

EFFECTS OF INDUSTRIAL WASTE DISPOSAL ON THE WATER QUALITY OF THE RIVER KOLAK

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ABSTRACT

About 6 mld of industrial waste water is discharged without proper treatment in the fresh water zone of the river Kolak. Parameters like suspended solids, pH, chloride, DO, BOD, phosphate, nitrate, boron, sulphate and trace metals were periodically determined at 8 stations spread over a distance of 35 km from the mouth. The river flow decreases considerably during the dry season and is negligible after February. Severe pollution conditions, therefore, prevail during the dry season. Appreciable tidal influence with strong flood and ebb currents is observed upto about 3.5 km only, from the mouth. The effluent if discharged in this region would be effectively washed to the sea during the ebb tide.

INTRODUCTION

The river Kolak which runs almost in the east-north-west direction through South Gujarat joins the Arabian Sea near the Kolak village. The riverine flow is quite pronounced during the period July to September due to the influence of south-west monsoon and the occurrence of floods during this period is quite common. The flow, however, progressively decreases after September and becomes negligible from February onwards. The rocky river bed is then seen exposed at several places and the water flows through narrow channels in between the rocks. The rocky outcrops at the shallow river mouth are exposed during the low tide which almost isolate the river basin from the sea. In recent years there has been growing fear that the quality of water is deteriorating due to the discharge of industrial waste water. The present work is, therefore, undertaken to determine the extent of pollution and to suggest remedial measures.

MATERIALS AND METHODS

A 35 km stretch of the river shown in Fig. 1 was studied during the present investigation. About six measurements at each location were conducted from January to August, 1977. High and low tide samples were collected for the stations in the tidal zone. Dissolved oxygen, salinity and pH were measured over a tidal cycle at the stations 6 and 8 during February and May. Cross sections in the fresh water zone were obtained by making the breadth and depth measurements at the selected locations. Fathometer Model DE 719D was used to obtain cross-sectional profiles at the stations 7 and 8. Currents over complete tidal cycles were measured at the station 8 during spring and neap tides. Ekman-Mertz type current meter was used for obtaining current speed. Surface and bottom currents were measured when the depth was more than 3 m. For shallow regions, digital current meter of General Oceanics was used. Water level measurements were made by installing graduated staff gauges near the stations 5, 6 and 8.

Salinity was determined by argentometric titration (Strickland and Parsons, 1965). Modified Winkler's method was employed for the estimation of dissolved oxygen (DO) (APHA, 1975). For the determination of BOD direct method was employed for samples expected to have BOD less than 4 mg/l. Unseeded dilution method was used for the samples having higher BOD. Seeded dilution method was used for industrial effluents (Martin, 1970). In all cases samples were incubated at $20^{\circ} \pm 1^{\circ} \text{C}$ in a BOD incubator for 5 days. pH was determined on Philips Model PP9040 portable pH meter. The instrument was standardised with standard buffers just before its use. Phosphate, nitrate and ammonia were determined by known procedures (New Baltic Manual, 1972). Phenolics were determined by aminoantipyrine method. Chromium was determined by the procedure reported elsewhere (APHA, 1975). Other trace metals were determined by atomic absorption as follows. About 500 ml of the filtered water sample from the fresh water zone was evaporated with concentrated nitric acid and the residue was dissolved in 1N hydrochloric acid and aspirated. The standards and blanks were treated similarly. Samples from the estuarine zone were preconcentrated by solvent extraction procedure prior to analysis (FAO, 1975). Arsenic was determined either by Gutzeit procedure (for industrial effluents) (APHA, 1975) or by the molybdate colorimetric procedure (for estuarine samples) (Johnson and Pilson, 1972). Boron was determined by curcumin colorimetric procedure (APHA, 1975).

RESULTS AND DISCUSSION

Industrial waste water discharge:

Major industrial waste water discharge in the river Kolak is from the industrial complex at Vapi set up by the Gujarat Industrial Development Corporation (GIDC). This complex occupies an area of about 830 hectares and is divided into the north and south sectors by the Vapi-Selvasa road. The fresh water consumption of the estate is about 9 mld out of which about 7.7 mld is released as waste. In the absence of suitable treatment plants and drainage facilities, the waste water flows through storm water drains. The waste water amounting to about 4.3 mld from the north

