Jour. Indian Association of Sedimentologists, Vol. 11 (1992), pp. 55-69

SPATIAL AND TEMPORAL DISTRIBUTION OF TOTAL SUSPENDED MATTER AND OTHER ASSOCIATED PARAMETERS IN THE ZUARI ESTUARY, GOA

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Abstract

The total suspended matter (TSM) during the fair weather season increases from the mouth to about one third of the length (Cortalim) of the Zuari estuary and then it decreases towards upstream. Although the TSM content increases remarkably with the onset of the monsoon at its peak the amount of TSM decreases considerably reaching a minimum in September. The zone of high TSM concentration (about 5 km length) occurs during the fair weather season towards the downstream side of Cortalim, and then it disappears gradually during the monsoon. At any given place in the Zuari estuary the TSM value is always higher in the near bottom waters than in the near surface waters. Salinity decreases from the mouth towards upstream. The *p*H and salinity share a direct relationship in the tidal reaches of the estuary and the temperature of the water is influenced by the atmospheric temperature. The overall distribution of TSM and other parameters reflect the conditions associated with moderately high flood currents within the estuary. The study also reveals that the estuary assumes a partly mixed state during the monsoons and returns to completely mixed nature during the fair weather season.

Introduction

Sediment is transported from land to sea through rivers and discharged into the sea through estuaries, mainly in the form of suspension load. The total discharge of suspended sediment by the world's rivers to the marine environment is estimated by Holeman (1968) at about 18 billion tons per year. Milliman (1980) said that most rivers have an average suspended sediment concentration between 100 and 1000 mg/l. Concentration of the total suspended matter (TSM) at any point in the estuary depends upon the sediment input and sediment movement. The sediment input to the estuary may be from three sources, viz., the catchment area, the marginal cliffs on the river banks, and the sea, although frequent regional patterns of dominant source from land or sea are discernible (McManus, 1975). Sediment movement inside the estuary is related to turbulence or other circulation patterns. These patterns are complete interplays of ever-changing river and tidal flows, complicated by fresh water rate, the tidal range, salinity gradient, the effect of topography and estuarine geometry (Dyer 1972; Markofsky *et al.*, 1986).

In the present study an attempt is made to understand spatial and temporal distribution of TSM, salinity, *p*H and temperature in the Zuari estuary.

The Zuari Estuary

Nature has bestowed upon the state of Goa an excellent system of interconnected and navigable waterways. The rivers that contribute to this remarkable waterways system are mainly the Zuari and the Mandovi, and are therefore rightly called the 'lifeline' of the state. These rivers originate in the Western Ghats and flow through the state to join the Arabian Sea. Confined between latitude 15° 09′ and 15° 33′N and longitude 73° 45′ and 74° 14′E their basins cover 69 percent of the total geographical area of the state. The

Zuari is about 70 km long with a catchment area of 550 sq km. The average annual fresh water runoff is estimated to be 9 cu. km. In upstream region of the estuarine portion, the Zuari is 0.5 km wide while at the mouth it is 5.5 km wide. The Mormugao harbour is situated at its mouth.

Materials and Methods

For the present study, a total of 23 stations were selected along the length of the Zuari estuary. Samples were collected from the near surface and near bottom at all the stations (Fig. 1) using a Niskin water sampler and aboard a trawler, except at stations 22 and 23 which are beyond navigable limits. At these stations only near surface water samples were collected using a bucket. Collection was carried for 12 months from March 1990 to February 1991 with an interval of one month. *p*H and temperature were recorded in the field. Samples were analysed for TSM content and salinity in the laboratory. TSM was estimated by filtering one litre of water through pre-weighed 0.47μ nucleopore membrane filter paper, which was then over dried at .60°C. Salinity was determined by Mohr-Knudson Chlorinity titration method.

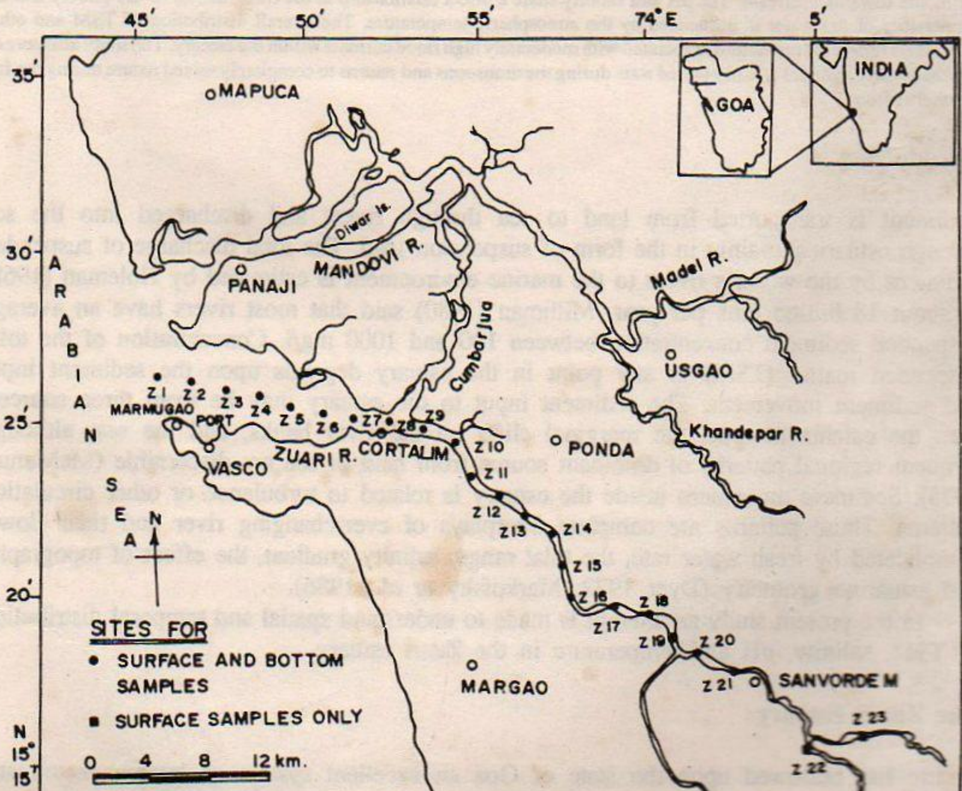

Fig. 1. Station location along Zuari river.

