

Physicochemical Studies on Coastal Pollution Off Bombay

M D ZINGDE, S K TRIVEDI & B N DESAI

Regional Centre, National Institute of Oceanography, Versova, Bombay 400 061

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Variations of salinity, dissolved oxygen (DO) and biochemical oxygen demand (BOD) in the creeks, bays and coastal region around Bombay were studied. Currents varied depending on the tide and their direction in creeks and streams was dominated by the physical features of the channel. Currents did not vary appreciably from the surface to bottom. Salinity varied widely from $<5\text{‰}$ during August to $>34\text{‰}$ after March. Generally, the monsoon period was characterised by well marked vertical salinity gradient except in the coastal region, which disappeared at most of the stations during the postmonsoon period. Coastal water was vertically homogeneous throughout the year while some lateral salinity gradient was observed during August. DO profiles were similar at most stations. In general, higher DO observed in August sharply decreased during September and then gradually increased to maximum in February, followed by a gradual decrease till May. This trend appears to be due to the combined effect of BOD, temperature and photosynthetic activity. Abnormally low DO and high BOD were observed at Upper Thana, Mahim Bay and Versova Creek due to the influence of waste water discharged at these locations. Mahim Bay was worst affected with DO levels sometimes falling to <1 mg/litre.

The combined waste water discharge from domestic and industrial establishments in and around Bombay (lat. $18^{\circ}55'N$, long. $72^{\circ}49'E$) imposes strain on the receiving marine environment and deteriorates the water quality. Preliminary report¹ indicates that the quality of water of the harbour region has deteriorated. Extensive survey has been carried out to determine the state of pollution of the receiving water mass and to locate suitable sites for discharge of treated waste water which can easily be diluted and dispersed. This paper presents data on variation of salinity, dissolved oxygen (DO), and biochemical oxygen demand (BOD) of the marine environment around Bombay.

Materials and Methods

Water quality at several stations (Fig. 1) around Bombay was monitored for 16 months from May 1976. The stations were grouped together as given below, to present a general picture of the region studied.

Thana Creek stations—Data on various parameters from sts 1 to 9 were monitored during ebb-flood and flood-ebb cycles every month at spring and neap tides. Normally, samples from each station were collected at every 2 hr interval. As no significant differences in the values from ebb to flood and flood to ebb cycles were observed, the values obtained during 1 month for a particular location were averaged. In addition samples were also analysed from tributaries (I to VIII, Fig. 1) which join Thana Creek.

Stream monitoring stations—Sts 10 to 17 were monitored over a complete tidal cycle once a month. Samples were collected at hourly intervals and the values averaged.

Coastal stations—Sts 18 to 20 including 18a were monitored once a month over complete tidal cycle.

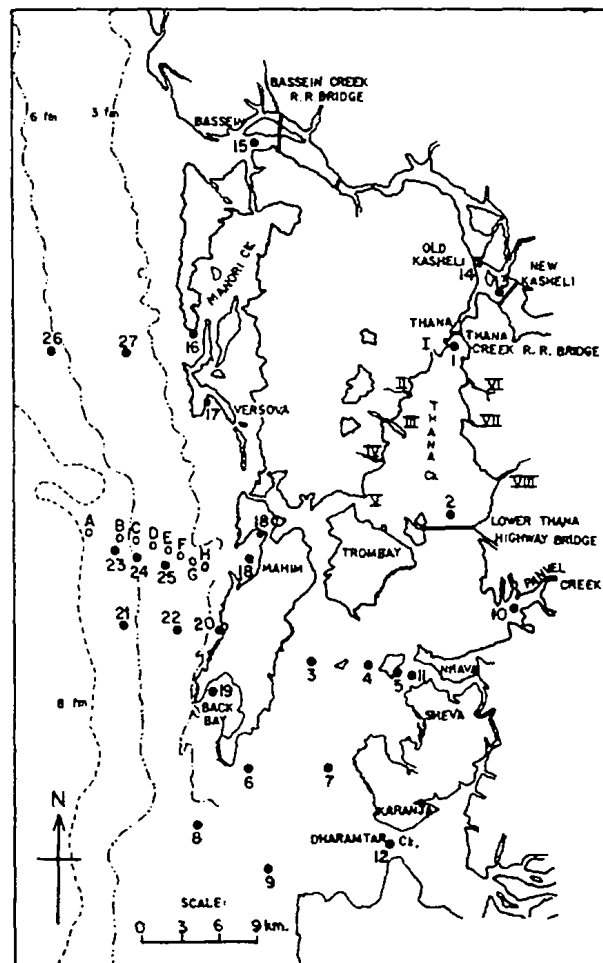


Fig. 1—Sampling stations

Other stations (21 to 27) were in the coastal region on 3 transects and were monitored once in a month. In addition sts A to H were monitored once in a month during August, September and October.

