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Environmental Studies of the Ambika and Associated River Estuaries

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The tide dominated coastal plain Ambika, Kaveri and Kareira estuarine system has been investigated to evaluate the influence of industrial and domestic wastewater discharges on the water quality. The wastewater streams were gauged and the pollution loads quantified. High sea water influx, strong currents and small low tide volume rendered the estuaries well mixed with excellent flushing characteristics. The fraction of freshwater method gave a flushing time of 2.5 and 5.8 tidal cycles in October and May, respectively. Although a tidal range of 1.2 m (spring) was observed 20 km inland, there was no intrusion of saline water except in May. The estuarine zone is characterized by high and variable suspended load. Nutrients, pH and trace metal concentrations in water were the natural background levels. The high BOD ($24\ 600\ \text{kg day}^{-1}$) and the riverine flow influenced the distribution of dissolved oxygen in the Ambika estuary to a considerable extent. About 10 km stretch of the estuary had DO below $3\ \text{mg l}^{-1}$ when the riverine flow was weak.

Rapid industrialization of Gujarat State, India, has resulted in several industrial pockets many of which are near the rivers for the convenience of not only obtaining the freshwater supply for industrial and domestic needs but also for the disposal of wastewater. The waste in several cases is released indiscriminately without prior treatment onto the adjacent vacant land where it either accumulates and stagnates or flows through natural stormwater drains to the nearby river or the estuary. Recent studies of the Damanganga (Zingde et al., 1980a), Kolak (Zingde et al., 1980b), Par (Zingde et al., 1979) and Narmada River estuaries (Zingde et al., 1981), all in Gujarat, have revealed significant deterioration of water quality of the first three estuaries.

Although, the water quality of the Ambika and other associated river estuaries is considered to have deteriorated, nothing is known about the effect of the wastewater discharges on the estuary and several factors which might be expected to influence it except for the behaviour of boron, calcium and magnesium which has

been reported recently (Narvekar *et al.*, 1983). During 1977–80 an extensive survey was undertaken in these estuaries for the preparation of a master plan for pollution control and some of the findings are given in this communication.

Material and Methods

Spring and neap tide collections at 11 locations along a 25 km stretch (Fig. 1) of the Ambika River estuary were obtained during September–December and May–October. High and low tide samples were collected at all the stations in the tidal zone. The Kaveri and Kareira River estuaries were also sampled at stations 12 and 13, respectively. Time-series studies over the complete tidal cycle of some physico-chemical parameters were also undertaken at stations 2, 8 and 10, normally twice a month. Wastewater streams were identified and sampled periodically. Locations I to VI indicate the stormwater drains carrying the wastewater. Samples were also collected in the estuaries about 20–50 m away from the discharge point to evaluate immediate impact on the water quality. Industrial and domestic wastewater was analysed by standard procedures (Franson, 1976). Chlorinity of the water samples was determined by argentometric titration; nitrate–nitrogen, nitrite–nitrogen, ammonium–nitrogen and reactive phosphate–phosphorus were estimated by colorimetric procedures. Dissolved oxygen (DO) was analysed by the Winkler method (Carlberg, 1972). Unseeded dilution method was used for the determination of biochemical oxygen demand (BOD) of water samples, while the seeded dilution procedure was used for industrial effluents. For the estimation of Fe, Cu and Zn, the samples collected in acid-cleaned polyethylene bottles were filtered through a 0.45 μm Millipore membrane filter

paper, acidified to pH 4 and deep frozen. The metals were then determined by AAS after preconcentration (FAO, 1975). Arsenic was estimated by Johnson & Pilsons (1972) colorimetric procedure. Most parameters (except trace metals) for water samples were determined within a few hours of collection of the samples.

Water level changes during time series studies were measured by installing graduated staff gauges as no tidal data was available for the estuary. Surveyor & Skipper shallow water echosounders were used to obtain cross-sectional profiles at Sections C₀ to C₄ and C₆ marked in Fig. 1. Remaining cross-sections were obtained by actual measurements as the regions were shallow. Currents over tidal cycles at Stations 2 and 8 were measured using NIO Rotor Induction Current Meter. Tidal excursion was estimated by following the movement of vane-floats released at stations 2 and 8 during high and low tides.

Description of the Area

The Ambika River estuary is broad and shallow and barely navigable during low tide, while medium sized craft can sail up to Billimora during high tide. Extensive sand banks which are exposed during low tide are present in the estuarine region and are subject to considerable shifting from season to season. The riverine zone has mud banks with mostly narrow and intricate channels between them. These rivers have pronounced seasonal cycle of freshwater discharge which is maximum during the south-west monsoon (July–September). Flooding is a recurring feature in this period. The flow decreases considerably after October and is minimal during May–June.

