

HYDROGRAPHY AND WATER QUALITY OF BOMBAY HARBOUR

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General hydrography and water quality of Bombay Harbour/Thana Creek is discussed on the basis of long term monitoring. The pollutants load associated with the domestic waste water are quantified. The water mass is vertically homogeneous except during monsoon when marked salinity gradient exists throughout the bay. The high suspended load is mainly inorganic in nature with organic carbon content of less than 6%. While DO is distinctly low at the head of Thana Creek (st 1) with high BOD, there is no evidence for decrease in DO in the harbour water over the years. NO_3^- -N and PO_4^{3-} -P levels are high in Thana Creek during dry season and decrease considerably in the harbour. The levels in the harbour water are however relatively higher than observed in the coastal water. The concentrations of Ni, Cu, Zn and Hg are marginally higher in Thana Creek water however, the harbour region reveals levels comparable to those of the open coast. Some enrichment of Cu and Zn and of Cu, Zn and Hg is also observed in particulate matter and sediments respectively of Thana Creek while, the harbour sediments did not reveal any excess entrapment of trace metals.

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INTRODUCTION

Unprecedented population growth and industrial development around Bombay Harbour/Thana Creek coupled with increased port activities have imposed considerable strain on the quality of the harbour water. Although the levels of some pollutants have been identified (Zingde, 1985; Zingde and Desai, 1981; Patel et al., 1985; Patel et al., 1975) and a few biological investigations reported (Gajbhiye and Desai, 1981; Govindan et al., 1976), much of the earlier studies were confined to currents, tides, circulation pattern and sediment transport in connection with the development of the port and other facilities. This paper reports the overall assessment of the water quality of the region on the basis of the extensive data collected during 1976-78 and continued monitoring at specific locations upto 1981.

MATERIAL AND METHODS

Several stations in Thana Creek/Bombay Harbour were monitored generally over a tidal cycle at least once a month for 16 months from May 1976. However, data only from stations marked in Fig. 1 are used in this paper. The monitoring was continued at sts 2, 3 and 6 during 1979-81 to understand long term variations. The surface samples were obtained by using a clean polyethylene bucket while, Niskin sampler was used to collect the bottom samples 1 m above the sediment level. Salinity was determined by argentometric titration while Winkler method (Carlberg, 1972) was used for the estimation of dissolved oxygen (DO). For the determination of BOD, direct unseeded procedure was employed when BOD was expected to be below 4 mg l^{-1} , while for samples having higher BOD, seeded dilution method was used (APHA, 1976). NO_3^- -N, NO_2^- -N, NH_4^+ -N and PO_4^{3-} -P were determined by standard procedures (Carlberg, 1972). the method developed by Hulthe, Uppstrom and Ostling (1970) was modified and applied manually for the determination of boron. Propionic anhydride, oxalyl chloride and acetone were replaced by acetic anhydride, hydrochloric acid and methyl isobutyl ketone respectively. Calcium and magnesium were analysed by following the procedure of Culkin and Cox (1966). Appropriate correction for strontium and for a systematic over estimate of about 1% in the titration end point were applied. Domestic waste water samples were analysed by standard procedures (APHA, 1976). Suspended solids were estimated by gravimetry

Hydrography & water quality of Bombay Harbour

after filtration through 0.45 μ Sartorius membrane filter paper. Trace metals in water were determined by AAS (Hilger-Watts, Atomспек Model H1550) after preconcentration (FAO, 1975). Sediment samples were obtained by using a van Veen grab. The samples were oven dried at 100°C. disaggregated, and digested with HF, HClO₄, HNO₃. The residue was brought into solution in 0.5 M HCl and analysed by AAS. Similar procedure was used for the determination of trace metals in particulate matter. For the determination of particulate organic carbon, known volume of water was filtered through Whatman GF/C filter paper and analysed by reported procedure (Strickland and Parson, 1972).

RESULTS AND DISCUSSION

General :

Bombay Harbour/Thana Creek (hereafter together termed as bay) is a semi enclosed basin open to the Arabian Sea at its southwest approach and is also connected at its northern extremity to the Ulhas River through a narrow channel. The tidal inlets of Dharamtar, Nhava-Sheva and Panvel Creeks are tributaries to the harbour, discharging into its eastern shore within the port limit.

Current speeds and directions within the bay and associated tributaries are largely due to the tidal movements and show little variation from monsoon to nonmonsoon (NIO, 1978). The maximum current speeds within the harbour often exceed 100 cm sec⁻¹ and the variation from surface to bottom (1 m above the sediment) is not significant. Lateral variations in speed are however present with the currents in the eastern area of the harbour being somewhat stronger. There is overall decrease in the current speed in Thana Creek (st 2) with the ebb currents stronger than the flood currents (NIO, 1978). The currents at st 1 are further weakened and the average speed here is around 10 cm sec⁻¹ during neap. The maximum current speeds at sts 6, 7 and 8 are generally between 30-60 cm sec⁻¹ with marked increase in the ebb velocity during monsoon due to the pronounced freshwater runoff into these creeks (MCGB, 1979).

Tidal variations in the bay are semidiurnal with an appreciable diurnal element. The flood tidal front advances

TABLE 1 : Some Pollutants^a entering Bombay Harbour/Thana Creek through domestic waste water.

Parameter	Range mg l ⁻¹	Average mg l ⁻¹	Kg day ⁻¹
Dissolved solids	980-2500	1500	52.5x10 ⁴
Suspended solids	127- 372	235	8.2x10 ⁴
BOD	109- 417	250	8.7x10 ⁴
Nitrogen	7- 62	35	12250
Phosphorous	2- 10	6	2100
Manganese	0.3 - 1.2	0.7	245
Iron	0.4 - 2.4	1.8	630
Cobalt ^b	10- 92	35	12
Nickel ^b	12- 136	78	27
Copper ^b	25- 126	98	34
Zinc ^b	75- 331	201	70
Lead ^b	7- 99	48	17
Boron ^b	220- 600	360	126

^a Estimated domestic waste water output - 350 mld

^b Values in ug l⁻¹

in northeasterly direction and ebbs towards the southwest. At st 1, the most northerly location, the average high tide lag time is 40 min with reference to Apollo Bandar and the low tide average lag time is 1 hr 37 min (MCGB, 1979). On an average about one third of the bay water is renewed per tide cycle with the ingress of the flood water (Patel, et al., 1985).