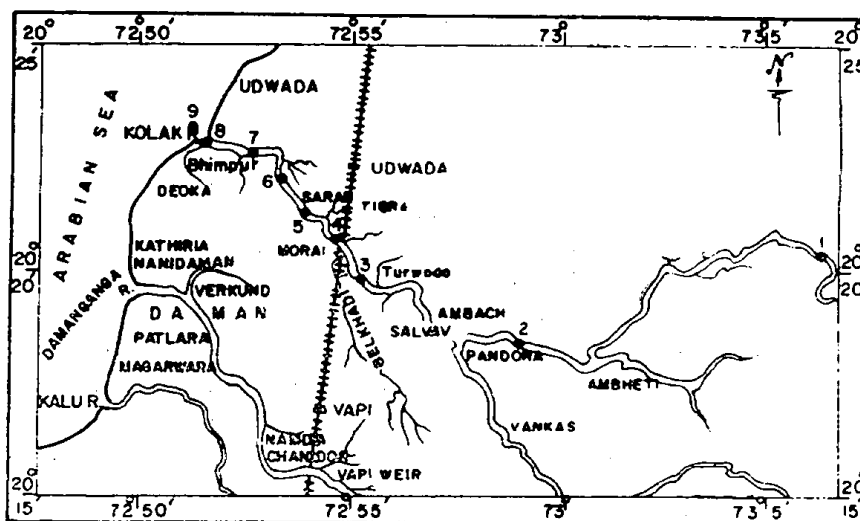


Fig. 1. Locations of sampling stations in the river Par.

sector which has a natural slope towards the Kolak river flows through a narrow channel called Belkhadi which ultimately carries the waste to the river a few metres upstream of the station 4 marked in Fig. 1. The waste water from the south sector (3.4 mld) is discharged in the river Damanganga. Discharges from some major industries of the north sector were analysed periodically and the data are given in Table I.

Table I. Characteristics of the waste water from some Industries of North sector.

Type of Industries	Quantity of effluent (mld)	BOD (kg/day)	COD (kg/day)	Suspended Solids (kg/day)	pH	
					Max.	Min.
Dye, dye-intermediate and textile	0.3	125	350	80	10.0	2.5
Organic chemicals and pharmaceuticals	0.3	275	630	80	11.6	6.5
Inorganic chemicals	0.05	5	—	4	8.0	6.0
Paper and pulp	2.5	1100	—	1200	6.5	8.5
Domestic sewage	0.8	100	—	70	—	—

It is evident that the combined effluent amounting to 3.95 mld had BOD and suspended load of 1600 and 1400 kg/day, respectively. The flow measured near the mouth of Belkhadi varied from 3.4 to 3.8 mld when the measurements were made in March and April. The samples periodically collected were analysed and the results are presented in Table II. The actual load on the river was, therefore, 827 kg/day of BOD and 388 kg/day of suspended solids. Thus substantial reduction in BOD and suspended solids occurs during the flow of waste water through Belkhadi. This is mainly due to the sluggish movement which removes a good fraction of suspended load by settling which also decreases the BOD. The levels of BOD, suspended solids and oil and grease at the mouth of Belkhadi, however, were quite in excess of the prescribed limit for industrial discharges in rivers. Concentration of phenolics varied in the range 2.0 to 5.5 mg/l which is close to the maximum permissible level.

In addition to GIDC discharge, a paper mill on the southern bank of the river discharges about 1.5 mld of waste water with an average BOD and suspended load of 300 and 500 kg/day respectively, just upstream of the station 3.

Tides and currents:

The extent of tidal influence varies distinctly from monsoon to non-monsoon period due to large variations in the riverine flow. The tidal influence during the pre-monsoon months was investigated by installing graduated staff gauges at convenient locations during the spring and neap tides. The rise in water level during the spring flood tide was about 5.5 m at the station 8 which decreased to about 3.5 m during the neap period. The corresponding levels at the station 6 were 4.0 and 2.5 m during spring and neap tide respectively. The observed tide level elevations indicated an appreciable tidal influence within the estuary upto the station 6. Just beyond the station 6, the river bed gradient increases abruptly due to the rocky outcrops which considerably weaken the tidal influence beyond this barrier. Thus during the spring flood tide, the rise in water level at the staff gauge 5 was only 0.5 m and was insignificant during the neap flood tide. Evidently, the industrial waste water discharges fall in the non-tidal zone and

Table II. Characteristics of the waste water at the mouth of Belkhadi.