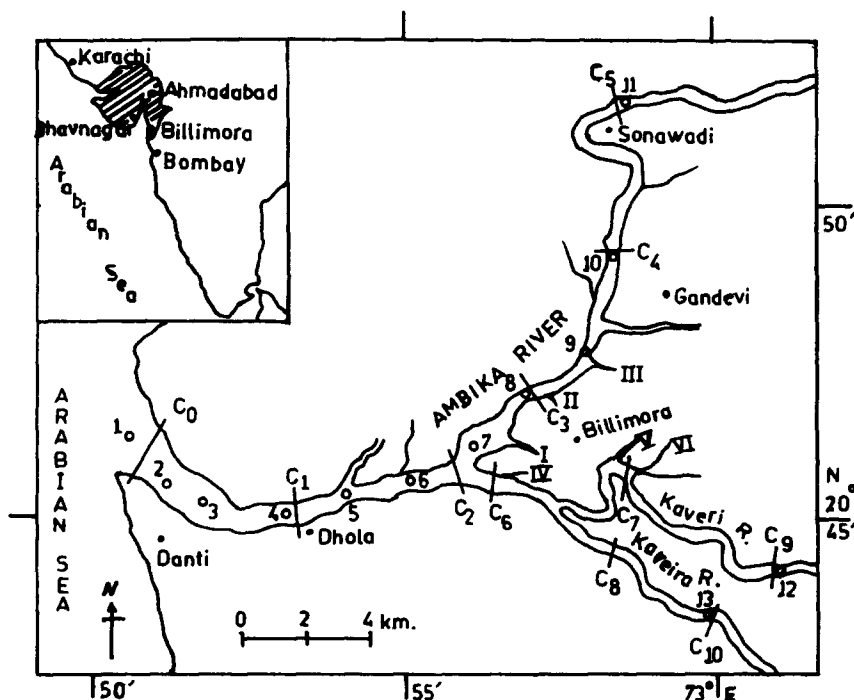


Fig. 1 Map showing sampling stations in the Ambika and associated river estuaries. Shaded area represents Gujarat State.

Wastewater discharges

The water of the Ambika, Kaveri and Kareira Rivers entering the estuary is fairly clean since the inland and catchment areas are under-developed and sparsely populated. Although the stormwater drains discharging directly to the estuary below Gandevi are relatively small, some of them are seriously polluted and thus make a significant contribution to the total pollution load in the tidal waters. All these wastewater streams were sampled periodically and gauged to quantify the pollution loads.

The untreated domestic sewage (0.5×10^6 l. day⁻¹) from Billimora town (population 35 000) is released through natural stormwater drains at I and IV. A textile mill manufacturing cotton and polyester fabrics releases untreated combined industrial and domestic wastewater amounting to 4.8×10^6 l. day⁻¹ at location II in the tidal waters. The effluent, generally devoid of DO, added a BOD load of 360 kg day⁻¹ and often contained phenolics to the extent of 2.8 mg l⁻¹ (Table 1). Location III is the discharge point of a chemical complex manufacturing industrial alcohol, textiles and related products. This complex releases 19 600 kg day⁻¹ of BOD to the Ambika River estuary. A paper and pulp mill releases 3.8×10^6 l. day⁻¹ of effluent with high suspended load and high BOD to the Kaveri River estuary at location V. The BOD load (24 100 kg day⁻¹) released at locations III and V is the major source of pollution in the estuarine complex. Combined wastewater from several small scale industries from an industrial estate at Billimora is released at location VI through a natural drain. The data given in Table 1 are the means of at least 10 analyses of all the effluents mentioned above collected during the study period.

Tides and Currents

The tide decreases in range upstream to station 10 where the vertical oscillations of water level are small during neaps (Table 2). The spring tide at the mouth was about 1 m higher than the neap and decreased to 1 m at 20 km inland. The pattern of tidal profile was also subject to variation from the mouth to the upper reaches. The flood period decreased with the corresponding

TABLE 2

Tidal and current speed data for Ambika River estuary

Parameter	Station		
	2	8	10
Tidal range (spring) (m)	3.4	2.3	1.2
Tidal range (neap) (m)	2.6	1.7	0.5
Average flood period (h)	4.5	3.0	2.0
Average ebb period (h)	7.5	9.0	10.0
Time lag* (high tide) (h)	—	0.5 to 1	1 to 2
Max. Current Speed (m s ⁻¹)			
Spring (surface)	1.15	1.20	—
(bottom)	0.82	0.98	—
Neap (surface)	0.82	0.79	—
(bottom)	0.63	0.60	—

*Compared with Station 1.

increase in the ebb period with the distance from the sea. The flood period was short (2–4.5 h) while the ebb extended over a period of 7.5–10 h.