Waste water discharges :

The domestic waste water estimated around 350 mld (million litres per day) received at the treatment plants and the pumping stations along the western shores of the bay is far in excess than the capacity of the treatment plants (MCGB, 1979). Waste water is therefore, often released untreated to the adjacent bay through point discharges. The waste water from some collection locations and treat-

Hydrography & water quality of Bombay Harbour

ment plants was periodically analysed to quantify the pollution loads. The levels of pollutants varies over a considerable range (Table 1) nevertheless, the averages taken for computations give an estimate of the magnitude of various contaminants entering the bay through domestic waste water alone.

TABLE 2 : Average trace metals (ppm dry wt) and organic carbon (%) in suspended load of Bombay Harbour/Thana Creek.

Station	Co	Ni	Cu	Zn	Pb	Organic C
1	35	136	157	206	38	5.3
2	37	139	163	229	26	4.7
3	28	85	119	135	32	2.3
4	32	102	137	162	29	2.9
5	27	116	105	159	35	3.8
6	30	159	132	127	29	4.1
7	25	101	98	138	19	1.7
8	-	-	95	121	8	2.2

In addition, Thana Creek receives industrial waste water estimated (MCGB, 1979) to exceed 180 mld. The major industries are fertilizer, petrochemical, thermal power station, nuclear, pharmaceutical, and chemical.

The pollutants released in Ulhas River can also enter the head of Thana Creek through the arm connecting the two water bodies. Such a flow is possible because of the difference in time of occurrences of high and low water in Thana Creek and Ulhas River estuary (Zingde, et al., 1979). It has been estimated that about 35 t suspended solids and 1250, 35, 20, 10 and 3 kg of Zn, Cu, Hg, Pb and Cr respectively are released daily into the Ulhas and Kalu-Waldhuni tributaries (Patel, et al., 1985).

Salinity :

The pattern of salinity distribution and its seasonal variation remained more or less similar over 1976-81 (Fig.2) although the range often changed significantly perhaps

Zingde et al.

TABLE 3 : Average trace metals ($\mu\text{g l}^{-1}$) in water of Bombay Harbour/Thana Creek.

Station	Fe	Co	Ni	Cu	Zn	Pb	Hg
1	18	0.5	1.8	15	27	7	0.32
2	15	0.3	0.5	15	28	12	0.30
3	29	ND	ND	12	18	8	0.16
4	15	ND	ND	14	21	5	0.25
5	25	ND	ND	9	17	6	0.20
6	14	0.2	0.5	10	23	9	-
7	7	ND	ND	11	21	5	-
8	12	ND	ND	8	15	4	-
Bombay Coast	20	ND	ND	9	18	4	0.08

ND - Not detectable

TABLE 4 : Average trace metals (ppm dry wt) and organic carbon (%) in sediments of Bombay Harbour/Thana Creek.

Station	Organic carbon	Mn	Fe ^a	Co	Ni	Cu	Zn	Pb	Hg
1	3.2	689	6.8	50	132	142	206	28	8.1
2	2.1	740	7.7	50	120	129	173	37	7.5
3	1.5	719	8.1	45	131	105	155	48	0.5
4	1.7	1042	7.9	45	121	126	163	41	0.3
5	1.5	980	7.8	42	128	132	127	21	0.1
6	1.8	860	7.1	44	146	133	132	40	-
7	1.1	810	6.7	35	112	124	139	12	-
8	1.3	792	7.5	40	126	129	137	21	-
Bombay Coast	1.1	1059	7.5	51	125	115	138	20	-

^a Values in percentage.

