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PHYSICO-CHEMICAL INVESTIGATIONS IN AURANGA RIVER ESTUARY (GUJARAT)

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ABSTRACT

The wastewater streams polluting the Auranga river estuary were sampled periodically and pollution loads were quantified. The shallow estuary is well mixed with excellent flushing characteristics due to the high sea water influx and strong tidal currents. The flushing time calculated (2.7–4.1 tidal cycles) by applying the fraction of fresh water method was at least three times higher than computed on the basis of the tidal prism method. The load retained in the estuary under continuous flow of pollutants and after a large number of tidal cycles was estimated to be less than 3 times the load introduced per tidal cycle. The suspended load in the estuary varied with the current speed and was mainly due to the dispersion of the bottom sediment into the water column. The inner estuary was freshwater dominated during October while sea water influence prevailed during May. The high dissolved oxygen and low BOD observed throughout the study period indicated good oxidizing conditions.

Key-words : Estuary, pollution, Auranga river.

INTRODUCTION

The coastal marine environment of Gujarat State is getting increasingly polluted due to the indiscriminate release of untreated or partially treated industrial and sewage wastewaters. Frequently, the waste is discharged on the vacant land adjacent to the factory site which either stagnate or get channelled through the storm water drains feeding the rivers and estuaries. Considerable deterioration of the water quality of Damanganga (Zingde, Narvekar, Sarma and Desai, 1980), Kolak (Zingde, Sabnis, Mandalia, and Desai, 1980) and Par (Zingde, Sarma and Desai, 1979) river estuaries has already been reported. During 1978–80, Auranga, Ambika, Purna and Mindhola river estuaries were studied extensively for the preparation of the master plan for pollution control. This paper reports some investigations undertaken in the Auranga river estuary.

MATERIALS AND METHODS

Fortnightly observations at 7 stations along 12 km stretch (Fig. 1) in the Auranga river estuary were undertaken during October, 1978 and January, May, October and December 1979. High and low tide samples from all the stations in the tidal zone were collected. Fresh water was sampled at station 8 just upstream of the weir which effectively prevents the penetration of seawater beyond 12 km during spring tide.

The surface samples were collected using a polythene bucket while Niskin sampler was used to obtain bottom samples 1 m above the sediment level. Time series studies over complete tidal cycles were also undertaken at stations 1, 4 and 6 twice in a month. The wastewater streams were identified and sampled at locations I and II marked in Fig. 1. and were analysed by

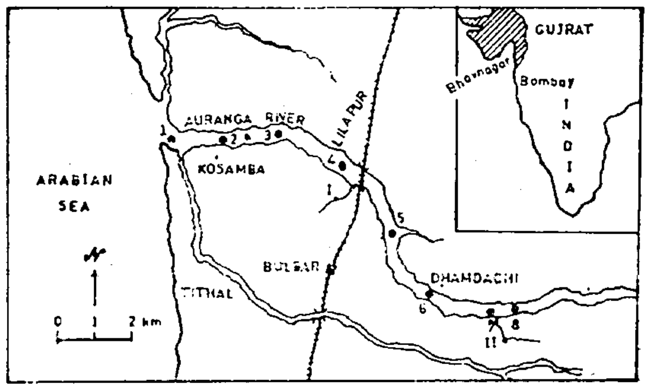

Fig. 1. Map showing sampling locations. (Shaded area represents Gujarat State)

standard procedures (APHA, 1976). Cu, Zn and Pb in the effluents were estimated by AAS after preconcentration by evaporation in presence of nitric acid--hydrochloric acid mixture and hence represent total (dissolved particulate) metal concentration.

Chlorinity of water samples was determined by argentometric titration, while NO_3^--N, NO_2^--N, NH_4^+-N and reactive PO_4^{3-}-P were estimated by colourimetric procedures (Carlberg, 1972). Dissolved oxygen was analysed by Winkler Method. Unseeded dilution method was used for the determination of biochemical oxygen demand (BOD) of water samples, while seeded dilution procedure was used for industrial effluents. For the determination of Cu, Zn and Pb in water, the sample collected in acid cleaned polythylene bottle was filtered through a 0.45 μ Millipore membrane filter paper, acidified to pH 4 and the metals were then determined by AAS after preconcentration by APDC-MIBK procedure. Mn and Fe were estimated colourimetrically (FAO, 1975).

Water level changes during the time series studies were measured by installing graduated staff gauges at stations 1, 4 and 6. Surveyor shallow water echosounder was used to obtain cross-sectional profiles at about every 2 km along the length of the estuary to calculate the estuary volume. Echo-sounding was mostly carried out during the slack periods of the tidal currents. Echograms were corrected for the tidal fluctuations by real time-tide recordings. Currents at stations 1 and 4 were measured using NIO Rotor Induction Current Meter. Surface and bottom currents were measured when the depth was more than 2 m.