Parameter	Maximum	Minimum	Mean	Mean during monsoons
Flow (mld)	3.88	3.44	3.66	—
Suspended solids (mg/l)	214	39	106	567
Chlorides (mg/l)	419	320	360	150
pH	8.5	6.8	—	7.5
Dissolved oxygen (mg/l)	0.8	0.0	0.1	1.1
BOD (mg/l)	372	98	226	11
Total phosphorus ($\mu\text{g/l}$)	742	203	548	137
Sulphate (mg/l)	1.29	0.13	0.72	0.8
Phenolics (mg/l)	5.5	2.0	3.6	0.2
Oil and Grease (mg/l)	770	13	197	49

significant tidal influence is observed only about 3.5 km downstream. It is, therefore, clear that very little water is available for dilution at the present discharge sites during the dry season when the river flow diminishes considerably.

Currents in the estuarine zone varied considerably depending upon the time and the tide. Typical plots of the instantaneous current speed with flood as positive y-axis and ebb as negative y-axis against time are shown in Fig. 2. The peak spring flood velocity of 1.1 m/sec decreased to 0.6 m/sec during the neap. The corresponding ebb currents were of the same order. Surface and bottom currents were also comparable. The observed currents indicate a swift water movement within the estuary and the waste water, if discharged beyond the station 6, would mix well with the sea water if discharged properly.

Flushing time was calculated by applying the tidal prism method (Dyer, 1973). The crosssectional profiles measured at about every 1.5 km from the mouth upto the staff

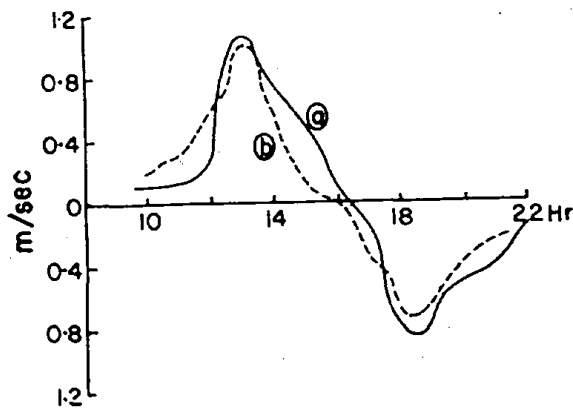


Fig. 2. Variation of current speed with time at station 8 on (a) 6-4-77, (b) 20-2-77.

gauge 5 were utilized to calculate the average low tide volume and the average intertidal volume. A typical profile is given in Fig. 3. From these measurements the average tidal prism and the average low tide volume were calculated to be 1437×10^3 and $256 \times 10^3 \text{ m}^3$ respectively. The flushing time then works out to be only 1.2 tidal cycles. The fraction of well mixed water that would be removed from the estuary after one tidal cycle under these conditions would be about 85% and the fraction remaining would be 15%. After an infinite number of tidal cycles,

under a continuous flow of pollutants, the load remaining is given as

$$L = Y/(1 - Y)$$

where Y is the fraction remaining after one tidal cycle and L is the multiple load introduced

per tidal cycle. In this case L is approximately 0.2. It is, therefore, clear that the major portion of effluent would be washed into the sea on every ebbing tide if discharged properly in the estuarine zone.

Flow characteristics:

When the present survey commenced, the weak river flow was only through the narrow channels. The flow calculated from the cross-sectional area and the average current speed decreased from 28.0 mld in March at the station 1 to 16.3 mld in April. The corresponding values near the station 4 were 9.7 and 1.8 mld respectively. The water available for diluting the effluent is, therefore, quite inadequate compared to the volume of waste water discharged. Evidently, worst pollution conditions occur during the dry season.

Chlorinity / Salinity:

Monthly variation of chlorinity is graphically represented in Fig. 4. In the fresh water zone, the chloride content generally increased from February to May perhaps due to the reduction in flow and higher rate of evaporation. Chlorinity in the tidal region also followed the similar trend but the value at any time varied with the tidal condition. Thus, at the station 6, the low tide chlorinity of 7.8‰ during February gradually increased to 14.9‰ with the corresponding flood tide and at the station 8, the high tide salinity of 33.7‰ decreased to 31.0‰ at the ebb slack (Fig. 5). From Fig. 5, it is evident that surface and bottom salinities differed only slightly. The water within the estuary is, therefore, well mixed with the absence of any appreciable diffusion boundary. This can be attributed to faster currents and the voluminous influx of sea water during the high tide.