Results

1. *Total Suspended Matter (TSM)*

The general behaviour of TSM during the pre-monsoon period in the Zuari estuary is that its concentration progressively increases from station 1 at the mouth to station 8/9 in the midstream region. However, further ahead the TSM concentration gradually decreases up to station 23 at the upstream end. The concentration ranges between 1.22 mg/l and 185.44 mg/l. One of the conspicuous features observed during this season is the presence of a high concentration zone lying between stations 7 and 9. At this zone TSM values are considerably high for both surface and bottom waters (Table 1).

The distribution pattern of TSM observed in pre-monsoon changes progressively with the onset of the monsoon in late May and continued through September. The TSM concentration during late May ranges from 3.01 to 219.53 mg/l and that in September from 2.38 to 17.59 mg/l. The main features during this season are the gradual decrease in the overall average concentration from late May to September, considerable decrease in range of concentration, gradual disappearance of the zone of high concentration and development of another zone of high concentration (from late May to August) between stations 18 and 21 (Table 1). The least variation in the range is observed in September showing virtually a homogeneous distribution of TSM.

The post-monsoon season begins to show the features dominant of this period. The TSM concentration gradually increases from station 1 to 8/10 and decreases further upstream. There is development of another zone of slightly higher concentration between stations 15 and 18. The TSM during this season ranges from 3.46 mg/l to 293.19 mg/l. The overall concentration of TSM also increases as compared to late monsoon. In January, bottom waters show high TSM concentration between stations 5 and 11 but the surface waters show a higher value at station 10 only. February shows a still higher concentration in this zone. Beyond the zone of high concentration, the TSM values gradually decrease in the upstream direction.

In all the seasons, the concentration of TSM in bottom waters is almost always higher than that of surface waters. The trend followed by both is, however, almost identical.

2. *Salinity*

Salinity is one of the conspicuous features of an estuary in defining its limits and characteristics. In the Zuari, during pre-monsoon the length of intrusion of sea water increases from March to May (Figs. 2 and 3). Salinity is high near the mouth (Station 1) and it remains nearly constant up to station 10-12 (Table 2). Beyond this, there is a sharp fall and salinity continues to decrease towards upstream. Presence of saline waters is observed up to station 22 during May in this estuary. Although the bottom waters are invariably more saline than surface waters, there is no such difference and the trend is identical at both the levels.

The monsoon season is marked by extreme fall in salinity as also the length of the salt water intrusion from June to August. Wide difference in salinity between surface and bottom waters exists up to the point of intrusion of saline waters (Figs. 2 and 3). In late May and September more saline waters are observed at station 16, and in August high salinity waters occur between stations 7 and 10 in the bottom waters (Fig. 4).

Salinity increases from September to February, and saline waters bore progressively longer length towards upstream. During December salinity reverts to its pre-monsoon characteristics of almost vertically homogeneous waters throughout the length of the estuary.

TABLE 1 : ZUARI – TOTAL SUSPENDED MATTER (TSM) (mg/l) 1990-91

Stn.	Depth	Mar	Apr	May	Late May	June	July	Aug	Sept	Nov	Dec	Jan	Feb
1	Surface	5.52	7.39	9.16	*	*	*	*	3.36	4.95	3.58	6.94	18.43
	Bottom	18.57	38.40	29.21					5.73	9.94	3.98	10.29	26.10
2	Surface	10.09	7.25	1.92	25.21	*	*	*	5.11	6.22	3.46	6.24	15.73
	Bottom	13.97	24.65	4.43	219.53				8.75	20.83	5.66	22.01	28.85
3	Surface	8.75	11.31	4.12	24.29	13.63	10.63	6.55	2.90	4.54	6.15	6.23	18.93
	Bottom	17.52	37.54	7.87	55.51	12.06	18.25	5.34	3.88	14.35	6.68	14.89	44.79
4	Surface	12.15	29.42	8.78	48.36	14.74	14.07	8.80	3.94	10.91	5.59	14.55	24.65
	Bottom	18.33	53.72	8.87	134.74	17.96	10.48	12.22	5.70	12.56	6.58	33.60	83.92
5	Surface	20.18	49.63	9.58	94.17	21.46	11.80	5.83	2.66	13.10	8.94	25.45	36.90
	Bottom	26.70	76.80	16.40	73.26	60.32	23.91	19.90	8.44	19.62	6.20	19.76	119.05
6	Surface	65.49	30.57	19.78	30.43	23.06	18.21	12.89	4.57	21.13	9.68	25.61	42.87
	Bottom	162.38	55.32	64.43	79.35	76.22	48.95	12.73	8.00	26.71	9.59	51.28	89.46
7	Surface	27.52	40.07	51.32	42.36	28.01	35.41	10.49	8.95	14.56	7.26	23.60	40.61
	Bottom	37.84	78.90	158.70	106.69	35.74	36.05	18.57	7.91	38.45	18.27	76.48	94.98
8	Surface	35.82	43.34	43.64	30.25	36.53	20.05	7.98	3.88	18.96	12.60	13.01	32.76
	Bottom	185.44	95.35	164.98	120.40	41.36	49.66	11.81	9.00	65.99	15.10	51.96	293.19
9	Surface		26.38	19.30	33.74	34.85	36.38	8.46	3.97	16.53	12.70	13.67	38.03
	Bottom		141.46	21.86	50.10	226.85	30.21	15.58	17.59	55.39	20.99	24.30	115.62
10	Surface	27.98	10.63	6.76	7.25	38.91	12.89	10.34	4.59	34.10	12.43	91.61	17.65
	Bottom	39.21	18.56	10.18	46.69	42.75	12.55	8.47	4.72	31.18	45.55	80.39	24.56
11	Surface	21.05	12.49	9.97	13.37	32.55	13.57	8.56	3.53	11.65	11.50	32.49	16.97
	Bottom	49.09	12.80	12.60	22.02	37.52	13.07	6.31	5.91	62.33	37.40	80.21	35.43
12	Surface	26.07	10.58	8.07	10.99	32.32	8.90	9.04	4.03	7.77	10.14	19.87	27.61
	Bottom	45.63	15.56	7.19	12.01	32.78	10.62	5.89	5.92	18.44	33.89	42.42	23.27
13	Surface	9.25	9.86	7.32	5.17	24.73	10.34	9.66	4.27	9.27	*	15.50	13.81
	Bottom	25.86	12.42	6.67	17.96	24.73	10.30	4.93	4.32	9.15		51.51	17.73
14	Surface	9.41	5.65	3.79	5.14	26.05	9.42	10.61	4.37	7.72	7.55	24.18	15.16
	Bottom	24.18	22.08	9.93	22.68	30.83	9.94	10.05	7.25	18.94	16.18	38.84	33.41
15	Surface	8.79	6.88	8.86	9.47	31.92	11.00	7.14	8.74	25.53	8.08	10.48	11.93
	Bottom	10.16	12.09	10.84	14.02	30.34	10.49	9.21	4.17	13.54	10.11	10.20	23.98
16	Surface	6.59	9.73	5.67	9.43	13.91	8.47	9.70	5.81	11.52	10.11	15.62	12.05
	Bottom	11.54	34.50	6.99	17.32	31.71	9.57	10.97	6.17	35.18	54.13	29.70	19.75