Samples were collected from surface, middle and bottom when the depth was > 5 m and from surface and bottom when the depth was < 5 m. Only surface samples were collected when the depth was < 1.5 m.

Oxygen was determined by Winkler's method². For the determination of BOD³, direct method was employed for samples having BOD < 4 mg/litre and for samples having higher BOD, unseeded dilution method was employed. The samples were incubated for 5 days at 20 ± 1°C in a BOD incubator. Salinity was determined by argentometric titration method.

Currents were measured either by continuous recording General Oceanics current meter or by Gurley impeller type current meter. Tidal elevations were measured by installing staff gauges.

Results and Discussion

Thana Creek stations—Thana Creek (Fig. 1) receives about 25 mld of waste water discharges from about 30 major industrial establishments.

Tides and currents: Tidal variations in Thana Creek are semi-diurnal with an appreciable diurnal element. A tidal exchange flow between Thana Creek and Ulhas

River/Bassein Creek is possible since the tidal effect is felt earlier at st 1 than st 13. As a result, during flood tide, the water may flow from Thana Creek to Bassein Creek depending on the relative levels of high water in the 2 creeks. During the ebb tide, however, the water recedes earlier at st 1 and the flow gets reversed. Hence, the possibility of effluents discharged in the Thana Creek entering the Bassein Creek and vice versa, cannot be ruled out.

Currents within Thana Creek are almost entirely due to the tidal ebb and flood flows and the velocity varies depending on the stage of the tide during the dry season. Between sts 8 and 9, maximum ebb velocity of 115 cm/sec was recorded during the spring ebb tide and 70 cm/sec during the spring flood tide. Higher velocities of the order of 150 cm/sec were observed in some instances. The currents maintained almost the same direction from the surface to bottom and their velocities decreased only slightly. The velocity, however, decreased appreciably from the mouth of the creek towards st 1, where the velocity rarely exceeded 25 cm/sec and the maximum velocity observed at st 2 was 50 cm/sec during the spring ebb tide. The monsoon fresh water flow influenced the current velocity.

Salinity: Salinity of sts 1 to 9 varied from 7.19 to 38.16‰ (Fig. 2). The minima attained in August may be due to the surface run off and the fresh water