Suspended solids and light penetration:

Maximum, minimum and mean values for the period January to June are given in the Table III. The mean of the monsoon collections is given separately. The mean values for the stations 1 and 2 varied in the range 77 to 54 mg/l. The increase at the station 4 (103 mg/l) is attributable to the contribution from the load of 900kg/day

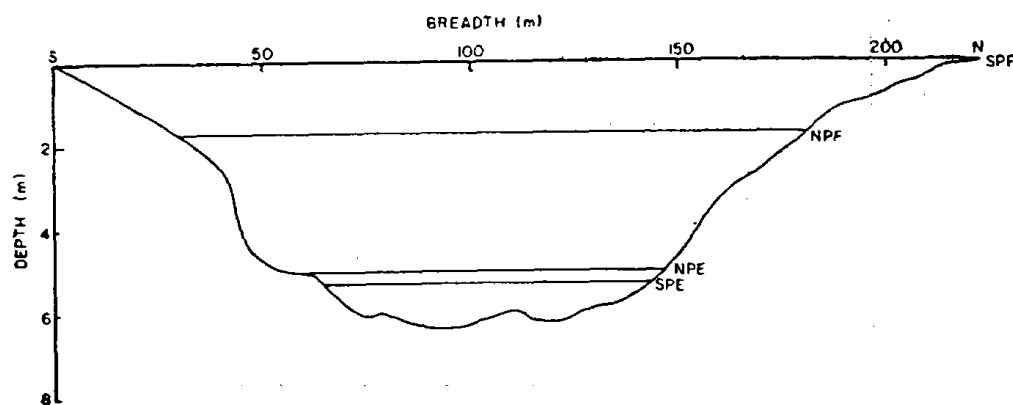


Fig. 3. Cross-sectional profile at station 8.

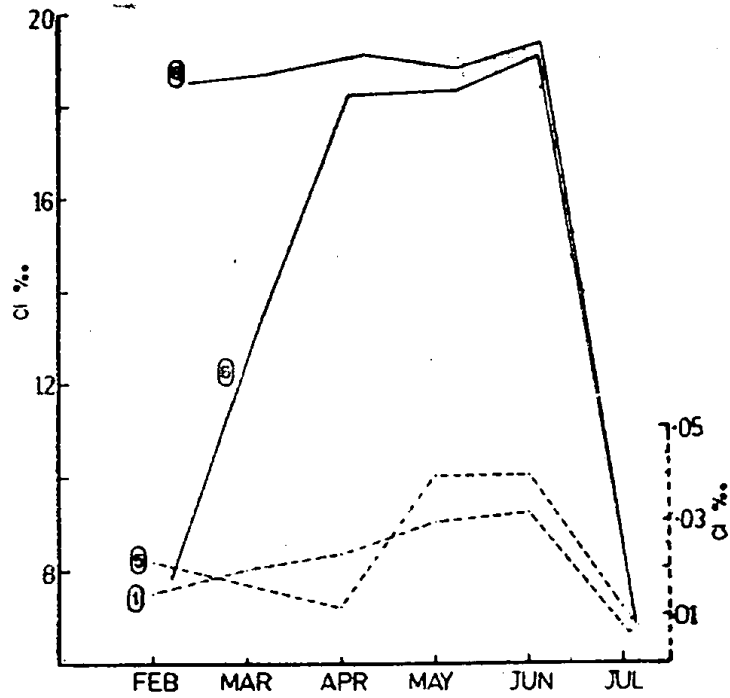


Fig. 4. Monthly variation of salinity/chlorinity at stations 1, 5, 6 and 8.