* Samples not collected.

Stn	Depth	Mar	Apr	May	Late May	June	July	Aug	Sept	Nov	Dec	Jan	Feb
17	Surface	5.76	7.04	8.09	15.52	31.58	7.86	8.13	6.26	16.36	13.02	5.76	17.23
	Bottom	16.66	12.80	8.72	15.78	32.94	8.35	9.94	4.41	38.15	32.89	8.35	17.62
18	Surface	8.79	5.57	7.36	25.54	26.01	5.71	12.38	3.79	11.22	9.58	6.41	12.17
	Bottom	9.18	7.06	9.42	35.73	26.64	5.17	11.74	4.39	20.72	15.50	7.57	15.95
19	Surface	9.85	12.51	8.88	22.02	41.29	4.60	11.28	2.90	13.77	9.20	6.24	11.22
	Bottom	14.50	10.33	11.32	46.32	42.40	5.03	14.42	4.03	15.77	14.41	8.36	17.52
20	Surface	6.30	8.12	9.72	21.44	47.45	2.12	14.63	3.40	13.66	7.82	4.71	5.34
	Bottom	6.84	10.39	8.39	25.62	70.64	5.76	15.80	4.12	14.35	9.52	6.39	7.45
21	Surface	6.51	18.05	7.58	28.93	56.85	3.54	16.37	2.38	12.55	7.36	10.87	13.17
	Bottom	8.12	17.16	7.73	26.46	70.08	8.10	14.25	2.39	15.77	8.81	13.56	14.59
22	Surface	2.77	1.38	1.94	3.01	13.86	146.07	28.80	8.87	4.65	6.12	7.34	7.60
23	Surface	1.22	3.83	3.96	14.11	24.18	19.15	17.71	6.56	4.01	4.71	9.26	3.59

TABLE 2 : ZUARI - SALINITY (PARTS PER THOUSAND) 1990-91

Stn	Depth	Mar	Apr	May	Late May	June	July	Aug	Sept	Nov	Dec	Jan	Feb
1	Surface	35.37	35.53	37.15	*	*	*	*	31.82	33.88	34.44	35.00	35.56
	Bottom	35.55	36.22	36.64					36.31	35.56	35.19	35.00	35.56
2	Surface	35.37	35.88	36.82	34.34	*	*	*	30.13	33.32	35.19	34.80	35.00
	Bottom	34.63	35.53	36.82	36.04				34.63	35.75	35.56	35.19	35.00
3	Surface	34.08	35.88	36.64	34.15	8.58	11.09	10.11	22.46	33.32	34.06	34.44	35.00
	Bottom	34.82	36.22	36.64	35.28	26.51	24.10	27.85	34.06	33.88	34.81	34.80	35.00
4	Surface	34.08	36.58	36.14	34.15	8.39	9.95	9.73	20.21	33.13	33.32	34.23	34.06
	Bottom	34.82	35.88	36.14	34.34	19.26	28.27	18.69	33.69	32.75	34.81	33.88	34.44
5	Surface	33.90	36.58	36.14	33.49	17.63	9.18	5.34	20.96	32.38	33.69	33.69	33.69
	Bottom	34.27	35.53	36.14	34.06	18.12	11.86	17.17	33.32	32.75	34.81	34.25	33.69
6	Surface	33.90	35.35	35.80	32.26	7.06	7.65	4.77	18.90	31.44	33.32	33.50	33.32
	Bottom	33.35	35.35	35.80	33.21	12.78	11.09	16.59	32.19	31.44	33.69	32.94	33.69
7	Surface	33.35	35.17	35.44	26.41	2.67	6.69	3.62	16.10	29.95	32.57	32.57	32.57
	Bottom	34.27	34.46	35.44	30.38	8.20	7.08	24.99	30.70	30.70	33.32	32.94	32.94
8	Surface	33.35	34.46	35.94	26.23	1.91	6.31	1.91	18.72	29.39	31.44	32.19	32.19
	Bottom	32.98	34.83	35.57	29.15	10.30	7.84	30.52	31.07	30.32	32.38	32.19	32.57

Table 2 (*contd. on* p. 60)

* Samples not collected.