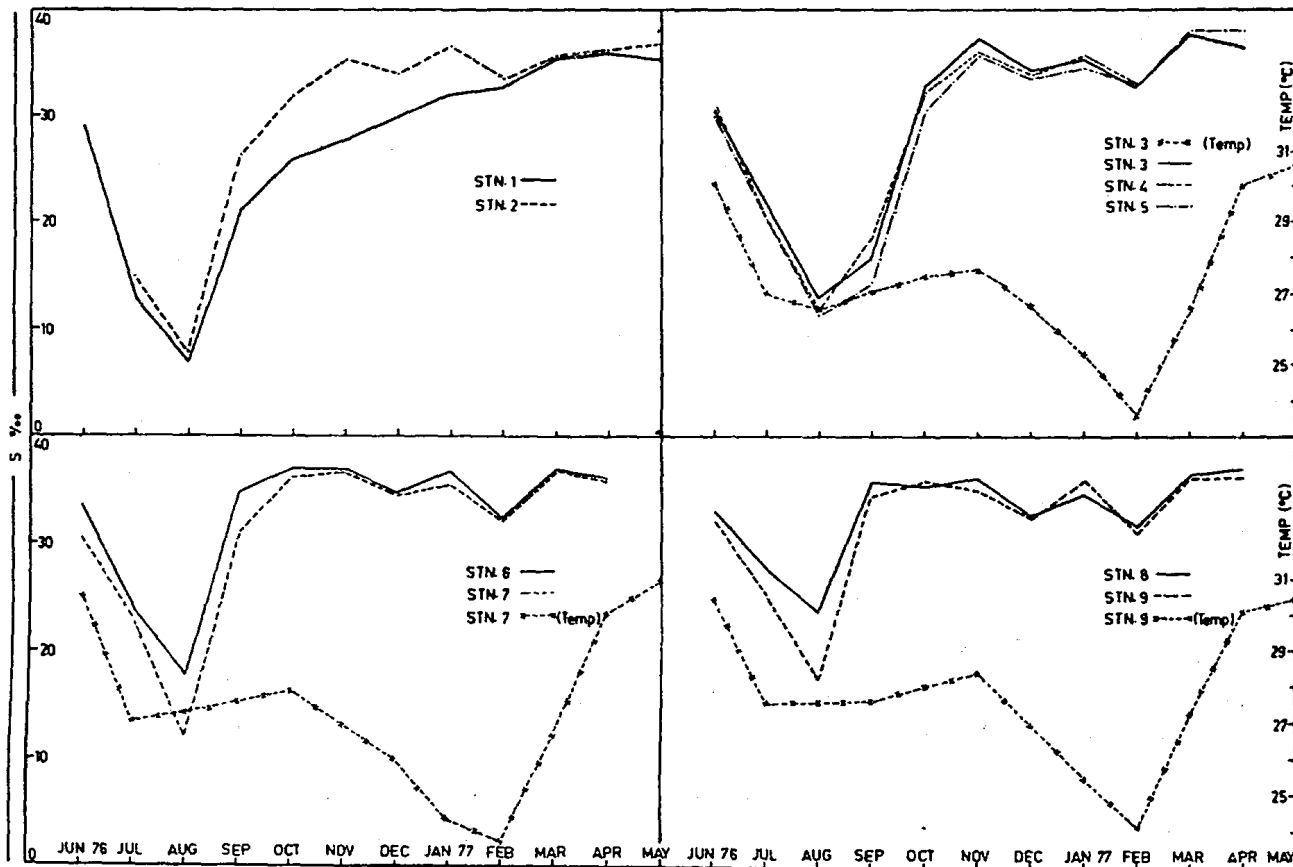


Fig. 2—Monthly variation of salinity and temperature at Thana Creek stations

discharge from the Ulhas River and other creeks. Although the peak salinity observed was 38.16‰, in some isolated instances, salinity as high as 40.32‰ was measured during March-May along certain shallow regions lying close to the salt pans, mud flats and mangroves. Comparatively high salinity (37-38‰) observed during March-April may result from some local factors as mentioned above, since the sea water outside the creek had a salinity around 36.5‰ during this period. Low salinity was observed during August with a definite salinity gradient from 7.19‰ (av.) at st 1 to 23.82‰ (av.) at st 8 (Table 1). Except at st 1, the salinity increased during October and attained a range of 32-36‰. There was no significant vertical salinity gradient except at st 1, during March (Table 1). Surface and bottom salinities differed markedly at st 1 from August till December. The overall salinity at st 1 was lower than that observed at the downstream stations in any month. The low salinity can be due to the discharge

of low saline water from the Ulhas River which is considerably reduced after January. The monsoon period was characterised by a well marked vertical salinity gradient (Table 1). With the influx of fresh water, the difference between surface and bottom layer was appreciable. Diurnal variations at sts 1 and 2 during August, indicated appreciable increase in salinity with the flood tide followed by a decrease with the ebb tide. Although there was great influx of fresh water, during the flood tide, there was intrusion of saline water along the bottom. The effect of this was felt up to st 1. Bottom salinity, however, was lower at this location as compared to st 2 indicating an appreciable mixing of both saline and fresh water.

Dissolved oxygen: DO content at sts 3 to 9 was more or less similar (Fig. 3). DO of 6 mg/litre recorded during August decreased to about 4 mg/litre during September and then gradually increased to attain a peak (8.5 mg/litre) during February. This was followed by a gradual decrease till May. This is perhaps due to the combined effect of temperature, photosynthetic activity and biochemical oxidation of the waste entering the marine environment. Although average values normally varied in the range of 3.7 to 9.2 mg/litre abnormal values were occasionally observed. Values < 2 mg/litre were observed at sts 3 and 4 in some collections during September. Highest DO of 10.1 mg/litre was observed at st 9 at the surface during February. DO distribution in the vertical water column was fairly uniform during the post monsoon period showing marginal decrease with depth. This supports the earlier conclusion that the water in the creek is well mixed in the postmonsoon season. DO decreased appreciably from surface to bottom during August. The differences in DO observed between surface and bottom layer (Table 1) could be due to the large influx of fresh water of high oxygen content (Fig. 2) which formed the major component of the surface since vertical mixing was partially restricted by the salinity gradient (Table 1). Low DO during September could be mainly because of the additional oxygen demand by the sinking suspended load brought in by the run off. Although the average surface and bottom values were 4.3 and 3.9 mg/litre respectively, lower values of 2-3 mg/litre were occasionally observed, specially at st 6 for the subsurface water. This may be due to biochemical oxidation of organic waste transported by run off. At the same time the supply of oxygen rich fresh water decreased substantially. Samples collected during August and May starting from the mouth of the creek to the Thana Railway Bridge (TRB) showed decrease in DO along the length of the creek (Fig. 4) from the mouth up to the bridge. The decrease in the creek region was more pronounced in May indicating the fall in water quality as a result of