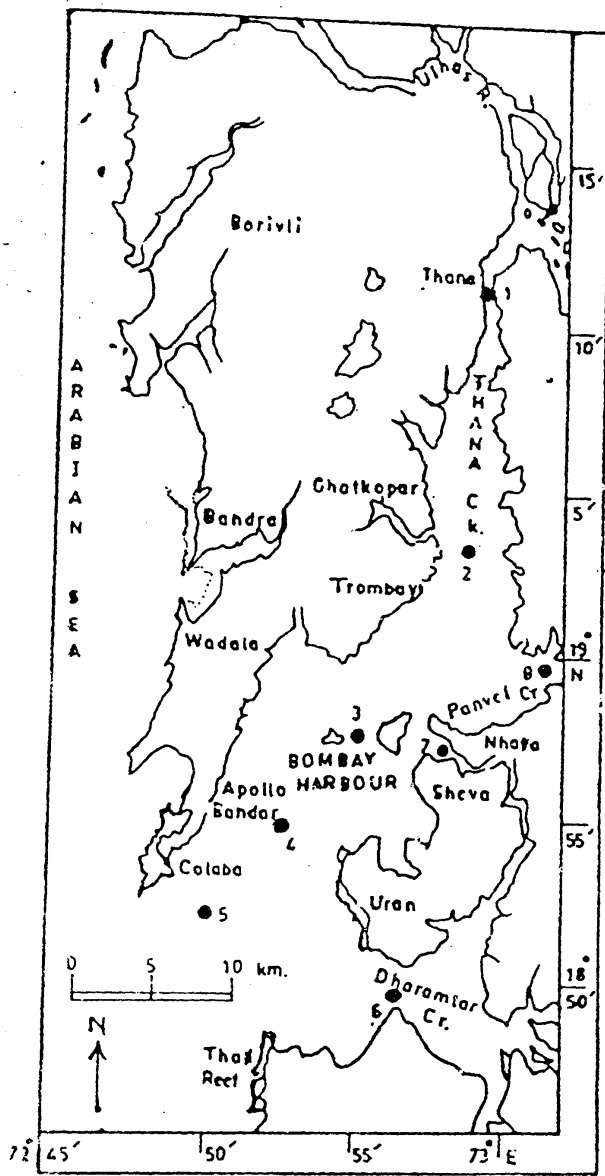


Fig. 1 Sampling locations in Bombay Harbour/Thana Creek

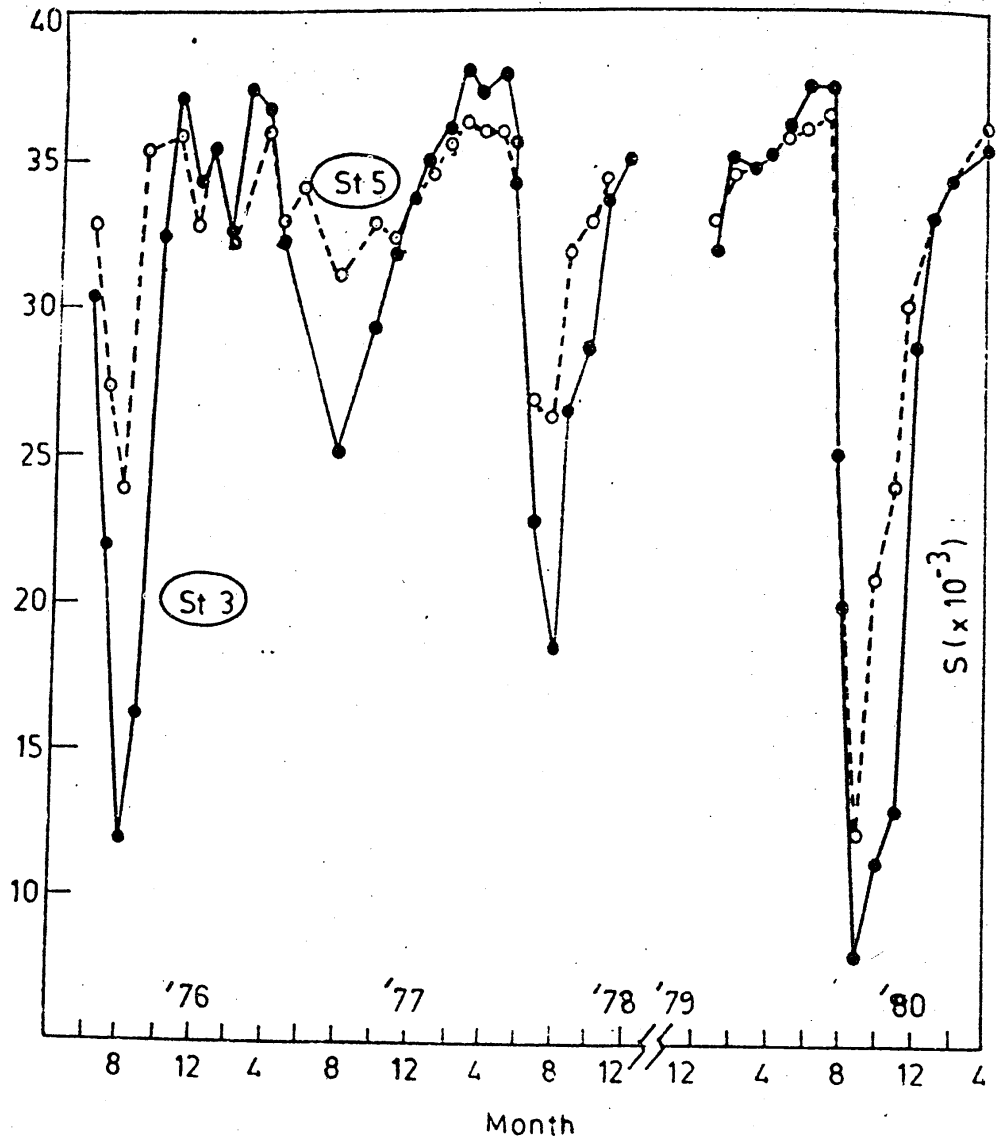


Fig. 2 - Salinity variation in Bombay Harbour during 1976-81

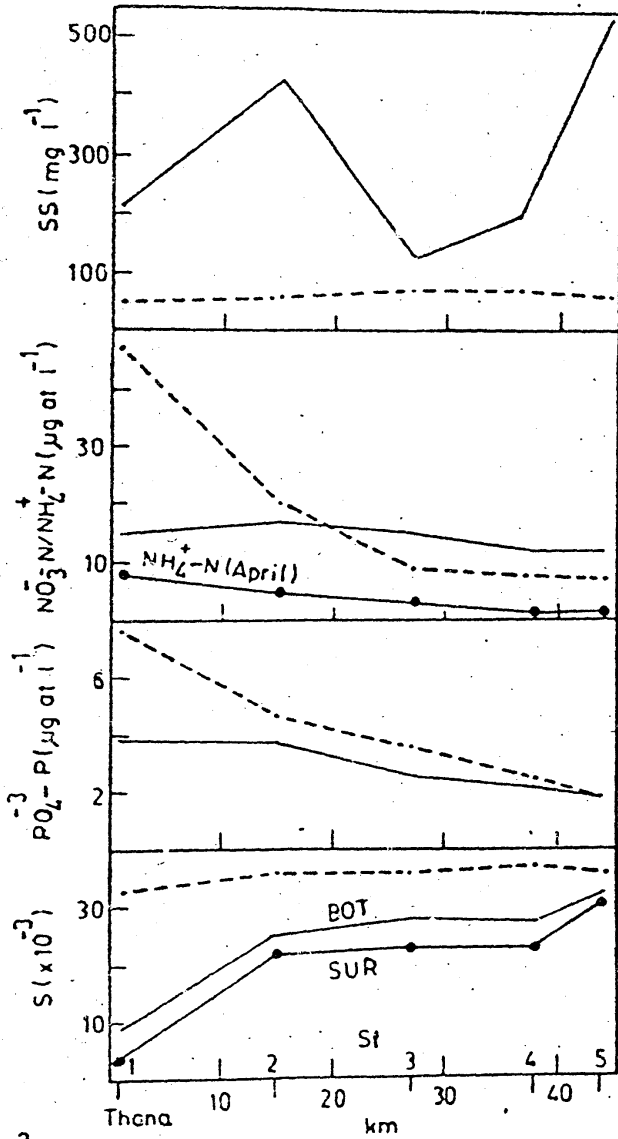


Fig. 3

Variation of some physico-chemical parameters along Bombay Harbour/Thana Creek during August (—) and April (----).