Table 2 (*contd. from* p. 59)

Stn	*Depth*	*Mar*	*Apr*	*May*	*Late May*	*June*	*July*	*Aug*	*Sept*	*Nov*	*Dec*	*Jan*	*Feb*
9	Surface	*	34.83	35.39	27.17	0.95	4.49	0.95	21.52	26.39	30.51	30.70	32.00
	Bottom		34.12	35.94	28.30	5.25	6.60	28.04	30.51	29.39	31.82	31.60	32.19
10.	Surface	32.25	34.12	34.63	23.02	0.19	1.34	1.14	11.98	23.40	28.82	28.60	31.44
	Bottom	31.52	34.12	35.20	29.24	0.19	2.96	27.66	29.39	26.02	29.57	29.20	31.44
11.	Surface	28.77	33.25	34.27	22.26	0	0.48	1.24	11.23	21.52	26.95	27.33	30.32
	Bottom	29.87	33.25	35.20	26.41	0.19	0.57	16.20	24.45	26.02	27.70	28.26	31.07
12.	Surface	28.77	32.03	34.45	19.80	0	0.38	0.38	10.11	20.96	25.08	24.89	24.71
	Bottom	29.32	32.03	34.64	23.21	0	0.29	16.02	27.40	23.40	*	26.58	26.20
13.	Surface	27.30	30.98	33.14	20.57	*	0.19	0.19	7.67	17.59		23.21	26.20
	Bottom	28.04	30.62	33.14	21.89		1.43	17.36	26.20	21.71		24.71	27.32
14.	Surface	25.29	27.78	31.10	13.02	*	0.09	0.14	6.74	15.35	21.34	20.78	22.65
	Bottom	25.47	28.14	31.84	16.41		0.09	1.43	25.01	16.66	23.21	21.71	24.52
15.	Surface	22.54	24.06	27.75	8.87	*	0.09	0	2.99	9.17	16.47	17.59	20.03
	Bottom	22.45	24.24	27.94	9.62		0.19	0	7.49	10.67	17.59	19.09	20.21
16.	Surface	21.07	22.29	26.63	13.58	*	0.09		3.56	5.43	13.85	16.47	17.78
	Bottom	21.63	22.65	25.70	14.90		0		15.35	7.67	15.35	17.78	19.09
17.	Surface	18.60	18.90	22.53	5.28	*	*	*	0.56	3.18	11.23	14.40	15.35
	Bottom	17.32	19.00	22.53	8.68				3.18	3.37	11.23	15.50	16.28
18.	Surface	14.48	14.30	18.25	1.89	*	*	*	0.09	0.94	7.11	10.67	9.92
	Bottom	14.66	14.58	18.63	1.89				0	1.31	7.11	11.60	10.29
19.	Surface	9.90	11.51	15.27	1.32	*	*	*	*	0.47	3.37	7.49	6.36
	Bottom	10.99	11.68	15.27	1.32					0.47	4.12	8.24	6.74
20.	Surface	5.50	6.47	9.87	0.94	*	*	*	*	0.28	1.31	4.12	2.43
	Bottom	5.50	6.83	9.49	0.75					0.28	1.50	3.93	2.43
21.	Surface	2.11	2.94	4.65	0.57	*	*	*	*	0	0	1.68	1.12
	Bottom	2.20	2.58	4.65	0.57					0	0.37	1.68	1.12
22.	Surface	0.18	0	0	0	*	*	*	*	*	0	0	0
23	Surface	0.09	0	0	0	*	*	*	*	*	*	*	*

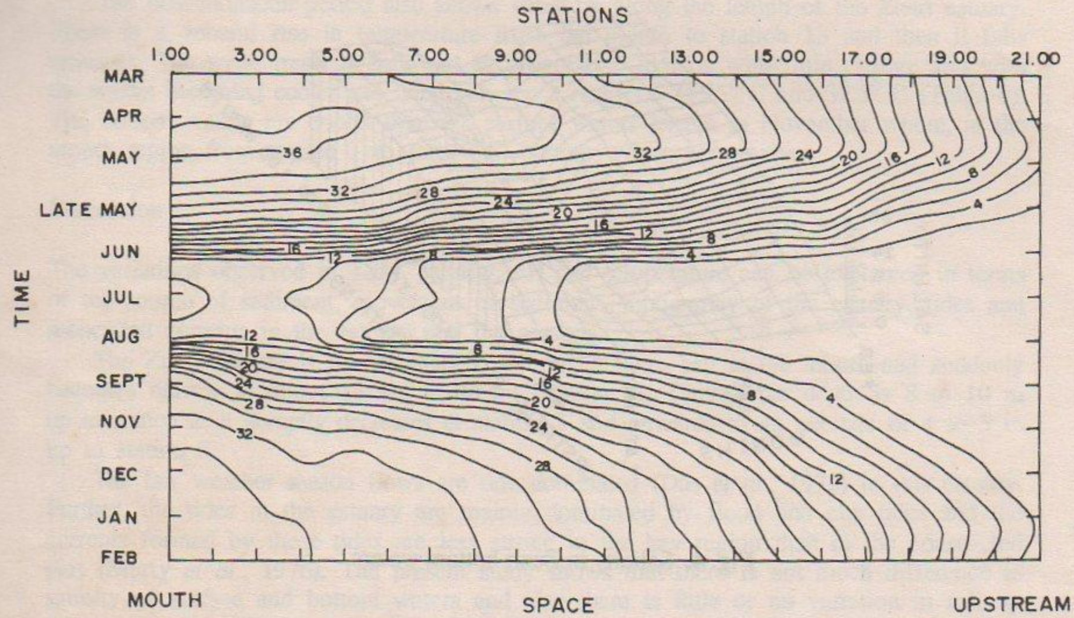

Fig. 2. Salinity in Zuari surface waters.