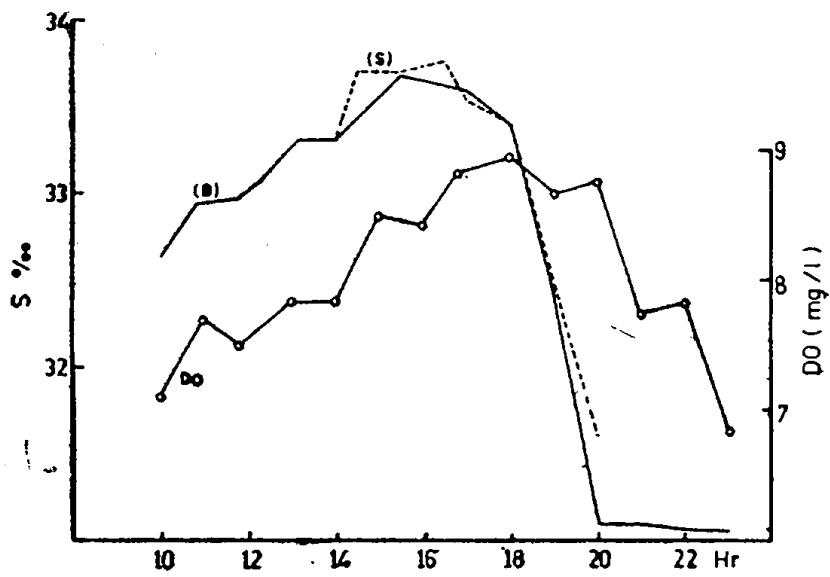


Fig. 5. Variation of Salinity (S=Surface, B=Bottom) at station 8 over the tidal cycle on 20-2-77.

discharged through the waste water. At the station 5, the mean suspended load was of the same order as observed for the other fresh water stations. This is because, beyond station 4, the river abruptly broadens into a deeper water pool about one kilometre in length and 30 m wide, the other end of which is bordered by rocky outcrops. The flow of water through this pool is slow due to weak currents and the major fraction of suspended load settles to the bottom. The suspended solids, however, increased considerably at the tidal stations which is of natural occurrence and results from the stirring up of bottom sediments into the water column by the strong tidal currents. Analysis of surface and bottom samples indicated higher suspended load at the bottom. Substantial increase in suspended solids during monsoon (Table III) is due to the load associated with land drainage.

At the stations 1 and 2, the water was clear and transparent upto the bottom. The light penetration at the station 4 was considerably reduced due to the dark colour of the waste water. Here, the Secchi disc visibility was frequently less than 20 cm which increased to about 50 cm near the station 5. In the estuarine zone the transparency was low due to the high suspended load and varied from 15 to 75 cm.

Table III. Suspended solids, pH and BOD for the river Kolak

Station No.	Suspended solids (mg/l)				pH			BOD (mg/l)			
	Max.	Min.	Mean	Monsoon	Max.	Min.	Monsoon	Max.	Min.	Mean	Monsoon
1	95	45	77	—	8.7	8.2	—	10.0	4.3	6.8	—
2	114	3	54	330	8.6	8.1	8.3	11.6	7.8	8.7	1.3
3	202	24	91	210	8.5	8.0	7.8	62.1	8.9	34.8	6.0
4	139	46	103	446	8.7	8.0	7.6	85.3	21.2	54.8	10.0
5	73	20	40	381	8.3	8.2	8.0	21.6	7.0	10.7	—
6	157	10	86	359	8.8	8.0	7.6	8.6	1.6	3.5	1.3
7	195	169	182	—	8.6	8.3	—	2.6	1.2	1.9	—
8	201	105	183	320	8.1	7.8	7.7	2.6	1.2	2.1	1.0
9	325	110	189	—	8.2	8.1	—	3.1	1.0	1.8	—

DO and BOD:

The general decrease in DO levels from February to May is evident from the DO profiles produced in Fig. 6. The minimum values observed at the unpolluted stations 1 and 2 were 6.9 and 4.2 mg/l, respectively. The decrease in DO can arise from several factors such as increase in temperature, decrease in photosynthetic activity, increase in biochemical oxidation etc. Temperature which in the present case increased from 18–23°C in February to 30–35°C in May was one of the factors which contributed to the reduction in DO by decreasing the rate of dissolution of atmospheric oxygen. A rise in temperature also enhances the rate of biochemical oxidation. The decrease in DO at the stations, 3, 4 and 5 was greater than that of the upstream stations 1 and 2 and the levels fell to less than 0.5 mg/l during May at the stations 3, 4 and 5. From Fig. 6 and 7 it is clear that during May about 4 km stretch of the river between stations 3 and 5 had oxygen levels of less than 0.5 mg/l and during April the levels were less than 3.5 mg/l. Severe pollution conditions, therefore, existed during May. Evidently, the whole area smells of decomposing organic matter and the environment almost becomes anaerobic with the evolution of hydrogen sulphide during May and early June. Quantitative estimation of hydrogen sulphide was not done but its presence was indicated by the formation of blue

colour when the water sample was treated with solutions of N N-dimethyl-p-phenelene diamine dihydrochloride and ferric chloride. The conditions then become highly toxic to the aquatic organisms and the animals transported in the lower part of this zone during the spring tide were seen struggling and ultimately dying. General decrease in DO from February to May was also observed at the estuarine stations. The levels of about 8 mg/l in February were reduced to about 5.5 mg/l in May at the stations 7 and 8, although the concentration also varied with the stage of the tide. Thus, from Fig. 5, it is observed that the DO of 7.1 mg/l during the ebb slack increased to 8.9 mg/l at the flood slack at the station 8. The difference between the high tide and low tide values at the station 6 was about 4 mg/l indicating the influence of the effluents during the ebb tide. The levels, however, seldom fell below 4.5 mg/l in the estuarine zone due to good tidal flushing.