Table 1—Salinity and DO at Some Stations during August and March

Station	Salinity (‰)			Oxygen (mg/litre)		
	S	M	B	S	M	B
	August					
1	0.8	8.86	11.9	5.4	4.4	4
3	9.65	12.65	16.88	7.6	7.2	3.7
5	5.72	10.14	18.08	6.9	6	3.8
6	11.19	18.04	24.76	7	6	5
7	9.68	13.88	17.94	7.8	6.9	4.2
8	17.34	22.39	31.73	6.9	6.3	5.6
9	14.2	16.97	22.44	7.8	6.4	4.5
10	4.05	8.18	13.84	6.3	5.7	5.5
13	1.22	1.22	1.91	4.1	4.2	4
14	0.68	1.53	1.76	4.1	4	4.1
16	16.82	16.86	18.44	7.2	—	5.8
17	15.39	16.95	17.87	7.2	6.1	5.6
18	6.28	—	12.27	3	—	2.6
18a	2.8	—	—	0.5	—	—
19	27.5	27.92	34.51	8	2.2	2
22	29.5	30.21	30.82	6.6	6.3	5.2
	March					
1	35.23	—	35.68	4.6	4	3.5
3	37.85	—	38.08	6.5	6.3	5.1
5	36.8	—	38.12	6.8	6.3	5.6
6	37.16	36.67	36.64	6.7	5.8	6
7	36.23	37.06	37	6.2	5.9	5.5
8	36.35	—	36.35	6.8	6.8	6
13	28.06	28.86	30.01	4.3	3.2	4
14	29.8	30.06	30.24	3.6	—	4
16	34.52	—	35.23	6.9	—	7.2
17	27.07	34.91	35.28	3	4.6	5.2
18	32.63	—	35.48	1.3	—	2.6
18a	32.9	—	—	0.5	—	—
19	35.14	35.5	36.67	6.5	6.2	6.1
22	36.29	36.15	36.82	7.4	6.9	6.8