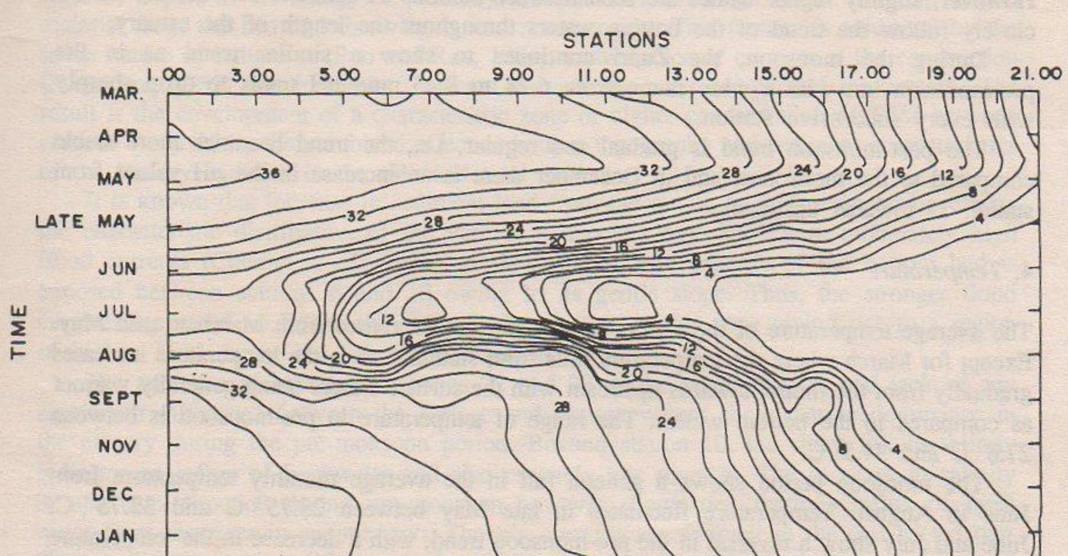

Fig. 3. Salinity in Zuari bottom waters.

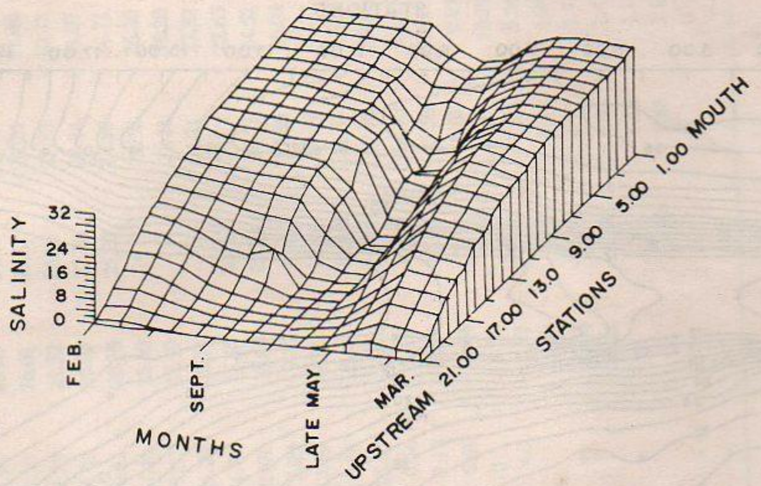

Fig. 4. Salinity in Zuari bottom waters.

3. *pH*

The pre-monsoon period shows little change in the trend of *p*H, and the *p*H value decreases from the mouth towards upstream over a range of 7.08 to 8.15 (Table 3). However, slightly higher values are seen between stations 19 and 21. The surface waters closely follow the trend of the bottom waters throughout the length of the estuary.

During the monsoon, the Zuari continues to show a similar trend as in the pre-monsoon but with a wide range from 6.24 to 8.25, and *p*H tends to drop sharply with every successive station.

The post-monsoon trend is gradual and regular, i.e., the trend becomes more stable compared to the monsoons, and in December there is an increase in the *p*H values from station 19 towards upstream.

4. *Temperature*

The average temperature of the waters in pre-monsoon increases from March to mid May. Except for March where the temperature falls from station 1 to 6, the temperature increases gradually from the mouth towards upstream with the surface waters being generally warmer as compared to the bottom waters. The range of temperature in pre-monsoon is between 27.8° C and 34.5° C.

The monsoon period shows a general fall in the average monthly temperature from June to August. Temperature fluctuates in late May between 28.75° C and 32.75° C. June and July show a reversal in the pre-monsoon trend, with a decrease in the temperature from the mouth towards upstream. Both surface and bottom waters follow the same trend with slight difference from mouth to about station 10. In August and September, the temperature of the surface waters decrease from the mouth to upstream, but that of the bottom waters increase from the mouth to upstream up to station 16. Bottom waters were observed to be cooler than surface waters.

The post-monsoon period also shows variation along the length of the Zuari estuary. There is a general rise in temperature from the mouth to station 13 and then it falls onwards. The same trend is followed in progressive months with little change and with the waters becoming cooler and lying between a range of 24.25° C and 32.5° C (Table 4). The bottom waters are cooler than the surface waters except in November where, at the mouth region from station 1 to station 8, bottom waters are warmer.

Discussion

The variations observed in TSM, salinity, *p*H and temperature can be explained in terms of the source of sediment, movement of sediment, topography of the estuary, tides and associated currents in the estuary and the seasons.

The Zuari estuary is funnel shaped, forming a large bay at the mouth and suddenly becomes narrow at about 18 km upstream (station 9). Though the depth is 8 to 10 m up to station 2, it abruptly decreases at station 3 and onwards to an average of 4 to 5 m up to station 8.

The fair weather season flows are tide dominated (Das *et al*., 1972) in this estuary. Further, the tides in the estuary are mainly dominated by flood and ebb tides and the currents formed by these tides are less strong in the bay region than in the constricted part (Murty *et al*., 1976). The present study shows that there is not much difference in salinity of surface and bottom waters and also there is little or no variation in salinity from station 1 to station 10-12 during the fair weather season. This indicates that during this period the sea water is boring into the estuary *en masse* with the tidal surge, replacing the brackish or fresh water. The specific relation existing between tide and salinity was also shown earlier (Singbal, 1976; Purandare, 1988). As the tidal surge encounters shallow regions, a part of its energy is probably dissipated. This brings about churning of the material from the bed and throwing it into resuspension. This feature is enhanced by the softer nature of sediments (Rao and Rao, 1974), convergence of currents at the constriction (Purandare, 1989) and increasing currents towards the narrower part of the estuary. The result is the development of a characteristic zone of higher concentration of TSM between stations 7 and 10 by the combined effect of bottom topography and sediment characteristics of the estuary and rise in the tide and tidal currents.

It is known that increase in sediment load from the mouth to midstream fairly reflects the characteristic distribution of the various parameters associated with moderately high flood currents (Cherian *et al*., 1975). At low tide, a vast expanse of the bottom bed is exposed between stations 6 and 10 owing to its gentle slope. Thus, the stronger flood currents may tend to disturb the sediment by attrition in this zone giving rise to a region of higher TSM during the fair weather season.