RESULTS AND DISCUSSION

Description of the area and wastewater discharges :

Auranga river which is narrow and shallow travels more or less in the east-west direction before meeting the Arabian Sea. Extensive sand banks and mud flats which are exposed during the ebb renders the estuary non-navigable during low tides while, medium size crafts can sail upto Lilapur during flood tide. The intertidal region is generally muddy while the bottom is sandy in the mouth region. A weir has been constructed at about 12 km upstream for supply of freshwater to the Bulsar city. The area of present investigation stretched from the mouth of the estuary to the weir.

Table I. Physico-chemical characteristics of the effluents released in Auranga river.

Parameter	Location I			Location II		
	Max	Min	Av	Max	Min	Av
Flow (mld)	6.9	1.8	3.2	1.6	0.2	0.6
Suspended solids (mg l-1)	231	56	123	197	28	124
	(679)	(85)	(278)	(159)	(12)	(67)
Total dissolved solids (g l-1)	2.8	1.3	1.8	1.3	0.5	0.8
	(28.7)	(0.4)	(21.6)	(1.5)	(0.2)	(1.2)
Temperature (°C)	36.5	26.3	32.3	31.9	27.8	30.1
	(32.2)	(26.8)	(29.7)	(33.2)	(25.3)	(30.0)
pH	8.5	6.2	—	3.2	1.1	—
	(8.6)	(7.5)		(7.5)	(6.3)	
Chlorides (g l-1)	1.8	0.4	1.1	3.4	0.4	1.8
	(15.7)	(0.2)	(12.3)	(0.8)	(0.1)	(0.5)
DO (mg l-1)	3.2	0	1.8	0	0	0
	(9.7)	(4.3)	(6.3)	(8.2)	(2.3)	(5.4)
BOD (mg l-1)	107	21	69	859	125	206
	(12)	(2.4)	(4.8)	(19)	(2.8)	(6.5)
COD (mg l-1)	231	72	136	1650	205	730
				(131)	(15)	(43)
Total phosphorous (mg l-1)	2.3	0.1	1.2	1.6	0.3	0.9
	(0.8)	(0)	(0.2)	(0.8)	(0.1)	(0.4)
Total nitrogen (mg l-1)	14	0.2	3.6	18	7	10
	(1.3)	(0.2)	(0.4)	(1.7)	(0.1)	(0.6)
Sulphates (g l-1)	0.2	0	0.1	0.9	0.1	0.4
	(2.0)	(0.1)	(0.8)	(0.2)	(0)	(0.1)
Phenolics (mg l-1)	0.6	0	0.2	0.2	0.1	0.1
	(0)	(0)	(0)	(0)	(0)	(0)
Oil & grease (mg l-1)	0.5	0	0.2	3.2	0.6	1.1
	(0.1)	(0)	(0)	(1.0)	(0.1)	(0.1)
Copper (mg l-1)	0.3	0.1	0.1	0.1	0	0
	(0)	(0)	(0)	(0)	(0)	(0)
Zinc (mg l-1)	0.5	0.1	0.2	0.3	0.1	0.1
	(0)	(0)	(0)	(0)	(0)	(0)
Lead (mg l-1)	0.2	0.1	0.1	0.1	0	0
	(0)	(0)	(0)	(0)	(0)	(0)

Values in parenthesis represent conditions in the receiving waterbody about 50 m away from the wastewater discharge points.

The domestic wastewater from the Bulsar city amounting to 3.2 mld (million litres per day) is released into the river through a natural drain at location I. An industry manufacturing nitrocellulose releases 0.6 mld of acidic wastewater having BOD 206 mg l^{-1} at location II. The wastewater characteristics are given in Table I.

Tides and currents:

As no information on tides was readily available, the water level variations at stations 1, 4 and 6 were measured simultaneously to coincide with the spring and neap during each month to estimate the extent of tidal influen-