S = surface; M = middle; B = bottom

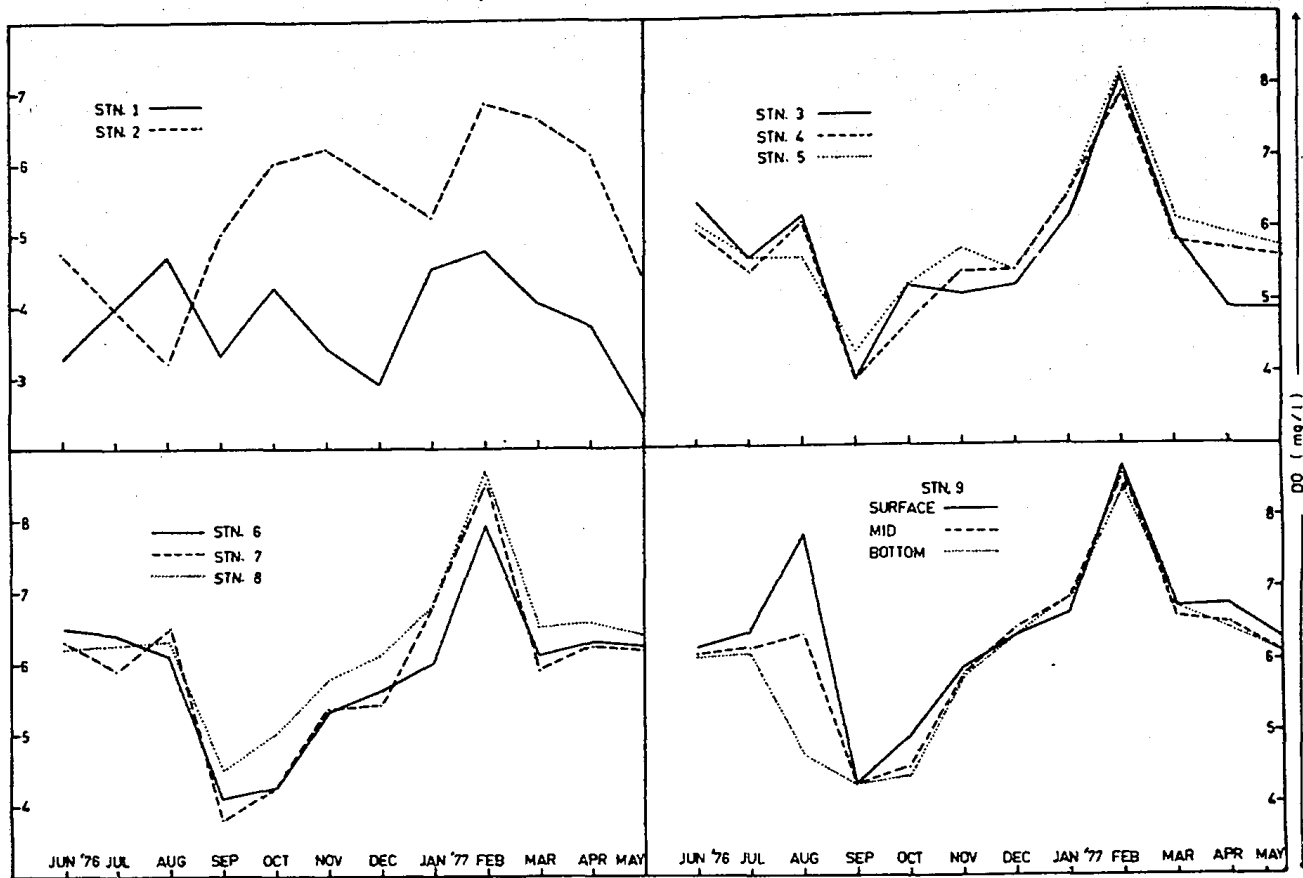


Fig. 3—Monthly variation of dissolved oxygen at Thana Creek stations

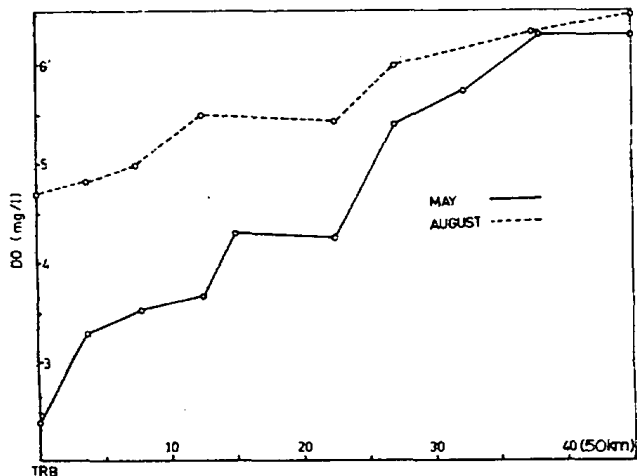


Fig. 4—Variation of dissolved oxygen in Thana Creek/Bombay Harbour during August and May

effluent discharge. Comparison of DO profiles at sts 1 and 2 (Fig. 3) with those at other stations reveals the inconsistency in DO levels at sts 1 and 2.

Sampling during flood tide was also done inside the small tributaries joining the Thana Creek (sts I to VIII; Fig. 1), weekly during September. DO values (Table 2) varied from 6.7 to 0.9 mg/litre. Some of these tributaries receive industrial and domestic waste water discharges and hence large variation in DO.

No definite pattern in the variation of BOD within the creek was observed. In general, BOD values

Table 2—DO and BOD (mg/litre) for Tributaries Joining Thana Creek

Date	Parameter	Tributaries							
		I	II	III	IV	V	VI	VII	VIII
01.9.77	DO	5.6	5.9	4.7	4.4	6.4	5.9	4.6	3.8
	BOD	14.5	3.3	3.8	14	3.4	2.7	3.3	1.2
09.9.77	DO	3.8	4.4	5.6	0.9	5.6	6.7	3.2	6.1
	BOD	13.2	2.3	—	—	2.1	3	—	4.1
14.9.77	DO	5	4.7	5.3	—	6.1	—	—	—
	BOD	2.2	13	15	—	4.5	—	—	—
22.9.77	DO	1.1	3.9	1.5	3.5	—	3.4	1	3.6
	BOD	—	—	—	—	—	—	—	3.6
29.9.77	DO	3.7	3.7	4.7	2.3	5.3	3.4	—	—
	BOD	1.6	12.3	13.3	11.2	4.8	2	—	—

exceeding 2 mg/litre were observed (Table 3) during August and September which were associated with the high organic matter received through the run off. Values > 5 mg/litre were often observed at st 1 in April-May which may be due to the sewage effluents. Sometimes during the ebb tide, values of the order of 8-10 mg/litre were observed at this station during March

to May which may also be due to sewage discharge having high BOD.

Stream monitoring stations—Panvel, Nhava Sheva and Dharamtar Creek (Fig. 1) which open in the eastern region of the Thana Creek/Bombay Harbour are relatively clean. Bassein Creek on the other hand receives waste water (35 mld) discharged in the Ulhas River. Unlike Manori Creek which is relatively free of pollution, Versova Creek receives about 80 mld of sewage waste from the Versova treatment plant.

Tides and currents: The flood tide effects are first felt at st 12 (av. high tide lead 30 min and av. low tide lead 1 hr) which receives high water earlier to Apollo Bundar. At st 10, the average high tide lag was 52 min and the low tide lag was 30 min.

Current direction and speed at these stations were mainly influenced by the tidal condition and were dominated by physical feature of the stream channel. Comparison between spring and neap tide conditions indicated faster currents during the spring tide and the ebb velocity was generally greater than flood velocity. The ebb velocity increased substantially during August, and on several occasions, attained a value > 130 cm/sec specially at sts 10 and 14 due to the fresh water discharge. The current did not vary appreciably in speed and direction from surface to bottom.