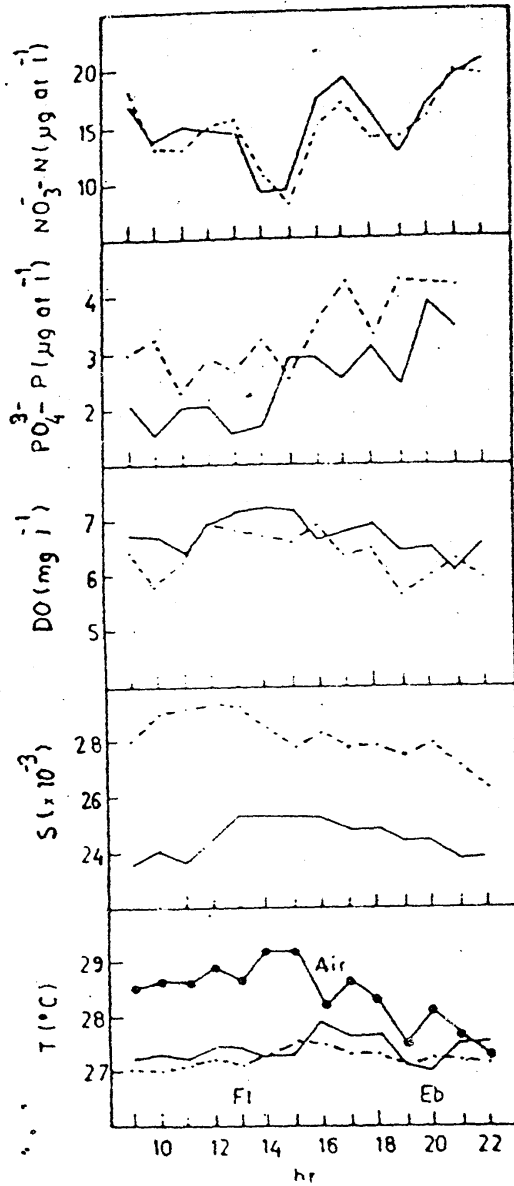


Fig. 4

Diurnal variation of some physico-chemical parameters at st 5 on 1 Aug 1981. Surface (—): bottom (----).

Hydrography & water quality of Bombay Harbour

due to the variation in the volume of monsoonal fresh water discharge to the bay. The longitudinal gradient (Fig 3) with low salinities (5×10^{-3}) at st 1, and high salinities (30×10^{-3}) at st 5 develops due to the fresh water entering Thana Creek through the arm of the Ulhas River during July-September. This gradient decreases as the dry season progresses and the bay is nearly homogeneous during April (Fig 3). The transport of a large volume of fresh water through Dharamtar, Nhava-Sheva and Panvel Creeks to the eastern section of the harbour results in some lateral gradient which is pronounced during July-September specially during the low tides. The water mass is vertically homogeneous except during monsoon when marked salinity gradient exists throughout the bay (Fig 3). The presence of cold, high saline and low DO subsurface water off Karwar (Gopinathan and Joseph, 1980), Mandovi-Zuari estuaries (Sankaranarayanan *et al.*, 1978) and Cochin back waters (Sankaranarayanan and Qasim, 1972) during monsoon has been attributed to the transport of upwelled water on the shelf to the nearshore regions. The vertical salinity gradient observed in the bay does not seem to be due to the intrusion of upwelled water because of the comparable surface and bottom temperatures and high DO (Fig 4). Also the upwelled water is expected to have high $PO_4^{3-}P$ and NO_3^-N , however, surface and bottom NO_3^-N values are more or less comparable in the bay (Fig 4). Figure 4 reveals higher $PO_4^{3-}P$ in the bottom layer. This was also observed during April when there was no salinity gradient. The higher $PO_4^{3-}P$ therefore appears to be due to the release of phosphate from the sediment to the overlying water column. The salinity gradient in the bay which disappears after October therefore, appears to be due to the incomplete mixing of the low saline surface water and high saline bottom water.

Suspended Solids :

The strong currents sweeping the bay disperse the fine grained and poorly sorted bottom sediment into the water column resulting in high suspended matter in water. The load though variable is generally below 100 mg l^{-1} (Fig 3) throughout the bay during the dry season. The increased turbulence during monsoon and the high particulate matter normally associated with the runoff results in substantial increase in the suspended matter

Zingde et al.

and the values exceeding 200 mg l^{-1} are commonly observed (Fig 3). The organic carbon content of the suspended matter which is $< 6\%$ (Table 2) indicates the inorganic nature of the particles and the load of 80 t day^{-1} released through domestic waste water (expected to have high organic component) does not seem to influence the composition of the particulate matter.