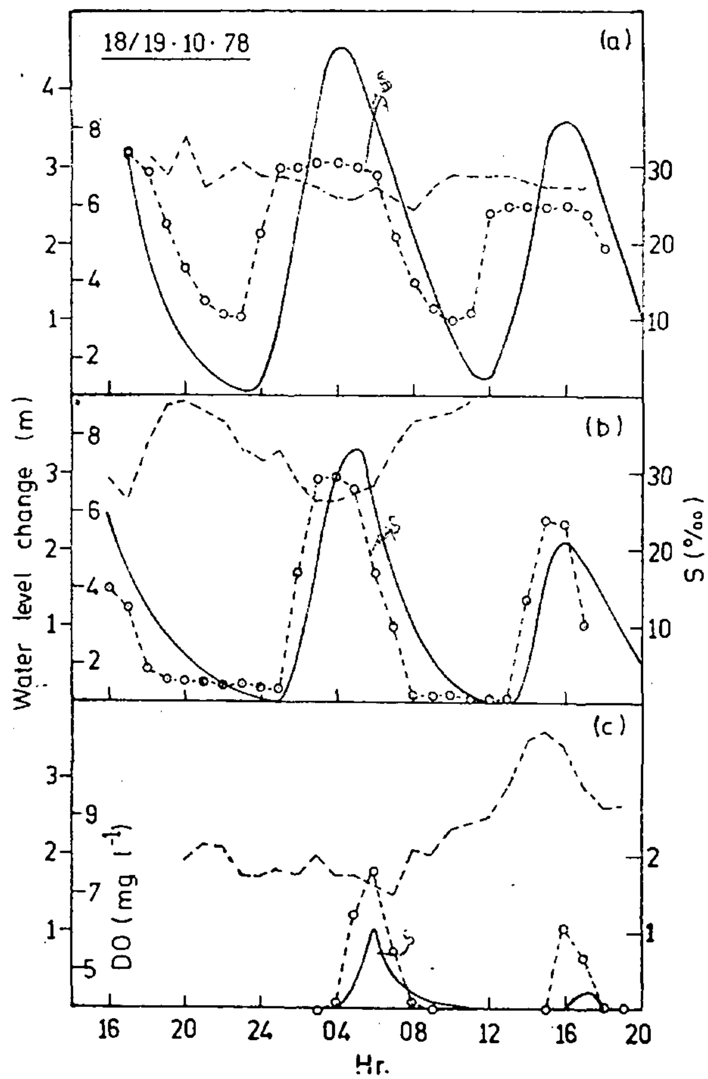

Fig. 2. Variation of water level (——), salinity (o——o) and dissolved oxygen (– – –) at (a) station 1, (b) station 4 and (c) station 6 on 18-19 October 1978.

-ces. The estuary experiences semidiurnal tides with two high and two low waters occurring each tidal day with non-equal tidal amplitudes. Figs. 2 to 4 represent water level fluctuations and their influence on some physico-chemical parameters while, the average tidal data for measurements during the study

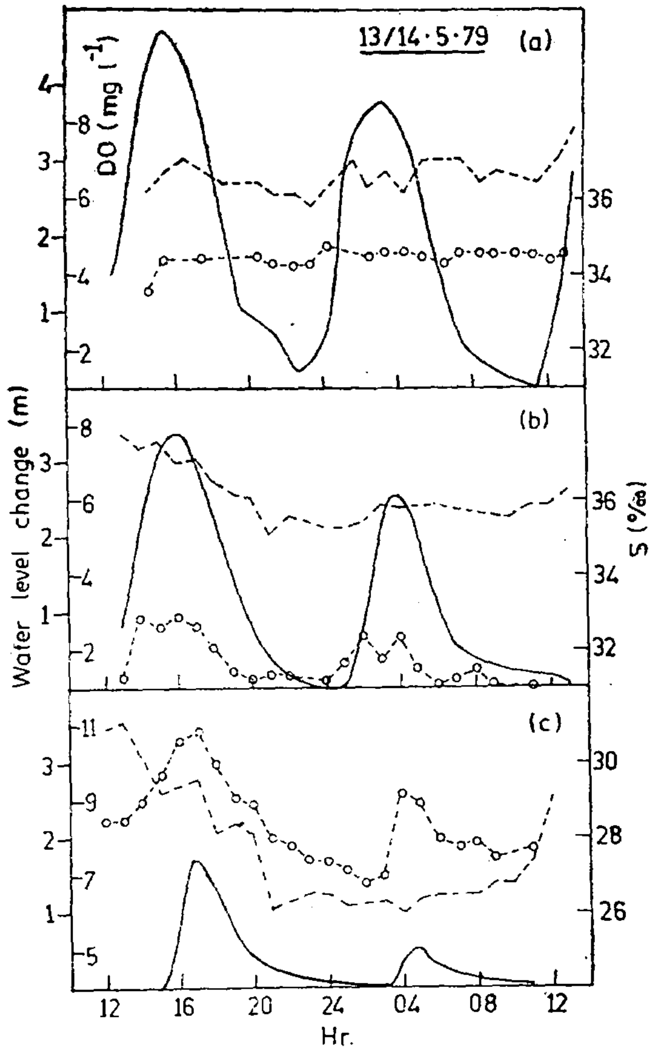

Fig. 3. Variation of water level (——), salinity (o- - -o) and dissolved oxygen (— — —) at (a) station 1, (b) station 4 and (c) station 6 on 13-14 May 1979 (Spring).

period are given in Table II. The tidal heights, ranges and durations of flood and ebb varied along the estuary and were also influenced by the river runoff specially during October. The tide decreased in range in the upstream direction and the influence was only 0.5 m at station 6 as against 3.3 m near the mouth during neap. The spring at the mouth (4.5 m) was about 1.5 m higher than the neap and decreased to 1.1 m at station 6. Although in the offshore,