Tidal range along the north-west coast of India increases considerably from Bombay to Bhavnagar and hence the ranges at the mouth of rivers which open in the Arabian Sea are expected to show an increase in the northward direction. Tidal ranges of 5.6 m (spring) and 3.6 m (neap) have been reported at the mouth of the Damanganga River (Zingde *et al.*, 1980a) which is 40 km south of the Ambika River estuary. The lower tidal range in the Ambika River estuary appears to be due to the presence of prominent sand bars and mud flats around the mouth which affect the tidal profile considerably.

High sea water influx generates strong tidal currents with the maximum current speed exceeding 0.7 m s⁻¹ up to station 8 (Fig. 2) during neap tides, which facilitate good mixing of the wastewater released in the estuarine region. The nature of the current profile does not vary appreciably at the bottom though the speed is marginally lower. Due to the frictional effects, currents were greater at the middle of the stream specially at station 8.

Tidal Excursion

Theoretical computation as well as direct measurements have been considered to understand the tidal excursion pattern. To predict tidal excursion, it is necessary to know the volume of water between the mouth and at any point in the estuary under different tidal conditions. This was calculated by utilizing cross-sectional

TABLE 1
Physico-chemical characteristics (mean) of effluents and the receiving water near the discharges point

Parameter	Location											
	I	Ia	II	IIa	III	IIIa	IV	IVa	V	Va	VI	VIa
Flow (1×10^6)	0.2	—	4.8	—	4.3	—	0.3	—	3.8	—	3.8	—
Suspended solids (mg l ⁻¹)	76	178	171	191	445	249	135	147	2420	138	84	118
Total dissolved solids (g l ⁻¹)	0.2	—	3.2	—	2.2	—	0.2	—	1.7	—	0.4	—
Temperature (°C)	30.2	29.5	34.9	29.5	34.8	29.9	30.7	29.3	33.4	30.1	39.9	29.2
pH	8.2	8.3	6.9	8.4	5.3	8.0	8.2	8.2	7.8	8.1	6.8	7.9
Chlorides (g l ⁻¹)	0.1	10.5	0.3	9.3	0.3	3.8	0.1	6.8	0.3	4.3	—	0.5
DO (mg l ⁻¹)	1.3	6.7	0.0	6.1	0.0	0.8	0.0	4.9	0.0	1.2	2.1	5.2
BOD (mg l ⁻¹)	75	6	75	8	4550	64	82	5	1200	15	25	6
COD (mg l ⁻¹)	175	—	582	—	28 000	—	128	—	3300	—	143	—
Sulphate (g l ⁻¹)	0.1	1.5	—	1.3	0.2	0.7	0.1	1.4	—	0.8	0.2	0.2
Phenolics (mg l ⁻¹)	0.0	0.0	2.8	0.1	3.4	0.5	0.0	0.0	0.1	0.0	0.1	0.0
Oil and grease (mg l ⁻¹)	1.1	1.0	1.8	0.9	3.8	1.0	0.2	0.2	0.9	0.1	0.3	0.1
Total phosphorus (mg l ⁻¹)	2.3	0.3	0.3	0.2	—	0.2	2.3	0.3	1.8	0.2	—	0.1
Total nitrogen (mg l ⁻¹)	12	0.6	0.9	0.3	—	0.7	10	1.1	7.0	0.3	—	0.2

Ia, IIa etc. represent stations in the estuaries 20–50 m from discharge point.

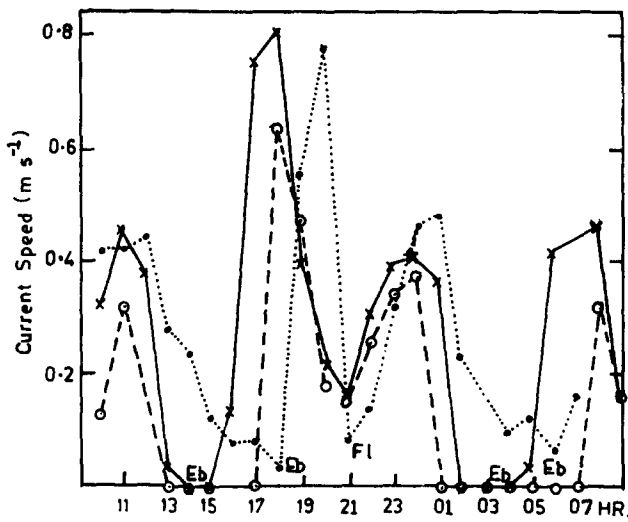


Fig. 2 Variation of current speed with time on 3-4 May 1979 at surface (—x—) and at bottom (o---o) at Station 2 and at surface (•- - - -o) at station 8.

profiles, some of which are produced in Fig. 3, and the tidal data. The cumulative segment volume was plotted against distance (Fig. 4). Tidal excursion may then be calculated by drawing a horizontal line between the low and high tide curves (HMSO, 1964). The excursion length decreases from 10 km at the mouth to 8 km, 12 km inland during spring tide and from 8 to 6 km, respectively, during neaps.