The presence of salinity at stations 22 and 23 in the upper reaches and lack of any significant difference between the surface and bottom waters show marine dominance in the estuary during the pre-monsoon period. Beyond station 10, the sharp fall in salinity indicates an influx of freshwater and also probably tide reversal. The decrease in salinity in upstream direction during pre-monsoon however shows that there is influx of fresh water from the river in summer too. Though, currents are stronger in the constricted part than in the bay region (Murty *et al*., 1976) and carry high TSM, the concentration of TSM drops beyond station 10 because of dilution of the sea water by fresh water.

Within the tidal reaches of the *p*H seems to be directly related to salinity. The sudden rise in *p*H values from station 19 onwards in the Zuari during fair weather season may be due either to the influence of the Quepem tributary or to the wetlands around the region.

TABLE 3 : ZUARI *p*H–1990-91

Stn	*Depth*	*Mar*	*Apr*	*May*	*Late May*	*June*	*July*	*Aug*	*Sept*	*Nov*	*Dec*	*Jan*	*Feb*
1	Surface	8.06	8.06	8.12	*	*	*	*	7.92	8.00	8.04	7.97	8.04
	Bottom	8.00	8.11	8.12					7.76	8.00	8.11	7.96	8.09
2	Surface	8.10	8.06	8.12	7.98	*	*	*	7.98	8.02	8.11	7.98	8.07
	Bottom	8.06	8.05	8.08	7.92				7.79	8.07	8.14	7.99	8.08
3	Surface	8.04	8.06	8.15	7.98	7.70	7.99	7.93	7.97	7.98	8.09	8.01	8.07
	Bottom	8.05	8.04	8.12	7.96	7.73	7.76	7.68	7.97	8.10	8.13	8.01	8.08
4	Surface	8.03	8.04	8.15	7.98	7.70	8.12	7.97	7.95	8.05	8.14	7.98	8.00
	Bottom	8.05	8.04	8.15	7.97	7.73	7.95	7.81	7.97	8.03	8.15	7.97	8.04
5	Surface	8.01	8.00	8.13	7.96	7.75	8.25	8.02	7.95	7.99	8.10	7.96	7.95
	Bottom	7.99	8.01	8.14	7.97	7.68	8.09	7.71	7.89	7.96	8.11	7.96	7.97
6	Surface	7.96	7.98	8.13	7.99	7.68	8.23	8.07	7.89	7.95	8.06	7.90	7.89
	Bottom	8.02	7.97	8.13	7.96	7.68	7.91	7.55	7.82	7.94	8.06	7.91	7.95
7	Surface	7.93	7.95	8.10	7.94	7.63	8.15	7.67	7.86	7.88	8.03	7.87	7.83
	Bottom	8.01	7.97	8.08	7.93	7.63	7.99	7.50	7.78	7.90	8.03	7.88	7.77
8	Surface	7.98	7.93	8.10	7.95	7.56	8.14	7.36	7.86	7.84	7.98	7.85	7.83
	Bottom	7.96	7.97	8.07	7.93	7.57	7.76	7.53	7.84	7.83	8.03	7.86	7.77
9	Surface	*	7.90	8.08	7.92	7.38	8.14	7.17	7.86	7.90	7.92	7.82	7.77
	Bottom		7.95	8.08	7.90	7.19	8.02	7.56	7.81	7.83	7.97	7.82	7.77
10	Surface	7.91	7.88	8.06	8.10	6.86	7.49	7.17	7.84	7.63	7.89	7.71	7.77
	Bottom	7.91	7.87	8.08	7.85	7.00	7.43	7.54	7.75	7.62	7.89	7.72	7.77
11	Surface	7.89	7.86	8.04	8.09	7.06	7.47	7.06	7.86	7.58	7.85	7.70	7.74
	Bottom	7.88	7.85	8.03	7.84	7.05	7.38	7.41	7.69	7.60	7.84	7.68	7.74
12	Surface	7.90	7.84	8.03	8.05	7.07	7.30	7.11	7.65	7.52	7.79	7.67	7.67
	Bottom	7.89	7.83	8.04	7.70	7.04	7.24	7.35	7.67	7.52	7.82	7.67	7.70
13	Surface	7.90	7.84	8.00	7.94	7.05	7.25	6.93	7.55	7.45	*	7.65	7.63
	Bottom	7.88	7.83	8.01	7.69	7.05	7.18	7.25	7.61	7.47		7.63	7.63
14	Surface	7.82	7.78	7.98	7.52	7.03	7.05	6.89	7.50	7.35	7.69	7.60	7.35
	Bottom	7.80	7.75	7.95	7.99	7.01	7.05	6.73	7.54	7.14	7.70	7.54	7.57
15	Surface	7.76	7.76	7.91	7.67	6.99	7.03	6.70	7.25	7.16	7.57	7.41	7.43
	Bottom	7.75	7.75	7.91	7.47	6.99	7.00	6.71	7.28	7.19	7.53	7.45	7.45
16	Si face	7.69	7.70	7.88	7.50	6.97	6.95	6.68	7.27	7.08	7.22	7.33	7.33
	Bottom	7.67	7.75	7.88	7.28	6.91	6.82	6.65	7.31	7.09	7.20	7.35	7.35

* Samples not collected

Stn	Depth	Mar	Apr	May	Late May	June	July	Aug	Sept	Nov	Dec	Jan	Feb
17	Surface	7.52	7.64	7.85	7.17	6.88	6.87	6.69	7.18	6.99	6.98	7.28	7.27
	Bottom	7.49	7.64	7.76	7.21	6.91	6.87	6.69	7.06	6.94	7.04	7.29	7.26
18	Surface	7.35	7.31	7.67	7.08	6.87	6.83	6.65	7.14	7.02	6.95	7.17	6.96
	Bottom	7.31	7.40	7.75	7.05	6.87	6.79	6.60	7.08	6.93	6.89	7.15	6.97
19	Surface	7.45	7.15	7.62	6.99	6.84	6.80	6.64	7.04	6.95	6.82	7.03	6.96
	Bottom	7.45	7.10	7.61	7.01	6.84	6.70	6.63	7.03	6.92	6.82	7.02	6.94
20	Surface	7.52	7.08	7.62	7.00	6.83	6.71	6.55	7.01	6.85	7.02	7.08	7.01
	Bottom	7.53	7.44	7.54	6.93	6.84	6.71	6.58	7.02	6.84	6.90	7.01	6.93
21	Surface	7.40	7.32	7.65	7.20	6.82	6.74	6.63	7.02	6.85	7.12	7.01	7.04
	Bottom	7.35	7.31	7.58	7.23	6.85	6.70	6.55	6.96	6.84	7.02	7.00	7.05
22	Surface	7.14	7.22	7.46		6.78	6.24	6.45	7.13	6.81	7.16	7.17	7.14
23	Surface	7.17	7.33	7.17		6.76	6.32	6.65	7.19	6.86	7.04	6.84	7.02