Salinity: Salinity varied widely from 1.32‰ during August to 30.03‰ during March (Table 1) at st 14. Except at st 14, the salinity of 18-30‰ during September increased to 30-35‰ after October (Fig. 5). At st 14 salinity was lower in September (1-3‰) and increased to 10-13‰ during October. It is evident from Fig. 5 that the average salinity observed at st 14 was lower than the other stream monitoring stations during all the months and the maximum salinity of 30.24‰ observed during March indicates the supply of fresh water through Ulhas River throughout the year. As in the Thana Creek region, high salinity in the range 38 to 39‰ was observed in isolated instances at sts 10 to 12, 16 and 17 during March-May. Variation in salinity from surface to bottom was not appreciable (< 1‰) during October to June, except at sts 14, 15 and 17, indicating good mixing. Slight salinity gradient (2-3.5‰) observed at sts 14 and 15 during October to

Table 3—BOD (mg/litre) at Some Stations from August 1976 to May 1977

Station	1976					1977				
	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
1	2.2	6.3	2.7	—	3.4	—	1.3	3	5.8	5.8
3	2.5	5.6	1.5	0.8	1	0.8	—	2.1	1.5	2.2
5	2.8	2.8	1.6	1	0.6	1	1.4	3.1	1.7	2.3
7	2.6	—	0.6	0.7	0.9	1.9	1.6	3.8	2.3	1.4
9	2.1	3.2	—	—	2.4	0.9	2.6	—	1.6	1.4
10	2.7	2	0.8	—	—	2	2.9	0.3	1.6	2.8
12	0.8	—	2.5	3.9	—	0.8	1.2	3.6	4.5	—
17	2	4.3	—	2.3	1.5	1.1	2.4	3.7	4	5.1
18	5.3	6.8	10.3	8.4	8.6	9.2	6	12.6	20.8	28.6

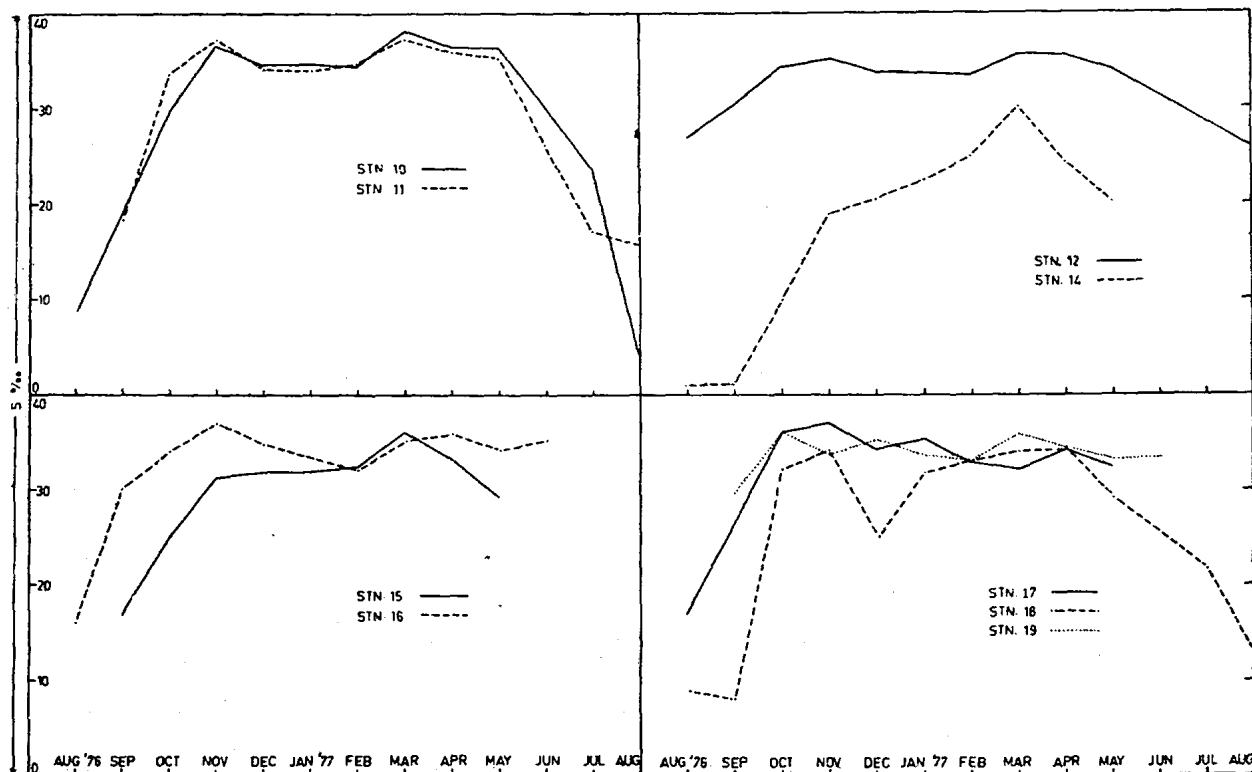


Fig. 5—Monthly variation of salinity at some stream monitoring and coastal stations

February was due to the fresh water discharge. Measurements carried out during March at st17 showed salinity gradient from surface to bottom (Table 1). No such difference was observed at other stream monitoring stations and the gradient at st 17 may be ascribed to some local factors. It is possible that during March, Versova sewage treatment plant might have released effluent which formed some component of surface water. This was supported by DO levels (Table 1). Low DO of surface water compared to bottom layer indicates the presence of sewage effluents in the surface layer. Salinity in the vertical water column at all stations except sts 13 and 14 varied from surface to bottom in August and was due to the incomplete mixing of the fresh water with the underlying saline water. Diurnal observations conducted at sts 13 and 14 during August showed that the variation in the salinity with the change in tide was not appreciable. With the decrease of fresh water, intrusion of saline water was observed and salinity increased in the postmonsoon season.

