} \rangle$

Stokes drift $V_2 = \langle \tilde{H} \tilde{V} \rangle / \langle H \rangle$

Salt transport due to residual fluxes of water $V_{s,1} = \langle Q \rangle \langle \bar{S} \rangle / \langle H \rangle$

Salt transport due to tidal pumping $V_{s,2} = \langle \tilde{Q} \tilde{S} \rangle / \langle H \rangle$

Salt transport due to vertical shear in the tidal and residual current $V_{s,3} = \langle H \tilde{V}' \tilde{S}' \rangle / \langle H \rangle$

$V_1, V_2, V_{s,1}, V_{s,2}, V_{s,3}$ are resultant of axial and transverse components $u_1, u_2, u_{s,1}, u_{s,2}, u_{s,3}$ and $v_1, v_2, v_{s,1}, v_{s,2}, v_{s,3}$ respectively such that $u_1^2 + v_1^2 = V_1^2$. Effective eddy diffusivity is calculated using the formula

$$K_z(\eta) = \langle H \rangle^2 \left[\frac{\partial \langle S \rangle}{\partial \eta} \right]^{-1} \left[\int_0^\eta \frac{\partial \langle S' \rangle}{\partial t} d\eta + \nabla \langle \bar{S} \rangle \int_0^\eta \langle \bar{V}' \rangle d\eta \right]$$

where $\langle S' \rangle = \langle S \rangle - \langle \bar{S} \rangle$
 $\langle V' \rangle = \langle V \rangle - \langle \bar{V} \rangle$

$\frac{\partial \langle S' \rangle}{\partial t}$ is the rate at which $\langle S' \rangle$ is changing

with time through successive tidal cycles. Since we had data for only one complete tidal cycle steady

state condition was assumed i.e. $\frac{\partial \langle S' \rangle}{\partial t} = 0$ and the

equation for K_z reduces to

$$K_z(\eta) = \langle H \rangle^2 \left[\frac{\partial \langle S \rangle}{\partial \eta} \right]^{-1} \left[\nabla \langle \bar{S} \rangle \int_0^\eta \langle \bar{V}' \rangle d\eta \right]$$

where $\nabla \langle \bar{S} \rangle = \frac{\partial \langle \bar{S} \rangle}{\partial X} + \frac{\partial \langle \bar{S} \rangle}{\partial Y}$

Results and Discussion

Section 1—Figs 2a and b show \tilde{H} and \tilde{S} against time at sts A and B respectively. There was no time lag between salinity and tide. In Figs 2c and d $\langle V \rangle$ and $\langle S \rangle$ at sts A and B were plotted against η . At st A, $\langle V \rangle$ increased from surface to $\eta = 0.4$ and thereafter decreased. Tide averaged current throughout the depth was seaward. Surface to bottom difference of tide averaged salinity $\langle S \rangle$ was 0.48×10^{-3} . For st B, $\langle V \rangle$ decreased from surface to bottom monotonically. Surface to bottom difference of tide averaged salinity $\langle S \rangle$ was 0.27×10^{-3} . From the vertical salinity structure of both stations it followed that estuary was well mixed during the period of observations.

Table 1 gives the transverse and axial components of residual fluxes at sts A and B in section 1 together with their mean values. Mean value was assumed as representative of the section. In this section, residual flux of water was the major factor influencing the salt and water budget. Salt transport due to vertical