TABLE 4 : ZUARI - TEMPERATURE (°C) 1990-91

Stn	Depth	Mar	Apr	May	Late May	June	July	Aug	Sept	Nov	Dec	Jan	Feb
1	Surface	29.50	31.50	31.50	*	*	*	*	30.50	29.75	27.90	25.40	27.20
	Bottom	28.50	30.00	30.75					26.50	30.25	28.25	25.00	27.30
2	Surface	30.00	31.50	31.50	30.00	*	*	*	30.00	29.75	29.70	25.50	27.20
	Bottom	28.30	30.50	30.50	30.20				26.80	30.25	28.20	24.95	27.00
3	Surface	29.50	31.25	32.00	30.00	29.90	28.50	29.30	31.75	29.80	28.10	25.90	27.20
	Bottom	29.00	30.25	31.75	30.10	28.75	29.50	26.60	28.80	30.25	28.10	24.85	27.10
4	Surface	29.00	31.00	32.00	30.00	29.90	29.75	29.50	31.70	29.80	28.00	25.50	27.20
	Bottom	29.00	31.00	32.00	30.00	29.00	28.50	27.50	29.25	30.00	28.00	24.40	27.00
5	Surface	28.10	31.00	31.75	30.00	29.75	29.50	29.40	31.80	30.00	28.10	25.00	27.30
	Bottom	28.00	31.00	32.25	30.00	29.00	26.00	28.00	29.25	30.25	28.10	24.60	27.30
6	Surface	27.90	31.25	32.00	30.00	29.00	29.00	29.60	32.00	30.00	28.50	24.90	28.00
	Bottom	28.00	31.00	32.05	30.00	29.00	29.00	27.90	29.50	30.25	28.10	25.35	26.90
7	Surface	28.20	30.75	32.75	29.80	29.25	30.00	29.40	31.95	30.25	28.60	25.15	27.10
	Bottom	28.10	31.00	32.25	29.75	28.75	29.25	26.90	29.75	30.45	28.30	24.35	26.90
8	Surface	28.20	32.00	32.25	29.50	29.00	29.75	29.25	31.70	30.25	29.00	24.75	27.10
	Bottom	27.90	31.50	32.50	29.80	28.90	29.00	26.10	29.50	30.25	28.20	24.25	26.90

* Samples not collected.

Table 4 (*contd. on* p.66)

Table 4 (*contd. from* p. 65)

Stn	Depth	Mar	Apr	May	Late May	June	July	Aug	Sept	Nov	Dec	Jan	Feb
9	Surface		31.50	32.75	29.50	29.00	29.90	29.10	31.60	30.25	29.00	25.25	27.15
	Bottom		31.25	32.75	28.75	28.75	29.50	26.40	29.80	30.25	28.75	24.25	27.00
10	Surface	27.80	30.80	32.00	30.75	28.50	29.75	29.20	30.80	31.80	29.50	25.05	27.30
	Bottom	27.80	30.50	*	30.50	28.50	29.50	26.00	28.50	30.50	28.90	25.25	27.00
11	Surface	27.90	30.80	31.75	29.80	28.25	29.75	28.75	30.75	32.05	29.80	25.05	27.30
	Bottom	27.90	30.80	32.00	30.50	28.25	29.75	27.50	28.50	30.50	28.90	25.35	27.10
12	Surface	28.00	31.00	32.15	30.25	28.50	29.50	29.10	31.70	31.25	29.80	25.60	27.40
	Bottom	28.00	31.00	32.25	29.90	28.50	29.50	27.60	29.50	30.50	28.90	25.45	27.50
13	Surface	28.20	31.25	32.25	30.25	28.50	29.50	29.20	30.80	32.50	*	25.80	27.55
	Bottom	28.20	31.25	32.25	29.90	28.75	29.50	27.60	29.80	30.80		25.65	25.50
14	Surface	28.80	31.80	32.50	30.75	28.25	29.50	29.40	30.75	31.75	30.25	26.05	27.95
	Bottom	28.60	31.80	32.75	30.75	28.50	29.50	28.80	30.50	30.80	29.10	25.75	27.80
15	Surface	28.80	31.80	32.75	30.50	28.00	29.50	29.10	31.50	31.25	29.50	25.85	27.80
	Bottom	28.80	31.80	32.80	30.25	28.25	29.50	28.90	30.75	30.80	29.10	25.75	27.50
16	Surface	29.00	32.25	33.25	29.40	28.00	29.50	29.00	31.25	31.75	29.75	26.00	27.90
	Bottom	28.90	32.25	33.00	29.90	27.75	29.50	28.90	30.50	31.00	29.10	25.65	27.00
17	Surface	28.90	32.25	33.25	30.30	27.75	29.25	28.80	31.25	30.10	29.75	26.00	27.85
	Bottom	28.80	32.50	33.25	30.00	27.75	29.50	28.80	30.50	30.70	29.00	25.50	26.75
18	Surface	28.80	32.00	33.50	29.50	27.50	29.25	28.60	30.50	30.50	28.75	26.75	27.00
	Bottom	28.80	31.80	32.80	29.75	27.80	29.00	28.50	30.25	*	28.75	25.50	26.75
19	Surface	28.70	32.25	33.25	29.75	27.60	29.25	28.30	30.20	30.00	28.90	25.40	26.50
	Bottom	28.60	31.80	33.25	29.50	27.60	28.90	28.30	30.25	30.00	28.20	25.10	25.40
20	Surface	28.60	31.80	33.25	29.75	27.60	28.75	27.90	30.25	29.80	28.00	25.10	26.40
	Bottom	28.60	31.25	33.25	29.80	27.60	28.75	27.90	30.00	29.90	28.10	24.90	25.85
21	Surface	29.00	32.25	34.00	31.00	28.00	28.50	27.80	30.75	29.80	28.10	25.40	26.95
	Bottom	28.60	32.00	34.00	30.10	27.75	28.75	27.75	30.25	29.80	27.90	24.90	25.85
22	Surface	29.80	31.75	34.50	31.60	26.50	26.10	26.80	26.90	31.00	28.50	*	27.00
23	Surface	27.80	31.25	32.75	32.75	27.50	27.00	28.10	30.10	30.00	29.80	*	27.25