Dissolved oxygen: DO content of Panvel, Nhava Sheva and Dharamtar Creek which join Thana Creek, varied from 4.9 to 9.4 mg/litre. The creeks had a better water quality and DO levels never fell below 4.6 mg/litre unlike at some Thana Creek stations. High DO levels during January-February were perhaps

associated with lower temperature and higher photosynthetic activity. DO distribution in the vertical water column was fairly uniform in the postmonsoon period and the difference was less in August as compared to that of Thana Creek stations.

DO profiles at sts 15 and 16 followed the general pattern observed at the Thana Creek stations. However, there was no appreciable vertical gradient even during the monsoons. DO levels at sts 13 and 14 were lower than at 15 specially during the nonmonsoon period (Fig. 6) reflecting the effect of effluents discharged in the Ulhas River. DO at st 17 was comparatively lower and attributable to the sewage discharge from the nearby sewage treatment plant.

Coastal stations—Coastal region survey extended from the Colaba Point in the south to the Bassein Creek in the north and up to a distance of about 12 km from the shore line. The continental shelf being wide, the depth at 12 km line was only about 17 m below the mean sea level. St 22 was most extensively studied among the coastal stations since that area has been considered for submarine disposal of waste from the city.

Currents: During November to February, maximum current velocity of 60 cm/sec (av. 45 cm/sec) and 45 cm/sec (av. 35 cm/sec) was recorded respectively for ebb and flood tide at st 22. During slack period, the