Dissolved Oxygen :

The marked decrease in DO along the length of the bay from the mouth to Thana during May reveals the stress due to the oxygen demand of organic matter released in the region (Zingde et al., 1979). Wide and irregular variations of DO in the bay (Fig 5) is typical of the marine waters receiving organic wastes. The DO was distinctly low at st 1 and the hourly measurements over two tide cycles revealed that the highest value of only 3.7 mg l^{-1} was attained at high tide while on 70% of the occasions the DO was below 3 mg l^{-1} (Fig 6). The other major creeks namely Dharamtar, Nhava Sheva and Panvel sampled simultaneously indicated better water quality with DO variation in the ranged 5.7 to 8.4 mg l^{-1} (Fig 6). The low BOD and high DO levels in these creeks (Fig 6) indicate that the major sources of organic inputs to the bay are from its western shore. As expected the st 1 had high and tide dependant BOD with values exceeding 10 mg l^{-1} around the low tide (Fig 6). The higher BOD observed in Dharamtar Creek as compared to adjacent Nhava Sheva Creek is due to the transport of pollutants through Patalganga River which opens in Dharamtar Creek. The variation of DO from the surface to the bottom is not appreciable (Fig 4) except during monsoon when marked gradient is sometimes observed. From Figure 5 it is apparent that there is no decrease in DO over the years thus implying that the organic matter which is being increasingly released is effectively assimilated.

Nutrients :

The long term variation of phosphate and nitrate (Figs 7 and 8) is quite irregular because of which definite conclusions are not possible though consistent decrease from st 3 to st 5 is observed. $\text{PO}_4^{3-}\text{-P}$ and $\text{NO}_3^{-}\text{-N}$ concentrations in the coastal waters of Bombay (10 m depth

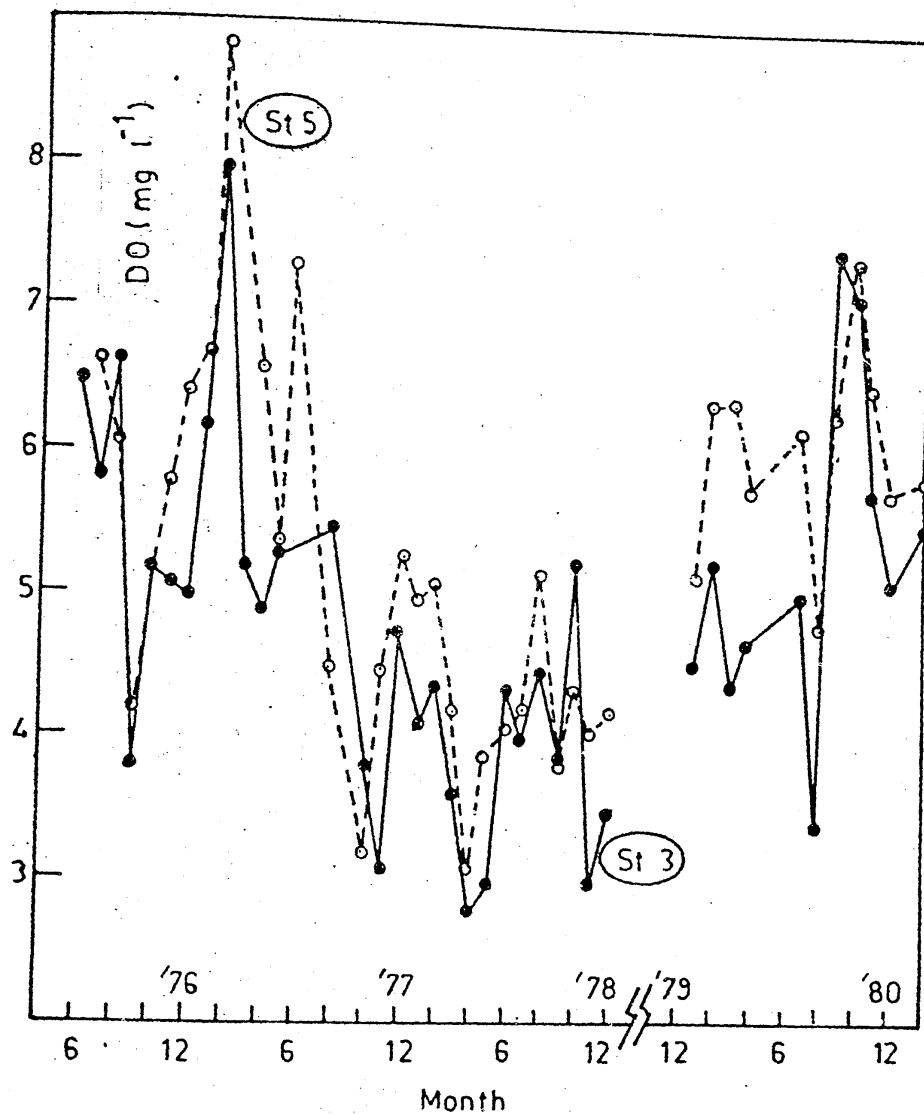


Fig. 5 Variation of DO in Bombay Harbour during 1976-81.