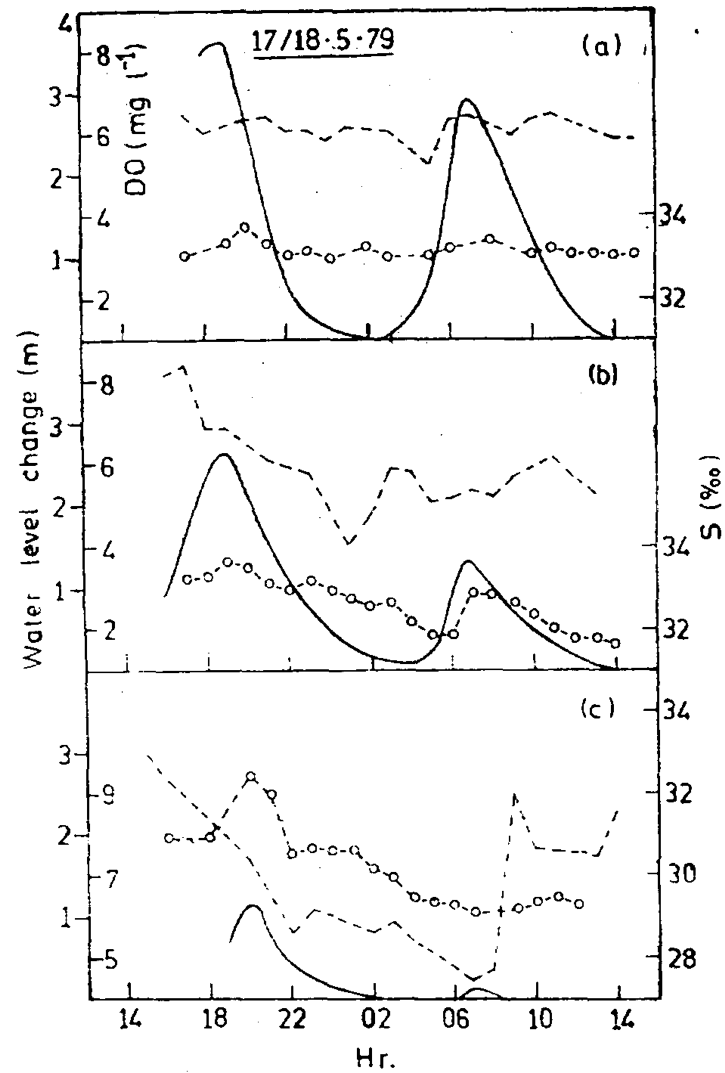

Fig. 4. Variation of water level (——), salinity (o– –o) and dissolved oxygen (– – –) at (a) station 1, (b) station 4 and (c) station 6 on 17-18 May 1979 (Neap).

floods and ebbs were of equal duration of about 6 h, the duration of flood progressively decreased along the estuary with flood period of only about 1.5 to 2 h at 10 km upstream from the mouth. Even at the mouth the flood was experienced over a duration of about 3.5 to 4.5 h with the ebb extended over a period of 7.5 to 8.5 h.

Due to the substantial increase in the tidal range from Bombay to Bhavnagar the estuaries in Gujarat State are under considerable tidal influence. The spring tidal ranges of 5.6, 5.5, 3.6 and 5.5 m have been reported in the mouth regions of Damanganga (Zingde, Narvekar, Sarma and Desai, 1980), Kolak (Zingde, Sabnis, Mandalia and Desai, 1980), Ambika (NIO, 1980) and

Table II. Tidal and current speed data for Auranga River estuary.

Parameter	Station		
	1	4	6
Spring tidal range (m)	4.5	3.0	1.1
Neap tidal range (m)	3.3	1.9	0.5
Average flood period (h)	3.5 to 4.5	3 to 4	1.5 to 2
Average ebb period (h)	7.5 to 8.5	8 to 9	10 to 10.5
High tide time lag[a] (h)	—	0.5 to 1	1 to 1.5
Max. current speed (cm s^{-1})	—	—	—
Spring (surface)	120	110	—
Spring (bottom)	115	84	—
Neap (surface)	76	52	—
Neap (bottom)	64	34	—

[a] Compared with station 1.

Mindhola (NIO, 1980) river estuaries respectively. Although the tides have been reported to be consistently increasing northward along the open coast, the distortion in the tidal pattern is evident in the mouth estuarine regions due to the presence of shifting sand bars. It is, therefore, not surprising to observe lower tidal ranges for Ambika and Auranga as compared to Damanganga and Kolak estuary mouths.

High tidal influence generated strong currents with the maximum current speed exceeding 100 cm s^{-1} during spring. The nature of the current profile did not vary appreciably at the bottom and the speed was only marginally lower (Figs. 5 & 6). The maximum ebb speed of flow was observed after 3–4 h of the commencement of the ebb while, maximum flood speed was within 2 h of the commencement of the flood at station 1. Dominated directions of flow in the estuarine region were mainly east-west modified by the channel geometry. However, the currents off South Gujarat are generally parallel to the coast reversing in direction with ebb and flood and thus more or less perpendicular to the directions in the estuary. This could be one of the reasons for the occurrence of prominent shoals and bars in the mouth estuarine regions of Auranga river estuary.