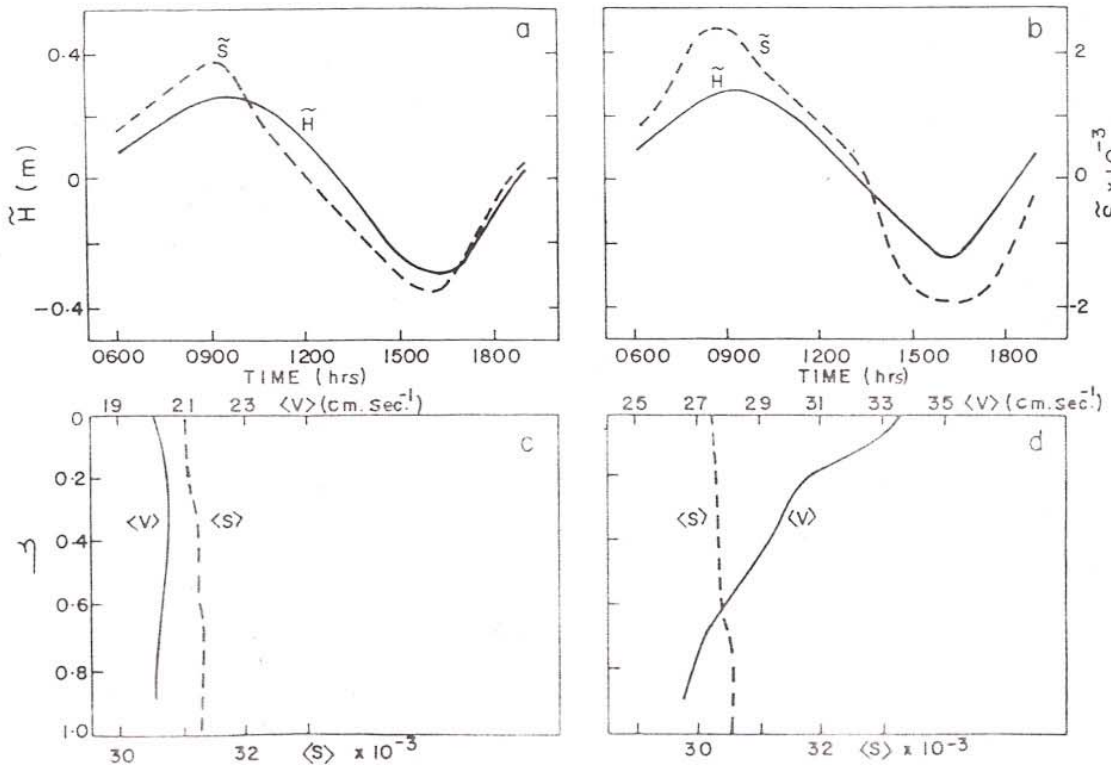


FIG. 2— \tilde{H} and \tilde{S} variation with time (a and b), $\langle V \rangle$ and $\langle S \rangle$ against η (c and d), at sts A and B respectively.

shear in the tidal and residual current was negligible compared to Stokes drift.

Effective eddy diffusivity at section 1 was calculated by taking the average of the values of $\langle S \rangle$ and $\langle V \rangle$ of sts A and B corresponding to each non-dimensional depth and using the averaged value of $\langle H \rangle$ for the 2 stations. Fig. 3a shows K_z values against η . K_z attains maximum value $16.40 \text{ cm}^2 \text{ sec}^{-1}$ at $\eta = 0.4$ and decreased towards either side. This obeyed the classical pattern that K_z tends to increase towards mid depth for near homogeneous condition where eddies are larger due to their less limitation by boundaries^{4,5}.

Section 2—A minor arm of the Chalakkudy river contributes fresh water to the Azikode estuary at a distance of 1 km seaward of this section. Influence of this river was very much reflected on the salinity variation with tide (Figs 4b, d and f). Unlike in section 1, an inverse relation between salinity and tide was observed—at high tide low salinity and at low tide high salinity. This was due to the impounding of the fresh water discharged by the Chalakkudy river by the flood tide and during low tide high surface velocity exposed the bottom water which was highly saline due to salt intrusion.

Figs 4a, c and e show $\langle V \rangle$ and $\langle S \rangle$ variations with η . At st C, tide averaged velocity was seaward at all depths, maximum value being at the surface. $\langle S \rangle$ increased from surface to bottom. For st D, $\langle V \rangle$ was seaward from $\eta = 0$ to $\eta = 0.54$ and landward thereafter. $\langle S \rangle$ shows the same pattern that of st C. For st E, $\langle V \rangle$ was seaward from surface to $\eta = 0.7$ and landward thereafter. Average of the tidal mean salinity $\langle S \rangle$ difference between the surface and bottom of all the stations in this section was 8×10^{-3} , which showed that estuary was highly stratified in this region.