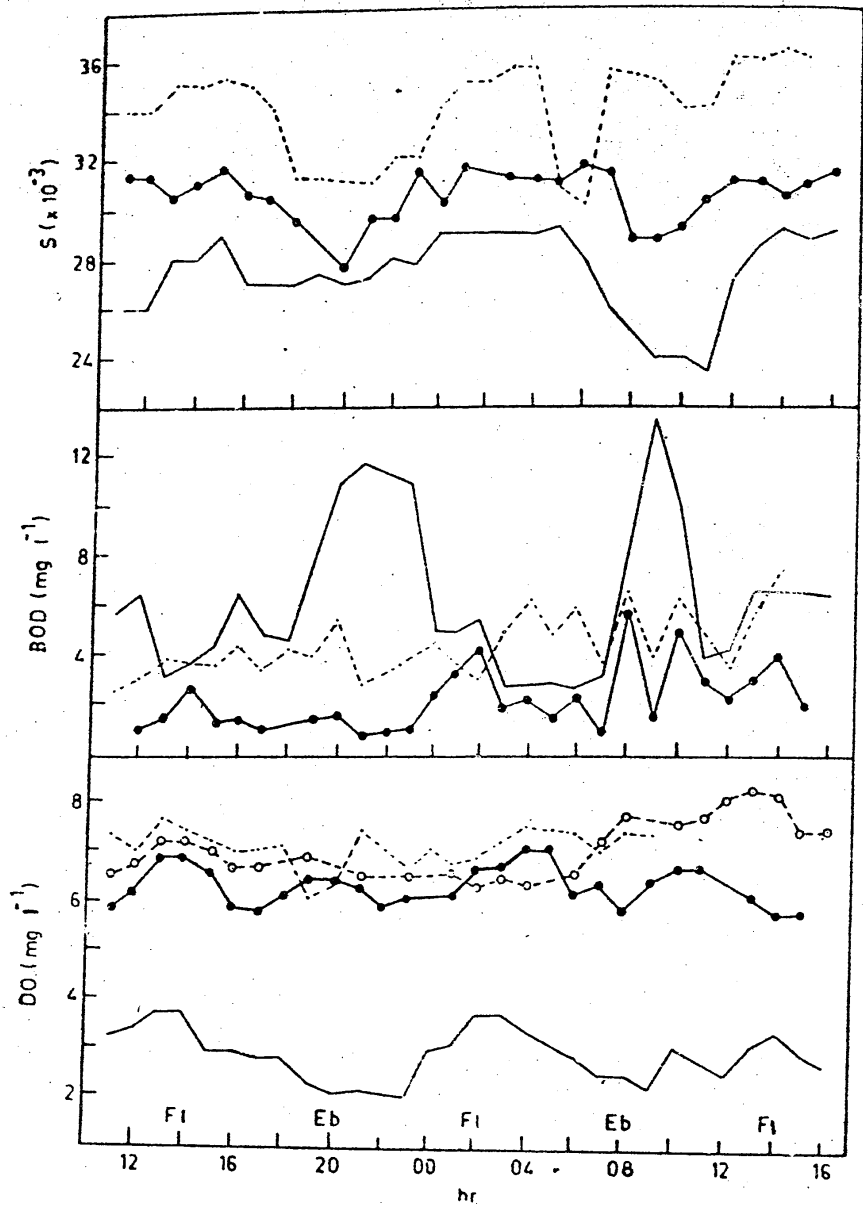


Fig. 6

Diurnal variation of DO, BOD and salinity at st 1 (—), st 6 (---), st 7 (o—o) and st 8 (●—●) on 28/29 Nov 1977.