Float studies were undertaken to compare the results predicted on the basis of estuary volume. Average excursion lengths of 15 and 10 km were observed at station 2 during spring and neap tide, respectively, in May. These were 12 and 9 km at station 8. These values are considerably higher than predicted. The greater excursion lengths from float studies may result, because normally the float travelled in the mid-channel where the currents were strong. Also the float was mainly influenced by surface currents which were marginally stronger in the Ambika River estuary (Table 2). Studies undertaken during September–October gave excursion lengths of 6 and 15 km, respectively, at stations 1 and 9 indicating the influence of freshwater flow which resulted in the net seaward movement.

Seawater Intrusion

The riverine flow which decreased considerably over the period August (maximum) to June (minimum) influenced the intrusion and distribution of sea water within the estuary. For instance in May when the riverine flow was weak, the mean salinity at station 8 (15 km inland) was 2.3‰, at low water and 15.2‰ at high water, while, in October when the flow was high, the salinity was 0.35‰ and 0.9‰ at low and high water, respectively, and the concentrations observed in May were not found until 5 km downstream of station 8 (Figs. 5, 6). Although a tidal range of 1.2 m (spring) was observed at station 10, the salinity data (Figs. 5, 6) did not indicate incursion of saline water for most part of the study period and the rise in water level may be due to the piling-up of freshwater as the flood tidal front advances through the estuary. Weak penetration with the chlorin-

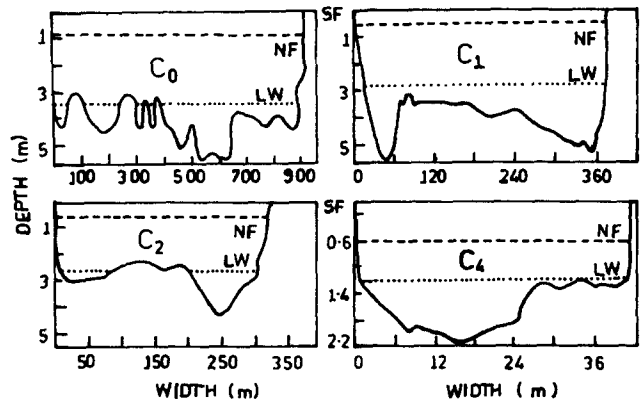


Fig. 3 Cross-sectional profiles. LW—low water; NF—neap flood; SF—spring flood.

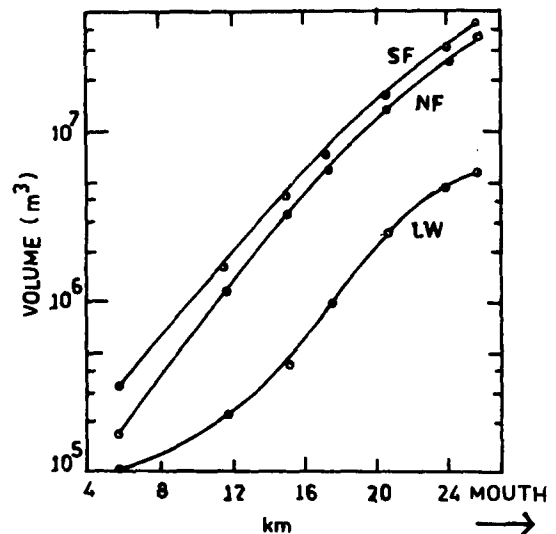


Fig. 4 Calculated volumes of water between station 10 and 7 points in Ambika River estuary under different tidal conditions. LW—low water; NP—neap flood; SF—spring flood.

ity rise up to 0.18‰ was observed only in May. The use of riverine zone up to station 9 for domestic needs and only weak sea water influence in May indicate that the river stretch upstream of station 9 may be classified as a freshwater zone for the purpose of release of wastewater and the appropriate standards should be met by treatment prior to release. The present wastewater discharges therefore, fall in the estuarine region. However, the appreciable upstream tidal excursion warrants caution since the pollutants released even at station 8 are likely to be carried at least up to the station 10 during spring-flood tides especially during May–June.

Flushing Characteristics

The flushing time t in tidal periods is given by

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

where V is the low water volume of the estuary and P is the volume of the tidal prism (Dyer, 1973). This assumes complete mixing in the estuary and thus sets only a lower limit to the flushing time since this assumption is rarely justified. The tidal prism for the estuary is estimated at 20.39×10^6 and 26.80×10^6 m³ during neap and spring tide, respectively. The average low tide