The reduction in the fresh water flow and its consequent decrease in DO resulted in a general increase in BOD. The value which was around 6.0 mg/l at the stations 1 and 2 in February increased to about 10.0 mg/l in May. This increase was several times greater at the stations 3, 4 and 5, -from 8.9 to 62.0 mg/l, from 21.2 to 83.0 mg/l and from 7.8 to 21.6 mg/l at the respective station from February to May. As expected the values decreased appreciably with the commencement of monsoon flow and were only 1.3, 6.0 and 10.0 mg/l at the stations 2, 3 and 4 respectively. At the estuarine stations the BOD was lower and values varied in 1.2 to 8.6 mg/l range (Table III).

Phosphorus and nitrogen compounds:

The distribution of phosphate, nitrate and ammonia varied from collection to collection (Table IV and V) although a general increase from February to May was observed. Values for phosphate, nitrate and ammonia were found to fall in the ranges 7-42 $\mu\text{g PO}_4^{3-}$ -P/l, 3-38 $\mu\text{g NO}_3^-$ -N/l and 11-81 $\mu\text{g NH}_4^+$ -N/l respectively during early February which

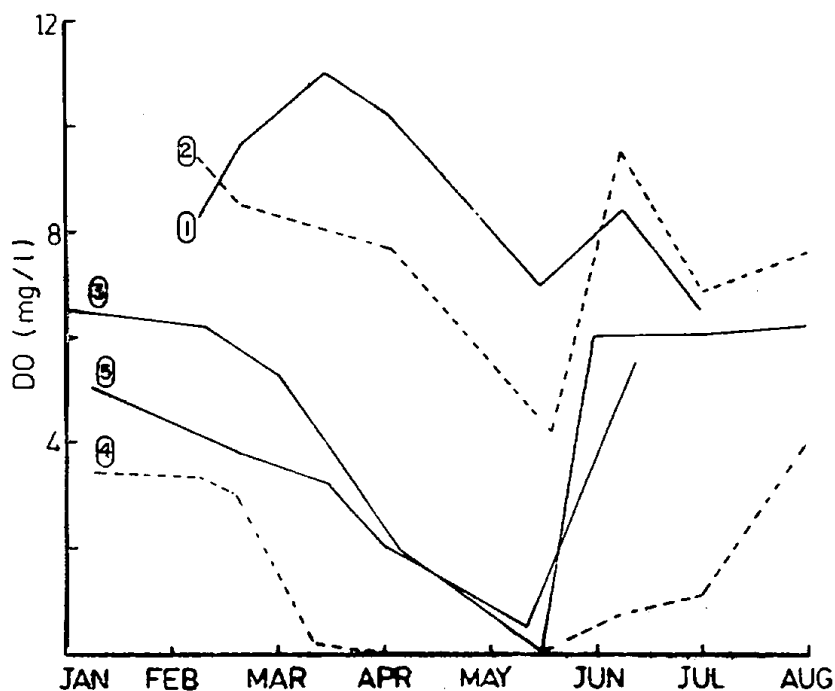


Fig. 6. Monthly variation of DO at stations 1, 2, 3, 4 and 5.

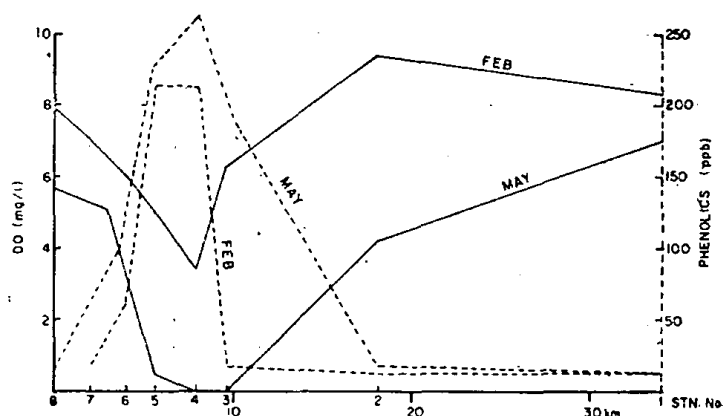


Fig. 7. Variation of DO and phenolics in the river Par.