With the onset of monsoon, the estuary bears a high sediment load in late May and June, but the sediment concentration drops considerably thereafter. This indicates that a large portion of the material from the catchment area is brought in to the system during the early monsoon period. Drop in TSM in the month of July and August, which is generally a period of heavy monsoons shows that the drainage possibly comes from a harder lithological terrain from which loose overlying material is washed off during the initial stages of the monsoon and afterwards clear water from here joins the estuary. The zone of high concentration diminishes with progressing monsoons. This is possibly because strong fresh water flows during the early monsoons may disrupt and then clear the bed of its softer material. Possibly because of this, very high concentration of TSM in bottom waters is observed at this location during June. A second zone of relatively higher concentration is observed between station 18 and 21. This may probably be due to the material brought in by the Quepem tributory which joins the Zuari near station 20. Besides, the mine dumps alongside the estuary in this zone might also be contributing to the load. The distribution obtained (Table 1) shows that the major portion of the material tends to settle down between stations 14 and 20.

Strong fresh water flow is also responsible for decreasing the salinity and *p*H during the monsoons in the whole estuary. The effect is greater near the surface than near the bottom, especially for salinity (Figs. 2 and 3). The higher value zone of *p*H observed during the fair weather season near station 19 disappears during the monsoon due to a strong flow of fresh water.

Progressive increase in salinity all through the post-monsoon period shows a declining level of freshwater influx in the estuary. Earlier studies on the Zuari and the Mandovi estuaries revealed similar character, and several workers have regarded both these estuaries as well-mixed during the pre-monsoon, stratified during the monsoon and partially mixed during the post-monsoon periods (Murty and Das, 1972; Varma *et al.*, 1975; Cherian *et al.*, 1975; Qasim and Sen Gupta, 1981). This classification is based on the one given by Pritchard (1952).

Features observed in pre-monsoon slowly prevail due to progressive increase in salinity with tidal surge of sea water in the estuary. The zone of higher concentration of TSM developed up to station 10, especially in bottom waters, is perhaps the result of the same reasons as for the pre-monsoon period. The second zone of higher TSM developed around station 16 corresponds somewhat with the maximum limit of intrusion of salt water. Hence, this zone of higher concentration is perhaps due to the conditions developed by mixing of entirely fresh water with saline waters, or possibly the zone of high concentration developed near station 18 during the monsoon must be slowly moving downstream.

At any given place in the Zuari estuary TSM value is always higher in the near bottom waters than the near surface waters. This relation is more prominent during the fair weather season (pre-monsoon and post-monsoon). This is mainly because sea water bore *en masse* with tidal surge to the estuary, which in turn disturbs the soft sedimentary bed resulting in resuspension. This effect is lesser during the monsoon due to strong fresh water flow.

The spatial variation almost always shows higher bottom water salinities. However, there are occasions when the surface waters are more saline (Table 2). This is considered as due to turbulence (Singbal, 1976) at this location.

During the late monsoon period wherein fresh water influx is still considerable, abnormally high salinity values are obtained (September) at station 16. The depth at this station was observed to be greater than at adjacent stations. Hence, high salinity at this station is due to greater depth, because local regions of increasing water depth and increasing runoff over the surface tend to show higher salinities at depth (Pritchard, 1967; Bowden and Hamilton, 1975).

In general, the surface temperatures are higher than bottom temperatures because of the solar heating of the land-locked estuaries. The cooler bottom waters at the mouth of the Zuari estuary in mid- and late-monsoons (August and September) is consistant with the conditions of intrusion of the sea water; the larger differences in the surface and bottom waters are indicative of this, since the zone is confined to the zone of saline waters intrusion. It could also be due to the upwelling phenomenon wherein cooler waters intrude into the estuary. The high temperature of bottom waters at certain places may be due to the mixing processes. Thus it can be seen that the temperature in an estuary could be affected by several factors, like atmospheric temperature (as evident from the average change in temperature from March to February in concordance with the atmospheric temperature), upwelling phenomenon, depth of the river bottom, etc.

The variations observed in TSM, salinity, *p*H and temperature indicate the sea as a source of the sediment during the fair-weather season for this estuary. It has been mentioned that during the fair-weather season, substantial amounts of sediment are added from the ocean side to the estuary in association with the low swell of west and northwest (Murty *et al.*, 1976). On the contrary, during the monsoons high concentration of TSM, and lesser value of salinity and *p*H indicate that the sediment is derived from terrestrial sources. Such high percentage of TSM has also been observed earlier for the Mandovi estuary (Dehadrai, 1970; Antony *et al.*, 1974) and the Kali River of Karwar (Harkantra, 1975). The present study also reveals that the estuary shows marine dominance and assumes completely mixed nature during the fair weather season and assumes partly mixed state due to strong river flow during the monsoon season. Distribution of TSM and salinity from mouth of midstream reflects the characteristic distribution of the parameters associated with moderately high flood currents (Cherian *et al.*, 1975).

Acknowledgements

One of the authors (G. N. Nayak) is grateful to the Department of Environment and Forests, Government of India, for funding the project entitled "Studies on sediment flux of rivers, estuaries and adjoining coastal waters of Goa, West Coast of India" under which this work was carried out. The authors are also thankful to Ms. B. Fernandes for assistance in the field and laboratory work and to Mr. Chodankar for providing onboard facilities.

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