Table 1 also gives the transverse and axial components of residual fluxes for sts C, D and E and their mean values. In this section salt flux due to the verti-

cal current shear was the second important factor next to salt transport due to residual flow of water. This also showed that the water column was highly stratified in this part of the estuary.

Fig. 3b shows the values of effective eddy diffusivity against non-dimensional depth η of section 2. K_z values were low in section 2 compared to section 1. This was due to the lesser tidal action and increasing stratification. Maximum value of K_z was at $\eta = 0.2$ and a second maximum was observed at $\eta = 0.8$. Similar pattern, observed in James estuary⁶, was attributed to the strong vertical mixing above and below the halocline and a region of relatively high stability in the vicinity of the halocline. However, in the present study the high values at $\eta = 0.3$ can be attributed only to the shear produced due to the steep velocity gradient from surface to mid-depth and the second maximum due to the near homogeneous condition below $\eta = 0.8$.

In Azikode estuary, salt and water budget is controlled by different flow factors in the estuary. In section 1, seaward residual flow of water and Stokes drift were the major components which determines

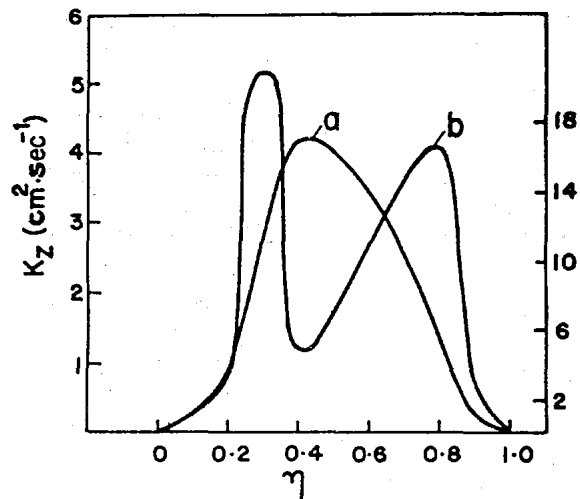


Fig. 3— K_z values against η at section 1, (a), and at section 2, (b)

Table 1—Axial (u) and Transverse (v) Components of Residual Fluxes of Water and Salt at Stations in Sections 1 and 2 and Their Mean Values

	u_1^*	u_2^*	$u_{c,1}^f$	$u_{c,2}^f$	$u_{c,3}^f$	v_1^*	v_2^*	$v_{c,1}^f$	$v_{c,2}^f$	$v_{c,3}^f$
Section 1										
St A	19.06	-6.07	422.0	-31.07	-0.20	2.40	-0.82	51.90	-3.87	-0.02
St B	22.45	-0.07	679.5	-11.34	-1.19	16.31	-0.05	494.20	-8.20	-0.86
Mean	21.02	-3.07	550.8	-21.20	-0.69	9.35	-0.44	273.10	-6.00	-0.44
Section 2										
St C	2.29	-0.05	68.60	2.26	-2.20	1.32	-0.03	39.60	1.30	-1.27
St D	2.05	-0.09	59.41	2.48	-11.33	1.28	-0.06	37.12	2.08	-7.08
St E	3.72	-0.10	106.33	0.89	-7.38	2.27	-0.06	65.35	0.54	-4.53
Mean	2.68	-0.08	78.11	1.87	-6.97	1.62	-0.05	47.35	1.30	-4.29

Units: *— $(\text{cm} \cdot \text{sec}^{-1})$; f— $(10^{-3} \text{ g} \cdot \text{cm}^{-2} \cdot \text{sec}^{-1})$