Tidal excursion:

Tidal excursion can be predicted if the volume of water between the mouth and at any point in the estuary during different tidal conditions is known. High and low tide volumes of the estuary were determined from the bathymetry and the tidal data. Some cross sectional profiles are produced in Fig. 7. The tidal excursion can then be calculated from the plot of the cumulative segment volume against the distance (Fig. 8) by drawing a horizontal line between the low tide and high tide curves in absence of displacement by freshwater. It is evident from Fig. 8 that any wastewater released upto a point about 5 km upstream at the flood tide would be flushed to the sea

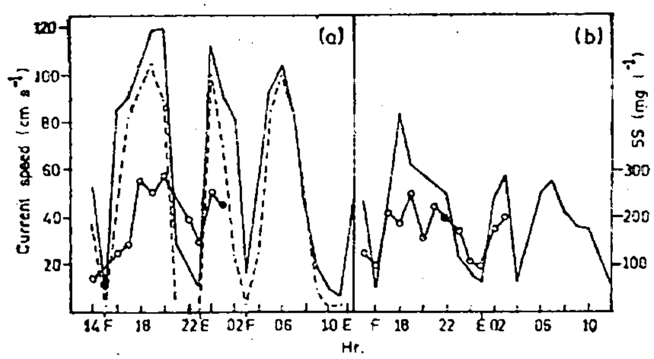

Fig. 5. Variation of current speed: Surface (——) and bottom (— — —), and suspended solids (o——o) at (a) station 1 and (b) station 4 on 13-14 May 1979.

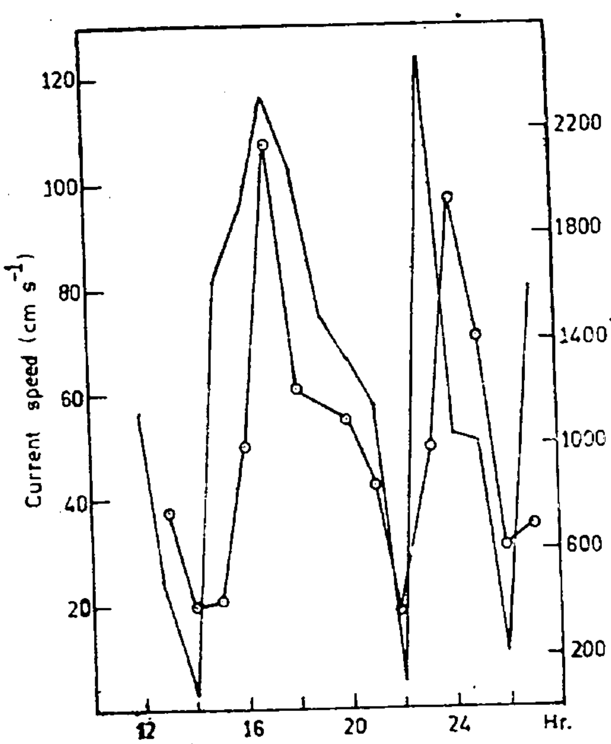

Fig. 6. Variation of surface current speed (——) and suspended solids (o——o) at station 1 on 5-6 October 1979.

during every ebb tide. This distance would be about 7 km during the spring tide. The excursion length decreased considerably in the inner estuary and was about 0.5 and 2 km during neap and spring tide respectively at a point about 7 km inland from the mouth. In practice, the direction of flow may be seaward throughout the tidal cycle near the head of the estuary at times of high flow, but even then this concept of tidal excursion is useful when considering the distribution of effluents within the estuary.

Float studies were undertaken to compare the results predicted on the basis of the estuary volume. The floats were released at station 4 just prior to the commencement of the ebb tide and the time required to travel uplo the estuary mouth was estimated. The floats were carried outside the mouth

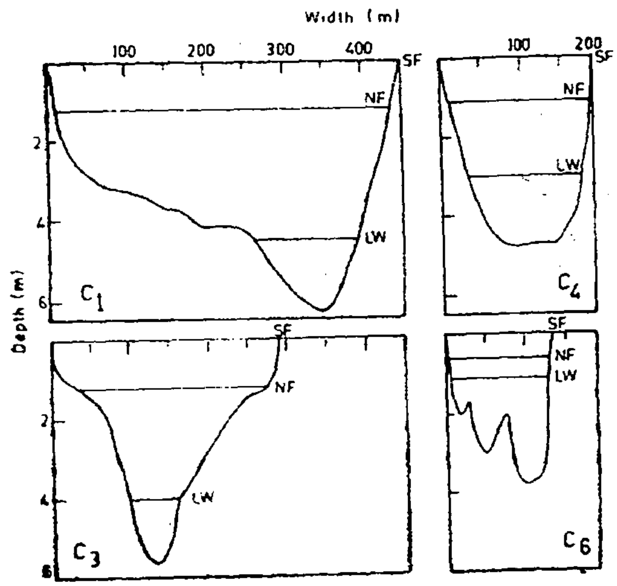

Fig. 7. Cross-sectional profiles. LW-low water; NF-neap flood; SF-spring flood.