increased to 46–369 $\mu\text{g PO}_4^{3-}\text{-P/l}$, 27–229 $\mu\text{g NO}_3^{-}\text{-N/l}$ and 37–162 $\mu\text{g NH}_4^{+}\text{-N/l}$ during March except at the station 4 where the nitrate levels decreased substantially and become almost zero in May. From the concentration of nitrate and phosphate it appears that nitrate is a limiting factor for algal growth in the river Kolak. With 'normal' composition of algal cells, the nitrogen-phosphorus atomic ratio would be 15:1, so that utilization of phosphate is less than that of nitrate. The low concentrations of nitrate observed at the station 4 (0 to 14 $\mu\text{g NO}_3^{-}\text{-N/l}$) during the survey period may result from the reduction of nitrate to nitrite by some bacteria which can use nitrate as oxygen source in deoxygenated water. Evidently, the nitrite levels here were high and often exceeded 200 $\mu\text{g NO}_2^{-}\text{-N/l}$. Evolution of hydrogen sulphide results from the reduction of sulphate when sulphate is utilized as an oxygen source after the complete reduction of nitrate and nitrite to ammonia.

Boron and sulphate:

The levels of boron at the stations 1 and 2 ranged from 0.06 to 0.63 mg/l (Table IV) and are well within the limit prescribed for the use of water for irrigation. The sharp increase in the estuarine zone results from the high concentration of boron in sea water. Boron in sea water bears a constant ratio of 0.223 with chlorinity (Dryssen, Uppstrom, 1972) and this ratio does not vary much in the coastal regions. Thus, for the

Table IV. Inorganic Phosphorus, total Phosphorus and Boron for the river Kolak.

Station No.	Inorganic Phosphorus ($\mu\text{g/l}$)				Total Phosphorus ($\mu\text{g/l}$)				Boron (mg/l)		
	Max.	Min.	Mean	Monsoon	Max.	Min.	Mean	Monsoon	Max.	Min.	Mean
1	128	7	60	—	208	47	150	—	0.63	0.09	0.37
2	369	7	132	206	442	29	212	269	0.41	0.06	0.21
3	128	11	76	241	278	24	107	318	0.19	0.05	0.12
4	128	7	61	236	212	69	140	362	0.52	0.25	0.39
5	86	8	42	—	245	98	181	—	0.31	0.13	0.23
6	84	20	43	204	269	71	163	239	4.20	0.64	3.05
7	76	39	48	—	205	89	150	—	3.13	2.82	2.95
8	190	42	101	—	530	136	382	—	3.38	3.07	3.22

Table V. Ammonia, Nitrate, Sulphate and Phenolics for the river Kolak

Sta- tion No.	Ammonia nitrogen ($\mu\text{g/l}$)			Nitrate nitrogen ($\mu\text{g/l}$)			Sulphate (gm/l)			Phenolics ($\mu\text{g/l}$)		
	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean
1	94	25	66	34	20	27	0.41	0.05	0.23	12	6	9
2	116	34	75	23	9	16	0.60	0.14	0.29	12	6	9
3	162	27	75	96	3	43	0.95	0.07	0.51	310	14	92
4	101	51	71	14	0	9	2.30	0.25	0.97	392	100	240
5	147	81	105	229	73	151	0.82	0.39	0.59	232	85	136
6	84	37	60	161	14	71	2.36	0.20	1.28	228	67	105
7	54	35	45	—	—	—	5.48	2.36	3.92	22	6	14
8	38	11	23	35	5	21	4.80	1.60	3.67	67	6	31

water of chlorinity 18‰ , the boron concentration is higher than 4 mg/l . The ratio varied for the water of low chlorinity and for samples from station 1 and 2 it varied considerably from 0.35 to 1.62. Like boron, sulphate also bears a constant ratio with chlorinity and the high concentration in the estuarine zone (Table V) results from sea water intrusion.

Phenolics:

The phenolic content at the stations 1 and 2 was low ($6\text{--}12\ \mu\text{g/l}$) and increased substantially at the downstream stations (Table V). The maximum concentration of $392\ \mu\text{g/l}$ was observed at the station 4 during May. The mean concentration at the station 6 was $105\ \mu\text{g/l}$. The sharp increase in the phenolic content at these stations arise from the GIDC industrial discharge which adds about 20 kg/day of phenolic compounds to the river water.