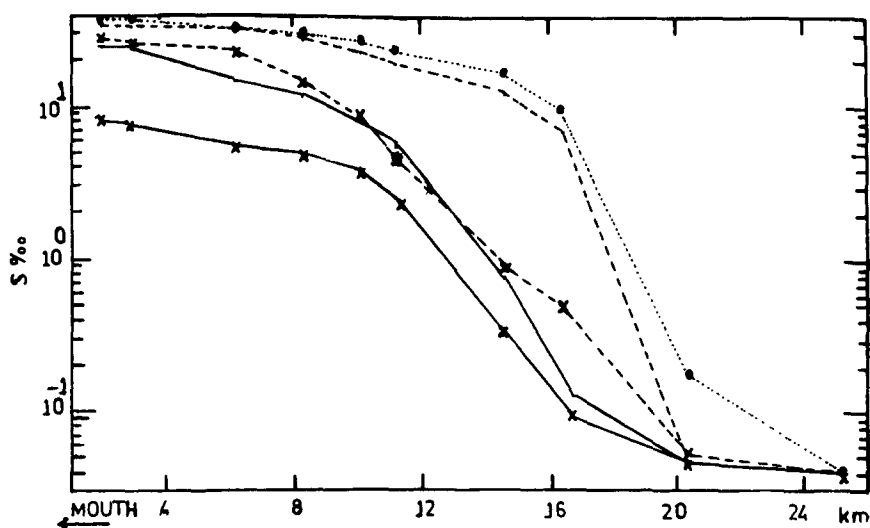


Fig. 5 Distribution of salinity during 1. high tide (x---x) and low tide (x—x) in October 1978, 2. high tide (---) and low tide (—) in December 1978 and 3. high tide (•••••) in May 1979 in Ambika River estuary.

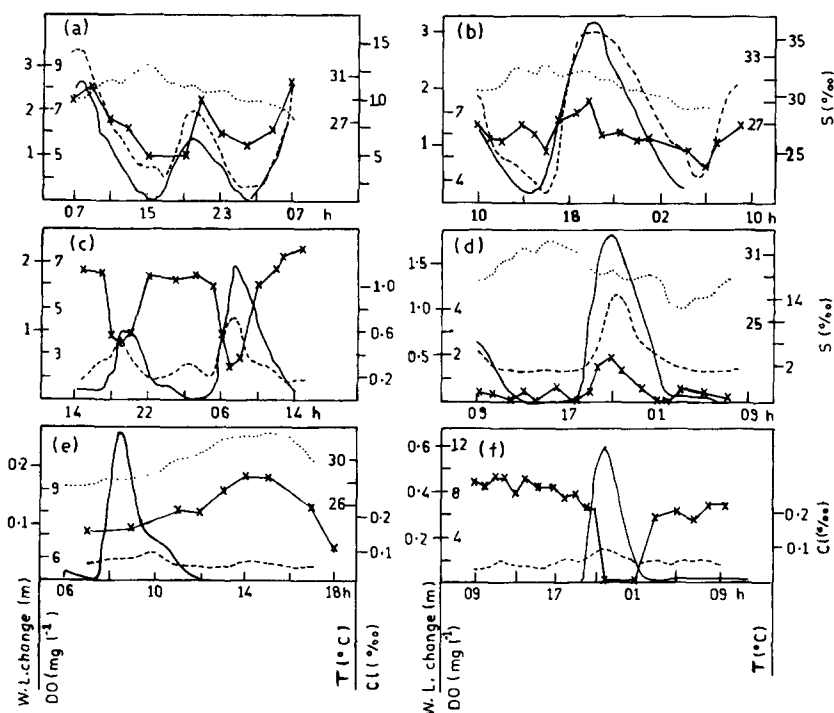


Fig. 6 Variation of water level (—), temperature (•••••), salinity (---) and DO (x---x) at a. Station 2 on 23-24 October 1978; b. Station 2 on 3-4 May 1979; c. Station 8 on 22-23 October 1978; d. Station 8 on 3-4 May 1979; e. Station 10 on 23 October 1978; and f. Station 10 on 3-4 May 1979.

volume is $5.72 \times 10^6 \text{ m}^3$. This gives a flushing time of about one tidal cycle indicating excellent flushing of the estuary. The fraction of well-mixed water removed from the estuary is then calculated to be 0.8, or 80% of the wastewater added every tidal cycle will be removed from the estuary. After an infinite number of tidal cycles under a continuous flow of pollutants in the estuary the load fraction L retained is given by

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

where y is the fraction remaining after one tidal cycle. L proves to be only 0.3.