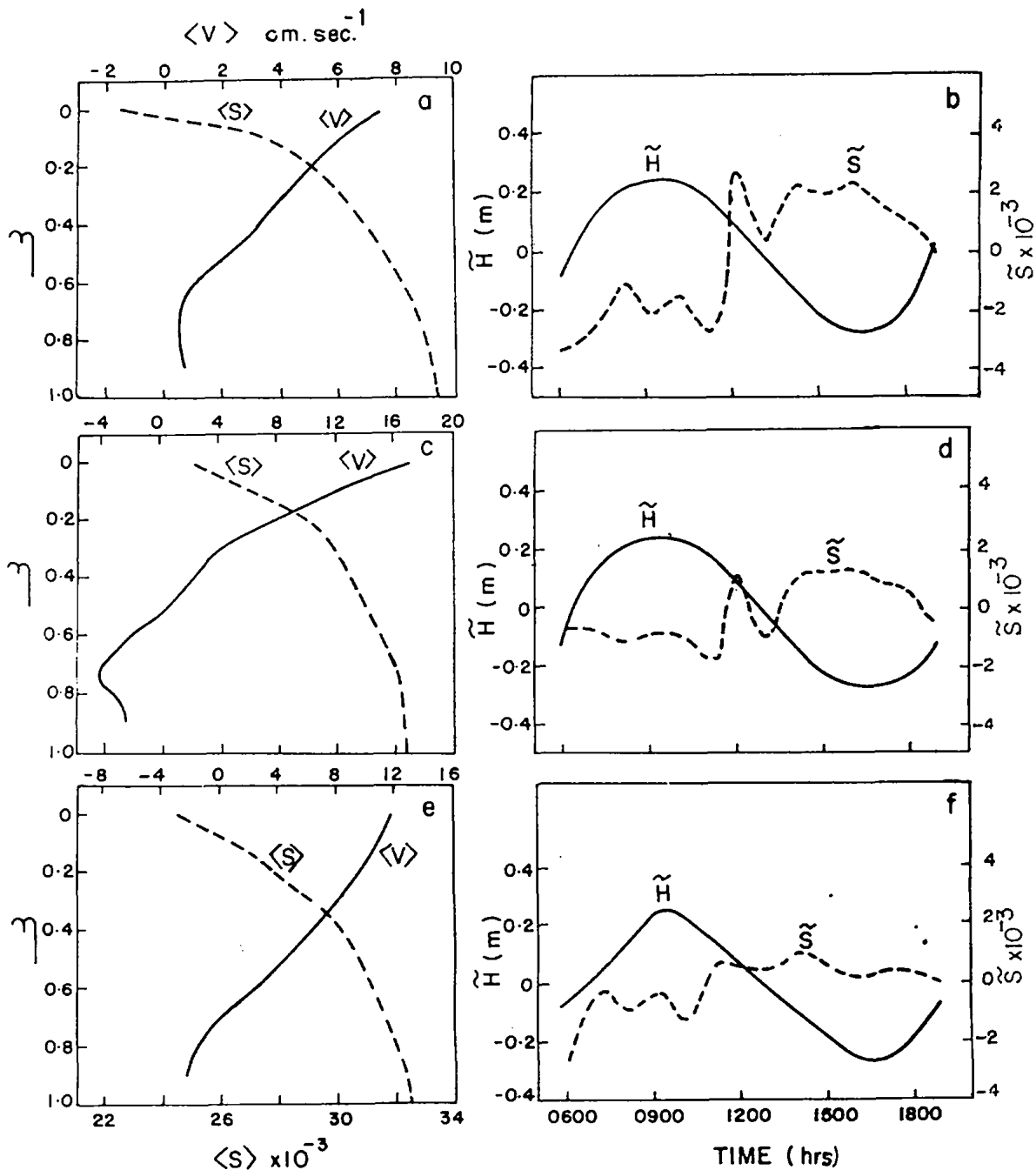


Fig. 4— $\langle \tilde{H} \rangle$ and $\langle \tilde{S} \rangle$ variation with time (a, c and e), and $\langle v \rangle$ and $\langle s \rangle$ against η (b, d and f) at st C, D and E respectively

the salt and water budget whereas in section 2, Stokes drift played only a minor role in the budget. Salt transport due to vertical shear was found to be increasing in section 2, where estuary was highly stratified.

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