Hydrography & water quality of Boabay Harbour

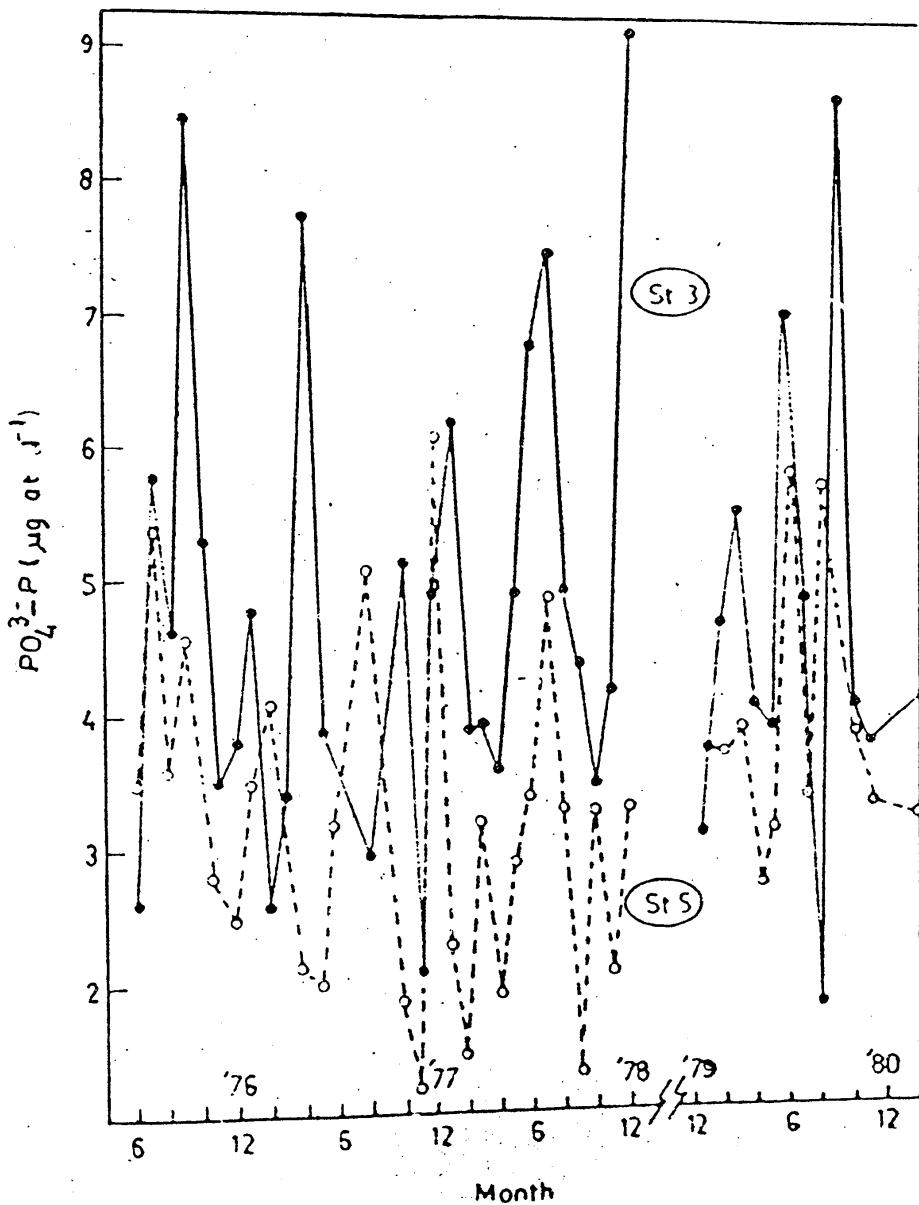


Fig. 7- Variation of $PO_4^{3-}-P$ in Bombay Harbour during 1976-81

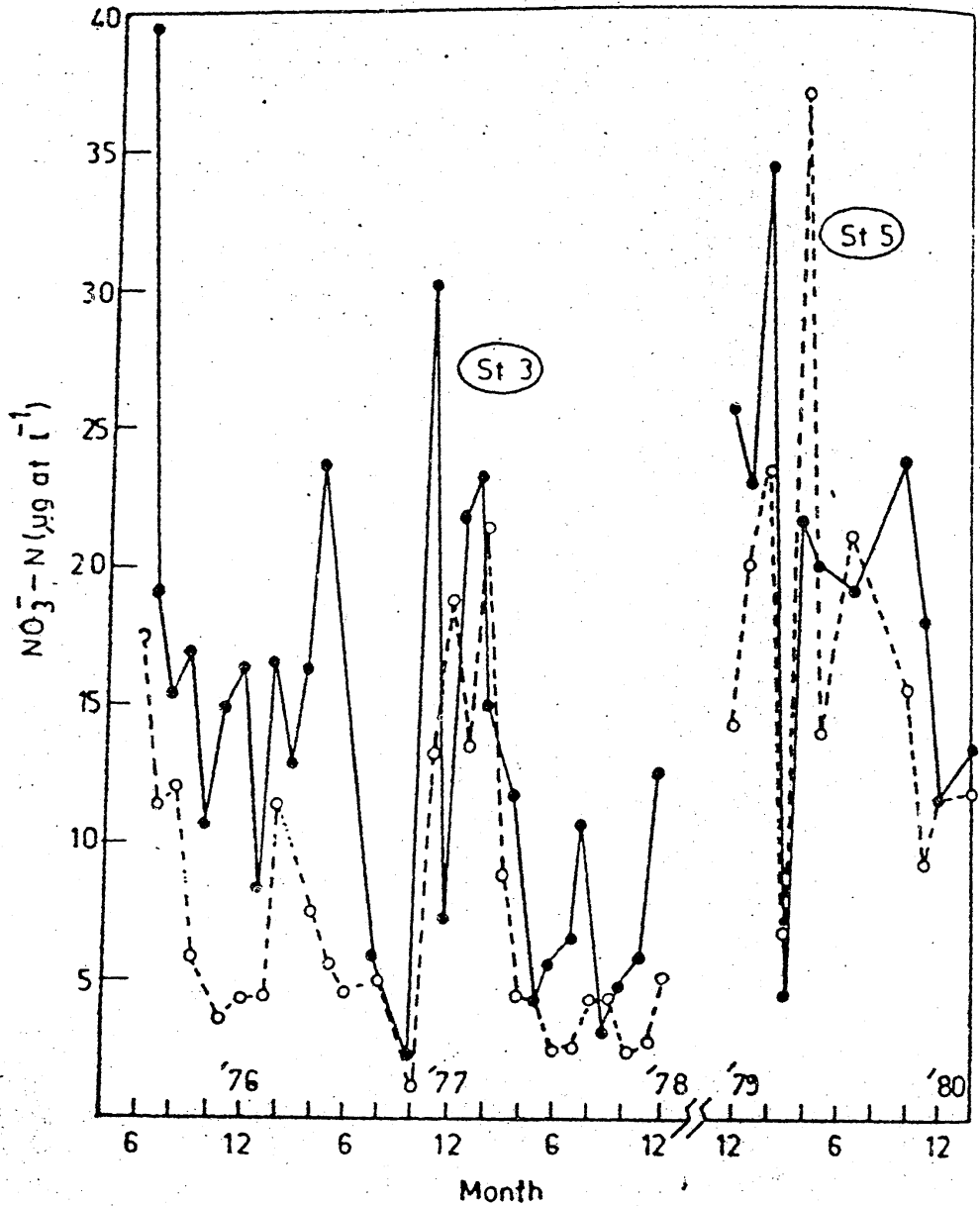


Fig. 8 Variation of $\text{NO}_3^- \text{-N}$ in Bombay Harbour during 1976-81.

Hydrography & water quality of Bombay Harbour

contour) are generally below $2 \mu\text{g-at l}^{-1}$ and $4 \mu\text{g-at}^{-1}$ respectively (NIO, 1978). These levels are enhanced considerably in Thana Creek specially during nonmonsoon period (Fig 3). The dilution due to the voluminous fresh water discharge from Ulhas River should be responsible for markedly lower levels observed at st 1 during August (Fig 3). Domestic waste water released in the bay contributes 12 t day^{-1} of nitrogen and 2 t day^{-1} of phosphorous (Table 1). In sewage which is generally devoid of oxygen, combined nitrogen is present mainly as ammonia and organically bound nitrogen which gets oxidized in the marine environment and ultimately broken down and mineralized into available nutrients. This process appears to be incomplete in the bay and the ammonia released in Thana Creek is not completely oxidized as evident from higher $\text{NH}_4\text{-N}$ value ($5 \mu\text{g-at l}^{-1}$) (Fig 3) as compared to those observed ($1.5 \mu\text{g-at l}^{-1}$) for the coastal waters of Bombay (NIO, 1978). The surface and bottom layer invariably contained similar levels of $\text{NO}_3\text{-N}$ while $\text{PO}_4^{3-}\text{-P}$ was often higher in the bottom layer specially in the harbour region (Fig 4). This suggests that the phosphate is released from the sediments while such a release may not be important in the case of nitrate. It is surprising that although abundant supply of nitrogen and phosphorous compounds is available in the bay, the utilization for primary production is not optimum as revealed by consistently high $\text{NO}_3\text{-N}$ and $\text{PO}_4^{3-}\text{-P}$ values in the bay. It is possible that some unknown micropollutants hamper the growth of phytoplankton in this region.