If the vertical distribution of chlorinity at a number of stations is known together with the volume increments between stations, flushing time can be calculated (Dyer, 1973). If Cl_0 is the chlorinity of water outside the estuary which is available for mixing and Cl is the chlorinity at any given point inside the estuary, then the freshwater content at that point is

$$f = \frac{Cl_0 - Cl}{Cl_0}$$

the total volume of freshwater accumulated in the estuary is

$$F = \int d(\text{Volume})$$

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

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

where R is the freshwater discharge. Since reliable flow data were not available, R was obtained from the knowledge of the cross-sectional area and the currents (surface and bottom) at four points across the cross-section where there was no tidal effect. The measurements were made hourly for 24 h. Chloride content was also simultaneously measured at fixed locations downstream in the tidal zone. R during one tidal cycle was found to be $2.32 \times 10^6 \text{ m}^3$ and $0.52 \times 10^6 \text{ m}^3$ for the Ambika River during October and May respectively. The combined values for the Kaveri and Kareira Rivers were 3.08×10^6 and $0.5 \times 10^6 \text{ m}^3$ during the same period. The mean of 24 measurements, spread over one tidal cycle, just outside the mouth of the estuary, was taken for obtaining Cl_0 . These were 16.2‰ and 19.8‰, during October and May, respectively. The calculated freshwater content and the flushing time for the estuary are given in Table 3. All measurements were made during neap tide. Comparison of the value obtained by the tidal prism method with Table 3, shows that the assumption of complete mixing leads to a flushing time which is lower than that obtained from the observed distribution of chlorinity. The higher value for flushing time observed during May is probably due to the substantial decrease in the freshwater runoff as compared to the October value.

Suspended Solids

The suspended load entering the estuarine complex through river water was normally below 25 mg l^{-1} . There was a marked increase (Fig. 7) in the estuarine zone and the concentration was widely variable (Fig. 8) particularly in the mouth region. The tidal dependance of particulate matter with increase with the current speed is evident from Figs. 2 and 8. The combined solids released through wastewater amounts to about $12 000 \text{ kg day}^{-1}$ out of which 9000 kg day^{-1} is contributed by the discharge at location V alone. Though this load is not very significant compared with the naturally occurring solids in the estuary, it is mainly organic in nature and on settling on the estuary bed releases obnoxious gases during the low tide from the intertidal area of the estuarine stretch of 2 km on either side of location V. The surface sediments collected from stations 1–5 and 10–13 had an organic carbon content of about 0.5–2.5%. However, the sediment from station 6 and locations IVa to VIa had an organic carbon content of 3–6%.

pH

The pH of water varied considerably (7.2–9.2) with a general tendency to increase during low tide which is perhaps due to the high pH of river water (8.1–9.2) entering the estuary. The wastewater, except at location III, had pH near to neutral. The influence of occasional acidic pH of effluents at location III (Table 2) could be traced to station 8 where decrease to 7.5 during ebb tide from the flood value of 8.0 was observed during May.

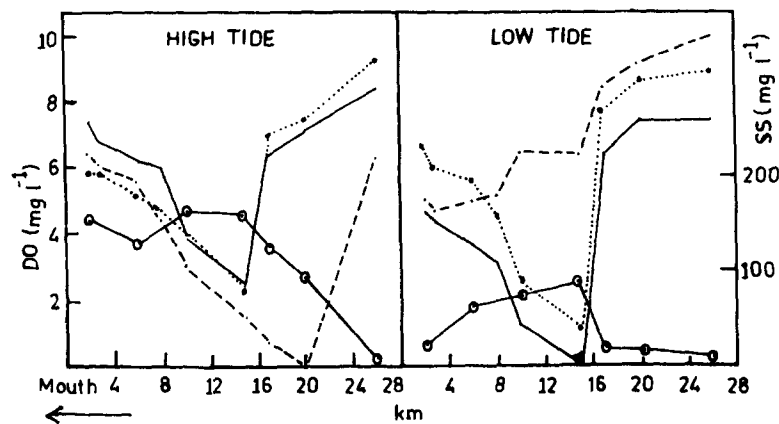


Fig. 7 Distribution of dissolved oxygen during October 1978, (—●—), December 1978 (●·····●) and May 1979 (---) and suspended solids during December 1978 (○—○).

TABLE 3

Flushing time for the Ambika River estuary calculated from chlorinity distribution

Segment	Average chloride (%)		Average Chloride downstream (%)		Average volume ($\times 10^6 \text{ m}^3$)	Average volume downstream ($\times 10^6 \text{ m}^3$)	Volume of fresh water ($\times 10^6 \text{ m}^3$)		Flushing time (tidal cycles)	
	Oct 78	May 79	Oct 78	May 79			Oct 78	May 79	Oct 78	May 79
C ₁₀ –C ₁	8.81	17.38	8.81	17.38	8.792	8.792	4.01	1.12	0.6	1.0
C ₁ –C ₂	5.31	15.26	7.53	16.60	5.071	13.863	7.38	2.20	1.1	2.1
C ₂ –C ₃	0.68	5.30	7.04	15.79	1.067	14.93	8.45	3.03	2.3	4.8
C ₃ –C ₄	0.06	0.55	6.82	15.32	0.472	15.405	8.93	3.51	2.4	5.6
C ₄ –C ₅	0.02	0.02	6.75	15.16	0.107	15.575	9.10	3.70	2.5	5.8