Trace metals:

The data given in the Table VI represent only soluble fraction of several metals in the water from the stations 1 to 8. The major objective was to determine the baseline concentrations which would serve a basis for future studies. The elements studied show two types of distributions. Except at the station 4, cobalt and nickel varied in a very narrow range with the maximum concentration observed being $3.3\ \mu\text{g/l}$ of nickel. Maximum variation was observed for manganese and iron and their concentration varied in the ranges 0.5 to 18.5 and 1.2 to $59.6\ \mu\text{g/l}$ respectively. In general, somewhat higher concentrations were observed in April than in June. The levels of metals were low in the GIDC effluent and did not increase the metal content of the receiving water body, appreciably.

Light absorption studies:

Absorption spectrum of the waste water from GIDC indicated a strong absorption peak around 195 nm in the UV range and a medium absorption around 400 nm on the tail of the strong band protruding in the visible region. The river water downstream of the station 4 was, therefore, characterised by similar absorption spectrum. The fresh water from the stations 1 and 2 absorbed very weakly in the ultraviolet region and was transparent throughout the visible range. It is, therefore, evident that the effluent increased the absorbance of the receiving water. From Fig. 8 where the absorbance values measured at 400 nm for water from different stations are plotted, it is evident that

Table VI. Concentration ($\mu\text{g/l}$) of some trace metals in the river Kolak

Stn. No.	Date	Manganese	Iron	Cobalt	Nickel	Copper	Zinc	Arsenic	Chromium
2	3-4-77	10.2	28.2	ND	1.3	8.4	3.5	—	—
	29-6-77	5.1	5.4	ND	ND	2.7	2.9	—	—
3	3-4-77	12.8	16.5	0.6	1.1	6.3	6.3	—	—
	29-6-77	0.5	1.2	ND	ND	2.4	2.5	—	—
4	3-4-77	18.5	59.6	ND	5.3	17.2	34.6	—	60
	29-6-77	6.0	8.6	ND	3.6	3.2	2.9	—	—
6	3-4-77	13.6	2.8	0.4	3.3	8.5	8.5	—	—
	29-6-77	3.8	6.5	ND	2.2	1.2	4.2	—	—
7	3-4-77	5.2	12.9	ND	ND	6.7	14.6	15.6	—
	29-6-77	13.1	18.6	1.1	ND	1.9	12.3	—	—
8	3-4-77	4.0	29.7	0.2	1.0	3.6	18.9	26.8	ND
	29-6-77	3.0	13.6	ND	ND	4.5	10.2	—	ND
E	3-4-77	106	268	17.3	22.6	20.1	20.2	500	98
	10-6-77	3.5	59	2.8	6.5	17.0	34.6	305	102
	29-6-77	5.5	22.5	6.2	7.0	6.2	1.9	—	—

ND=Not detectable

E=Effluent

during the low tide the effluent can be traced upto the mouth of the river. Comparing the absorbance values of the waste water itself with values at the station 5 it was concluded that at the station 5 the effluent had achieved only 4 times dilution.

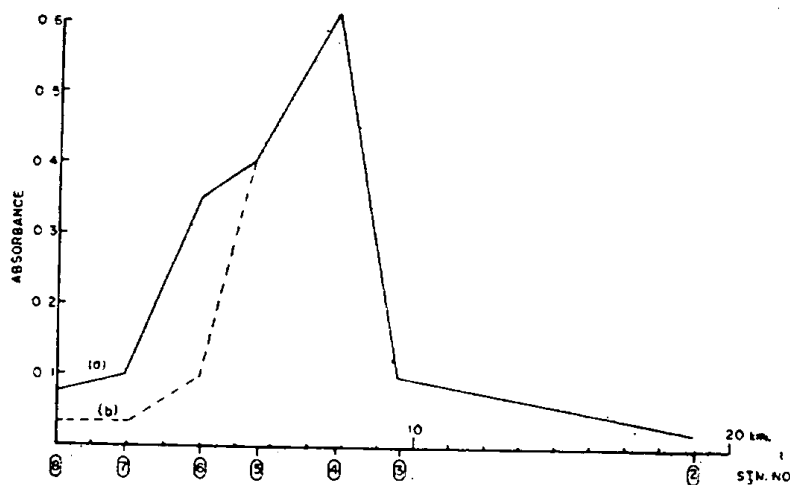


Fig. 8. Absorbance at 400 nm by water from different stations.

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