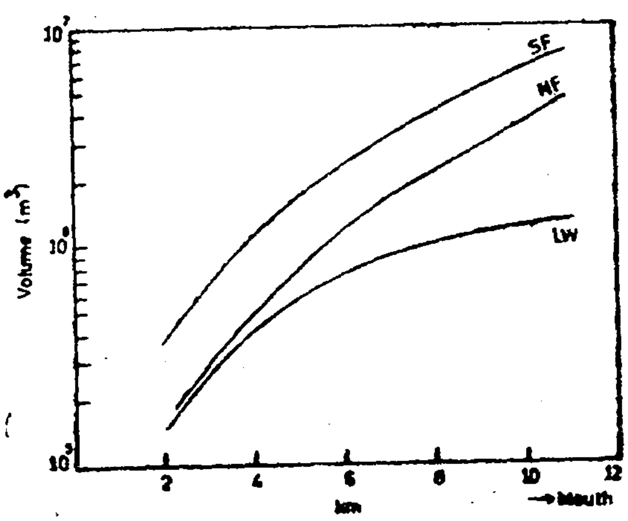

Fig. 8. Volume of water along the length of the estuary under varying tidal conditions. LW-low water; NF-neap flood; SF-spring flood.

of the estuary within 2–3 h depending on the tide. The time required is considerably lower than expected on the basis of volume considerations. This may be because the floats normally travelled in the channel where the currents were strong.

Sea water intrusion:

The distance up the estuary to which sea water may penetrate is of interest as an indication of the distance over which the polluting matter released to the saline reach may exert an influence. In Auranga river estuary, the incursion of sea water varied considerably depending on the tidal stage and the period of measurement (Fig. 9).

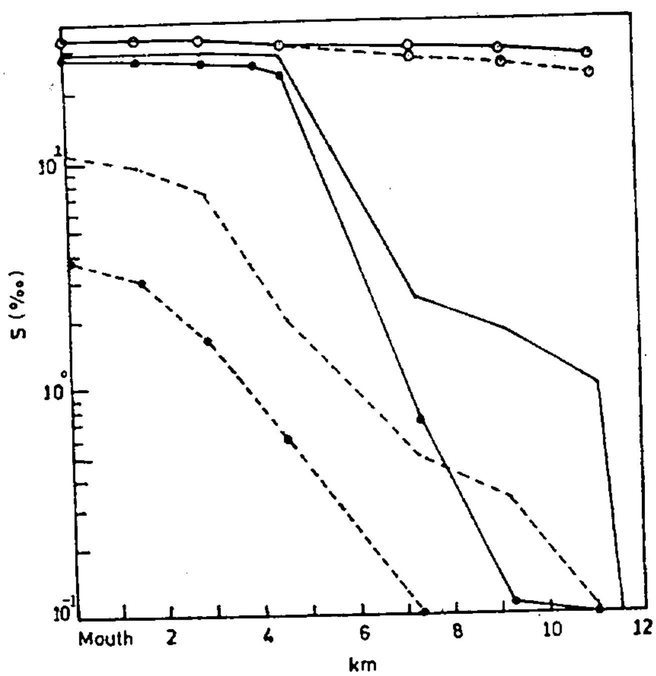

Fig. 9. Distribution of salinity during high tide (———) and low tide (– – –) on 18-19 October 1978; high tide (o——o) and low tide (o- - -o) on 13-14 May 1979; high tide (o——o) and low tide (o- - -o) on 5 October 1979.

During October when the riverine freshwater flow was substantial, at station 1, the salinity of 30‰ at the flood tide (Fig. 2) decreased to 10‰ at the ebb. This decrease was from 30‰ at the flood to 0.5‰ at the ebb. at station 4 and at station 6 it was mainly freshwater throughout the tidal cycle; the maximum sea water component bring only about 5% at the flood tide. Hence, the tidal range of 1 m observed at station 6 during October appears to be mainly due to the piling-up of freshwater as the flood tidal front advances through the estuary. Substantial tidal fluctuations in the region of no or weak sea water incursion have been commonly observed for the estuaries of Gujarat State. Spring water rise of 1.7 m has been reported for Narmada river at 60 km inland although the influence of sea water was only upto 45 km (Zingde, Chander, Rokade and Desai, 1981). Spring ranges of 1.2 and 1.9 m have been reported for Ambika and Mindhola rivers respectively where there was no penetration of sea water (NIO, 1980).

During May when the riverine flow was weak, the salinity at station 1 (33–35‰) was not tide dependent (Figs. 3 & 4) and at station 4, the flood salinity was only 2‰ higher than the ebb. This difference increased to 4‰ at station 6 with the minimum sea water component of 80 per cent as against 5 per cent during October. The estuary was generally well mixed vertically although gradient exceeding 2‰ between the surface and the bottom layer was occasionally observed during October.