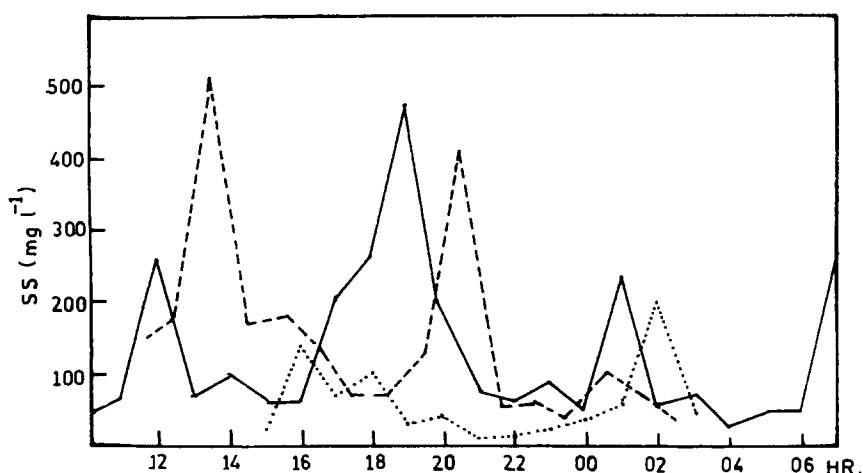


Fig. 8 Variation of suspended solids at Station 2 on 28-29 December 1978 (---), Station 2 on 3-4 May 1979 (—) and Station 8 on 28-29 December 1978 (●.....●).

DO and BOD

The Ambika River estuarine complex is subject to substantial pollution due to the organic loads associated with the wastewater discharges. Out of the total BOD of 24 600 kg day⁻¹, nearly 20 000 kg day⁻¹ is released at location III (Table 1) and 4000 kg day⁻¹ at location V. The high organic load influenced the oxygen balance in the estuary to a considerable extent as evident from Figs. 6 and 7.

At station 8 DO varied from 2.5 to 7.8 mg l⁻¹ over the tidal cycle in October, the period of considerable riverine flow (Fig. 6c) with low values around flood slack and high DO during ebb tide. It, therefore, appears that the wastewater accumulates during flood tide due to the opposing currents. The high riverine flow carries the wastewater downstream as the ebb begins, resulting in low DO in the mouth region during low tide (Fig. 6a). Conditions were precarious in May when the riverine flow was weak and critical level was approached. The maximum DO at station 8 was only 1.8 mg l⁻¹ and complete depletion was evident for most of the time (Fig. 6d). About 10 km stretch of the estuary (Fig. 7) had DO below 3 mg l⁻¹ for over 16 h in a day indicating severity of pollution in the estuary. The temperature which increased from 27.5–31°C in October to 30–32.5°C in May (Fig. 6) is not expected to have significant influence on the DO distribution.

In contrast to earlier observations, high DO was observed during the flood tide at station 8 during May (Fig. 6d) which may be due to weak riverine flow and strong tidal currents which carried the effluent upstream up to station 10 where complete depletion of oxygen was observed during flood slack and initial hours of the ebb tide (Fig. 6f).

Earlier work (Zingde *et al.*, 1981) has suggested that in some rivers of the Gujarat region, diurnal variation in DO is largely due to the photosynthetic activity and changes in temperature are of secondary importance. This is also true for the Ambika River. During October when there was no influence of wastewater at station 10, maximum DO of 9.7 mg l⁻¹ was observed between 1400 and 1500 h and low DO was recorded during early morning hours in support of the above view.

Nutrients and Trace Metals

Diurnal measurements of NO₃⁻-N, NO₂⁻-N, NH₄⁺-N and PO₄³⁻-P undertaken at stations 2, 8 and 10 did not show any regular variation over the tidal cycle. Low values for phosphate and nitrate observed during May (Table 4) were perhaps due to high phytoplankton productivity observed during this month (Desai *et al.*, in press). From the trend of variations it appears that nitrate is the growth-limiting factor. The relationship of nutrients with salinity was not evident and the values fluctuated considerably and randomly. In case of PO₄³⁻-P lower values were frequently associated with high salinities.

The levels of Fe, Cu, Zn and As did not reveal any regular trend of variation and appear to be natural background levels.