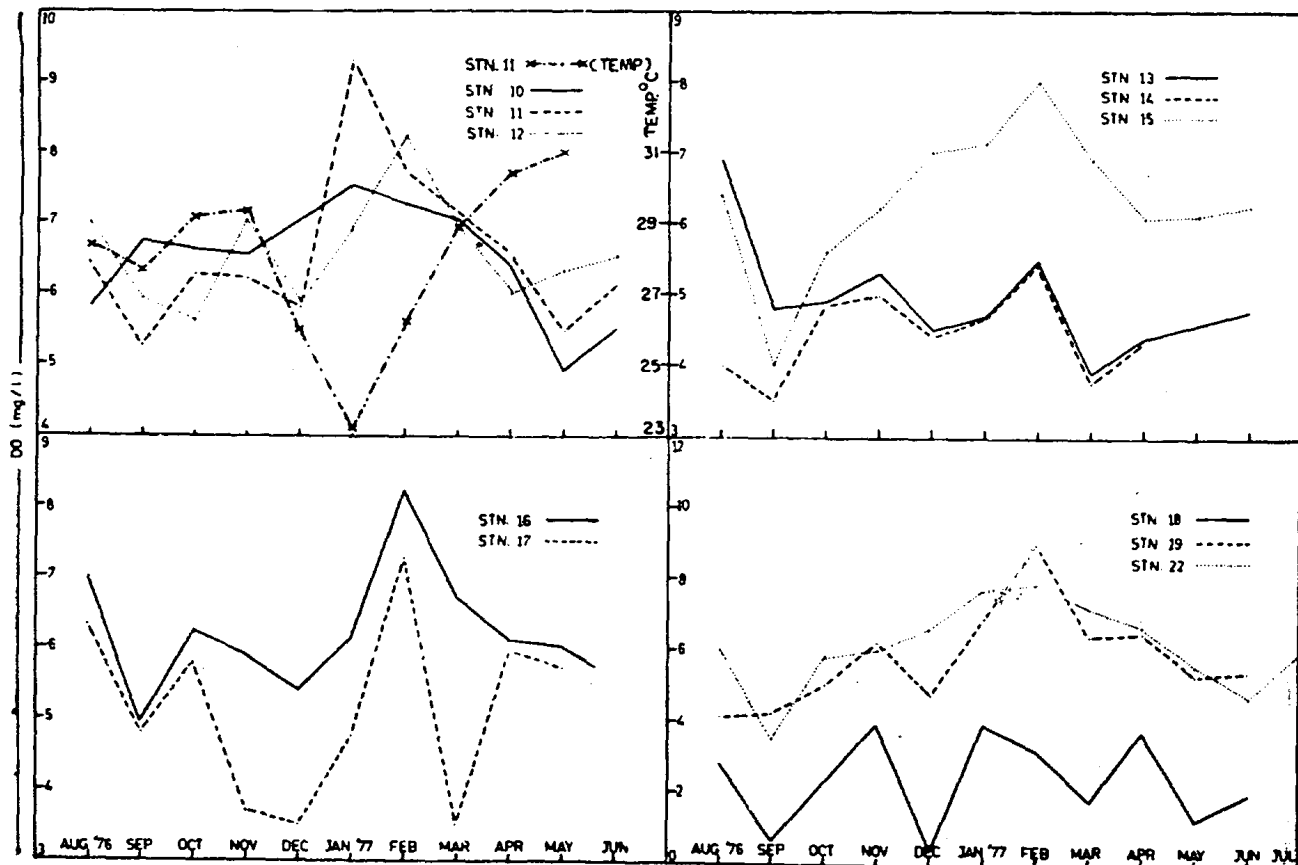


Fig. 6—Monthly variation of temperature (st 11) and dissolved oxygen at some stream monitoring and coastal stations

velocity was only 0.5 cm/sec. The currents maintained a similar direction from the surface to bottom and the velocity decreased only marginally. During the southwest monsoons the current velocity increased appreciably and often exceeded 125 cm/sec during the flood tide at st 22. The currents in general tend to move northeast during the flood tide and southwest during the ebb tide indicating a strong tidal influence on the coastal circulation. Sts 18 to 20 being in the bays the flood current velocity was appreciably smaller but the ebb velocity was almost similar to that observed at st 22.

Salinity: Salinity ranged from 29 to 33.5‰ during monsoon period. Unlike in the Thana Creek stations there was very small vertical salinity gradient indicating good mixing of fresh water brought in by the creeks and run off. There was, however, appreciable lateral salinity gradient from the shore to the farthest stations which disappeared after September and the water was well mixed during the postmonsoon period laterally as well as vertically. The salinity of the bay water varied depending on the tide in the monsoon season with gradual increase during the flood and decrease during ebb. There was appreciable salinity gradient. During August, the average surface and bottom salinities at st 18 respectively were 6.28 and 12.27‰. The salinity gradient was sometimes observed at st 18 even during the postmonsoon season. The average surface and bottom salinities were 32.63 and 35.48‰ respectively during November at this station which were due to local discharges in the bay.

Dissolved oxygen: The average DO levels show little variation throughout the coastal area during a particular month (Table 1). Also, there was an absence of vertical gradient in the DO levels except during September and October. In September-October, the surface water had DO of 6.4 mg/litre while the bottom layer had only 2.9 mg/litre which could be due to the additional oxygen demand of settled suspended load brought to the coastal region during the monsoon period. Generally, variation of DO levels at st 22 was similar to that of the Thana Creek stations (Figs 3 and 6).

Lateral variations of DO at sts A to H are given in Table 4. Except during September, there was no regular increase in DO from st H to A. DO levels, however, were somewhat lower at st H.

A comparison of DO profiles in Fig. 6, reveals differences in the variation of DO at st 18 as compared to the other stations. The values fluctuated randomly and varied from 0 to 4 mg/litre. This range is below the level required for the healthy growth of marine life. Mahim Bay where st 18 is located, appears to be the most polluted area of the Bombay waters. This bay which extends a few kilometres inside the coast receives

Table 4—DO (mg/litre) at Some Stations during August, September and October

Station	August		September		October	
	S	B	S	B	S	B
A	6.6	6.4	6.2	2.8	6.8	6.7
B	6.5	6.4	6.3	3	6.9	6.3
C	5.2	5.2	5.3	2.8	—	—
D	7.6	7	5.8	3	6.8	5.8
E	5.5	6.2	5.5	2.9	—	—
F	6.4	5.9	5.6	2.9	6.5	6.4
G	6.3	5.1	4.8	1.9	—	—
H	5.3	4.3	4	2.9	6.3	5.8

S=surface; B=bottom

about 160 mld of waste water from the nearby sewage treatment plants and pumping stations. The pollution load is more than the bay water can assimilate efficiently which is evident from the DO levels.

Steep vertical gradient of DO was frequently observed at st 18 during the ebb tide. During the flood slack, the surface and bottom water had similar DO. But during the ebb tide as the level fell at the bay entrance, water of lower salinity and low DO from the upper reaches of the bay advanced to st 18 and formed the surface layer. Eventually, surface layer had lower DO than the bottom layer.

At the Back Bay (st 19) the average DO varied from 2 to 9.1 mg/litre. As in the case of Thana Creek stations, September was characterised by low DO (4 mg/litre) increasing up to about 9 mg/litre during February which decreased to about 5.3 mg/litre during May. Pronounced vertical gradient was observed during August. Surface water (sal. 27.5‰) had DO of 2 mg/litre. The difference, however, decreased appreciably in the postmonsoon period.

BOD at the coastal stations varied from 0.2 to 2.3 mg/litre. Maximum BOD of 82 mg/litre was observed in May and June at 18a during neap tide. BOD levels at Worli Bay ranged from 0.8 to 8.3 mg/litre, the higher values being observed during the ebb slack.

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