For the purpose of release of wastewater the river stretch upstream of station 6 may be considered as freshwater zone and the wastewater should be treated accordingly before release.

Flushing characteristics:

The flushing time t in tidal cycles can roughly be estimated from the morphometry data and the tidal ranges by using the relation

$$t = \frac{V + P}{P}$$

where V is the low water volume of the estuary and P is the volume of the tidal prism (Dyer, 1973). As this assumes complete mixing in the estuary which is rarely justified, it sets only a lower limit to the flushing time. The tidal prism for the Auranga river estuary was estimated at 3.62×10^6 and 6.46×10^6 m^3 for neap and spring respectively with the average low tide volume of 1.35×10^6 m^3. A flushing time of just about one tidal cycle was then obtained indicating excellent flushing of the estuary. The fraction of well mixed water removed from the estuary works out to be 73 and 83 per cent respectively during neap and spring. The load fraction retained in the estuary after an infinite number of tidal cycles under a continuous flow of pollutants in the estuary is given by

$$L = \frac{Y}{1 - Y}$$

Y being the fraction remaining after one tidal cycle.

L works out to be only 0.37 and 0.2 during neap and spring respectively.

Flushing time can also be calculated by applying the fraction of freshwater method (Dyer, 1973). Salinity distribution in an estuary is a measure of the fraction of freshwater in each segment or the entire estuary. If S_o is the salinity of water outside the estuary available for mixing and S is the salinity at any given point inside the estuary, then the freshwater content at that point is

$$f = \frac{S_o - S}{S_o}$$

The total volume of freshwater accumulated in the estuary is

$$F = f \int d$$

integrated over the total volume. If steady state is assumed then

$$t = \frac{F}{R}$$

where R is the river discharge per tidal cycle.

Since reliable river discharge data was not available, R was obtained from the knowledge of the cross-sectional area and the currents at 5 points across the cross-section just upstream of station 7 where there was no tidal influence during neap tides. Measurements were made hourly over 24 h. Salinity was also simultaneously measured diurnally at fixed locations in the tidal zone and also in the coastal region just outside the mouth of the estuary. The results summarised in Table III were obtained during neap tide and close enough to the times of high or low water so that no substantial volume error was introduced in the calculations. It is evident that although the riverine freshwater flow decreased by 10 folds from October to May, the flushing time remained more or less of same magnitude indicating the importance of tidal

Table III. Flushing time of Auranga River estuary calculated from salinity distribution.

Segment	Tide	Salinity (‰)	Salinity downstream (‰)	Segment volume ($\times 10^6$ m^3)	Volume down stream ($\times 10^6$ m^3)	Freshwater in segment* ($\times 10^6$ m^3)	Flushing time (tidal cycles)
				18-19/10/78			
C_1-C_3	Fl	30.2	30.2	2.561	2.561	0.05	0.2
C_3-C_5	Fl	28.8	29.62	1.802	4.363	0.17	0.8
C_5-C_7	Fl	1.8	26.28	0.596	4.959	0.72	3.4
C_1-C_3	Eb	10.6	10.6	0.295	0.295	0.05	0.2
C_3-C_5	Eb	4.0	6.06	0.648	0.943	0.39	1.8
C_5-C_7	Eb	0.4	4.37	0.401	1.344	0.89	4.1
				4-5/1/79			
C_1-C_3	Fl	33.2	33.2	2.561	2.561	0.01	0.3
C_3-C_5	Fl	31.6	32.54	1.802	4.363	0.11	2.2
C_5-C_7	Fl	29.2	32.13	0.596	4.959	0.19	3.7
C_1-C_3	Eb	32.8	32.8	0.295	0.295	0.01	0.1
C_3-C_5	Eb	29.9	30.81	0.648	0.943	0.07	1.4
C_5-C_7	Eb	28.2	30.02	0.401	1.344	0.13	2.7
				17-18/5/79			
C_1-C_3	Fl	33.8	33.8	2.561	2.561	0.01	0.9
C_3-C_5	Fl	33.5	33.67	1.802	4.363	0.04	2.5
C_5-C_7	Fl	32.6	33.57	0.596	4.959	0.05	2.8
C_1-C_3	Eb	33.1	33.1	0.295	0.295	0.01	0.4
C_3-C_5	Eb	31.9	32.27	0.648	0.943	0.04	2.8
C_5-C_7	Eb	29.1	31.32	0.401	1.344	0.07	3.9

*Riverine freshwater flow per tide cycle was: i) 0.21 x 10^6 m^3 (18-19/10/78) ii) 0.05 x 10^6 m^3 (4–5/1/79) iii) 0.02 x 10^6 m^3 (17–18/5/79).

influence as compared to the freshwater flow on the flushing of the estuary. As expected, the fraction of freshwater method gave relatively higher value for the flushing time as compared to the tidal prism method because the assumption of complete mixing of fresh and sea water considered in the tidal prism method is not fully justified.

$$\text{Since, } r = \frac{1}{t} \text{ and } L = \left(\frac{1}{r}\right) - 1$$

where r is the exchange ratio, the load retained after a large number of tidal cycles under continuous flow of pollutants would be 0.8 to 2.9 times the load introduced per tidal cycle depending on the flushing time.