TABLE 4
Nutrients and trace metals in Ambika River estuary

Parameter	October '79			December '78			May '79		
	2	8	10	2	8	10	2	8	10
PO ₄ ³⁻ -P (μmol l ⁻¹)	1.6	1.7	1.1	2.6	3.4	1.5	1.0	8.5	0.5
NO ₃ ⁻ -N (μmol l ⁻¹)	8.5	12.8	7.6	8.5	6.2	7.8	2.1	0.4	0.6
NO ₂ ⁻ -N (μmol l ⁻¹)	0.1	0.2	0.1	0.3	0.8	0.5	0.3	0.1	0.3
NH ₄ ⁺ -N (μmol l ⁻¹)	1.2	1.2	0.9	2.7	5.1	4.2	0.8	0.6	2.5
Fe (μg l ⁻¹)	15.6	22.3	12.8	—	—	—	17.2	9.8	19.1
Cu (μg l ⁻¹)	7.2	3.6	5.5	—	—	—	2.3	4.6	5.2
Zn (μg l ⁻¹)	12.6	7.1	9.0	—	—	—	6.9	17.8	15.2
As (μg l ⁻¹)	32.5	19.7	28.0	—	—	—	15.8	18.3	18.6

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BASELINE

Marine Pollution Bulletin, Volume 17, No. 6, pp. 274-276, 1986.
Printed in Great Britain.

0025-326X/86 \$3.00+0.00
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Metals in Sediments off Trinidad, West Indies

The island of Trinidad lies just off the South American continent (61-61½°W long., 10½°N lat.) close to the mouth of the Orinoco river (Fig. 1). Recently its Government embarked on an industrialization programme geared to utilize effectively the island's reserves of natural gas. Since pollution problems frequently follow industrialization (Wharfe & Van den Broek, 1977; Forstner, 1980; Grosjean, 1983), it was decided to monitor the metals Fe, Mn, Cr, Ni, Cu, Pb and Cd in the vicinity of the proposed industrial estate. Monitoring was conducted over a 3-year period at twelve stations indicated on the map (Fig. 1).

Sediment samples were collected by a 15.2 cm × 15.2 cm Petite Ponar (Wildco, Michigan, U.S.A.) grab. Two grabs of top sediment were taken at each station and about 1 kg of a composite from the mixed sediment was kept frozen in polythene bags until required for analysis. Sediments were dried at 60°C for 24 h and duplicate samples from each sediment were digested with concentrated nitric acid in PTFE digestion bombs (R.A. Scientific, London, England) for 2 h at 100°C. The diluted digests were then filtered through Whatman 541 filter paper. The metals were then determined by atomic absorption spectrophotometry using a Pye Unicam SP9 spectrophotometer with automatic background correction.

Precision of Chemical Analyses.

The precision of the metal analyses was determined by the relative standard deviations for replicate determinations on a typical sediment. The data are presented in Table 1.

The metal levels in the sediments showed a dependence on dredging/reclamation activities and current movement.

The dredging/reclamation activities occurred within the period June 1980-August 1981 of the sampling interval which extended from December 1979 to December 1982. During the dredging period, the mobilization and redeposition of compounds of the

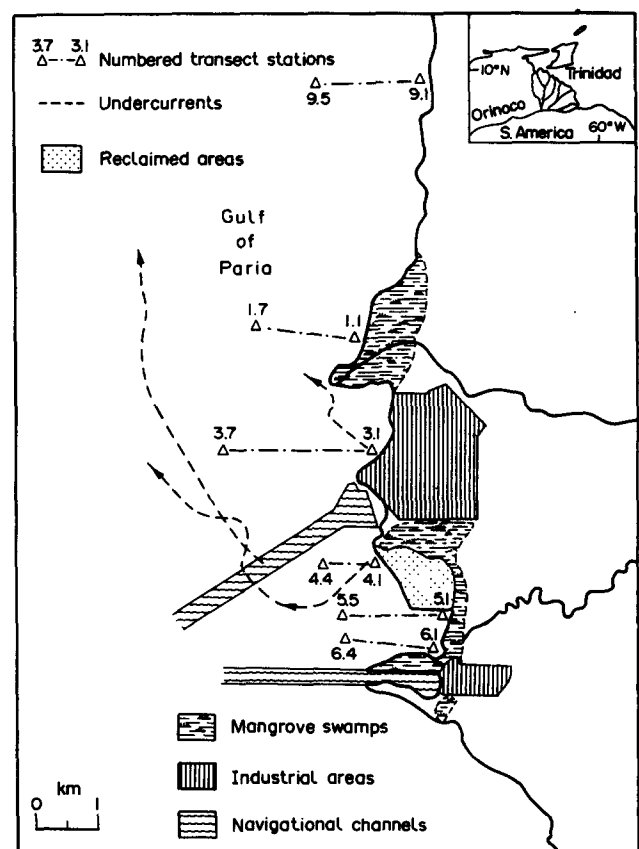


Fig. 1 Map of area sampled.

TABLE 1

Precision for Metal Determinations as Measured by Relative Standard Deviation ($n=5$)

Metal	Average relative standard deviation
Fe	25432.00 ± 1.2%
Cu	13.13 ± 1.8%
Cr	14.30 ± 7.0%
Mn	386.60 ± 1.8%
Ni	16.56 ± 5.1%
Pb	26.07 ± 1.8%
Cd	0.38 ± 4.0%

Average values in ppm