Trace metals :

The bay receives appreciable load of trace metals (Table 1). However, the concentrations of dissolved metals in the harbour (Table 3) are comparable to those observed in the coastal water. It is possible that the trace metals entering the bay in the dissolved state are hydrolysed in the marine environment and/or get rapidly fixed to the particulate matter and removed from the solution. It is known that even near the point of input, the metal content in the receiving water often decreases to its normal value because of rapid removal from the dissolved state. The levels of dissolved Ni, Cu, Zn, and Hg are however, somewhat higher in Thana Creek (sts 1 and 2). The water column in Thana Creek/Bombay Harbour has been reported to have about 77 kg of Hg in excess of the expected back-

ground (Zingde and Desai, 1981). The present studies and the results reported recently for samples collected off Trombay (Patel, et al., 1985) reveal that the dissolved trace metals in the water column of the harbour though vary appreciably, there are no major systematic fluctuations and there is no evidence for any increase in the concentrations over the years. The load of dissolved trace metals therefore appears to be more or less stabilized.

Trace metals in the suspended matter (Table 2) reveal only marginal enrichment of Ni, Cu and Zn in Thana Creek region while the levels at other stations are more or less comparable to those observed in other coastal environments (Borole, et al., 1982). The variation of elemental concentration with salinity revealed considerable scatter much above experimental uncertainties and no systematic trends were observed.

The Fe content of the bay sediment (Table 4) which is in the range 6.7 to 8.1% is similar to its concentration in the coastal sediments. Marginal enrichment of Ni, Zn and Hg in Thana Creek sediment is evident from Table 4. The sediment in the harbour region however, do not reveal any significant enrichment perhaps because the region is frequently dredged. The correlation between organic carbon and trace metals often observed in many regions (Borole, et al., 1982) was not significant. In the bay the total mercury concentration in the surface sediment varied from 0.17 to 8.21 ppm with definite enrichment in the creek suggesting major mercury inputs in the upper reaches of the creek (Zingde and Desai, 1981). The mercury enriched layer in the sediment cores was about 10-25 cm in the creek region and 0-8 cm in the harbour area. An excess of 14 tonnes of mercury over the natural background has been estimated to be trapped in the bay sediments.

The waste water from Bhabha Atomic Research Centre is the major source of low level radioactive waste to the bay. The main radio-nuclides present in the waste have been reported to be cesium-137, cerium-144, ruthenium-106, zirconium/niobium-95, strontium-90, uranium and its daughter products and traces of plutonium-239. The levels of various radionuclides in water, sediment and benthos have been found to be within permissible limits (Patel, et al., 1985).

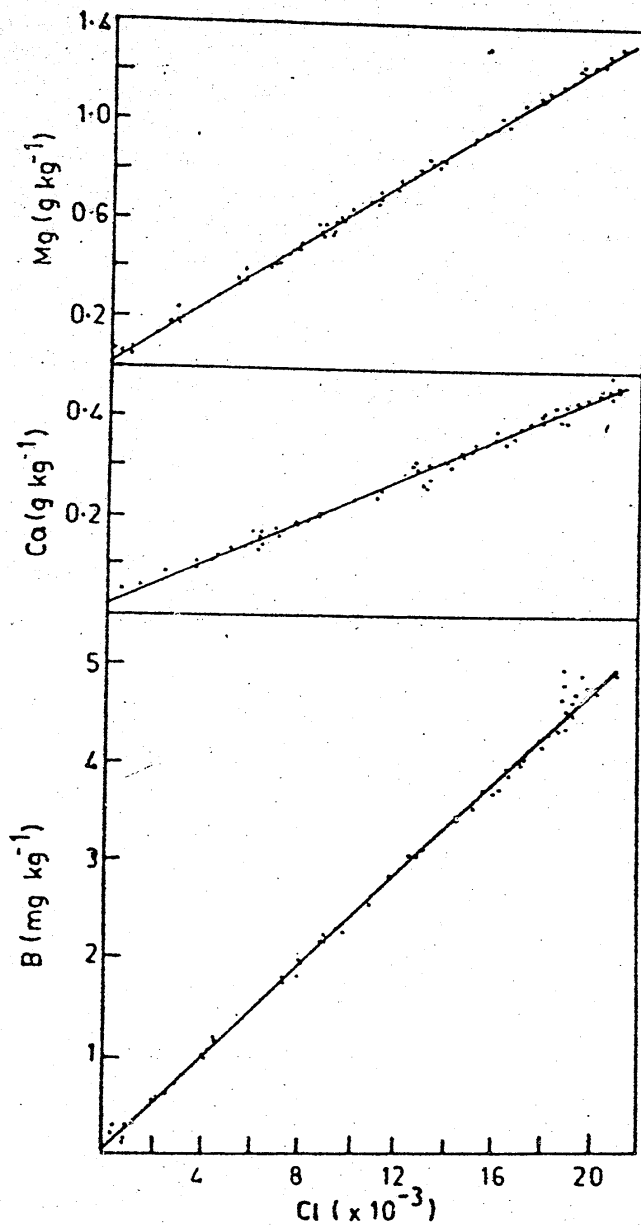


Fig. 9

Variation of B, Ca and Mg with chlorinity in Bombay Harbour/Thana Creek.

Boron, Calcium and magnesium :

The behaviour of B, Ca and Mg which is conservative in oceanic water can differ considerably in the mixing zones of sea water and fresh water. Addition, removal or conservative behaviour of these elements have been reported in estuaries (Liss, 1976). Release of wastes containing boron in the grossly polluted Ambika estuary has resulted in boron addition to the extent of 263% at the ebb tide in the inner estuary (Narvekar, et al., 1983). Although Thana Creek/Bombay Harbour receives 126 kg day^{-1} of boron (Table 1) through domestic waste water alone, its behaviour as evident from Figure 9, is near to conservative with a correlation coefficient of 0.96. The ratio of boron to chlorinity however varied over a wider range (0.231 to 0.267).

The behaviour of Ca and Mg (correlation coefficient of 0.99) was also conservative (Fig 9) with mean ratios with chlorinity of 0.0225 and 0.0663 respectively.

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Zingde et al

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