Suspended solids :

The suspended load entering the estuary through the river water (station 8) was generally below 25 mg l^{-1}. There was appreciable increase in the estuarine region and the concentration was widely variable. There was general tendency for the load to increase with the increase in the current speed (Figs. 5 & 6). Thus for example, during diurnal studies at station 1 on 13–14 May 1979, the load of 75 mg l^{-1} at the current speed of 52 cm s^{-1} increased to 280 mg l^{-1} with the increase in current speed to 120 cm s^{-1} (Fig. 5). Similar trend was also observed at station 4. This is typical of the estuaries of Gujarat region which are subjected to pronounced tidal influence and are shallow with the sediment material mainly composed of clay and fine sand.

Combined solids released through the wastewater amounts to about 500 kg day^{-1} which is not likely to influence the background levels to any significant extent.

DO and BOD :

The DO varied in 5.0–9.2, 4.1–11.0 and 2.8–12.4 mg l^{-1} range at stations 1, 4 and 6, respectively during the period of the survey. Although values below 3 mg l^{-1} were observed at station 6, the frequency of occurrence was negligible with 85 per cent values falling in 6–8 mg l^{-1} range.

Diurnal studies revealed random variations of DO at station 1 while definite tendency to decrease gradually to attain minimum during early morning hours was evident at stations 4 and 6 (Figs 2 to 4). Thus, the DO of 11 mg l^{-1} at station 6 on 13–14 May 1979 (Fig. 3) at 1200 h decreased to 7 mg l^{-1} at 0400 h and again increased to mg l^{-1} at 1200 h. This indicated that the biological influence of photosynthesis and respiration were more pronounced than the influence of temperature since the decrease in temperature in the nights (3–8°C) would result in higher DO levels if temperature was the main factor.

The BOD of the estuary varied in 0.5–9.2 mg l^{-1} range with the mean values always below 5.5 mg l^{-1} (Table IV). Although the freshwater flow decreased considerably during May, this was not reflected on the BOD. The present BOD inputs does not seem to have affected the estuary except in the immediate vicinity of the effluent release points.

Inorganic nutrients :

Diurnal measurements of NO_3^--N, NO_2^--N, NH_4^+-N and PO_4^{3-}-P undertaken at stations 1, 4 and 6 did not reveal any regular variations and

Table IV. Biochemical oxygen demand (mg l^{-1}) in Auranga River estuary.

Month	Station 1			Station 4			Station 6		
	Max	Min	Av	Max	Min	Av	Max	Min	Av
Oct 79	3.1	0.9	1.9	4.0	1.9	2.9	6.1	4.5	5.3
Jan 79	3.0	0.5	1.7	4.6	0.8	2.8	5.6	3.2	4.3
May 79	4.5	0.9	2.7	8.7	1.8	4.7	9.2	1.9	4.2
Oct 79	4.5	0.7	3.0	7.5	1.9	5.4	4.2	1.8	2.8
Dec 79	3.7	1.2	2.9	6.3	1.5	4.2	5.1	2.1	4.1

hence only average values are given in Table V. Interrelationships between some nutrients and also with salinity were not noticed and values fluctualed randomlly. It appears from Table V that the sea water is the major source of PO_4^{3-}-P to the estuary.

Trace metals :

The levels of dissolved Fe, Mn, Cu, Zn and Pb at various stations are given in Table VI. The concentrations of all metals did not show systematic variation with the change in salinity. The levels in general were within the limit observed for the Arabian Sea (Qasim and Sen Gupta, 1980).

Table V. Inorganic nutrients (μg-at l^{-1}) in Auranga River estuary.

Station	PO_4^{3-}-P	NO_3^--N	NO_2^--N	NH_4^+-N
		October 78		
1	2.1	4.6	0.6	0.3
4	1.6	3.9	0.5	0.4
6	1.3	2.9	0.2	0.1
		January 79		
1	3.2	5.1	0.1	0.1
4	1.9	10.4	0.3	0.2
6	0.6	10.9	0.3	0.7
		May 79		
1	3.8	16.1	0.3	0.5
4	3.6	20.8	1.2	0.7
6	2.5	23.7	1.2	1.9

Table VI. Dissolved trace metals ($\mu g\ l^{-1}$) in Auranga River.

Station	Mn	Fe	Cu	Zn	Pb
1	8.2	12	2.8	10	1.8
4	5.3	14	4.7	15	1.2
6	9.1	8	6.3	8	0.8
8	2.8	10	5.2	13	1.6

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